Evaluating the “Soil stabilisation and control of erosion” ecosystem service provided by agricultural ecosystems over the French territory

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Contents

Key note speeches

Soil erosion in the Anthropocene: do we still need more research ?

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Abstract

Taking steps to preserve the quality and quantity of global soil resources should require no justification. Our future ability to feed ourselves and live in an unpolluted environment in the Anthropocene depends on our ability to reduce the rates at which our soils are currently eroding. The current and expected unprecedented environmental changes at a global scale make this task even more urgent.

Soil erosion is a geomorphological and, at the same time, a major land degradation process that may cause environmental and property damage, loss of livelihoods and services as well as social and economic disruption. Erosion not only lowers the quantity and quality of soils on-site, but causes also significant sediment-related problems off-site. Addressing the problem of soil erosion therefore requires a thorough understanding of the various erosion processes, their interactions, their controlling factors and their spatial extent. Given the large number of research papers on this topic, one might think that we know now almost everything about soil erosion and its control so that little new knowledge can be added.

This conclusion can be refuted by pointing to some major research gaps. These are: (1) improved understanding of both natural and anthropogenic soil erosion processes and their interactions, (2) scaling up soil erosion processes and rates in space and time, and (3) innovative techniques and strategies to prevent soil erosion or reduce erosion rates.

Many soil erosion assessments have focused on sheet and rill erosion, particularly in cropland, yet an increasing number of field observations also points to other significant water water-erosion related processes (both in cropland as well as in rangeland) such as gully erosion and piping erosion which are rarely incorporated in assessments of soil erosion rates by water. In the Anthropocene, soil losses by human activities (anthropogenic soil erosion) have also become very significant: e.g. tillage erosion, soil erosion by land leveling, soil quarrying, crop harvesting (mainly root and tuber crops), explosion cratering and trench digging. Most soil erosion studies focused on a single erosion process. However, in many environments several erosion processes operate at the same time and may interact with each other resulting in a reinforcement or compensation of soil loss rates. Some examples are wind and water erosion, piping and gully erosion, gully erosion and landsliding, ephemeral gully erosion and tillage erosion/deposition, soil erosion by animal trampling and water or wind erosion. These erosion process interactions call for integrated assessments of soil erosion rates at various spatial and temporal scales. Too often researchers have been biased towards a particular (natural) erosion process. There is however, an urgent need to quantify also anthropogenic soil erosion rates in such assessments.

Addressing these research gaps will (1) allow us to better understand processes and their interactions operating at a range of spatial and temporal scales, to better predict their rates as well as their on-site and off-site impacts, which is academically spoken rewarding, and (2) put us in a better position to select the

most appropriate and effective soil erosion control techniques and strategies which are crucial for a sustainable use of our soils in the Anthropocene.

Keywords: sheet and rill erosion, gully erosion, piping, tillage erosion, land leveling, crop harvesting, anthropogenic erosion, process combinations

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References

Poesen, J. 2018. Soil erosion in the Anthropocene: Research needs. *Earth Surface Processes and Landforms,* 43: 64–84.

Decision supporting framework for foil erosion control and ecosystem services enhancement

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Abstract

The objective of this work is to propose a decision supporting framework for the planning, assessment, and policy of soil and water conservation, by integrating both soil erosion and ecosystem services. The WEB GIS-based portal system was developed as a tool for soil management using various datasets such as those that give soil properties, topography, hydrology, climate, maps, and land use at the watershed level. Through the portal system, soil erosion and quality can be predicted, and soil ecosystem services can be assessed based on soil function indicators, such as biomass production, groundwater recharge, biodiversity, organic carbon storage, and pollution buffering. After both soil erosion and ecosystem services are categorized into five levels, the priority areas for soil conservation can be designated. Soil and water conservation planning can be formulated using the specific best management practices (BMP) at designated areas, followed by the assessment of BMP effects on soil erosion and ecosystem services. The system provides the framework to develop a strategy and policy for soil and water conservation to enhance soil ecosystem services and minimize soil erosion. Accordingly, the conservation policy can incorporate an incentive, such as a direct payment along with a farmer's cross compliance, and this policy can be proposed to policymakers.

Key words: soil erosion, ecosystem services, Web-GIS soil management system, conservation policy

Introduction

Soil erosion is a primary cause of soil degradation. Soil erosion and degradation reduce food production, become threats to climate action and human health, and degrade air and water quality with particulates, sediment, and nutrient runoff. Thus, soil erosion is one of the major soil threats that can decrease the capacity of the soil ecosystem in providing diverse benefits (i.e., ecosystem services) to the environment and humans, which are closely related with the achievement of the UN Development Goals. Ultimately, the goals of sustainable soil management should increase soil ecosystem services and decrease soil threats. If soil erosion and other challenges, including population growth and food security, remain unconstrained from their current rates, humankind may lose the ability to feed itself (Ascough *et al.,* 2018).

A number of soil erosion models, with varying degrees of complexity and spatio-temporal scales, have been developed to predict the amount of soil erosion (empirical models) and to describe the soil erosion process (process-based models). Karydas *et al.* (2012) classified 82 soil erosion models into 8 categories based on spatial scale, temporal scale, and spatial methodology. Process-based models are used to assess the impacts of agricultural practices on water and air quality for both on-site and off-site erosion problems under specific environmental conditions (Ascough *et al.,* 2018). However, modelling output is, in many cases, confined to the assessment of the amount of soil erosion and not further linked to policy for implementation of sustainable soil management.

Ecosystem services (ES) are holistic concepts, and they consist of supporting, provisioning, regulating, and cultural services (MEA, 2005). These services can be estimated by integrating soil functions and properties, and soil values can be assessed quantitatively at different levels based on the ES estimated. Humanity will demand more ES from soil and water resources in the future.

Without implementing policies for conservation practices to confront the challenges that humanity faces in the future, we will not be able to achieve sustainable levels of food production needed to feed the growing world population (Delgado *et al.,* 2011; Sassenrath and Delgado, 2018). Policies for the implementation of sustainable soil management should consider both soil erosion and soil ES. The objective of this presentation is to propose a policy that supports the framework for the goal of sustainable soil management by considering both soil ecosystem services and soil erosion based on case studies in Korea and elsewhere.

WEB-GIS based soil portal system for soil management

The soil portal system (Figure 1) is composed of a data base; soil quality and value estimation modules; a soil erosion prediction module; and information about land use, watershed hydrology, and the climate. Using big data sets that include soil properties and erosion indicators, amounts of soil erosion are predicted by the Korea Soil Loss Equation (KORSLE) (Lim *et al.,* 2018; Rasal *et al.,* 2018), which is a modified version of USLE and predicts monthly soil erosion employing Korean soil and rainfall data. At the same time, soil quality and values are quantitatively assessed based on the ES that a specific soil can provide. Both soil erosion and soil value are categorized into five levels. The portal system can evaluate the impact of the best management practices (BMP) on the changes of soil erosion and ecosystem services, and the results can be the basis for policy development for soil and water conservation.

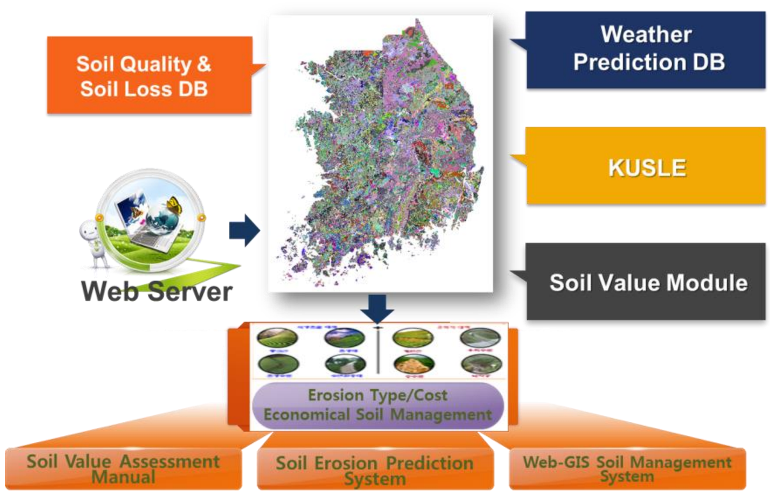

Figure 1: Basic concept of the WEB-GIS soil portal system for soil management.

Framework for soil erosion control and ecosystem services enhancement

Figure 2 shows a schematic flowchart of the framework for the development of a conservation policy to control soil erosion and increase soil ES. Using the soil erosion and ES levels assessed in the portal system, priority areas of soil conservation at the watershed level can be designated. Soil and water conservation planning, based on implementing a specific BMP and its impact assessment, is possible at the watershed level when considering changes of ES values. Accordingly, a conservation policy that incorporates an incentive, such as a direct payment along with a farmer's or land owner's cross compliance, can be proposed to policymakers.

This framework can be modified for different countries having different spatio-temporal scales, and it can depend on data availability. Further long-term validation is definitely needed to improve the credibility of the framework for use by farmers or land owners. However, the proposed framework provides a protocol useful for holistic planning of soil and water conservation and policy implementation.

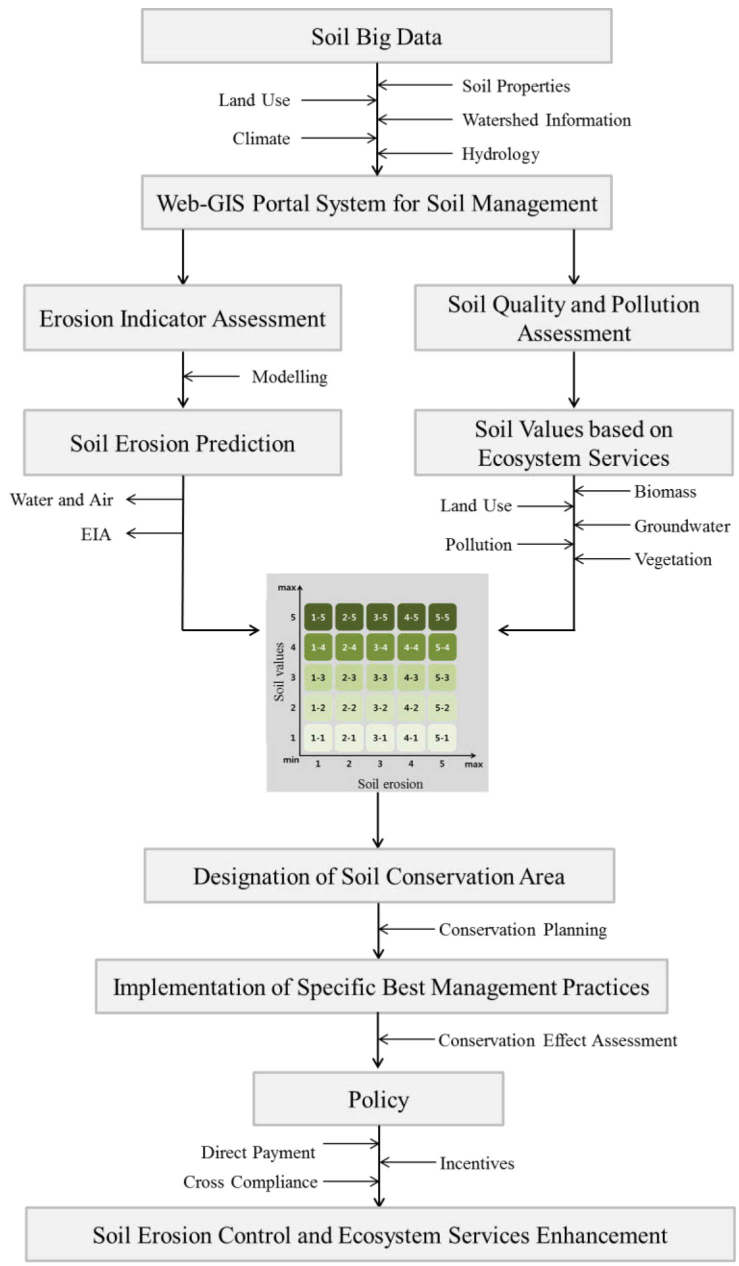

Figure 2: A proposal of the decision supporting framework for soil erosion control and ecosystem services enhancement.

Acknowledgement

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References

Ascough, J.C., Flanagan, D.C., Tatarko, J., Nearing, M.A. & Kipka, H. 2018. Soil erosion modeling and conservation planning. In: J.A. Delgado *et al.* (eds), *Precision conservation: geospatial techniques for agricultural and natural resources conservation.* Agronomy Monograph, Soil Science Society of America, Madison, WI, USA. p.1-25.

Delgado, J.A., Groffman, P.M., Nearing, M.A., Goddard, T., Reicosky, D., Lal, R., Kitchen, N.R., Rice, C.W., Towery, D. & Salon, P. 2011. Conservation practices to mitigate and adapt to climate change. *J. Soil Water Conserv.,* 66:118A-129A.

Karydas, C.G., Panagos, P. & Gitas, I.Z. 2014. A classification of water erosion models according to their geospatial characteristics*. Int. J. Digital Earth*, 7:229-250.

Lim, K.J., Park, Y.S., Kim, M.K., Jeong, J., Engel, B.A., Munoz-Carpena, R. & Kim, J. 2018. Design of vegetative filter strip using web-based system with groundwater table and pesticide degradation analysis modules. *Journal of Hydrological Engineering,* 23(2). DOI: 10.1061/(ASCE)HE.1943-5584.0001611.

Millennium Ecosystem Assessment (MEA). 2005. Millennium Ecosystem Assessment Full Reports. Island Press. Washington, D.C. USA.

Rasal, A., Lim, K.J., Bhattarai, R., Yang, J.E., Noh, H., Pathak, R. & Kim, J. 2018. Development of web-based WERM-S module for estimating spatially distributed rainfall erosivity index (EI30) using RADAR rainfall data. *Catena*, 161:37-49.

Sassenrath, G.F. & Delgado, J.A. 2018. Precision conservation and precision regulation. In: J.A. Delgado *et al.* (eds), *Precision conservation: geospatial techniques for agricultural and natural resources conservation.* Agronomy Monograph, Soil Science Society of America, Madison, WI, USA. p.361-384.

Accelerated Soil Erosion by Water as a Source of Gaseous Emissions

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Abstract

The urgency to limit the global warming to 1.5°C has enhanced interest in the identification of sources and sinks of greenhouse gasses (GHGs). Global land use and land use change (LULUC) are important source of GHGs both directly (i.e., farm operations, soil tillage, drainage of wetlands, grain drying) and indirectly (e.g., hidden carbon costs of inputs such as fertilizer, pesticides, food processing and transport). The atmosphere concentration of CO_2 at 405.5 ± 1 ppm in 2017, 146 % more relative to that in 1750, is increasing at the rate of 2.24 ppm/yr or 0.55%/yr (WMO, 2018). For the decade of 2008 – 2017, total average annual emission of 10.9 Pg C/yr comprised of 9.4 ± 0.8 Pg C/yr from fossil fuel combustion and 1.5 ± 0.7 Pg C/yr from LULUC. Of this, 4.7 ± 0.02 Pg C/yr was absorbed by the atmosphere, 2.4 ± 0.5 Pg C/yr by the oceans, 3.2 ± 0.8 Pg C/yr by land, and the remainder imbalance of 0.5 Pg C/yr (Le Quéré *et al.*, 2019). Thus land-based sinks absorbed about 29.4% of the total emissions. However, not all the sources of GHGs are identified in the global carbon budget presented above. Emission of GHGs from transport, redistribution and deposition of C-laden sediments by water and wind erosion at global scale are not being considered in the global carbon budget. Yet, erosion is a source of GHGs at all the four stages (i.e. detachment, transport, redistribution, and deposition) (Figure 1). Depending upon the soil moisture content and the degree of saturation, soil organic matter (SOM), being transported and deposited by erosional processes, is subject to both aerobic and anaerobic processes leading to emissions of CO_2, CH_4, and N_2O (Worrall *et al.*, 2016). Soil erosion processes by water transport as much as 60.6 Pg C/yr with reservoir trapping (Walling, 2008, 2009). Global soil erosion by water redistributes a large quantity of SOC prone to mineralization under aerobic and anaerobic conditions. Assuming delivery ratio of 10 %, SOC concentration of 2 % and mineralization rate of 20 %, the magnitude of C emitted by erosional processes may be as much as 2.4 Pg C/yr. Lal (2003) estimated the global erosion-induced emissions at 1.1 Pg C/yr. Further, the problem of soil erosion may be exacerbated by the current and projected climate change (Segura *et al.*, 2014). These estimates neither account for the methanogenesis nor the nitrification/denitrification which cause emission of CH_4 and N_2O, respectively. Thus, soil erosion being a large and net source of GHGs (Worrall *et al.*, 2016; Kirkles *et al.* 2014), must be appropriately considered while assessing the global C budget. Further land use and soil/crop management practices must be adopted that can control soil erosion within the permissible limits to minimize the off-site damage of gaseous emission and non-point source pollution. Implementation of negative emission technology, especially those that effectively control soil erosion (i.e., conservation agriculture, vegetative contour hedges) and restore degraded soils (cover cropping, afforestation, 4 per thousand initiative) are important to creating a positive soil/ecosystem carbon budget and removing CO_2 from the atmosphere. Reducing gaseous emissions caused by erosion and restoring degraded and desertified soils are in accord with the goal of achieving land degradation neutrality.

Keywords: Gaseous emissions, sediment transport, climate change, conservation agriculture

Introduction, scope and main objectives

Achieving land degradation neutrality is an important goal of UNCCD and is also integral to the Agenda 2030. Therefore, reducing risks of soil erosion and restoring degraded soils is critical to sustainable land use.

The objective of this article is to describe the impact of erosional processes on the fate of soil organic carbon being transported and redistributed over the landscape, and deliberate innovative soil management options to reduce risks of erosion-induced emission of GHGs. The article is global in geographical scope, but is limited to the emission of CO_2. Erosion-induced emissions of N_2O and CH_4, despite being significant in amount and characterized by high global warming potential, are not specifically discussed in this article.

Methodology

The data presented are based on collation and synthesis of articles published in peer reviewed journals. Information on gaseous emission and the fate of carbon transported at four different stages (Figure 1) was discussed and critically reviewed in this article.

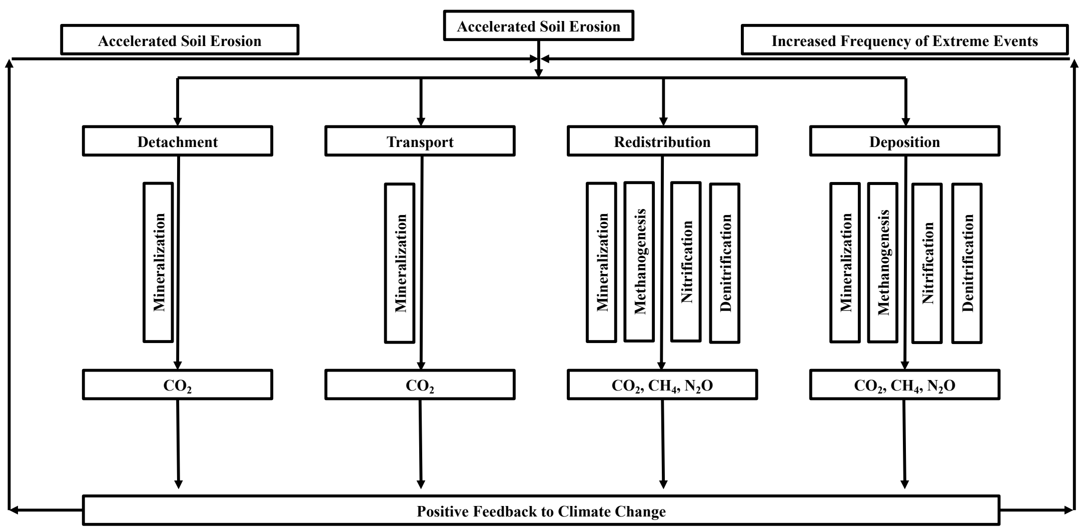

Figure 1: Gaseous emissions at different stages of accelerated soil erosion by water.

Results

Global estimates CO_2 – C emissions by water erosion range from 1.1 Pg C/yr to as much as 2.4 Pg C/yr. However, long-term data on watershed scale are needed to provide credible information on emissions of GHGs from diverse land use systems (e.g., croplands, grazing lands, forest lands, urban lands, mine lands) on major soil groups and eco-regional biomes.

Discussion

There is a strong need to strengthen scientific knowledge on processes, factors, and causes affecting the magnitude of emission of GHGs through soil erosion by water, wind, gravity, and other agents of erosion. Predictive models must be developed and validated against experimental data obtained from long-term field studies conducted on watershed basis.

Conclusions

Accelerated soil erosion is an important source of GHGs. Thus, site-specific conservation-effective management options must be identified and promoted to minimize the C-footprint of agroecosystems, to reduce the off-site impacts, and advance Sustainable Development Goals of the United Nation.

Acknowledgements

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References

Chaplot, V. 2015. Soil erosion contributes significantly to global carbon emissions. *Earth Surface Processes and Landforms*.

Chestney, N. 2012. Soil erosion increasing global warming threat: UNEP. Reuters, London, Environment.

Favis-Mortlock, D.T. & Guerra, A. J. T. 2000. The influence of global greenhouse – gas emissions on future rates of soil erosion: a case study from Brazil using WEPP-CO_2. Schmidt J. (eds) *Soil Erosion*. Springer, Berlin, Heidelberg, pp. 3-31.

Kirkels, F.M.S.A., Cammeraat, L.H. & Kuhn, N.J. 2014. The fate of soil organic carbon upon erosion, transport and deposition in agricultural landscapes — A review of different concepts. *Geomorphology*, 226: 94-105.

Lal. R. 2003. Soil Erosion and the global carbon budget. *Environ Int*, 29(4): 437-50.

Le Quéré, C., Andrew, R.M., Friedlingstein, P., Sitch, S., Hauck, J., Pongratz, J., Pickers, P.A., Korsbakken, J.I., Peters, G.P., Canadell, J.G., Arneth, A., Arora, V.K., Barbero, L., Bastos, A., Bopp, L., Chevallier, F., Chini, L.P., Ciais, P., Doney, S.C., Gkritzalis, T., Goll, D.S., Harris, I., Haverd, V., Hoffman, F.M., Hoppema, M., Houghton, R.A., Hurtt, G., Ilyina, T., Jain, A.K., Johannessen, T., Jones, C.D., Kato, E., Keeling, R.F., Goldewijk, K.K., Landschützer, P., Lefèvre, N., Lienert, S., Liu, Z., Lombardozzi, D., Metzl, N., Munro, D.R., Nabel, J.E.M.S., Nakaoka, S., Neill, C., Olsen, A., Ono, T., Patra, P., Peregon, A., Peters, W., Peylin, P., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Resplandy, L., Robertson, E., Rocher, M., Rödenbeck, C., Schuster, U., Schwinger, J., Séférian, R., Skjelvan, I., Steinhoff, T., Sutton, A., Tans, P.P., Tian, H., Tilbrook, B., Tubiello, F.N., van der Laan-Luijkx, I.T., van der Werf, G.R., Viovy, N., Walker, A.P., Wiltshire, A.J., Wright, R., Zaehle, S. & Zheng, B. 2018. Global Carbon Budget 2018. *Earth System Science Data*, 10(4): 2141–2194. https://doi.org/10.5194/essd-10-2141-2018.

Liang, Y., Lal, R., Guo, S., Liu, R. & Hu, Y. 2018. Impacts of simulated erosion and soil amendments on greenhouse gas fluxes and maize yield in Miamian soil of central Ohio. *Scientific Reports,* 8:520.

Segura, C., Sun, G., McNulty, S. & Zhang, Y. 2014. Potential impacts of climate change on soil erosion vulnerability across the conterminous United States. *Journal of Soil and Water Conservation,* 69(2):171-181.

Walling, D.E. 2008. The changing sediment loads of the world's rivers. *Sediment Dynamics in Changing Environments* (Proceedings of a symposium held in Christchurch, New Zealand, December 2008). IAHS Publ. 325.

Walling, D.E. 2009. The Impact of Global Change on Erosion and Sediment Transport by Rivers: Current Progress and Future Challenges. *UNESCO Soil Water Assessment Programme*, Paris France. ISBN 978-92-3-104135-8.

WMO. 2018, WMO Greenhouse Gas Bulletin: The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2017. Available at: https://public.wmo.int/en/resources/library/wmo-greenhouse-gas-bulletin.

Worrall, F., Burt, T.P. & Howden, N.J.K. 2016. The Fluvial flux of particulate organic matter from the UK: Quantifying in-stream losses and carbon sinks. *Earth Surface Processes and Landforms,* 41(1): 61-71.

Modelling post-fire soil erosion in recently burned areas

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Abstract

Wildfires have become a recurrent threat for many Mediterranean forest ecosystems. The particularities of the Mediterranean climate make this region prone to wildfire occurrence as well as post-fire soil erosion.

The wide recognition of wildfires as a driver for runoff and erosion in forest areas has created a strong demand for model-based tools that can predict the post-fire hydrological and erosion responses as well as the impacts of post-fire land management (e.g. logging and erosion control measures) on these responses.

In this work, we wanted to analyse how well hydrological and erosion modelling results can be transferred between hillslopes, burnt areas and post-fire land management operations. To this end, we performed a series of model calibration and validation exercises using a compilation of data sets from several field experiments in recently burnt areas in north Portugal and north-west Spain. The selected models were the Revised Universal Soil Loss Equation and the revised Morgan-Morgan-Finney model. The prior studies with the individual data sets found the performance of both models to be satisfactory, both without and with erosion mitigation measures. The preliminary results obtained here, however, suggested that a standardised model parameterization across the study region might have a limited model performance, especially at sites with elevated soil burn severity.

Keywords: wildfire, post-fire impacts, runoff, soil erosion, RUSLE, MMF, calibration-validation

Introduction, scope and main objectives

Wildfires have been a recurrent threat in the Mediterranean since the Holocene (Burjachs and Expósito, 2014). This especially applied to the Iberian Peninsula, where some 100 000 hectares of woodlands burn every year (San-Miguel-Ayanz *et al.*, 2017). The Mediterranean's wildfire regime is expected to further intensify because of climate and socio-ecological changes (Turco *et al.*, 2016; Nunes *et al.*, 2018).

Fire-induced changes in forest hydrology and geomorphology can deteriorate forest ecosystem services, including provisioning of raw materials, (drinking) water delivery, erosion and flood control, and biodiversity maintenance (Carvalho-Santos *et al.*, 2016; Nunes *et al.*, 2018). One of the best-studied fire impacts is that on soil erosion. Fire typically enhances soil erosion, due to removal of vegetation and litter combined with heating-induced changes in topsoil properties (Shakesby, 2011; Moody *et al.*, 2013; Shakesby *et al.*, 2016).

The erosion response of burnt areas tends to be highly complex, depending on the interplay of several factors such as burn severity, rainfall regime, slope angle and length, soil infiltration capacity and protective ground cover (Moody *et al.*, 2013). Erosion models are viewed as valuable tools for guiding post-fire land management decisions, for example on the need to apply erosion mitigation or ecosystem restoration measures (Fernández *et al.*, 2010; Robichaud and Ashmu, 2012; Fernández and Vega, 2016). The main challenge, however, is that these models need to be validated and, typically, calibrated using field data to achieve acceptable uncertainties in their predictions (Larsen and MacDonald, 2007; Fernández *et al.*, 2010; 2016).

In the Mediterranean region, post-fire erosion modelling studies have focused on the plot-to-field scale but have typically been hampered by rather limited field data sets for a robust model assessment (Vieira *et al.*, 2018). To address this research gap, the present study has compiled the data from a large number of field experiments that have been carried out in the western part of the Iberian Peninsula over the past decade. This extensive data set is used here for a comprehensive comparison of the performance of two contrasting erosion models, to predict the post-fire erosion response both without and with selected land management measures. The empirical (RUSLE) and semi-empirical (MMF) models were selected for their reduced data input requirements, as our ultimate goal is to extend this work to the entire SUDOE region.

Methodology

This study focuses on post-fire land management by mulching-based erosion mitigation measures, as their effectiveness in burnt areas is now well established to the point that they are now being applied on a routine basis in operational post-fire land management in the USA as well as Galicia. The compiled data set covered a range of different mulch materials (eucalypt forest residues, hydromulch, pine needles, pine chips, straw). As shown in Figure1, parameterization of both models (RUSLE, Renard *et al.*, 1997; MMF, Morgan, 2001) explicitly addressed ground cover removal by fire and its reestablishment by mulching, post-fire reduction in infiltration as a result of (enhanced) soil water repellence (Keizer *et al.*, 2008; Shakesby, 2011) was also explicitly addressed in both models but only for the seasonal predictions.

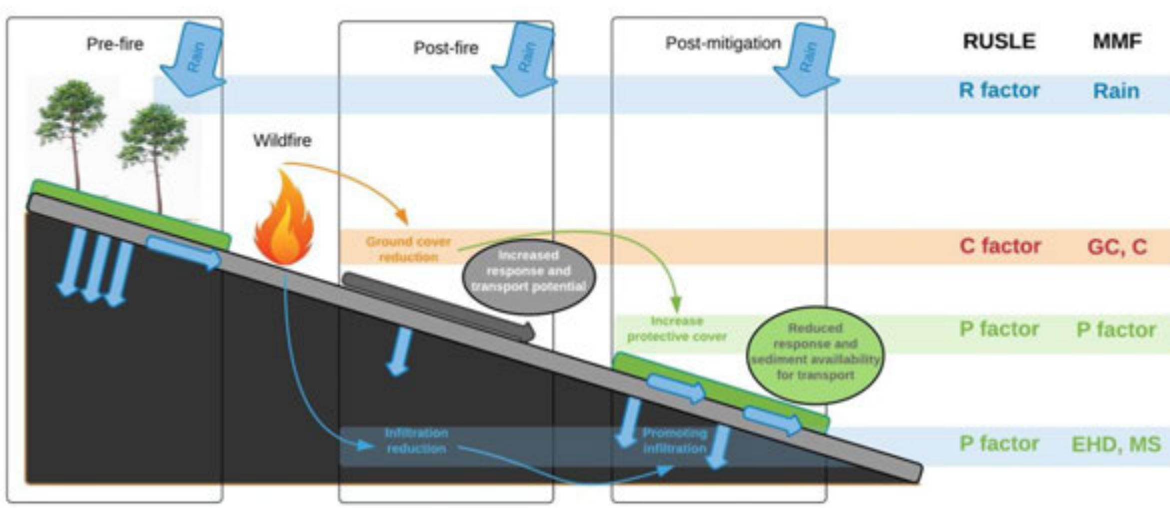

Figure 1: Post-fire runoff-erosion processes and their parameterization in the RUSLE and MMF models (adapted from Vieira *et al.*, 2018).

Results

Table 1 gives an overview of the modeling results obtained by the previous studies on NW Spain and N Portugal. Overall, the calibration of RUSLE by Fernández *et al.* (2010) and Vieira *et al.* (2018) provided satisfactory modeling results, as both the NSE and R^2 were above 0.5. Even so, Vieira *et al.* (2018) noted a tendency for annual sediment losses to be underestimated for the untreated plots and to be overestimated for the mulched plots. MMF appeared to perform similarly well as RUSLE in Fernandez *et al.* (2010) but somewhat better than RUSLE in Vieira *et al.* (2018). In Vieira *et al.*, (2018), MMF allowed a clear distinction between untreated and mulched plots, independent of the type of mulch used, and its calibration (Calibration 6) was accurately validated at higher scale (Validation 6a), as well in other locations (Validation 6b).

Modelling efforts with the compiled data set are still ongoing but the preliminary results suggested that model performance is reduced by using a standardised model parameterization across the study region. This reduction is most noticeable for sites with high soil losses, for example in case of elevated soil burnt severity.

Table 1: Model efficiency obtained in prior studies for predicting post-fire soil erosion for different land uses. Nash-Sutcliffe efficiency coefficient - NSE, coefficient of determination - R2, Root mean square error – RMSE, percent of bias – PBIAS.

Land use	Models	time-step	Calibration or Validation	Location	Size (m^2)	NSE	R^2	PBIAS	RMSE	Publication
Pine and Shrub-land	RUSLE	annual	Calibration 1	Verín and Soutelo, Spain	500	0.87	-	-	6.3	Fernández *et al.*, 2010
	MMF	annual	Calibration 2	Verín and Soutelo, Spain	500	0.74	-	-	9	
Pine and Euca-lypt	MMF	annual	Calibration 3	Pessegueiro do Vouga, Portugal	16	0.55	-	-		Vieira *et al.*, 2014
	MMF	seasonal	Calibration 4	Pessegueiro do Vouga, Portugal	16	0.89	-	-	0.9	
	MMF	annual	Validation 4	Caramulo, Portugal	16	0.93	-	-	0.12	
Pine	RUSLE	annual	Calibration 5	Colmeal, Portugal	0.5	0.63	0.75	-11.7	1.06	Vieira *et al.*, 2018

	RUSLE	annual	Validation 5	Colmeal, Portugal	10	0.70	0.89	-20.1	1.62	
	MMF	annual	Calibration 6	Colmeal, Portugal	0.5	0.97	0.98	5.2	0.3	
	MMF	annual	Validation 6a	Colmeal, Portugal	10	0.77	0.79	1.9	1.43	
	MMF	3 months	Validation 6b	Loriga, Portugal	16	0.70	0.80	5.5	1.2	Un-published

Discussion

Although RUSLE and MMF differ in underlying concepts, both models seem reasonably suitable to estimate soil losses following wildfire as well as mulch-based erosion mitigation measures. In support of operational post-fire land management, RUSLE would seem most suited for a "quick&dirty" identification of burnt areas with elevated erosion risk that are upstream of relevant values-at-risk. In a second phase, MMF could be applied to these priority areas, to assess the connectivity between hillslopes and the streams with the relevant downstream values-at-risk. In a third phase, MMF could be then used to elaborate and test plans for post-fire interventions.

Conclusions

Comparison of existing studies using RUSLE and MMF to model post-fire erosion in the western Iberian Peninsula as well as initial RUSLE and MMF results for a comprehensive, multi-site field data set across this same region indicated as main conclusions that:

1. both models can give satisfactory predictions of soil losses for recently burnt areas, including following mulching in order to reduce erosion risk;
2. both models can be calibrated using field data from small erosion plots (<1 m^2) to obtain satisfactory predictions for substantially larger plots (10 m^2);
3. a comprehensive assessment of both models for burnt areas still require substantial additional efforts, including through field monitoring of emergency stabilization measures applied in operational settings;
4. assessing soil burn severity and predicting post-fire vegetation recovery are two key challenges for accurately predicting post-fire erosion with both models.

Acknowledgements

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References

Burjachs, F. & Expósito, I. 2015. Charcoal and pollen analysis: Examples of Holocene fire dynamics in Mediterranean Iberian Peninsula. *Catena,* 135: 340-349.

Carvalho-Santos, C., Nunes, J.P., Monteiro, A.T., Hein, L. & Honrado, J.P. 2016. Assessing the effects of land cover and future climate conditions on the provision of hydrological services in a medium-sized watershed of Portugal. *Hydrol. Process*., 30: 720–738.

Fernández, C. & Vega, J.A. 2016. Evaluation of RUSLE and PESERA models for predicting soil erosion losses in the first year after wildfire in NW Spain. *Geoderma,* 273: 64-72. https://doi.org/10.1016/j.geoderma.2016.03.016.

Fernández, C., Veja, J.A. & Vieira, D.C.S. 2010. Assessing soil erosion after fire and rehabilitation treatments in NW Spain: performance of RUSLE and revised Morgan–Morgan–Finney models." *Land Degrad. Develop*., 21(1): 58-67.

Keizer, J.J., Doerr, S.H., Malvar, M.C., Prats, S.A., Ferreira, R.S.V., Oñate, M.G., Coelho, C.O.A. & Ferreira, A.J.D. 2008. Temporal variation in topsoil water repellency in two recently burnt eucalypt stands in north-central Portugal. *Catena,* 74: 192-204.

Larsen, I.J. & MacDonald, L.H. 2007. Predicting postfire sediment yields at the hillslope scale: Testing RUSLE and Disturbed WEPP. *Water Resources Research,* 43(11).

Moody, J.A., Shakesby, R.A., Robichaud, P.R., Cannon, S.H. & Martin, D.A. 2013. Current research issues related to post-wildfire runoff and erosion processes. *Earth-Science Reviews*, 122: 10–37.

Morgan, R.P.C. 2001. A simple approach to soil loss prediction: A revised Morgan–Morgan–Finney model. *Catena,* 44: 305–322.

Nunes, J.P., Naranjo Quintanilla, P., Santos, J.M., Serpa, D., Carvalho-Santos, C., Rocha, J., Keizer, J.J. & Keesstra, S.D. 2018. Afforestation, Subsequent Forest Fires and Provision of Hydrological Services: A Model-Based Analysis for a Mediterranean Mountainous Catchment. *Land Degrad. Develop*., 29: 776 -788.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. & Yoder, D.C. (co-ordinators). 1997. Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE). Agriculture Handbook n- 703. USDA, Natural Resources Conservation Service: Washington, DC.

Robichaud, P.R. & Ashmun, L.E. 2012. Tools to aid post-wildfire assessment and erosion-mitigation treatment decisions. *International Journal of Wildland Fire,* 22: 95–105.

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Libertà, G., Branco, A., de Rigo, D., Ferrari, D., Maianti, P., Vivancos, T.A., Schulte, E. & Loffler, P. 2017. Forest Fires in Europe, Middle East and North Africa 2016. EUR 28707 EN, Publications Office, Luxembourg, 2017, ISBN 978-92-79-71292-0.

Shakesby, R.A. 2011. Post-wildfire soil erosion in the Mediterranean: Review and future research directions. *Earth-Science Reviews,* 105: 71–100.

Shakesby, R.A., Moody, J.A., Martin, D.A. & Robichaud, P.R. 2016. Synthesising empirical results to improve predictions of post-wildfire runoff and erosion response. *International Journal of Wildland Fire,* 25: 257–261.

Turco, M., Bedia, J., Di Liberto, F., Fiorucci, P., von Hardenberg, J., Koutsias, N., Llasat, M., Xystrakis, F. & Provenzale, A. 2016. Decreasing Fires in Mediterranean Europe. *PLoS ONE,* 11(3): e0150663.

Vieira, D.C.S., Prats, S.A., Nunes, J.P., Shakesby, R.A., Coelho, C.O.A. & Keizer, J.J. 2014. Modelling runoff and erosion, and their mitigation, in burned Portuguese forest using the revised Morgan-Morgan-Finney model. *Forest Ecology and Management,* 314:150-165.

Vieira, D.C.S., Serpa, D., Nunes, J.P.C., Prats, S.A., Neves, R. & Keizer, J.J. 2018. Predicting the effectiveness of different mulching techniques in reducing post-fire runoff and erosion at plot scale with the RUSLE, MMF and PESERA models. *Environmental Research,* 165: 365-378.

Theme 1: Soil erosion assessment tools and data; creation, consolidation and harmonization

Badland and gully erosion assessment using remotely sensed data, non-invasive field techniques and stochastic modelling approaches

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Abstract

Badlands and gullies are a typical erosional landform occurring prevailingly in semiarid to sub-humid areas. Badland and gully formation processes are driven by i) natural settings, like highly erodible soils and substrates, intensive precipitation and/or scarce vegetation cover and by ii) human activity such as climate change or land use change. In this study we present an assessment of different badland and gully erosion areas in Italy, Canada and Southern Africa. Therefore, we applied innovative detection methods based on aerial photo interpretation and satellite remote sensing applications to derive detailed inventories. Moreover, we show how driving factors can be assessed using stochastic modelling approaches, multispectral satellite data and high-resolution global DEM information. The information about driving factors and environmental settings finally allows a spatial assessment of badland and gully erosion susceptibilities.

Keywords: Badlands, gully erosion, stochastic modelling, multispectral data, Terrain Analysis

Introduction, scope and main objectives

Semiarid to sub-humid climates such as the Mediterranean regions, are more and more affected by the interacting pressures of climatic and anthropogenic environmental changes, driving the environmental systems towards almost irreversible modifications (Scheffer *et al.*, 2001; Märker *et al.*, 2011). Several studies analysed the wide-ranging consequences of these changes in terms of land degradation and erosion processes and the issues they raise for land management (Wainwright and Thornes, 2003). Moreover, the socio-economic context is rapidly changing. In this context Badlands and gully areas are highly-erosive landscapes that are characterized by severe degradation processes. Badlands as well as gullies are considered as areas endangering agricultural activities though they have important ecological functions and are often hotspots of biodiversity.

There is a long history in studying i) the factors influencing the soil erosion processes and the resulting forms, ii) the dynamics of soil erosion processes, and iii) the spatial and temporal scales covered by these processes (e.g. Alexander, 1980; Clarke and Rendell, 2000; Capolongo *et al.*, 2008). However, studies are often conducted at the plot scale and only little work has been done on sub-catchment or catchment scale. Especially for the assessment of soil erosion processes and related sediment transport it is essential to know at which locations in the catchment what kind of process is active or might become active. Thus, methods were proposed that use relevant environmental and socioeconomic information to determine the disposition to specific erosion processes (e.g. Märker *et al.*, 2011).

In this study we present an integrated approach that applies innovative detection methods based on aerial photo interpretation and satellite remote sensing to derive detailed badland and gully erosion inventories. Moreover, we show how driving factors can be assessed using stochastic modelling approaches, multispectral satellite data and high-resolution global DEM information. The information about driving factors and environmental settings finally allows a spatial assessment of badland and gully erosion susceptibilities.

Methodology

The characterisation of badlands and gully systems in the three study areas followed a common systematic approach that consists in different steps illustrated by the flow chart (Figure 1) and described below.

Identification of forms and features

Badlands and gully systems were identified and mapped through field observations as well as Orthophotos, Google Earth and UAV based image interpretation (Zakerinejad & Märker 2014; Flügel & Märker 2002). Subsequently, a morphological classification of badland areas and gully systems' forms and features was performed based on the remotely sensed information and their interpretation, following specific classifications like the ones developed by Moretti and Rodolfi (2000) or Van Zuidam (1989). Finally, an inventory map of the study area or of a smaller characteristic sub catchment can be generated and used as dependent or target variable in the stochastic modelling approach.

Derivation of environmental predictors

The morphometric factors (Slope, Aspect and General Curvature etc.) were automatically derived from a digital elevation model (DEM). In this study we used TerraSAR-X with 30m resolution, TanDEM-X DEM with 12.5 m cell size and a local Canadian model (SGIC) with 15 m resolution. The DTMs were hydrologically corrected to eliminate sinks. The DEM derivatives as well as additional information such as landuse maps or lithology/geology maps, soil maps were used as environmental predictor or independent variable.

Stochastic modelling approaches

In order to get information on the triggering factors and the spatio-temporal distribution of the badland forms and gully systems data mining techniques can be applied (e.g. Vorpahl *et al.,* 2012). Common practices involve the use of stochastic and/or data mining methods relying on presence/absence techniques (e.g. Lombardo *et al.*, 2014) for calibrating the predictive model. If classified target variables are used classification methods such as Boosted regression trees (e.g. Treenet) can be applied. If instead the target variable is consisting of only one class or one feature, presence-only approaches can be applied such as the Maximum Entropy (MaxEnt) (e.g. Phillips and Dudik, 2008; Park, 2014).

Model validation techniques

Normally, the dataset is split in a test and a train dataset for validation purposes (e.g. 75 % train data and 25 % test data). The model performance can be investigated by the the area under the receiver operating characteristics curve (AUC), which represents true occurrence predictions as a function of false occurrence predictions (Swets, 1988). The area under this curve (AUC) theoretically ranges from 0 to 1. A random model would result in an AUC value of 0.5, while a perfect model discrimination leads to an AUC value of 1.

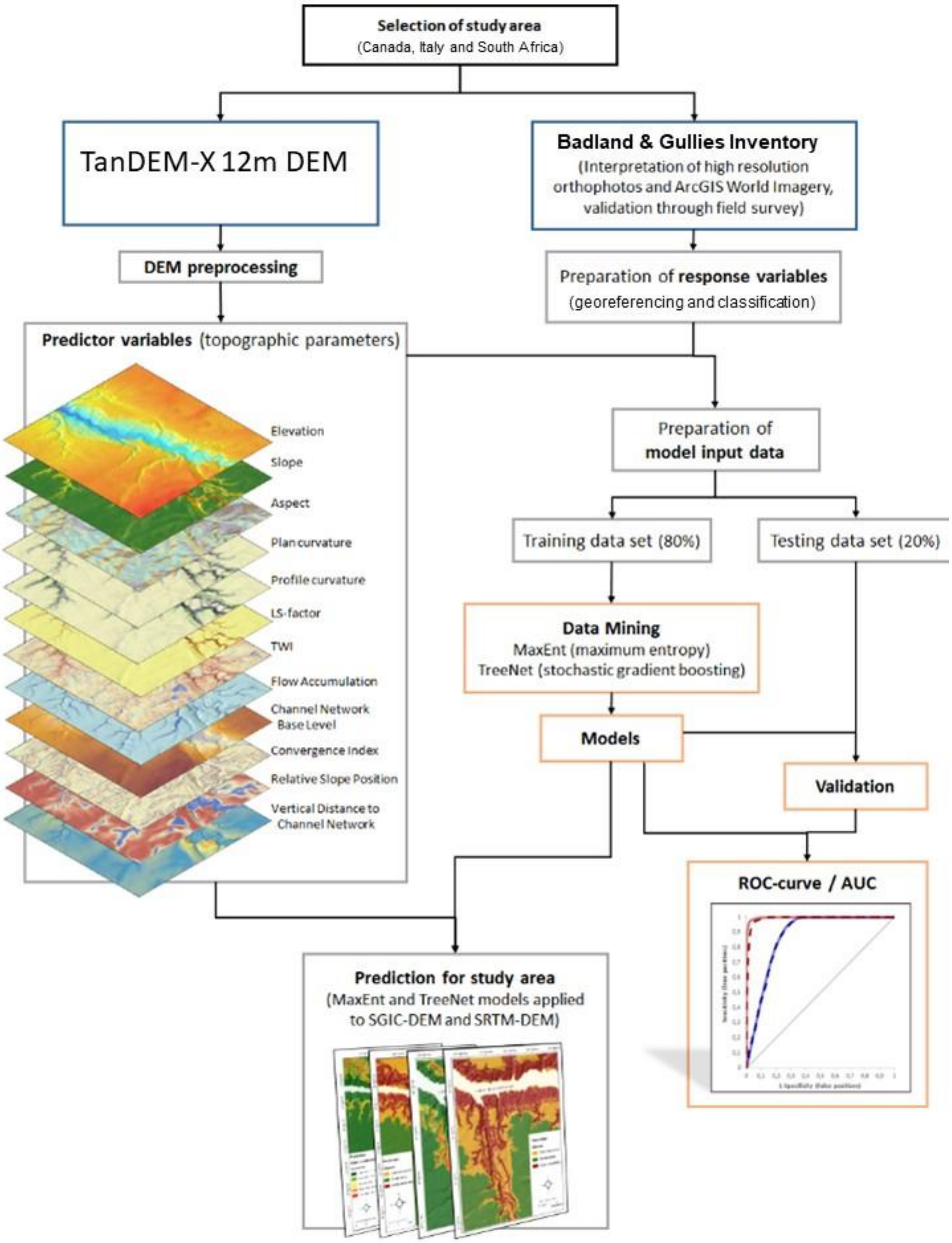

Figure 1: Flow chart of Methodological approach used in the three study areas in Canada, Italy and South Africa

Results

In the following we show preliminary results of analysis we conducted in Canada (Lake Diefenbaker), South Africa (Kwa Zulu Natal/ Mkomaazi basin) and Italy (Oltrepo Pavese).

In Figure 2 the distribution of badland areas in the Oltrepo Pavese is shown. The badlands have been classified according to Moretti and Rodolfi (2002) in two classes. This information is used then in the modelling phase as dependent or target variable. In the next step the independent variables or predictor variables were prepared. In the modeling procedure we use DEM derivatives such as illustrated in Figure 3a and b (Lake Diefenbaker, Canada), as well as additional information on landuse and substrates (soils, geology, lithology).

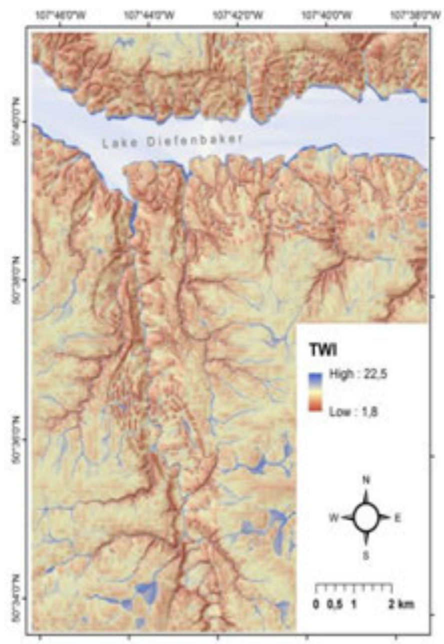

Figure 2: Badland (Calanchi) inventory of the Oltrepo Pavese (b) Example of Calanchi type A; (c) Example of Calanchi type B. (from Bosino *et al.* in press)

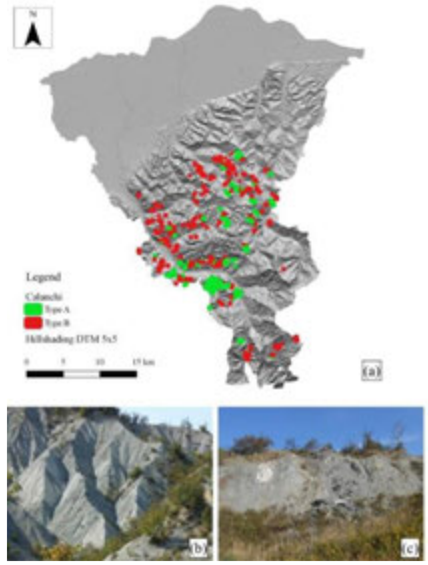

Figure 3a and b: Examples for predictor variables: a) LS-Factor b) Topographic Wetness Index

We conducted a detailed terrain analysis based on different DEMs with 12.5 m; 15 m and 30 m resolution. We separated the dataset in test and train data for model validation. In Figure 4 we illustrate some AUC plots of the Lake Diefenbaker area in Canada. Normally different methods are tested to assess model performance and robustness. Here, MaxEnt and a Treenet (Boosted Regression Trees) model are illustrated in Figure 4 with train and test data. As shown Boosted regression trees perform generally better. However, the models show a good robustness since all AUC values are above 0.8 (excellent performance) for both, test and train data sets. Moreover, also the variable importance can be assessed by the models.

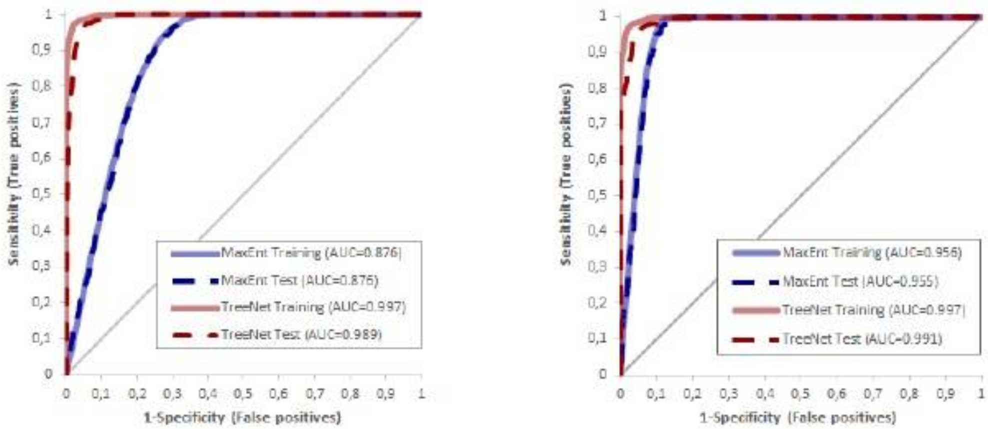

Figure 4: AUC curves for badland areas in the Lake Diefenbaker, Canada. Different modelling approaches are reported for two different DEM resolutions. Left 15 m; Right 30 m resolution

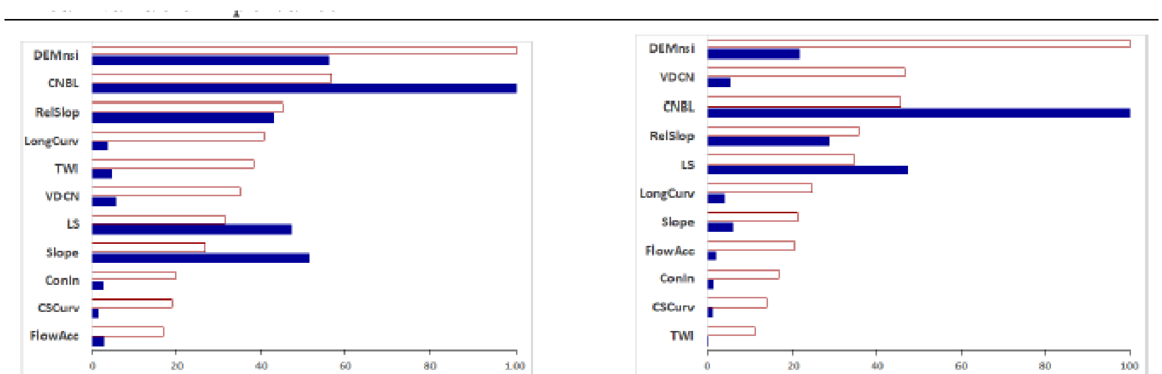

Figure 5: Variable importance for 15m (left) and 30m DEM resolution (right) for MaxEnt (blue) and Treenet (red).

The variable importance reported in Figure 5 shows that the approach is consistent concerning the different models. However, some differences can be noted for the two DEM resolutions.

Discussion

The presented integrated method allows an assessment of badlands and gully forms and features. Aerial Photo Interpretation and/or Remote Sensing/UAV data interpretation together with fieldwork yield forms and processes inventories. Using environmental information on Landuse/Landcover, Geology, Lithology and Soil available through maps and digital data as well as DEMs, and DEM derivatives form terrain analysis we have valuable information to assess the processes driving forces. Therefore, we can apply stochastic modelling approaches that must be evaluated using train and test data in order to guarantee a proper model performance and robustness of the modelling results. As shown, one should test different spatial resolutions that are fitted to the respective process investigated. If the models are validated and calibrated successfully, they yield also information about the potential spatial distribution (susceptibility) of the process's forms and features.

Conclusions

The integrated method presented in this study was applied successful in three different semiarid to sub-humid environments. We were able to define and discriminate the forms and features related to badlands and gully erosion. Thus, we derived inventory data, that together with additional environmental information was stochastically assessed. The stochastic model applications yield valuable information about the process drivers as well as on the spatial distribution of process potentials, the so-called susceptibility. This is a major step forward in river catchment scale assessment of soil erosion processes. Once we know where processes might occur, we can apply coping and mitigating strategies to prevent soil loss.

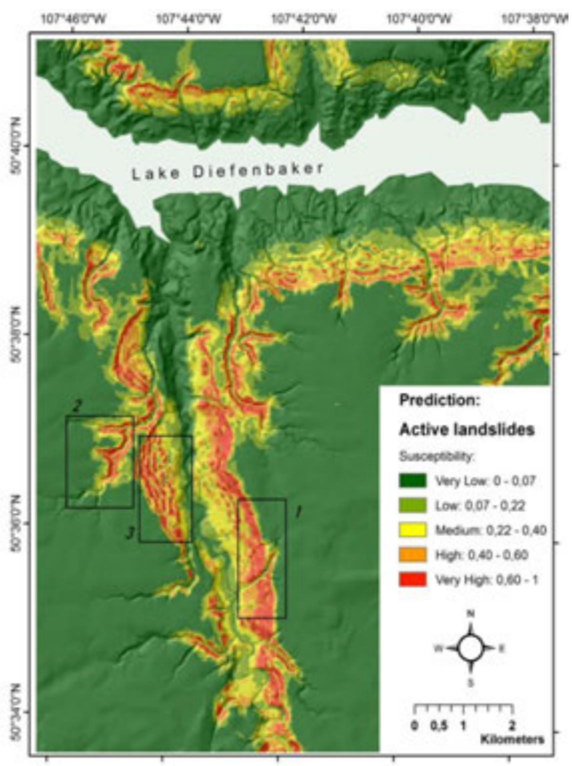

Figure 6: Spatial distribution of susceptibility of badlands and gullies showing active landslides using MaxEnt and the 15, SGIC DEM. Susceptibilities in %.

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References

Alexander, D.E. 1980. I Calanchi — accelerated erosion in Italy. *Geography,* 65: 95–100.

Bosino, A., Omran, A. & Maerker, M. in press. Identification, characterization and analysis of the Oltrepo Pavese Calanchi in the northern Apennines, Italy. Submitted to Geomorphology.

Capolongo, D., Pennetta, L., Piccarreta, M., Fallara, G. & Boenzi, F. 2008. Spatial and temporal variations in soil erosion and deposition due to land-levelling in a semiarid area of Basilicata (Southern Italy). *Earth Surface Processes and Landforms*, 33: 364–379.

Clarke M.L. & Rendell, H.M. 2000. The impact of the farming practice of remodeling hillslope topography on badland morphology and soil erosion processes. *Catena,* 40(2): S. 229-250.

Flügel, W.A. & Märker, M. 2002. The Response Units Concept and Its Application for the Assessment of Hydrologically Related Erosion Processes in Semiarid Catchments of Southern Africa. *ASTM STP,* 1420: 163-177.

Lombardo, L., Cama, M., Maerker, M. & Rotigliano E. 2014. A test of transferability for landslides susceptibility models under extreme climatic events: application to the Messina 2009 disaster. *Natural Hazards,* 74(3): 1951–1989.

Märker, M., Pelacani, S. & Schröder, B. 2011. A functional entity approach to predict soil erosion processes in a small Plio-Pleistocene Mediterranean catchment in Northern Chianti, Italy. *Geomorphology,* 125(4): 530-540.

Moretti, S. & Rodolfi, G. 2000. A typical calanchi landscape of the Eastern Appennine margin (Atri, Central Italy): geomorpholog-ical features and evolution. *Catena*, 40:217–228.

Park, N.W. 2014. Using maximum entropy modeling for landslide susceptibility mapping with multiple geoenvironmental data sets. *Environment and Earth Science,* 73(3): 937–949.

Phillips, S.J., Dudık, M. & Schapire, R.E. 2004. A maximum entropy approach to species distribution modeling. Proceedings of the 21st International Conference on Machine Learning. ACM Press: New York; 655–662.

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C. & Walker, B. 2001. Catastrophic shifts in ecosystems. *Nature*, 413: 591–596.

Swets, J.A. 1988. Measuring the accuracy of diagnostic systems. *Science*, 240 : 1285–1293.

Van Zuidam, R.A. 1985. Terrain analysis and classification using aerial photographs. International institute for aerial survey and earth sciences, ITC-TextbookVII-6, 2. Aufl., Enschede.

Wainwright, J. & Thornes, J.B. 2003. Land degradation in drylands: current science and future prospects. *Special Issue: Advances in Environmental Monitoring and Modelling,* 1(2).

Zakerinejad, R. & Märker, M. 2014. Prediction of Gully Erosion Susceptibilities using detailed Terrain Analysis and Maximum Entropy Modeling: A case study in the Mazayjan Plain, Southwest Iran. *Geografia Fisica e Dinamica Quaternaria,* 37(1): 67-76.

Resilience of red ferralitic soils in the karst regions of Mayabeque, Cuba

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Abstract

There is an ongoing global debate on soil degradation, its magnitude and agro-environmental impact, where long-term experimentation provides quantitative criteria for its capacity for restauration with rational use and management. In this context, research in the last 30 years has confirmed that the resilience of Red Ferralitic soils in the karst regions of western Cuba is a multifactorial process, conditioned not only by the intrinsic properties of the soil surface and use conditions, but also dependent on geological-geomorphological and use conditions. This study determined the capacity of Red Ferralitic soils for blocking karst-erosion to be a period of 50 years in the San Jose de Las Lajas polje. They would recover, but depending on the amount of limestone impurities, it would take from 100 to 600 years. In any case, there are very few similar studies, not only because of the time necessary to achieve reliable results, but because in the case of karst ecosystems, they are subjected to constant disturbances impeding resilience research.

Keywords: erosion, karst regions, polje, resilience

Introduction

One important limitation of most ecological studies, especially when they deal with practical applications, is that they have been done in relatively small areas and for short periods of observation or experimentation. However, the phenomena being studied occur on different spatial-temporal scales, which could span thousands of hectares or hundreds of years. The design of long-term studies on karst ecosystem management generates practical results and significant contributions to their understanding and justifies the research done over the last 30 years by Febles González *et al.* (2014) in Red Ferralitic soils in the southern Habana - Matanzas Karst Plain.

This is particularly important, since Red Ferralitic soils, with an area of 5 731 km^2, represent 23.56 % of Cuban farmland and occupy 80 – 85 % of the karstified surface of the of Mayabeque and Artemisa Provinces, coinciding with the most productive agricultural areas, heaviest population density and most important watersheds in the territory (Febles González *et al.,* 2009), with strategic importance for national food security and unquestionable value as soil assets.

With this background in mind, the purpose of this study was to evaluate the resilience of Red Ferralitic soils to water and karst erosion in reference sites in the karst plain in Mayabeque Province.

Resilience of Red Ferralitic soils

Soil degradation is a major problem in Cuban agriculture and there are a diversity of approaches for evaluating soil erosion based on a very superficial adaptation of the Soil Survey Staff (1951) classification, which does not objectively express the specific types of soil cover erosion in Western Cuban karsts, nor the capacity for resilience proposed by Kay *et al.* (1994), Lal (1997, 1998), Blanco-Canqui & Lal (2008). Where soil resilience (Rs) may be defined as the rate of change in soil quality (Sc) over time (t).

$$R_S = ds_C \,/\, dt \cong \Delta s_C \,/\, \Delta t \qquad (1)$$

It is noteworthy that none of these values for estimating the time required to reach steady state or recover potential ecosystem services was arrived at in karst regions.

Methods

Description of study areas

This study was carried out at sites in the middle of Mayabeque Province, specifically in the San José de Las Lajas polje at the Rosafé Signet and Aljibe reference locations (Figure 1), with soils historically subjected to tropical anthropogenesis, where karst-erosion dynamics show different degrees of development depending on the use and management conditions to which they have been subjected in the last 30 years.

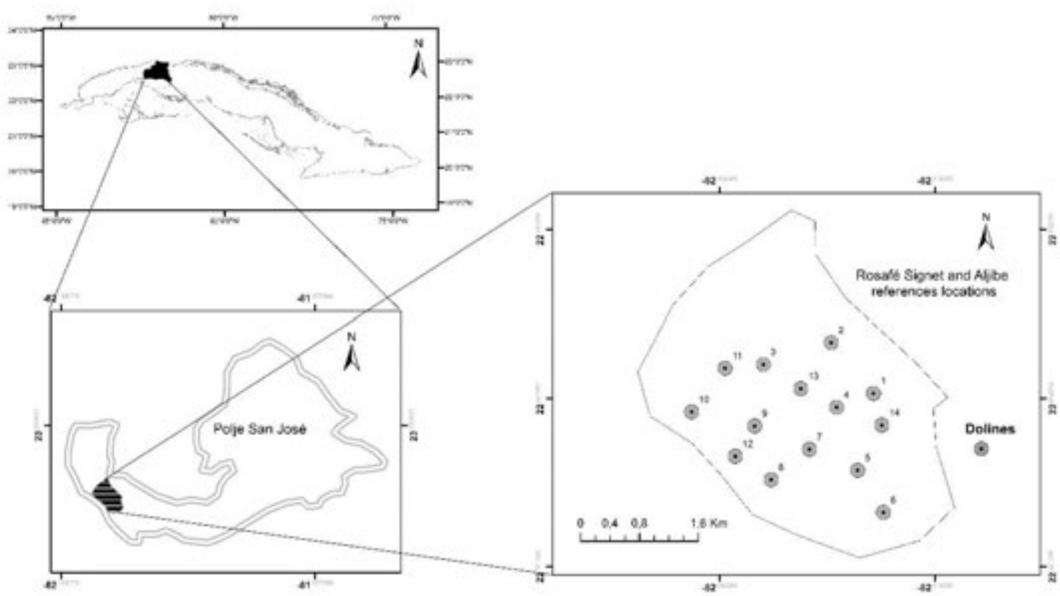

Figure 1: Location of the towns Rosafé Signet and Aljibe in the polje San José de Las Lajas. Mayabeque Province, Cuba

The soil samples were taken from dolines and sectors of influence with a drill in a radial scheme including a total of 122 points and 12 main profiles and control, and were described following the methodology proposed by Febles González *et al.* (2014). Sampling and characterization were done to depths never less than 100 cm to examine by descriptive-comparative analysis the manifestation and intensity of erosion related to climate factors, plant cover and soil characteristics.

The $C_{1(\textbf{no apparent erosion})}$, located in an area of biostasy and with an original $A_{0-490\ mm}$ horizon depth was taken as the reference, to evaluate the magnitude of Red Ferralitic soil loss in various scenarios across karst depressions applying the MMF model (Morgan, 2001), considering climate variability and its physical, physicochemical and chemical properties (Vega and Febles González, 2006).

The equation by Kay *et al.* (1994) was used to calculate resilience as follows:

$S_{(t)} = S^0 + S_{max}(1 - exp^{-k\,(t - t1)})$ (2)

Where S^0 (mm) is the value of S when a new use of the soil starts, where t = starting time, S_{max} is the maximum change predicted in S, k (mm yr^{-1}) is the rate constant and t_1 is the time since introduction of the new soil use during the measurement period (t = 0).

Results and Discussion

Resilience of Red Ferralitic soils in the San José de Las Lajas Polje

Application of equation (2) takes the results of studies done by Febles González *et al.* (2012) as its reference to simulate the time that Red Ferralitic soils would take to reach steady state in this subregion.

$S_{(t)} = 1.078 + 490.02(1 - exp^{(k*years)})$ *(3)*

S^0 =1.078 mm is the measured Red Ferralitic soil loss per years recorded *in situ* under cultivated pastures in 1986 - 2009.

S_{max}=Profile $C_{1(\textbf{No apparent erosion})}$, described by Febles González *et al.* (1986), located in an area in biorhexistasy, with a starting depth in the A horizon of 0 – 490 mm

According to the selected soil formation rates, under normal agricultural practices, 100 % of the $A_{0-490\ mm}$ horizon would be renewed in 50 years, while depending on the percentage of impurities in the limestone, that same depth would be reestablished in 100 and 600 years respectively, since limestones dissolve slowly releasing their insoluble impurities which increase the depth of the overlying soil as eluvium. This eluviation process is slow and has lasted for hundreds of thousands to a few million years.

It is worth mentioning that renovation of the A horizon in these time lapses, are assumed considering exclusively Red Ferralitic soil properties and not the geological environment associated with its genesis and evolution, since the equation does not consider the inevitable widening of the karst depressions or "dolinization" of the polje, possible changes in use of cover, impact of extreme hydro meteorological events associated with climate change, seismic movements and so forth, which make recovery of the soil much slower and even irreversible if it arrives at its paroxysmal stage or soil retrogression, which coincides with the results of Wang *et al.* (2004) and Jaimez (2006) in similar regions. Based on the results shown on, three scenarios all are equally valid. Coefficient k=0.25 under normal agricultural practices (Pimentel *et al.,* 1995) represents natural recovery of ecosystem on agriculture practice. While k=0.05 and 0.01 represent the recovery of the system under not sustainable agriculture practice (Figure 2).

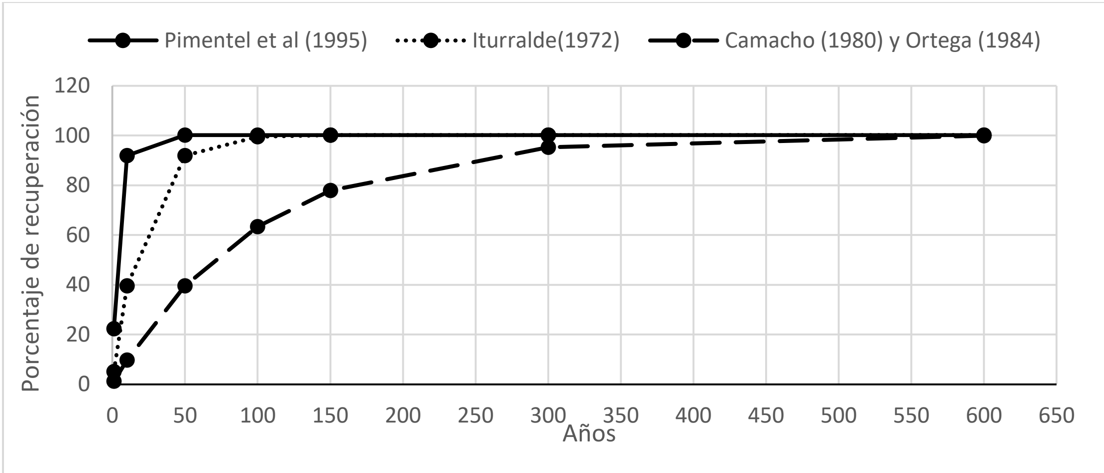

Figure 2: Resilience of Red Ferralitic soils in the Rosafé Signet and Aljibe localities, Mayabeque Province, Cuba

Permanent cultivation of pastures since 1966 has also made these localities authentic sinks promoting entry of C stored in the soil after its use (Ramaswamy *et al.,* 2001), where the soil zone is responsible for most of the chemical aggressiveness of CO_2-enriched water, which causes gradual advance of karst morphogenesis, characterized by irreversibility of the process in its one-directional evolution, a result practically unheard of in soil science literature.

In addition to the surface loss described, subsurface removal is going on in the deepest soil horizons in the karst depressions which work like local base levels, with well-defined micro catchments, especially around the ponor and through fissures with different degrees of fracturing (from 2-mm capillaries) and up to 15 – 20 m deep in the bedrock as confirmed by geophysical research in the territory (Febles González *et al.* 2008).

However, in the absence of experiments to evaluate the resilience of Red Ferralitic soils in karst regions, these values state should be interpreted as a first estimate for designing agroecological strategies for protecting and improving soils in risk scenarios in Habana–Matanzas Karst Plains.

Conclusions

The resilience of Red Ferralitic soils is the result of a multifactorial process conditioned not only by intrinsic properties of the soil cover, but depending on geological-geomorphological and use conditions with a unidirectional evolution of the karstic morphogenesis practically unpublished in the pedological literature.

The Red Ferralitic soil under normal agricultural practices would take about 50 years to return to its original condition and depending on the amount of limestone impurities, this period could last from 100 to 600 years.

References

Blanco, C. & Lal., R. 2010. *Principles of Soil Conservation and Management.* London, New York, USA: Springer Dordrecht Heidelberg.

Febles González, J. M., Martin Alonso, N. J. & Hernandez, S. 1986. L'érosion et l'utilisation des sols dans la plaine karstique de Cuba: étude de plusieurs cas. *Sol et eau: résumés des actes du séminaire. Suelo y agua: resumenes de las actas del seminario* (págs. 717 – 728). Paris: ORSTOM. Available at: http://www.documentation.ird.fr/hor/fdi:24560.

Febles González, J. M., Tolón, A., Vega, M., Moura Amaral Sobrinho, N., Tolón, A. & Lastra, X. 2012. Soil loss from erosion in the next 50 years in karst regions of Mayabeque province, Cuba. *Land Degradation & Development*. doi:10.1002/ldr.2184.

Febles González, J. M., Vega, M. B., Moura Amaral - Sobrinho, N., Tolón, A. & Lastra, X. 2014. Good Soils in Extinction: Degradation of Red Ferralitic Soils in Western Cuba. *Soil Science, 179*(6): 304 – 313. doi:10.1097/SS.0000000000000070.

Febles, J. M., Vega, M. B. & Febles, G. 2008. Integrating system of qualitative and quantitative methods to assess the erosion of the soils in the karstic regions of cattle rearing use in Cuba. *Cuban Journal of Agricultural Science*, 42(3).

Jaimez Salgado, E. 2006. Los suelos del Parque Nacional Viñales, Pinar del Río, Cuba. Condiciones genéticas y ambientale. (I. d. Regional, Ed.) *Rev. Cuadernos Geográficos, 38*: 195 – 205.

Kay, B., Rasiah, V. & Perfect, E. 1994. Structural aspects of soil resilience. En D. Greenland, Szabolcs, & S. I. use (Ed.), *Soil resilience and sustainable land use* (págs. 449 – 469). Oxon U.K.: CABI Wallingford.

Lal, R. 1997. Degradation and resilience of soils. *Philosophical Transaction Royal Society London Series B-Biological Science*, 352: 997–1008.

Lal, R. 1998. Mulching effects on runoff soil erosion, and crop response on alfisols in western Nigeria. *Journal Sustainable Agriculture*, 11: 135 – 154.

Morgan, R. P. 2001. A simple approach to soil loss prediction. a revised Morgan–Morgan–Finney model. *Catena, 44*: 305 – 322.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M. & Blair, R. 2004. Environmental and economic cost of soil erosion and conservation benefits. *Science*.

Ramaswamy, V., Boucher, O. & Haigh, J. 2001. Radiative forcing of climate change. En J. Houghton, L. Meira Filho, J. Bruce, H. Lee, B. Callender, E. Haites, K. Maskell, *Climate change 2001: the scientific basis* (págs. 349 – 416). Cambridge, R.U.: Cambridge University Press.

Soil Survey Staff. 1951. Soil survey manual. En *USDA Handbook* (Vol. Handbook 18). Washington.

Vega, M. B. & Febles González, J. M. 2006. Evaluation of the rainfall erosion in cattle regions from the central part of Havana province. *Cuban Journal of Agricultural Science, 40*(2): 203 – 208.

Wang S., J., Liu, Q. & Zhang, D. 2004. Karst rocky desertification in southwestern China: geomorphology, landuse, impact and rehabilitation. *Land Degradation and Development, 15*: 115 –121.

Recalibration of a modified version of the WaTEM/SEDEM model for the assessment of soil erosion, sediment transport and the impact of soil erosion measures in Flanders

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Abstract

To calculate soil erosion and sediment transport in Flanders the WaTEM/SEDEM model is recalibrated using updated input data, algorithms and parameter choices. This recalibration is based on the data of 26 measuring points of sediment loads in rivers, spread over the erosion sensitive area of Flanders. The outcome of the recalibration is a new set of sediment transport coefficients (kTC) to be used for modelling soil erosion and sediment transport on a resolution of 20 m. The kTC_{high} to be used for arable land is determined as 12, whereas the kTC_{low} for grassland and forests is set on 3. The recalibrated model is used to create maps that visualise soil erosion, sediment streams, sedimentation on the land and sediment delivery to rivers. The model outcome can be used to analyse the impact of land use choices, agricultural practices and erosion control measures. In this way, the effects of policies can be evaluated, priority areas for area-oriented actions can be determined and prognoses can be made of the effectiveness of future actions.

Keywords: soil erosion, sediment transport, erosion control, sediment management, WaTEM/SEDEM, model recalibration, Flanders

Introduction, scope and main objectives

Soil erosion and sediment transport cause numerous environmental problems such as loss of soil quality, decline of agricultural productivity, mud streams in urban areas and high sediment loads in sewage and river systems. These problems give rise to substantial ecological, financial and emotional damages. Policies are needed that stimulate appropriate land use and erosion control measures. The modelling of soil erosion and sediment transport is a valuable tool to support decision-making processes to determine the areas of highest priority and to select the most effective actions needed. For this objective the government of Flanders uses a modified version of WaTEM/SEDEM, a spatially distributed soil erosion and sediment delivery model. This model was developed by the KULeuven through the aggregation of WaTEM (Van Oost *et al.*, 2000), calculating soil erosion, and SEDEM (Van Rompaey *et al.*, 2001), simulating sediment transport to rivers (Verstraeten *et al.*, 2002). The initial version of this model has been adapted and recalibrated several times. Recalibration is needed whenever algorithms or parameters are changed or input data with different accuracy or resolution are used (Verstraeten, 2006). The version of WaTEM/SEDEM that is currently implemented by the government of Flanders, required recalibration as new input data were available and some algorithms and parameters were changed. Furthermore, recent measurements of sediment loads offered the opportunity to create a more extensive calibration dataset.

Methodology

An extensive description of the WaTEM/SEDEM methodology is provided by Van Rompaey *et al.* (2001) and Verstraeten *et al.* (2002). Here we briefly reiterate the main concepts and changes to the previous applications of the model to catchments in Flanders.

The WaTEM/SEDEM model calculates the mean annual soil erosion rate by means of the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997). In the current version the slope length factor (L) is based on the two-dimensional flux decomposition algorithm of Desmet and Govers (1996) in combination with the slope length exponent of Van Oost (2003). The routing algorithm takes into account the effect of roads and parcel borders. The equation of Nearing (1997) is used for the slope steepness factor (S). The digital elevation model is based on recently collected (2013-2015) high-resolution LIDAR elevation data with a density of 16 points per m^2. The soil erodibility factor (K) is derived from the soil texture classes of the Belgian soil map. The rainfall erosivity factor (R) has been calculated from the 10-min rainfall depth time series of the meteorological station in Ukkel (Brussels, Belgium) for the period 1988-2017. These data showed that R is augmenting and has reached a mean value of 1 250 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$ for the last three decades, which is substantially higher than the mean value of 870 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$ for the period 1898-2002 (Verstraeten *et al.*, 2006). This high value is confirmed by the mean value of R for 43 meteorological stations for the period 2001-2017. The crop management factor (C) was set on 0.37 for arable land and 0.1 for grassland. All input data are combined and converted to 20 m grids.

The mean annual transport capacity (TC) is determined with the equation of Van Rompaey *et al.* (2001), which relates TC to the factors L, S, K and R. Transport capacity coefficients (kTC) for arable land (kTC_{high}) and grassland and forests (kTC_{low}) have to be assessed by means of calibration. This is done by running the model with a wide range of kTC values and comparing measured and modelled sediment loads. The optimal combination of values is determined by the model efficiency (ME) (Nash and Sutcliffe, 1970), the gradient of the regression line and the ratio between the kTC values. Measured sediment loads (ton/year) for 26 catchments in Flanders are used for this calibration. These measurements reflect sediment loads during the last three decades for periods of variable length. The older data (1990-2000) are based on amounts of sediment trapped in retention ponds (Verstraeten and Poesen, 2001). The more recent data (2000-2017) are derived from continuous measurements of sediment loads, registered at gaging stations in rivers (Van Hoestenberghe *et al*., 2008).

The modified and recalibrated model is implemented for a small river basin of 830 ha to demonstrate the model output and possibilities for analyzing erosion, sediment transport on the land, sediment delivery to the river and the impact of erosion control measures.

Results

The calibration of the WaTEM/SEDEM model on a 20 m resolution led to kTC_{high} and kTC_{low} values of 12 and 3, respectively (Deproost *et al.* 2018). The relationship between the measured and the modelled sediment loads (tons/year) for these selected kTC values had a correlation coefficient (R^2) of 0.71 and the model efficiency (ME) was 0.70 (Figure 1).

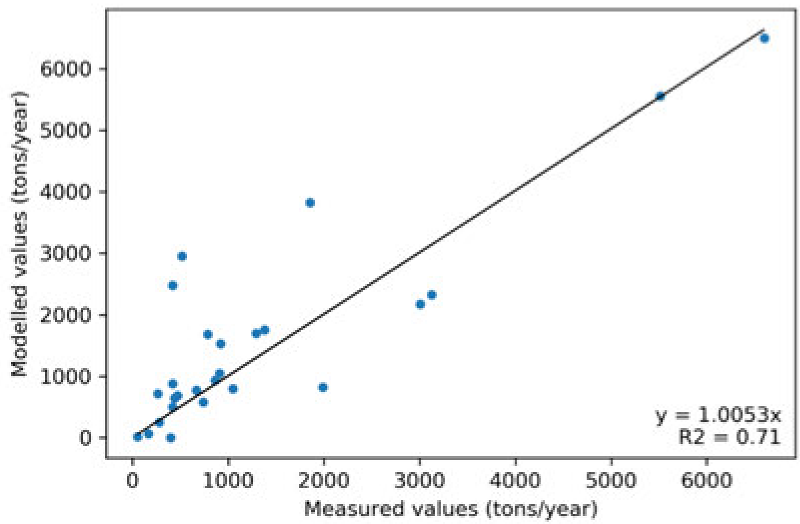

Figure 1: Relationship between measured and modelled sediment loads (tons/year) for 26 catchments in Flanders (Deproost *et al.*, 2018)

The routing of the sediment flows in the river basin of the case study is visualized in Figure 2. The subcatchment responsible for the highest sediment delivery is indicated. Currently 48 ha of grass buffer strips are realized as erosion control measures by farmers. These buffer strips reduce the soil erosion with 15% and the delivery of sediment to the river with 18%. Additional riparian vegetated filter strips along all waterways (8 ha on arable land) have almost no effect on erosion, but reduce the sediment delivery with 25 %. Reduced tillage on the most erosion sensitive arable land (388 ha with erosion amounts higher than 10 $tons.ha^{-1}.year^{-1}$) leads to reductions of 47 % of erosion and 23 % of sediment delivery. The realization of 2 buffers basins lowers the sediment load in de river with 17 %. A maximal scenario combines all the previous erosion control measures, which leads to reductions of total erosion and sediment delivery of 47 % and 56 %, respectively.

Discussion

The model output of the recalibrated WaTEM/SEDEM model is of high value in analyzing the amounts of soil erosion, sediment transport, sedimentation on the land and sediment delivery to rivers. These processes can be visualized on maps in order to identify the areas with the highest need for source-oriented erosion control measures, like appropriate crop choices and land management practices, and to determine the most effective locations for buffering measures, like grass buffer strips, ditches and buffer basins. When the main goal is to reduce the sediment delivery in a river basin, the model can indicate the river cells with the highest sediment input and delineate the corresponding source catchments. In the same way, the source areas of mud floods on the land or critical sediment deliveries to sewage systems can be identified.

When considering erosion control measures, the WaTEM/SEDEM model can simulate the reduction of soil erosion, mud streams and sediment delivery for different scenarios. These results can support local actors to choose and prioritize measures on the basis of their effectiveness. In the same way, the model can be applied to calculate erosion or sediment delivery indicators at different spatial scales and to evaluate the effects of policies.

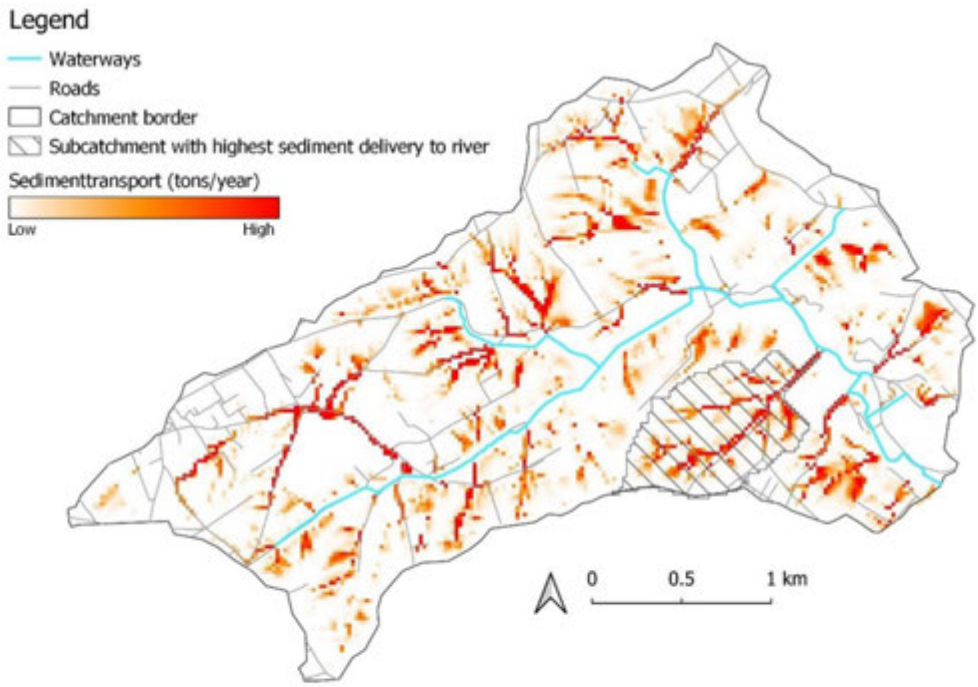

Figure 2: Sediment transport flows with indication of the area responsible for the highest sediment delivery in a river basin (830 ha) in Flanders

Conclusions

The actualization and recalibration of the WaTEM/SEDEM model for Flanders is realized with the objective of using the model as an operational tool to calculate and visualize erosion and sediment transport at different scales. For Flanders the calibration parameters kTC_{high} and kTC_{low} are determined in the current settings as 12 and 3, respectively. The model can be used to evaluate the impact of current or future land use choices, agricultural practices and erosion control measures. A case study for a river basin of 830 ha demonstrates the possibilities of modelling the impact of erosion control measures on the total erosion in the catchment and the sediment delivery to the river. The maximal scenario that combines all suggested measures, reduces the total erosion with 47 % and the sediment delivery to the river with 56 %.

References

Deproost P., Renders D., Van de Wauw J., Van Ransbeeck N. & Verstraeten G. 2018. Herkalibratie van WaTEM/SEDEM met het DHMV-II als hoogtemodel: eindrapport. Departement Omgeving, Brussel, 47 pp.

Desmet, P.J.J. & Govers, G. 1996. Comparison of routing algorithms for digital elevation models and their implications for predicting ephemeral gullies. *Int. J. Geographical Information Systems*, 10: 311-331.

Nash, J.E. & Sutcliffe, J.V. 1970. River flow forecasting through conceptual models. Part I. A discussion of principles. *Journal of Hydrology,* 10: 282–290.

Nearing, M.A. 1997. A single, continuous function for slope steepness influence on soil loss. *Soil Science Society of America Journal*, 61: 917-919.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. & Yoder, D.C. 1997. *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE) (Vol. 703)*. Washington, DC: United States Department of Agriculture.

Van Hoestenberghe, T., Voet, M., Eylenbosch, J. & Cabus, P. 2008. Sedimentexport door onbevaarbare waterlopen in Vlaanderen: metingen 2003-2007. Vlaamse Milieumaatschappij (VMM), Erembodegem, 126 pp.

Van Oost, K., Govers, G. & Desmet, P.J.J. 2000. Evaluating the effects of changes in landscape structure on soil erosion by water and tillage. *Landscape Ecology*, 15(6): 579-591.

Van Oost, K. 2003. *Spatial modeling of soil redistribution processes in agricultural landscapes*. Unpublished PhD thesis, Faculty of Sciences, KU Leuven, 239 pp.

Van Rompaey, A., Verstraeten, G., Van Oost, K., Govers, G. & Poesen, J. 2001. Modelling mean annual sediment yield using a distributed approach. *Earth Surface Processes and Landforms*, 26(11): 1221-1236.

Verstraeten, G. & Poesen, J. 1999. The nature of small-scale flooding, muddy floods and retention pond sedimentation in central Belgium. *Geomorphology*, 29(3-4): 275-292.

Verstraeten, G. & Poesen, J. 2001. Factors controlling sediment yield from small intensively cultivated catchments in a temperate humid climate. *Geomorphology*, 40(1-2): 123-144.

Verstraeten, G., Van Oost, K., Van Rompaey, A., Poesen, J. & Govers, G. 2002. Evaluating an integrated approach to catchment management to reduce soil loss and sediment pollution through modelling. *Soil use and management*, 18(4): 386-394.

Verstraeten, G. 2006. Regional scale modelling of hillslope sediment delivery with SRTM elevation data. *Geomorphology*, 81(1-2): 128-140.

Verstraeten, G., Poesen, J., Demarée, G. & Salles, C. 2006. Long-term (105 years) variability in rain erosivity as derived from 10-min rainfall depth data for Ukkel (Brussels, Belgium): Implications for assessing soil erosion rates. *Journal of Geophysical Research: Atmospheres*, 111(D22).

Soil erosion modelling using RUSLE1 in Shida Kartli Region, Georgia

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Abstract

The potential loss of soil through water erosion was assessed using the revised universal soil equation (RUSLE) in Kvemo Kartli region, Georgia. It was a first attempt to use and evaluate effectiveness and validity of RUSLE1 on a regional scale in Georgia with an integration of GIS and RS technologies, which can be extended later for the whole country and will support an establishment of a regular monitoring system on soil water erosion in Georgia. The results of the study are in good correlation with field measurements and this approach can be easily extended to a country scale after some improvement.

Keywords: soil water erosion, potential soil loss, RUSLE, soil degradation

Introduction, scope and main objectives

Soil erosion is a major threat causing soil degradation. Both types of erosion take place in Georgia, but water erosion plays the main role in soil loss through erosion, which is conditioned by relief, location of arable lands on steep slopes, high pressure on pasturelands and climate peculiarities.

Erosion causes the loss of the most fertile part of soil substantially declining soil fertility and having an adverse impact on agricultural production. Furthermore, it is practically impossible to recover soil up to the initial state.

The conducted study was aimed to determine average annual soil loss due to water erosion in the region of Shida Kartli, Georgia, the creation of the map of erosion intensity and assessment of the level of soil physical degradation.

The following objectives were defined within the study to achieve the aims of the research:

1) Study of soil in field and laboratory conditions (soil field studies were not conducted within the occupied territories being out of control of Georgian Government, therefore existing soil data from the 70-es and 80-es of the past century were used);
2) Estimation of soil erodibility factor;
3) Creation of a digital elevation model;
4) Computation of slope length and degree of steepness;
5) Definition of rainfall erosivity index;
6) Creation of digital maps of land use and land cover based on satellite imageries (Sentinel-2, ESA)

Methodology

In our study we used the RUSLE methodology, which is used worldwide to conduct a risk assessment of soil water erosion. It is widely used in EU member states (Panagos *et al*, 2014, 2015a, 2015b, 2015c, 2015d, 2015e, 2015f). This methodology is based on a common approach of the USLE (Universal Soil Loss Equation) methodology, initially elaborated in the USA to forecast a soil water erosion on arable lands (Wischmeier WH, Smith D, 1978) and represents its simplified version to address the need of soil water erosion assessment for large territories on a municipal, regional and country scale.

The RUSLE methodology is represented in the following form:

$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$

Where,

A is a predicted soil loss ($t \cdot ha^{-1} \cdot year^{-1}$)
R - rainfall and runoff factor ($MJ \cdot mm \cdot ha^{-1} \cdot year^{-1}$)
K - soil erodibility factor ($t \cdot ha \cdot MJ^{-1} \cdot mm^{-1}$)
L - slope length factor (dimensionless)
S – slope steepness factor (dimensionless)
C - crop and cover management factor (dimensionless)
P - conservation practice factor (dimensionless)

Results

The results of our study show that the average annual loss of soil from water erosion in the lowlands and in the Alpine and Subalpine zone of Shida Kartli region varies from 1 to 6 tons per hectare, while in the foothills and in the mountainous part of the regions is in the range from 11 to 33 tons per hectare.

Table 1 describes distribution of degraded land areas due to water erosion according to municipalities of Shida Kartli region.

Table 1: Distribution of degraded land areas due to water erosion.

Municipality	Area, total, ha	Moderately, severely and very severely degraded lands, ha	% from total area
Khashuri	56 186.8	5 210.1	9.27
Kareli	118 090.4	22 017.6	18.60
Gori	141 137.3	7 590.7	5.38
Kaspi	79 608.6	8 936.9	11.23
Kurta	98 633.1	22 260.4	22.60
Java	95 059.4	22 260.4	23.40
Total in Shida Kartli	588 715.6	88 276.1	14.99

Discussion

The results show that the area of potentially strong and very strong degraded lands caused by water erosion in Shida Kartli equals to 96 894 hectares, which is 14.99 % of the total area of the region, indicating that soil water erosion is the major driver of soil degradation in the region.

Method of USLE is already used in Georgia to assess of soil erosion potential (Gogichaishvili *et al.*, 2003), but it was the first time to use its revised version – RUSLE in Georgia, which undergone considerable changes, including integration of GIS and remote sensing methods, giving the capacity to assess soil erosion potential not only on a single plot but on a municipal, regional and country scale.

Conclusions

RUSLE methodology reduces time and financial resources necessary to assess soil erosion potential and performing regular monitoring on a country scale, an obligation of which has taken by our country in the frame of UN convention in achieving Sustainable Development Goals (UN SDGs) and LDN (Land Degradation Neutrality) by 2030.

Consequently, the results of our study can be used to identify lands under high risk of water erosion on a country scale and to elaborate and apply suitable soil protective measures to prevent or minimize soil losses. Besides that, the study will support to expand scientific research in that direction and can be used in reporting in the frame of international conventions.

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References

Gogichaishvili, G.P., Urushadze, T.T. & Gordzhomeladze, O.L. 2003. Universal soil loss equation for application in Georgia. *Eurasian Soil Science*, 36(2): 227-229.

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P. & Alewell, C. 2014. Soil erodibility in Europe: A high-resolution dataset based on LUCAS. *Science of the Total Environment*, 479–480: 189–200.

Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., Rousseva, S., Tadic, M.P., Michaelides, S., Hrabalíková, M., Olsen, P., Aalto, J., Lakatos, M., Rymszewicz, A., Dumitrescu, A., Beguería, S. & Alewell, C. 2015a. Rainfall erosivity in Europe. *Science of the Total Environment*, 511: 801-814.

Panagos, P., Borrelli, P., Meusburger, C., Alewell, C., Lugato, E. & Montanarella, L. 2015b. Estimating the soil erosion cover-management factor at European scale. *Land Use policy,* 48C: 38-50.

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E.H., Poesen, J. & Alewell, C. 2015c. Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European Scale. *Environmental Science & Policy,* 51: 23-34.

Panagos, P., Borrelli, P. & Meusburger, K. 2015d. A New European Slope Length and Steepness Factor (LS-Factor) for Modeling Soil Erosion by Water. *Geosciences*, 5: 117-126.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & Alewell, C. 2015e. The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, 54: 438-447.

Panagos, P., Borrelli, P. & Robinson, D.A. 2015f. Common Agricultural Policy: Tackling soil loss across Europe. *Nature,* 526: 195.

Wischmeier, W.H. & Smith, D.D. 1978. Predicting rainfall erosion losses—a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.

Interpretation of Land use and Soil Conservation Measures in the Pan-Third Pole area using Google Earth High Resolution Remotely Sensed Images

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Abstract

Soil erosion is one of severe global environmental problems, soil erosion survey is the scientific basis for soil and water conservation. In order to improve the methods applied in soil erosion sampling survey, and use the results to calculate soil erosion rates accurately and rapidly, interpretation methods for land use and soil conservation measures have been studied which are based on high spatial resolution remote sensing images. The sampling design has been developed using a stratified variable probability systematic sampling method in which spatio-temporal characteristics of soil erosion and conservation are derived based on the Geographic Information Science, virtual global tool, and finer resolution images accessible in Google Earth. Land use and soil conservation measures in the sampling units have been interpreted from the free access, high-resolution remote sensing images using visual interpretation. More than 20 thousand sampling units have already been interpreted, and information on the land use and soil conservation measures has been extracted; the soil erosion rate has been calculated using the Chinese Soil Loss Equation (CSLE) for some of the units, and the accuracy and applicability of the interpretation results has been analyzed. The results of the study show that this kind of sampling survey of soil erosion for a very large region can be completed, information about land use and soil conservation measures can be interpreted based on free access, fine resolution remote sensing images, stratified variable probability systematic sampling method can be used in regional soil erosion survey and mapping.

Keywords: the Pan-Third Pole Area, land use, soil conservation measures, remote sensing, variable probability sampling

Introduction, scope and main objectives

The Pan-Third Pole (Pan-TP) area is the vulnerable area of global environment and climate change (Yao *et al.*, 2017). So, quantitative evaluation of soil erosion in the Pan–TP area is of great significance for soil conservation in countries of the region.

Regional soil erosion survey and mapping can be summed up into two kinds of methods, including remote sensing mapping (Oldeman *et al.*, 1009; Lu and Yu, 2002; Panagos *et al.*, 2015; Borrelli *et al.*, 2017) and sample survey method (Nusser and Goebel, 1997; USDA, 2018; Liu *et al.*, 2013). The former method is the evaluation of potential soil erosion in the survey area and the latter one refers to the calculation of the actual soil loss rate for each survey unit.

In this study, a sample survey method of soil erosion in the Pan-TP area is introduced from three aspects, including sampling designing, the interpretation for sampling units (SU) and the results analysis of the interpretation. Meanwhile, the preliminary analysis of land use and soil erosion based on SU is carried out in order to provide reference for global soil erosion mapping.

Methodology

Study area

The Pan-TP is with a total area 5.14 * 10^7 km^2 and is accounting for 34.95% of the global land area (Figure 1; Yao *et al.*, 2017).

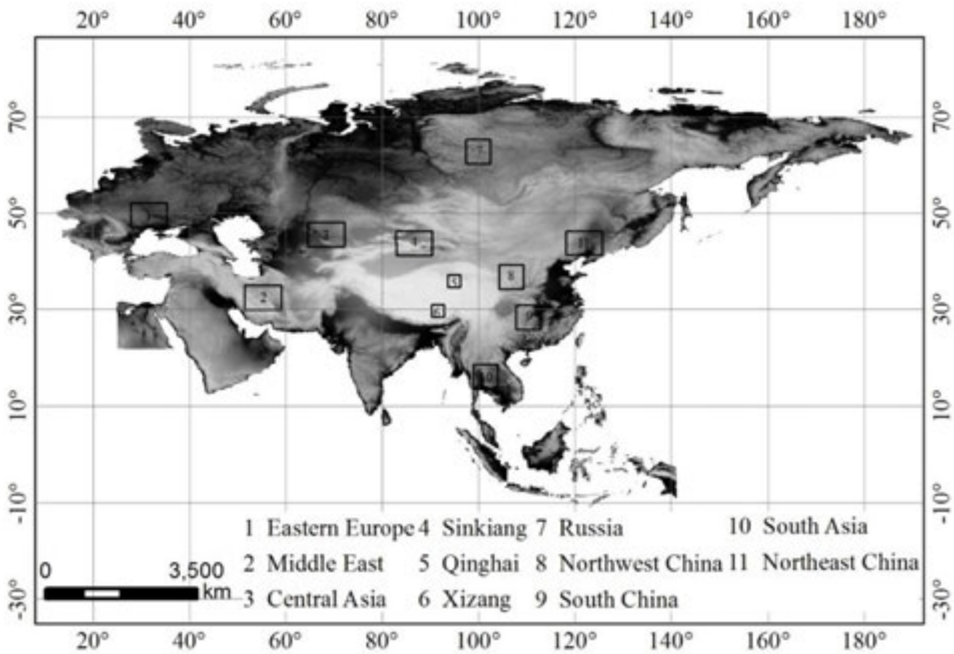

Figure 1: The Pan -Third Pole of national position

Source Data

The basic data for this study are Google Earth images, with auxiliary data of 1 arc –second resolution SRTM and 30 m resolution land cover map (GLS30) (Ban *et al.*, 2015).

Sampling designing and interpretation

Using the stratified unequal probability systematic sampling method, 20880 SUs were identified in the study area. Specifically, each unit in the hilly & mountain area is a small watershed of 0.5-3 km^2 and the flat area is a rectangular grid of 1 km^2. For each SU, the visual interpretation of landuse and soil and water conservation measures is completed under ArcMap.

Data analysis

In 11 large sampling area (Figure 1, dark box, contains 100 SUs for each box), GLS30 data (Ban *et al.*, 2015) were used to analyze the regional representative characters of the interpretation results; field check work has been conducted to evaluate the accuracy of interpretation results; the soil loss rate has been calculated based on the CSLE model and analyze the applicability of the sampling method.

Results

Macroscopic analysis

The comparative analysis of landuse types and GLC30 data (Ban *et al*., 2015) for SU interpretation shows that the similarity of two set of data in most area is greater than 0.75, and the results of sample interpretation can represent the macroscopic structure of land use. There are some differences between the sample interpretation and GLC30 in Tibet (No 6) area of China in some extent, which have been modified in the final data.

Microscopic analysis

The results of the interpretation were checked in the field in typical sections in southern Tibet and northern Thailand. The results showed that the average of kappa coefficient and accuracy in Tibet was 0.7 and 80.04 %, and the northern Thailand was 0.5 and 85.78 %, respectively. All problems have been systematically corrected after the field work, so the accuracy of final data has been improved.

The applicable analysis of interpret results

The soil loss rate for each SU has been calculated using CSLE, the results show that the calculated results (a map of soil loss rate) can reflect the spatial heterogeneity of soil erosion; There is a significant difference between potential loss (RKLSB) and actual loss rate (RKLSBET); The soil loss rate shown is basically consistent with other literature reports (Zhang *et al.*, 2019; Ma *et al.*, 2018).

Discussion

(1) The method reported in this paper is the extension of USDA NRI and also similar to the method in China (Liu *et al.*, 2013), which completes the interpretation of land use, soil conservation measures based on Google Earth high resolution images. The method is hopefully to be extended to the global scale.

(2) The results of field check show that the accuracy of the methods reported in this paper can reach up to 80%, but the accuracy for orchard and shrub is low, and this problem should be paid some attention.

(3) The interpretation of land use and soil conservation measures should go to automatic and rapid method based on digital image processing of high resolution images, and big data method.

Conclusions

(1) A rapid sampling survey of soil erosion at the regional and even global scales can be completed based on the method of free access high resolution remote sensing image and visual interpretation. This method is mainly based on remote sensing interpretation, and emphasizes field investigation. The method meets the needs of rapid survey of soil erosion in large regions.

(2) The soil loss rate of the SU can be calculated accurately based on the interpretation and CSLE, and the results are satisfactory. This method can make up for the shortcoming that traditional remote sensing mapping can only represent the risk of soil erosion (or potential erosion rate), and will be a technical basis for global soil erosion mapping.

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References

Ban, Y., Gong, P. & Gini, C. 2015, Global land cover mapping using Earth observation satellite data: Recent progresses and challenges. *ISPRS journal of photogrammetry and remote sensing*, 103(1): 1-6.

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K. Van, Montanarella, L. & Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8(1): 2013. https://doi.org/10.1038/s41467-017-02142-7.

Liu, B., Guo, S., Li, Z., Xie, Y., Zhang, K & Liu, X. 2013. Sampling Survey on water erosion in China. *Soil and Water Conservation in China*. (10): 26-34.

Lu, H. & Yu, B. 2002. Spatial and seasonal distribution of rainfall erosivity in Australia. *Australian Journal of Soil Research*, 40(6): 887-901.

Ma, B., Zhang, J. & Shui, J., Zhao, C., Yang, L., Wang, H., Chen, T., Liu, X., Cao, X., Zhao, G., Yi, Y., An, S., Guo, M. & Jiao, J. 2018. Report on field Survey of Soil Erosion in Central and Eastern Tibet. *Bulletin of Soil and Water Conservation*. 38(5): 1-8.

Nusser, S.M. & Goebel, J.J. 1997. The National Resources Inventory: A Long-Term Multi-Resource Monitoring Programme. *Environmental and Ecological Statistics*, 4(3): 181- 204.

Oldeman, L.R., Hakkeling, R.T.A. & Sombroek, W.G. 1991. World map of the status of human-induced soil degradation: An explanatory note. 2nd revised.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & Alewell, C. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, 54: 438–447. https://doi.org/10.1016/J.ENVSCI.2015.08.012

USDA. Summary Report: 2018, 2015 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. http://www.nrcs.usda.gov/technical/nri/15summary.

Yao, T.D, Chen, F.H, Cui, P., Ma, Y., Xu, B., Zhu, L., Zhang, F., Wang, W., Ai, L. & Yang, X. 2017. From Tibetan Plateau to Third Pole and Pan-Third Pole. *Bulletin of the Chinese Academy of Sciences*, 32(9): 924-931.

Zhang, J., Ma, B., Shui, J., Li, Y., Zhao, C., Wang, H., Cao, X., Li, R. & Jiao, J. 2019. Investigation Report on Soil Erosion in Northern Mountain Area of Thailand. *Bulletin of Soil and Water Conservation*, 39(1): 1-8.

Soil erosion modelling tools for the use in Earth system models

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Abstract

We present the parsimonious process-based Carbon Erosion DYNAMics model (CE-DYNAM) that links sediment dynamics resulting from water erosion with the carbon (C) cycle along a cascade of hillslopes, floodplains and rivers. The model simulates horizontal soil and C transfers triggered by erosion across landscapes and the resulting changes in land-atmosphere CO_2 fluxes at a resolution of about 8 km at the catchment scale. CE-DYNAM is the result of the coupling of a previously developed coarse-resolution sediment budget model and the ecosystem C cycle and erosion removal model derived from the ORCHIDEE land surface model.

We applied the model at the Rhine catchment in Europe and found that soil erosion mobilized 159 Tg (10^{12} g) of C under a changing climate and land use during the period 1850-2005, assuming that the erosion loop of the C cycle was in near steady-state by the year 1850. This caused a net C sink equal to 1 % of the Net Primary Productivity of the Rhine catchment over the whole period. This sink is a result of the dynamic replacement of C on eroding sites that increases in this period due to rising atmospheric CO_2 concentrations enhancing the C input to the soil.

Keywords: soil erosion, regional carbon cycle, carbon sink, Rhine catchment, Earth system modelling

Introduction, scope and main objectives

Soil erosion by rainfall and runoff is an important process behind the redistribution of soil organic carbon (SOC) over land, hereby impacting the exchange of carbon (C) between land, atmosphere and rivers (Doetterl *et al.*, 2012; Lal, 2003; Lugato *et al.*, 2018; Van Oost *et al.*, 2007, 2012; Stallard, 1998; Wang *et al.*, 2017). However, the net role of soil erosion in the global C cycle is still unclear as it involves small-scale SOC removal, transport and re-deposition processes that can only be addressed over selected small regions with measurements and models. This leads to uncertainties in future projections of SOC stocks and complicates the evaluation of strategies to mitigate climate change through increased SOC sequestration.

To address this knowledge gap, we present a parsimonious process-based modelling approach that integrates sediment dynamics resulting from water erosion with SOC dynamics and the horizontal transport of sediment and C in the continuum from hillslopes, to floodplains and rivers. With this approach we are not only able to simulate lateral soil and C transfers triggered by erosion across landscapes but also the resulting changes in the land-atmosphere CO_2 fluxes. The modelling approach uses a simple sediment budget model which is coupled to SOC erosion removal, C input from litter fall, and SOC decomposition processes diagnosed from the ORCHIDEE global land surface model (LSM) in an offline setting (Naipal *et al.*, 2018). We parameterized and applied the resulting model, known as CE-DYNAM for the Rhine catchment, although it is intended to be made applicable to other large catchments globally. CE-DYNAM combines soil erosion processes, for which small scale differences in topography are of utter importance, with a state-of-the-art representation of large-scale SOC dynamics driven by land use and environmental factors (climate, atmospheric CO_2) as simulated by the ORCHIDEE LSM. The flexible structure of CE-DYNAM makes the model adaptable to the SOC dynamics of any other LSM. In this way it is possible to study the main processes behind the linkages between soil erosion and the global C cycle.

Methodology

CE-DYNAM is the result of coupling a large-scale erosion and sediment budget model (Naipal *et al.*, 2016) with the SOC scheme of the land surface model ORCHIDEE, part of the French IPSL Earth system model (Krinner *et al.*, 2005). The most important features of CE-DYNAM are (1) the spatially explicit simulation of lateral sediment and C transport fluxes linking hillslopes and floodplains, (2) consistent simulation of vertical C fluxes coupled with horizontal transport, (3) the low number of parameters that allows running the model at large spatial scales and over long time-scales up to several thousands of years, (4) generic input fields for application to any region or catchment, and (5) compatibility with land surface models (LSMs).

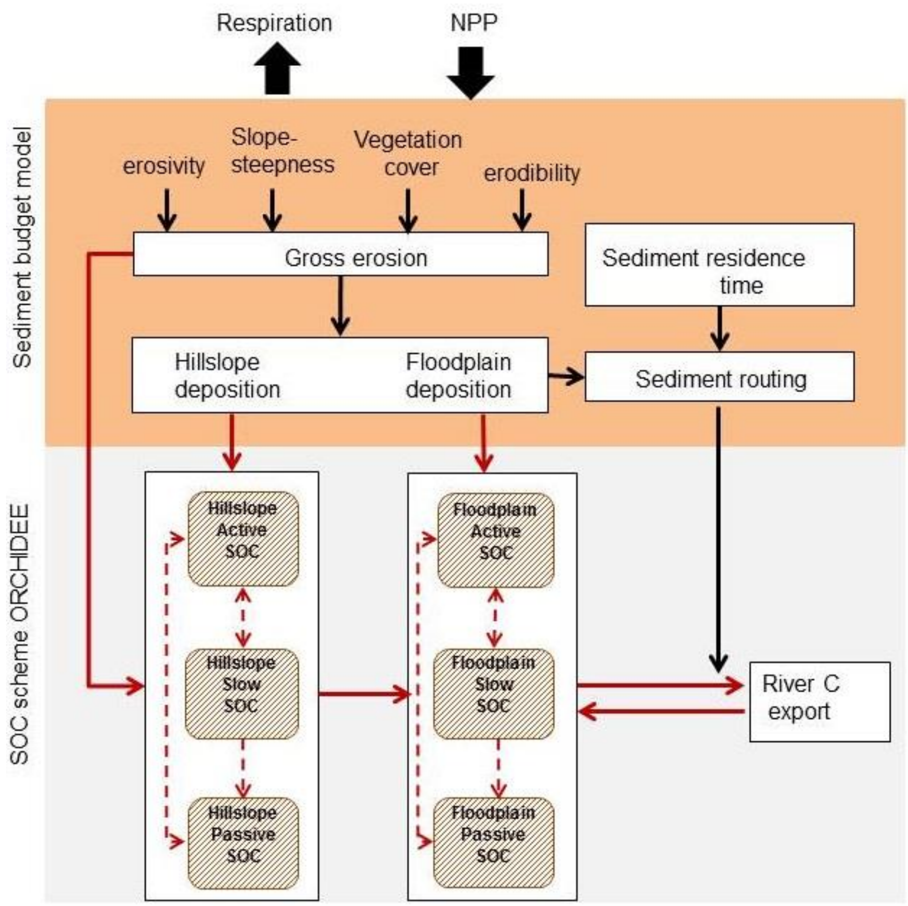

Figure 1: A conceptual diagram of CE-DYNAM. The red arrows represent the C fluxes between the C pools/reservoirs, while the black arrows represent the link between the erosion processes (removal, deposition and transport). Source: In review for GMD (Naipal *et al.*, 2019)

Results

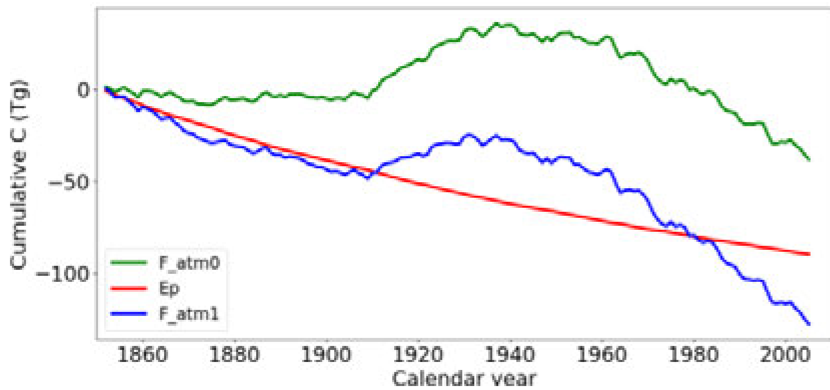

Figure 2: Cumulative C emissions from the soil to the atmosphere under land use change and climate change without soil erosion (F_atm0), with soil erosion (F_atm1), due to additional respiration or stabilization of buried soil and photosynthetic replacement of C under erosion (Ep) of the entire Rhine catchment. Positive values indicate net C emissions to the atmosphere and negative values indicate net C uptake from the atmosphere by the soil. Source: In review for GMD (Naipal *et al.*, 2019)

Conclusions

The application of CE-DYNAM for the Rhine catchment for the period 1850-2005 AD reveals three key findings:

- Soil erosion leads to a cumulative net C sink of 90 Tg by the end of the period, which is equal to one fourth of the cumulative land C sink of the Rhine without erosion. This C sink is a result of an increasing dynamic replacement of C on eroding sites due to the CO_2 fertilization effect, despite decreasing soil and C erosion rates over the largest part of the catchment. We conclude that it is important to take global changes such as climate change into account to better quantify the net effect of erosion on the C cycle.
- The erosion-induced C sink decreases over time due to decreasing erosion rates and increasing respiration of deposited C in alluvial and colluvial reservoirs. In contrast to colluvial reservoirs, alluvial reservoirs experience a net C burial. However, this net C burial can become net C respiration due to changes in the climate such as global warming. We conclude that burial of eroded C in floodplains plays an essential role in the strength of the erosion-induced C sink.
- Initial climate and land cover conditions and the transient period over which erosion under global changes takes place are essential for the determination if soil erosion is a net C sink or source and to what extent.

Altogether, these results indicate that despite model uncertainties related to the relative coarse spatial resolution, missing or simplified processes, CE-DYNAM represents an important step forwards into integrating soil erosion processes and sediment dynamics in Earth system models.

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References

Doetterl, S., Van Oost, K. & Six, J. 2012. Towards constraining the magnitude of global agricultural sediment and soil organic carbon fluxes. *Earth Surf. Process. Landforms*, doi:10.1002/esp.3198.

Krinner, G., Viovy, N., de Noblet-Ducoudré, N., Ogée, J., Polcher, J., Friedlingstein, P., Ciais, P., Sitch, S. & Prentice, I. C. 2005. A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system. *Global Biogeochem. Cycles,* 19(1), 1–33. doi:10.1029/2003GB002199.

Lal, R. 2003. Soil erosion and the global carbon budget. *Environ. Int*, 29(4), 437–50. doi:10.1016/S0160-4120(02)00192-7.

Lugato, E., Smith, P., Borrelli, P., Panagos, P., Ballabio, C., Orgiazzi, A., Fernandez-ugalde, O., Montanarella, L. & Jones, A. 2018. Soil erosion is unlikely to drive a future carbon sink in Europe*, Sci. Adv.,* 4(November), eaau3523.

Naipal, V., Reick, C., Van Oost, K., Hoffmann, T. & Pongratz, J. 2016. Modeling long-term, large-scale sediment storage using a simple sediment budget approach, *Earth Surf. Dyn.,* 4, 407–423. doi:10.5194/esurf-4-407-2016.

Naipal, V., Ciais, P., Wang, Y., Lauerwald, R., Guenet, B. & van Oost, K. 2018. Global soil organic carbon removal by water erosion under climate change and land use change during AD 1850 – 2005, *Biogeosciences,* 15(July), 4459–4480. doi:https://doi.org/10.5194/bg-15-4459-2018.

Van Oost, K., Quine, T., Govers, G., De Gryze, S., Six, J., Harden, J. W., Ritchie, J. C., McCarty, G. W., Heckrath, G., Kosmas, C., Giraldez, J. V, da Silva, J. R. M. & Merckx, R. 2007. The impact of agricultural soil erosion on the global carbon cycle. *Science,* 318(5850), 626–9, doi:10.1126/science.1145724.

Van Oost, K., Verstraeten, G., Doetterl, S., Notebaert, B., Wiaux, F. & Broothaerts, N. 2012. Legacy of human-induced C erosion and burial on soil – atmosphere C exchange. *PNAS,* 109(47), 19492–19497. doi:10.1073/pnas.1211162109/ /DCSupplemental.www.pnas.org/cgi/doi/10.1073/pnas.1211162109.

Stallard, R. F. 1998. Terrestrial sedimentation and the carbon cycle: Coupling weathering and erosion to carbon burial. *Global Biogeochem.* Cycles, 12(2), 231–257.

Wang, Z., Hoffmann, T., Six, J., Kaplan, J. O., Govers, G., Doetterl, S. & Van Oost, K. 2017. Human-induced erosion has offset one-third of carbon emissions from land cover change. *Nat. Clim. Chang*e, 7(5), 345–349, doi:10.1038/nclimate3263.

Measuring gullies and evaluating soil properties in a mountainous region of Rio de Janeiro State, Brazil

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Abstract

Gully erosion is usually not registered on regional survey's maps, due to the scale, but it has a high impact on production of sediments and potential pollution of water sources. The objectives of the study were to evaluated soil chemical and physical attributes of two gullies with different erosional stages (initial and senile), and to use images generated by drone to characterize gullies morphology, complemented by Google Earth images from 2016. The qualitative assessment was performed using the digital field-elevation curvature model with field validation. Samples were collected at 0.0-0.10 m depth, inside and outside each gully, for analyses of soil fertility, total organic carbon, bulk density, particle density, and calculation of total porosity. Soil attributes were submitted to Kruskal-Wallis test with 5% of significance. The usage of drone allowed to measure the gully´s area and volume, and to assess development stages. The comparison of soil chemical and physical attributes showed differences according to the evolution stage and location of the samples (inside and outside of the gully). In the senile stage gully the best edaphic conditions were observed on the inside, where vegetation is already stablished.

Keywords: gully erosion, geotechnologies, soil management and reclamation.

Introduction

Erosive processes are a natural phenomenon in the formation of landscapes; however, factors such as topography, pluviometry, vegetation cover and land use history may accelerate soil erosion. Inadequate land usage and lack of protection from vegetation culminate in soil sealing, thus increasing surface runoff, mainly in hilly regions such as the "*Mar de Morros*" region (Santos *et al.*, 2017). The impact of raindrops on exposed soil surface breaks the aggregates, individualizing the particles and favoring their transportation through surface flow. One of the extreme consequences of these processes is formation of gullies with different sizes and development degrees.

Pinheiral municipality is located in the mountainous region of Rio de Janeiro State, Atlantic Forest biome. The soils have a high erosion susceptibility, due to topography, parent material and history of occupation with agriculture along the years (Menezes *et al.* 2010); thus, several gullies are observed in the landscape. To developed strategies for reclamation of these areas it is necessary to characterize the level of degradation, and the capacity to respond to vegetative, edaphic and mechanical practices. Another demand is the measurement and assessment of the gullies stage of degradation, since they are not usually mapped in regional surveys, with small scale, but they have a high impact on production of sediments and pollution of water sources.

This work hypothesized that the gullies edaphic attributes have different patterns depending on evolutionary stages and the surface, inside and outside of the gully. The objective was to evaluate soil chemical and physical attributes in two gullies with different erosion evolution degree (initial and senile), with the goal of providing information for reclamation of degraded areas. In addition, aerial images generated by drone were tested to map the gullies, as a proposal of technology to expedite the assessment of their evolution degree.

Methodology

The study was carried out in the Cachimbal river sub-basin, Pinheiral municipality, Rio de Janeiro State. The climate is classified as a Cwa (Alvares *et al.* 2014). Vegetation is represented by forest fragments with pastures in different degrees of degradation. The soils are deeply weathered, predominantly Ultisols and Oxisols, and in some steeper slopes, Inceptisols.

To map the gullies Google Earth images (from 2016) with a spatial resolution of 2.34 m were used. Two gullies were selected, both in convex pedoforms, according to evolutionary stages (identified as initial and senile). A qualitative classification was conducted using a digital elevation surface curvature model, generated from topographic charts (scale of 1:50000) of Volta Redonda and Piraí municipalities, using ArcGIS 10.5. The selected gullies coordinates were plotted using digital field-elevation curvature model (DFECM), thus obtaining a convex surface model, and the results were validated through field analysis. A systemized flight with pre-defined positioning was performed using the Phanthom 4 PRO drone (SZ DJI Technology Co, Ltd). In the flight, 84 images were captured, with 4 cm of spatial resolution, thus obtaining an orthophoto of the area (Figure 1A). The gullies in the convex pedoform were classified according to Dobek *et al.* (2011), based on their morphology and size, as initial (Figure 1B) or senile (Figure 1C) stages. The Pix4Dmapper Pro version 4.1.10 software was used to measure volume (m^3) and area (m^2) of the gullies.

For soil sampling, the gullies surface was divided in inside and outside. Disturbed and undisturbed soil samples were taken at 0.0–0.10 m depth, with 10 samples in the initial gully (Figure 1B) and 18 in the senile (Figure 1C). The soil chemical and physical attributes evaluated were: fertility, bulk density (Bd), particle density (Pd), total pore volume (TPV), value S (sum of bases), value T, and V%. They were quantified according to Teixeira *et al.* (2017) and total organic carbon (TOC) according to Yeomans and Bremner (1988). Soil attributes were compared by using Kruskal-Wallis test with 5% of significance

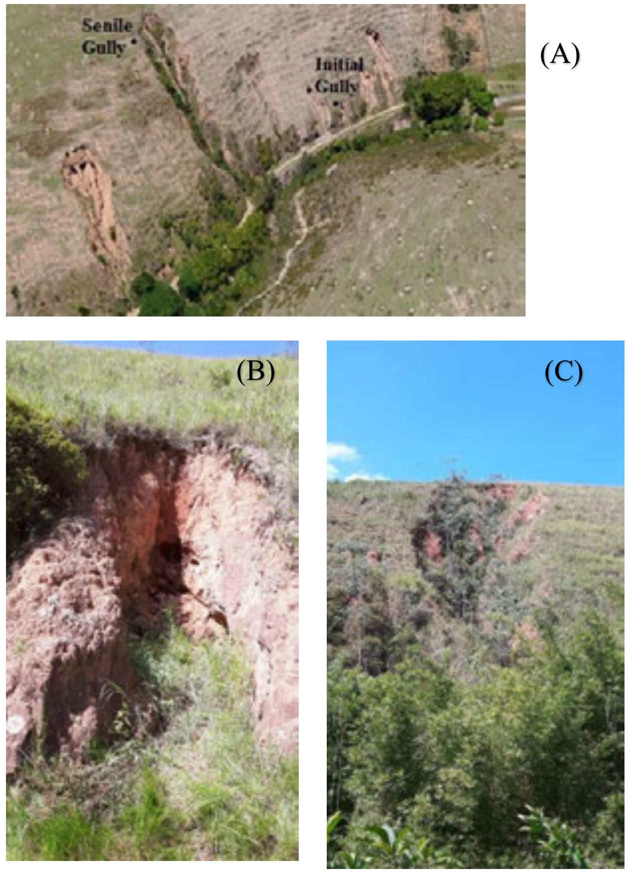

Figure 1: Morphological classification of two gullies in different evolutional stages, initial (B) and senile (C), Pinheiral municipality, Rio de Janeiro State.

Results

The aerial images and maps generated by using the drone showed an increase of the area between evolutionary stages of the gullies, with the lowest value of 54.83 m² for the initial stage and the highest of 1 069.23 m² for the senile stage. A similar pattern was observed for volume, the lowest value (32.44 m³) in the initial stage and the highest (1 709.35 m³) in the senile gully.

The average values of chemical and physical attributes from soil sampled at 0 – 0.10 m depth, on the inside and outside areas of the gullies (initial and senile stages), are presented in Table 1.

Table 1: Attributes of soil samples, at 0-0.10 m depth, from the inside and outside surfaces of the initial and senile gullies.

Gully Stages	Chemical and physical attributes of soil samples (0-0.10 m depth)					
	pH		**Ca^{2+} ($cmol_c\ kg^{-1}$)**		**Mg^{2+}($cmol_c\ kg^{-1}$)**	
	Inside	Outside	Inside	Outside	Inside	Outside
Initial	5.01aA	4.98aA	0.99cA	0.97bB	1.15aA	1.18aA
Senile	4.99aA	4.98aA	1.26aA	1.28aA	0.87cA	0.86bB
	Al^{3+} ($cmol_c\ kg^{-1}$)		**H+Al ($cmol_c\ kg^{-1}$)**		**Na^{+} ($cmol_c\ kg^{-1}$)**	
	Inside	Outside	Inside	Outside	Inside	Outside
Initial	0.81aB	0.99bA	1.75bA	2.42abA	0.010aA	0.010aA
Senile	0.98aA	0.99bB	2.47aA	2.92aA	0.010aA	0.010aA
	K^{+} ($cmol_c\ kg^{-1}$)		**TOC ($g\ kg^{-1}$)**		**Sum of Bases ($cmol_c\ kg^{-1}$)**	
	Inside	Outside	Inside	Outside	Inside	Outside
Initial	0.010aA	0.012aA	6.57bB	10.38aA	2.20aA	2.14abA
Senile	0.008cB	0.007bA	13.42aA	14.20aA	2.18aA	2.16abA
	T Value ($cmol_c\ kg^{-1}$)		**Base saturation (V%)**		**Bulk density ($Mg\ m^{-3}$)**	
	Inside	Outside	Inside	Outside	Inside	Outside
Initial	4.50abA	4.77bcA	56aA	45aA	1.12abA	1.47aA
Senile	4.00aA	5.08abA	47bA	45aA	1.28aA	1.43aA
	Particle density ($Mg\ m^{-3}$)		**Total Pore Volume (%)**			
	Inside	Outside	Inside	Outside		
Initial	2.48aA	2.37aA	54aA	38aA		
Senile	2.28bB	2.33aA	44bA	38aB		

Same lowercase letters in the column and uppercase letters in the row do not differ by the Kruskal-Wallis test at 5 % significance.

There were statistical differences between soil attributes according to the gully stage (initial and senile) and location of samples (inside and outside). The greatest pH values were observed inside the gullies, with the highest in the initial stage gully. The highest Al^{+3} values were observed in the outside surface in both gullies. The TOC values followed the same pattern verified for H + Al, higher TOC values in the senile stage and in the inside face. For both attributes, there was a difference between the initial and senile stages on the internal surface. For Ca^{+2}, the highest values were observed in the senile gully, showing the same pattern as

TOC. For the Mg^{+2} and K^{+}, the highest values were observed in the outside surface of gullies and in the initial stage. The highest V% values were in the initial gully and in the inside surface.

The physical attributes showed no difference in the bulk density; but particle density was highest inside the initial stage gully. The higher values of total pore volume were observed in the inside surface of the initial gully, with significative difference between the inside and outside surfaces.

Discussion

The volume and area of the gullies are a suitable measurement of the erosive process intensity. According to Vieira's (2008), in the early stages the sediment losses are smaller and as the process continues, if preventive measures are not taken, they increase gradually in size.

The results of organic carbon (TOC) are associated with the addition and decomposition of residual material (litter and roots) by the vegetation already stablished at the gully with a senile evolutionary stage. The distribution of Ca^{+2} may be related to absorption of this nutrients by plants on the outside surface in the senile stage gully. The same pattern was observed for Mg^{+2} and K^{+}; but with higher values in the initial gully, which may be related to grasses vegetation and their higher nutrient cycling due to the root system. The V % variation is associated to vegetation distribution, with more cycling and bases from litter addition.

As for the physical attributes, in general, higher Bd values indicate a lower porosity, reducing the inner water flow and favoring the superficial runoff. The area has a long history of usage and occupation, with cycles of coffee and pasture, which may have contributed to the Bd increase. Values of Bd are frequently high in areas intensively managed with crops and pasture, mainly due to soil compaction (Sousa *et al.,* 2014). Similar pattern of total pore volume was observed by Deng *et al.* (2016) in Anxi county, China, studying the effect of land use in physical and chemical properties and erodibility of gully sediments.

Conclusions

The usage of drone to obtain detailed maps and to measure the gully´s area and volume was a valid method, and to assess gully stages.

The gully on senile stage showed better edaphic conditions for the inner face, where vegetation has already stablished.

Overall, there were differences in soil properties among the gully stages and sampling surfaces, which may be used to guide reclamation practices to control sediment production and to ensure the reinstatement of vegetation.

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References

Alvares, C.A., Stape, J.L., Sentelhas, P.C., Gonçalves, J.L de M. & Sparovek, G. 2014. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, 22, 711-728.

Deng, Y., Xia, D., Cai, C. & Ding S. 2016. Effects of land uses on soil physic-chemical properties and erodibility in collapsing-gully alluvial fan of Anxi County, China. *Journal of Integrative Agriculture,* 15, 1863-1873.

Dobek, K., Demczuk, P., Rodzik, J. & Holub, B. 2011. Types of gullies and conditions of their development in silvicultural loess catchment (Szczebrzeszyn Roztocze region, Poland). *Landform Anal,* 17, 39–42.

Dos Santos, G.L., Pereira, M.G., Delgado, R.C., de Moraes, L.F.D. 2017. Padrões da regeneração natural na região de Mar de Morros, Pinheiral-RJ. *Floresta e Ambiente,* 24 1-11.

Menezes, C.E.G., Pereira, M.G., Correia, M.E.F., Anjos, L.H.C. Dos, Paula R.R. & de Souza M.E. 2010. Litter contribution and decomposition and root biomass production in forests at different sucessional stages in Pinheiral, RJ. *Ciência Florestal*, 20, 439-452.

Sousa, E.L., Andrioli, I., Almeida, R.G., Macedo, M.C.M. & Lal, R. 2014. Physical quality of an Oxisol under an integrated crop-livestock-forest system in the Brazilian Cerrado. *Revista Brasileira de Ciência do Solo*, 38, 608-618.

Teixeira, P.C., Donagemma, G.K., Fontana, A. & Teixeira, W.G. 2017. Manual de *Métodos de Análise de Solo.* Embrapa Solos, 264pp.

Yeomans, J.C. & Bremner, J.M. 1988. A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Analysis,* 19, 1467-1476.

Comparing erosion rates and processes after land use conversion from rainfed to irrigated crops in fragile areas with water scarcity

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Abstract

Soil erosion rates and processes were assessed in two common types of crops of SE Spain. Those two types represent a typical land use conversion from rainfed cultivated crops on terraces into irrigated cultivated crops on levelled fields, with a ridge-street morphology. This research was carried out on those two types of land uses on gently sloping crop fields next to each other. Both have similar basic characteristics in terms of soil lithology, climate but a different land use and management: irrigated mandarin trees on levelled land and rainfed almond trees on large terraces, not properly maintained. Three methods were used to quantify soil erosion by water: 1) a field inventory method, 2) erosion pins, and 3) a drone was used to create a DEM of Difference. Results show mainly sheet and bank erosion of the ridges in the irrigated mandarines fields and sheet, rill and gully erosion in the rainfed almond fields. Minimum long-term erosion rates obtained showed very similar results at both land uses (1.31 versus 1.25 tha^{-1}year^{-1} in irrigated crops and rainfed crops, respectively). Short-term erosion rates were higher for the rainfed area and differed very much between areas and methodologies, depending on which erosion processes were activated and could be measured by each specific method on a rain event scale. Overall conversion from rainfed to irrigated land, with all the morphological and soil management changes involved in this case, does not decrease soil erosion rates on the long term. Lack of proper maintenance of terraces on the rainfed crops are a risk for high erosion rates. But the high level of mechanization, the drastic change of landscape morphologies and the low perception by farmers of the soil erosion problem on the irrigated crops, generate the risk of irreversible loss of soil resources and associated ecosystem services also in these areas.

Keywords: soil water erosion, Spain, Murcia, UAV, remote sensing, erosion pins, field inventory

Introduction, scope and main objectives

Erosion is the most important factor of land degradation in many parts of the world (Eswaran, 2001). Soil erosion has been classified as one of the types of soil degradation, within a wider context of land degradation. The characteristics of the climate, lithology and land use history of Mediterranean ecosystems, in particular those in sub-humid and semiarid zones, make these areas very vulnerable to soil erosion by water (Boix-Fayos *et al.*, 2005). An example of an area very susceptible to soil erosion by water is the region of Murcia in SE Spain. This research was carried out at two agricultural properties next to each other with the same characteristics and land use in the past. One of them has maintained the traditional rainfed schemes (Escuderos), while the other one has experienced a land use conversion in the last 25 years. This land use conversion was from the traditional rainfed schemes, cultivating almond crops on terraces for soil and water conservation to irrigated intensive agricultural schemes, cultivating mandarins on a ridge-street morphology where terraces were removed and levelled resulting into rolling topographies (Canteras). The area has an average temperature of 18.5 ºC and 325 mm of annual rainfall (García-Lorenzo *et al.*, 2015) and is on marls lithology and Regosols. This type of parent material is very susceptible for erosion and create weak aggregates (Corti *et al.*, 2011). Traditionally in the area only non-irrigated almonds with a low input soil management were extensively cultivated on terraces for soil and water conservation (Escuderos area, 81.74 ha). The terraces are large and they have a gentle slope. To make the land more profitable in large areas, the terraces were removed and cultivation changed into irrigated monocrop schemes (drip irrigation) on large levelled fields (Canteras area, 167.29 ha). The new terrain morphologies are adapted to the higher level of mechanization with high inputs of water, herbicides and fertilizers. There are many open questions about the sustainability of the new system, which does not use any soil and water conservation measures. The effect of these changes on soil erosion is not described yet. The main objectives of this research were to explore how erosion processes and rates differ between the different land uses using several methods. Three erosion measurement methodologies were used in this research: 1) a field inventory method to identify and quantify all visible erosion features, 2) erosion pins to measure sheet and rill erosion in the field and 3) a drone to create a DEM of Difference to quantify erosion rates.

Methodology

In this study three different methodologies to quantify erosion rates were applied. First, erosion processes were identified and quantified using a field inventory of erosion features, following the methodology of Stocking and Murnaghan (2000) (Figure 1). Erosion features that were found, but which were not described well by Stocking and Murnaghan (2000), were described and quantified in a similar way. Undisturbed soil samples (45 samples) were taken to estimate bulk density and to convert volumetric data from the field into mass data. Areal and temporal corrections were carried out, and erosion rates were calculated. The second methodology used erosion pins to quantify sheet and rill erosion. In total 9 plots were installed in the rainfed area in a 3x3 replicates scheme, 3 plots of 1 m^2 with 9 pins at each 50 cm distance at three different agricultural terraces within 300 m. In the irrigated area 8 plots of 1 m^2 with 9 pins were installed in a 2x2x2 scheme (2 plots by morphological situation (ridge; street) x 2 replicates x 2 (bare, vegetated) to cover the spatial variation of erosion rates (Figure 1). All pins were measured once per month and after each rain event during 4 months. After corrections by bulk density and time, erosion rates were calculated.

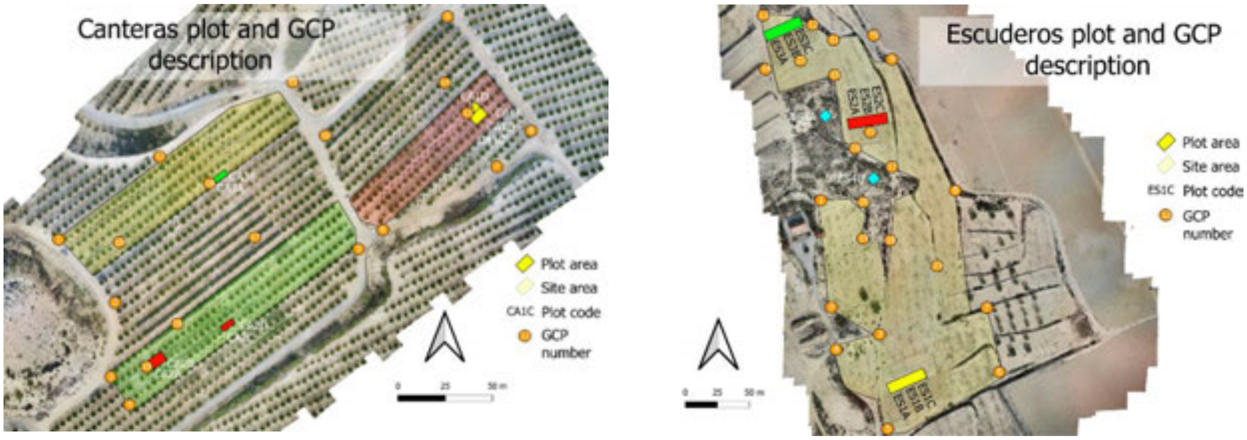

Figure 1: Study area: Canteras (mandarins, Left) and Escuderos (almonds, Right), erosion pin plots and GCP locations

The last method applied was based on aerial photographs taken by a drone, and a DEM extraction from them. When two DEMs made at different moments in time are compared, a DEM of Difference (DoD) can be made to reveal the locations of erosion or deposition that were formed within the time between the two drone flights. Georeferenced Ground Control Points (GCPs, Figure 1) were been installed in the field to correct for errors in height caused by differences in bending of the images. After this correction the point cloud was converted into a DEM and was further analysed using ArcGIS. The field inventory took place in October – December 2018. The erosion features identified in the first part of the fieldwork represent features formed before half November 2018. Half November 2018 heavy rainfall occurred in the area (>100 mm in a week). After these events, the inventory therefore represents the new erosion features formed as a consequence of these events. The data given by the erosion pins and the drone method represent the erosion as happened during the rainfall events of half November 2018. The data of erosion inventory taken in Oct-Nov 2018 represent long term erosion data.

Results

In Figure 2 the results of the erosion measurements are shown for the field inventory method. The long-term erosion rates were very similar for both land uses (1.31 versus 1.25 $tha^{-1}year^{-1}$ in Canteras mandarins and Escuderos almonds respectively). However at the short-term (several events accounting for 115 mm in 96 hours), erosive responses were very different (0.40 versus 4.51 $tha^{-1}year^{-1}$ in Canteras mandarins and Escuderos almonds respectively).

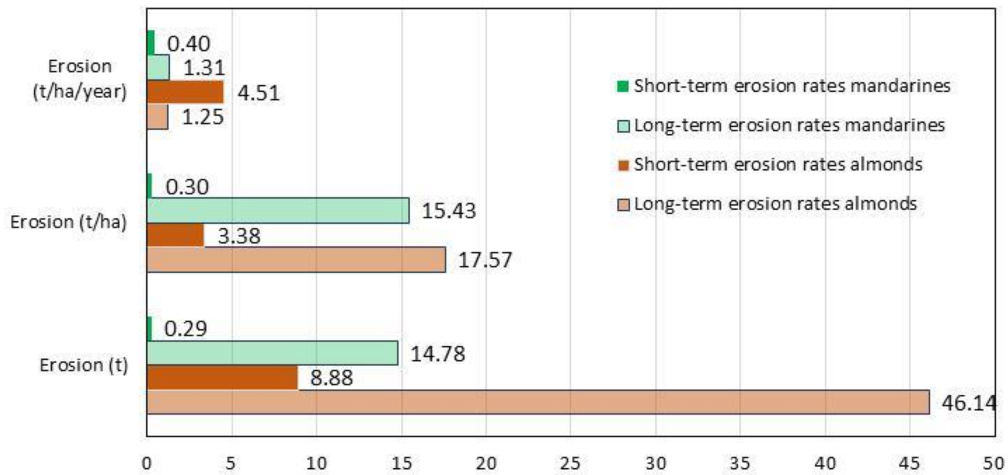

Figure 2: Results of the field erosion inventory method for both land uses and periods of investigation.

Concerning the type of erosion processes identified at each land use, root exposure was observed often at the sides of the ridges under the mandarines trees due to sheetwash erosion. This feature was not well described in Stocking and Murnaghan (2000) but has been incorporated in this study. Another very frequent erosion feature was erosion holes caused by converging water, for example due to leaking irrigation tubes and bank erosion of the ridges as a combination of tillage and water erosion. The dominant erosion feature found in Canteras was sheet erosion which contributed 86% to the total soil loss in this area, while in the rainfed almond area mainly gullies (92% of contribution to soil loss) was found.

Results from the erosion pins showed remarkable differences between the two locations. In the rainfed almond fields deposition was measured (65.49 t, 24.94 tha^{-1} and 33.25 $tha^{-1}year^{-1}$) while in the irrigated citrus fields erosion was measured (17.19 t, 17.95 tha^{-1} and 23.93 $tha^{-1}year^{-1}$). When comparing the erosion rates between the inventory method and the erosion pin method it can be found that the pins show much higher rates.

During the research the GCPs measurements could unfortunately not be obtained at the desired resolution due to instrument failure. Therefore, no accurate measurements could be done by using remote sensing techniques in this research. Nevertheless, remote sensing with the help of a drone is a promising technique. With improving technologies, DoDs can be made with better resolution for larger areas. Besides the use of the obtained DEMS for quantitative information, in this study from the obtained DEMS, a drainage pattern could be extracted. This overlapped very well the gullies pattern which was opened after the heavy rains at the end of November 2018. Further work with those data could inform of potential connectivity patterns in apparently ploughed stable fields, as it was the case.

Discussion

Both methods to measure erosion: pins and field inventory, seem to be complementary to get a complete field assessment of the erosion on the area. Field inventory of erosion features help to identify and understand the processes in the field, as well as it gives an indication of relative long-term erosion rates for an area at a very low cost, particularly related to non-interrill erosion processes. Some new indicators can be used for the assessment of interrill erosion processes (small stone pedestals, root exposure). Erosion pins are a quick, cheap and reliable assessment method at the event, seasonal and annual scale, although it measures mainly interrill and small rills erosion.

With respect to the erosion rates in the areas, on the long term those are very similar for both land uses. On the short term some differences between the areas and local behaviour of erosion-deposition patterns make them difficult to compare them, giving sometimes contradictory results between methods that are measuring different processes.

Besides, in the rainfed cultivated almonds area still soil and water conservation measures (terraces) are (badly) conserved, still this implies that this area is collecting sediment provided from upper sources. In the irrigated crop area no soil conservation measures are applied, but trees are located on ridges. Depending on their parallel or perpendicular orientation to the main slope, they can occasionally act as a soil conservation measure. Also many different processes of erosion were identified on the ridges, however the perception of them by the farmer is very low.

Conclusions

According to those first results the land use conversion to irrigated crops does not improve substantially soil conservation, and it results in the same long-term erosion rates as rainfed traditional schemes, with large variations at the event scale.

With a high level of mechanization, the drastic change of landscape morphologies and the low perception by farmers of the soil erosion problem in the irrigated crop areas, this type of land use conversion generate the risk of irreversible loss of soil resources and associated ecosystem services.

Acknowledgements
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References

Boix-Fayos, C., Martínez-Mena, M., Calvo-Cases, A., Castillo, V. & Albaladejo, J. 2005. Concise review of interrill erosion studies in SE Spain (Alicante and Murcia): erosion rates and progress of knowledge from the 1980s. *Land degradation and development*, 16(6): 517-528.

Corti, G., Cavallo, E., Cocco, S., Biddoccu, M., Brecciaroli, G. & Agnelli, A. 2011. Evaluation of erosion intensity and some of its consequences in vineyards from two hilly environments under a Mediterranean type of climate, Italy. *Soil Erosion in Agriculture*. Intech Open Access Publisher Eds., pp. 113–160.

Eswaran, H., Lal, R. & Reich, P. F. 2001. Land degradation: an overview. *Responses to Land degradation*, 20-35.

García-Lorenzo, M. L., Martínez-Sánchez, M. J., Pérez-Sirvent, C., López-Sánchez, J., Molina-Ruiz, J. & Tudela, M. L. 2015. Geogenic Distribution of Arsenic (As) and Antimony (Sb) in Soils of the Murcia Region in Spain. *Environmental Forensics*, 16(1): 88-95.

Stocking & Murnaghan. 2000. Handbook for the field assessment of land degradation, Chapter 4, pp. 49.

Using PAP/RAC model and GIS tools for mapping and study of water erosion processes in the Mediterranean environment: Case of the Asfalou watershed (Oriental Rif, Morocco)

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Abstract

Soil erosion is a growing problem in the Asfalou watershed, northern Morocco. This agricultural area is the seat of intense erosive activity. The intensification of water erosion processes is one of the main constraints to its protection and development. The evaluation of erosive states, causal factors and trends in the risk of water erosion via the use of cross matrices from the PAP/RAC model was the subject of this study. The model focuses on integrating the causal factors of water erosion, which uses slope and friability of facies to determine susceptibility. The friability parameter of facies has been replaced by the factor soil types. This parameter has been classified and integrated according to the model guidelines. The method is based on three main approaches: predictive, descriptive and integration. The correlation analysis identified the main risk factors for water erosion, their interaction and distribution in the Asfalou watershed. These results have identified factors and areas that require rapid and effective intervention to counteract the effects of water erosion. The results can be a basic tool for land use planning and decision support in erosion control, management and control projects in an effective and sustainable way.

Keywords: Modeling, GIS Tools, Water erosion, PAP/RAC, Erodibility, Causative factors, Soil erosion

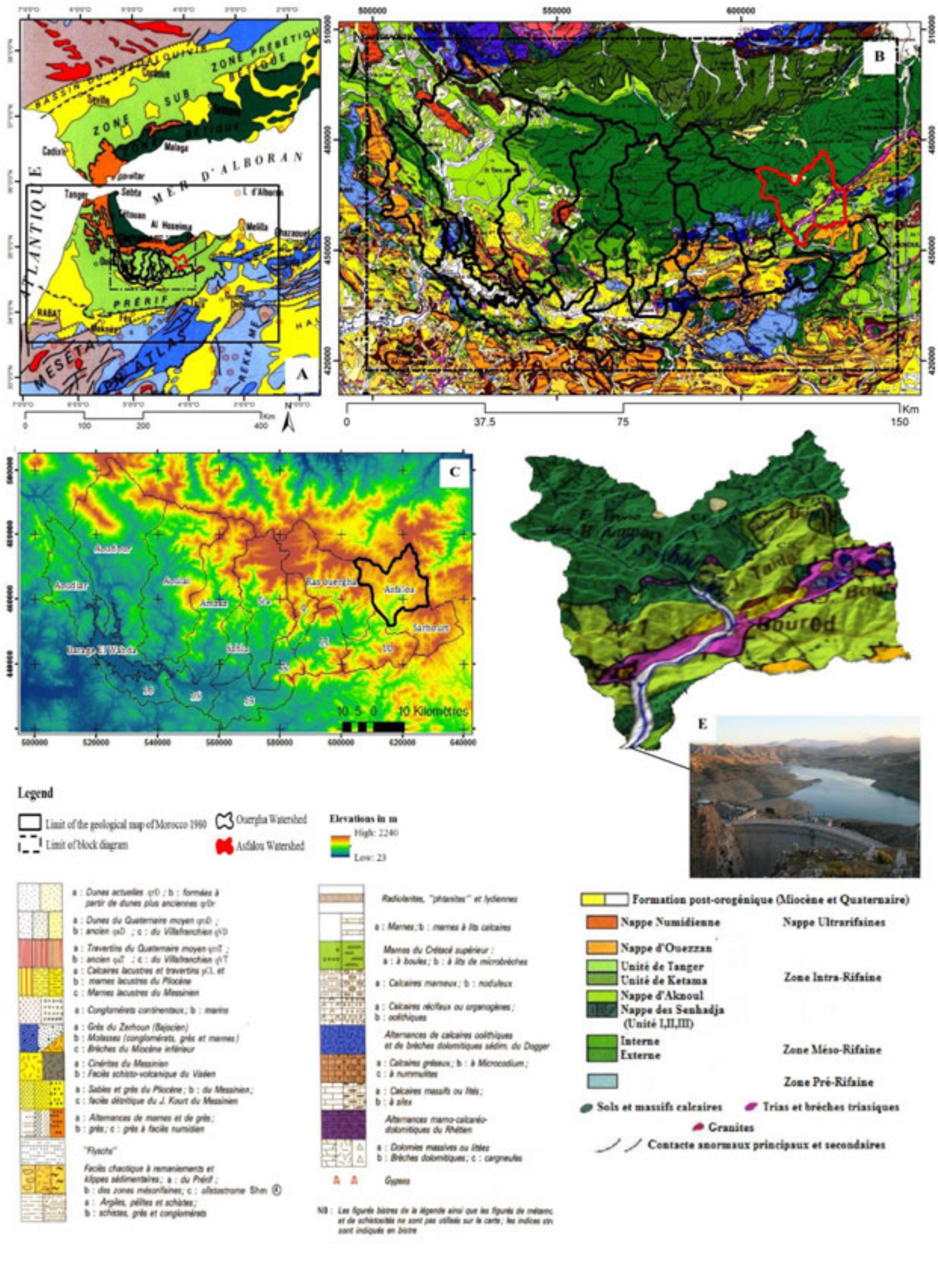
Introduction

Soil degradation through water erosion is one of the most important environmental issues for the sustainable development that affects the natural landscape (Tahouri *et al.*, 2017). This evolving phenomenon is influenced by the action of natural and anthropogenic factors, such as aggressive climate, soil vulnerability, rugged topography, deforestation, overgrazing, increasing of plot sizes, changes in practices/ excessive land use and increased impervious surface. Their mixed game contributes to the triggering and amplification of the water erosion process on soils, offering varying resistance capacities. In this respect, an acceleration of the runoff phenomenon can have adverse consequences such as flooding, degradation of vegetation cover, degradation and loss of soil fertility and siltation of dams. Several publications devoted to the study of erosion (Attia *et al.,* 2005; Sadiki *et al*., 2012; Mesrar *et al.,* 2015; Tahouri *et al.,* 2016) have demonstrated their reliability through the use of the advocate consolidated PAP/RAC (Priority Action Program of the Regional Activity Center) method, UNEP/MAP/PAP (2000) for the assessment of land degradation. This study is conducted for the first time in the Asfalou watershed; its objectives are to evaluate the water erosion process by studying the distribution, interaction, and interdependence of the factors influencing the erosive state of soils and their degree of influence, using an operational approach of checking maps and analyzing databases.

Study area

The watershed Asfalou is located on the Atlantic side of the Rif chain (Figure 1A); it occupies a position quite at the north-eastern end of the great Ouergha watershed. The Asfalou watershed is shaped in the eastern Prerif (Figure1B) on an area of about 810.23 km². Morphologically (Figure 1C), the catchment has an average altitude of 1 314 m, the upstream parts have 914 m high peaks; the slopes are steep and often exceed 35 %. To the south, dominate the low mountains and hills offering an airy relief and less abrupt slopes.

Geologically, the watershed is part of a morpho-structural context marked by the predominance of a mainly marly and sandy-marly substrate of Cretaceous and Upper Tertiary (Figure 1D), soft and friable, and is a preferred soil for water erosion (Tribak *et al.,* 2009). The watershed is characterized by the impermeability of these lands formed mainly of Cretaceous marls.



A
B
C
E
Km
0
100
200
400
0
37.5
75
150
Km
10 5 0 10 Kilomètres
Legend
Limit of the geological map of Morocco 1980
Limit of block diagram
Ouergha Watershed
Asfalou Watershed
Elevations in m
High: 2240
Low: 23
a : Dunes actuelles ; b : formées à partir de dunes plus anciennes
a : Dunes du Quaternaire moyen ; b : ancien ; c : du Villafranchien
a : Travertins du Quaternaire moyen ; b : ancien ; c : du Villafranchien
a : Calcaires lacustres et travertins et b : marnes lacustres du Pliocène
c : Marnes lacustres du Messinien
a : Conglomérats continentaux ; b : marins
a : Grès du Zerhoun (Bajocien)
b : Molasses (conglomérats, grès et marnes)
c : Brèches du Miocène inférieur
a : Cinérites du Messinien
b : Faciès schisto-volcanique du Viséen
a : Sables et grès du Pliocène ; b : du Messinien ;
c : faciès détritique du J. Kourt du Messinien
a : Alternances de marnes et de grès ;
b : grès ; c : grès à faciès numidien
"Flyschs"
Faciès chaotique à remaniements et klippes sédimentaires ; a : du Prérif ;
b : des zones mésorifaines ; c : olistostrome Shm
a : Argiles, pélites et schistes ;
b : schistes, grès et conglomérats
Radiolarites, "phtanites" et lydiennes
a : Marnes ; b : marnes à lits calcaires
Marnes du Crétacé supérieur :
a : à boules ; b : à lits de microbrèches
a : Calcaires marneux ; b : noduleux
a : Calcaires récifaux ou organogènes ;
b : oolithiques
Alternances de calcaires oolithiques et de brèches dolomitiques sédim. du Dogger
a : Calcaires gréseux ; b : à Microcodium ;
c : à nummulites
a : Calcaires massifs ou lités ;
b : à silex
Alternances marno-calcaréo-dolomitiques du Rhétien
a : Dolomies massives ou litées
b : Brèches dolomitiques ; c : cargneules
Gypses
NB : Les figurés bistres de la légende ainsi que les figurés de métamc et de schistosités ne sont pas utilisés sur la carte ; les indices str sont indiqués en bistre
Formation post-orogénique (Miocène et Quaternaire)
Nappe Numidienne
Nappe Ultrarifaines
Nappe d'Ouezzan
Unité de Tanger
Unité de Ketama
Zone Intra-Rifaine
Nappe d'Aknoul
Nappe des Senhadja (Unité I,II,III)
Interne
Externe
Zone Méso-Rifaine
Zone Pré-Rifaine
Sols et massifs calcaires
Trias et brèches triasiques
Granites
Contacte anormaux principaux et secondaires

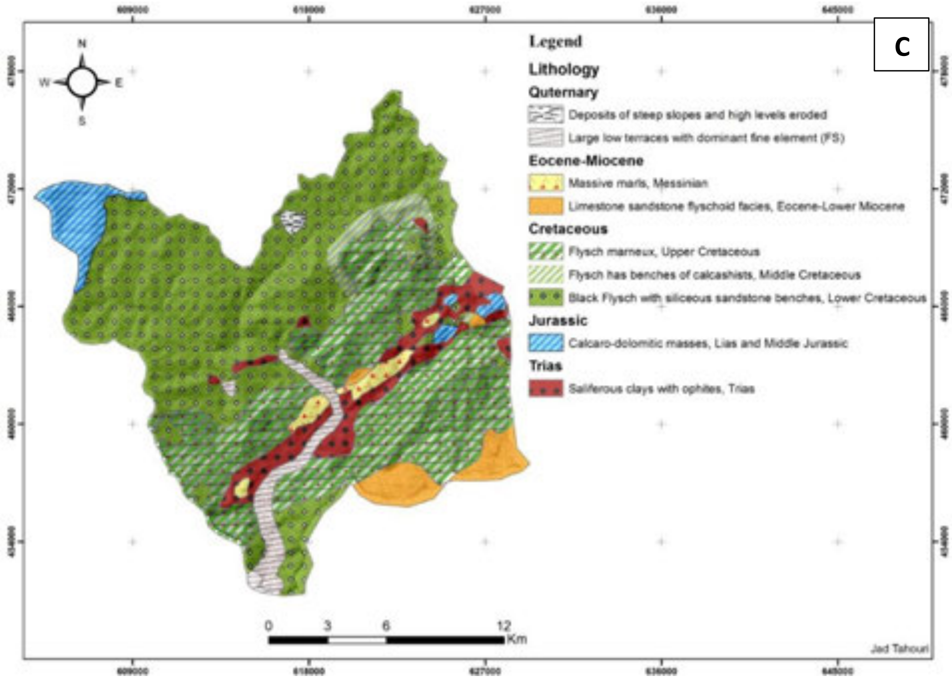


Figure 1a, b and c: Geological Context of the Asfalou Watershed in the Geological Map of Morocco - Geological Map of the Rifain Range (1980) - Tectonic Map of Africa (UNESCO 1968) and lithological map of Asfalou watershed

Methodology and procedures

PAP/RAC method

The qualitative PAP/RAC method is based on three approaches:

- **The predictive approach**: Mapping homogeneous units of erosive states, providing the framework for mapping general erosion trends. This phase is based on data processing in a sequence of 7 operations:
  - Operations 1 and 2: Development of slope and soil map;
  - Operation 3: Erodibility map by overlaying the soil map and the slope map;
  - Operations 4 and 5: Development of land cover maps and cover density;
  - Operation 6: Soil protection map by overlaying the land cover map and the cover density;
  - Operation 7: Map erosive states by overlaying the erodibility and soil protection map.
- **The descriptive approach**: Qualitative assessment complementary to the predictive approach based on the cartographic delineation of the degrees attained for each form and erosion process, in order to allow the development of the map of erosion forms.

- **The integration approach:** The final results of this approach are the trend map or susceptibility to erosion. Obtained by overlaying and integrating qualitative information from the predictive and descriptive approach.

✓ We represent the end products of each approach exposed: The erosive state map; map of erosion patterns and map of erosion trends in the Asfalou watershed.

The following flowchart summarizes the adapted procedure:

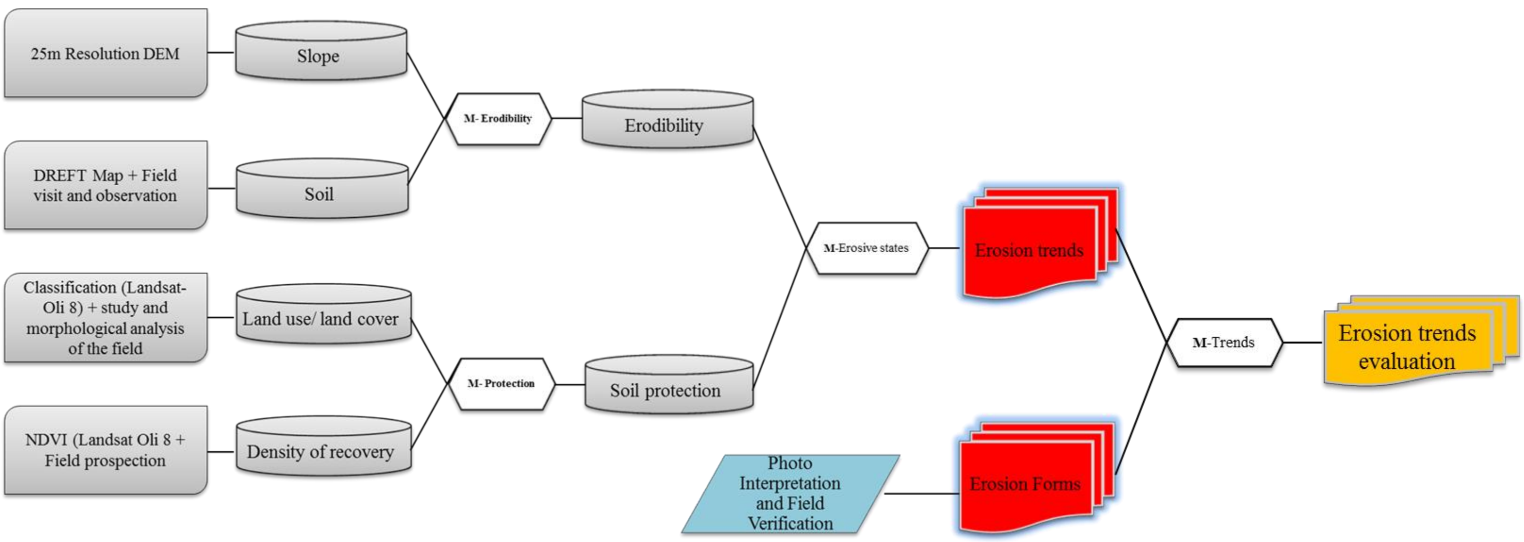


Figure 2: The conceptual model of the PAP/RAC methodology

Results and discussion

Predictive approach

The final product of the predictive approach is the map of erosive states resulting from overlaying the erodibility map and that of soil protection by applying the matrix (Table 1):

Table 1: Matrix of soil erosive states

Degree of soil protection	Degree of Erodibility				
	1	2	3	4	5
1	1	1	1	2	2
2	1	1	2	3	4
3	1	2	3	4	4
4	2	3	3	5	5
5	2	3	4	5	5

Table 2: Class of erosive states

Classes	Degrees of erosive states
1	Very weak erosion
2	Low erosion
3	Significant erosion
4	High erosion
5	Very high erosion

The analysis of the resulting map (Figure 3) shows that the most representative class is the very high erosion with 25.49 %, followed by noticeable erosion states accounting for 24.78 %, high and low erosion record successively 23.14 % and 21.56 % of the total area. The very low erosion class represents 5.12 %. The Asfalou watershed unveils a vast area for very high, noticeable, high and low erosion classes. These erosive states occupy the entire watershed; the most eroded areas are located in the upstream areas and in the northeastern part of the Asfalou dam. Elsewhere, erosion is low to very low. Erosion does not necessarily increase on high erodibility facies, but especially in places where the degree of soil protection is not important. Indeed, the presence of a dense vegetation cover on less eroded parts can reduce the state of erosion.

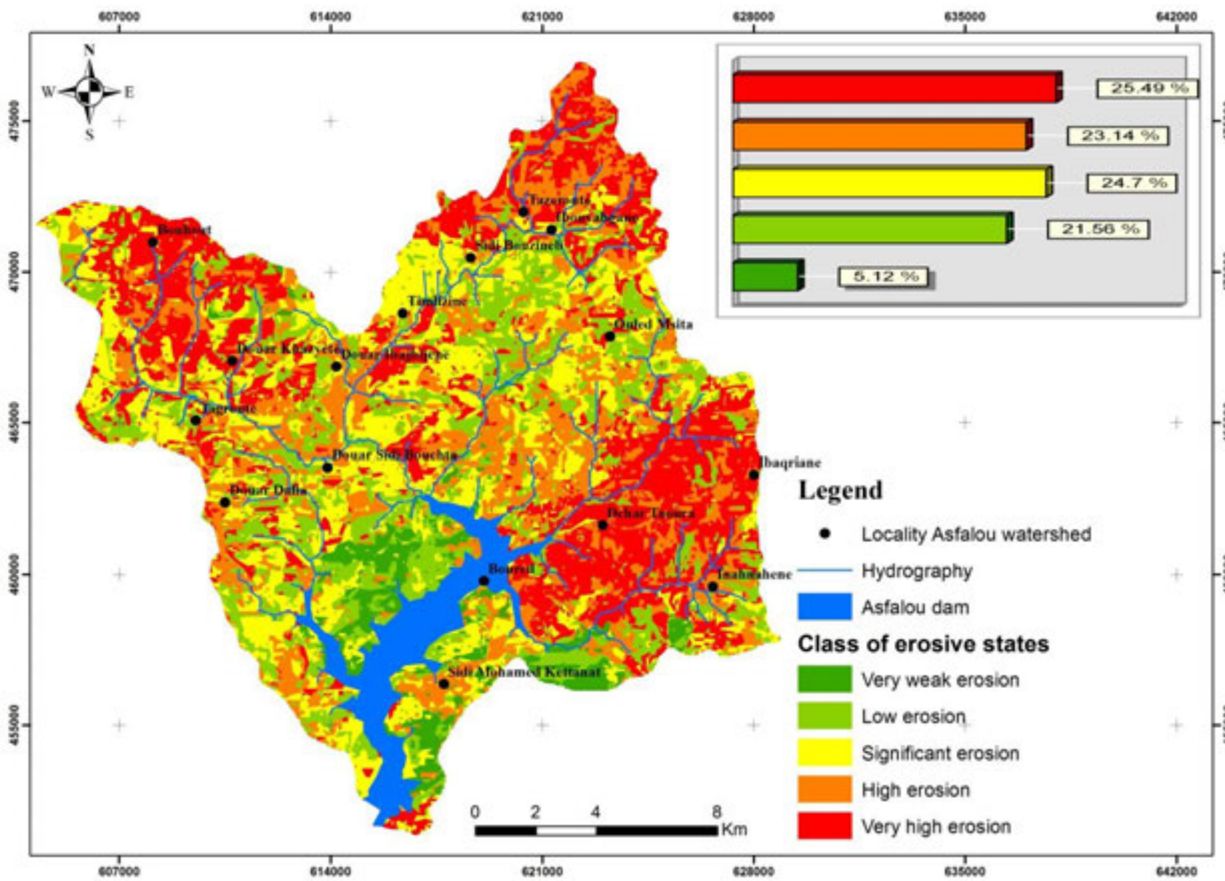


Figure 3: Map of erosive states of Asfalou watershed

Descriptive approach

Information on erosional forms (Figure 4) has been mapped according to the PAP/RAC model guidelines. Capital letters and numbers in summer are used to describe patterns of erosion and the intensity of each erosive process (Table 2).

Table 3: Codification of the forms of erosion encountered in Asfalou watershed

PAP / RAC indication	Forms of erosion of the Asfalou watershed
L1	Low erosion, restricted vegetation cover, flat erosion
L2	Low erosion, intense sheet erosion
L3	Slow erosion, cutting, diffuse runoff, sheet erosion
D1	Slow erosion, rills, and superficial gullies on slopes.
C1	Severe erosion, moderately deep gully.
MX	Signifiante erosion, Solifluxion.
CX	Severe erosion, Badlands area.

The analysis of the resulting map of the forms of erosion made it possible to deduce that:

- Sheet erosion and stripping (L1, L2, and L3): Affects 79.95 %, manifested by variegation of the soil surface which takes on the lightest colors, shows that the soil is not very developed, adding the weak presence of nutrients;
- Erosion in gullies and gullies (D1): Appears at the beginning of the winter period in the soil plowed after each climatic downpour, they are erased following the plowing action. Affects about 2.56 % of the lands;
- Gully erosion (C1): Develops at the expense of growing land on soft, steeply sloping soils, resulting in the incision of ravines by runoff water. It affects approximately 17.84 %;
- Erosion by solifluction (MX): Produced on slopes, muddy materials are attenuated by increasing their liquid water content. It affects 0.34 %;
- Generalized gullying or bad-lands (CX) reaches an area of no more than 0.11 %, mainly locating steep limestone intercalation marls.

These forms are reactivated during the winter period, typical of the Mediterranean areas.

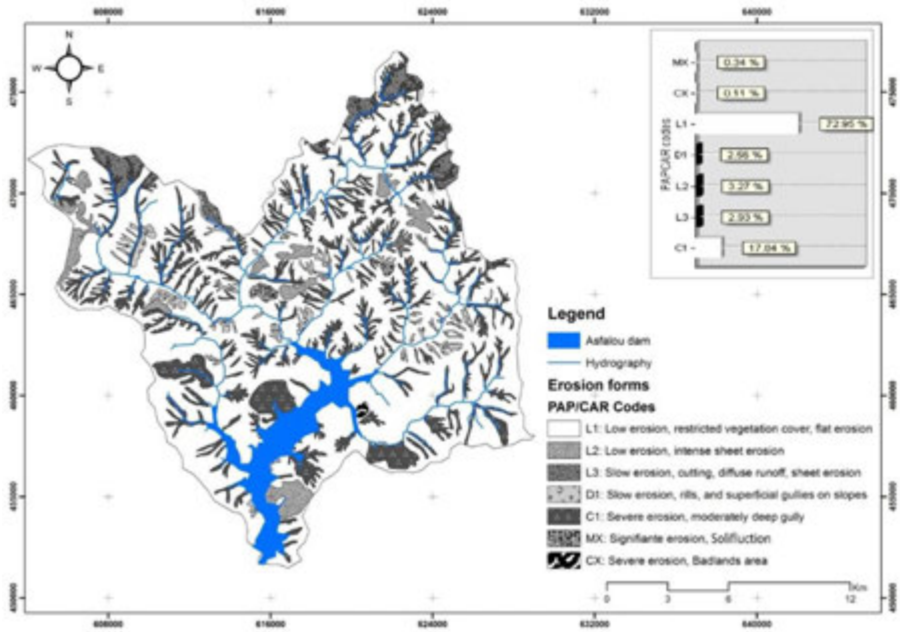


Figure 4: Forms of erosion and their occupation in accordance with PAP/RAC guidelines

Integration approach

Offers probabilistic potential information on the different aspects of erosion (Figure 5). Trend assessment is done by overlaying the tables of erosive states and erosion patterns. Its shows:

- A predominance of the localized tendency to expand or intensify the erosion process, representing 48.08 %, mainly located in the upstream parts of the basin and near Asfalou water body.
- The trend of widespread degradation towards to an irreversible situation is 25.02 %, mainly located in the downstream part of the basin and near watercourses.
- The stabilization, regression or limitation of the spatial expansion of the erosion process, representing 15.89 %, scattered over the entire catchment.
- The generalized tendency of expansion or intensification representing 11.02 %, take place when the erosive states are low and the real erosion is greater.

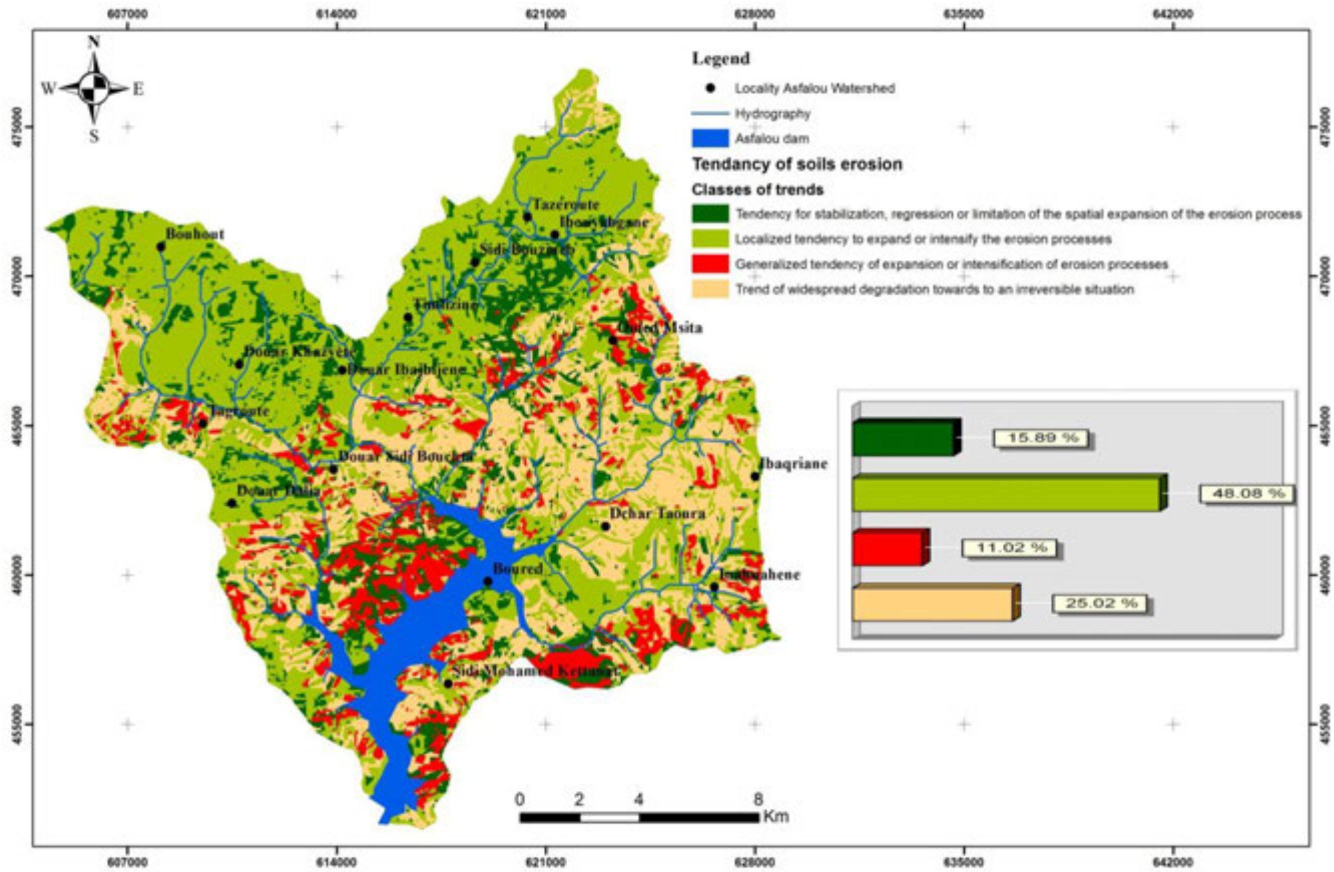


Figure 5: Map of water erosion trends in the Asfalou watershed

The most advanced forms of erosion are located in the places with the highest classes of erosive states. There is, therefore, a positive correlation between the forms of erosions and the erosive states (Figure 6).

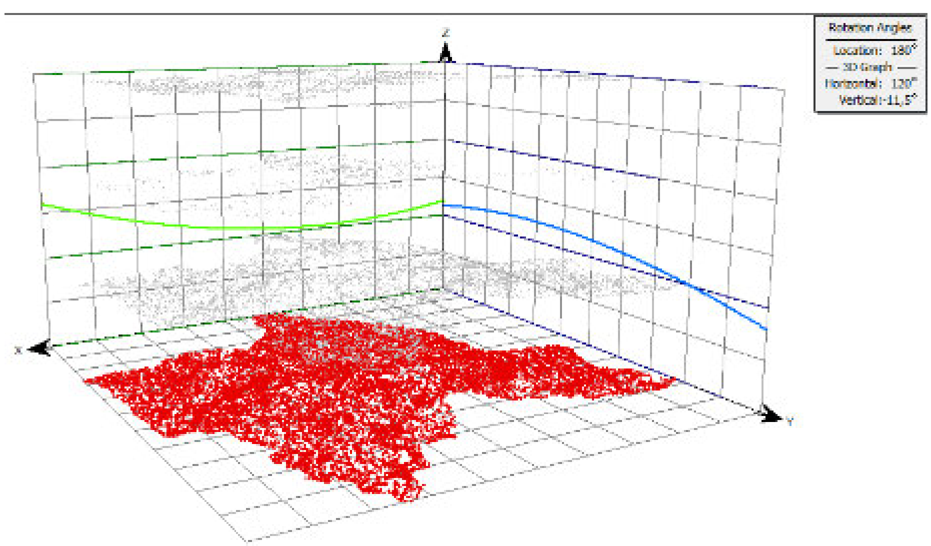


Figure 6: Land loss trend analysis

Conclusions

Soil and water resources, as well as the infrastructure of the Asfalou watershed, are threatened by degradation. Significant soil losses will contribute to the siltation and eutrophication of the Asfalou Dam. The repercussions will be felt on the quality of life of the inhabitants from an economic and social point of view. It is essential to take action to combat erosion in a comprehensive and innovative way, by clarifying the interactions between different erosion factors and by reconciling the important needs of a growing population and the limited potential of resource depletion due to over-exploitation.

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We would especially like to thank all that has helped in the realization of this work.

References

PAP/CAR. 1998. Directives pour la cartographie et la mesure des processus d'érosion hydrique dans les zones côtières méditerranéennes. [Section du livre]. - [s.l.] : PAP-8/PP/GL.1. Split, Centre d'activités régionales pour le Programme d'actions prioritaires (PAM/PNUE), en collaboration avec la FAO.

Attia, R., Sadok, A. & Hédi, H. I. 2005. Application des Directives CAR/PAP pour la formulation d'un programme de gestion de contrôle de l'érosion et de la désertification Cas du bassin versant de l'Oued Rmel. – Programme d'Actions Prioritaires, Centre d'Activités Régionales, Tunisie, pp. 72.

Mesrar, H, Sadiki, A. Navas, A. Faleh, A. Quijano, L. & Chaaouan, J. 2015. Modélisation de l'érosion hydrique et des facteurs causaux, Cas de l'oued Sahla, Rif Central, Maroc [Revue]. - [s.l.] : Zeitschrift für Geomorphologie, 2015. - Vol. DOI: 10.1127/zfg/2015/0169 .

Sadiki, A., Mesrar, H. & Faleh, A. 2012. Modélisation et cartographie des risques de l'érosion hydrique: Cas du bassin versant de l'oued Larbaa, Maroc. *Papeles de Geografia*, 55-56, 179-188.

Tahouri, J., Karrat, L. & Mesrar, H. 2016. Utilisation du modèle PAP/RAC et des outils SIG pour la cartographie et l'evaluation des processus d'érosion hydrique en milieu méditerranéen cas du bassin versant de l'oued Asfalou-Maroc. https://www.academia.edu/22181609/.

Tahouri, J., Mouhssine, M. & Mesrar, H. 2017. *Les géosites du Rif de la région de Moyen Ouergha : Identification, valorisation et protection.* Saarbrücken, Publisher : Edition universitaires européennes, 2017, ISBN : 978-3-8416-7674-0.

Tribak, A., El Garouani, A & Abahrour, M. 2009. Evaluation quantitative de l'erosion hydrique sur les terrains marneux du Prerif oriental (Maroc) : cas du Sous-bassin de l'oued Tlata. *Revue Sécheresse*, vol. 20, n° 4, pp 333-337.

Calibration and validation of an USLE model to map soil erosion by water in the Sicilian Region (Italy)

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Abstract

Assessing the soil erosion by water (SEW) at the regional level is important for current and future planning of land use and environmental actions to combat land degradation. The Universal Soil Loss Equation (USLE) is an empirical model well known to estimate SEW. USLE was originally formulated and calibrated at field scale, but it is currently widely used also for mapping purposes, at wider scales, even continental ones. This extrapolation needs a previous calibration of the whole parameters and an afterwards validation. USLE model consists of a multiplication of 6 factors, therefore the wrong calibration of one factor, strongly affects the others. Measured SEW data are scarcely available, especially in natural environments, which should be necessary both for calibration and validation. Aims of the research work were to find an optimal calibration procedure of the USLE model at the regional scale of Sicily (Italy), and to validate the final result on the base of plenty available qualitative SEW field data, with a Bayesian procedure. USLE model resulted highly sensitive to the procedure adopted for the rainfall erosivity factor, strongly influencing all the other factors. The qualitative validation resulted an effective way to overcome the lack of measured field data.

Keywords: empirical modelling, assessment of soil erosion, qualitative field observations, GIS, mapping soil erosion, Bayesian validation

Introduction, scope and main objectives

Assessing the soil erosion by water (SEW) at the regional level is important for current and future planning of land use and environmental actions to combat land degradation. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is an empirical model well known to estimate SEW. USLE was originally formulated and calibrated at field scale, but it is currently widely used also for mapping purposes, at wider scales, even continental ones (Grimm *et al.,* 2003; Van Rompaey *et al.,* 2003; Panagos *et al.*, 2015). The mapping application of USLE model sometimes it's not preceded by a rigorous calibration procedure, and the validation is rarely performed. Especially practitioners use to apply different estimation procedures to estimate and map the 6 USLE factors, without an idea of the error in which they can fall in the choice of a specific procedure rather than another. Concerning the validation, it is rarely performed also due to the scarcity of SEW measured data, especially in natural environments. Aims of the present research work were: 1) to test a calibration procedure of the USLE model at the regional scale of Sicily (Italy), exploring the consequences derived by the choice of different estimation procedures, 2) to test a specific Bayesian validation procedure of the final SWE map, by which it was possible to exploit qualitative SEW field data, plenty available in the Sicilian territory.

Methodology

The rate of soil erosion by water (tons ha^{-1} $year^{-1}$) was obtained by applying the USLE empirical model (Wischmeier and Smith, 1978), which is based on the equation $E = R \times K \times L \times S \times C \times P$ linking soil losses (E, tons ha^{-1} $year^{-1}$) to rainfall erosivity (R, Mj mm ha^{-1} h^{-1} y^{-1}), soil erodibility (K, t h MJ^{-1} mm^{-1}), slope length and steepness (LS), land cover and management (C) and conservation practices (P).

In the original formulation the R factor calculation needs pluviographic data which are not readily available in many parts of the world, therefore many authors have developed regression formulas to estimate it on the base of easily available rainfall data such as mean annual and/or monthly rainfall amounts. We considered 5 of these regression formulas (Arnoldous, 1977; Arnoldous, 1980; Banasik and Górski, 1994; Renard and Freimund, 1994; Yu and Rosewell, 1996; Ferro *et al.,* 1999) which gave very different values for the R factor as a result. In order to choose the best one for Sicily, we used the pluviographic data published by Agnese *et al.* (2006) for 5 different Sicilian locations, and calculated the R factor applying the original procedure. For each storm, rainfall data were aggregated at Δt = 5, 15 and 60 min and the total storm kinetic energy, E (MJ ha^{-1}), maximum 30-min rainfall intensity, I_{30} (mm h^{-1}), and single storm erosion index, EI (MJ mm $ha^{-1}h^{-1}$), were calculated for each Δt value (Δt = 5, 15 and 60 min). The mean annual rainfall erosivity (MJ mm ha^{-1} h^{-1} y^{-1}) of each of the 5 stations were calculated multiplying the single storm erosion indexes EI_5, EI_{15} and EI_{60} (with Δt = 5, 15 or 60 min, in MJ mm $ha^{-1}h^{-1}$) with the mean number of erosive storms during a year (y^{-1}). At the 5 stations locations we calculated the R factors applying the 5 regression formulas. The formula which gave the lowest error, expressed as root mean squared error (RMSE), was chosen. The K factor was mapped on the basis of soil texture and soil organic carbon content of the topsoil (averaged for the first 50 cm of soil depth) applying the coefficients of Stone and Hilborn (2012). Soil texture and soil organic carbon content were derived from the 1:250 000 scale Soil Map of Sicily (Fantappiè *et al.,* 2011). The soil erodibility factor was corrected using the reduction coefficient of Poesen *et al.* (1994) ($e^{-0.04(Rc-10)}$) which considers the rock fragment cover Rc (the percentage of particles > 2 mm diameter on the soil surface, including stoniness and rockiness). In the case of volcanic soils, we follow Van der Knijff *et al.* (1999) and assigned a K factor of 0.08. The slope-length and slope gradient (LS) factors were derived from the Digital Terrain Model of Sicily (20×20 m) using the formulas proposed by Wischmeier and Smith (1978), and revised by McCool *et al.* (1987, 1989), as explained in detail by Fantappiè *et al.* (2015). The potential SWE was calculated by multiplying the R, K, L and S factors, and attributed to 1926 georeferenced observations where no field evidence of SEW was detected by the surveyors, and the type of land use was described. C factors were calibrated for 9 great grouping types of land uses by dividing the actual soil erosion (equal to 2 tons ha^{-1} $year^{-1}$, which is a 'tolerable soil erosion rate' by Jones *et al.* (2012), by the mean estimated potential SWE calculated for each of the 9 great grouping types of land uses, as explained in detail by Fantappiè *et al.* (2015).

The delineation of the terraced landscapes of Sicily (Barbera *et al.,* 2010) was used to map the P factor, with P equal to zero in the case of presence of terraces, and equal to 1 in the case of absence. The map of the actual rate of SEW was obtained by multiplying the maps of the 6 factors, and the final risk map was elaborated evaluating the risk in terms of years necessary for a complete loss of the soil cover, on the base of soil depth and bulk density (Fantappiè *et al.,* 2015). We performed a qualitative validation of the SWE map obtained, which was done, for a comparison, also on the estimations done by PESERA (Kirkby *et al.* 2004), USLE (Grimm *et al.,* 2003; Van Rompaey *et al.,* 2003), and MESALES (Le Bissonnais *et al.,* 2002) projects of JRC. For the qualitative validation we collected 6 191 punctual georeferenced evidences of presence or absence of SWE. Our USLE map, the PESERA and the JRC- USLE maps were converted into maps of presence/absence of soil erosion considering a threshold of 2 tons ha^{-1} $year^{-1}$. The MESALES map was converted considering absence in the case of very low risk, and presence in the case of low, medium, high and very high risk. The positive and negative predictive values of the 4 maps were elaborated using the Bayes theorem (Lesaffre *et al.,* 2012), expressing respectively the probability of occurrence of SWE, given that the model estimated its occurrence, and the probability of absence of SWE, given that the model estimated its absence.

Results

In the table 1 are reported the results of the R factor calibration.

Table 1: RMSE obtained for the R factor estimated with 5 regression formulas, compared to the R factors calculated with the pluviographic data published by Agnese *et al.* (2006)

Δt (min)	(Ferro *et al.* 1999)	(Arnoldous, 1977)	(Yu and Rosewell, 1996)	(Renard and Freimund, 1994)	(Arnoldous, 1980)
60	571.07	943.79	1 749.86	2 414.33	3 309.00
15	1 380.34	863.72	1 014.91	1 572.87	2 413.89
5	1 594.79	1003.85	940.50	1 427.69	2 236.95

In the table 2 are reported the results of the Bayesian validation.

Table 2: Results of the validation of the 4 SWE maps expressed in terms of positive and negative predictive values calculated with the Bayes theorem (Lesaffre *et al.,* 2012)

SWE map	Positive predictivity	Negative predictivity
Our USLE	0.815	0.610
JRC-USLE	0.704	0.487
PESERA	0.566	0.321
MESALES	0.599	0.287

Discussion

The estimation errors obtained applying the 5 R estimation formulas were significantly different, greatly influencing the other USLE factors, and particularly the C factor, which is specifically obtained on the base of the potential SWE. The calibration procedure applied for the R factor resulted effective and reproducible.

Our USLE model obtained the best results in the validation, both as positive and negative predictivity. Empirical USLE models gave better validation results compared to PESERA physically based model, and MESALES conceptual model.

Conclusions

The research demonstrated how much the fine calibration of models is necessary in order to obtain better accurate results. The research, also, suggested innovative procedure in the qualitative validation of SWE models, which made use of widely available qualitative surveyed data on the presence/absence of SWE, given the scarcity of measured ones.

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References

Agnese, C., Bagarello, V., Corrao, C., D'Agostino, L. & D'Asaro, F. 2006. Influence of the rainfall measurement interval on the erosivity determinations in the Mediterranean area. *Journal of Hydrology,* 329: 39-48. doi:10.1016/j.hydrol.2006.02.002.

Arnoldous, H.M.J. 1977. Methodology used to determinate the maximum potential average soil loss due to sheet and rill erosion in Morocco. In: Assessing soil degradation. *FAO Soils Bulletin,* 34: 39–51.

Arnoldous, H.M.J. 1980. An approximation of the rainfall factor in the Universal Soil Loss Equation. In De Boodt, M., Gabriels, D., (eds). *Assessment of Erosion.* Wiley and Sons, UK, 127-132.

Banasik, K. & Górski, D. 1994. Rainfall erosivity for South-East Poland. In Rickson (ed), *Conserving soil resources. European perspectives. Lectures in soil erosion control.* Silsoe College, Cranfield University, UK, 201-207.

Barbera, G., Cullotta, S., Rossi Doria, I., Rühl, J. & Rossi Doria, B. 2010. I paesaggi a terrazze in Sicilia: metodologie per l'analisi, la tutela e la valorizzazione. *ARPA Sicilia, Collana Studi e Ricerche* n. 7, Palermo. 531 pp.

Fantappiè, M., Bocci, M., Paolanti, M., Perciabosco, M., Antinoro, C., Rivieccio, R. & Costantini, E.A.C. 2011. Realizzazione della carta digitale dei suoli della Sicilia utilizzando il rilevamento GIS-oriented e un modello CLORPT. In: Dazzi, C. (Ed.), *La Percezione Del Suolo - Atti Del Workshop.* Collana, Scienza Del Suolo. Le Penseur, pp. 139–142.

Fantappiè, M., Priori, S. & Costantini, E.A.C. 2015. Soil erosion risk, Sicilian Region (1:250,000 scale). *Journal of Maps*, 11(2): 323-341, doi: 10.1080/17445647.2014.956349

Ferro, V., Porto, P. & Bofu, Y. 1999. A comparative study of rainfall erosivity estimation for southern Italy and southeastern Australia. *Hydrological Sciences Journal*, 44(1): 3-24.

Grimm, M., Jones, R.J.A., Rusco, E. & Montanarella, L. 2003. Soil Erosion Risk in Italy: a revised USLE approach. *European Soil Bureau Research Report No.11*, EUR 20677 EN. Office for Official Publications of the European Communities, Brussels, Luxembourg, 28 pp.

Jones, A., Panagos, P., Barcelo, S., Bouraoui, F., Bosco, C., Dewitte, O., Gardi, C., Erhard, M., Hervás, J., Hiederer, R., Jeffery, S., Lükewille, A., Marmo, L., Montanarella, L., Olazábal, C., Petersen, J.E., Penizek, V., Strassburger, T., Tòth, G., Van Den Eeckhaut, M., Van Liedekerke, M., Verheijen, F., Viestova, E. & Yigini, Y. 2012. The state of soil in Europe. A contribution of the JRC to the EEA Environment State and Outlook Report - SOER 2010. *Report EUR 25185 EN*. ISBN 978-92-79-22806-3. doi: 10.2788/75626.

Kirkby, M.J., Jones, R.J.A., Irvine, B., Gobin, A., Govers, G., Cerdan, O., Van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., Van Lynden, G.J. & Huting, J. 2004. Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). Office for Official Publications of the European Communities, Brussels, Luxembourg. EUR 21176, *European Soil Bureau Research Report 16*, 18pp.

Le Bissonnais, Y., Montier, C., Jamagne, M., Daroussin, J. & King, D. 2002. Mapping erosion risk for cultivated soil in France. *Catena*, 46: 207-220.

Lesaffre, E. & Lawson, A.B. 2012. *Bayesian Biostatistics*. John Wiley & Sons, UK. ISBN 978-0-470-01823-1, 16-17.

McCool, D.K., Foster, G.R., Mutchler, C.K. & Meyer, L.D. 1987. Revised slope steepness factor for the Universal Soil Loss Equation. *Transactions of the American Society of Agricultural Engineers*, 30(5): 1987–96.

McCool, D.K., Foster, G.R., Mutchler, C.K. & Meyer, L.D. 1989. Revised slope length factor for the Universal Soil Loss Equation. *Transactions of the American Society of Agricultural Engineers*, 32(5): 1571–1576.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & Alewell, C. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, 54: 438–447.

Poesen, J.W., Torri, D. & Bunte, K. 1994. Effects of rock fragments on soil erosion by water at different spatial scales: A review. *Catena*, 23: 141–166.

Renard, K.G. & Freimund, J.R. 1994. Using monthly precipitation data to estimate the R factor in the revised USLE. *Journal of Hydrology*, 157: 287-306. doi:10.1016/0022-1694(94)90110-4.

Stone, R.P. & Hilborn, D. 2012. Universal Soil Loss Equation (USLE). *Fact Sheet, Agricultural Engineering, Ontario Ministry of Agriculture, Food and Rural Affaires*. Available at: http://www.omafra.gov.on.ca/english/engineer/facts/12-051.pdf.

Van der Knijff, J.M, Jones, R.J.A. & Montanarella, L. 1999. Soil erosion risk assessment in Italy. European Soil Bureau. *EUR 19022 EN*, 54 pp.

Van Rompaey, A.J.J., Bazzoffi, P., Jones, R.J.A., Montanarella, L., Govers, G. 2003. Validation of Soil Erosion Risk Assessments in Italy. European Soil Bureau Research Report No.12, *EUR 20676 EN*. Office for Official Publications of the European Communities. Brussels, Luxembourg, 25pp.

Wischmeier, W.H., Smith, D.D. 1978. *Predicting rainfall erosion losses. A guide to conservation planning*. USDA Agriculture Handbook 537, Agricultural Research Service, Washington, DC, 58 pp.

Yu, B. & Rosewell, C.J. 1996. A robust estimator of the R factor for the Universal Soil Loss Equation. *Transactions of the American Society of Agricultural Engineers*, 39(2): 559-561.

Possibilities and precision of volumetric analyses of ephemeral gullies via UAV monitoring

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Abstract

Team of the CTU in Prague focused on monitoring of ephemeral gullies and rills in Benesov region (Czech Republic) since 2012 and summarized some volumetric data from single fields and single event UAV studies. For Bykovice watershed in the Benesov region (8 km^2) in 2015 all available aerial photographs since 1998 were collected, rectified and inspected to derive temporal variations of ephemeral gullies. For Postupice field (0.125 km^2) the total volume of ca 2 000 m^3 was estimated to emerge in erosion rills and ephemeral gullies, after 40 mm (120 min) rainfall event in 27th April 2013. For nearby Lbosin field (0.29 km^2) the estimated volume of rills caused by single rainfall (ca 38 mm/30 min) in 11th August 2017 reached 3 300 m^3. Based on the UAV studies the methodology for semi-automated volumetric analyses of rills has been developed (Báčová *et al.*, 2018). Based on the insights we can conclude, that after single events, large systems of rills and ephemeral gullies can emerge, that rise up to hundreds of tons per ha of the field. UAVs can effectively be used to better estimate actual soil erosion losses.

Keywords: UAV, soil erosion, photogrammetry, rill volume

Introduction, scope and main objectives

To estimate potential soil losses, traditionally the soil erosion by water is assessed by empirically or process based models. Validation of these tools is based on plot data, and sediment yield measurement in outlets. In between these two scales, sediment transport over agricultural field and spatial redistribution of soil was hardly described by traditional approaches. Rills and ephemeral gullies have been measured for long term in many studies, but only by transects in several rill profiles.

The convergence and extension of photogrammetry, digital imaging technology and geographical information systems (GIS) have contributed to the use of multi-temporal digital surface models (DSM) to compute soil loss by erosion. Very detailed UAV digital terrain model with a resolution of 0.05 x 0.05 m and errors of position below 0.01 m was presented as a basis for volume quantification on a local scale (Peter *et al.*, 2014). However, gully measurements by means of photogrammetric techniques are strongly affected by the rill (gully) morphology. The indirect measurements from imagery are known to depend on factors like image resolution, quality of ground control, vegetation cover and image evaluation technique, which strongly influence the measurement accuracy (Carollo *et al.*, 2015).

Team of the CTU in Prague (Krasa *et al.*) focused on monitoring of ephemeral gullies and rills in Benesov region (Trebesice, Bykovice, Postupice, Lbosin) since 2012 and summarized some volumetric data from single field and single event UAV studies. An automated approach to compute rill volumes was presented

(Báčová *et al.*, 2018). Using this tool, several large parcels were completely analysed concerning rill patterns and extent.

Based on the insights we can conclude, that after single events, large systems of rills and ephemeral gullies can emerge, that rise up to hundreds of tons per ha of the field. UAVs can effectively be used to better estimate actual soil erosion losses.

Methodology

The study field area is located near the city of Benešov in the Central Bohemian Region. The average altitude ranges from 397 to 453 m. a. s. l. Average annual precipitation is between 600-700 mm with average monthly temperatures varying from -3 °C (January) to 18 °C (August). Most of the highly-erosive storms in the Czech Republic usually occur from June to August. The main soil type is shallow Cambisol which covers a large area in the Czech Republic. In recent years within several research project the operational erosion monitoring was established here, including also sheet erosion. After 5 mm rain (monitored by automatic stations) the episode monitoring is provided, linear features are monitored via UAV (30 – 100 m flight elevations), searching for thresholds in rain/vegetation cover to induce erosion and rill evolution. The data is processed by Agisoft Photoscan to get DSM and orthophotos in desired resolutions (5mm – 2 cm). Afterwards, rill boundaries are manually digitized. Ephemeral gullies are all edited, smaller rills are edited in representative squares where UAV data with higher precision (5mm) are available. Finally, the multiscale approach is used to estimate rill volumes in entire fields.

Results

For Bykovice watershed in the Benešov region (8 km^2) in 2015 all available aerial photographs since 1998 were collected, rectified and inspected to derive temporal variations of ephemeral gullies. For a single parcel of 0.34 km^2 the data was published (Báčová and Krása, 2016).

Figure 1: Rill and ephemeral gully pattern in Lbosin field (August 2017)

For Postupice field (0.125 km^2) the total volume of ca 2 000 m^3 was estimated to emerge in erosion rills and ephemeral gullies, after 40 mm (120 min) rainfall event in 27th April 2013. The field was in seedbed condition (after clover seeding). The field was split in 11 regions of different erosion intensity, with soil loss varying from 40 – 70 mm of washed soil profile. In bottom of the slope 130 mm deep sedimentation cone emerged (containing 150 m^3 of deposited soil). In USLE language, for the entire field we would talk about 250 t.ha^{-1} of the soil loss. Computed by 2D USLE (Desmet and Govers, 1996), the parcel would reach soil loss of ca 50 t.ha^{-1} for seedbed conditions (C factor 1.0), and typical total annual R-factor being 620 MJ.ha^{-1}.mm.h^{-1}.

For nearby Lbosin field (0.29 km^2) the UAV estimated volume of rills caused by single rainfall (ca 38 mm/30 min) in 11th August 2017 reached 3 300 m^3. The eroded field was in seedbed conditions of freshly seeded oil rape. The field was split in 27 regions of different erosion intensity, with soil loss varying in average from 1 – 20 mm of washed soil profile. The comparison of DSM and rill form precision was provided by flight elevations from 5 – 100 m. The area specific soil loss in rills in the Lbosin field measured by UAV reached 182 t.ha^{-1}.

Discussion

It is necessary to have in mind that the method described here provides a volumetric assessment of erosion objects such as rills, gullies or caverns, but that sheet erosion or deposition of erosion material cannot be quantified by this method. For these erosion effects, long-term monitoring and knowledge of the prior ground surface are needed. Our method is useful for cases when prior information is not available, which is a common situation, and the method estimates only the volume of in-depth erosion objects.

The UAV photogrammetry can be used in different crop stages, but under the vegetation, usually only orthophoto can be used to estimate the spatial extent of formed ephemeral gullies, and small rills do not have to be detectable. The volumetric analyses can be performed usually only in bare soil conditions, that is a case of seedbed conditions of the fields. But these are also the cases with severe destructions of soil profiles and massive soil transports.

Conclusions

UAVs have become the most widely used and the most suitable instruments for small to medium scale monitoring. It can be used effectively and quite promptly for photographing erosion damage of fields from a relatively low height level, so it is still possible to detect rills and other erosion objects. Naturally, the resolution and the accuracy of DSM generated from photos are lower than the resolution and accuracy from terrestrial observations. These parameters depend mainly on the type of camera, the flight altitude, the use of GCPs, and image overlaps. Generally, the resolution of UAV DSMs can reach centimeters or sub-centimeters. If there is no requirement for a high-precision result, this resolution is sufficient for estimating the volume of eroded material from rills over larger areas. In addition, terrestrial measurements can be applied for checking.

Measured rill volumes indicate that typically used models (e.g. USLE) can heavily underestimate soil losses and field destructions caused by erosion events.

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References

Báčová, M. & Krása, J. 2016. Application of historical and recent aerial imagery in monitoring water erosion occurrences in Czech highlands. *Soil and Water Research*, 11: 267–276. https://doi.org/10.17221/178/2015-SWR.

Báčová, M., Krása, J., Devátý, J. & Kavka, P. 2018. A GIS method for volumetric assessments of erosion rills from digital surface models. *European Journal of Remote Sensing*, 1–12. https://doi.org/10.1080/22797254.2018.1543556.

Carollo, F.G., Di Stefano, C., Ferro, V. & Pampalone, V. 2015. Measuring rill erosion at plot scale by a drone-based technology. *Hydrological Processes,* 29: 3802–3811. https://doi.org/10.1002/hyp.10479.

Desmet, P.J.J. & Govers, G. 1996. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *Journal of Soil and Water Conservation*, 51: 427–433.

Peter, K.D., d’Oleire-Oltmanns, S., Ries, J.B., Marzolff, I. & Ait Hssaine, A. 2014. Soil erosion in gully catchments affected by land-levelling measures in the Souss Basin, Morocco, analysed by rainfall simulation and UAV remote sensing data. *Catena,* 113: 24–40. https://doi.org/10.1016/j.catena.2013.09.004.

Protocol to identify and assess soil degradation by erosion in Colombia

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Abstract

Erosion is considered as the main soil degradation processes in Colombia. A Protocol to identify and assess soil degradation by erosion at national, regional and local tiers was establish. This protocol became the main support for the preparation of the "Baseline of Soil Degradation by Erosion in Colombia"; its main objective was to determine the conceptual and methodological framework, methods, processes and techniques to develop the zoning, characterization, analysis and evaluation which allows monitoring of soil degradation by erosion at several tiers in order to find out considerations and practical recommendations to stop soil degradation. This protocol offers planning guidelines and technical tools to regional and municipality environmental agencies. The importance of the Protocol lies in the unification of concepts and methodologies that allow replicable results at different tiers to carry out a monitoring system for the state and identify causes and impact of the degradation process by erosion in the country.

Keywords: Protocol, degradation, erosion, monitoring

Introduction, scope and main objectives

Colombia is concerned about the soil degradation mainly due to its consequences in the decrease of productivity and the deterioration of ecosystem services. The national government in order to stop soil degradation launched the "Policy for Sustainable Soil Management" through the Ministry of Environment and Sustainable Development - MADS (MADS, 2016). The scope of this policy demands the assessment and monitoring of the soil quality status in the country. The Institute of Hydrology Meteorology and Environmental Studies of Colombia - IDEAM, is in change to evaluate soil degradation; for this reason, it has created an instrument for assessment and monitoring the soil quality status, "The Protocol for the identification, analysis and evaluation of soil degradation by erosion" (IDEAM, MADS, U.D.C.A, 2015), which is presented below.

The mentioned protocol is the result of an inter-institutional effort and it was developed due to the need to unify concepts and methodologies to monitor and assess soil degradation process by erosion. It offers planning guidelines and technical tools in order to stablish the baseline of soil degradation status by erosion at national, regional and local tiers. The protocol contains a methodological structure by phases, stages and activities, based on the conceptual model of the DPSIR indicators (driving forces, pressures, state, impacts and responses). The DPSIR approach allows to identify and characterize the causes of the soil degradation process and also to assess the impacts on ecosystems, population and economic activities. DPSIR indicators were proposed according to information availability, in order to evaluate and prioritise actions for decisions making preventing/mitigating soil degradation by erosion.

Methodology

The methodology is addressed according to a structure of phases, stages and activities. The zoning phase of includes the stages of planning, field preparation, field work and post-field work.

For the zoning phase, erosion processes are identified and classified by type (factor), degree (intensity and severity) and class (features in the terrain). The characterization phase identifies the current soil degradation status by erosion process through interrelationship between the biophysical conditions and socio-economic characteristics of certain area. Indicators of drivers, pressure, status, impact and response are defined. Erosion processes are described in land units based on the review of primary and secondary information of biophysical, social, economic and cultural components.

The last phase, analysis and evaluation phase, integrates gathered variables in the zoning and characterization phases. Explanatory and causal indicators of soil degradation by erosion are calculated or estimated; driving forces as indirect causes and pressures as current and direct cause. The evaluation of impacts and responses is carried out by stakeholders including local community and authorities.

In the analysis stage, the results of soil degradation status by erosion are compared with the prioritized indicators and statistical, and graphic reports of spatial distribution are generated. Then determinants are the state indicators of erosion degradation were analysed according to behaviours and relationships evidenced during the analysis by means of a semi quantified assessment.

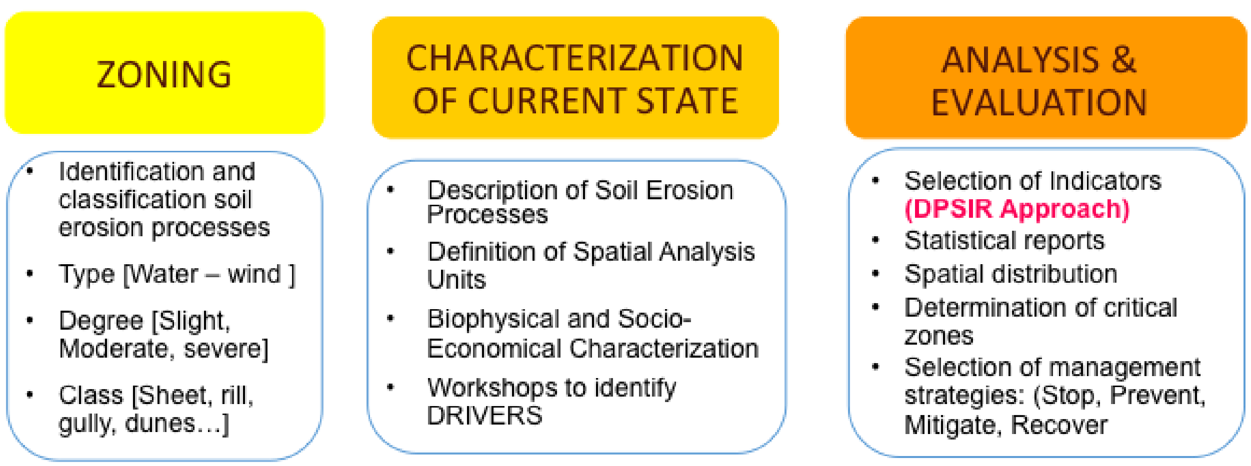

Figure 1: Methodological scheme proposed to identify and assess soil degradation by erosion process (IDEAM, MADS, U.D.C.A, 2015)

Results

The Protocol is a validated methodological document that allows the study of soil degradation by erosion process in tropical zones of America and can be potentially applied worldwide. It is considered as a support instrument for Sustainable Soil Management in Colombia, which allows obtaining knowledge about the current state of soil quality caused by erosion processes. It defines the procedures in order to collect, analyse and report data for the assessment and monitoring soil degradation by erosion. The analytical processes described explain the causes or drivers and impacts of the erosion process from a social, economic, cultural and ecological perspective. This tool ensures detection of changes in the monitoring that can occur within and over the soils of the national territory, in order to achieve comparable results at temporary and spatial tiers.

Conclusions

Nowadays, Colombia has a official document which presents in detail the procedures and techniques to carry out the evaluation of soil degradation by erosion processes at different tiers, from national, subnational (regional) up to local analysis.

This document has allowed the country to start carrying out the identification, zoning and evaluation of the current state of erosion (baseline) and to generate a first approach in assessment and monitoring process in order to develop control and mitigation strategies.

This publication could be considered as a reference in different regions within the country and also worldwide having in account similar latitudes.

Figure 2: Example of Severe erosion degree (notice the details of soil surface around the trees).

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References

CORINE. 1994. Soil erosion risk and important land resources in the southern regions of the European Community. European Environment Agency.

FAO. 2007. Proyecto Evaluación de la degradación de Tierras en Zonas Áridas LADA. Manual de Evaluación local de la degradación de Tierras Áridas (LADA – L). Versión Final. Roma, Italia: Mecanismo Global de la UNCCD, UNEP, WOCAT.

FAO. 2008. Proyecto Evaluación de la degradación de Tierras en Zonas Áridas (LADA). República Argentina. Informe de avance a escala local.

FAO. 2015. Funciones y servicios ecosistémicos del Suelo. http://www.fao.org/soils-2015/es/

IDEAM. 2012. Corine Land Cover. Bogotá D.C.: Subdirección de Ecosistemas e Información Ambiental - IDEAM.

IDEAM, U.D.C.A. 2015. Protocolo para la identificación y evaluación de la degradación de suelos por erosión. Bogota.

LEÓN, P. J. 2001. Estudio y control de la erosión hídrica. Medellín, Colombia: Centro de Publicaciones. Universidad Nacional de Colombia.

MAVDT. 2004. Plan de acción de lucha contra la desertificación y la sequía en Colombia - PAN. Bogotá D.C.: Ministerio de Ambiente, Vivienda y Desarrollo Territorial. Viceministerio de Ambiente. Dirección de Ecosistemas.

Soil erosion assessment using RUSLE and Projection Augmented Landscape Model (PALM) as a participatory tool in a Mexican peasant community

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Abstract

The soil erosion evaluation lacks local indicators of soil degradation, and this research shows a participatory 3D mapping methodology for assessing soil erosion in south Mexico by integrating the local understandings in a map derived from the Revised Universal Soil Loss Equation (RUSLE). In order to support trade-offs between scientific/academic outcomes and the local communities' knowledge, a large 3D model of Coyuca was produced to showcase a preliminary soil evaluation using the short-throw projector for identifying the degraded areas and defining the soil erosion levels. Results showed that 12% of the Coyuca surface area faced severe soil loss. Results show demonstrated that, in a relatively short time, local people could share and expand their knowledge on soil erosion by improving the RUSLE map and exploring the causes and consequences of soil degradation and the potential solutions.

Keywords: local soil knowledge, participatory mapping, boundary object

Introduction

Soil erosion affects 42 % of the surface territory of Mexico with direct impact on the water retention in soil and a decrease in fertility, compromising the sustained production of food and provision of ecosystem services (SEMARNAT – UACh, 2003). Local communities often have their own indicators for analyzing the soil quality and determining soil erosion along with its underlying causes. The Revised Universal Soil Loss Equation is commonly used to investigate the physical processes and mechanisms governing the erosion rates (Mitasova *et al*., 2013). However, such evaluation ignores the local people's knowledge and perceptions. A comprehensive soil evaluation is especially required in the mountainous regions of Mexico where local communities depend on subsistence agriculture and there is a decline in soil productivity because of severe soil loss. By involving local people in the soil erosion analysis, the spatial variability and the planned conservation measures to be implemented can be improved. This research shows a participatory mapping exercise with farmers in Coyuca, Mexico, and integrates the understanding of local farmers on the RUSLE soil erosion map by means of PALM (Projection Augmented Landscape Model). We adopted PALM as the "boundary object" to engage locals and researchers on a participatory mapping research based on soil erosion, with regards to a) the identification/checking of areas with soil erosion; b) collectively exploring the underlying causes; and c) assessing the usefulness of PALM.

Methodology

Before the implementation of project activities, a general meeting was organized to define and agree on the project's methodology and the participatory mapping activity procedures, as well as to clarify doubts with the local leaders in the community.

Estimation of soil erosion factors

Soil erosion includes the function of terrain, rainfall, soils, land cover, and land use as well as the management practices (Renard and Foster, 1983). In this research, the RUSLE model was used for obtaining a preliminary spatial assessment of soil erosion. The RUSLE model is given as:

$$A = R\ K\ LS\ C\ P$$

Where A = annual erosion rate (ton/ha per year); R = rainfall erosivity (MJ mmha^{-1} h^{-1} y^{-1}); K = soil erodibility (t ha h (ha MJ mm) $^{-1}$); LS = slope-length factor (-); C = land use/cover (-); and P = conservation/management (-) factor.

The key steps employed to derive the six erosion factor components are described below:

- Factor R

Since the rainfall intensity data is not available in most developing countries, we used the Cortes's model (1991) to calculate the R factor, given as:

$$6.8938P + 0.000442P^2$$

Where P = average annual rainfall (mm).

The monthly rainfall data acquired over the years 1902 to 2011 from the nearest rainfall stations of the study area were obtained from the "Atlas Climático Digital de México". The average annual rainfall precipitation and R-map were calculated using simple raster algebra.

- Factor K

For this study, data on soil properties of texture and organic matter content were derived using 25 pit descriptions and laboratory analysis from INEGI (2014). Ordinary Kriging was used to produce k-factor maps. The K values of each type of soil were obtained from Martínez (2005).

- Factor LS

We used the Wischmeier and Smith model (1978) to produce LS in SAGA, given as:

$$LS = \left(\frac{\lambda}{22.13}\right)^m * (65.41 sin^2(\beta) + 4.56 \sin(\beta) + 0.065)$$

Where: λ = length of the slope (m); m = 0.5 for slopes superior to 5 %; 0.4 to slopes varying from 3.5 % to 4.5%; 0.3 to slopes varying from 1 % to 3 %; 0.2 to slopes less than 1 % and β slope angle.

- Factor C

To account for the role of surface cover and drive C-factor values, the land use/cover (LUC) data were obtained from the INEGI maps (2017).

Due to the "patchiness" of parcels and the relative similarities between grazing areas and cultivated fields, different enhancements such as fieldwork and Normalized Difference Vegetation Index (NDVI) were used to aid the separability of cover types. Once the LUC maps were available, C-factor values were assigned to each grid cell based on Martínez (2005).

- Factor P

In this study, P factor values were assigned considering the local management practices and were also based on values suggested by Martínez (2005) and informed literature. The data related to management practices were collected based on fieldwork.

Projection Augmented Landscape Model (PALM)

Due to the participatory nature of the methodology, a large 3D model of Coyuca was produced covering an area of approximately 10 141.43 km^2 as a "boundary object" to support the trade-offs between scientific/academic soil mapping outcomes and the local communities' knowledge and perceptions.

Participatory soil erosion mapping

The participatory mapping activity took place in Bajos del Ejido using a high-resolution satellite base map to delineate boundaries of the degraded areas and define soil erosion levels using colored markers. A total of 20 peasants participated in this workshop.

Once this activity was completed, the PALM showing the RUSLE map was presented to participants using a short-throw projector (Figure 1). People started to familiarize themselves with the 3D model by adding names of places. Then, the participants were asked to transfer the polygons from the base map to the PALM in order to compare and validate the RUSLE model by annotating in a specific format both the coincidences and disagreements. Polygons were marked using Playdoh provided by facilitators. The soil erosion levels and boundaries were collectively refined and approved after discussions and the underlying causes were also analyzed.

Figure 1: Process of comparison/integration of the RUSLE map with the polygons of the basemap.

Results and discussions

Validation of the RUSLE map

Within a relatively short time (one day), local experts learned about the implications of soil erosion for their livelihoods and outsiders understood the underlying causes of soil erosion in Coyuca. Participants drew nine polygons of soil erosion on the base map varying from 50 to 200 hectares reflecting both their landscape knowledge and their use. Then, the polygons were transferred to the PALM using the RUSLE map for validating them. Interestingly, only 22.2 % of the cases of soil erosion coincided with the RUSLE map, while differences were found in 66.7 % of the cases, leading the participants to change their preliminary assessments. Few cases (11.1 %) were judged as showing wrong levels of soil erosion. The process used to produce a refined soil map also helped the participants explore different options for solving soil degradation.

Levels and types of soil water erosion

Currently, the soils of Coyuca experience some type of erosion ranging from incipient to severe. About 12 % of their soil has severe erosion; meaning that more than 200 ton/ha of soil is annually lost (Figure 2). Considering that the rate of soil formation is up to 1 cm every 100 years, at this rhythm there will not be arable soil in Coyuca to grow crops. Moreover, findings suggest that more soil is lost in the farming plots cropped with maize, the reason being most of the farmers still use the slash and burn practices in lands with more than 15 % of slope inclination. The absence of effective public policies to support peasant agriculture and promote sustainable management practices seems to be the underlying factor explaining the changes in land use, deforestation, and overgrazing that ultimately cause soil erosion.

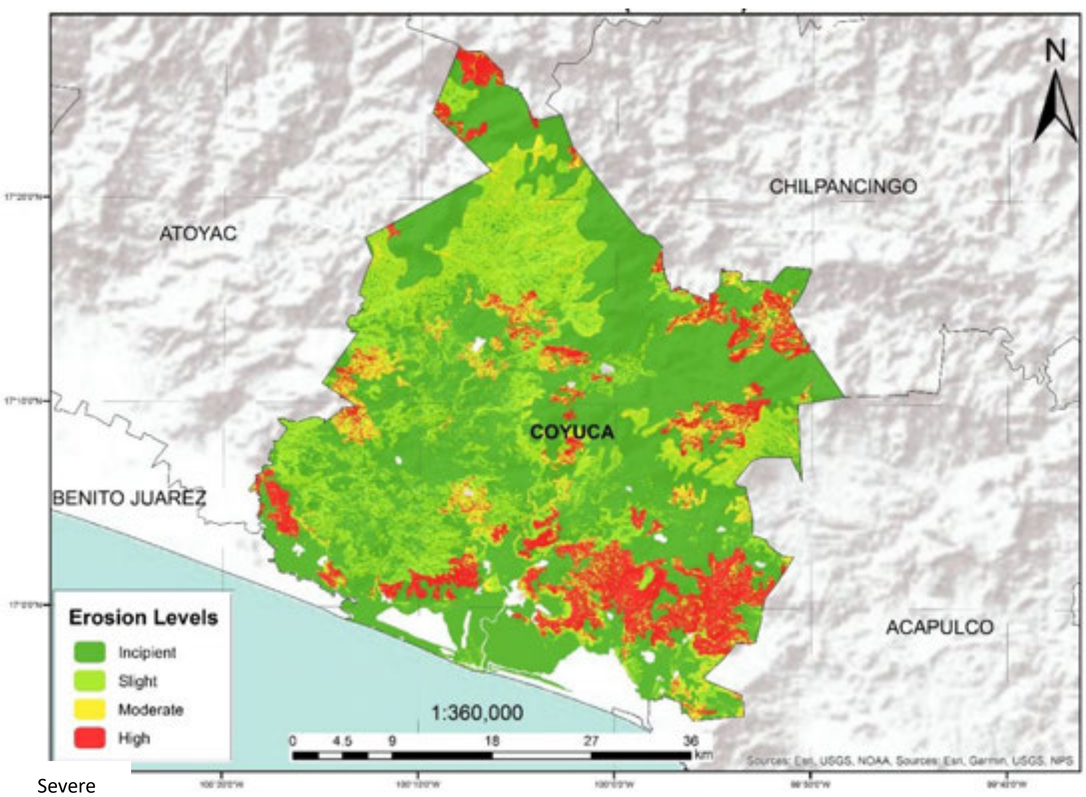

Figure 2: Evaluation of RUSLE map showing different levels of erosion in Coyuca, Mexico.

Innovative tool and communication

The PALM realistically shows routes and hills of Coyuca as well as elevation and slopes. Participants were able to easily recreate their cognitive process to familiarize themselves with perceiving landscapes and gaining new spatial knowledge related to the soil erosion process. It also helped them better communicate the issues through visual and tactile experiences and debate stimulations.

Contrasting and integrating different forms of knowledge with PALM

The mapping process exposed the existing differences between local and scientific knowledge. The local knowledge is specific and detailed and is limited to communities, while scientific knowledge is general and expressed in large scales. The PALM was also a useful tool for integrating both confronting and completing perspectives. The projection of layers informed about the extent and spatial variation of soil erosion, while the local knowledge helped to validate the content of layers and qualify them in terms of type and degree of spatial manifestations.

Conclusions

The study demonstrates that a combination of spatially-distributed models with local perceptions of soil erosion is an effective methodology for providing a reasonable guide for assessing soil degradation and identifying solutions while engaging the local people. It helped spread awareness among participants about soil erosion and build a common view on the impact it has on their practices. The RUSLE map showed that the rate of soil erosion is above the rate that can be tolerated. PALM demonstrated to be a useful and user-friendly boundary object in the workshop facilitating spatial learning and the co-creation of new knowledge.

References

Cortés-Torres, H. 1991. Caracterización de la erosividad de la lluvia en México utilizando métodos multivariados. Tesis de Maestría. Colegio de Postgraduados. Montecillos, México.

INEGI. 2014. *Conjunto de datos de erosión de suelos, escala 1:250 000 serie I, continuo nacional*. Elaboración de mapas 2009–2013.

INEGI. 2017. *Uso de suelo y vegetación serie VI escala 1:250 000*. Elaboración de mapas 2014–2017.

Martínez-Ménez, M. 2005. *Estimación de la erosión del suelo*. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, Colegio de Postgraduados: México, 30 pp.

Mitasova, H., Batron, M., Ullah, I., Hofierka, J. & Harmon, R.S. 2013. GIS-based soil erosion modelling In: J.F. Shroder and M.P. Bishop (Eds.), *Treaties on Geomorphology*, *3 Remote Sensing and GIScience in Geomorphology*. San Diego: Academic Press, pp. 228–258.

Renard, K.G. & Foster, G.R. 1983. Soil conservation: Principles of erosion by water. In H.E. Degne and W.O. Willis (Eds.). *Dryland Agriculture, Agronomy Monogr. 23.* Am. Soc., Crop Sci. Soc.: Madison, Wisconsin, pp. 156–176.

SEMARNAT, Universidad Autónoma de Chapingo. 2002. *Evaluación de la pérdida de suelo por erosión hídrica y eólica en la República Mexicana a escala 1: 1000 000*. Secretaría de Medio Ambiente y Recursos Naturales. México: SEMARNAT, Universidad Autónoma de Chapingo. 70 pp.

Wischmeier, W. H. & Smith, D.D. 1978. Predicting rainfall erosion losses: a guide to conservation planning. Washington D.C: U.S. Department of Agriculture (Agriculture Handbook No. 537), p.58.

How reliable are our methods for estimating soil erosion by water?

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Abstract

Soil erosion is a problem of global significance for land management. Attempts to assess soil erosion by water encompass plot studies, monitoring, modelling, and the use of tracers. All of these approaches are shown to have shortcomings, calling into question the reliability of current estimates. There is an urgent need to develop a better understanding of where individual soil particles travel to during an erosion event, and to use that understanding both to improve the representation of processes in models of soil erosion and to parameterize such models. Only then can reliable estimates of soil erosion be made on which to base reliable land-use and policy decisions.

Keywords: soil erosion, plot studies, monitoring, tracer, modelling.

Introduction, scope and main objectives

Attempts to assess soil erosion by water encompass plot studies, monitoring, modelling, and the use of tracers (mainly radionuclides). It is the aim of this survey to evaluate these methods, to assess their shortcomings in terms of the reliability of the estimates they produce, and to consider how these shortcomings might be overcome in the future to provide more reliable estimates on which future land-management and soil-conservation decisions may be based. The focus of the survey is on (i) prediction of rates for purposes of soil conservation; and (ii) methods adopted rather than the results of individual studies. The scale of the focus is from the field to the small catchment.

Plot Studies

Plot studies comprise closed plots and open plots, the former being by far the more common. There are significant issues around the meaning of data obtained from closed plots. The first of these arises from the rainfall events that are monitored on such plots. The choice is either to use a rainfall simulator or to monitor natural rainfall events. In general, relatively high intensities have been used in rainfall-simulation experiments, for the practical reason that such intensities will generate a significant erosion event. The degree to which such an event is representative of natural conditions is questionable. A second issue arises from the fact that rainfall simulations typically use a constant rate of vertical rainfall, although in some simulators the rainfall may be pulsed. However, natural rainfall exhibits both significant temporal variability and pronounced wind-driven effects. Using natural rainfall on closed plots usually requires that the plots remain in use for a considerable period of time. Because closed plots are starved of input of sediment at the upslope end, the surface becomes increasingly a function of this artificial boundary condition. More serious than any of these issues, however, is the scale dependency of measured erosion rates (Parsons *et al.* 2004). Erosion rates obtain from rainfall-simulation experiments or monitoring on closed plots pertain only to plots of the size used and under the conditions of the experiment or monitoring. Extrapolation beyond these limits is unwarranted, and erroneous. Unbounded plots avoid some of the problems of bounded ones, in particular they avoid the problem of artificially preventing the influx of sediment from upslope. However, inasmuch as unbounded plots explicitly do not have a presumed contributing area for measured sediment flux, interpreting that flux in terms of soil loss per unit area becomes problematic. Although plot studies may be useful for studying the effects of different treatments (crop type, surface mulches etc.), it should be recognised that they provide only relative values for sediment fluxes under different conditions. They cannot provide reliable estimates of erosion at the field or catchment scale (Evans 2002).

Monitoring

For the most part, monitoring is based upon field surveys and mapping the sizes of erosion features such as rills (and gullies). The approach is based on the assumptions that splash and sheetwash are of minor importance in redistributing soil within a field other than over a distance of a few metres and it is rills and gullies that redistribute soil within a field or a landscape (Evans 1990). However, this argument fails to recognise the role of splash and sheetwash in providing sediment to rills and gullies. Eroded soil is not simply that which is detached by the concentrated flow in rills and gullies (which can be determined by measuring their volume) but the total amount of soil transported through rills and gullies. Splash and sheetwash may not, of themselves, transport soil particles very far, but they are important as suppliers of sediment to rills and gullies. Consequently, measuring the sizes of the rills (and gullies) is likely to produce not only an underestimate of overall erosion but also one that depends to a significant degree on the magnitude of recent storm events. Because events with sufficient intensity to cause rill and gully erosion occur only infrequently, extrapolating results from such observations into average annual rates is problematic.

Modelling

Modelling seeks to provide predictive estimates of soil erosion based upon some form of predictive equation(s). Ultimately, all models depend on the empirical foundation on which they rest. The extent to which this empirical foundation represents soil erosion processes (or at least their outcomes) determines how good models can be. Many model equations are simply based on best-fit lines through observed data from field and laboratory plots (e.g. Wischmeier and Smith, 1978). Inherently, any model to predict soil erosion that is based best-fit lines through observed data suffers from the limitations of the data used to develop those best-fit lines. Recently, process-based models have been developed based on the argument that they can be extrapolated to a broad range of conditions which may not be practical or economical to field test (Lane *et al.,* 1992). However, the limitations, in terms of the empirical base on which such models rest (mainly field- and laboratory-plot experiments) and the dangers of extrapolating beyond it, may be less explicit in process-based models, but they are no less present. Furthermore, because all regression equations explain only part of the variance in the predicted quantity, the greater the number of equations in any model the greater is the likely uncertainty in the predicted rate of soil erosion. Paradoxically, the cost of more explicit representation of processes in models of soil erosion may well be greater levels of uncertainty in model predictions. Estimates of soil erosion based on modelling can be reliably useful only if (i) estimates of uncertainty in model predictions are given, and (ii) these uncertainty levels are sufficiently small that the predictions provide the basis for decision-making. Such conditions have seldom been met.

The Use of Radionuclides

In an attempt to overcome many of the weaknesses characteristic of the approaches discussed above, several authors have sought to use natural and fallout radionuclides to assess soil erosion. Three main radionuclides have been employed: ^{137}Cs, ^{210}Pb and ^{7}Be. For ^{137}Cs, the most commonly used radionuclide, the approach, however, relies on a set of key assumptions namely: that (1) the fallout is locally, spatially uniform, (2) the fallout is rapidly and irreversibly fixed onto soil particles; (3) the subsequent redistribution of fallout is due to the movement of soil particles; and (4) estimates of soil erosion can be derived from measurements of ^{137}Cs inventories (Walling and Quine, 1992). Evidence, however, challenges the validity of all four of these assumptions (Parsons and Foster, 2011). Furthermore, because converting supposed changes in ^{137}Cs amounts to amounts of soil erosion relies on some conversion model, these estimates are then subject to the same constraints as discussed above in relation to modelling soil erosion, in general. Finally, the approach has depended on the same conceptual understanding of erosion processes as underpins most process-based models. Because of these weaknesses, it must be concluded that no current rates of soil erosion that are based upon the use of this technique are reliable, and that "^{137}Cs cannot be used to provide information about rates of soil erosion. There is a rich literature on ^{137}Cs in the environment because of concerns about its wider impact on human health on which to base this assessment. In contrast, the literature on the naturally produced radionuclides ^{210}Pb and ^{7}Be is less abundant. Consequently, there is less information on which to base an assessment of the validity of the same assumptions that underpin the use of these elements. The reliability of estimates of soil erosion based upon these two radionuclides thus remains unproven, at best, and as questionable as that of ^{137}Cs, at worst.

Conclusions

These shortcomings call into question the reliability and usefulness of estimates of soil erosion by water that are based on any of the current approaches, either singly or in combination. There is an urgent need to develop a better understanding of where individual soil particles travel to during an erosion event, and to use that understanding both to improve the representation of processes in models of soil erosion and to parameterize such models. Only then can reliable estimates of soil erosion be made on which to base reliable land-use and policy decisions.

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References

Evans, R. 1990. Soil erosion: its impact on the English and Welsh landscape since woodland clearance. In: J. Boardman, I.D.L. Foster and J.A. Dearing (eds) *Soil erosion on agricultural land*. Chichester, England, John Wiley & Sons, pp. 231-254.

Evans, R. 2002. An alternative way to assess water erosion of cultivated land - field-based measurements: and analysis of some results. *Applied Geography,* 22: 187-207.

Lane, L.J., Nearing, M.A., Laflan, J.M., Foster, G.R. & Nichols, M.H. 1992. Description of the US Department of Agriculture water erosion prediction project (WEPP) model. In: A.J. Parsons and A.D. Abrahams (eds) *Overland Flow: hydraulics and erosion mechanics.* London, UCL Press, pp: 377-391.

Parsons, A.J. & Foster, I.D.L. 2011. What can we learn about soil erosion from the use of ^{137}Cs? *Earth Science Reviews*, 108: 101-113.

Parsons, A.J., Wainwright, J., Powell, D.M., Kaduk, J. & Brazier, R.E. 2004. A conceptual model for determining soil erosion by water. *Earth Surface Processes and Landforms* 29: 1293-1302.

Walling, D.E. & Quine, T. 1992. The use of caesium-137 measurements in soil erosion surveys. *International Association of Hydrological Sciences Publication*, 210: 143-52.

Wischmeier, W.H. & Smith, D.D. 1978. Predicting rainfall erosion losses—a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537.

Evaluating the “Soil stabilisation and control of erosion” ecosystem service provided by agricultural ecosystems over the French territory

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Abstract

The “soil stabilisation and control of erosion” ecosystem service (ES) has been evaluated for the French territory at 100 m spatial resolution. The MESALES model was used at the seasonal frequency. It was parameterised with i) the Land Parcel and Identification System and MODIS remote sensing data for agricultural vegetation covers; ii) the 1/1 000 000 European Soil Geographical Database for soil characteristics, iii) the IGN French Digital Elevation Model for the topography, and iv) the Météo France data for rainfall characteristics. The analysis of seasonal ES maps evidences that, depending on rainfall characteristics and duration of bare soil periods, the ES value can be higher either during autumn and winter, or during summer. The model prototype developed in this work can be applied at the European level, and used to evaluate land-use or land cover policies.

Keywords: ecosystem service, erosion, soil, modelling, France, EFESE, MESALES

Introduction, scope and main objectives

Land use has changed a lot over the past few decades – about 4 million hectares of permanent grassland were removed in France between 1971 and 2007 – which results in a significant increase in soil erosion, and its corollaries: removal of the surface layer of soils, rich in organic matter, and increased risks of mudslides. Due to the low rate of soil formation with regard to soil erosion (Verheijen *et al.*, 2009), agricultural zones are becoming more or less vulnerable depending on agricultural practices. The challenge for the farmer is to develop land use practices that preserve his soil capital and associated potential production; the challenge for the whole society is to promote such practices to limit flooding and associated mudslides. In an ecosystem service perspective, their common objective is to develop agricultural ecosystems exhibiting a high level of control of erosion. In this context, the objective of this work was to propose a robust methodology to quantify this ES level, at fine scale over large areas such as Europe, in order to assess the impact of land-use public policies. This work was achieved in the framework of the French National

Assessment of Ecosystem Services – the EFESE program – within which the "agricultural ecosystems" part (EFESE-EA) has been carried out by the French National Institute for Agricultural Research (INRA).

Methodology

As far as erosion is concerned, the Common International Standard for Ecosystem Services (CICES classification) was used in 2013 to define an ES called "Mass stabilisation and control of erosion rates". For clarity, in the following, we have renamed it "Soil stabilisation and control of erosion". In the EFESE-EA study, the conceptual framework developed to describe ES provided by agricultural ecosystems considers the ecosystem as the ecological system made up of the association of the soil and its vegetation cover (Tibi and Therond, 2018). The level of ES provided by this ecosystem is a result of both biophysical determinants (underlying the provision of ES) and exogenous factors (that affect the provision level of ES). The two major biophysical determinants of the "Soil stabilisation and control of erosion" service are the spatio-temporal configuration of vegetation cover and, to a lesser extent, the soil mineral and organic composition. Exogenous factors are rainfall (depth and intensity), topography (slope intensity and runoff contributing area) and agricultural practices (especially tillage and irrigation, the latter being not considered in this study due to a lack of fine scale data over a large area like France).

The level of the "Soil stabilisation and control of erosion" service supplied by agricultural ecosystems was calculated by comparing the erosion rate estimates for the current situation (with the current vegetation cover) to a reference situation. Two fictive reference situations were defined: a "bare soil" situation – with the highest erosion risk – and a "permanent cover" situation – assumed to supply the highest possible level for this ES.

The difference in erosion rates between the current situation and the "bare soil" situation was used to assess a first ES indicator which is the current level of ES supply, i.e. the quantity of soil stabilized by the ecosystem considering its current spatio-temporal vegetation cover configuration. The ratio of the current ES level over the theoretical maximum ES level (calculated as the difference in erosion rates between the "permanent cover" and the "bare soil" situations) was used as a second ES indicator to help interpretation of the first indicator. Being a "relative" ES level, this second indicator expresses the percentage of the maximum ES currently supplied by the existing agricultural ecosystems.

The erosion rates for each situation were estimated according to the MESALES methodology developed by Le Bissonnais *et al.* (2002). This model has been chosen due to both its ease of use at regional to global scales, and to its sensitivity to soil characteristics linked to agricultural practices (for instance soil cover and soil crusting). It relies on a decision tree that evaluates an erosion risk on a semi-quantitative scale, which is then converted into an erosion rate (t/ha/year). This model sequentially depicts the effects of physical processes on runoff and erosion. It requires data on i) the percentage of soil protected by vegetation, ii) soil crusting and erodibility characteristics, iii) topographic characteristics, and iv) rainfall characteristics. The MESALES model has been evaluated at the French level by comparing the model outputs to the French national mud floods database (Le Bissonnais *et al.*, 2002).

Originally, our methodology was based on the use of fine scale data about spatio-temporal delineation and configuration of agricultural vegetation (crop and cover crop). It made use of several sources of data (Figure 1): i) the 2012 French Land Parcel Identification System to accurately delineate agricultural areas; ii) 4 classes of percentage of soil protected by vegetation – from bare soil to fully vegetation covered soil – estimated as the mean seasonal NDVI indices derived from MODIS remotely sensed data; iii) soil crusting and erodibility evaluated from existing pedotransfer rules using the 1/1 000 000 European Soil Geographical

Database (Le Bissonnais *et al.*, 2005); iv) a relief factor computed from the French IGN Digital Elevation Model at 25 m resolution averaged to 100 m resolution as a combination of slope intensity and runoff contributing area; and v) rainfall characteristics calculated from both 30 years of meteorological SAFRAN data at 8 km resolution providing rainfall depths, and 13 years of hourly precipitation values at 1 km resolution from the Aurhély model (Benichou and Le Breton, 1987) providing rainfall intensity indices. Rainfall characteristics were averaged by season, over 30 years. The model thus provided one indicator for 4 averaged seasons, then averaged for the year.

Results

In flat areas with very low slopes – e.g. sandy soils of Landes in the South-West part; loamy-clay soils of Beauce in Central France; Elsass in the North-East part of France – the current ES level is close to zero due to a very low erosion rate for bare soils (Figure 2). In grassland areas (Britany, Normandy, Massif Central, Alps, Jura), the permanent cover is large, which enables both a high current ES value, and a high value of relative ES. In cropping areas, like in the Paris basin, both the current and relative ES are low.

A statistical analysis confirms these statements: for areas of grasslands or forests, values exceed 10 t/ha/year of stabilised soil over more than 60% of the surface area. On the contrary, for cropping areas, values are close to 0 for about 60% of the surface area. The seasonal analysis evidences that the ES levels are generally higher in winter and autumn due to cover crops, especially for Britany and Normandy, as rainfall are important during these periods. On the contrary, in the South-West, ES levels are higher in summer, probably because a larger share of areas remains bare during the fallow period.

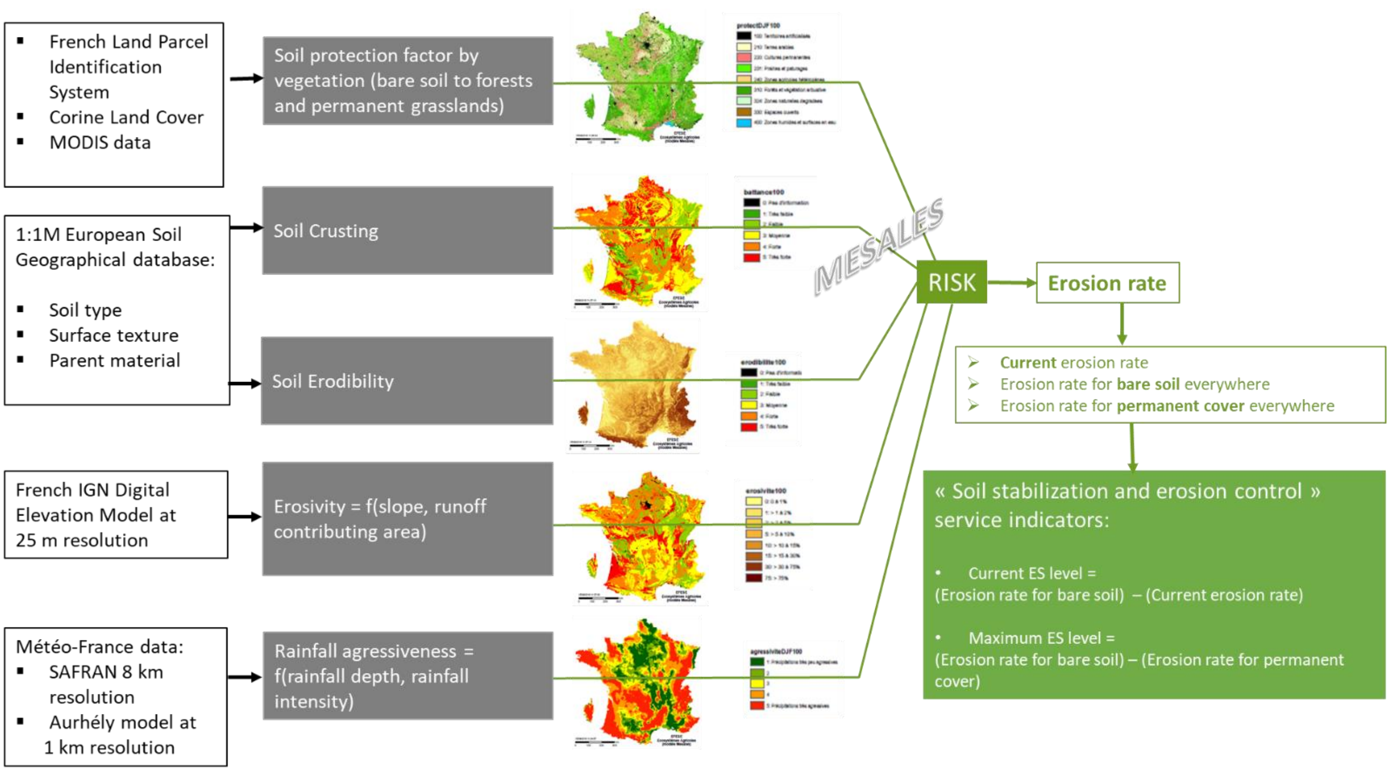

Figure 1: Flowchart of the evaluation of the “Soil stabilisation and control of erosion” ecosystem service in the EFESE-EA study.

> 3 to 5

> 5 t/ha/year of stabilised soil

0.8 to 0.95

0.95 to 1

because serviceMax is = 0

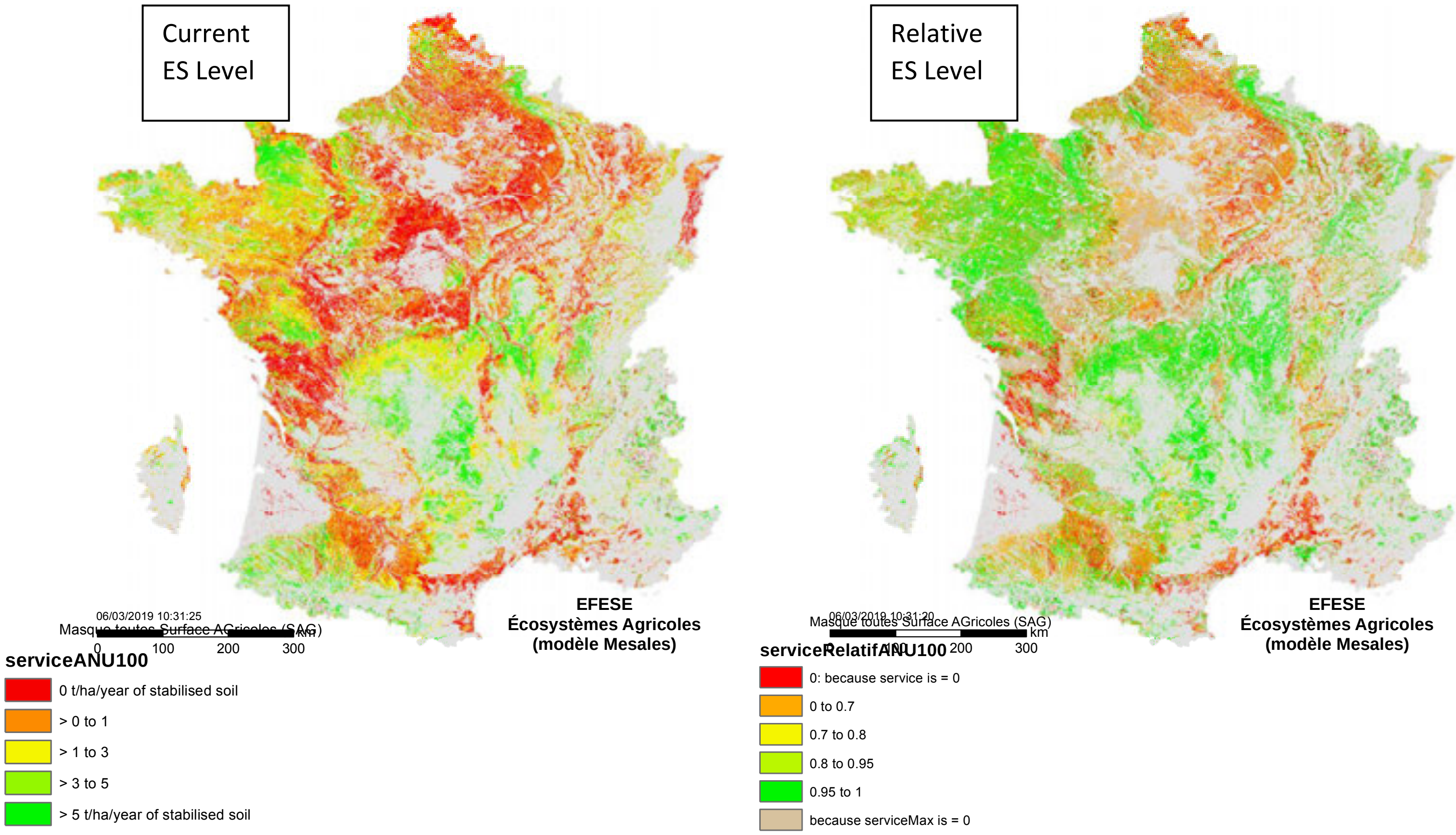

Figure 2: Level of "Soil stabilisation and control of erosion" ecosystem service over the French territory for agricultural ecosystems. On the left: absolute current level of ES, defined as the amount of soil stabilized per hectare per year (in comparison to a bare soil situation); on the right: "relative" ES level, evaluated by reference to the theoretical maximum ES level (associated to a "permanent cover" situation). For both maps, the spatial resolution is 100 m.

Discussion

The ES quantification over the whole French territory highlights the predominant role of the vegetation cover and its seasonal phenology. It also demonstrates the efficiency of agricultural practices leading to a permanent cover of soils by vegetation – cover crops during fallow period, management of surface residues, sowing under permanent cover –, especially for cropping areas with intense autumn and winter rainfalls.

The main weakness of previous applications of the MESALES model was due to the large uncertainties in some input data, especially land cover data and, to a lesser extent, soil properties derived from the 1/1 000 000 European Soil Database. In the EFESE-EA study, among significant improvements of this methodology, a very important one has been achieved by estimating the seasonal variation of the vegetation cover. The comparison of stabilised soil in different situations hence allowed to finely assess the absolute and relative ES levels. Additional improvements would be possible i) by using more accurate soil

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km

0 100 200 300

EFESE
Écosystèmes Agricoles
(modèle Mesales)

databases, ii) by developing more accurate pedotransfer functions for erodibility, and iii) by implementing a retroaction of the vegetal cover on the soil organic matter.

Conclusions

The methodology developed to evaluate the "Soil stabilisation and erosion control" ES has been applied to the whole French territory at a very fine spatio-temporal scale. Its ease of use and robustness, assessed by erosion experts, should allow its application to the European level. The comparison between the current and the relative ES levels in the case of land cover and land use changes scenarios should be of particular interest to promote political tools dedicated to a high service level at the European scale.

Acknowledgements

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References

Benichou, P. & Le Breton, O. 1987. Prise en compte de la topographie pour la cartographie des champs pluviométriques statistiques. *La Météorologie*, 7: 23-34.

Le Bissonnais, Y., Montier, C., Jamagne, M., Daroussin, J., King, D. 2002. Mapping erosion risk for cultivated soil in France. *Catena*, 46: 207-220.

Le Bissonnais, Y., Daroussin, J., Jamagne, M., Lambert, J.J., Le Bas, C., King, D., Cerdan, O., Léonard, J., Bresson, L.M. & Jones, R. 2005. Pan-European soil crusting and erodibility assessment from the European Soil Geographical Database Using pedotransfer rules. *Advances in Environmental Modelling and Monitoring*, 2:1-15.

Tibi, A. & Therond, O. 2018. *Services écosystémiques fournis par les espaces agricoles. Caractériser et évaluer*. Editions Quae, 186 pp.

Verheijen, F. G. A., Jones, R. J. A., Rickson, R. J. & Smith C. J. 2009. Tolerable versus actual soil erosion rates in Europe. *Earth-Science Reviews*, 94: 23-38.

Integrated Approach to Conduct Global Soil Erosion Survey and Assessment under FAO Leadership

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Abstract

Global soil erosion assessment is most important for land degradation and food security estimating. There were currently available methods or records for soil erosion inventory and assessment from the US, Europe, Australia and China. Although the valuable information was obtained, it could not be used directly due to incompatibility. To achieve the most out of the limited time, a Review-Apply-Revise-Complement approach was suggested, which means some data could be almost applied directly after reviewing, some data could be used by revision, and data could be complemented by using the sampling method for those countries or areas without available data currently. For the sampling method, we could mainly use remote sensing interpreting with little field verify to get the information on land use and soil conservation practices. Factors of R, K, L and S could be calculated globally, and those of 65 countries of the Pan-Third-Pole regions have been estimated last year by the state key laboratory of soil erosion and dry land farming of China, which could be pooled into global datasets. By integrating all different sources of datasets and methods, we can develop a universally applicable protocol to generate global soil erosion rates and maps in practicability and reliability.

Keywords: Global, soil erosion, soil erosion mapping, soil erosion assessment, soil erosion inventory, soil erosion survey, regional soil erosion

Current Methods and Primary Results of Regional Soil Erosion Survey and Assessment

The earliest soil erosion survey was conducted in the US in 1940's and the sampling protocol was then developed in 1952. Since 1977, consecutive soil erosion surveys had been conducted as a part of the National Resources Inventory (NRI) in the US every five years and then every year since 2000 (Schnepf and Flanagan, 2018). During the surveys, primary sample units (PSUs) and points were determined using stratified two-stage unequal probability area sample method. Soil loss was estimated by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) only for slope farmland where sampling points were fallen. Both state and national soil erosion were estimated by point-weighted area of land use within each

PSU (Nusser and Goebel, 1997). There were also soil erosion risk assessments with grids in Pan-Europe (Grimm *et al.*, 2001) and Australia (Lu *et al.*, 2001), but their RUSLE-based assessments did not consider soil erosion control practices. In China, national soil erosion survey was completed in 2013 (Liu *et al.*, 2013; 2010). Soil loss for total 32364 sample units at grid of 1 km × 1 km or watershed of 0.2-3 km^2 at grid of 10 m × 10 m were calculated by the Chinese Soil Loss Equation (CSLE) (Liu *et al.*, 2002), following the stratified unequal probability systematic area sampling method. Soil erosion area ratio, namely the area with soil loss larger than soil tolerance to the sampling unit area, was then derived, interpolated, and summarized at provincial and national scales. Panagos *et al.* (2015) obtained the most recently available Pan-Europe datasets after improving European soil erosion assessment by applying a modified version of the Revised Universal Soil Loss Equation (RUSLE2015) for the reference year 2010. Borrelli *et al.* (2017) presented an unprecedentedly high resolution (250 × 250 m) global potential soil erosion model. They also estimated the spatial and temporal effects of land use change between 2001 and 2012 and the potential offset of the global application of conservation practices.

Approach of Review-Apply-Revise-Complement (RARC)

As briefly reviewed above, there were currently available soil erosion methods or records from the US, Europe, Australia and China etc. In order to achieve the most out of the limited time, a top-down approach to develop a widely applicable methodology for individual countries to be involved is much more practical than asking each country to provide national but very likely incompatible data. To do so, we should make the best use of the readily available methods and datasets by systematically reviewing them, revising or modifying the incompatible ones, and then applying or extrapolating them to other regions or countries. For those regions or countries where no data is available, we should complete them with local field surveys. Only integrating all different sources of datasets and methods can we develop a universally applicable protocol to generate global soil erosion rates and map affected area with reliable data within the project period.

Specific Suggestions for Global Soil Erosion Assessment

As mentioned in Section 2, we can employ the approach of Review-Apply-Revise-Complement (RARC):

(1) A global map of soil erosion risk is much less useful than a map of quantitative real soil erosion rates. The latter one can identify regions or fields exceeding T values, so as to conduct soil and water conservation measures much more effectively. Therefore, instead of relying on risk assessment, we recommend to conducting a real soil erosion rate and erosion affected area.

(2) Factor R, K, L and S can be derived at global scale by selected groups or by each country (if practically possible with open-source codes). Factor C and P must be collected by sampling a certain number of catchments or fields all over the world and identify their C and P to represent regional facts. To validate the C and P or other factors for sampling catchments or fields, we can first make a full use of Google Earth Imaginary to have an interpretation for global or regional scale. For those images with great uncertainty or poor representativeness, we can ask the relevant countries to validate in the real world to help improve the accuracy and precision.

(3) Data from Soil erosion rate of the US National Resources Inventory (NRI) can be directly used as part of global soil erosion assessment, after solving the spatial distribution issues.

(4) Data from Soil Erosion Risk Assessment in Europe can also be used as a part of global soil erosion assessment, after revised by local soil and water conservation measures.

(5) Data from Field Survey on Soil Erosion in China (2012) and Soil Erosion Monitoring (2018) can be integrated and included as a part of global soil erosion assessment.

(6) Data of rainfall erosivity (R) and soil erodibility (K) in Australia can also be directly used as a part of global soil erosion assessment, while the data of LS factor can also be referenced if appropriate or used to validate the model.

(7) Field surveys and remote sensing calculations conducted in 65 countries in the Pan-Third-Pole regions (Qinghai-Tibet Plateau and surrounds are) can also be included as a part of global soil erosion assessment.

(8) For regions or countries without readily available data, the sampling method can be used to assess the soil erosion.

References

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K.V., Montanarella, L. & Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8: 2013.

Grimm, M., Jones, R.J.A. & Montanarella, L. 2001. Soil Erosion Risk in Europe (No. EUR 19939). Office for Offical Publication of the European Communities, Luxembourg. *EUR 19939 EN.* Available at: https://esdac.jrc.ec.europa.eu/resource-type/scientific-technical-reports.

Liu, B.Y., Guo, S.Y., Li, Z.G., Xie, Y., Zhang, K.L. & Liu, X.C. 2013. Chinese soil erosion survey by sampling method. *Soil and water conservation in China*, 10: 26–34.

Liu, B.Y., Li, Z.G., Xie, Y., Fu, S.H. & Zhang, W.B. 2010. *Water Erosion Survey Method, in: Technical Handbook No. 6 for Soil Conservation Survey*. Head Office of the State Council for the First National Water Conservancy. China Water & Power Press, Beijing, pp. 206–214.

Liu, B.Y., Zhang, K.L. & Xie, Y. 2002. An empirical soil loss equation, in: *Proceedings-Process of Soil Erosion and Its Environment Effect*. Presented at the 12th International Soil Conservation Organization Conference, Tsinghua University Press, Beijing, pp. 21–25.

Lu, H., Gallant, J., Prosser, I.P., Moran, C. & Priestley, G. 2001. Prediction of Sheet and Rill Erosion Over the Australian Continent, Incorporating Monthly Soil Loss Distribution (No. 13/01), National Land & Water Resource Audit. *CSIRO Land and Water Technical Report 13/01*. Available at: http://www.clw.csiro.au/publications/technical2001/tr13-01.

Nusser, S.M. & Goebel, J.J. 1997. The National Resources Inventory: a long-term multi-resource monitoring programme. *Environmental and Ecological Statistics,* 4: 181–204.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & Alewell, C. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, 54: 438–447.

S**chnepf, M. & Flanagan, P**. 2018. A History of Natural Resource Inventories Conducted by the USDA's Soil Conservation Service and Natural Resources Conservation Service. Soil and Water Conservation Society. *A Special Report by the Soil and Water Conservation Society*. Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1212208.pdf.

Wischmeier, W.H. & Smith, D.D. 1978. Predicting Rainfall Erosion Losses: A guide to conservation planning. U.S. Dep. Agric., *Agric. Handbook No.537*. Washington, D.C.

Introduction of three nuclear techniques integrated in order to strengthen in the Latin American and Caribbean region, the strategies and programs of surveillance/monitoring of the sedimentation phenomenon in water reservoir superficial

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Abstract

The introduction of novel technical are shown in order to strengthen in the region of Latin America and the Caribbean, the surveillance and monitoring of the negative sedimentation phenomenon in the water superficial reservoirs (natural and artificial).

With the development of a regional project, supported by the International Agency of Atomic Energy (IAEA), Cuba acts as technical director for 15 countries (Argentina, Bolivia, Brazil, Chile, Colombia, CUBA, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Dominican Republic, Uruguay and Venezuela), to foment and to implement the integrated application of 3 nuclear techniques (Fallen Radionuclides Rain (^{137}Cs, ^{7}Be and ^{210}Pb), Compound specific of stable isotopes (fatty acids of the ∂13Cand the Isotopic Hydrology (^{18}O, ^{2}H and ^{3}H)), which are validated as effective tool for the decisions takers in the definition of best strategies and national programs linked to the sustainable the land and the hydric resources. The integrated application of these 3 techniques allows evaluating, in the hydraulic facilities and water superficial reservoirs (natural or artificial), the negative sedimentation impacts in natural and anthropic process as environmental and social risk. Each technique values the whole process and its synergy, contributing results that they expose, from the quantification of the soil redistribution in the landscape, the exact definition of the soil origin that is deposited until the later dynamic characterization of the water body like receiver of that soil that is moved.

Keywords: nuclear technique, sedimentation, sustainable, soil, land, hydric resources

Introduction, scope and main objectives

The introduction of technical novels is shown to strengthen in the region of Latin America and the Caribbean, the surveillance and monitoring of the negative sedimentation phenomenon in the water reservoirs superficial (natural and artificial). The development of several regional projects support by the International Organism of Atomic Energy (IAEA), has allowed a substantial advance in the nuclear techniques uses, as technical tools that contribute their results to the evaluation of the water, soil and sediment, allowing to decision makers, to definition of better strategies and national environmental programs that assure finally the land and the hydric resources sustainable.

Among other important regional projects (ARCAL) developed in the last 10 years, we have 2 projects that have been the fundamental ones to impel the nuclear techniques use in the Latin American and Caribbean region. These 2 projects support the development of the knowledge on the nuclear techniques to evaluate the soil redistribution in the landscape and the soil origin that is deposited like silt.

- *Project RLA5051* (2009-2013). "Using environmental radionuclides as indicator of land degradation in Latin American, Caribbean and Antarctic ecosystems" (ARCAL C); with the participation of these countries (Argentina, Bolivia, Brazil, Chile, Cuba, Dominican Republic, El Salvador, Haiti, Jamaica, Mexico, Nicaragua, Peru, Uruguay, Venezuela and IAEA, Spain). 16 countries.

- *Project RLA 5064* (2014-2016). "Strengthening Soil and Water Conservation Strategies at the Landscape Level by Using Innovative Radio and Stable Isotope and Related Techniques" (ARCAL CXL); with the participation of these countries (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Jamaica, México, Nicaragua, Panamá, Paraguay, Peru, Uruguay and Venezuela). 21 countries.

Being both very important projects in the soil and sediment assessment, applying nuclear technical, it is also a reality that none contributes knowledge about the valuation of other important environmental element as the water. Nevertheless, both begin the complex on the way to showing the big advantages that have these novels technical as evaluation tools that contribute with their results to will be sustainable the life in the earth planet.

Assisting to the results obtained in the region during the implementation use of these techniques and the acquired knowledge about it, the countries advance to more complex investigations to Basin scales. The necessity arises of studying in the landscape, phenomena that degrade a lot the earth and the hydric resources and for this reason Cuba intends the integrated use of 3 nuclear techniques to evaluate the negative impacts of the sedimentation phenomenon in water superficial reservoirs (natural and artificial).Responding to this necessary zeal of approaching new results with superior technician reaches, was proposed in 2017 and begun to develop starting from the year 2018, the project ARCAL.

- RLA 5076 (2018-2020), belonging to the cycle 2018-2019 "Strengthening Surveillance Systems and Monitoring Programmes of Hydraulic Facilities Nuclear Using Techniques to Assess Sedimentation Impacts ace Environmental Social and Risks" (ARCAL CLV).

With the development of this regional project, with support by the International Agency of Atomic energy (IAEA), Cuba acts as technical director for 15 countries of the region (Argentina, Bolivia, Brazil, Chile, Colombia, CUBA, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Republic Of the Dominican Republic, Uruguay and Venezuela), in order to foment and to implement the integrated application of 3 nuclear techniques (Fallen Radionuclides Rain (^{137}Cs, ^{7}Be and ^{210}Pb), Compound specific of stable isotopes (fatty acids of the ∂13C and the Isotopic Hydrology (^{18}O, ^{2}H and ^{3}H), which are validated as effective technical tool for the decisions taking in the definition of strategies and national programs linked to achieve the land and the hydric resources more sustainable.

In this project that it is executed at the present time, the countries of the region take knowledge about the third nuclear technique very useful to characterize the dynamics of the dam to be able to value the impact of the body of water reservoir superficial.

Methodology

The integrated application of these 3 techniques allows evaluating, in the hydraulic facilities and water superficial reservoirs (natural or artificial), the negative impacts of the sedimentation in natural and anthropogenic process, as environmental and social risk. Each technique values the whole process and its synergy, contributing results that expose from the quantification of the soil redistribution in the landscape, the exact definition of the soil origin deposited until the later dynamics characterization of the body water as receiver of that soil moves.

Each one of these 3 nuclear techniques expose particular results, which show a synergy in the process of the phenomenon assessment:

- FRN: Uses the ^{7}Be; ^{137}Cs and ^{210}Pb, to evaluate the soil redistribution to landscape scale and other scales. It quantifies the losses and earnings of the soil in a study region, allowing determining areas of lost (erosion) and deposition areas (sedimentation) in the landscape.

- CSSI (compound specific of the stable isotopes): Uses the fatty acids of the C chain to evaluate the origin of the soil deposited, allowing determining with great precision and accuracy, the sediment origin that was transported and deposited.

- Isotopic Hydrology: Uses the ^{3}H; ^{2}H and ^{18}O, to evaluate the water dynamics (superficial and underground water) in a study region. It allows determining several technical aspects, as are the water origin, to identify recharge areas, the relationship water-superficial and underground-water, vulnerability of the aquifers to the contamination and the saline intrusion, to classify the sources of renewable and not renewable waters, to detect areas of water mixtures, to date the water, residence times of water, etc.).

Results

The integrated application of these techniques is a fundamental tool to support the sedimentation impact assessment, seeing this phenomenon like a process, because each nuclear technique for itself and its synergy; contribute very valuable results to the stages of the described process. The process of soil redistribution in the landscape, after the erosion and its transport, originates in final stage the deposition, when this sedimentation happens in a dam like water reservoir, the mentioned nuclear techniques, for the technical benefits that show in the described process, can be applied in way integrated to evaluate their impacts very efficiently. The diagram shows in the Figure 1, the integration of the nuclear techniques to apply in each stage of the process.

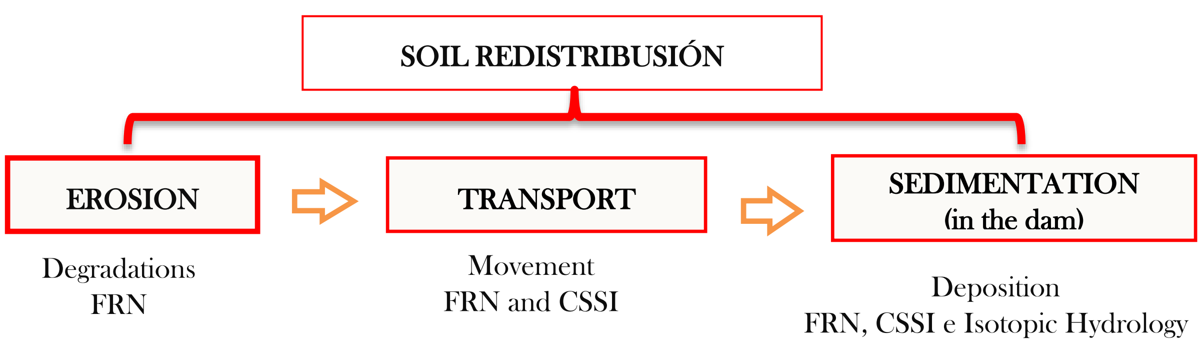

Figure 1: Integration of the nuclear techniques to apply in each stage of the process.

In the synergy and integration of the 3 nuclear techniques, they should be evaluated like it is shown next:

The nuclear technical "FRN", quantifies and exposes the areas that lose (-) and the area that add (+) soil in the study region. The nuclear technical "CSSI", show possible sources areas (areas -) and possible mixture areas (areas +), also contributing potential points like hot spot, in those traffic areas during the transport of the soil degraded that are in moving. This allows to the technical CSSI, a first approach of the sampling points to collect to evaluate the sediment origin (deposited soil). Once quantity the soil redistribution and certain the origin of the soil deposited, the nuclear technical named "Isotopic Hydrology", plays their role in clarifying the dynamics of the water body where the soil is deposited.

The integrated use of the 3 nuclear techniques, in execution always of their application methodologies, allows finally determining the sediment impacts in water superficial reservoirs (natural and artificial).

Discussion

The processes of soil redistribution happen to different scales in the landscape, being shown in big extensions at Basin levels. This redistribution always exposes 3 stages or moments: first the soil degradation appears, later this soil moves and after it is deposited. These stages in the redistribution soil process, can be evaluated by using the integrated use of the 3 nuclear techniques shown (FRN, CSSI and isotopic hydrology), which describe each stage, analyzing the erosion process in the areas where lost the soil and deposition processes in the areas where the soil accumulates. Whenthe soil transported is accumulated in water surface reservoirs, then the third nuclear technique (isotopic hydrology), allows characterizing the dynamics of this water (for example: DAM, lakes, etc.) and this way to clarify the impact of this sedimentation phenomenon, always seen as a natural or anthropic process.

We thinks about to evaluate the sedimentation phenomenon in water superficial reservoir, applying these 3 nuclear techniques in an integrated way, we recommend to carry out the interpretation of the results, analyzing the phenomenon like a process, in which the soil is degraded, after is transported, and it is redistributed in the landscape, being shown areas where the soil is deposited and other areas where the soil is lost (this soil redistribution is obtained with the application of the first nuclear technique (FRN)). If we show these areas in a map, where we put sign (-) to those that lose soil and sign positive (+) to the areas where it is accumulated, then we could have preliminary information to the second nuclear technique (CSS), showing the areas that contribute soil, which are called "potential sources" (-) and showing the areas that receive soil, which are called "mixtures" (+); keeping in mind it, we can value the origin of the soil that arrives to the area (+).

Warning:

We always recommend having very in bill the differences that could exist in the temporary scale of the events that we are analyzing (nevertheless, these results could have their inertia and we can to use it); keeping in mind this, we can value the origin of the soil that arrives to the area (+).

If this soil redistribution in the landscape, evidences that the soil is accumulated in a water reservoir, then we value the results obtained in the first 2 nuclear techniques (FRN and CSSI) and we integrate the third nuclear technique (isotopic hydrology) in order to characterize this water reservoir and so to achieve, finally, to value the sedimentationimpact in this reservoir.

The soil accumulation in water superficial reservoir, evidence the “sedimentation” phenomenon and the impacts are always negative. The integrated use of these 3 nuclear techniques (FRN, CSSI, isotopic

Hydrology), allows to evaluate the whole impact, responding the uncertainties of the described process stage.

Conclusions

1. The new Project RLA 5076 (2018-2020). "Strengthening Surveillance Systems and Monitoring Programmes of Hydraulic Facilities Nuclear Using Techniques to Assess Sedimentation Impacts ace Environmental Social and Risks" (ARCAL CLV), allow to 15 countries of the region (Argentina, Bolivia, Brazil, Chile, Colombia, CUBA, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Republic Of the Dominican Republic, Uruguay and Venezuela),the uses integrated of three nuclear techniques in order to strengthen in the Latin American and Caribbean region, the strategies and programs of surveillance/monitoring of the sedimentation phenomenon in water reservoir superficial.
2. The integrated application of these nuclear techniques (Fallen Radionuclides Rain (^{137}Cs, ^{7}Be and ^{210}Pb), Compound specific of stable isotopes (fatty acids of the ∂13C and the Isotopic Hydrology (^{18}O, ^{2}H and ^{3}H) are validated as effective technical tool for the decisions makers in the definition of strategies and national programs linked to achieve the land and the hydric resources more sustainable.
3. In the project RLA5076, the countries of the region take whole knowledge Isotopic Hydrology, like very useful tool to characterize the dynamics of the dam to be able to value the impact of the body of water reservoir superficial.

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The International Agency of Atomic Energy (IAEA). The support received in Latin American and Caribbean, is fundamental to develop the nuclear techniques application like important assessment tool in the environment degradations.

References

Banowetz, G.M., Whittaker, G.W., Dierksen, K.P., Azevedo, M.D., Kennedy, A.C., Griffith, S.M. & Steiner, J.J. 2006. Fatty acid methylester analysis to identify sources of soil in surface water. *Journal of Environmental Quality,* 35: 133–140.

Benmansour, M., Mabit, L., Nouira, A., Moussadek, R., Bouksirate, H., Duchemin, M. & Benkdad, A. 2013. Assessment of soil erosion and deposition rates in a Moroccan agricultural field using fallout ^{137}Cs and $^{210}Pb_{ex}$. *Journal of Environmental Radioactivity*, 115: 97-106.

Boyd, T.J., Osburn, C.L., Johnson, K.J., Birgl, K.B. & Coffin, R.B. 2006. Compound specific isotope análisis coupled with multivariate statistics to source-apportion hydrocarbon mixtures. *Environmental Science & Technology*, 40: 1916–1924.

Dapeña, C., Panarello, H.O., Peralta Vital, J.L., Gil Castillo, *et al.* 2010. Environmental Isotopes in a coastal karstic aquifer, Cuba. Preliminary Report. VII South American Symposium on Isotope Geology- Vol. CD Paper S0647: 487-491. Brasilia, Brasil.

Dapeña, C., Peralta Vital, J.L., Panarello, H.O., GilCastillo, R., Leiva Bombouse, *et al.* 2013. Isotope and hydrochemical study of seawater intrusion into the aquifers of a coastal zone. Cuba. International Symposium on Isotopes in Hydrology, Marine Ecosystems, and Climate Change Studies. (CN-186) IAEA CN-082, Vol 1: 349-356 Ed. IAEA. Vienna, Austria.

Davis, C.M. & Fox, J.F. 2009. Sediment fingerprinting: review of the method and future improvements for allocating non point source ascription*. J. Environ. Eng e ASCE,* 135: 490-504.

Díaz Asencio, M., Corcho Alvarado, J.A, Cartas Aguila, H., Pulido-Caraball, A. *et al.* 2017. ^{210}Pb and ^{137}Cs as tracers of recent sedimentary processes in two water reservoirs in Cuba. *Journal of Environmental Radioactivity,* 177: 290-304.

Gil, R. H., Peralta, J. L., Carrazana, J., Riverol, M., Aguilar, *et al.* 2015. Utilización de técnicas nucleares para estimar la erosión hídrica en plantaciones de tabaco en Cuba. *Revista Cultivos Tropicales*, 36(4): 7-13. ISSN 1819-4087.

IAEA. Project RLA5051. *Using environmental radionuclides as indicator of land degradation in Latin American, Caribbean and Antarctic ecosystems*, (ARCAL C); (2009-2013).

IAEA. Project RLA 5064. *Strengthening Soil and Water Conservation Strategies at the Landscape Level by Using Innovative Radio and Stable Isotope and Related Techniques*, (ARCAL CXL);(2014-2016).

IAEA. ProjectRLA5076. *Strengthening Surveillance Systems and Monitoring Programmes of Hydraulic Facilities Nuclear Using Techniques to Assess Sedimentation Impacts ace Environmental Social and Risks*, (ARCAL CLV); (2018-2020).

Iurian, A.R., Mabit, L., Begy, R.& Cosma, C. 2013. Comparative assessment of erosion and deposition rates on cultivated land in the Transylvanian Plain of Romania using 137Cs and 210Pbex. *Journal of Environmental Radioactivity*, 125: 40-49.

Mabit L., Benmansour M & Walling D.E. 2008. Radioactivity. Comparative advantages and limitations of the fallout radionuclides^{137}Cs, ^{210P}bex and ^{7}Be for assessing soil erosion and sedimentation. *Journal of Environmental Radioactivity*, 99: 1799–1807.

Mabit, L., Benmansour, M. & Walling, D.E. 2008. Comparative advantages and limitations of Fallout radionuclides (^{137}Cs, ^{210}Pb and ^{7}Be) to assess soil erosion and sedimentation. *Journal of Environmental Radioactivity*, 99(12): 1799–1807.

Mabit, L., Meusburger, K., Fulajtar, E. & Alewell, C. 2013. The usefulness of ^{137}Cs as a tracer for soil erosion assessment: A critical reply to Parsons and Foster (2011). *Earth-Science Reviews*, 127: 300-307.

Mabit, L., Meusburger, K., Iurian, A.R., Owens, P.N., Toloza, A. & Alewell, C. 2014. Sampling soil and sediment depth profiles at a fine-resolution with a new device for determining physical, chemical and biological properties: the Fine Increment Soil Collector (FISC). *Journal of Soils and Sediments*, 14(3): 630-636.

Marestoni, L.D, Appoloni, C.R., Andrello, A.C, & Martins, E.L. 2009. ^{7}Be fallout for superficial soil erosion assessment. International Nuclear Atlantic Conference. INAC 2009. Rio de Janeiro, Brazil. Associacao Brasileira de Energía nuclear – Aben. ISBN 978-85-99141-03-8.

Meusburger, K., Mabit, L., Park, J.H., Sandor, T. & Alewell, C. 2013. Combined use of stable isotopes and FRNs as soil erosion indicators in a forested mountain site, South Korea. *Biogeosciences*, 10: 5627-5638.

Minella, J.P.G., Walling, D.E. & Merten, G.H. 2008. Combining sediment source tracing techniques with traditional monitoring to assess the impact of improved land management on catchment sediment yields. *J. Hydrol*, 348: 546-563.

Peralta Vital, J.L., Gil Castillo, R. Molerio León, I., Leyva Bombuse, D., Dapeña, C., Panarello, H.O., Vera, M.C. & Ibarra, E.D. 2003. Isotope hydrology application in Cuba for assessment of water resource management in the most important Basin of Havana City. *Advances in Isotope Hydrology and its role in Sustainable Water Resources Management* (HIS-2007), IAEA Proceedings, 2003. Vol. 2: 245-253. CN151-3. Vienna, Austria.

Peralta Vital, J.L, GilCastillo, R., León, L.F.M., Panarello, O.H., Dapeña, C., Gonzáles, *et al.* 2011. Cuban experience in the applications of the nuclear techniques as valuable evaluations tools for the sustainable management water resources. International Symposium on Isotopes in Hydrology, Marine Ecosystems, and Climate Change studies oceanographic museum, Monaco.

Peralta Vital, J.L, GilCastillo, R, *et al.* 2011. Radioisotope monitoring network designed for the best hydrodynamic characterization of a Karstic Basin". International Symposium on Isotopes in Hydrology, Marine Ecosystems, and Climate Change Studies Oceanographic Museum, Monaco.

Peralta Vital, J.L., Gil Castillo, R., Molerio León, I.F., Dapeña, C & Acosta, J. Improving a radioisotope monitoring network for the hydrodynamic characterization of a karstic basin. International Symposium on Isotopes in Hydrology, Marine Ecosystems, and Climate Change Studies. 2013. (CN-186) IAEA CN-232, Vol 1:263.272 Ed. IAEA, Vienna, Austria.

Peralta Vital, J.L., Gil Castillo, R., Dapeña Dapeña, C., Valdez González, L., Olivera Acosta, J. & Morejón Miranda, Y.M. 2015. *Hidrología isotópica, herramienta nuclear para la gestión sostenible del recurso hídrico.* Centro de Investigaciones Hidráulicas, Instituto Superior Politécnico José Antonio Echeverría. 57–72 pp. (also available at http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1680-03382015000100005).

Proyecto Nacional/OIEA. Consolidación y mejora de las capacidades nacionales para soportar las evaluaciones y acciones de adaptación y mitigación del cambio climático en Cuba, a través del uso de técnicas isotópicas y nucleares (2018-2019).

Schuller, P., Walling, D.E., Iroumé, A., Quilodrán, C., Castillo, A. & Navas, A. 2011. Using^{137}Cs and ^{210}Pbex and other sediment source fingerprints to document suspended sediment sources in small forested catchments in south-central Chile. *Journal of Environmental Radioactivity*.

Taylor, A., Blake, W.H., Smith, H.G., Mabit, L. & Keith-Roach, M.J. 2013. Assumptions and challenges in the use of fallout beryllium-7 as a soil and sediment tracer in river basins. *Earth-Science Reviews*, 126: 85-95.

Walling, D.E. & Collins, A.L. 2000. Integrated Assessment of Catchment Sediment. Budgets: a Technical Manual. University of Exeter.

Is an expert-based model able to map erosion in agricultural catchment ?

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Abstract

Intensive agricultural practices on sensitive soils induce high erosion rates in central Belgium. Expert-rules models quantify runoff and erosion at watershed scale avoiding over-parameterization. The aim of this study is to test the ability of an expert-based model, LandSoil, to quantify runoff and to locate erosion and deposition areas in a small agricultural watershed in Belgium. For that purpose, Chastre catchment behavior is modeled using LandSoil during 3 years. Measurements of runoff and observation of spatial erosion/deposition patterns permit to assess the reliability of the model. Runoff modeling gives satisfactory results with good linear adjustments (r^2 of 0.94, Nash-Sutcliffe criterion of 0.92). However, 3 events tend to greatly overestimate runoff production. Graduated rulers and runoff samplings demonstrate that the model is able to provide a coherent pattern of erosion/deposition. The study highlights more sensitive effect of land use compared to landscape design. Grass strips induce a deposition of eroded particles when slopes are gentle (<2%), wood strip decreases connectivity by cutting erosion stream and deposit thicker sediment layers (up to 5 cm). This modeling validation in the Belgian loess context allows us to use expert based models in other similar environments and to estimate the effect of landscape management scenarios.

Keywords: Erosion, connectivity, modeling, expert rules, field validation

Introduction, scope and main objectives

Sediment production from agricultural field and transport after a rainfall event have significant consequences on environment and population (Verstraeten and Poesen, 1999). It underlines the need to better understand erosion processes including production, transport and sedimentation in order to find solutions.

Among all different types of models, expert-based models try to represent the watershed taking into account only major erosion processes in a specific situation in order to prevent from over-parameterization (Cerdan *et al.*, 2002b).

The objective of the study is to test LandSoil about the capacity to represent runoff, erosion and deposition patterns in an agricultural watershed with a particular attention on spatial distributions around major connectivity points. For that purpose, the whole watershed behavior between 2014 and 2016 is modeled to then focus on some linear features (grass strips, wood strip and field limits). These results are confronted to field measurements (erosion and deposition height measured by graduated rulers, eroded particles mass measured by automatic samplers). This aims to assess the reliability of the model in the Belgian loamy context and particularly to evaluate the capacity of the model to quantify the effect of linear features as observed in the watershed.

Methodology

Study area

The study area is an experimental watershed situated in the town of Chastre (Figure 1) in the middle of the Belgian loess belt (50°36'23.02" N, 4°35'42.33" E).

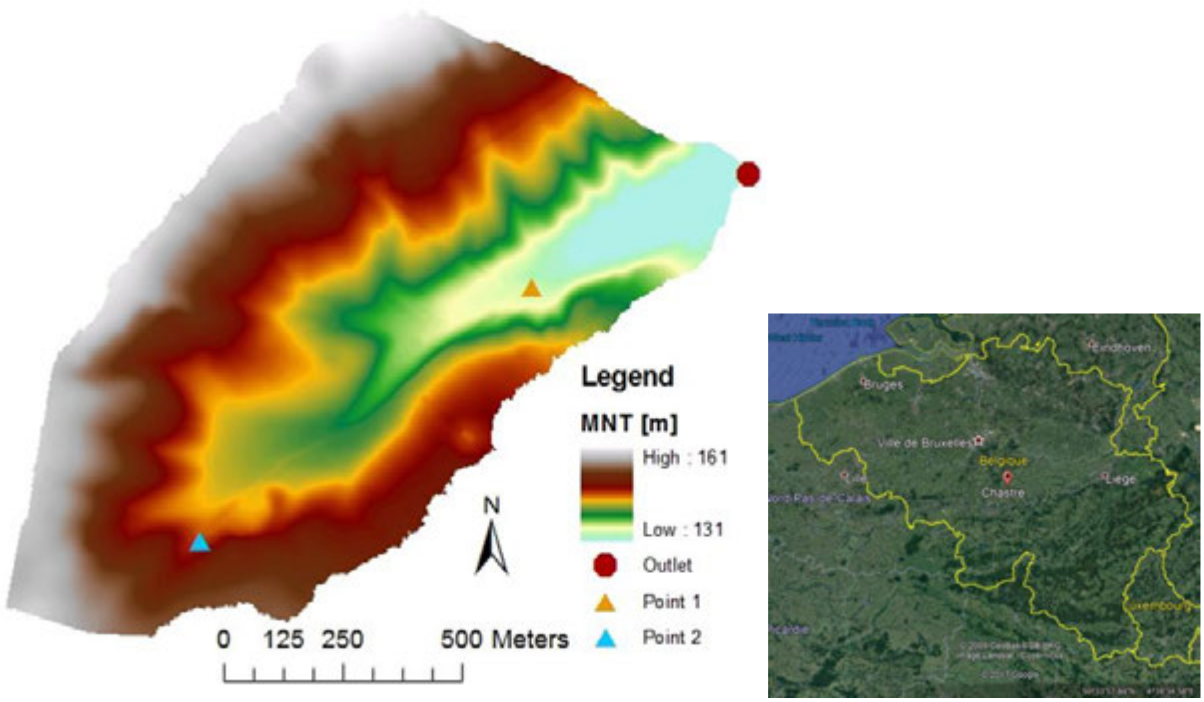

Figure 1: Study area presentation (location, DEM and outlet)

Model

LandSoil is a spatially distributed model based on the STREAM erosion (Cerdan *et al.*, 2002a, 2002b; Souchère *et al.*, 2003; Souchere *et al.*, 1998) and the WaTEM/SEDEM tillage erosion model (Govers *et al.*, 1994). STREAM models runoff and erosion at plot/ small catchment scale spatially and at rainfall event timely. It is adapted as an ArcGis template which provides ready-to-use layouts to make interface easy to understand. The objective with LandSoil is to analyze topographic evolution in agricultural landscape resulting from soil redistribution in the catchment (Ciampalini *et al.*, 2012). After each rainfall or ploughing event, a new digital elevation model is calculated taking into account all eroded or deposited soil transported in the runoff water flow.

Field measurements

For comparison purpose, rulers with graduated scales are placed at some locations in the catchment to measure erosion and deposition. 15 zones with several rulers for each are identified in the watershed, respectively 6, 3 and 6 for 2014, 2015 and 2016.

Two automatic samplers are located at the two discharge measurement points in the watershed.

Results and discussion

Runoff

Table 1 presents rainfall and runoff amounts for 2014, 2015 and 2016. Runoff coefficients are quite small between 1 and 3 % compared to literature (Cerdan *et al.*, 2004; Evrard *et al.*, 2008; Ryken *et al.*, 2018), bigger for 2016 with 5.7 % of runoff. This is linked to the proportion of row crops respectively at 45, 39 and 90 % for 2014, 2015 and 2016. In addition, the disappearance of grass strips and some field limits explains the finding of bigger hydrological connectivity for 2016.

Figure 2 presents results for point 1. There is a good comparison between measurements and modeling with a linear adjustment of 0.89*x and a r^2 of 0.94, and a Nash-Sutcliffe criterion of 0.92. Results are comparable to those from Cerdan *et al.* (2002b) and Evrard *et al.* (2009). But three events (12/05/2014, 29/07/2014, 23/06/2016) are out of the adjustment where modeled runoffs are much higher than measured ones (King *et al.*, 2005). These outliers have a high quotient of rainfall amount and effective duration.

Table 1: Rainfall and runoff amount for 2014, 2015 and 2016

	Rainfall amount [mm]	**Selected rainfall [mm]**	**Runoff [mm]**	**Runoff coefficient [%]**
2014	266.6	195.2	6.3	3.2
2015	76.8	64.6	0.9	1.4
2016	283	260.8	14.8	5.7

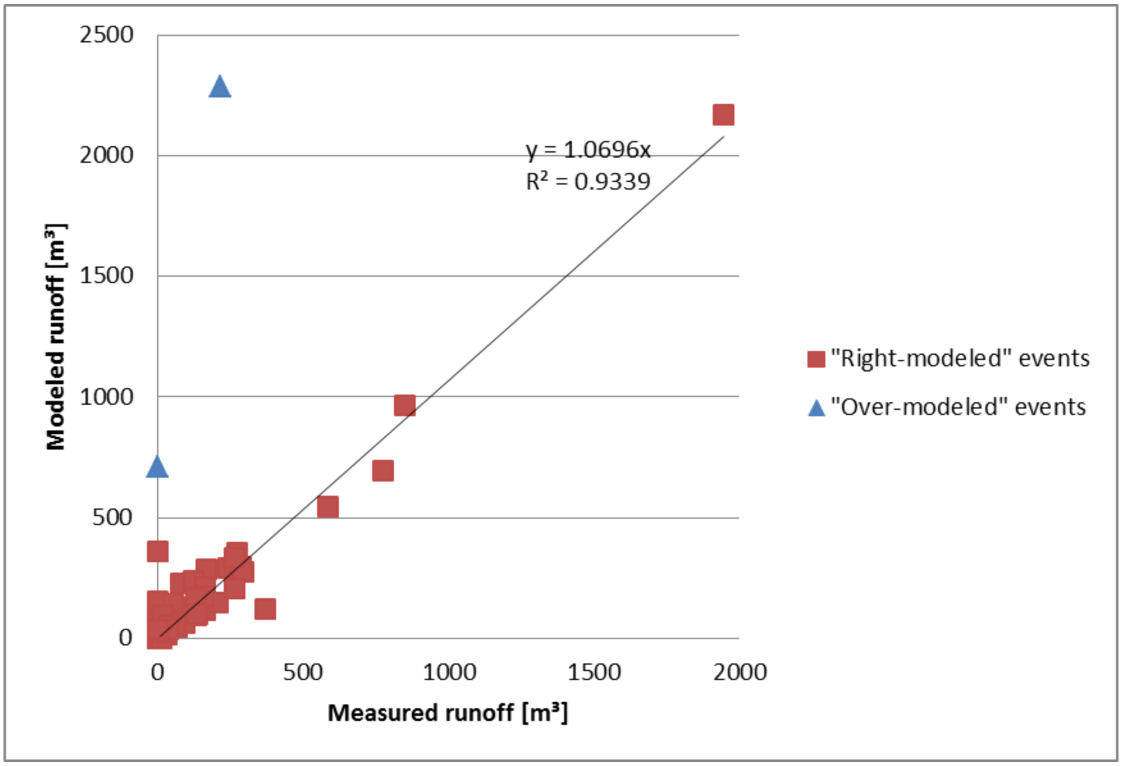

Figure 2: Comparison between measured and modeled runoff for point 1 (2014, 2015 and 2016)

Erosion

Figure 3 presents results for the comparison between graduated rulers measurements and erosion modeling for the different linear features. The new DEM at the end of the period of interest is compared to the original one. That way, it is possible to compare observed and modelled erosion and deposition depths. For each zone, a mean and a standard deviation of the rulers heights are calculated. For the model, in order to take into account the uncertainty on the exact location, local pixel value and close neighbors are considered.

Globally, there is a good comparison between measurement and modeling with a regression slope of 1.07 and a r^2 of 0.70. It seems to correctly represent the reality of the erosion processes and their spatial pattern. But standard deviations for all measurements and modeling are high, often bigger than the mean. There are much more results for deposition than for erosion (4 erosion cases and 14 deposition cases). This is directly linked to the position of rulers in fields.

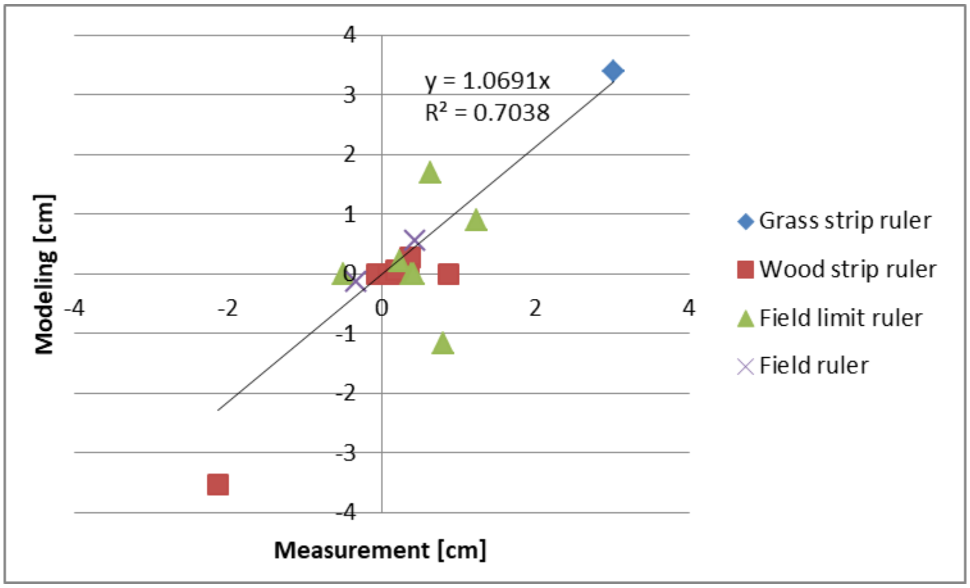

Figure 3: Comparison between graduated rulers measurements and erosion modeling for different types of features

About grass strip, the zone 2014_7 directly upstream of a grass strip shows a deposit of more than 3 cm, between 01/04/2014 and 03/06/2014. That underlines the role of the grass strip to reduce runoff speed, to deposit eroded soil particles and thus to decrease connectivity (Ciampalini *et al.*, 2012). The really low slopes of this zone reinforce the deposition process. The other grass strips deposit less sediment because of steeper slopes.

Conclusions

The objective of the study is to test an expert-based model (LandSoil) on representing erosion and deposition in an agricultural watershed in Belgium. A specific attention is given to behavior of connectivity features, especially linear features.

Comparison between measured and modeled runoff volumes shows very close correspondence. Three events (2 in 2014 and 1 in 2016) get out of the adjustment for point 1. These rainfalls have a high quotient between rainfall amount and effective duration. For point 2, there are too few runoff events to conclude about the good apparent modeling. This good parallelism between measurements and model allows comparing erosion pattern, which is calculated on the basis of the runoff volume.

Graduated rulers permit to validate modeling at some locations in the watershed. The comparison for the 15 measurement zones is satisfying even if standard deviations of measurements and modeling remain high. Field limits do not seem to have big impact on amount of eroded and deposited particles. But it plays a role in the transport acting as a channel for small erosion rates lower than 0.5 T/event or around. It shows that land use has more influence than landscape design in the erosion management and thus in the global connectivity.

All these measurements permit to validate erosion processes modeling for the studied watershed. The role of linear features can be highlighted. But a study with more rulers could improve results. Rulers were placed between April and September; it would be interesting to have results for winter period as well. Other methods could also help to reach objectives, like drones for example. However, the rather good behavior of the model allows us to use LandSoil modeling in other environments, with other land use and other slopes than those from study zone and to quantify the impact of management scenarios.

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References

Cerdan, O., Le Bissonnais, Y., Couturier, A. & Saby, N. 2002a. Modelling interrill erosion in small cultivated catchments. *Hydrological Processes,* 16 : 3215–3226. https://doi.org/10.1002/hyp.1098.

Cerdan, O., Souchère, V., Lecomte, V., Couturier, A. & Le Bissonnais, Y. 2002b. Incorporating soil surface crusting processes in an expert-based runoff model: Sealing and Transfer by Runoff and Erosion related to Agricultural Management. *CATENA*, 46 : 189–205. https://doi.org/10.1016/S0341-8162(01)00166-7.

Cerdan, O., Le Bissonnais, Y., Govers, G., Lecomte, V., van Oost, K., Couturier, A., King, C. & Dubreuil, N. 2004. Scale effect on runoff from experimental plots to catchments in agricultural areas in Normandy. *Journal of Hydrology*, 299: 4–14. https://doi.org/10.1016/j.jhydrol.2004.02.017.

Ciampalini, R., Follain, S. & Le Bissonnais, Y. 2012. LandSoil: A model for analysing the impact of erosion on agricultural landscape evolution. *Geomorphology*, 175-176: 25–37. https://doi.org/10.1016/j.geomorph.2012.06.014.

Evrard, O., Bielders, C.L., Vandaele, K. & van Wesemael, B. 2007. Spatial and temporal variation of muddy floods in central Belgium, off-site impacts and potential control measures. *CATENA*, 70: 443–454. https://doi.org/10.1016/j.catena.2006.11.011.

Evrard, O., Vandaele, K., Bielders, C. & van Wesemael, B. 2008. Seasonal evolution of runoff generation on agricultural land in the Belgian loess belt and implications for muddy flood triggering. *Earth Surface Processes and Landforms*, 33: 1285–1301. https://doi.org/10.1002/esp.1613.

Evrard, O., Cerdan, O., van Wesemael, B., Chauvet, M., Le Bissonnais, Y., Raclot, D., Vandaele, K., Andrieux, P. & Bielders, C. 2009. Reliability of an expert-based runoff and erosion model: Application of STREAM to different environments. *CATENA*, 78: 129–141. https://doi.org/10.1016/j.catena.2009.03.009.

Fiener, P., Auerswald, K. & Van Oost, K. 2011. Spatio-temporal patterns in land use and management affecting surface runoff response of agricultural catchments—A review. *Earth-Science Reviews*, 106: 92–104. https://doi.org/10.1016/j.earscirev.2011.01.004.

Govers, G., Vandaele, K., Desmet, P., Poesen, J. & Bunte, K. 1994. The role of tillage in soil redistribution on hillslopes. *European Journal of Soil Science*, 45: 469–478. https://doi.org/10.1111/j.1365-2389.1994.tb00532.x.

King, C., Lecomte, V., Le Bissonnais, Y., Baghdadi, N., Souchère, V. & Cerdan, O. 2005. Remote-sensing data as an alternative input for the "STREAM" runoff model. *CATENA*, 62: 125–135. https://doi.org/10.1016/j.catena.2005.05.008.

Ryken, N., Vanden Nest, T., Al-Barri, B., Blake, W., Taylor, A., Bodé, S., Ruysschaert, G., Boeckx, P. & Verdoodt, A. 2018. Soil erosion rates under different tillage practices in central Belgium: New perspectives from a combined approach of rainfall simulations and 7Be measurements. *Soil and Tillage Research,* 179: 29–37. https://doi.org/10.1016/j.still.2018.01.010.

Souchère, V., Cerdan, O., Ludwig, B., Le Bissonnais, Y., Couturier, A. & Papy, F. 2003. Modelling ephemeral gully erosion in small cultivated catchments. *CATENA*, 50: 489–505. https://doi.org/10.1016/S0341-8162(02)00124-8.

Souchere, V., King, D., Daroussin, J., Papy, F. & Capillon, A. 1998. Effects of tillage on runoff directions: consequences on runoff contributing area within agricultural catchments. *Journal of Hydrology*, 206: 256–267. https://doi.org/10.1016/S0022-1694(98)00103-6.

Verstraeten, G. & Poesen, J. 1999. The nature of small-scale flooding, muddy floods and retention pond sedimentation in central Belgium. Geomorphology 29: 275–292. https://doi.org/10.1016/S0169-555X(99)00020-3.

Assessment of soil erosion by R/USLE – A case study of the applications of R/USLE in the mining industry

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Golder Associates*

Abstract

Understanding the extent and magnitude of the impact mining activities have on soil throughout the life of mine, has grown in the African context. Soil loss and soil performance have been indicated as the key aspects affecting the success of surface rehabilitation in the South African mining industry. To understand the extent and magnitude of soil loss and to recommend appropriate impact mitigation measures, soil loss was modelled before and after mining activities with the Revised Universal Soil Loss Equation (R/USLE) integrated with ArcGIS for three project sites located in the Democratic Republic of Congo (DRC), Ghana and South Africa. Using the mining activities which directly impact soils as hypothetical scenarios, the spatial extent and magnitude of soil loss was predicted for the various phases of the mining projects.

Since erosion modelling had not been a standard component of soil assessments for environmental impact assessment in the mining industry, the introduction thereof provides the mining industry with a tool to measure the impact their project activities or interventions have on the soil. We have recommended the use of R/USLE to our clients, for monitoring mining activities impacts on soil losses, due to the model's relative simplicity.

Keywords: soil loss prediction, DRC, Ghana, South Africa

Introduction

The assessment of environmental impacts on soil generally includes the determination of baseline soil conditions to evaluate the potential impacts on the soil due to planned project activities. An aspect which has recently grown in demand as part of environmental impact assessments, is the mapping of the soils' erodibility and predicting soil loss.

The risk to soil erosion, associated with the inevitable soil disturbance which will take place during the project life (particularly during the construction and rehabilitation phases), are frequently highlighted as significant during environmental impact assessments (EIA). To reduce these impacts, appropriate mitigation measures need to be recommended and implemented for land owners to obtain the required environmental authorizations to commence with a particular project.

The importance of understanding the erosive behaviour of soil has also grown due to the demand for suitable available soil for post mining land rehabilitation. Soil loss and soil performance have been indicated as the key aspects affecting the success of surface rehabilitation in the mining industry in South Africa (Chamber of Mines South Africa, 2007).

In both the construction and rehabilitation phases, the assessment of soil loss has been conducted to provide clients with an understanding of i) the distribution of land prone to erosion, ii) which soils are less prone to erosion and thus more suitable for handling and placement during surface rehabilitation. To address both client needs, the Revised Universal Soil Loss Equation (R/USLE) integrated with ArcGIS was used to determine the spatial distribution of soil erodibility and trend in potential soil loss for three project sites.

Methodology

Study area description

The project sites are located in the Katanga province of the Democratic Republic of Congo (DRC), the Brong-Ahafo region of Ghana and the Mpumalanga province of South Africa. The three sites have mean annual rainfalls of 1 200 mm, 1 186 mm and 785 mm for the DRC, Ghanaian and South African sites respectively.

Most of the soils in the DRC project area consist of Alisols (66 %), Ferralsols (19 %), and Plinthosols (13 %), which are well distributed across the site, with a few Cambisols and Anthropogenic also occurring. For the Ghanaian project site Acrisols (44 %), and Plinthosols (29 %) mainly occur, with Leptosols, Regosols, Ferralsols, Gleysols and Fluvisols each occupying < 10% of the project site. For the South African project site, Ferralsols (~40 %), Lithosols (~27), Luvisols (~23 %), and Gleysols (~10 %) were recorded.

Both the DRC and Ghanaian project sites are covered in predominantly forest vegetation. These areas are envisioned to be cleared for mining. The South African site is categorised as a wetland, with portions thereof used for grazing.

Method of data analysis

The assessment of potential annual soil loss through sheet erosion was estimated using the Revised Universal Soil Loss Equation (R/USLE). The predicted average annual soil loss expected is based on the following equation:

$A = R \times L \times LS \times C \times P$ Eq. 1

where, A = computed spatial average soil loss (ton per hectare per year (t $ha^{-1}.yr^{-1}$)), R is the rainfall-

runoff erosivity factor (MJ mm. $ha^{-1}h^{-1}yr^{-1}$), K is the soil erodibility factor (t.ha.h. ha^{-1} MJ^{-1} mm^{-1}), LS = topographic factor (*unitless*), C is the cover management factor (*unitless*) and P is the support practice factor (*unitless*).

Data Sources

The R-factor was calculated based on the long-term rainfall data (at least 25 yrs). The K-factor was calculated using the topsoil characteristics (soil organic matter, very fine sand, silt, soil structure and permeability) by means of the algebraic approximation of the monograph by Wischmeier & Smith, 1978. The topographic (LS) factors were derived from the Digital Elevation Model (DEM) and contour maps. The C-factors were determined by assigning C-factor values obtained from literature (Panagos *et al.*, 2015; Benavidez *et al.*, 2018) to the land cover classes. As with the C factor, the support practice factor (P) was obtained from literature. The average predicted soil loss for a particular project area (in its current condition as indicated on the land cover map) was then calculated in ArcGIS and a soil erosion probability map generated. The overall approach to the assessment of potential annual soil loss is illustrated in the flowchart below (Figure 1):

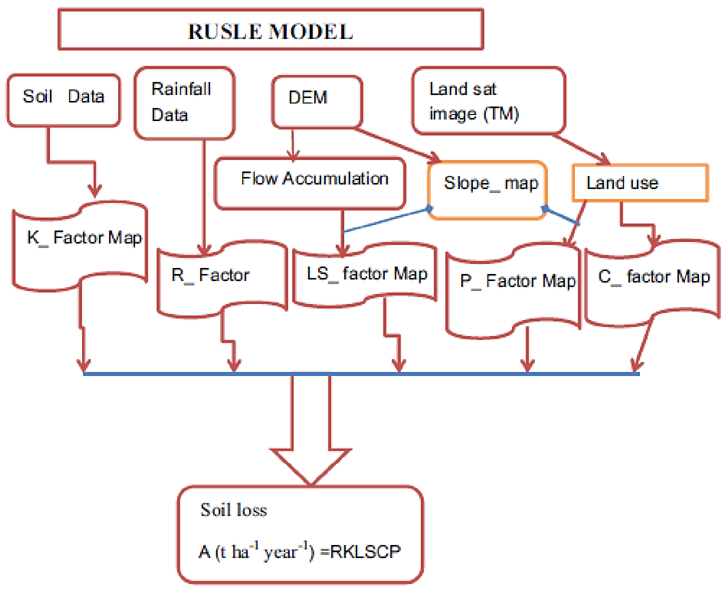

Figure 1: Flowchart indicating approach to estimating the potential soil loss for case studies (extracted from Gelagay and Minale, 2016)

Results

R-factor

The R factor is usually determined from calculated rainfall intensity measured in 30 min events. Since such data is not readily available for remote areas, and generally not a standard component of climate data collected, the R-factor was calculated using the Modified Fournier Index (MFIe*, Eq. 2*), also previously used for erosion modelling studies conducted (Oduro-Afriyie, 1995; Essel *et al.*, 2015; Kusimi *et al.*, 2015).

$R = 227MFIe^{0.548}$ Eq. 2

$MFI = \sum_{i=1}^{12} \frac{pi\char`^2}{p}$ Eq. 3

Where pi is the monthly rainfall amount for the ith month (mm) and P is the annual rainfall amount (mm).

The mean R-factor was used in the calculation of the soil loss equation. The study areas calculated average rainfall erosivity of 4 400 mm. $ha^{-1}h^{-1}yr^{-1}$ for the DRC project site, 3 683.5 MJ mm. $ha^{-1}h^{-1}yr^{-1}$ for the Ghanaian project site and 2 873 MJ mm. $ha^{-1}h^{-1}yr^{-1}$ for the South African site.

K factor

The soil erodibility (K-factor) was calculated using the topsoil characteristics (soil organic matter, very fine sand, silt, soil structure and permeability) of each RSG by means of the algebraic approximation (Renard *et al.*, 1997) of the nomograph by Wischmeier & Smith, 1978. The soil erodibility factor values were assigned to the different RSGs in GIS. The ranges of K-factor values obtained for each of the sites vary from 0.03 to 0.07 t ha h ha^{-1} MJ^{-1} mm^{-1} for the DRC project site, 0.016 to 0.059 t ha h ha^{-1} MJ^{-1} mm^{-1} for the Ghanaian project site and 0.005 to 0.01 t ha h ha^{-1} MJ^{-1} mm^{-1} for the South African site.

LS factor

The LS factor was calculated in ArcGIS, using the methodology detailed in previous soil erosion related studies (Devatha *et al.*, 2015; Panagos *et al.*, 2015; Gelagay *et al.*, 2016; Van Remortel *et al.*, 2001). The flowchart in Figure 3, illustrates how the LS factor was calculated. The average calculated LS factor for the three study areas were 0.49, 6.3 and 0.89 for the DRC, Ghanaian and South African sites respectively.

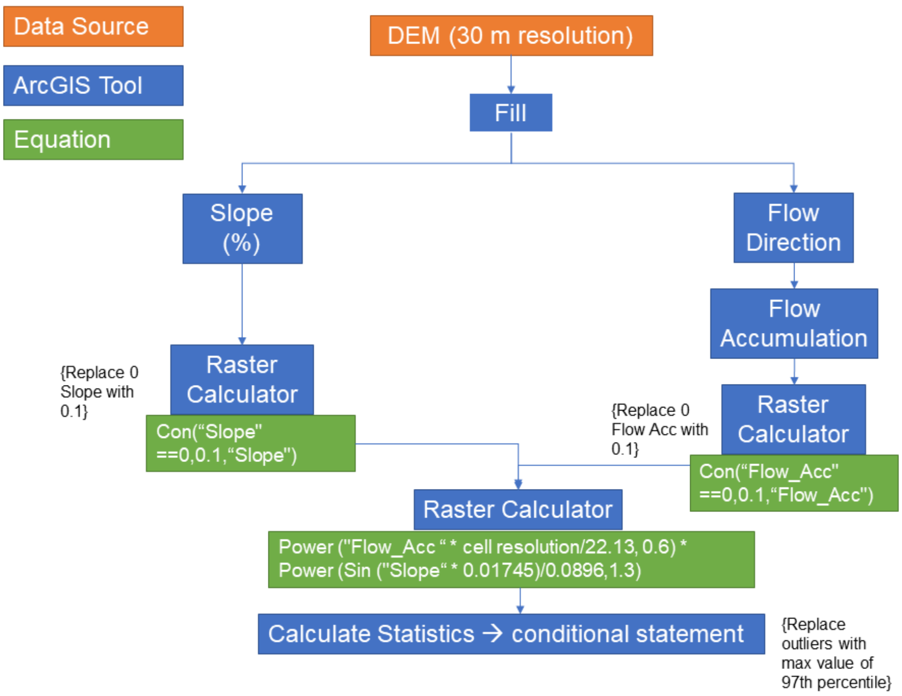

Figure 2: Flowchart for calculating the LS factor

C factor

The recent aerial imagery for each study area was used to create the land cover classes using Semisupervised Remote Sensing Image Classification. The C-factors were determined by assigning C-factor values obtained from literature (Panagos *et al*, 2015; Benavidez *et al*, 2018) to the land cover classes.

P factor

As in the case of the C-factor, values for the P-factors can be taken from literature and if there are no support practices observed, P=1.0 (Adornado *et al.*, 2009) was assigned.

A factor

The annual soil loss (A) was computed by multiplying the developed raster data from each of the model parameters. The baseline soil loss (prior to mining activities) and the predicted soil loss (A) due to the soil disturbance during the construction phase were calculated in this way. The average annual soil loss for each project site was calculated as 13 $ton.ha^{-1}.yr^{-1}$, 100 $ton.ha^{-1}.yr^{-1}$ and 0.9 $ton.ha^{-1}.yr^{-1}$ for the DRC, Ghanaian and South African sites respectively. These values were taken as the baseline potential soil loss for each of the sites prior to the anticipated soil disturbance.

Discussion

The calculated annual soil loss values were taken as the baseline potential soil loss for each of the sites prior to the anticipated soil disturbance. For the DRC and Ghanaian project sites, the impact of vegetation clearance on soil loss was also calculated by assigning an overall C-factor of 1 (as with bare ground). The soil loss values were then compared to the FAO soil loss tolerance level of 12 $ton.ha^{-1}.yr^{-1}$ in order to rate the magnitude of the erosion risk. Areas which exceeded the tolerance level were highlighted as zones where erosion control measures need to be implemented.

In previous soil impact assessments, the assessment of erosion risk only included consideration of the reference soil groups known to be susceptible to erosion, without the consideration of topography, rainfall erosivity, crop management or support practices. Erosion control measures recommended based on only soil susceptibility were very general and typically include avoiding the disturbance of the susceptible RSG's, an unpracticable recommendation where susceptible RSG's comprise the majority of the project footprint.

Overlaying the GIS layer of zones which exceeds the tolerance level, over the susceptible RSG layer for the project sites, highlighted that smaller portions of project footprint required intervention, instead of an entire project footprint.

The resultant effect of implemented erosion control measures, such as progressive or gradual vegetation clearing as mining progresses in comparison to a once-off vegetation clearance in preparation of land for mining infrastructure; altering the landform slope; and revegetation of disturbed land, can easily be predicted using R/USLE. The application of the model in mining projects was also useful in understanding the potential cumulative soil losses during the project life, and how this impacts the quantity of soil available for rehabilitation.

Conclusions

Since erosion modelling had not been a standard component of soil impact assessments in our industry, the introduction thereof in these studies provide our clients with a tool to measure the impact their project activities or interventions have on the soil. We have recommended the use of R/USLE for monitoring project impacts on soil losses, due to the model's relative simplicity and since the input data it requires is already monitored as part of Environmental Management in the case of mining projects. Additionally, our clients are encouraged to undertake site-wide erosion monitoring. In future, this information can be used to refine the model parameters, by incorporating these field observations.

Acknowledgements

We wish to thank Golder Associates for opportunity to present these case studies.

References

Benavidez R., Bethanna Jackson, B., Maxwell, D. & Norton, K. 2018 A review of the (Revised) Universal Soil Loss Equation (R/USLE): with a view to increasing its global applicability and improving soil loss estimates. *Hydrol. Earth Syst*. Sci. Discuss., https://doi.org/10.5194/hess-2018-68. *Manuscript under review for journal.*

Chamber of Mines of South Africa (CMSA)/Coaltech. 2007. Guidelines for the rehabilitation of mined land. 13-19p, http://www.coaltech.co.za.

Devatha, C.P., Vaibhav D. & Renukaprasad, M.S. 2015. Estimation of Soil loss using USLE model for Kulhan Watershed, Chattisgarh- A case study. *Aquatic Procedia*, 4(2015): 1429 – 1436.

Essel, P.G., Eric, T., Yeboah, S., Adjei-Kyereme, Y., Yawo, I.N.D., Nyarku, M., Asumadu-Saskyi, G.S., Gbeddy, G.K., Agyiri, Y.A., Ameho, E.M & Aberikae, E.A. 2016. Rainfall Erosivity Index for the Ghana Atomic Energy Commission site. *SpringerPlus*, 5(465).

FAO. 2006. Guidelines for soil description, fourth edition, FAO, Rome 95pp; Resources Reports N°103, 116p. Available at http://www.fao.org/ag/agl/agll/wrb/ [accessed 08.03.2019]

Soil water available capacity affected by erosion in olive groves under semi-arid climatic conditions

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Abstract

Soil erosion is especially important in sloping agricultural land. Farmers plow their fields to maximize water retention, but they are not aware about the long-term consequences of continuous tillage. The plot of study, located in the south of Madrid, Spain, is used for olive tree cultivation, covering c.a. 3 ha with 12% slope. Thirty core samples were collected and analyzed up to 30 cm depth for water available capacity and soil organic carbon. In these gypsiferous soils, there was a correlation between soil loss and soil surface color, due to erosion, light-color lower layers emerge. Brightness and HUE indices were obtained from Sentinel 2 images to be used as indirect indicators of erosion. In addition, a progressive decrease in soil moisture was found across depth. In this study topsoil layers (0-10 cm depth) show 12±3 % water available capacity; 10±4 % at 10-20 cm, and light-color lower layers (20-30 cm depth) 8±5 % (n=30). Aerial and remote sensing images are powerful tools to be used to convince land users as they can clearly see changes in color, which can be translated into water retention changes, a priority for them in this semi-arid context. This type of knowledge transfer will help them to make decisions for better land management.

Keywords: soil brightness, gypsiferous soils, desertification, olive groves

Introduction, scope and main objectives

Soil erosion in olive groves has been frequently addressed in the literature and particularly in Spain where the majority of olive groves are rainfed, managed by tillage and located in sloping lands (Gómez *et al.,* 2005; Francia *et al.,* 2006). These studies tend to focus on soil losses; other works are focused on sustainable management practices (Sastre *et al.,* 2017) or in social aspects, aiming at knowing the visions of land users. These studies revealed the scarce willingness of farmers to make changes (Franco and Calatrava, 2006; Marques *et al.*, 2015) mainly due to lack of awareness of erosion consequences in long-term sustainability of crops, especially when water is a limiting factor. This work was carried out in an olive grove in the south of Madrid, Spain, where annual rainfall is less than 400 mm. This research team has been studying soil loss in this plot for several years and found that there is a chronicle soil loss, being around 1 Mg ha^{-1} in years of low erosivity; but they also realized that high-intensity episodes, like the one in October 2007 with a I_{10} of 55 $mm.h^{-1}$, can produce rill erosion of 94 $Mg.ha^{-1}$ (Bienes and Marques, 2008). They demonstrated the benefits of sustainable management of olive groves in soil protection (Sastre *et al.,* 2017). Currently one of their concerns is to transfer this knowledge to land users. In order to do so, there is a need to find high impact messages, as loss or soil organic carbon, loss of biodiversity, or loss of ecosystem services seem to be inefficient to provoke the shift of management practices. In this context, this paper presents the on-site consequences of soil loss. One of these consequences is the loss of water available capacity (WAC). Water scarcity is one of the major concerns of farmers in the study area (Barbero *et al.*, 2016) and the main reason to maintain traditional practices as frequent tillage is seen as the way to increase water capture. This study is intended to demonstrate that business as usual leads to loss of water in these soils.

As farmers prioritize water, a first objective of this study is to clearly establish the impact of erosion on the soil's ability to store water. Secondly, this work is aiming at finding a remote sensing indicator to show the magnitude of this impact and further use of detailed maps. This pilot work is laying the foundations for establishing a relationship between soil WAC and an indirect indicator like brightness index (BI) to elaborate detailed maps.

Methodology

The study area is located in the south of Madrid, Spain. The region is under Mediterranean semi-arid climatic conditions, having cool winters, average annual temperature 13.6 ºC, accumulated annual precipitation 380 mm and reference evapo-transpiration (ET0 Penman-Monteith) 1 112 mm. The experimental plot under study belongs to the *Finca la Chimenea*, IMIDRA (at ETRS89 UTM 30 latitude: 40º4'25"N; longitude: 3º31'20"W), it covers c.a. 3 hectares and its average altitude is 550masl with 12 to 14% slope; the soil plot is developed over gypsic soils (Gypsiric Regosol, WRB, 2014). Young olive trees were planted in this field in 2006 spaced 7x7 m and managed by minimum tillage up to 25 cm depth.

Thirty 30 cm deep soil cores were randomly collected across the slope (Figure1-left). Sub-samples each 10 cm of core samples were analyzed. Soils were oven dried and sieved (2 mm).

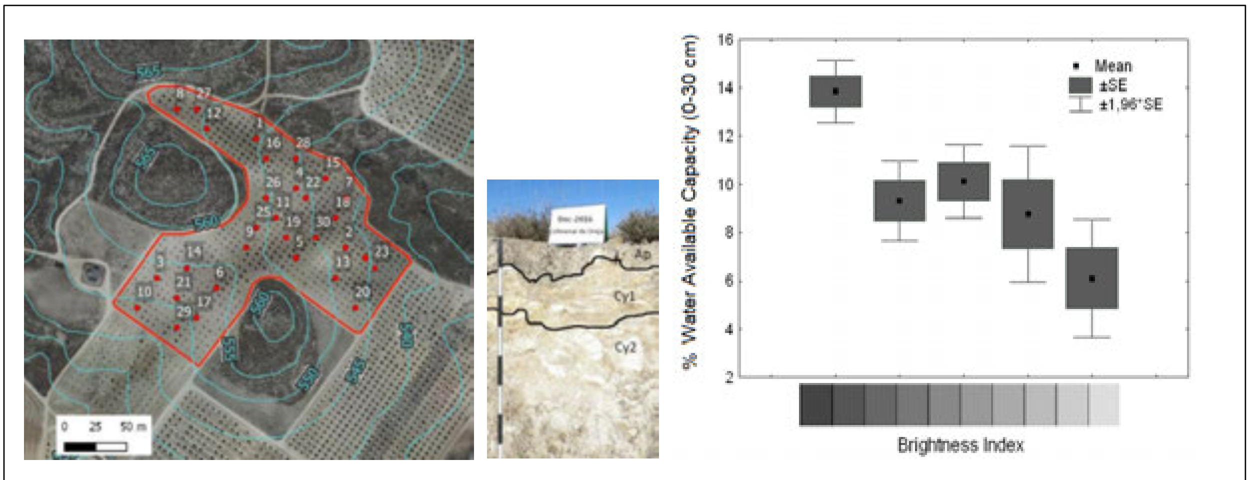

Figure 1: Left, experimental plot and sampling sites. Center, soil profile with 3 different horizons. Right, change in water available capacity (m^3/m^3) average of 0 to 30 cm according to Brightness Index, n=90

Pressure plates (Richards, 1941) were used to determine soil moisture using soil matric potential ranging from 2.54 to 4.2 pF; dry soil weight was obtained by oven dry process in disturbed soil samples. WAC was calculated as the difference between water content at 2.54-pF, Field Capacity, and water at 4.2-pF, Permanent Wilting Point in 90 disturbed sub-samples. Soil organic carbon was estimated by Loss On Ignition method (Schulte and Hopkins, 1996).

A cloud-free Sentinel-2 image obtained the 15th Nov 2017 was downloaded from ESA Sentinels Scientific Data-Hub considering the closest date of sampling after tillage and with dry soils. The relationships between spectral data and soil properties were analyzed using digital soil mapping methods. Spectroradiometer (Analytical Spectral Devices. Boulder Colorado) was used to obtain spectra of 90 soil samples.

Brightness index (BI) and HUE index were calculated for both spectroradiometer results and pixels from Sentinel 2 image, 10 m resolution, which wavelengths are B2 490 nm; B3 560 nm; B4 665 nm and B8 (VNIR) 842 nm.

$$BI = \sqrt{B8^2 + B4^2 + B3^2} \qquad HUE = \frac{2\,B4 - B3 - B2}{B3 - B2}$$

Significant differences were established by one way ANOVA analysis, regressions analysis were performed to find relationships between water available capacity and BI and HUE indicators (Statistica 6.1).

Results

In the set of samples, WAC decreased with depth in parallel to soil organic carbon (Table 1). There was a significant correlation between these two variables (R= 0.69; p < 0.001; N=90). When comparing WAC and BI, there was a significant difference in the ability of soil to provide water. Darker samples, hold in average 14% of water, compared to 6% in lighter samples (Figure 1-right).

Table 1: Mean and standard deviation of water available capacity (WHC) and soil organic carbon (SOC) at different depths of core-samples. Significant differences are marked with different letters between depths.

Depth	n	WAC (%)	SOC (g kg^{-1})
0-10 cm	30	12.3 $\pm$ 2.8 a	12.7 $\pm$ 4.2 a
10-20 cm	30	9.8 $\pm$ 4.4 b	10.6 $\pm$ 4.8 a
20-30 cm	30	7.7 $\pm$ 5.0 b	7.1 $\pm$ 4.7 b
	F	0.09	11.39
	p	0.00025	0.00004

The spectral signatures of 30 sampled soils allowed obtaining a significant relationship between BI and HUE indices and WAC (Table 2).

Table 2: Variance of WAC explained by BI and HUE indices obtained for 30 topsoil samples (0-10 cm) spectra using ASD spectroradiometer.

REGRESSION SUMMARY FOR DEPENDENT VARIABLE: WAC R=0.734902 R^2=0.540080 ADJUSTED R^2=0.506012 F(2.27)=15.853 P<0.00003 STD.ERROR OF ESTIMATE:0.01992						
	Beta	St. Err.	B	St. Err.	t(27)	p-level
INTERCEPT			-0.071	0.068	-1.029	0.312
BI_I	-0.282	0.135	-0.076	0.036	-2.094	0.045
HUE_I	0.611	0.135	0.099	0.022	4.529	<0.001

The application of this relationship to pixels of the remote sensing image yields the image of water available capacity of the plot (Figure2).

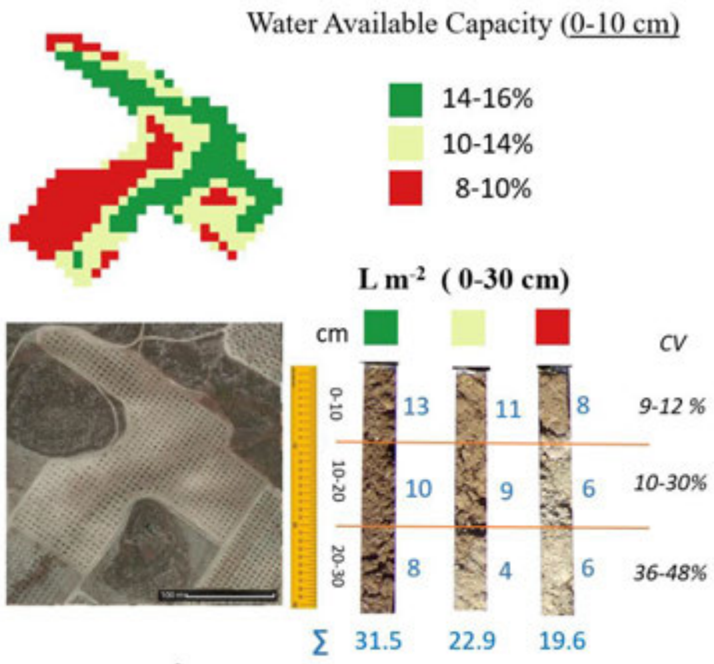

Figure 2: Simple image of Water Available Capacity (WAC) resulting from the application of BI and HUE indices to the image of Sentinel-2. Average WAC across depth and Coefficient of Variation (CV) of results.

Discussion

Most semi-arid Mediterranean environments show low soil thickness, as is found in the plot under study. Topsoil horizons tend to accumulate organic carbon, nutrients and water; erosion processes swept away these fertile layers and other deeper, compact and poor horizons emerge. The particular soil of this study has some edaphic characteristics that can be used to estimate the severity of erosion. The upper horizon Ap, with 1.2 $Mg.m^{-3}$ bulk density has 10 to 15 cm depth. The next Cy1-horizon appears at 15-20 cm deep and it is followed by the Cy2-horizon by 30 cm depth, both with 1.4 Mg m^{-3} bulk density (Sastre *et al.*, 2018). A progressive increase of gypsum content is found over depth, being between 20-50 % at the surface, and 30-70 % at 30 cm depth (Robledo *et al.*, 2017). In parallel to these variations, soil is progressively more whitish over depth (Figure 1-center). Due to the above-mentioned edaphic characteristics, the sustained erosion in these fields can be easily related to changes of surface color.

It is well known that optical properties of soils in remote sensing can be influenced by mineral composition, texture, soil moisture and soil organic carbon. In this study, the two latter factors play an important role.

BI and HUE indices show the effects of erosion in these sloping soils, and can be used as a proxy of progressive decrease of WAC. Due to constant tillage operations, there is no opportunity for soil formation; therefore, the system tends to a constant loss of depth, organic carbon and water.

Currently the information of the spectral signatures of 90 sampled soils are used to find out the best relationships with water available capacity and carbon content to be applied to Sentinel-2 images over time. Geostatistical techniques will be used to obtain sound representation of these data in detailed maps in order to know the magnitude of the impaired surface. Brigtness and HUE indices can be used in other gypsiferous fields. Water scarcity maps will be elaborated and used to increase farmers' awareness regarding erosion.

Conclusions

Losing shallow soil horizons by erosion means losing water retention that is a priority for farmers. Scientific studies on erosion in agricultural fields should produce more effective messages to transfer knowledge to other stakeholders out of the Academy. As an example, this study allows to affirm that eroded and paler soils have 38% less water availability than darker soils in average. This type of information can be translated into detailed maps using geostatistical techniques so that the message reaches the target population.

Acknowledgements

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References

Barbero-Sierra, C., Marques, M.J., Ruíz-Pérez, M., Bienes, R. & Cruz-Macéin, J.L. 2016. Farmer knowledge, perception and management of soils in the Las Vegas agricultural district, Madrid, Spain. *Soil Use and Management,* 32: 446–454.

Bienes, R. & Marques, M.J. 2008. Interrill erosion in a bare soil. An experience of 12 years. In Proceedings of EUROSOIL 2008 Control No. 2008-A-836-. August 25 – 29, Vienna, Austria.

Blake, G.R. 1965. Bulk Density in Methods of Soil Analysis, *Agronomy*, 9, Part 11, C.A. Black, ed. pp. 374-390.

Francia Martınez, J.R., Durán Zuazo, V.H. & Martínez Raya, A. 2006. Environmental impact from mountainous olive orchards under different soil management systems (SE Spain). *Science of the Total Environment,* 358: 46–60.

Franco, J. & Calatrava, J. 2006. Adoption of soil erosion control practices in southern Spain olive groves. In: *Internat. Association of Agricultural Economists Conference*. Gold Coast. pp. 1–16.

Gomez, J.A., Giráldez, J.V. & Fereres, E. 2005. Water erosion in olive orchards in ´ Andalusia (Southern Spain): a review. *Geophysical research Abstracts*, 7: 08406.

Marques, M.J. & Bienes, R., Cuadrado, R., Ruiz-Colmenero, M., Barbero-Sierra, C. & Velasco, A. 2015. Analysing Perceptions Attitudes and Responses of Winegrowers about Sustainable Land Management in Central Spain. 2015. *Land Degradation & Development*, 26(5): 458–467.

Richards, L.A. 1941. A pressure-membrana extraction apparatus for soil solution. *Soil Science*, 51:377–386.

Robledo, I., Marqués Pérez, M.J., Hernandez, Z., Carral, C., Crittenden, S., Sastre, B. & Bienes, R. 2017. The use of soil gypsum concentration as an indicator of arable land degradation. Geophysical Research Abstracts. Vol.19, EGU2017-5025. April 2017. Vienna. Austria.

Sastre, B., Barbero-Sierra, C., Bienes, R., Marques, M.J. & García-Díaz, A. 2017. Soil loss in an olive grove in Central Spain under cover crops and tillage treatments, and farmer perceptions. *Journal of Soils and Sediments*, 17(3): 873-888.

Sastre, B., Marques, M.J., García-Díaz, A. & Bienes, R. 2018. Three years of management with cover crops protecting sloping olive groves soils, carbón and wáter effects on gypsiferous soil. *Catena,* 171: 115-124.

Schulte, E.E & Hopkins, B.G. 1996. Estimation of organic matter by weight loss-on-ignition. In Magdoff, F. R. *et al.* (eds.) *Soil Organic Matter: Analysis and Interpretation*. SSSA Spec. Pub. No. 46. SSSA, Madison. pp.21–31.

Gelagay, H.S. & Minale, A.S. 2016. Soil loss estimation using GIS and remote sensing techniques: A case of Koga watershed, northwestern Ethiopia. *International Soil and Water Conservation Research,* 4(2): 126-136.

Kusimi, J.M., Yiran, G.A.B. & Attua, E.M. 2015. Soil Erosion and Sediment Yield Modelling in the Pra River Basin of Ghana using the Revised Universal Soil Loss Equation (RUSLE). *Ghana Journal of Geography,* 7(2): 38–57.

Oduro-Afriyie, K. 1996. Rainfall erosivity map for Ghana. *Geoderma,* 74: 161-166.

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P. & Alewell, C. 2014. Soil erodibility in Europe: A high-resolution dataset based on LUCAS. *Sci. Total Environ.*, 479–480(1) : 189–200. https://doi.org/10.1016/j.scitotenv.2014.02.010.

Panagos, P., Borrelli, P. & Meusburger, K. 2015. A New European Slope Length and Steepness Factor (LS-Factor) for Modeling Soil Erosion by Water. *Geosciences*, 5(2): 117–126. https://doi.org/10.3390/geosciences5020117.

Renard, K.G., Foster, G.R., Weessies, G.A. & McCool, D.K. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE).

Yoder DC, editor. U.S. Department of Agriculture, Agriculture Handbook 703.

Van Remortel, R., Hamilton, M. & Hickey, R. 2001. Estimating the LS factor for RUSLE through iterative slope length processing of digital elevation data. *Cartography*, v. 30, no. 1, pp. 27-35.

Wischmeier, W. H. & Smith, D.D. 1978. Predicting rainfall erosion losses-A guide to conservation planning. Predicting rainfall erosion losses-A guide to conservation planning.

Preliminary progress on global soil erosion assessment

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Abstract

Currently many scientists and agencies are working to perform global soil erosion assessments at various scales. Here we would like to introduce the preliminary progress of the Project (Global Soil Erosion Assessment) implemented by a joint group of scientists from China and Europe. In the past 2 years the project was mainly concentrated on the driving factors of global soil erosion. We selected the newest available datasets and suitable methods to calculate and extract the soil erosion factors. In order to get better data of soil conservation practices and more realistic soil erosion assessment, the sampling survey based on high resolution Remote Sensing images and field checking was conducted. Integrated the data (natural factors and practices of soil conservation), water erosion rate is calculated at each sampling unit based on the Chinese Soil Loss Equation (CSLE). This method has been tested in the Pan Third Pole area and the results are satisfying suitable for erosion assessment at regional scale.

Keywords: Global soil erosion assessment, Erosion factors, sampling survey, high resolution, water erosion

Introduction

Soil erosion is one of the global key environmental problems, which leads to serious land degradation and threat to sustainability of agriculture. Many scientists and agencies are working to perform soil erosion assessments at various scales. Panagos and his team (2015) made a new assessment of soil erosion by water in Europe. In China the national soil erosion survey was organized and the new inventory was produced. In a later study Borrelli *et al.* (2017a) investigated global soil erosion dynamics by means of high-resolution spatially distributed modelling (ca. 250 × 250 m cell size). As a result the technology of regional soil erosion assessment has been improved. Based on these achievements World Association of Soil and Water Conservation (WASWAC) initiated a research project on global soil erosion assessment under the support from Chinese Academy of Sciences. In 2018 the project was developed as an international cooperation project between China (ISWC) and

Europe (JRC). The objectives of the project are to make a global soil erosion inventory and develop suitable method for global soil erosion assessment. Here we would like to share the preliminary progress of the project and make a contribution to GSOEMap.

Methodology

Extraction and calculation of natural soil erosion driving factors

We selected the newest available datasets and selected (or developed) suitable methods to calculate and extract the regional erosion factors such as rainfall erosivity (R), soil erodibility (K), the slope length and steepness factor (LS), and FVC (land-use and cover, partially C) at the global scale. R was calculated based on daily rainfall product from Climate Prediction Center (CPC) with resolution of 0.5° from 1986 to 2016. In order to improve the accuracy, the datasets for global R is calculated based on sub-hourly and hourly pluviographic records interpolated spatially interpolation using advanced techniques. K has been calculated based on RUSLE2 algorithm and 250m Soil-Grids. The land use and cover have been analyzed using agricultural inventory data, conservation agriculture statistics, remote sensing data and a probabilistic land use allocation approach. The LS has been calculated mainly from 1 arc second (ca. 30m at the equator) SRTM and Aster GDEM. As DEM resolution can influence LS accuracy, a down scaling model is to be used to downscale LS to 10 m, taking various sources of relative high resolution DEMs at sampled typical areas for compared data source.

Extraction of soil conservation practices information

It is a very big challenge for us to get the spatial data of practices of soil conservation. But it is very important for assessment of actual soil erosion. In order to cope with this demand we used the method of CSLE in which the soil conservation practices are defined as BET. B stands for biological measures, E stands for engineering measures and T stands for tillage measures. We selected the sampling units (small watersheds or rectangular box) based on high resolution images in research areas. Then the soil conservation practices were extracted from image interpretation and the field checking,

CSLE sampling survey method

In order to get better data of soil and water conservation practices and more realistic soil erosion assessment, the sampling survey based on high resolution Remote Sensing images (such as Google Earth images) and field checking was conducted. Integrated the data (natural factors and practices), water erosion rate is calculated at each sampling unit (Liu *et al.*, 2015; Yin *et al.*, 2018; Zhu *et al*, 2019). The result provides a good base for the regional soil erosion assessment. Using this method the quantitative assessment of actual soil erosion status can be realized.

Results

Global soil erosion driving factors extraction

At the first period, R was calculated based on daily rain fall product from Climate Prediction Center (CPC) with resolution of 0.5° from 1986 to 2016. The annual average R value (Rcpc) and the ratio of R per half month were calculated after removing the non-erosive rainfall (< 10 mm). R value was also calculated from the daily rainfall data of 2 358 meteorological stations provided by China Meteorological Administration (Rchn). Later, the dataset for R is calculated based on sub-hourly and hourly pluviographic records interpolated spatially interpolation using advanced techniques. For global K, a transformation relationship between soil structure types and soil structure class (s in USLE algorithm) was established using Ped-transfer function (PTF; Tempel, 1996) method based on soil profile data (Batjes, 2000) and profile description information of the world soil map (FAO, 1974). And then global K was calculated based on SoilGrids 250 dataset and has been checked with observed the reports in literatures. LS is to be derived from 1arc SRTM elevation data (about 30 m) globally. LS is to be derived from 1arc SRTM elevation data globally with LS algorithm in CSLE (Liu *et al.*, 1994). The result of the slope and slope length will be downscaled by histograms matching method (Yang *et al.*, 2008) to 10m resolution (5 m in some area).

Extraction of soil conservation practices

In order to get better data of soil conservation practices and more realistic soil erosion assessment, the sampling survey based on high resolution remote sensing images (such as Google Earth images) and field checking was conducted. The comparative analysis of land-use types and GLS30 data for Sampling Unit (SU) interpretation shows that the similarity of two set of data in most area is greater than 0.75, and the results of sample interpretation can represent the macroscopic structure of land-use. The results of the interpretation were checked in the field by in typical sections in southern Tibet and northern Thailand. The results showed that the average of kappa coefficient and accuracy in Tibet was 0.7 and 80.04 %, and the northern Thailand was 0.5 and 85.78 %, respectively. All problems have been systematically corrected after the field work, so the accuracy of final data has been improved.

The application of CSLE Sampling survey for water erosion rate calculation

Integrated the regional factors and practices data, water erosion rate for each SU has been calculated using CSLE, the results show that the calculated results (a map of soil loss rate) can reflect the spatial heterogeneity of soil erosion. There is a significant difference between potential soil loss (RKLSB) and actual soil loss rate (RKLSBET). This method is using in the Pan Third Pole area and the typical surveying examples showed that the quantitative assessment of actual soil erosion status can be realized.

Discussion

1. The available databases in the world can meet the requirements to calculate and extract natural driving factors of global soil erosion assessment. It is necessary to develop a special division map of soil erosion which can show the regional differences of physical climate, geography and geomorphology.

2. There are many available digital data to be used for slope gradient and slope length (LS) extraction and calculation. As detected by our research, we suggest a downscaling processing in LS calculation based on lower resolution DEMs and sampled higher resolution DEMs, which will improve the accuracy of LS where the higher resolution DEMs are not available.

3. Practices of soil conservation are very important to assess the actual soil erosion. Now we have obtained dataset in about 20 000 sampled units in the Pan Third Pole area using Google Earth images. The results showed soil conservation practices can be extracted. But it is necessary to have more local field observation data.

4. Integrated the data (natural factors and practices of soil conservation), water erosion rate is calculated at each sampling unit based on the Chinese Soil Loss Equation (CSLE). This method has been tested in the Pan Third Pole area and showed that the results are satisfying suitable for erosion assessment at regional scale.

Conclusions

There are available databases for extraction of global soil erosion driving factors. It is predicted that the recommended data and methods for global soil erosion assessment will be proposed from our project. Integrated the data (natural factors and practices of soil conservation), water erosion intensity is calculated at each sampling unit based on the CSLE. The results showed it is satisfying suitable for erosion assessment at regional scale. But it is necessary to have more local data and need more field testing in different geographical regions.

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References

Batjes, N. H. (ed.). 2000. Global Soil Profile Data (ISRIC-WISE). [Global Soil Profile Data (International Soil Reference and Information Centre - World Inventory of Soil Emission Potentials)]. Data set. Available on-line [http://www.daac.ornl.gov] from ORNL Distributed Active Archive Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A. doi:10.3334/ORNLDAAC/547.

Borrelli, P., Robinson, D. A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K.,V., Montanarella, L. & Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion-Supplementary Information. *Nature Communications*, 8(1): 1-131.

FAO. 1974. FAO-UNESCO soil map of the world, 1:5000000 vol. I. legend, Rome, Italy.

Liu, B.Y., Guo, S. Y., Li, Z.G, Xie, Y., Zhang, K.L. & Liu, X.C. 2013. Sampling survey of soil erosion by water in China. *China water and soil conservation*, (10): 26-34.

Liu, B., Nearing, M.A. & Risse, L.M. 1994. Slope gradient effects on soil loss for steep slopes. *Transactions of the ASAE*, 37(6): 1835-1840.

McCool, D., Brown, L., Foster, G., Mutchler, C., & Meyer, L. 1987. Revised slope steepness factor for the Universal Soil Loss Equation. *Transactions of the ASAE*, 30(5): 1387-1396.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & Alewell, C. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental science & policy*, 54: 438-447.

Yang, Q. K., David, J., Li, R. & Liang, W. 2008. Re-scaling lower resolution slope by histogram matching. *Advances in Digital Terrain Analysis*, Q. Zhou, B.G. Lees & G.A. Tang. New York, USA, Springer: 193-210.

Tempel, P., Batjes, N.H. & van Engelen, V.W.P. 1996. IGBP-DIS soil data set for pedotransfer function development. Wageningen.

Yin, S.Q., Zhu, Z.Y., Wang, L., Liu, B.Y., Xie, Y., Wang, G.N. & Li, Y.S. 2018. Regional soil erosion assessment based on a sample survey and geostatistics. *Hydrology and Earth System Sciences*, 22(3): 1695-1712.

Zhu, Y., Yang, Q. K., Wang C. ***et al***, Interpretation of Land use and Soil Conservation Measures in the Pan -Third Pole Area using stratified sampling of High Resolution Remotely Sensed Images. *Journal of Soil and Water Conservation*, 2019 (under review, in Chinese).

Soil erosion in Russia: state, dynamics, and forecast

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Abstract

The state of land erosion in Russia is described. It is shown that the modern period is characterized by decrease in the overall rates and volumes of erosion, especially in boreal areas, due to the abandonment of arable land due as a result of the economic downturn of 1990-2000. At present, concerning the forecast scenarios of climate change, the growth of water and wind erosion is expected, especially in the southern part of the agricultural area of Russia. The forecast of soil erosion associated with changes in spring snowmelt linked with the climate change remains still an unclear component.

Keywords: Russian Federation, soil erosion, water erosion, wind erosion, climate change

Introduction, scope and main objectives

Soil erosion is the most common problem of land degradation in Russia, covering not only agricultural, but also pasture and forest lands. Unfortunately, despite the developed network of soil surveys in Soviet times, in modern Russia the intensity of surveys in the vast territory of the country is weak, although the modern technologies based on the remote sensing and GIS is under certain development. In this work, the main task was to collect information from various sources, reliably reflecting the current state of land erosion in Russia at the national level, and then to set tasks for future research on this basis.

Methodology

The research methodology consisted in collecting and summarizing disparate data from state official statistics, scientific research carried out at different scales, and various materials of cartographic and mathematical modeling.

Results (distribution of soil erosion processes in the Russian Federation)

Soil erosion is the most common process of land degradation in Russia. Sheet, rill and gully erosion during snowmelt (March-April) and rainstorm (May-September) seasons are the main factors for soil degradation of agricultural lands. In the southern regions wind erosion is important additional factor of soil degradation.

According to the state monitoring of agricultural land (State report, 2016, 2017; EMISS, 2018) the total area of eroded, deflated and lands potentially prone to deflation and water erosion is over 50 %, with some tendency to increase in the past few years (Figure 1). The processes of erosion especially affect the recently highly fertile black soil (Chernozems), which constitute more than 40 % of the total arable land of the country. For example, in the central part of Russia, 34 % of arable land and 51 % of pasture area are dangerous in terms of potential water erosion, and 18 % and 15 %, respectively, in terms of potential wind erosion. In the southern regions, two thirds of the total agricultural land area are risky for deflation, where actual wind erosion is manifested in 11.3 % of the agricultural land area. The highest soil erosion (up to 75 % of the total land area) occurs in the Volga region, mountains and foothills of the Caucasus, the Urals and Altai. In the boreal regions of Siberia, the Far East, and the north of the European territory of Russia, a high water and wind erosion hazard and risk persists where the natural balance of forest ecosystems is disturbed, for example, during forestry, fire, oil and transport infrastructural development.

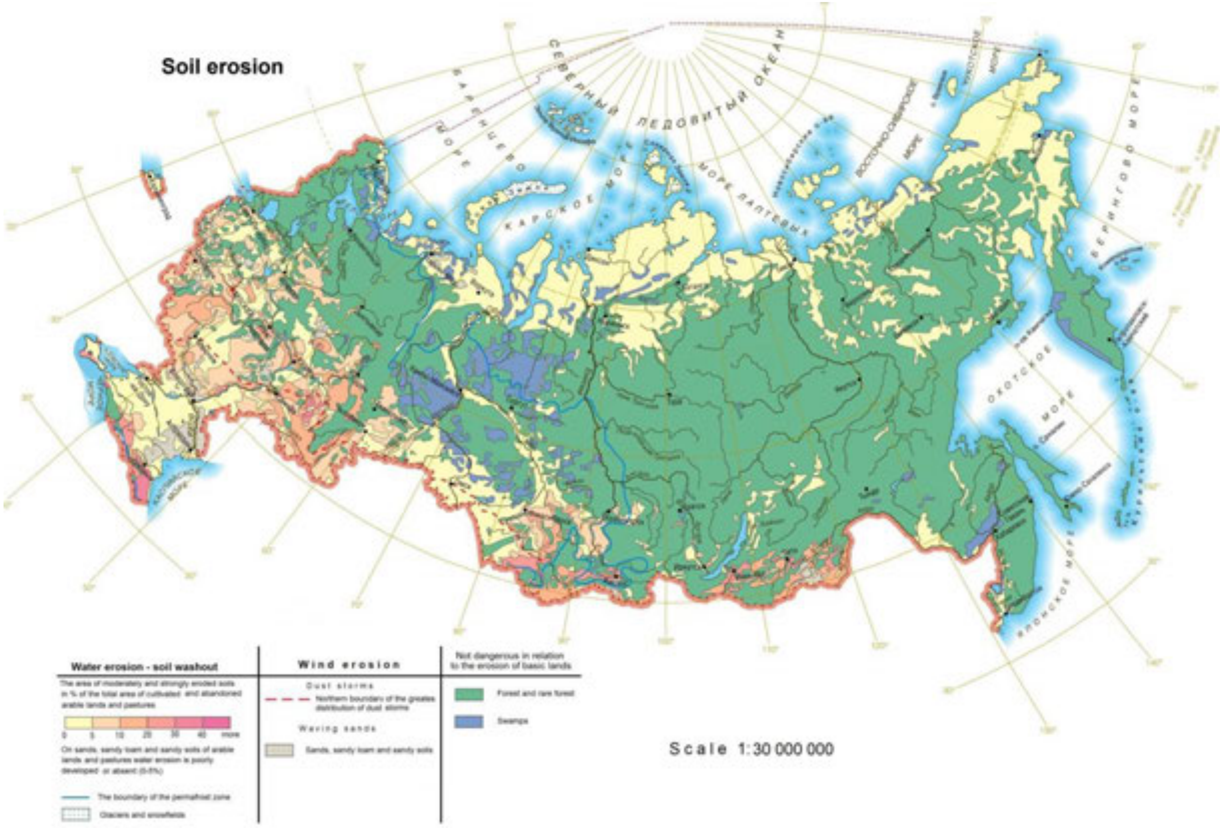

Figure 1: Soil erosion map of the Russian Federation (M. Kuznetzov and A. Kashtanov, in National Soil Atlas (2011))

The annual ***water erosion*** from the cultivated land is evaluated as 0.56 billion tons. The flow of water and sediments from the slopes in the agricultural zone supplies up to 80-90 % of phosphorus, nitrogen and pesticides to rivers and water bodies. According to expert estimates soil fertility decreased by 30-60 % only due to water erosion of arable land. From 80 to 90 % of ravines in the agricultural zone of Russia have the anthropogenic origin due to improper cultivation of arable lands. Here there are more than 2 million of individual ravines, with a total length of about 300 thousand km and an area of about 6 million hectares. The rate of gullying in the past run up to 10-15 thousand hectares per year.

The largest area of strongly eroded lands is in the Siberian Federal District (FD), medium eroded - in the South FD, weakly eroded - in the Privolzhsky FD. Among the total area of the land prone to water erosion, weakly eroded soils occupy 87 %, medium- and strongly eroded occupy 13 %. The strongest development of gully erosion (quantity of ravines is more than 5/km^2, length density is more than 1.3

km/km^2) is observed in forest-steppe and steppe zones, in areas of long-term and old agricultural development. These include deeply dissected and intersected parts of the uplands (south of Central Russian Elevation, separate parts of the Volga Elevation and Kalachskaya Elevation), composed of silty loess-like sediments.

Among those agricultural lands prone to wind erosion, 76 % are characterized by a low degree, and 24 % by moderate and strong deflation. Significant areas (about 50 % of the total) of agricultural lands having certain risk of wind erosion are located in southern Siberia, although the southern European territory of Russia and the North Caucasus are characterized by the strongest deflation (Figure 1). Here, in open plain areas, the intensity of deflation reaches 50-100 tons/ha per year or even more, in some areas not protected by forest belts, a decrease in soil thickness during last 30-40 years can reach 30-35 cm. On sandy and sandy loam soils in the south of Western Siberia in some spots the deflation also may be higher than 50 tons/ha per year, however, due to the widespread use of flat-cut tillage, the common development of deflation is unlikely here.

Due to erosion, the area of regions prone to desertification is constantly expanding (Kust *et al.*, 2011). General information on the spread of land erosion in the Russian southern belt is given in Table 1.

Table 1: Area of soil erosion as the cause of desertification in the arid belt of Russia (Kulik *et al.*, 2007), thousand hectares

	Water erosion	Wind erosion	Joint manifestations of water and wind erosion
European part	13 493.2	4 146.6	351.5
Asian part	3 290.7	7 303.2	533.4
Total	16 783.9	11 449.8	884.9

Various models are used to predict the dynamics of soil erosion in Russia. The main difference between the Russian approaches from the well-known universal models of rain erosion USLE (Universal Soil Loss Equation) and WEPP (Water Erosion Prediction Project) is that they are adapted for Russian soil forming and climatic conditions, among them the most important are those correctly taking into account the results of soil flushing out during the snowmelt period (Demidov, 2016), and different land use scenarios during crop rotations (Sukhanovsky, 2013). Verification of complex models that describe not only water erosion, but also soil formation and transformation of organic matter on Typical Chernozems shows that the erosion rate over the past 200 years has been much higher than the rate of soil formation (Sukhanovsky *et al.*, 2011).

Discussion (peculiarities in changes of erosion processes over the past 30 years and climate change forecasting)

In concern with climate change, the forecast of the development of erosion processes in Russia is of particular interest. At the same time, despite the possibility of using various models, the solution of this problem is complicated by significant socio-economic reasons that have drastically changed the general trend of erosion development in the last 30-40 years.

Considerable land use transformation began in late 80-s as a result of economic crisis. In the forest area with a relatively small proportion (< 20 %) of arable land most of them were abandoned as a result of their low productivity, and in the dry steppe zone with a high proportion of cropland (40-80 % of the total area) the lack of resources to support irrigation systems was the main reason for the reduction of cultivated area. The modelling of the total annual soil losses in the territory of the Russian Plain (Golosov *et al.*, 2018) showed that it reduced from 436 Mt in 1960-1980 to 245 Mt in 1991-2012, mainly due to the decrease in cropland area. The highest reduction was identified for the forest zone, where soil losses reduced by 75 % and the mean annual erosion rate decreased from 7.3 to 4.1 ton/ha yr, although some experts consider that these data are overestimated by 5-15 %. The increasing frequency of heavy rain-storms in the southern part of steppe zone, on the contrary, led to the negligible intensification of soil erosion rate.

The density of active gully decreased considerably during last decade. On the Russian Plain the trend of reduction of gully head retreat is confirmed by the results of long-term monitoring in the south of the forest zone (Medvedeva *et al.*, 2018). The main reason for this is likely the decrease in soil freezing depths, which results in a significant reduction in surface runoff during snowmelt.

Conclusions

The studies of climate change scenarios indicate that rainfall intensities in Russia may increase in the region, while it remains unclear how a further warming of air temperatures can affect snowmelt-related runoff. It is more likely that sheet, rill and gully erosion rates will increase mostly in the agricultural area of the Russian Plain in whatever climate change trends. The gradual restoration of arable land areas in the steppe and notably in forest-steppe zone during last years are additional important factor of possible increase of soil loss and land degradation in nearest future.

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References

Demidov, V.V. 2016. *Patterns of formation of erosion processes during snowmelt in the forest-steppe zone of central Russia: Theory and experimental studies.* Center for the Development of Scientific Cooperation. Novosibirsk, 62 p. [in Russian]

EMISS. Unified interdepartmental information and statistical system. 2018. Available at https://www.fedstat.ru [assessed 04 Mar 2019].

Golosov, V., Yermolaev, O., Litvin, L., Chizhikova, N., Kiryukhina, Z. & Safina, G. 2018. Influence of climate and land use changes on recent trends of soil erosion rates within the Russian Plain. *Land Degradation and Development*, 29(8): 2658– 2667.https://doi.org/10.1002/ldr.3061

Kulik, K.N., Gabunshchina, E.B., Kruzhilin, I.P., Kust, G.S., Manaenkov, A.S., Pavlovsky, E.S., Petrov, V.I., Savostyanov, V.K. & Tulokhonov, A. 2007. *Desertification and complex amelioration of dryland agrolandscapes.* Volgograd. VNIALMI., 86 p. [in Russian]

Kust, G., Andreeva, O. & Dobrynin, D. 2011. Desertification assessment and mapping in Russian Federation. *Arid Ecosystems,* 1(1): 14–28.

Kuznetzov, M. & Kashtanov, A. Soil Erosion. National Soil Atlas. 2011. Available at https://soilatlas.ru/rasprostranenie-erozii-pochv [assessed 04 Mar 2019].

Medvedeva, R.A., Golosov, V.N. & Ermolaev O.P. 2018. Spatio-temporal assessment of gully erosion in the zone of intensive agriculture in the European part of Russia. *Geography and Natural Resources*, 39(3): 204–211.

State report "On the state and environmental protection of the Russian Federation in 2016". 2017. Moscow. 760 p. [in Russian].

State report on the state and use of land in the Russian Federation in 2015. 2016. Moscow. 207 p. [in Russian].

Sukhanovskii, Yu. P. 2013. Probabilistic Approach to the Calculation of Soil Erosion Loss. *Eurasian Soil Science*, 46(4): 431- 437.

Sukhanovskii, Yu. P., Prushchik, A.V., Solov'eva, Yu.A. & Sanzharova, S.I. 2015. Evaluation of trends of erodible chernozems of arable lands in the Central Black Earth Region. *Zemledelie*, 6: 19-22 [in Russian].

A Survey of Soil Erosion in China of 2011

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Abstract

Three national soil erosion surveys had been performed in China since 1980s, which only considered three factors of land use, vegetation cover, and slope degree. To quantitatively access soil erosion and effect of soil conservation, Chinese Soil Loss Equation (CSLE) and stratified unequal probability systematic area sampling method were used for the fourth survey in 2010. Data covering the continental China were collected, including daily rainfall of 1981-2010 from 2 678 stations, soil features and maps, TM & MODIS images and Land use maps. Total 32 364 sample units of 1 km × 1 km grid or watershed of 0.2-3 km^2 were determined and investigated on site for soil conservation practices. After calculating soil loss for each unit in 10 m x 10 m grids, soil erosion ratio, area with soil loss larger than soil tolerance to unit area, was derived, interpolated, and summarized for province and national scales. Water erosion area was 1.29 million km^2, 13.65 % of the country continent. Soil erosion in the Loess Plateau has been effectively controlled, but severe soil erosion was found in the northeast black soil region due to long slope and heavy conventional tillage, Tibet plateau due to overgrazing, southwest region due to steep slope farmland, and Hainan island due to slope orchard plantation.

Keywords: National soil erosion survey, CSLE, sample units, soil loss, soil erosion ratio, spatial interpolation

Introduction, scope and main objectives

Periodical regional survey provides soil erosion current status and changes for soil conservation plan and effect assessment. Three national soil erosion surveys had been performed in China since 1980s, which only three erosion influencing factors of land use, vegetation cover, and slope degree were considered without conservation practices (Guo and Li, 2009). Similar soil erosion risk assessments were carried out in Pan-Europe (Grimm *et al.,* 2001) and Australia (Lu *et al.,* 2001) without considering measures for soil erosion control. Consecutive soil erosion surveys as parts of the National Resources Inventory (NRI) were conducted in the USA every five years from 1977 and every year from 2000 (Schnepf and Flanagan, 2016). Both primary sample units (PSUs) and points were determined using stratified two-stage unequal probability area sample method. Soil loss was estimated by USLE (Wischmeier and Smith, 1978) only for slope farmland where points fallen, and both state and national soil erosion were estimated by point weighted area of land use within each PSU (Nusser and Goebel, 1997). The point weighted method is difficult to provide spatial distribution of soil erosion. The objective of this study is to develop a watershed sampling method and applying soil erosion model to assess national soil erosion to satisfy the conservation practice need.

Methodology

Stratified Unequal Probability Systematic Area Sampling

Four strata of county level, township level, sample control level, and primary sample unit (PSU) level were designed for selecting sample units (Figure 1). One sample of 1 km × 1 km in each control area of 5 km × 5 km, 4 % (one of 25 grids) was the basic density. The actual density was 1-0.025 % by each county of total about 2600 counties in China due to survey resources and time limited, and no samples in glacier, snow cover, and desert. Center latitude and longitude of each control area for choosing topographic maps in scale of 1:10 000, and 1 km × 1 km grid or small watershed area of 0.2-3 km^2 connected with the central grid of the map was determined as sampling units for field survey (Head office of the State Council, 2010).

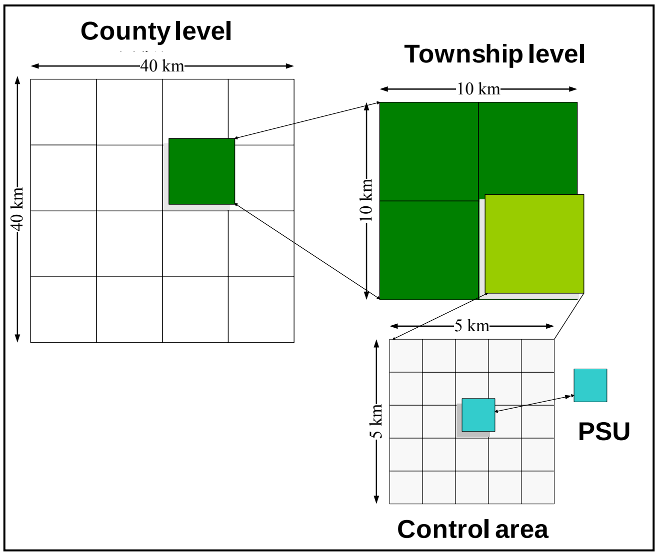

Figure 1: Four strata for sampling (Head office of the State Council, 2010)

Data Gathering

Two groups of data were gathered. One was basic data on rainfall, soil, and vegetation covering the whole continental China, and the other was field investigated data on soil conservation practices for the total sample units. Basic data included daily rainfall of 1981-2010 from 2 678 stations, soil series map and related features of more than 7 000 soil profiles, TM NDVI and MODIS NDVI images and land use/cover map for estimating fraction of vegetation cover (FVC) of twenty-four half-months through one year in spatial resolution of 30 m × 30 m. While MODIS NDVI was used for the time resolution of 24 half-months, and TM NDIV was used for spatial resolution of 30 m × 30 m. Total 33 000 sample units were visited on site to collect data on distributions of soil conservation practices by accomplishing a survey map and a form for each unit. Information on land use/cover and conservation practices of plots, continuous area with the same land use/cover, conservation measures, and similar vegetation cover fraction (difference <=10%), was filled in the form, and boundaries of plots were drawn in the map identified by the plot codes both in the map and in the form.

Calculations of soil loss for each sample unit and interpolation by each province

Chinese Soil Loss Equation (CSLE) was used to estimate soil loss for each sampling unit in grid of 10 m × 10 m under the ArcMap software of Geographical Information System (GIS). The equation is $A=R{\cdot}K{\cdot}L{\cdot}S{\cdot}B{\cdot}E{\cdot}T$ (Liu *et al.,* 2002), where *A* is soil loss in t/ha, *R* is rainfall erosivity in $MJ{\cdot}mm{\cdot}ha^{-1}{\cdot}h^{-1}{\cdot}yr^{-}$

^{1}, K is soil erodibility in $t·h·MJ^{-1}·mm^{-1}$, and other five were dimensionless factors of slop length L, slope steepness S, vegetation cover and biological practice B, engineering practice E, and tillage T. Different from factors of C (coverage and management) and P (conservation practices) in the USLE (Wischmeier and Smith, 1978), B factor only refers to tress, brushes, and grasses, and T only refers to farmland for tillage practices such as contour, no till, or residue managements, and E only refers to the machinery conservation measures such as terraces.

After calculations of R and K factor grid values with 30 m × 30 m interpolated by kriging method, and FVC grid values with 30 m × 30 m by using images covering the whole nation, each sample unit was overlaid with these grid maps to obtain values of *R, K*, and *FVC* within sample unit, and then was resampled as 10 m × 10 m girds. Factors of *L, S, B, E*, and *T* were developed by DEM, investigated map and form within each sample unit. *A* value was calculated and soil erosion area larger than soil tolerance was determined for each grid within sample units, and soil erosion ratio, soil erosion area to unit area was obtained for each unit. Soil erosion ratio of total 33 000 sample units were interpolated using kriging method for each province to make erosion maps and statistics for both province and national scales.

Results

China is divided into three zones with eastern monsoon climate, northwestern dry climate, and Tibet plateau highland climate. Rainfall erosivity varied from the southeastern coast larger than 10 000 $MJ·mm·ha^{-1}·h^{-1}·yr^{-1}$ to the northwestern inland less than 100 $MJ·mm·ha^{-1}·h^{-1}·yr^{-1}$. In eastern China, areas where R was larger than 6000 $MJ·mm·ha^{-1}·h^{-1}·yr^{-1}$ were in the south, and 1000-6000 $MJ·mm·ha^{-1}·h^{-1}·yr^{-1}$ were in the north of Chang Jiang River. Rainfall erosivity in both northwest and Tibet plateau varied 50-1000 $MJ·mm·ha^{-1}·h^{-1}·yr^{-1}$. Resulted from monsoon and continental climate, rainfall erosivity had high percentage of annual values during warm season from May to September, varying 20-30%. Soil erodibiliy decreased from the north to the south due to clay components decreased, varied from 0.007 to 0.035 $t·h·MJ^{-1}·mm^{-1}$ mainly. B values in most hilly regions covered by forest varied 0-0.01, 0.05-0.1 for inland grass regions. Thirty-eight crop rotation groups were classified, and their T values were determined and varied 0.147-0.669 (Guo *et al.*, 2015).

Total water erosion area was around 1 293 200 km^2, 13.65 % of surveyed region. From province scale, there were seven provinces having the soil erosion area percentage larger than 25 % to total province land, which distributed in hilly regions mostly.

Discussion

There were some new findings different from surveys before. Soil erosion in the Loess plateau have been effectively controlled which showed great impacts of Grain for Green Project. However, severe soil erosion was found in the northeast black soil region resulted from long slope and heavy conventional tillage, in the Qinghai-Tibet plateau resulted from overgrazing pasture, and in the Hainan island resulted from slope orchard and rubber plantations. These were ignored before. In addition, Southwest region still had serious soil erosion due to steep slope farmland.

Conservation measures were obtained from this survey, especially terraces for rice, farmland, orchard, trees and grassland (Figure 2), which never had information on spatial distributions before. Terraces mainly distributed in the south area for rice and farmland such as provinces of Chongqing, Guizhou, Yunnan, Sichuan, Hunan, Hubei, Jiangxi and Anhui, and in the Loess Plateau for farmland such provinces of Gansu, Shanxi, Shannxi and Ningxia.

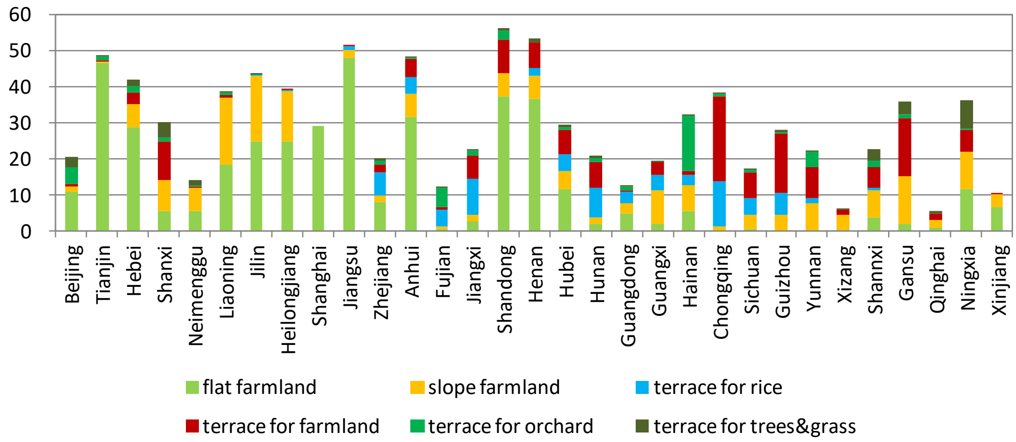

Figure 2: percent of flat and slope farmland, and terrace land for farmland, orchard, and trees and grassland to total province land area (%)

Conclusions

A stratified unequal probability systematic area sampling method was developed, combining with Chinese Soil Loss Equation (CSLE), to obtain soil erosion current status for the fourth survey in 2010. After collecting rainfall, soil, and vegetation data, and gathering conservation information of total 32 364 sample units on site, soil erosion ratio was derived for each unit and interpolated for province and national scales. Water erosion area was 1 293 200 km^2, 13.65 % of surveyed area of continental China. Soil erosion in the Loess Plateau has been effectively controlled, but severe soil erosion was found in the northeast black soil region due to long slope and heavy conventional tillage, Tibet plateau due to overgrazing, southwest region due to steep slope farmland, and Hainan island due to slope orchard plantation. Terrace distributions were obtained, which mainly distributed in the south area for rice and farmland, and in the Loess Plateau for farmland.

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References

Grimm, M., Jones, R.J.A. & Montanarella, L. 2001. Soil Erosion Risk in Europe. Office for Official Publications of the European Communities, Luxembourg. *EUR 19939 EN*. Available at: https://esdac.jrc.ec.europa.eu/resource-type/scientific-technical-reports

Guo, Q., Liu, B., Xie, Y., Liu, Y. & Yin, S. 2015. Estimation of USLE crop and management factor values for crop rotation systems in China. *Journal of Integrative Agriculture*, 14(9): 1877-1888.

Guo, S. & Li, Z. 2009. Development and achievements of soil and water conservation monitoring in China. *Science of Soil and Water Conservation*, 7(5): 19-24.

Head office of the State Council for the first national water conservancy. 2010. *Technical handbook No.6 for soil conservation survey*. Beijing: China Water & Power Press, 206-214 pp.

Liu, B., Zhang, K. & Xie, Y. 2002. An empirical soil loss equation. In: *Proceedings-Process of soil erosion and its environment effect.* 12th international soil conservation organization conference. Beijing: Tsinghua University Press, pp. 21-25.

Lu, H., Gallant, J., Prosser, I.P., Moran, C. & Priestley, G. 2001. Prediction of sheet and rill erosion over the Australian continent, incorporating monthly soil loss distribution. *CSIRO Land and Water Technical Report 13/01*. Available at: http://www.clw.csiro.au/publications/technical2001/tr13-01.

Nusser, S.M. & Goebel, J.J. 1997. The national resources inventory: a long-term multi-resource monitoring programme. *Environmental and Ecological Statistics,* 4(3): 181-204.

Schnepf, M. & Flanagan, P. 2016. A History of Natural Resource Inventories Conducted by the USDA's Soil Conservation Service and Natural Resources Conservation Service. *A Special Report by the Soil and Water Conservation Society*. Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1212208.pdf.

Wischmeier, W.H. & Smith, D.D. 1978. Predicting rainfall erosion losses: A guide to conservation planning. Washington, D.C: U.S. Dep. Agric., *Agric. Handbook No.537.*

National Assessment of Soil Erosion in Canada from 1971 to 2016

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Abstract

Management of soil erosion is essential to maintain the sustainability of Canada's agricultural lands, and for it to be a competitive global supplier of agriculture and food products. The Soil Erosion Risk Indicator was developed and used to assess the state and trend of the risk of soil erosion by water, wind and tillage on the Canadian agricultural landscape. Soil loss due to the combined effects of wind, water and tillage erosion decreased in most provinces between 1981 and 2011. Over that period, the proportion of cropland in the *Very Low* risk class increased from 36 % to 74 %, with most of this change occurring between 1991 and 2006. The improvement in soil erosion risk reflects the reduction in the risk of wind and tillage erosion (decrease of 11 % and 22 %, respectively, compared to 1 % for water erosion). Much of this improvement is attributable to the shift to reduced tillage and no-till practices. 10 % of cropland remains in the *Moderate* to *Very High* risk classes. Soil conservation and restoration efforts are needed to further reduce the current rates of soil erosion and to rebuild the productivity on land that still suffers from past soil erosion.

Keywords: Soil erosion, Wind erosion, Water erosion, Tillage erosion, Integrated soil erosion modelling, National-scale assessment

Introduction

Soil erosion poses a significant threat to the sustainability of agriculture in Canada and around the world. Since the process of erosion impacts the organic-rich, topmost layer of soil, it typically results in decreased soil fertility and inefficient use of cropping inputs, as well as productivity and profitability losses due to reduced crop yields and quality. In extreme cases, severe degradation can result in land being permanently lost to agriculture. The transport and deposition of nutrients, pesticides, pathogens and toxins attached to soil particles also contributes to water and air quality degradation.

There are three main forms of soil erosion: wind erosion, water erosion and tillage erosion. The combined effects of wind, water and tillage erosion pose a more serious threat than each of these forms of erosion on its own. Prudent management of wind, water and tillage erosion is critically important and very complex because the practices used to control one type of erosion may exacerbate another type, and because the level of erosion risk is affected by multiple variables, including cropping systems, climate and topography. Identifying the landscapes and factors that present the greatest risk is an important step in targeting and developing localized management approaches where they are most needed, in order to maintain soil health and reduce environmental degradation and economic losses. To this end, the Government of Canada through Agriculture and Agri-Food Canada initiated the agri-environmental indicators (AEI) program in 1993 as part of the Organisation for Economic Cooperation and Development AEI program. The national assessment of soil erosion is a key component of these AEI programs, with the most recent assessment in Canada extending from 2016 back to 1971. An overview of the methodology and the major findings of this assessment are presented.

Methodology

The Soil Erosion Risk Indicator (SoilERI) model was developed and used to assess the risk of soil erosion due to the combined effects of wind, water and tillage erosion on cultivated agricultural lands. This indicator and its component indicators for wind, water and tillage erosion reflect the characteristics of the climate, soil and topography and respond to changes in farming practices over the 45-year period from 1971 to 2016.

Soil erosion was calculated at the Soil Landscapes of Canada (SLC) polygon scale (1:1 000 000) using landform data and the associated topographic data in the National Soil Database. Each SLC polygon is characterized by one or more representative landforms, and each landform is characterized by hillslope segments (upper, middle and lower slopes and depressions). Each hillslope segment is characterized by a slope gradient and a slope length.

Land use and management data was acquired from the Census of Agriculture (every five years from 1971 to 2016). Soil erosion was calculated on cropland using census data for cropping and tillage practices. This data was reconFigured from census reporting areas to SLC polygons by Statistics Canada. The distribution of landforms, soils, crops and tillage systems within SLC polygons was determined using spatial allocation models trained using expert knowledge and validated using surveys and remote sensed imagery.

The risk of soil erosion by wind, water and tillage was calculated as the amount of soil loss for all segments of a given landform. However, the highest rates of soil loss due to wind and tillage erosion are recorded on upper slopes, whereas the highest rates due to water erosion are on mid-slopes. The SoilERI was assessed as the cumulative soil loss rate for the slope segment with the greatest rate of loss, because the slope segment with the highest rate of loss largely determines changes in management. For analysis and reporting purposes, the erosion rates were summed across areas to the SLC polygon, provincial, regional and national levels.

The Water Erosion Risk Indicator (WatERI) was estimated using a model developed to combine features of the Universal Soil Loss Equation (USLE) and the Revised USLE (RUSLE2). This model accounts for rainfall/runoff, crop type and area, landform, and soil erodibility. The Wind Erosion Risk Indicator (WindERI) was estimated using a modified version of the Wind Erosion Equation. The model incorporates soil factors related to soil texture and landform, a vegetation factor based on crop residue levels, and wind speed and rainfall after seeding, when residue levels are lowest and wind speeds are high. The Tillage Erosion Risk Indicator (TillERI) was calculated as the product of tillage erosivity and landscape erodibility. Erosivity values are assigned based on the characteristics of the tillage operations carried out within the various agro-ecosystems across Canada, and based on experimental data. Landscape erodibility values are calculated for each landform as a function of slope length and gradient characteristics. These models were validated separately and in combination using fallout radionuclides (FRNs, ^{137}Cs) on eight field-scale sites across Canada.

The erosion indicator calculation estimates the annual rate of soil loss in tonnes per hectare. These values are reported in five classes: *Very Low* (<6 t ha^{-1} yr^{-1}); *Low* (6 to 11 t ha^{-1} yr^{-1}); *Moderate* (11 to 22 t ha^{-1} yr^{-1}); *High* (22 to 33 t ha^{-1} yr^{-1}); and *Very High* (>33 t ha^{-1} yr^{-1}). Areas in the *Very Low* risk class are considered capable of sustaining long-term crop production and maintaining agri-environmental health under current conditions. The other four classes represent increasingly unsustainable conditions that call for soil conservation practices to support crop production over the long term and to reduce risk to soil quality. Areas in the *Moderate* to *Very High* risk classes typically experience substantial losses in soil organic carbon and crop production. This assessment is limited to annual rates of soil erosion; it does not provide information on cumulative rates of soil loss or cumulative impacts on soil and crop productivity and the environment.

Results and Discussion

In 2011, 74 % of cropland area was in the *Very Low* risk class. This is a considerable improvement over 1981, when only 36 % was in this risk class. The total combined cropland area in all other risk classes decreased by 60 % during this time period, falling to 26 % in 2011. The integrated erosion risk indicator results are less positive than the results from the individual component indicators for water, wind and tillage erosion (see Figures 1 and 2, and Table 1), but better reflect the actual risk of soil degradation by erosion.

The risk of soil erosion on Canadian cropland steadily declined between 1981 and 2011. Most of the decrease in risk occurred between 1991 and 2006. The improvement in soil erosion risk reflects the reduction in wind and tillage erosion risk (decrease of 11 % and 22 %, respectively, compared to 1 % for water erosion).

The decrease in all forms of erosion across Canada is largely attributable to the widespread adoption of conservation tillage, particularly no-till systems. No-till is now the most common tillage practice used for cereal crops in the Prairies, the largest agricultural region in the country. Changes in the share and mix of crops grown were less of a contributing factor. Crops such as corn, potatoes and beans that are typically produced using more intensive tillage (making them more erosive) increased their share of cropland area from 5 % in 1981 to 11 % in 2011. Southern Ontario has the largest amount of area in the higher erosion risk classes due to its high proportion of these types of row crops. However, improvements in conservation tillage techniques (permitting a minimum amount of tillage) have reduced tillage intensity. Therefore, although the share of cropland planted to such crops has risen since 1981, the average tillage intensity associated with the crops has decreased, with the result that no notable increase in risk has been recorded in this region.

The decline in overall erosion risk is also attributable to a decrease in summerfallow use on the Prairies, from 24 % in 1981 to 6 % in 2011, and to an increase in high-residue crops requiring very little tillage (e.g. alfalfa and hay), from 14 % in 1981 to 18 % in 2011. Although most crops have seen a reduction in tillage intensity, the adoption of no-till in cereals has had the greatest influence in terms of reducing soil erosion risk owing to the large share of cropland devoted to cereals on the Prairies.

Among the cropping systems found across Canada, the highest risk of soil erosion is associated with potato production in the Atlantic Maritimes, which requires intensive tillage and is not conducive to the adoption of conservation tillage practices. The cropping system that presents the next highest risk of erosion is corn and soybean produced with conventional tillage. However, in this case there is considerable potential to reduce the erosion risk through conservation tillage. On landscapes across Canada, the highest risk of soil erosion is associated with slopes of 10 % or more, especially in Eastern Canada, where there is an inherently high risk of water erosion owing to the climatic conditions. Soil erosion is of particular concern in situations where cropping systems involving a high erosion risk are paired with soil landscapes with high erosion risks. This is the case for a significant proportion of the cropland in southern Ontario and in Atlantic Canada. However, there are areas in every province that present risks of unsustainable soil erosion.

Conclusions

- The annual rates of soil erosion by wind, water and tillage, and their combination, have declined over that past 45 years in response to the decline in use of intensive tillage practices. However, considerable amount of cropland remain at moderate to very high rates of soil erosion.
- Tillage erosion is a major cause for moderate to high rates of soil erosion, and should be the focus of soil conservation efforts. Conservation tillage must focus on the amount of soil movement during tillage as well as the amount of crop residue left on the soil surface.
- An integrated approach to managing all forms of soil erosion is necessary to minimize soil loss and restore eroded soils. However, this can be challenging. Some soil conservation practices will reduce one form of erosion while exacerbating another form. In particular, tillage practices that are effective in reducing wind and water erosion are not necessarily effective against tillage erosion; the chisel plough leaves more crop residues on the soil surface than the moldboard plough, providing more protection against wind and water. At the same time, the chisel plough can move soil over a much greater distance and cause more tillage erosion.
- The assessment of soil erosion must consider both the annual rates and cumulative total of soil loss. It is necessary to know the historical impact of soil erosion to target effective management practices to sustain or enhance soil and crop productivity and profitability.

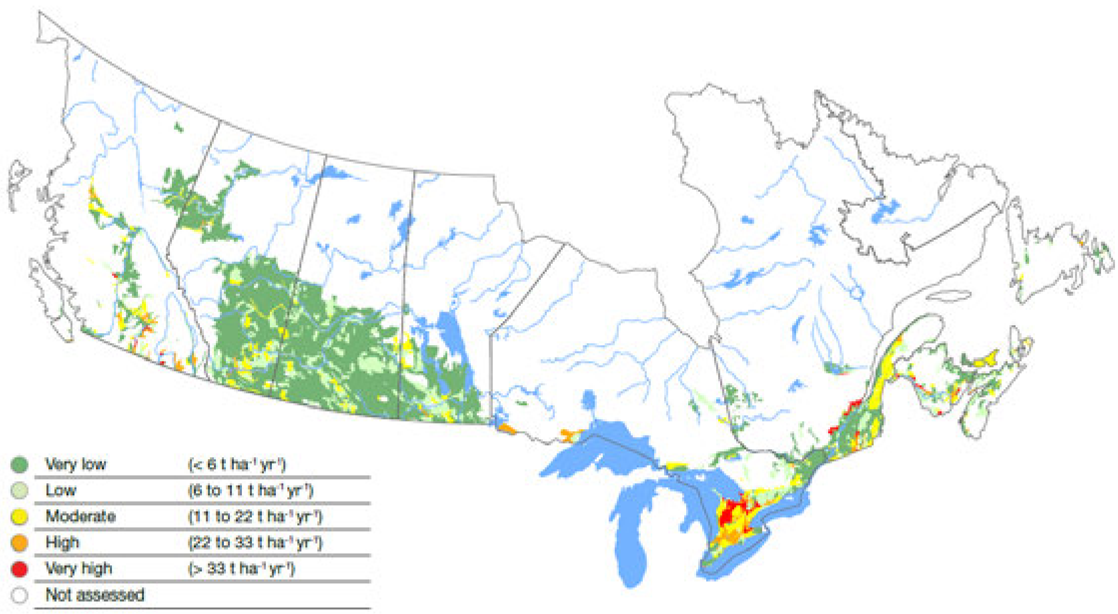

Figure 1: Integrated risk of soil erosion (water, wind and tillage erosion combined) in Canada, 2011.

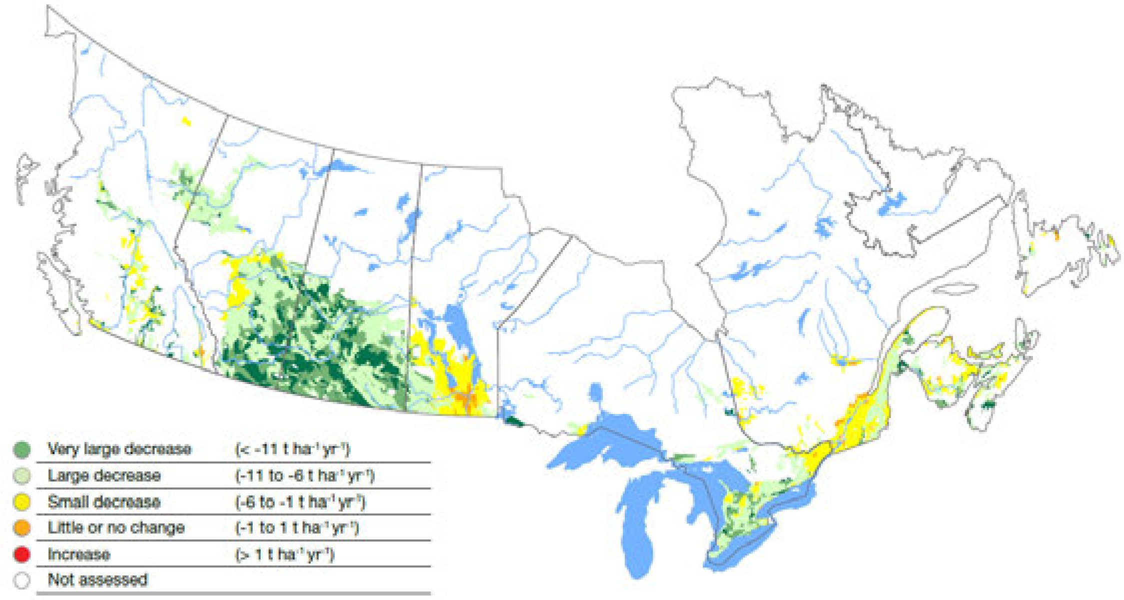

Figure 2: Change in integrated risk of soil erosion in Canada, 1981 to 2011.

Table 1: Percentage of cropland in soil erosion risk classes in Canada between 1981 and 2011

Soil Erosion Risk	Wind Erosion							Water Erosion							Tillage Erosion							Soil Erosion						
	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011	1981	1986	1991	1996	2001	2006	2011
Very Low (<6 t $ha^{-1} yr^{-1}$)	85	85	88	92	94	96	97	90	91	91	91	91	92	92	67	67	68	70	76	80	89	36	38	41	51	58	65	74
Low (6 to 11 t $ha^{-1} yr^{-1}$)	11	11	9	6	5	3	3	3	3	3	3	3	3	3	13	13	12	11	14	15	9	28	27	28	21	18	22	16
Moderate (11 to 22 t $ha^{-1} yr^{-1}$)	3	3	2	2	1	1	1	3	3	2	3	3	3	3	15	15	15	16	10	4	2	23	24	22	21	17	10	7
High (22 to 33 t $ha^{-1} yr^{-1}$)	0	0	0	0	0	0	0	2	2	2	2	2	1	1	5	5	5	3	1	1	0	8	6	6	6	3	4	2
Very High (>33 t $ha^{-1} yr^{-1}$)	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	6	5	4	2	2	1	1

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

References

Lobb, D.A, McConkey, B.G. & Li, S. 2016. Soil Erosion. *In:* Clearwater, R.L., T. Martin, T. Hoppe (eds) Environmental sustainability of Canadian agriculture: Agri-environmental indicator report series – Report #4. Agriculture and Agri-Food Canada. Ottawa, Canada. pp. 77-89.

National study of soil degradation by erosion in Colombia

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Abstract

Soil erosion is the most important degradation process in Colombia and drives negatives consequences in topics as climate change, deforestation, poverty, food security, social safety and violence, life quality. It increases natural risks to landslides, floods and droughts, among others. A soil erosion study in Colombia was carried out in order to identify and assess its causes, pressures, state, impacts and responses obtaining a baseline for monitoring soil degradation by erosion. The methodology involves zoning, characterization, analysis and evaluation of soil erosion processes. LANDSAT images (2010-2011) were interpreted using a methodology proposed by IDEAM and U.D.C.A. with field verification, analysis of the official national coverage information and laboratory analysis of soil samples. Results indicate that 40% of Colombia presents some degree of degradation by erosion; from which 20 % of the land presents slight erosion, 17 % moderate erosion, 3 % severe erosion and 0.2 % very severe erosion. For the first time, the country elaborates the baseline for the monitoring and monitoring of soil degradation by erosion at a scale of 1: 100 000, which includes the map, analysis and assessment of causes, driving forces, state, impacts and actions that are taken to prevent and mitigate this problem.

Keywords: Soil erosion, erosion map, soil degradation

Introduction, scope and main objectives

Colombia, aware of the importance of soil resources, has recently formulated the National Policy for Sustainable Soil Management (MADS, 2015), which establishes, within other actions, the monitoring and assessment of soil quality. This policy aims to develop mechanisms and actions to mitigate and avoid the effects of soil degradation.

To comply with this policy, the Institute of Hydrology, Meteorology and Environmental Studies -IDEAM, together with the University of Applied and Environmental Sciences -UDCA have developed the first national study of soil degradation by erosion in Colombia, obtaining a baseline of soil degradation by erosion and the identification of causes and consequences as a reference for the land management plans carried out by regional and local environmental authorities.

This study provides valuable information about soil degradation due to erosion in Colombia, which also triggers other environmental and social problems. The results are important for decision-makers who deal with the Sustainable Soil Management at diverse temporal and spatial scales and to contribute with the Colombian compromises and goals with the United Nations Framework Convention on Climate Change, UN Convention on Biological Diversity, RAMSAR and UN Convention to Combat Desertification and Global Soil Partnership among others.

Methodology

The general methodology is based on the model proposed by the LADA project (FAO, 2007) that considers the evaluation of the driving forces, pressures, state, impacts and responses of the biophysical and socioeconomic factors that are involved in the degradation of soils by erosion at national, regional and local tiers. This model includes the phases of zoning, characterization, analysis and evaluation.

In the zoning phase, soil degradation by erosion is identified, qualified and classified for water and wind erosion, using parameters of type (water or wind erosion), degree (slight, moderate or severe) and class or erosion form. This phase involved a remote sensing interpretation for which LANDSAT images from 2010 to 2011 were digitally analysed with adjustment and verification from field, obtaining a map of the state of soil erosion process at 1:100 000 scale. A standardized classification system of erosion grade, class and type was defined in order to analyse all the regions of the country within the same criteria, that allows to compare all different bio-geographical regions of Colombia.

In the characterization phase, the indicators of the ecological, economical, socio-cultural, and political components were selected. The social and institutional actors regarding soil and land management were involved through workshops and surveys in order to obtain and adjust source data.

In the analysis phase, the causality relationships between the selected pressure indicators and the indicators of erosion status were evaluated. Likewise, the consequences of soil erosion and its relation to the impacts for each component were evaluated.

The evaluation was based on establishing the relationships between the indicators and the selected components, obtaining a relationship between actors and causative actions such as the effects caused by soil erosion. Table 1 shows some pressure factors by component, evaluated.

Table 1: Some factors related with soil erosion

Component	Factor	Variable
Biophysical	Climate	Climate aggressiveness
	Soil	Soil erodability
	Land coverage	% Soil cover, and management practices
Economical	Land use	Historical and actual land use
Social	Inhabitants	Population increase rate
	Stakeholders	Land property and distribution, Gini index
Hazards and disasters		Burns, floods, mass movements
Political	Territorial ordering	Land management plans, protected areas

Results

The first and one of the maim results of the study corresponds to the map of the current state of soil degradation by erosion, which is shown in Figure 1. In the zoning phase, five categories were established to classify the degree of erosion: without erosion, light, moderate, severe and very severe. Light degree corresponds to the loss of less than 25 % of the "A" horizon. The moderate degree corresponds to the loss of up to 75 % of the "A" horizon. Severe erosion corresponds to loss of more 75 % of the "A" horizon and the very severe total loss of the "A" horizon and partial loss of the subsurface horizons.

According to this map, 40 % (45 379 058 ha) of Colombian soils present some degree of soil degradation due to erosion. 20 % of the country presents light erosion (22 821 889 ha), 17 % moderate (19 222 575 ha), 3 % severe (3 063 204 ha) and 0.2% very severe (271 390 ha).

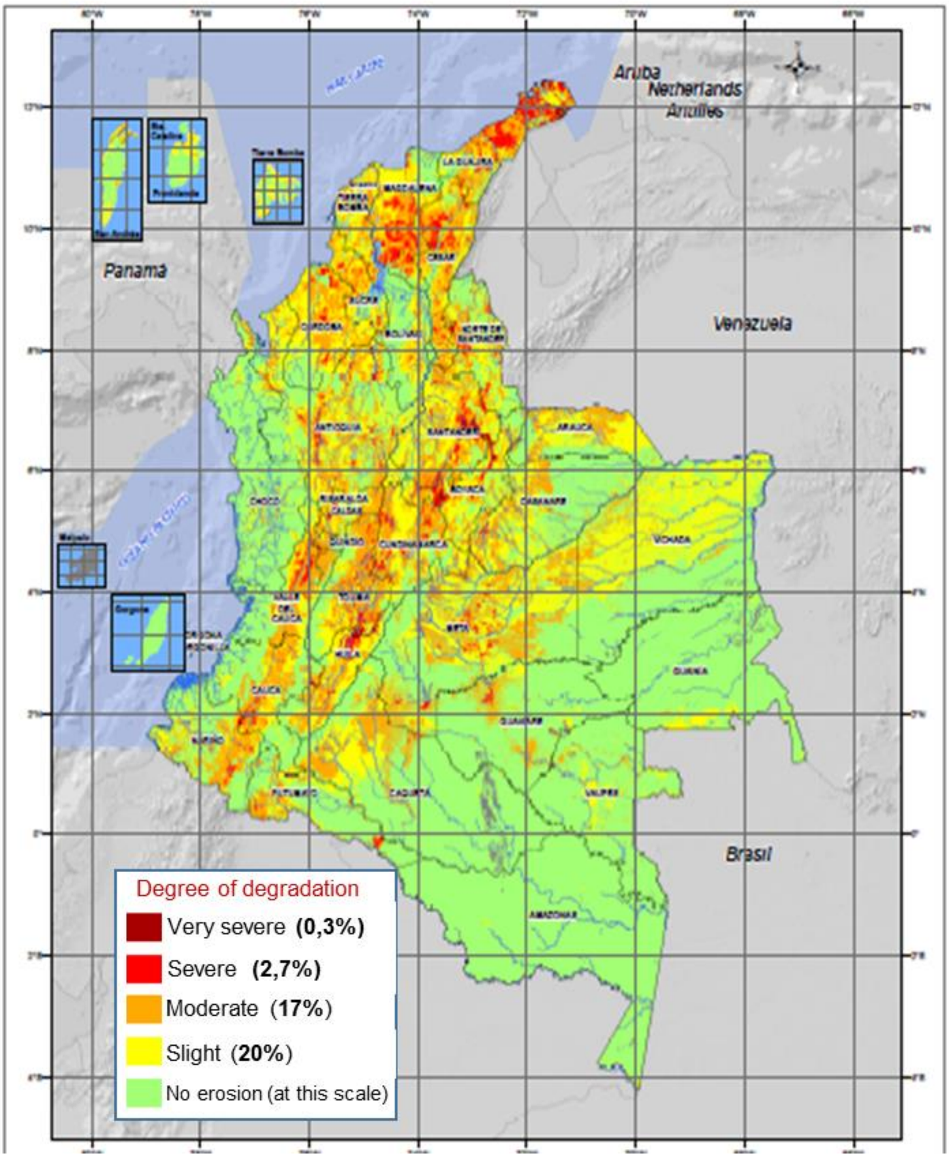

Figure 1: State of soil degradation by erosion in Colombia 2010 - 2011

The main direct causes of soil degradation within the erosion indicators are climate, land use and forest fire practices. New 34 erosion critical zones were identified mainly in the Andean and Caribbean regions, but also some of them in the Orinoquia and Amazonia regions. Most of the soils with degradation by erosion occur in dry lands of the country.

Regarding the land use, 29.8 % of the lands of Colombia has been used for livestock, from which 77.3 % of the soils are affected with degradation by erosion. 1.8 % of the country lands is exclusively in agriculture and soil erosion occurs in 93 % of those soils. 6.6 % of the country lands has mixed agricultural uses (agriculture and livestock), from which 88 % also show some degree of erosion. Likewise, the soils under irrigation districts present 94 % of the area affected by this process and, which indicates that the erosion is highly related to the unsustainable or inadequate practices of human activities or inappropriate uses. 60 % of the country's soils with agricultural vocation are affected by erosion, 4.6 % with erosion in severe degrees, which means that nearly one million hectares have been lost in soils with this vocation. In areas of environmental importance such as legal protected lands, 23.5 % of them have some degree of erosion and 23 % of the priority areas for conservation also show erosion. 5 % of Colombia's land corresponds to basins that supply reservoirs, of which 67.5 % are already affected by erosion.

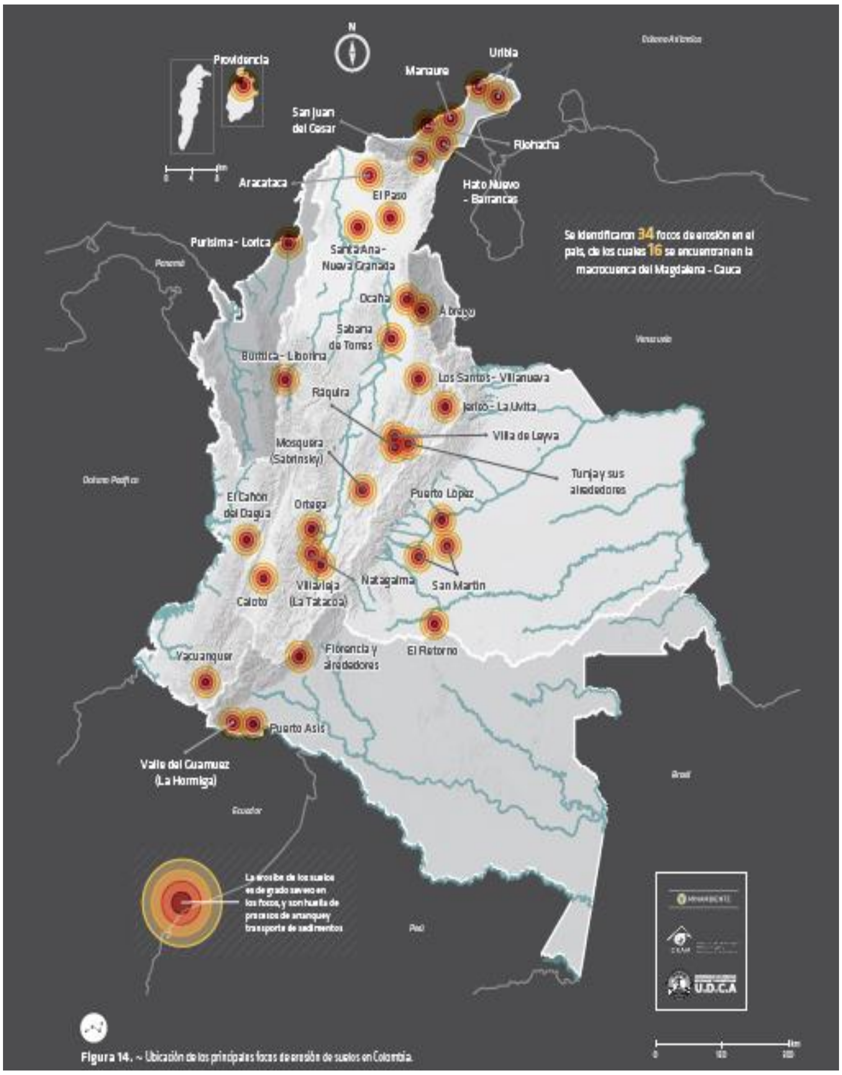

Figure 2: Critical zones with degradation by erosion processes in Colombia

Discussion

Soils with the highest degree of erosion (severe and higher) are only 3.2 % of the country land, meanwhile soils with moderate erosion covers 17 % of the country and the concern is that moderate erosion can easily become severe if inadequate practices or misuses continue, which will trigger alarming environmental and social problems which can occur in very short time.

Most of the erosion occurs in dry climates, where precipitation is scarce or poorly distributed, therefore soils have less coverage and protection which makes them more vulnerable to soil erosion due to extreme conditions such as the intensity of rainfall and runoff.

The presence of 34 new soil erosion zones in the five natural macro-regions of the country (Andean, Caribbean, Pacific, Orinoco and Amazonas) infers in the affectation to the hydrogeological cycle, threatening water quality and availability for current and future generations.

According to the IGAC (2015), only 19 % of the Colombian territory has agricultural vocation and 60.4 % of these soils present erosion, while the soils with agroforestry aptitude are only 3.6 % of the country of which 57.2 % is already eroded, which indicates a low potential for productivity and food security.

Livestock occupies almost a third of the lands of Colombia, covering almost 30 % of the area, with a serious impact, considering that close to 80 % of the area with livestock is currently eroded, a Figure that can alarmingly increase because only 13 % of the country lands have aptitude for livestock. This means that if use for livestock continues, erosion will increase considerably in those soils.

Priority conservation zones have a considerable percentage of erosion, which is critical in terms of decrease of ecosystem functions and services. In other words, erosion is a process that is not only affecting productive areas but also those destined for conservation.

Conclusions

Although the situation of Colombia is delicate in the state of erosion in terms of affected area and degrees of erosion, we have the information identified using the protocol in order to take corrective measures.

Not only the areas where this process is presented have been identified, but also their causes and impacts on the social, economic, ecological and socio-cultural components that allow a real knowledge of the problem are known. The study is considered as a base line for regional and local environmental authorities to initiate appropriate land management plans, which should be applied in the different land-use instruments of departmental, municipal or watershed management tiers.

Acknowledgements

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References

FAO. 2007. *Proyecto Evaluación de la degradación de Tierras en Zonas Áridas LADA*. Manual de Evaluación Local de la degradación de Tierras Áridas. (LADA-L). Roma, Italy: Global Mechanism of the UNCCD, UNEP and WOCAT.

IDEAM, MADS & U.D.C.A. 2015. *Estudio nacional de la degradación de suelos por erosión en Colombia* – 2015. IDEAM, Bogotá, Colombia. 188 pp.

IGAC. 2015. *Suelos y tierras de Colombia*. Imprenta Nacional de Colombia. Bogota, Colombia. Vol. 2.

MADS. 2016. Política para la gestión sostenible de los suelos - PGSS. Ministerio de Ambiente y Desarrollo Sostenible. Bogotá Colombia. 94 pp.

Assessment methods or tools in soil erosion control in the Pacific Island Countries and Territories

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Abstract

Erosion has a strong impact on terrestrial and coastal ecosystems of the Pacific Island Countries and Territories (PICTs) and is taking place in different forms due to the geophysical nature of the Islands. The mountainous islands were formed by volcanoes and have steepland areas. The atoll islands were formed by corals growing on extinct seamounts or volcanoes that have eroded or subsided and are only a few meters above sea level and are therefore vulnerable to sea-level rise and coastal erosion. The geophysical nature of the islands and different forms of erosion determines use of various erosion assessment methods ranging from simple reconnaissance methods such as visual observation and pin or rod; use of the Revised Universal Soil Loss Equation to runoff plots and use of Geographical Information System and Remote Sensing. The assessments confirmed erosion is happening and a serious threat to environment and sustainable development for most PICTs. Climate change which includes extended periods of drought and intense rainfall will exacerbate the problem in coming decades and beyond. This paper focuses on the different methods or tools employed to assess and control erosion under the changing climate in PICTs.

Keywords: Soil, erosion, Pacific islands, assessment, measurement methods

Introduction, scope and main objectives

Erosion has a strong impact on terrestrial and coastal ecosystems of the Pacific Island Countries and Territories (PICTs). The mountainous islands were formed by volcanoes and have steepland areas, elevated coral platforms and fringing coral reefs. Erosion is a problem in mountain and traditional cropping areas and alluvial plains from runoff and mud slips due to adverse effects of excessive rainfall or prolonged drought spells. Erosion is occurring at much higher rates in countries with uncontrolled land clearing and logging like Papua New Guinea and the Solomon Islands. Unsustainable rates of erosion are also likely to be occurring in marginal and hilly lands used for sugarcane in Fiji (Liedtke, 1989). The atoll islands are only a few meters above sea level and are therefore vulnerable to sea-level rise and coastal erosion (Wairiu, 2016).

A good understanding of the extent and impacts of erosion in PICTs requires data and information on different forms of erosion and appropriate methods for its assessment. Whilst erosion has not been extensively assessed across many PICTs, relevant studies have used simple reconnaissance methods such as visual observation and pin or rod (Tuivavalagi, 2019, pers. comm.), use of the Revised Universal Soil Loss Equation (RUSLE) for the mapping and quantification of the potential soil erosion (Dumas and Fossey, 2009); runoff plots (Liedtke, 1988; Howlett, 1995) and use of Geographical Information System (GIS) and Remote Sensing (RS) (Rouet *et al.*, 2009, Dumas, 2015). GIS and RS are powerful tools that could play a significant role in tackling land degradation and unsustainable land use. This paper describes and assesses the different methods employed to assess soil erosion in PICTs.

Methodology

The following methods of assessing erosion have been used by researchers across the PICTs:

1 Visual Assessment of Eroded Lands - This method has been used in Samoa (Tuivavalagi *et al.,* 2002). A perceptive erosion scale of 0-100 was agreed upon by the assessors. They then made an evaluation of degree of erosion based on their perception and in view of their 0-100 scale.

2 Visual Assessment of Turbidity - Turbidity of stream, river and ocean was assessed by in Samoa in the 80's to informally estimate the degree of soil loss after a rainfall event (N. Tuivavalagi, 2019, pers. comm.).

3 Exposed Roots - The degree of exposure of tree roots have been used in all Pacific islands as a measure of soil erosion on sloping lands, river banks and coastal areas. This method was tried out in the IBSRAM PacificLAND (Samoa) Project during the 1980s (N Tuivavalagi, 2019, pers. comm.) and has also been used by others (e.g., Carrara and Carroll, 1979).

4 Pin or Rod – This method was trialled in the IBSRAM Pacificland runoff plots across in Papua New Guinea, Vanuatu, Solomon Islands, Fiji and Samoa. A metal rod was driven to the ground and soil level was marked on the pin or rod, and rod mark is compared with ground surface over periods of time to monitor soil erosion or build up (Howlett, 1995).

5 Photography - Photos taken of the same place over different times can provide evidence of soil loss. It is a simple method taught to, and used by students in Pohnpei to assess erosion, as well as soil rejuvenation, over time (N Tuivavalagi, 2019, pers. comm.)

6 Rainfall simulators - A rainfall simulator would include water droplets falling from a shower-head box (possibly 1.2 m x 1.2 m) above a slanting box of soil to simulate rainwater falling on a sloping land. Garnier (1988) used this method to measure soil loss from different soil types under different management.

7 Runoff plots – Runoff plots method was used by IBSRAM Pacificland research network on high volcanic islands including Papua New Guinea, Solomon Islands, Vanuatu, Fiji and Samoa. Defined plots were established and runoff and soil loss from the plots were determined using automatic tipping budget or half-drums (44 gallon drum cut in half lengthwise) (Howlett, 1995).

8 Flume sampling from river or stream - The method was used in Samoa by Anand (2007) to investigate the effects of landuse type on the variability of selected soil properties and their relationship with rainwater-induced soil erosion. A concrete box (flume) was installed in the stream so all the water goes through the flume and measurements of water flow and sampling of stream water with eroded soil could be conveniently carried out in the flume.

9 Modelling using the Revised Universal Soil Loss Equation - Soil loss could be estimated and/or predicted by using the RUSLE. This was carried out in Fiji (Morrison, 1981), Guam (Scheman *et al.*, 2002), Efate Island in Vanuatu (Dumas and Fossey, 2009), and Tahiti Iti island in French Polynesia (Dumas, 2015).

10 Geographical Information System and Remote Sensing – In New Caledonia, a GIS and RS based mapping method to assess erosion across landscapes was developed involving the analysis of satellite images and topographical data (Rouet *et al.*, 2009).

11 Coastal Erosion - Multi-temporal aerial photographs and high resolution satellite images have been used to assess shoreline changes on Wotje Atoll in Marshall Islands (Ford, 2013).

Results

Using RUSLE, Dumas (2015) reported that the mean annual soil loss predicted by the model was 2.4 t/ha/yr. The results show that some 85 % of areas of interest on Tahiti Iti island in French Polynesia has a potential erosion rate of less than 5 t/ha/yr but an extended part of the area is undergoing severe erosion with a potential soil loss up to 50 t/ha/yr. Dumas and Fossey (2009) estimated the values of the potential erosion on the site on Efate Island in Vanuatu to be between 0 and 1 720 t/ha/year (between 0 and 163 mm/yr). The areas most affected by the erosion risk are primarily located around coastal regions including the plains and low hills.

The IBSRAM PacificLand soil management network set up runoff plots to quantify soil loss from sloping lands under the current farming practices in Fiji, PNG, Vanuatu, and Samoa in the 1990s. Results showed soil loss by erosion ranging from 0.2 t/ha (Tapatapao, Samoa) to 36.1 t/ha (Lakura, Vanuatu) (Howlett, 1995).

Rouet *et al.* (2009) using GIS and RS based mapping reported that preliminary results suggest that erosion assessment could become more efficient in the near future in New Caledonia. The mapping method is rapid and efficient and identifies erosion-linked areas in the most sensitive geological regions. In the Marshall Islands, Ford (2013) found shoreline variability between 1945 and 2010 but that overall accretion had been more prevalent than erosion on Wotje Atoll up until 2004. From 2004 to 2013, 17 out of 18 islands became net erosive, potentially corresponding to the high sea-levels in the region over the last decades. A previous study in the Marshall Islands showed that coastal erosion was widespread (Ford, 2012).

Discussion

Various erosion assessment methods have been used in the Pacific Islands region to determine the extent and severity of erosion. Different methods have advantages and disadvantages but they provide some indication of the rate and extent on soil erosion which is important for making informed decision on land use practices and management. Coastal erosion due to sea level rise is becoming an area of major concern for coastal communities and practical methods for assessing coastal erosion as well as projections for adaptations measures will be important considerations.

Conclusions

Research results confirm the seriousness of soil erosion on most PICTs; different assessment methods gave varying magnitude of soil erosion; and there is a need to develop simple, low cost but effective assessment methods.

Much has been achieved but more remains to be done and we look forward to the Pacific Soil Partnership taking a key role in the implementation of the required activities.

References

Anand, S. 2007. Effects of landuse type on the variability of selected soil properties and their relationship with rainwater-induced soil erosion of Alafua watershed in Samoa. MSc thesis, The University of the South Pacific, Alafua Campus, Samoa.

Carrara, P.E. & Carroll, T.R. 1979. The determination of erosion rates from exposed tree roots in the Piceance Basin, Colorado. *Earth Surface Processes*, 4: 307-317.

Dumas, P. 2015. Predicting Potential Soil Loss in Pacific Islands: Example in Tahiti Iti - French Polynesia. *Pacific Geographies*, (44): 4-10.

Dumas, P. & Fossey, M. 2009. Mapping Potential Soil Erosion in the Pacific Islands – A case study of Efate Island (Vanuatu). 11th Pacific Science Inter-Congress, « Pacific Countries and their ocean, facing local and global changes » 2-6 March 2009, 5 pp.

Ford, M. 2012. Shoreline changes on an urban atoll in the central Pacific Ocean: Majuro Atoll, Marshall Islands. *Journal of Coastal Research*, 28(1): 11-22.

Ford, M. 2013. Shoreline changes interpreted from multi-temporal aerial photographs and high resolution satellite images: Wotje Atoll, Marshall Islands. *Remote Sensing of Environment*, (135): 130-140.

Garnier, C. 1988. Residue effects on runoff and erosion under simulated rainfall from steeply sloping tropical soils. PhD thesis, University of Hawaii at Manoa, Department of Agronomy and Soil Science.

Howlett, D. 1996. The IBSRAM Pacificland network: Tackling land degradation in the South Pacific. P267-280. In: S. Rogers, and P. Thorpe (eds), Agroforestry research and practices in the Pacific. Project 1: Farming systems in the lowlands: PRAP Report no. 3, Suva, Fiji.

Liedtke, H. 1989. Soil erosion and soil removal in Fiji. Applied Geography and Development, 33: 68-92.

Morrison, R.J. 1981. Factors determining the extent of soil erosion in Fiji. Suva, University of the South Pacific. INR Environmental Studies Report n°7, 18 pp.

Rouet, I., Gay, D., Allenbach, M., Selmaoui, N., Ausseil, A.G., Mangeas, M., Maura, J., Dumas, P. & Lille, D. 2009. Tools for soil erosion mapping and hazard assessment: application to New Caledonia, SW Pacific. 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009

Scheman, N., Khosrowpanah, S., Golabi, M. & Heitz, L. 2002. Identification of erosion processes and sources of exposed patches in the La Sa Fua watershed of Southern Guam. Technical Report No. 99, University of Guam Water and Environmental Research Institute of the Western Pacific UOG Station, Mangilao, Guam 96923.

Tuivavalagi, N., Hunter, D. & Amosa, F. 2002. Tackling land degradation and unsustainable land use in Samoa – with emphasis on the agricultural sector. *Samoan Environment Forum*, (3): 40-49.

Assessment of water and wind erosion risk over the Eastern Africa region

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Abstract

We aim to assess the spatial patterns of water and wind erosion risk over the Eastern Africa region. We adopted spatially distributed Revised Universal Soil Loss Equation for water erosion assessment and validated against observed sediment yield data from 100 watersheds ($r^2 = 0.4$). A wind erosion index was developed by integration of factor layers using fuzzy logic technique and validated against frequency of dust occurrence predicted from SeaWiFS Level-3 daily data, with an overall accuracy of 70 %. Mean annual gross soil erosion by water amounts to 4 billion ton, of which about 50% is originating from Ethiopia. Nearly 10% of the Eastern Africa region is experiencing moderate and above water erosion risk (> 10 t ha^{-1} yr^{-1}). Among land cover types, nearly 50 % of the soil erosion is originating from the cropland, which accounts 15% the total area coverage. Nearly 25 % of the study area is under moderate and above wind erosion risk (equivalent to frequency of dust occurrence > 45 days yr^{-1}), of which Sudan and Somalia (bare/sparse vegetation cover) take the largest share (ca. 90 %). Nearly 8 million ha of the total area is experiencing moderate and above soil erosion both by water and wind.

Keywords: land degradation, water erosion, RUSLE model, wind erosion index, drought-prone

Introduction, scope and main objectives

Understanding land susceptibility to water and wind erosion is essential to design effective management strategies to control land degradation. Most previous studies in the Eastern Africa region have focused on assessing soil erosion by water at plot- to basin-scale; whereas wind erosion risk assessment has been overlooked mainly due to poor data availability. The geographical distribution and severity of soil erosion by water and wind in the region is therefore only very roughly known (e.g. Oldeman *et al.,* 1990). Lack of information at sufficient detail has been a challenge for national and regional planning towards reducing land degradation (Liniger *et al.,* 2011). This highlights the need to identify critical water and wind erosion-prone areas where remedial actions should be implemented. Therefore, the main objective of this study was to assess the spatial patterns of land susceptibility to separate and combined water-wind erosion risk over the Eastern Africa region based on best available data.

Methodology

Revised Universal Soil Loss Equation (RUSLE)-based models have been widely used in the scientific literature mainly due to their moderate data demand and ability to integrate with GIS database which facilitates the process of upscaling. In this study, a simplified application of the RUSLE model at 100 × 100 m resolution is proposed for the Eastern Africa region based on best available data. For this purpose, the approach paved by previous regional- to global-scale studies dealing with upscaling procedures (e.g. Borrelli *et al.,* 2017; Haregeweyn *et al.,* 2017; Panagos *et al.,* 2015) was followed. The main difference from previous studies that modeled soil erosion using RUSLE at regional/global-scale is the improved quality of input factor layers used in the present study. Moreover, we validated RUSLE-based erosion estimates against sediment yield observations from 100 watersheds as well as against plot-scale data from previous studies across the Eastern Africa region.

Wind erosion is a complex geomorphic process that integrates multiple factors which makes it difficult to comprehensively parameterize the factors for large scale studies. The most advanced field-scaled models are too complex to be adequately up-scaled for large scale assessment. Regional-scale wind erosion studies therefore resort to a complexity reduction approach (e.g. Borrelli *et al.* 2015, 2016), yet keeping the key factors that express the complex interactions between the wind erosion variables. We developed wind erosion index at 100 × 100 m grid cell by integrating factor layers (climatic erosivity, wind erodible fraction, soil crust, vegetation cover and surface roughness) using fuzzy logic technique. The wind erosion severity map was validated against frequency of dust occurrence derived from long-term SeaWiFS Level-3 daily aerosol optical depth (AOD) and angstrom exponent (AE) data. The frequency of dust occurrence was calculated as the number of days for which AOD > 0.25 and AE < 0.5, which satisfy the criteria to detect freshly emitted dust particles (Ginoux *et al.,* 2009).

Results and discussion

The spatial pattern of soil erosion by water is illustrated in Figure 1. Areas classified as having very slight, and slight water erosion rates, represent about 73 % and 17 % of the total area coverage, respectively. Areas experiencing soil erosion rates in excess of the generic tolerable soil erosion threshold (>10 t ha^{-1} yr^{-1}) constitute about 10% of the study region. The mean annual gross soil erosion by water is estimated to 4 billion ton, with mean soil erosion rate of 6.3 t ha^{-1} yr^{-1}, of which nearly 50 % is originating from Ethiopia. The highest mean soil erosion rate (at country level) is found in Rwanda (34.2 t ha^{-1} yr^{-1}), followed by Eritrea (23.2 t ha^{-1} yr^{-1}), Burundi (18.7 t ha^{-1} yr^{-1}) and Ethiopia (16.9 t ha^{-1} yr^{-1}). Very high estimates of soil erosion rates are often locally exacerbated by a combination of high rainfall erosivity (*R*-factor; Fenta *et al.*, 2017) and relatively steep slopes (LS-factor). Looking for soil erosion hot-spots higher than 20 t ha^{-1} yr^{-1}, the largest and most intensively eroded regions are predicted to be in Ethiopia (22 million ha; 19 % of the country), followed by Kenya (5 million ha; 9 % of the country) and Tanzania (4 million ha; 5 % of the country). Validation of RUSLE-based soil erosion estimates against sediment yield data from 100 watersheds of size ranging from less than 1 km^2 over 3×10^5 km^2 showed significant positive relation (Figure 2).

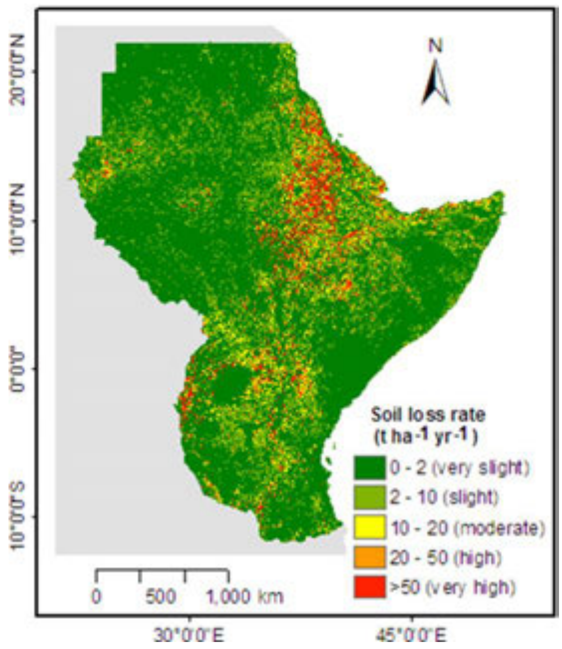

Figure 1: Map of soil erosion rates by water and corresponding erosion severity classes in the Eastern Africa region.

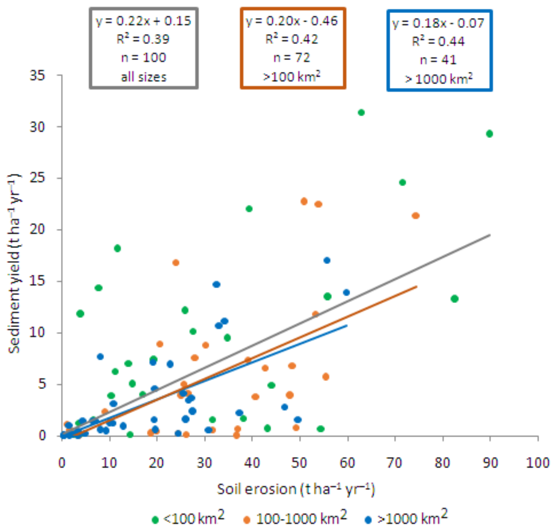

Figure 2: Soil erosion rate estimated using the RUSLE model versus sediment yield (source: Vanmaercke *et al.,* 2014).

Comparing soil erosion based on land cover types, we observed a remarkable decrease in the estimates of soil erosion rates from croplands to forest cover and other forms of natural vegetation (Figure 3). Cropland covers about 15 % of the study region, but is responsible for nearly 50 % of the total predicted soil erosion. The predicted average soil erosion in croplands (18.4 t ha^{-1} yr^{-1}) is about three times higher than the overall soil erosion rate (6.3 t ha^{-1} yr^{-1}). Despite the fact that forest covers more than 20 % of the study region, it has the lowest soil erosion estimate with about 0.25 t ha^{-1} yr^{-1}, thus being responsible only for ca. 1 % of the total soil erosion estimates.

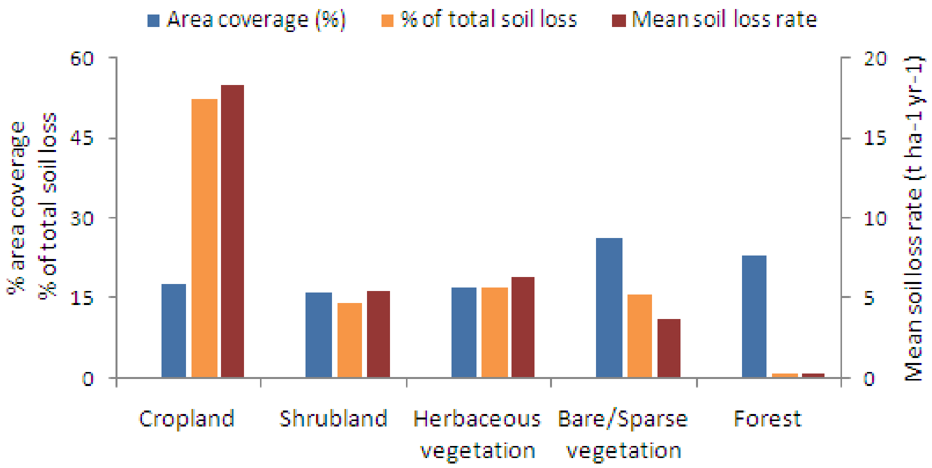

Figure 3: Area proportion (%) of major land cover types, mean soil erosion rates (t ha^{-1} yr^{-1}) per land cover type and corresponding shares (%) of each land cover type to the total soil erosion.

Figure 4 shows the wind erosion index outcomes whereby the modeling results were ranked into five classes using variance minimization classification scheme. Approximately 75 % of the Eastern Africa region showed low to very low susceptibility to wind erosion, whereas moderate susceptibility was reported for about 8 % of the area. The remaining 18 % of the study area showed high to very high susceptibility to wind erosion. About 90 % of areas with moderate and above wind erosion risk were found in Sudan and Somalia (bare/sparse vegetation cover type). Other highly susceptible regions are found along the coastal area s of Eritrea (Figure 4). Overlay analysis between the water and wind erosion risk maps revealed that nearly 8 million ha of the total area is experiencing moderate and above water and wind erosion equally. Regarding the accuracy of wind erosion index, comparison with frequency of dust occurrence (Figure 5) derived from long-term SeaWiFS Level-3 daily AOD and AE data showed 70 % overall accuracy.

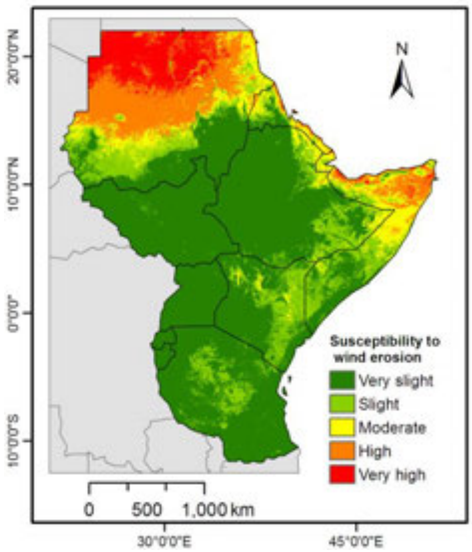

Figure 4: Land susceptibility to wind erosion predicted for the Eastern Africa region.

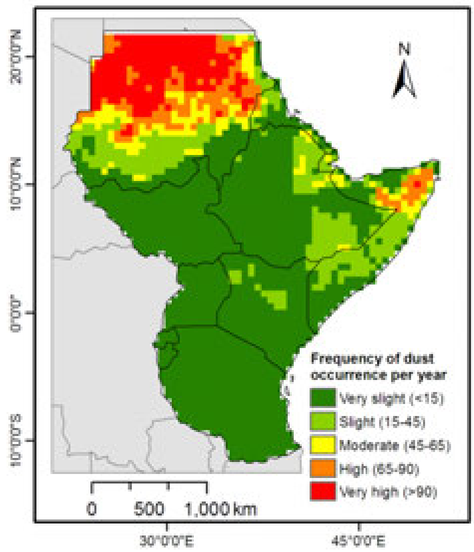

Figure 5: Mean annual frequency of dust occurrence derived from SeaWiFS data.

Conclusions

Lack of information about soil erosion risk by water and wind at sufficient detail has been a major obstacle for the Eastern African countries from taking actions aimed at an effective mitigation of the resulting land degradation. To close such information gap, we produced the first water and wind erosion risk maps at unprecedented high resolution (100 m × 100 m). The results of the current study constitute an important step towards a better understanding of the spatial patterns of water and wind erosion risk over the Eastern Africa region. These insights are essential to prioritize regions where further investigations are needed and where remedial actions should be implemented.

Acknowledgements

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References

Borrelli, P., Panagos, P., Ballabio, C., Lugato, E., Weynants, M. & Montanarella, L. 2016. Towards a pan-European assessment of land susceptibility to wind erosion. *Land Degradation and Development,* 27: 1093–1105.

Borrelli, P., Panagos, P. & Montanarella, L. 2015. New insights into the geography and modelling of wind erosion in the European agricultural land. Application of a spatially explicit indicator of land susceptibility to wind erosion. *Sustainability,* 7: 8823–8836.

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro., V. & Bagarello, V. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications,* DOI: 10.1038/s41467-017-02142-7.

Fenta, A.A., Yasuda, H., Shimizu, K., Haregeweyn, N., Kawai, T., Sultan, D., Ebabu, K. & Belay, A.S. 2017. Spatial distribution and temporal trends of rainfall and erosivity in the Eastern Africa region. *Hydrological Processes,* 31: 4555–4567.

Ginoux, P., Garbuzov, D. & Hsu, N.C. 2010. Identification of anthropogenic and natural dust sources using Moderate Resolution Imaging Spectroradiometer (MODIS) Deep Blue level 2 data. *Journal of Geophysical Research: Atmospheres*, *115*(D5).

Haregeweyn, N., Tsunekawa, A., Poesen, J., Tsubo, M., Meshesha, D.T., Fenta, A.A., Nyssen, J. & Adgo, E. 2017. Comprehensive assessment of soil erosion risk for better land use planning in river basins: Case study of the Upper Blue Nile River. *Science of the Total Environment,* 574: 95–108.

Liniger, H.P., Studer, R.M., Hauert, C. & Gurtner, M. 2011. Sustainable land management in practice–Guidelines and best practices for sub-Saharan Africa. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO). Available at: http://www.fao.org/3/a-i1861e.pdf [accessed 12.03.18].

Oldeman, L.R., Hakkeling, R.T.A. & Sombroek, W.G. 1990. World map of the status of human-induced soil degradation: an explanatory note. Available at: http://wedocs.unep.org/handle/20.500.11822/19660 [accessed 03.01.18].

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & Alewell, C. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science and Policy,* 54: 438–447.

Vanmaerckea, M., Poesen, J., Broeckx, J. & Nyssen, J. 2014. Sediment yield in Africa. *Earth Science Reviews,* 136: 350–368.

Spatio-temporal monitoring of soil erosion events

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Abstract

The monitoring of soil erosion events is crucial to adapt measures for farmers, support decision making and refining soil policies especially in the context of climate change. A precondition for an effective monitoring is the availability of a data base, which allows the calculation of indices representing the spatio-temporal dynamic of influencing factors like precipitation or soil coverage. On the example of a parcel in the Uckermark district situated in north-eastern Germany, we introduce a process chain, which aims at the localization of parcels characterized by a potentially high risk of soil erosion during sensitive crop growing periods. The algorithm couples phenological information with a satellite-based soil coverage indicator and a heavy rain event indicator. Since these data sets are country-wide available, any parcel in Germany can be in principle assessed regarding the historical and up-to-date situation. In doing so, known soil erosion events can be analyzed or parcels can be localized where soil erosion events occurred, occur or will occur very likely.

Keywords: soil erosion, monitoring, phenology, MODIS, SAVI, soil coverage, climate change

Introduction, scope and main objectives

Climate change can be considered as a main reason for the increase of extreme weather events (Field *et al.* 2012). It can be assumed that climate change leads to higher crop yield variability in some regions of Germany (Gömann *et al.,* 2015, Lüttger and Feike, 2018). The monitoring of extreme weather events is crucial to adapt measures for farmers, support decision making and refining soil policies.

Since soil erosion by water is an event-related phenomenon, an effective monitoring of soil erosion effects require the availability of indices representing the spatio-temporal dynamic of influencing factors like precipitation or soil coverage (Möller *et al.,* 2017). Since precipitation data and satellite indices as proxies for soil coverage are increasingly available in high temporal and geometric resolutions, solutions are needed for an efficient data coupling and analysis. In this study, we are introducing a geodata integration approach, which can be considered as a first step for an operational and automatic detection of parcels, which are affected by a high risk of soil erosion during sensitive crop growing periods.

Methodology

Geodata integration means that data of different spatial and temporal resolutions are related to reference units, like parcels. The geodata integration result can then be used for the calculation of erosion indices with a particular temporal resolution. In doing so, the fact has to be considered that the impact of extreme weather events is strongly related to phenological development phases of crops. Figure 1 illustrates the principle workflow for the derivation of parcel-specific time series of phenological soil cover and precipitation data sets:

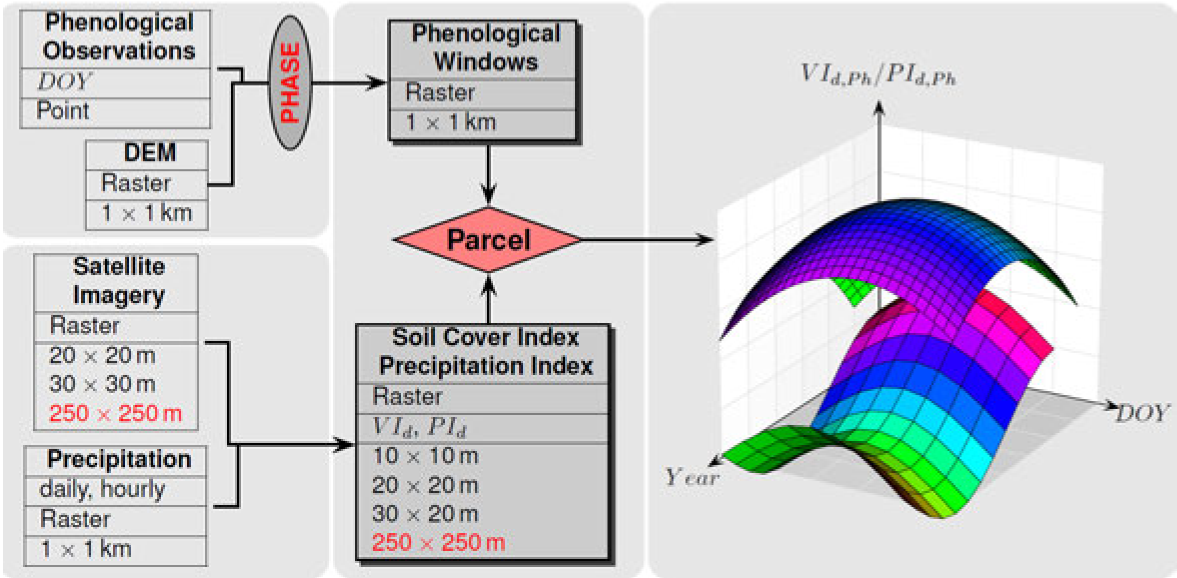


Figure 1: Workflow for the derivation of parcel-specific time series of phenological dependent soil cover and precipitation data (DOY – day of the year | DEM – digital elevelation model | *VI* – Vegetation Index | *PI* – Precipitation index)

- The model PHASE has been applied to generate Germany-wide phenological raster data sets (Gerstmann *et al.,* 2016). They are used for an automatic and dynamic determination of phenological windows, which represent periods between beginning (interpolated) phenological phases.
- As a proxy for historical and up-to-data parcel-specific soil coverage information, a MODIS vegetation index (*VI*) product is used with a temporal resolution of 8 days and a geometric resolution of 250 m (MOD09Q1; Vermote *et al.,* 2015).
- The German Weather Service provides temporally highly resolved adjusted radar rain data with a geometric resolution of 1 km (RADOLAN[1]). They have been aggregated to a precipitation index (*PI*) expressing the hours per day exceeding a threshold of 10 mm.

All data sets are referred to parcels, which represent reference units for soil conservation. As a result, each parcel contains values characterizing the inter- and intra-annual dynamic and variability of a spectral ($VI_{d,ph}$) and precipitation index ($PI_{d,ph}$) considering crop's phenology.

Results

Figure 2a shows an aerial image from 26th September 2016 (*DOY*=270) provided by Google Earth™. The parcel is situated in the north-eastern German district Uckermark (Lat 58.38; Lon 13.94), where winter barley was grown during the vegetation period 2016/2017. The image reveals erosion patters like rills, gullies and accumulation zones, which are marked by red arrows. Figure 2b characterizes the

[1] ftp://opendata.dwd.de/climate_environment/CDC/grids_germany/5_minutes/radolan/

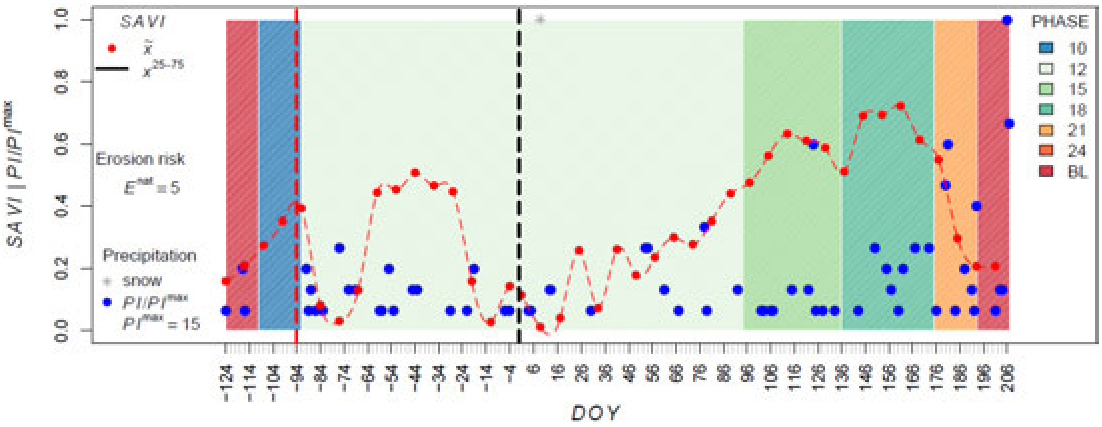
parcel-specific situation regarding phenology, soil coverage and heavy rain events. Positive days of the year (DOYs) represent the year of harvest in 2017, negative DOYs the year of sowing in 2016. The black dashed line marks the turn of the year; the red dashed line indicates the acquisition date of the image.

The parcel is characterized by a hilly terrain and sandy soils. The long-term natural risk at soil erosion by water is assessed as high (E^{nat}=5) in a five-tier rating scale. Vital crop development stages (= phenological phases) are associated with green colors (emerging, shooting, heading), whereas orange colors stand for “yellow ripeness” and “harvest”. Red is related to bare land after harvest or before the beginning of tillage operations. The latter period is colored in blue.

The red dots represent *VI* values derived from MODIS imagery. In this study, the soil-adjusted vegetation index (*SAVI*) was used (Huete, 1988). The temporal *SAVI* variation reveals that there is a relation to phenological phases, and in turn, also to soil coverage. Accordingly, lower *SAVI* values are related to bare land, the periods of tillage operations or the phase “emerging”. Beginning with “shooting”, the *SAVI* values increase until the phase “heading”. The phase “yellow ripeness” is associated with lower *SAVI* values. This means that the *SAVI* information value is temporally restricted to the vital phases “emergence”, “shooting” and “heading”. Minimal *SAVI* values are an indicator for snow coverage, which is linked to the MODIS snow flag marked as a grey symbol.

The precipitation index (*PI*) values are shown as blue dots. They indicate heavy rain events. The higher the *PI* value, the more hours have been measured, which exceeds a rain amount of 10 mm. The *PI* values are normalized by the maximum number of hours during the total vegetation period (here: PI^{max}=15). Accordingly, higher *PI* values (*PI*>=3) can be often found in 2016 during the phase “emerging” and especially with the beginning of tillage operations. On *DOY*=250 or about three weeks before image acquisition, a heavy rain event occurred, which might have caused the observed erosion patterns.

(a) Google Earth image with soil erosion patterns marked by red arrows



(b) Winter Barley 2016/2017

Figure 2: Google earth image from 26th September 2016 (*DOY*=270/-94) (a) and coupling result of phenological, *SAVI* and *PI* data for the vegetation period 2016/2017 and a parcel in Uckermark region (b). The red dots represent *SAVI* values, the blue dots stand for standardized *PI* values. *PI* – precipitation index | *SAVI* – Soil-adjusted vegetation index | E^{nat} – potential natural soil erosion risk | *DOY* – day of the year. IDs of phenological phases: 10 – tilling |12 – emerging |15 – shooting |18 – heading | 21 – yellow ripeness | 24 – harvest | BL – bare land.

Discussion

In this study, we have shown how phenological information can be coupled with indicators representing both soil coverage and heavy rain events. The knowledge about crops' phenology has proved to be crucial especially in order to correctly analyze *SAVI* values regarding soil coverage. Since these data sets are country-wide available, any parcel in Germany can be in principle assessed regarding their historical and up-to-date situation. In doing so, known soil erosion events can be investigated or parcels can be localized where soil erosion events occurred, occur or will occur very likely.

Although MODIS imagery is characterized by a high temporal resolution and a long-term historical archive until the year 2000, the practical applicability of our approach is restricted to parcels with a certain overlap to MODIS pixels. In addition, we are not able to analyze within-field variability. An alternative especially for historical analysis is the usage data fusion products, which combine coarse spatial/fine temporal resolution imagery, such as MODIS, with fine spatial/coarse temporal resolution imagery, such as Landsat (Möller *et al.,* 2017). Nowadays, new multi-temporal products based on the analysis of the Landsat archive are emerging (e.g. Rogge *et al.,* 2018), which have to be tested. Since 2017, Sentinel-2 imagery with a high temporal, spectral and geometric resolution is operationally available, which enables the derivation of high-quality vegetation index time series and also the detection of inner-field soil erosion patterns.

Conclusions

The monitoring of extreme weather events is crucial to adapt measures for farmers, support decision making and refining soil policies especially in the context of climate change. A precondition for an effective monitoring is the availability of indices representing the spatio-temporal dynamic of influencing factors like the occurrence of heavy rain events or soil coverage.

On the example of a parcel in the Uckermark district situated in north-eastern Germany, we introduced a process chain, which aims at the localization of parcels characterized by a potentially high risk of soil erosion during sensitive crop growing periods. The algorithm couples phenological information with a satellite-based soil coverage indicator and a heavy rain event indicator. The development of a data base including both observed soil erosion events as well as explaining dynamic variables like phenology, vegetation and terrain indexes and weather data opens up the opportunity to apply machine learning algorithms to detect and forecast soil erosion situations.

Acknowledgements

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References

Field, C., Barros, V. & Stocker, T. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*: *Special Report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge: Cambridge University Press.

Gerstmann, H., Doktor, D., Gläßer, C., Möller, M. 2016. PHASE: A geostatistical model for the kriging-based spatial prediction of crop phenology using public phenological and climatological observations. *Computers and Electronics in Agriculture*, 127, 726-738.

Gömann, H., Bender, A., Bolte, A., Dirksmeyer, W., Englert, H., Feil, J-H., Frühauf, C., Hauschild, M., Krengel, S., Lilienthal, H., Löpmeier, F-J., Müller, J., Mußhoff, O., Natkhin, M., Offermann, F., Seidel, P., Schmidt, M., Seintsch, B., Steidl, J., Strohm, K. & Zimmer, Y. 2015. Agrarrelevante Extremwetterlagen und Möglichkeiten von Risikomanagementsystemen, *Thünen-Report* 30.

Huete, A.R. 1988. A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*, 25: 259-309.

Lüttger, A.B. & Feike, T. 2018. Development of heat and drought related extreme weather events and their effect on winter wheat yields in Germany. *Theoretical and Applied Climatology*, 132: 15-29.

Möller, M., Birger, J., Gidudu, A. & Gläßer, C. 2013. A framework for the geometric accuracy assessment of classified objects. *International Journal of Remote Sensing*, 34: 8685-8698.

Möller, M., Gerstmann, H., Gao, F., Dahms, T.C., Förster, M. 2017. Coupling of phenological information and simulated vegetation index time series: Limitations and potentials for the assessment and monitoring of soil erosion risk. *CATENA*, 150: 192-205.

Rogge, D., Bauer, A., Zeidler, J., Mueller, A., Esch, T. & Heiden, U. 2018. Building an exposed soil composite processor (SCMaP) for mapping spatial and temporal characteristics of soils with Landsat imagery (1984–2014). *Remote Sensing of Environment*, 205: 1-17.

Vermote, E., Roger, J. & Ray, J. 2015. *MODIS surface reflectance user's guide – collection 6 Version 1.4*. NASA GSFC Terrestrial Information Systems Laboratory, MODIS Land Surface Reflectance Science Computing Facility, Greenbelt, USA.

A large-scaled analysis on the spatial variability of soil parameters and its relation to soil erodibility and landscape characteristics in Southern Italy (Molise Region)

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Abstract

Soil erosion is one of the main environmental problems in the Mediterranean area. This problem is becoming even more important especially in the central Apennines, where several erosive processes, frequently favoured by intensive land use, occur due to the action of concentrated running water in few hours. The erodibility of a soil is a measure of its susceptibility to erosion and depends on many soil properties. Soil erodibility factor varies greatly over space and is commonly estimated using the Universal Soil Loss Equation. To investigate the relationships between soil characteristics and soil erodibility features, a study was carried out in the southern part of Italy, in Molise region. Systematic sampling of topsoil was performed by means of geostatistical techniques. The results show clear evidence about the relation between the topsoil characteristics and morphometric indexes. The observed relationships reflect the possibility to better evaluate both the soil erodibility factor (K), used within the USLE equation, and the spatial variability of physical and chemical soil characteristics. The proposed methodology is able to highlight areas characterized by higher soil erodibility. Erodibility may be compared with other territorial information, such as crops and agricultural practices, to identify potential erosion risk areas.

Keywords: soil erosion, USLE equation, soil erodibility factor.

Introduction, scope and main objectives

Soil erosion is the process of detachment and transport of soil particles caused by water and wind action (Parysow *et al.,* 2003; Morgan, 2005). The progressively increasing exploitation of agricultural areas in the Central Apennines (Italy) is largely favouring soil loss related on particular to the action of running water with a sensible reduction of the top soil. This kind of soil degradation is caused mainly by intensive tillage. The concept of soil erodibility is generally accepted that is related to the susceptibility of the soil to erosion and it is influenced by a large number of soil properties related with the soil pedon, which characteristics influence its depth and the vegetative growth.

The main soil properties, which control soil erodibility factor, include particle size distribution, shape, size and stability of aggregates, shear strength, bulk density, porosity and permeability, organic matter and clay content, and chemical composition (Faulkner *et al.,* 2004; Pulice *et al.,* 2009). The USLE equation and its modified version RUSLE are widely used to predict soil losses and to plan soil conservation (Wischmeier and Smith, 1978). One of the important USLE factors is soil erodibility (K). For areas where there is no field experimental data, the K values are predicted from a multi-regression equation that relates soil loss and soil properties or from a nomograph, being a graphical interpretation of the equation. Predictive methods to reliably estimate soil erodibility (K) are generally based on the analysis of spatial variability of a few soil properties, such as soil structure, soil texture and organic matter content (Wischmeier and Smith, 1978). Statistical methods such as kriging interpolation have been widely used in spatial prediction of physical and chemical soil parameters (Castrignanò *et al.,* 1998; Diodato and Ceccarelli, 2004). The effects of erosive processes on soil features and their consequent spatial distribution in relation to local morphologic and morphometric slope features, can be observed along a soil "catena" located along the slope profile (Birkeland, 1999). Based on such considerations, to estimate on particular the relationships between soil features and erodibility, type and distribution of erosive processes and local slope features, a large-scaled analysis was carried out in a small test area located in southern of Italy (Molise). Within the test area, two soil "catena" have been developed to determine the main soil characters along an alignment crossing different morphologic slope units, which are distinguished with reference to specific dominant erosive phenomena. Then, spatial statistical procedures were applied for spatial prediction of soil erodibility factor K.

However, the direct estimation of soil erodibility is both costly and time consuming. In the USLE and revised USLE equations (RUSLE) (Renard *et al.,* 1997), the concept of soil erodibility was introduced as the K factor, which was defined as the average rate of soil loss per unit of rainfall erosion index from a cultivated continuous fallow plot, on a 9 % slope 22.1 m long.

Methodology

The studied area

The Rivo catchment is located along the Adriatic flank of the Molise sector of the Apennine chain, built up by sedimentary rocks and clay loamy soils. It is characterized by a temperate climate, with mean annual rainfall and temperatures ranging respectively between 650 and 800 mm and 5 and 30 °C. Extensive agricultural land use and a prevailing pelitic and scarcely permeable substratum (mainly marly-clayey and sandy-arenaceous rocks) are cropping out.

The selected test area (about 2.67 km^2) has a test plot station for soil erosion measuring several climatic parameters, as well as soil erosion rates and liquid discharges in relation to different land cover (Aucelli *et al.,* 2006a; Aucelli *et al.,* 2006b). The geological substrate is made of clayey and marly-arenaceous rocks characterized by low permeability, above which mainly Vertisols and Inceptisols showing outstanding vertic characteristics have developed. From a geomorphological point of view, the study area shows a remarkable variety of hillslope forms and erosive processes, resumed on a map that classifies the whole territory into seven morphodynamic unit. Agriculture and pasture are the main economic activities.

Pedological sampling

Ten soil profiles were sampled along a 1.7 km long transect, which defines two soil "catena" extending from the valley. For each profile, a detailed fact sheet was compiled. Moreover, soil samples taken from the main diagnostic horizons were subjected to physical and chemical laboratory analyses to classify soils according to FAO (2006). Systematic topsoil sampling was carried out based on a net of sampling points (located at regular distances of about 300 m each one from another) in order to characterize the upper soil portion (20 cm thick). Furthermore, also the spatial distribution of superficial bulk density and calcium carbonate content was analyzed, as they can be considered good indicators of accelerated topsoil erosion.

Soil erodibility factor estimation

The values of the soil erodibility factor K of the topsoil samples were calculated using the following formula of Wischmeier and Smith (1978):

K=2.1*10-4(12-OM)M1.14*3.25(S-2)+(2.5(P-3)/7.59)*100,

where K is expressed in t*ha*h/h*MJ1.14*mm, OM represents the organic matter content (%), M defines the relations between percentages of silt, very fine sand and clay content (% silt + % very fine sand)/(100 - % clay), S represents the soil structure code and P the permeability class.

Spatial variability of the examined parameters was evaluated by means of a geo-statistical analysis. The results were then compared with the spatial distribution of soil types, morphodynamic units and with different morphometric parameters, extracted from a high-resolution (5 m) digital terrain model (DTM).

Results

Ten different soil types characterize the study area. Figure 1 shows the pedological section. The dominant soil types are Grumic and Calcaric Vertisols, which represent about 60-70 % of the test area. All soil types have an organic matter content of less than 5.7 % and most of them are poorly drained. Field and laboratory analysis showed that the soils along the transect can be classified as Grumic Mollic Vertisols (clayey up to 1.5-2 m thick, well structured, deeply fissured and characterized by a moderately deep calcic horizon), Vertic Calcisols (about 1 m thick with a superficial calcic horizon) and Leptosols (very thin soils with a massive structure and a strong sandy texture). Analyses of soil profiles along the catena have shown that the position of the profile on the slope is crucial for the development of diagnostic physical and chemical characteristics of soils, as well as type and intensity of local dominant hillslope processes.

The results show important correlation between spatial distribution of soil parameters, soil types and its morphodynamic units. The soil erodibility map derived using a kriging interpolation is shown in Figure 2.

The determined K values range from 0.01 to 0.085 t*ha*h/h*MJ1.14*mm. The soil erodibility map shows significant differences of K values between the various examined soil profiles, which depend on local soil variability. The spatial distribution of the K factor confirms that some of the chemical and physical properties of topsoils are clearly linked to the spatial distribution of certain morphometric indexes.

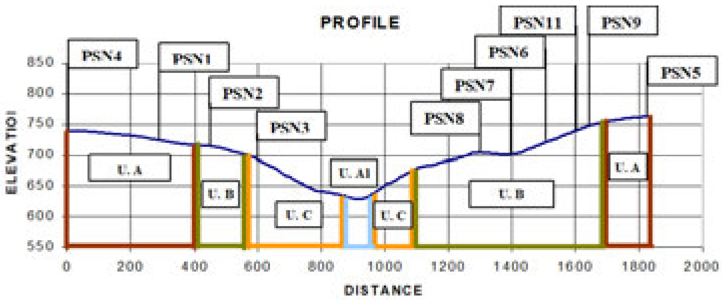
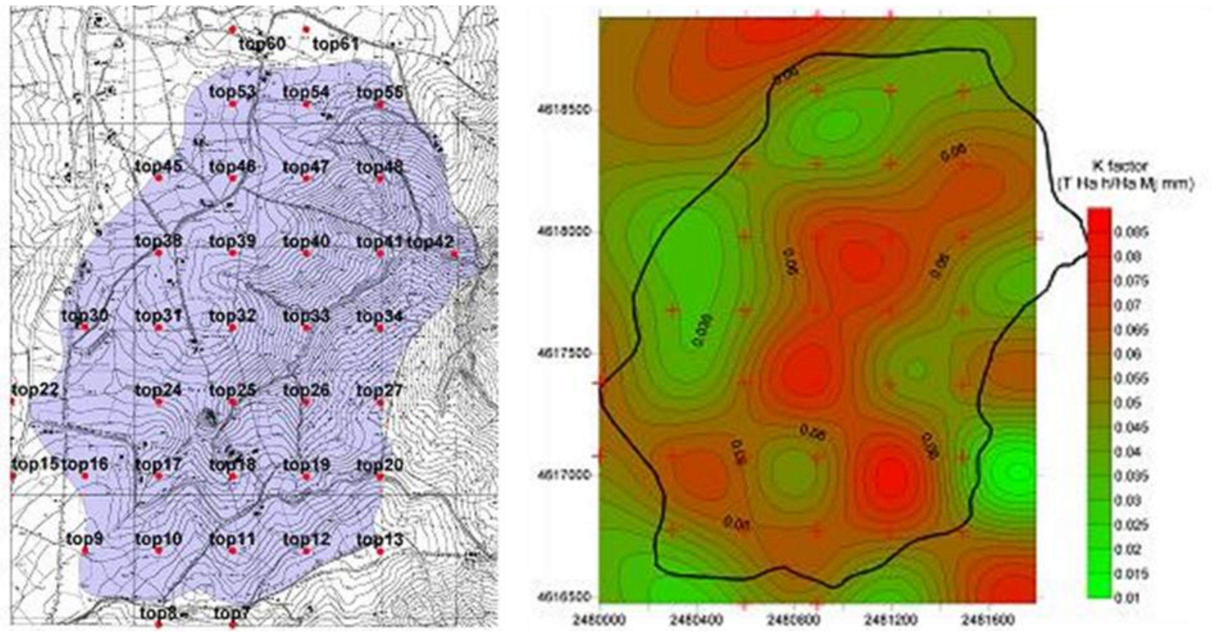


Figure 1: Topographic profile along the catena with indications about the location of soil profiles. Distances and elevations are expressed in meters. PSNx: soil profile code; Ux: morpho-dynamic unit.



a) b)

Figure 2: a) Location of topsoil samples within the test area; b) spatial interpolation of the K factor calculated by the formula of Wischmeier and Smith (1978).

Discussion

The observed relationships reflect the possibility to better evaluate both the soil erodibility factor (K), used within the USLE equation, and the spatial variability of physical and chemical soil characteristics on the basis of digital terrain analyses. On one hand, the preliminary results will be useful for a more precise evaluation of the parameter K of the USLE equation and a better prediction of soil loss. On the other hand, the results suggest important relationships between local geologic-environmental conditions, erosive phenomena, soil features and soil degradation.

Conclusions

The results of the study encourage developing methods and techniques to quickly and economically derive from DTMs some important soil characteristics, whose estimate generally requires a lot of time and resources. The preliminary results will be useful for a more precise evaluation of the parameter K of the USLE equation and a better prediction of soil loss, and suggest important relationships between local geologic-environmental conditions, erosive phenomena, soil features and soil degradation. The proposed methodology is able to highlight areas characterized by higher soil erodibility. Erodibility may be compared with other territorial information, such as crops and agricultural practices, to identify potential erosion risk areas in extensive contexts.

References

Aucelli, P.P.C., Caloiero, T., De Angelis, A., Gaudio, R. & Rosskopf, C.M. 2006a. Analisi del rapporto afflussi-deflussi in alcuni piccoli bacini idrografici molisani impostati su litologie a forte componente pelitica (Italia meridionale) attraverso la misura diretta e la modellizzazione. Proceedings of the final workshop of the PRIN 2002 project “water erosion in Mediterranean environment: direct and in direct assessment in test areas and catchments”. Brigati, Geniva, 145-157.

Aucelli, P.P.C., De Angelis, A., Colombo, C., Palumbo, G., Scarciglia, F. & Rosskopf, C.M. 2006b. La stazione sperimentale per la misura dell’erosione del suolo di Morgiapietravalle (Molise, Italia): primi risultati sperimentali. Proceedings of the final workshop of the PRIN 2002 project “water erosion in Mediterranean environment: direct and in direct assessment in test areas and catchments”. Brigati, Geniva, 87-104.

Birkeland, P.W. 1999. Soils and Geomorphology. Oxford University Press: New York.

Castrignanò, A., Mazzoncini, M. & Giugliarini, L. 1998. Spatial characterization of soil properties. *Advances in Geoecology*, 31: 105-111.

Diodato, N. & Ceccarelli, M. 2004. Multivariate indicator Kriging approach using a GIS to classify soil degradation for Mediterranean agricultural lands. *Ecological Indicators*, 4: 177-187.

FAO. 2006. A framework for international classification, correlation and communication. IUSS Working Group WRB. World Soil Resources Reports N° 103. FAO, Rome.

Faulkner, H., Alexander, R., Teeuw, R & Zukowskyj, P. 2004. Variations in soil dispersivity across a gully head displaying shallow sub-surface pipes, and the role of shallow pipes in rill initiation. *Earth Surf. Process. Landforms*, 29: 1143-1160.

Morgan, R.P.C. 2005. Soil Erosion and Conservation. 3rd Ed. John Wiley & Sons, New York, NY.

Parysow, P., Wang, G., Gertner, G. & Anderson, A.B. 2003. Spatial uncertainty analysis for mapping soil erodibility based on joint sequential simulation. *Catena*, 53: 65-78.

Pulice, I., Cappadonia, C., Conoscenti, C., Robustelli, G., Rotigliano, E. & Scarciglia, F. 2009. Calanchi landforms in south Italy: a comparison between Calabria and Sicilia case studies. In Epitome, 418 pp.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. & Yoder, D.C. 1997. Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook N° 703, 404 pp.

Wischmeier, W.H. & Smith, D.D. 1978. Predicting rainfall erosion loss: a guide to conservation planning. Handbook N° 537, U.S. Department of Agriculture, Agricultural Research Service: Washington D.C., 58 pp.

Water erosion and the ENSO phenomenon over *Penisetum chilense* steppe of Puna region

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Abstract

Desertification is a process of degradation of arid lands that occur as a result of the combination of several factors, including water erosion. Plant cover is a key factor in determining the degree of water erosion and in Puna region is strongly influenced by rainfall and inter-annual variability is mainly due to the ENSO phenomenon (El Niño - Southern Oscillation). The objectives of this work were to generate a semiautomatic model that allows estimating the potential water erosion in the Puna of Jujuy from remote sensing and evaluating the changes of potential erosion for different phases of the ENSO. For this, the USLE equation was applied to a GIS. Coverage (C), Topographic (LS), Soil Erodability (K), Conservation Practices (P), and Rain Erosivity factors were estimated through different methods, including remote sensing indexes, maps, and other sources. The phases of the ENSO phenomenon were determined with the SOI index. It was possible to observe the temporal variation of erosion over the years, with the greatest loss of soil associated with La Niña years through a water erosion model development. This was conducted by applying the USLE equation from satellite images integrated into a GIS for the Puna region of Jujuy.

Keywords: Puna, Remote Sensing, USLE, Water erosion, ENSO, Desertification, Land degradation, GIS

Introduction, scope and main objectives

The Puna is an ecoregion of the high plains that extends in Argentina, from the northwest of Mendoza province from 2000 meters above sea level until the limit with Bolivia to 4500 masl. Soils are immature and the climate is cold and dry. The precipitation decreases from East to West. The type of dominant vegetation is the shrub steppe, but there are also herbaceous steppes, grass steppes, fertile plains, and other physiognomic types (Cabrera, 1971). Low vegetation cover is one of the factors that greatly increase the risk of water erosion and is one of the most important causes of soil erosion (Casas, 1998). At Maggi *et al.* (2015) a tendency was identified in the record of rainfalls above the historical average in La Niña phases and rainfalls below the historical average in El Niño phases. These changes had a positive correlation in the calculated NDVI values, being higher in La Niña phases and smaller in El Niño phases. The objectives of this research were to generate a semiautomatic model that would allow estimating the potential and current water erosion in the Puna region from remote sensors and evaluate the changes for the different phases of the ENSO phenomenon.

Methodology

The study area of this work is located in the closed basins of the Puna, specifically in the sub basin of the Pozuelos lagoon. The soil type is represented by Torrihortentes, Torripsamentes and Paleargides associated with rocky outcrops. The main economic activity is transhumance livestock.

The ENSO is a phenomenon that consists of three phases: El Niño, La Niña and Neutral phase. These phases were identified with the SOI index. With data extracted from the Climate Prediction Center

(CPC) of the National Oceanic and Atmospheric Administration (NOAA). The intensity classification of the phases was carried out according to the work of Chowdhury *et al.* (2010).

Soil loss due to water erosion was estimated quantitatively from the USLE equation (Wischmeier and Smith, 1978), that is an empirical model that calculates the potential average loss of soil by water erosion in an area from the compilation of few variables in a simple model through the following formula: A = R x K x LS x C x P.

Since

- A $(Tn/(ha * year)$ the average of the soil loss,
- R $(MJ * cm)/(ha * h))$ is the rain erosivity factor,
- K $(Tn * h)/(MJ * cm))$ is the factor of soil erodability,
- L is the dimensional factor of the length of the slope,
- S is the gradient factor of the slope,
- C is the factor of the vegetation cover,
- P is the factor of the cultural practices.

The integration of the data of the different factors allowed to obtain images in a raster format for each monsoon period. The period analysed was comprised between years 2001 and 2010.

The C factor (Coverage) of the USLE equation was obtained by the shape of the hypothetical NDVI-C curve in Van der Knijff *et al.* (2000). The NDVI was obtained from images of the MODIS sensor on board the Terra satellite corresponding to the product MOD13Q1.

The LS (Topographic) factor was calculated by multiplying *L x S* from the equations used in Van der Knijff *et al.* (2000). To obtain the slope, the images from NASA's Shuttle Radar Topographic Mission (SRTM) project were used in a 3 '' arc raster format. The S factor was calculated as a percentage and the contribution area was determined at a fixed value based on the spatial resolution of the pixel (90 meters). The K factor (soil erodability) is the rate of soil loss for a given soil type. It was calculated from the equation of Wischmeier & Smith and the data needed for this factor were obtained from the work of "Adaptation to a Geographical Information System of the Study of Soils of the NOA (Salta and Jujuy)" (Nadir and Chafatinos, 1990) prepared by the National Agriculture Technology Institute (INTA) and the National University of Salta in 2009, both from Argentina. The most erodable dominant soils of each soil association were studied in order to represent the greatest vulnerability scenario. The percentages of organic matter, silt, clay and textural classes were obtained from the data of soils subgroups provided at Paoli *et al.* (2009). A rasterized map with the value of K was obtained. The P factor was determined in the value 1 because the realization of specific conservation practices was not taken into account considering that most of the lands are dedicated to extensive grazing and this also represents the worst scenario.

Monthly precipitation data were obtained from the estimates made by the Global Precipitation Climatology Center (GPCC) in a grid with a spatial resolution of 0.5º x 0.5º, Meyer-Christoffer, *et al.* (2011). This estimation presents a good adjustment with the rainfall records of meteorological stations installed on the study area, as expressed at Maggi *et al.* (2015). These data allowed us to estimate the

R factor for different monsoon periods of the 2001-2010 series through the NOA monsoon precipitation (Maggi, 2002):

The values obtained were multiplied by 2.242 and divided by 9.81 to be able to carry out a unit conversion. The integration of the precipitation grid by monsoon period (October to April) was carried out and its R factor was calculated for each period in raster images.

Polygons sampling was established to the south of the town of Santa Catalina and identifies the location of *Pennisetum chilense* community (Ruthsatz and Movía, 1975) to determine the effect of vegetation cover on the estimation of potential erosion and current erosion over different ENSO phases. The polygons represent a total sample of 1037 pixels.

The years classified according to ENSO phases obtained by applying SOI were included with three years per phase. Within the period studied (2001-2010) the potential erosion estimation is greater than current erosion due to the attenuating influence of vegetation cover (Gitas *et al*., 2009).

Results

The years classified according to ENSO phases obtained by applying SOI were included with three years per phase. Within the period studied (2001-2010) the potential erosion estimation is greater than current erosion due to the attenuating influence of vegetation cover (Gitas *et al*., 2009).

The period with the greatest estimated soil loss due to potential erosion was 2007-08, exceeding 6 Tn per hectare per year and corresponds to a La Niña phase. In contrast with this, the estimated current erosion had its greatest soil loss in 2009-10 corresponding to the El Niño phase. On the other hand, the year with the lowest loss for all estimates was 2004-05 with 1 Tn ha^{-1} yr^{-1} corresponding to El Niño phase. It can also be distinguished that for both potential and current erosion, this was greater in La Niña phases, followed by Neutral phase and El Niño. It was possible to identify that 78 % the potential erosion and 75 % of current erosion pixels maintain the tendency identified in Figure 1.

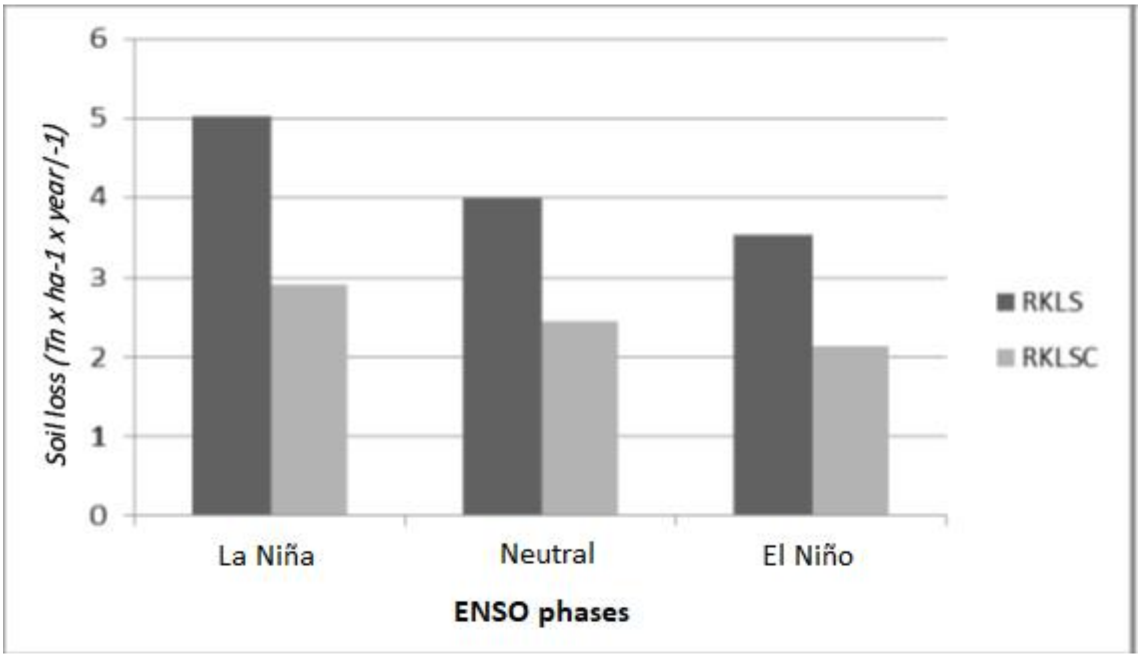

Figure 1: Average of potential Soil loss according to ENSO phases

Discussion

These results show that although the ENSO phenomenon is one of the most influential factors in the temporal variation of rainfall and therefore its incidence in water erosion, there are other sources of rainfall variation that affect them and cumulative annual amount as demonstrated by Garreaud and Aceituno (Garreaud and Aceituno, 2001). This could be because the teleconnections in the Puna Region of the northwest of Argentina, are not as marked as other parts of the world.

Therefore, the community of *Pennisetum chilense* would be a good indicator of the increase in water erosion caused by presence of the La Niña phase. Previous survey work already noted a high intensity of both water and wind erosion due to continuous grazing and low soil stability (Ruthsatz and Movia, 1975).

It is important to highlight that the values estimated in this work are relative, since the USLE equation presents limitations in areas of great slope magnitude (Farrish *et al*., 1993) and the data obtained show margins of error that were not included in the present work and that are mostly absorbed by the regional scale character of this study.

Conclusions

It was possible to develop a water erosion model based on satellite images integrated in a GIS for the Puna region in Jujuy. The USLE equation results from a practical and simple tool to integrate the factors involved and carry out the estimation of erosion, making the necessary adjustments for the adaptation to the study area. This model allowed to advance in the better understanding of the temporal and spatial variations of water erosion in a regional scale for an area of difficult access that lack availability of information.

The results obtained were those expected based on previous studies carried out in the region for both temporal and spatial variation, which would indicate the validity of the development of the erosion model through GIS and remote sensing. The values of erosion estimated in this work would allow to establish criteria for the determination of measures that could be incorporated in the decision making process for sustainable management and development of the region, especially for responsible authorities in the management of natural resources. More exhaustive studies will be required in order to establish the significant relationships of the factors involved in the process of water erosion in the Puna of Jujuy and the adjustment values of the intervening variables.

References

Cabrera, Á. L. 1971. Fitogeografía de la República Argentina. *Boletín de la Sociedad Argentina de Botánica*, XIV (1-2), 1-42.

Chowdhury, M. R., **Barnston, A. G.**, **Guard, C.**, **Duncan, S.**, **Schroeder, T. A. & Chu, P. S.** 2010. Sealevel variability and change in the US affiliated Pacific Islands: Understanding the high sea levels during 2006-2008. *Weather*, 65(10): 263-268.

Farrish, K. W., **Adams, J. C. & Thompson, C. V.** 1993. Soil conservation practices on clear-cut forestland in Louisiana. *Journal of Soil and Water Conservation,* (48): 136-139.

Garreaud, R. D. & Aceituno, P. 2001. Interannual rainfall variability over the South American Altiplano. *American Meteorological Society,* (14): 2779-2789.

Gitas, I. Z., Douros, K., Minakou, C., Silleos, G. N. & Karydas, C. G. 2009. Multi-temporal soil erosion risk assessment in N. Chalkidiki using a modified USLE raster model *EARS eLe Proceedings* 15*(1):* 40-52.

Maggi, A. E. 2002. Una propuesta para predecir el factor de erosividad "R" para el centro y norte de la Argentina. *Revista de la Facultad de Agronomía UBA*, 22: 133-138.

Maggi, A. E., **Di Ferdinando, M. A. & Barrera, D.** 2015. Influencia del fenómeno ENOS sobre la productividad vegetal en dos comunidades vegetales de la puna argentina. CONGREMET XII.

Meyer-Christoffer, A., **Becker, A.**, **Finger, P.**, **Rudolf, B.**, **Schneider, U. & Zeise, M**. 2011. GPCC.

Paoli, H. P., Volante, J. N., Noe, Y. E. & Vale, L. M. 2009. Adecuación a un sistema de información geográfica del estudio "Los Suelos del NOA (Salta y Jujuy), Nadir A. - Chafatinos T., 1990". INTA.

PROSA - FECIC. Centro para la Promoción de la Conservación del Suelo y del Agua. (2015). El deterioro del suelo y del ambiente en la Argentina. Bueno Aires.

Ruthsatz, B. & Movía, C. P. 1975. Relevamiento de las estepas andinas del noreste de la Provincia de Jujuy. República Argentina. Buenos Aires: Fundación para la educación, la ciencia y la cultura (FECIC).

Secretaría de Ambiente y Desarrollo Sustentable de la Nación. 2007. 2º Comunicación Nacional de la República Argentina a la Convención Marco de las Naciones Unidas sobre Cambio Climático. Buenos Aires.

Van der Knijff, J. M., **Jones, R. J. & Montanarella, L**. 2000. Soil erosion risk assessment in Italy. European Soil Bureau.

Wischmeier, W. H. & Smith, D. D. 1978. Predicting rainfall-erosion losses: A guide to conservation planning. United States Department of Agriculture, Agriculture Handbook Nº.537.

Erosion model testing – are doing enough?

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Abstract

If soil erosion models are to be used for developing appropriate erosion control measurements, they must be evaluated against empirical data. However, testing erosion models is difficult: measured erosion rates are uncertain and not always comparable to model outputs. In order to understand how model evaluation has been approached in erosion modeling research, we performed a scientometric term co-occurrence analysis. The query “soil erosion model*” on the Web of Science database returned 550 articles, from which titles and abstracts were retrieved. This information was used to construct a network map, in which co-occurring terms were clustered according to their association strength. The map allowed us to identify different erosion modelling research fronts. The results illustrate how model evaluation topics are clustered separately from model application themes, indicating that models are frequently used without rigorous performance assessment. Furthermore, the results show that model testing is mainly restricted to system outlet responses. We conclude that the evaluation of soil erosion models should be encouraged by the modelling community. Moreover, evaluation should be expanded to encompass multiple tests and multiple sources of data. Ultimately, defining fit-for-purpose tests that allow for model rejection would benefit modelers and stakeholders.

Keywords: Soil erosion models, evaluation, validation, scientometrics, co-occurrence analysis

Introduction

Soil erosion models are used to estimate soil redistribution rates for a variety of scenarios, spatial scales, and time steps. Such estimates should ultimately help the development and allocation of appropriate erosion control measures. However, if models are to be used in matters where public interests are at stake, the level of (dis)agreement between models and reality must be explicitly stated (Oreskes *et al.,* 1994). The degree of confidence which attributed to model estimates can only be asserted by evaluating their performance against empirical observations.

Nonetheless, evaluating soil erosion models is difficult. Erosion is a complex, spatially and temporally variable phenomenon, driven by an interaction of non-stationary processes (Quinton, 2004). Gathering empirical data to test erosion models therefore requires multiple and constant measurements, which can be expensive and time-consuming. Such measurements can also be considerably uncertain (Stroosnijder, 2005), and may not always be directly comparable to model outputs (Favis-Mortlock *et al.,* 2001).

As formal descriptions of complex systems, models are meant to be tested. Failing to test our models therefore also means a failure to evaluate (and ultimately develop) our knowledge regarding these systems.

Although different procedures for erosion model evaluation have been developed, a guideline for defining fit-for-purpose tests that allow for model rejection is lacking. In this study we undertake a scientometric analysis to understand how model evaluation has been approached in soil erosion research. We build on the results from this analysis to stress the necessity of continuous model testing and to suggest a way forward to improve the evaluation of erosion models.

Methodology

Term co-occurrence analysis is commonly employed in scientometric investigations to identify conceptual structures in research fields (Mora-Valentín *et al.,* 2018). The frequency with which terms co-occur in scientific articles is used to establish the relatedness of research topics. Particularly, VOSviewer software allows for the creation of distance-based co-occurrence maps, where abstract and title terms are clustered according to a similarity matrix (Van Eck and Waltman, 2010).

A bibliographic research from the Web of Science database was carried out in October 2018. The query "soil erosion model*" returned 550 articles, with publishing dates between 1985 and 2018. Titles, abstracts, and bibliographic records of the articles were exported to a text file used as an input for the term co-occurrence analysis in VOSviewer. Prior to the analysis, a thesaurus file was used to exclude general expressions (i.e. aim, conclusion) and to merge synonyms. A threshold of 15 occurrences was established for including terms in the analysis. Finally, a relevance score filtered informative terms that more adequately represent the research topics (Van Eck and Waltman, 2018). This process resulted in the selection of 106 terms, which were clustered and mapped according to their relatedness and association strength.

Results

The term co-occurrence network map allows for the distinction of four clusters in erosion modeling research (Figure 1). Cluster 1, on the left side of the map, is primarily concerned with large scale, spatially distributed model applications, as denoted by the presence of terms such as "region", "world", "map", "remote sensing", and "DEM". USLE and RUSLE seem to be the preferred models in this research front.

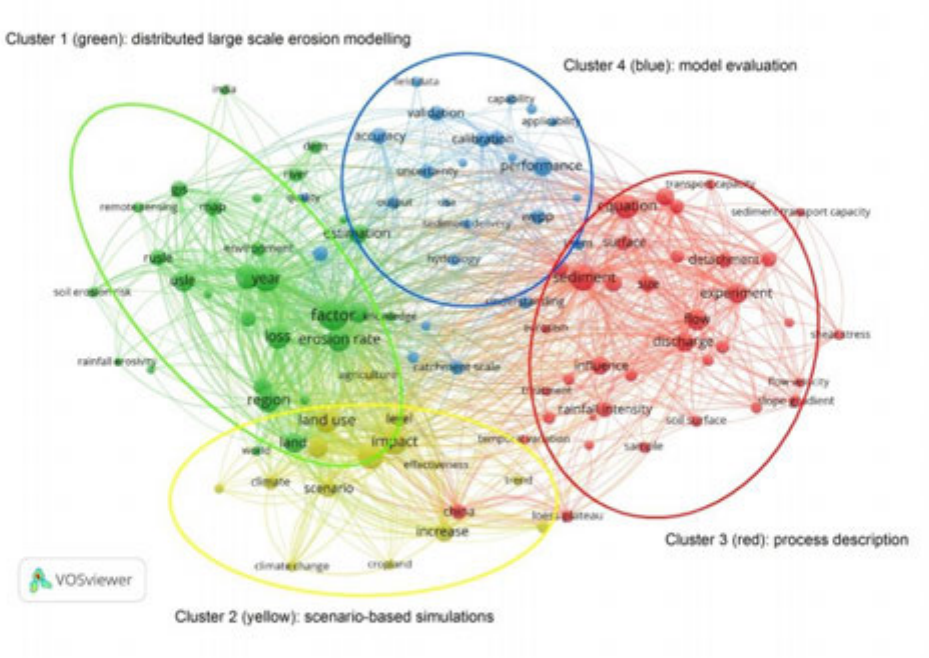

Figure 1: Network map of the term co-occurrence analysis. Circle and label sizes are proportional to the number of occurrences. Lines connecting terms indicate main links between them. Line thickness is proportional to association strength, which is also represented by the distance between labels.

On the bottom-left-side of the network map, Cluster 2 represents a research front focused on scenario-based simulations. This is expressed by the occurrence of the terms “scenario”, “trend”, “increase”, and “decrease”. Climate change and land use changes appear to be the main concerns. The location of Cluster 2 on the network map indicates a close link with Cluster 1.

On the right-side of the map, Cluster 3 identifies a research interest on process description. Terms within this cluster are related to erosion-driving processes (e.g. “infiltration”, “sediment transport”, “overland flow”), mathematical description of these processes (e.g. “coefficient”, “equation”), and to experimental data (e.g. “experiment”, “treatment”, “sample”).

On the top of the network map, the research front depicted by Cluster 4 is concerned with model evaluation. Terms that describe model efficiency (e.g. “capability”, “limitation”, “applicability), as well as terms that address model evaluation topics (e.g. “validation”, “uncertainty”, “sensitivity analysis”) are grouped within this cluster. Moreover, the occurrence of the terms “outlet”, “discharge”, and “sediment transport” demonstrates how erosion model testing is commonly associated to outlet measurements of sediment transport rates. This is corroborated by the strong link between the terms “outlet”, “calibration”, “validation”, and “catchment”.

The co-occurrence analysis also revealed that terms associated to erosion model evaluation have overall earlier publication dates than current popular topics. For instance, the articles that contain the terms “uncertainty” and “validation” have 2009 as their average year of publication. Contrarily, the average years of publication for terms such as “climate change”, “land use change”, “soil erosion risk”, “RUSLE”, and “scenario” range from 2012 to 2013. Moreover, the analysis showed that the terms “validation”, “validate”, or “validated” only occurred in 8 % of the abstracts and titles from the examined articles.

Discussion

The results from the term co-occurrence analysis demonstrate that there is a specific interest in model evaluation within erosion modeling research. However, the results also illustrate that such interest might be somewhat limited: models are mainly tested in evaluation-oriented studies, whereas common model applications are often carried out without testing. This is corroborated by the infrequent occurrence of terms such as “validation”, and the by the fact that evaluation topics are clustered separately from other research fronts. Our analysis also highlights that when erosion models are evaluated, tests are mostly restricted to comparisons against system outlet measurements of sediment fluxes. This can be problematic, as calibrated models have been known to provide adequate estimates of sediment yield while misrepresenting internal erosion dynamics (see Govers, 2011).

Moreover, results indicate a recent focus on large scale distributed modeling and scenario-based simulations compared to process description and model evaluation. This research trend might indicate that scientists are confident about the capacity of erosion models to quantify soil redistribution rates in complex landscapes and to simulate erosion responses to land use and climate changes. Such confidence is not supported by the scientific literature, which demonstrates that the predictive accuracy of un-calibrated erosion models at field and catchment scale is limited (Jetten *et al.,* 1999), that spatial predictions regularly mismatch observed patterns of erosion and deposition (Takken *et al.,* 1999; Evans and Brazier, 2005), and that model outputs are fairly uncertain (Quinton, 1997).

So why aren’t we testing are models? One obvious answer is that evaluating erosion model is not an easy endeavor: measuring erosion rates, - particularly beyond the plot scale - is complicated, expensive, and uncertain. However, different technologies, such as sediment tracing/ fingerprinting, field monitoring, and remote sensing are available. What is needed, perhaps, is defining fit-for-purpose tests that enable the evaluation of erosion models according to the framework, scale and finality of the application. Furthermore, we believe there is a necessity for establishing tests that will allow for model rejection in light of epistemic and random uncertainties associated to model structures, model parameterization, and to the observed empirical data (see Beven, 2018). The further development of erosion model evaluation (and of erosion modeling itself) will require, however, “the understanding that all models are wrong, and humility about the limitations of our knowledge” (Sterman, 2002).

Conclusions

If soil erosion models are to influence decision making in matters of public interest they must be constantly evaluated. Our scientometric analysis demonstrates they are not. It also indicates that model testing is frequently restricted to system outlet responses, which are often unsatisfactory to evaluate model performance.

We argue that model evaluation should be expanded to multiple tests, based on multiple sources of data. Tests should also be fit-for-purpose and allow for model rejection while representing the uncertainties in both models and empirical data. The development of evaluation guidelines that consider the purpose, scale and structure of the model application would benefit the erosion modeling community and encourage model testing.

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References

Beven, K.J. 2018. On hypothesis testing in hydrology: Why falsification of models is still a really good idea. *WIREs Water*, 5: e1278.

Evans, R. & Brazier, R. 2005. Evaluation of modelled spatially distributed predictions of soil erosion by water versus field-based assessments. *Environtal Science Policy*, 8: 493–501.

Favis-Mortlock, D., Boardman, J. & MacMillan, V. 2001. The limits of erosion modelling: why should we proceed with care. In: Harmon RS, Doe WW (Eds), *Landscape erosion and evolution modeling*. Boston: Springer, pp. 477-516.

Govers, G. 2011. Misapplications and misconceptions of erosion models. In: Morgan RCP, Nearing MA (Eds), *Handbook of erosion modelling*. Oxford: Blackwell Publishing, pp. 117-134.

Jetten, V., de Roo, A. & Favis-Mortlock, D. 1999. Evaluation of field-scale and catchment-scale soil erosion models. *Catena*, 37: 521–541.

Mora-Valentín, E.M., Ortiz-de-Urbina-Criado, M. & Nájera-Sánchez, J.J. 2018. Mapping the conceptual structure of science and technology parks. *Journal of Technological Transfer*, 43: 1410–1435.

Oreskes, N., Shrader-Frechette, K. & Belitz, K. 1994. Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences. *Science*, 263: 641–646.

Quinton, J.N. 1997. Reducing predictive uncertainty in model simulations: a comparison of two methods using the European Soil Erosion Model (EUROSEM). *Catena*, 30: 101–117

Quinton, J.N. 2004. Erosion and sediment transport. In: Wainwright J, Mulligan M (Eds), *Environmental modelling: finding simplicity in complexity*. Chichester: John Wiley & Sons, pp. 187-196.

Sterman, J. 2002. All models are wrong: Reflections on becoming a systems scientist. *System Dynamics Reviews*, 18: 501–531.

Stroosnijder, L. 2005. Measurement of erosion: Is it possible? *Catena*, 64:162–173.

Takken I, Beuselinck L, Nachtergaele J, *et al.* 1999. Spatial evaluation of a physically-based distributed erosion model (LISEM). *Catena*, 37: 431–447.

Van Eck, N.J. & Waltman, L. 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84: 523–538.

Van Eck, N.J. & Waltman, L. 2018. Vosviewer Manual. Available at: http://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.8.pdf [accessed 05/03/2019]

Long-term monitoring of sediment yield in typical agricultural watersheds of Navarre, Spain

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Abstract

Four experimental watersheds appointed by the Government of Navarre (Spain) for assessing the effect of agricultural activities on the environment were monitored –rainfall, runoff and sediment yield– during 10 years (2007-2016). They are representative of wide areas of Navarre and Spain as regards their morphology, soils, climate, land use and management. Sediment yield was more related to current soil conditions and to the erosive capacity of few rainfall events. An important inter-annual variability of sediment yield was observed, which is in agreement with the climatic characteristics. Sediment yield presented a noticeable variation depending on the type of land use. In general, cereal crops > forest > pasture. However, under similar land use, morphology and topography of the watershed could play an important role on sediment production. The results highlight the complexity of Mediterranean agricultural landscapes and the need for further studies to gain insight into the soil erosion processes and conditioning factors.

Keywords: soil erosion, sediment yield, Mediterranean region, land use

Introduction, scope and main objectives

Soil erosion in agricultural lands is an important problem in Navarre (Spain). As a result, the local government decided to establish a network of experimental agricultural watersheds in order to provide data for assessing the effect of agricultural activity on soil and water resources and, consequently, for identifying and implementing environmentally-sound land management practices. Additionally, the data collected at the experimental watersheds are of great utility for the evaluation of several modelling tools. The experimental watershed network consists of 4 watersheds (http://cuencasagrarias.navarra.es/index.cfm). Two of them, Latxaga and La Tejería, are located within high productivity winter grain farming areas, the third watershed, Oskotz, is in an area of intensive cattle-breeding, whereas the fourth, namely Landazuria, is an irrigated, intensively cultivated area (Casalí *et al.*, 2008; Casalí *et al.* 2010, Giménez *et al.*, 2010, Merchán *et al.*, 2019).

Experimental watersheds provide the possibility of studying soil erosion and related processes from a systemic point of view allowing us to relate and hierarchize the influence of the different factors involved in the phenomenon; besides incorporating the effects of land use changes.

In this paper, rainfall, runoff and sediment yield (ssy) continuously recorded at the outlet of different agricultural watersheds during 2007-2016 are analysed. These watersheds can be considered as being representative of wide areas of Navarre and Spain as regards their morphology, soils, climate, land use and management.

Methodology

Experimental watersheds

Latxaga watershed (207 ha) is located in the central eastern part of Navarre (Spain). Its climate is humid submediterranean, with an average annual precipitation of 835 mm and an average annual temperature of 12 ºC. The valley bottom minimum slopes are about 5-7 %, whereas the hillslopes can reach up to 30 %. The area is underlined by clay marls and Pamplona grey. Soils are shallow (less than 0.5 m deep) on eroded hillslopes and deeper (over 1 m deep) on swales and deposition areas. In general, topsoil is silty-clay-loam in texture. The watershed is almost completely cultivated with winter grain (wheat and barley usually cover 80 % or 90 % of the total area). Tillage is conventional, and frequently parallel to contour lines. Tillage practices are performed in such a way that a vegetation strip around the streams is maintained, thus allowing the growth of sometimes dense riparian vegetation.

La Tejería watershed (169 ha) is located in the central western part of Navarre. Its climate is also humid submediterranean, with an average annual precipitation of approximately 725 mm. The average annual temperature is around 13 ºC. Slopes are very homogeneous with an average value of 15 %. The watershed is underlined by marls and sandstones of continental facies. Soil is shallow (<0.5 m) on eroded areas and deeper on deposition ones. The soil upper horizon has a clayey-silty texture. Land use and soil management practices are very similar to those described for the Latxaga watershed. However, the stream beds and banks within the La Tejería watershed are poorly vegetated, favouring the occurrence of bank erosion processes.

Oskotz watershed (1.674 ha) is located in the north-eastern part of Navarre. Its climate is Sub-Atlantic, with an average annual precipitation of 1200 mm and an average annual temperature of 12 ºC. The hillslopes are in the range of 10-65% but only around 5 % in the valley bottom. The area is underlined by clay marls and Pamplona grey. Soils are fine and more than 1 m deep except for those in the eroded hillslope that are shallow (0.5-1 m deep). Most of the watershed is covered with forest (1021 ha, 61 %) mainly by Fagus sylvatica, Quercus pyrenaica and Pinus spp., whereas the remaining area is devoted to pasture (653 ha, 39 %) with cattle-breeding (cows and sheep) and a small part dedicated to cropping.

Landazuria watershed (480 ha) is located in southern Navarre. Its climate is dry Mediterranean, with an average annual precipitation of 417mm and average annual temperature of 13.2 °C. The watershed is relatively flat, with slopes between 3 % and 5 %. Dominant soils are shallow with clay loam or silt loam textures. Over 88% of the watershed area is cultivated, with about 60 % of the total cultivated area under pressurized irrigation systems. The rest of the cultivated surface is rainfed agriculture. Barley is the main rainfed crop while maize, winter cereal, tomatoes and onions are the main crops in the irrigated areas.

Measurement devices

The instrumentation in each watershed includes (i) an automatic weather station where air temperature, rainfall, relative air moisture, wind speed and direction, soil temperature, and solar radiation are recorded on a 10 min basis. (ii) An hydrological station at the watershed outlet where the water level and turbidity are recorded also every 10 min. Water samples are taken every six hours and then mixed together prior to analysis, to provide a representative daily average sample for determining sediment and water quality parameters. Water samples are analysed following the standard methods at agricultural laboratories of the Government of Navarre.

In Oskotz watershed 2 automatic hydrology stations were installed. The first one named *Oskotz principal* (Op) monitors the whole watershed (forest and pasture). The second one named *Oskotz woodland* (Ow) is located at the outlet of a ca. 500-ha sub-watershed almost fully covered with forest –approximately 90 %– and pasture.

Results

In all the watersheds the rainfall and runoff showed a seasonal pattern: winter was the wettest period, whereas summer is usually the driest. (e.g. Figure 1) The inter-annual variability of rainfall and runoff was high especially in winter.

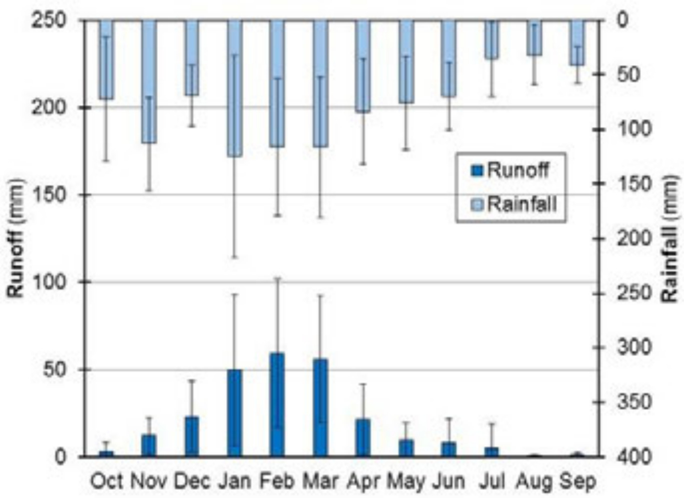

Figure 1: Monthly average rainfall and runoff at La Tejería watershed (2007-2016). Vertical bars are standard deviation. Similar pattern was observed in the remaining watersheds.

Annual average precipitation ranged between 423 mm in Landazuria and 1391mm in Oskotz, with intermediate values in La Tejería (793 mm) and Latxaga (950 mm). Runoff in La Tejería ranged from 4 to 415 mm with an average runoff coefficient of 28 %; in Latxaga it ranged from 38 to 513 mm, runoff coefficient of 26 %; in Oskotz principal runoff ranged from 349 to 1161 mm, runoff coefficient of 46 %; in Oskotz woodland it ranged from 353 to 1275 mm, runoff coefficient of 46 %; and finally in Landazuria runoff ranged from 42 to 143 mm, with a runoff coefficient of 23 %. Note that irrigation is not considered for the computation of runoff coefficient in this last watershed.

Regarding ssy (average values), Landazuria, presented the lowest values (0.3 Mg ha^{-1} $year^{-1}$) followed by Oskotz (Principal and Woodland) (0.9–1.1 Mg ha^{-1} $year^{-1}$). Then, Latxaga (1.4 Mg ha^{-1} $year^{-1}$) and finally La Tejería with by far the highest sediment production (4.3 Mg ha^{-1} $year^{-1}$) (Table 1).

Table 1: Average suspended sediment yield (Mg ha^{-1}) for the studies watersheds (hydrological years 2007-2016). Values in parentheses indicate coefficient of variation (%).

La Tejería	Latxaga	OP	OW	Landazuria
4.3 (87)	1.4 (123)	1.1 (76)	0.9 (83)	0.3(172)

Discussion

In general, sediment yield mainly occurred during winter and beginning of springtime when most of the rainfalls had low erosivity (Casalí *et al.*, 2008). During winter, soils are usually almost saturated and the vegetation cover is scarce especially in the grain-producing watersheds. This led to large runoff rates flowing over unprotected and then vulnerable soils. On the contrary, the higher erosivity of summer rainfalls (Casalí *et al.*, 2008) were mainly offset by more protected and drier soils (i.e., with more infiltration capacity). On the other hand, most of the annual sediment yield could be a result of just a few precipitation events (Casalí *et al.*, 2008).

In Oskotz watersheds ssy were relatively low despite the steep hillslopes frequently present along the landscape. The presence of forest and almost permanent coverage of soils by pastures may have influenced the lower ssy. However, it should be pointed out that Oskotz is prone to eventually suffer from high erosion rates due to forest clearance as was the case in Oskotz principal in 2003 (Casalí *et al.*, 2010).

La Tejería presented three times more ssy than Latxaga. This may be explained largely by both some morphological characteristics of the watersheds, and different vegetation amount in stream channels. In La Tejería, a rather circular shape, flatter topography and higher average slope gradient of stream channels may afford a more efficient removal of watershed precipitations and promote larger peak discharges that tend to reach the outlet simultaneously from all source areas in the watershed. On the contrary, the quite complex topography, gentler slopes and larger vegetation of the stream channels at Latxaga should favour the sedimentation of eroded particles at intermediate locations within the watershed. This sedimentation offsets to some extent sediment yield. The low ssy registered at Landazuría could be explained by the low rainfall and a relative flat landscape. Besides, more than half of the soils are well protected by the vegetation promoted by irrigation.

Conclusions

Sediment yield was more related to current soil conditions and to the erosive capacity of few, infrequent and (highly) erosive rain events, typical of the current climate. An important inter-annual variability of sediment yield was observed, which is also in agreement with the climatic characteristics.

In general, agricultural land use tends to increase sediment yields in our watersheds. However, erosion rate is highly variable depending on a complex (inter)action of a number of natural and man-induced factors such as differences in morphology, topography, vegetation cover of the soils and/or vegetation cover of the stream channel of the watersheds.

Acknowledgements

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To the agricultural watersheds monitoring network of the Government of Navarre.

References

Casalí, J., Gastesi, R., Álvarez-Mozos, J., De Santisteban, L.M., Lersundi, J.D.V., Giménez, R., Larrañaga, A., Goñi, M., Agirre, U., Campo, M.A., López, J.J. & Donezar, M. 2008. Runoff, erosion, and water quality of agricultural watersheds in central Navarre (Spain). *Agricultural Water Management*, 95: 1111-1128.

Casalí, J., Giménez, R., Díez, J., Álvarez-Mozos, J., Del Valle de Lersundi, J., Goñi, M., Campo, M.A., Chahor, Y., Gastesi, R. & López, J. 2010. Sediment production and water quality of watersheds with contrasting land use in Navarre (Spain). *Agricultural Water Management*, 97(10): 1683-1694.

Giménez, R., Casalí, J., Grande, I., Díez, J., Campo, M.A., Álvarez-Mozos, J. & Goñi, M. 2012. Factors controlling sediment export in a small agricultural watershed in Navarre (Spain). *Agricultural Water Management,* 110: 1-8.

Merchán, D., Luquin, E., Hernández-García, I., Campo-Bescós, M.A., Giménez, R., Casalí, J. & Del Valle de Lersundi, J. 2019. Dissolved solids and suspended sediment dynamics from five small agricultural watersheds in Navarre, Spain: A 10-year study. *Catena*, 173: 114-130.

Merging remote and in-situ land degradation indicators in soil erosion control system

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Abstract

The objectives. To determine the land degradation indicators based on satellite and in-situ data for soil erosion assessing and monitoring. **Methods.** The logical model of soil erosion detection and assessment is developed, based on the plane and gully erosion identification by merging the high-spatial resolution Earth observation and in-situ data. The Landsat 8, RapidEye, Sentinel 1,2 satellite data, map materials and data of ground observations were used for erosion identification. The plane soil erosion was determined by humus content modelling using soil spectral characteristics, obtained by satellite data. The gully erosion was identified by using the decision tree, based on the land degradation indicators. **Results**. Remote and in-situ indicators of erosion degradation were developed. The gully erosion distribution within the research area was mapped based on the Sentinel 1,2 radar and multispectral data for 2016-2017. The possibility of soil water erosion assessment and classification using regression models is proved. The areas of plane soil erosion were identified by the humus content modeling using regression models of soil spectral characteristics and in-situ data

Keywords: land degradation, indicators, satellite, in-situ data, humus, gully, modelling

Introduction, scope and main objectives

Erosion degradation is one of the unresolved agricultural problems in many regions of the world, including Ukraine. In Ukraine, more than 15 million hectares of agricultural land are affected by water erosion, that is more than half of arable land. The annual rate of washing away of highly fertile topsoil reaches the 15-20 tonnes ha^{-1} yr^{-1} in some years due to water erosion, and the area of eroded lands is increasing annually by 100 thousand hectares. In Ukraine, the negative trends of land degradation and desertification, as well as soil fertility depletion are getting deeper, and in recent decades have become a global problem, targeting the agricultural lands in all natural and climatic zones. Along with land erosion degradation there is dehumidification of soils, which negatively affects not only the nutritional soil regime, but also its biodiversity and anti-erosion stability.

Soil erosion poses a major threat to global food security and to the achievement of the Sustainable Development Goals, especially Target 15.3: "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world" (UN, 2015).

To monitor the implementation of Target 15.3, an indicator "The ratio of the degraded land area to the total land area" was adopted. (*Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators 2016*).

Traditionally, aerospace materials were used in conjunction with ground-based observations to detect soil erosion or to obtain input data for its simulation, but with the development of space-based systems of high spatial resolution, satellite images have become widely used. The use of multi and hyperspectral remote sensing systems, combining various remote sensing data (Metternicht, Zinck, 1998), ground data (Mathieu *et al*., 2007) and models (De Jong *et al*., 1999) makes it possible to obtain quantitative characteristics of spectral reflection and radiation for automated classification of eroded lands and soil erosion mapping in agricultural landscapes.

With current availability of high spatial resolution satellite images it becomes possible to identify the spatial distribution of eroded soils and gully systems. That causes the necessitates for the identification of complex erosive degradation indicators, development and testing of water erosion classification models based on multispectral satellite images of high spatial resolution.

Thus the creation of up-to-date soil erosion control system using the data of the Earth's remote sensing becomes urgent. The actual aim is the development of modern indicators for this system to determine the soil erosion and assess the area of degradated land.

Methods

Soil erosion indication with remote sensing data is related to the assessment of the erosion determinants, which include soil properties, vegetation, topography and the land use type. The method of integrated assessment of land degradation using GIS / RS technologies is based on the integrated index of soil erosion degradation, which is used for land degradation mapping. This index is calculated by three main characteristics: the land degradation type, spatial extent and rate. To assess the extent and rate of degradation, the relevant model is used in accordance with the type of degradation. Two types of water erosion are considered in this study: plane and gully erosion.

Gully erosion is the most rapidly evolving form of erosion. One of the most important aspect of its monitoring, is the analysis of the conditions of its formation, which could be divided into following groups: landscape relief, climate, geological structure, soil conditions, vegetation cover. This gully formation conditions are used for the development of gully erosion indicators and geospatial models using satellite data to determinate the erosion manifestations and predict the risk of its development. For gully development risk modeling, we developed a decision tree based on the determined indicators of gully erosion (Figure 1). This method allows to carry out the classification of gully objects on satellite images without the prior in-situ data collection on the basis of defined conditions in the form of a decision tree (D'Oleire-Oltmanns *et al*., 2014, Shruthi *et al*., 2011). In-situ data in this case is used to validate the simulation results.

Another type of water soil erosion is *plane erosion*. The spectral brightness of soil reflects the humus content. When the upper genetic horizons of the soil are washed out, the humus content in topsoils decreases accordingly, which leads to the changes in soil spectral characteristics. The detection of these changes makes it possible to estimate the spatial and temporal intensity of erosion processes.

The classification of soil erosion rates by the remote sensing data is based on the integrated use of space-based data of high spatial resolution and supporting thematic information on soil cover characteristics (spectral, agrochemical).

Quantitative characteristics of spectral reflection and radiation make it possible to apply an automated classification of eroded lands based on the ground-based calibration data. The correlation between spectral brightness and humus content is analyzed using satellite image and in-situ sampling data for different soil classes. At each sampling point, the values of the spectral brightness in all spectral bands of satellite image are derived and humus content is determined in the laboratory.

There are two approaches for plane erosion detection using satellite data connected to the soil surface conditions. The first approach is based on the analysis of soil spectral characteristics to assess the changes in humus content. The erosion rate is determined by the mathematical-statistical modeling of the humus content as an indicator of plane erosion. Required stages are the validation of multiply regression models and mapping of spatial distribution of plane erosion within homogeneous regions. The second approach is based on the analysis of spectral vegetation characteristics to assess the vegetation condition as an indicator of soil fertility (Petrychenko *et al*., 2014).

Results

The research was carried out in Kanivsky district of Cherkasy region and Myronivsky district of Kyiv region, as the typical area of agricultural landscapes of the Central Forest-steppe climatic zone. There is a high risk of soil erosion in the study area, in particular the gully development, due to the complex relief. The raster layers for each indicator were derived from satellite data. The indicator of the relief impact, in particular the index of length and slope steepness was calculated based on the elevation model of the study area. The land use type impact was determined on the basis of land cover map, derived by Landsat-8 and Sentinel-1,2 image processing. The following land cover classes were allocated: forest, forest bands, herbal vegetation, agricultural lands. For each class, an indicator of the level of favorable development of erosion was determined.

On Figure 1 the decision tree, developed based on the proposed soil erosion indicators, is demonstrated. The decision tree could be applied in random forest classification method in GoogleEarthEngine environment.

The next stage was model validation for gully erosion detection using ground investigations, and a final map of the gully erosion formation in Kanivsky and Mironivsky regions was obtained (Figure 2).

Plane soil erosion detection was carried out within the mask of arable lands, divided into homogeneous areas in terms of soil type, slope and slope exposure. Five homogeneous by optical characteristics soil classes were identified: dark grey soils, grey sandy loam soil, dark grey light loam soils, black typical low-humus soils, black typical light loam soils.

The correlation between spectral brightness and humus content was analyzed using Landsat satellite image and in-situ sampling data for different soil classes.

The correlation coefficient of spectral brightness, vegetation indices and percentage of humus was quite high, ranging from 0.42 for gray sandy loam soils to 0.78 for dark gray soils and black regressed light loam. As a result, the multiple regression equations of the dependence between the values of humus content as depended variable and the spectral brightness of different spectral bands of Landsat 8 image (R1-8) were obtained by the linear multiple regression method:

1) for dark gray and black soils regressed light loam

$$H = 1.95 + 1.21 \times R1 + 2.55 * R2 – 1.15 * R3 - 3.26 * R4 + 1.25 * R5 + 1.67 * R6 – 0.44 * R7 – 0.58 * R8,$$

2) dark grey light loam

$$H = 1.07 - 6.54 * R1 + 0.73 * R2 - 0.71 * R3 + 1.87 * R4 + 10.83 * R5 + 0.26 * R6 - 3.05 * R7 + 0.84 * R8$$

3) grey sandy loam

$$H = -1.7 – 13.72 * R1 + 3.3 * R2 + 5.78 * R3 + 8.79 * R4 + 6.12 * R5 + 8.21 * R6 – 0.69 * R7 – 0.16 * R8$$

4) black soils typical little humus

$$H = -3.37 – 2.49 * R1 + 80.92 * R2 + 16.37 * R3 - 22.27 * R4 + 3.96 * R5 + 1.9 * R6 – 12.42 * R7 + 2.03 * R8$$

5) black soils typical light loam

$H=0.4+0.19*R1+0.93*R2+0.14*R3+0.56*R4+4.52*R5+0.39*R6+1.25*R7-0.32*R8$;

6) black soils typical little humus, covered by winter wheat (by RapidEye image)

$H=0.16343*BI - 0.00044*BI^2 - 0.30913*BIRE + 0.00074*BIRE^2 + 18.68743$,

where

H – humus, Ri – spectral bands, $BI=sqrt((R2^2 +R3^2)/2)$, $BIRE=sqrt((R2^2 +R4^2)/2)$.

Average relative error of the model is 14.8 %, calculated by the comparative analysis of modeled humus content and soil samples data, which were not included in multiple regression model.

The spatial distribution of soil erosion degradation was assessed based on the ratio of eroded lands in the region. Up to 9.8 % of the territory of Kanivsky region are considered to be highly eroded lands, resulting in more than 20 tonnes ha^{-1} yr^{-1} of soil loss, and up to 1.9 % in Myronivsky region. The results may be used for the development of land conservation plans.

Discussion

The main objective of the study was to demonstrate the possibility of combining in-situ and satellite data to obtain the soil degradation indicators and use it in erosion control.

The increase of extreme rainfall, growth of cultivated crops areas, lack of the anti-erosion measures, degradation of field-protecting forest bands create the conditions for the development of catastrophic erosion processes. Thus, the results of feasibility study on integrated use of remote and in-situ indicators of gully and plane erosion are highly important.

Conclusions

The use of up-to-date remote sensing and geoinformation technologies enables to obtain the accurate and up-to-date information on the state of soil cover at various spatial levels. The decision tree for logical model of soil erosion determination and assessing, based on the merging of remote sensing data of high spatial resolution with in-situ data is proposed. The possibility of soil water erosion assessment and classification using regression models is proved with the accuracy of 85 %. The results of erosion process risk assessment using remote sensing are the basis for the planning and implementation of the anti-erosion measures to optimize the structure of agricultural landscapes and land use systems.

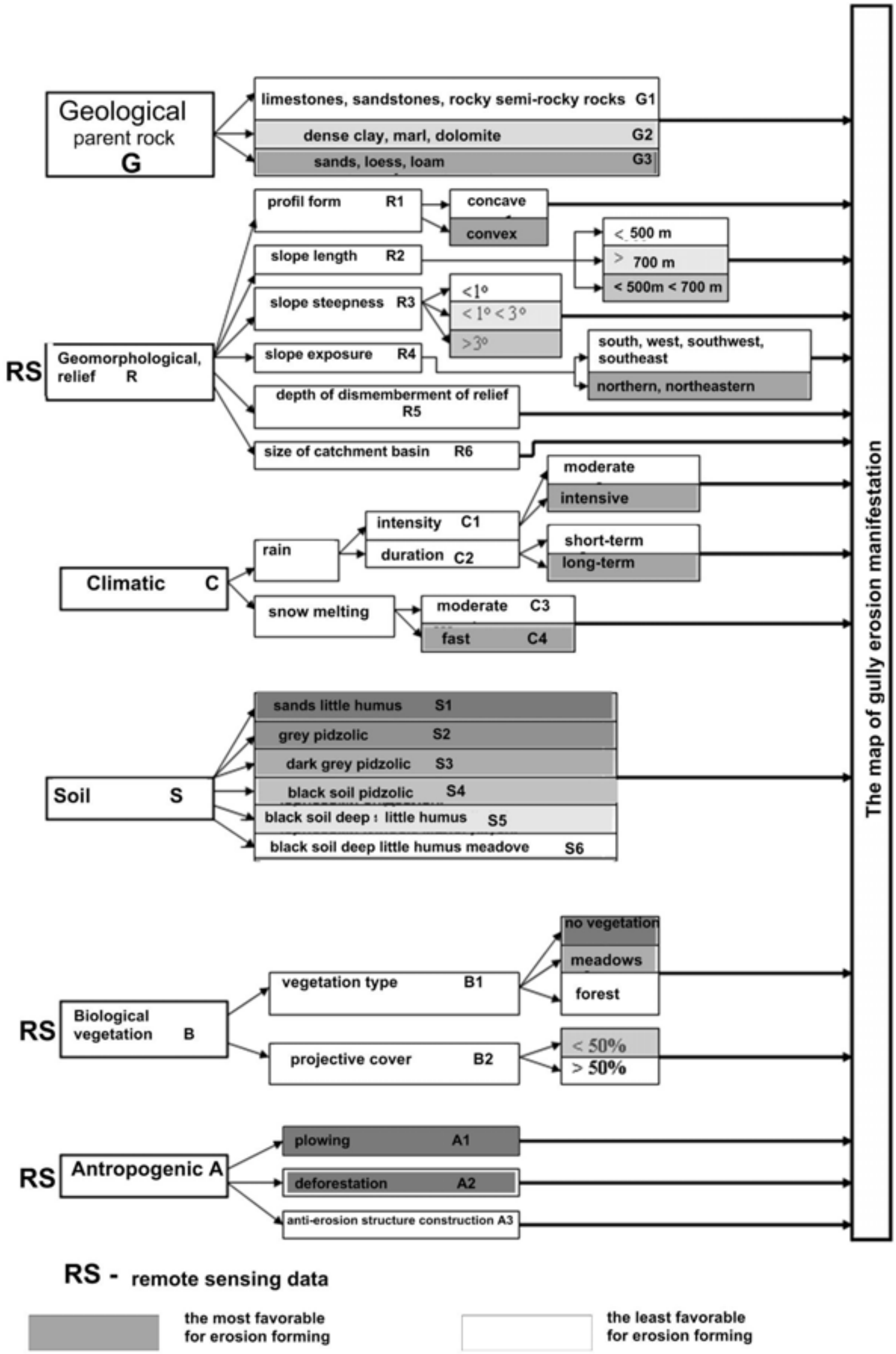

Figure 1: Indicators of the gully erosion formation

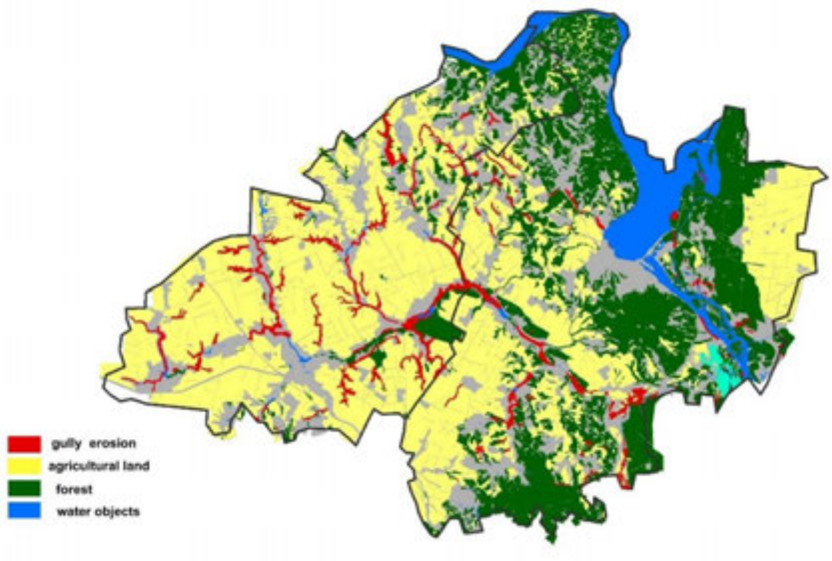

Figure 2: Map of the gully erosion formation in Kanivsky and Myronivsky regions

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The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

References

De Jong, S.M., Paracchini, M.L., Bertolo, F., Folving, S., Megier, J. & De Roo, A.P.J. 1999. Regional assessment of soil erosion using the distributed model SEMMED and remotely sensed data. *Catena*, 37(3−4): 291−308.

D'Oleire-Oltmanns, S., Marzolff, I., Tiede, D., Blaschke, T. 2014. Detection of Gully-Affected Areas by Applying Object-Based Image Analysis (OBIA) in the Region of Taroudannt, Morocco. *Remote Sens*., 6: 8287-8309; doi:10.3390/rs6098287.

Mathieu, R., Cervelle, B., Remy, D. & Pouget, M. 2007. Field-based and spectral indicators for soil erosion mapping in semi-arid mediterranean environments (Coastal Cordillera of central Chile). *Earth Surf. Process. Landf*., 32(1): 13−31.

Metternicht, G.I. & Zinck, J.A. 1998. Evaluating the information content of JERS-1 SAR and Landsat TM data for discrimination of soil erosion features. ISPRS J. *Photogramm*, 53(3): 143−153.

Petrychenko, V.F., Tarariko, O.H. & Syrotenko, O.V. 2014. Space Technologies in Agri-Environmental Monitoring System. *Agric. sci. pract.*, 1(1): 3-12.

Shruthi, R.B., Kerle, N. & Jetten, V. 2011. Object-based gully feature extraction using high spatial resolution imagery. *Geomorphology*, 134: 260–268.

UN. 2015. Transforming our world: the 2030 Agenda for Sustainable Development. Available at: https://sustainabledevelopment.un.org/post2015/transformingourworld/publication.

UNSTATS. 2016. Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators. Available at: https://unstats.un.org/unsd/statcom/47th-session/documents/2016-2-IAEG-SDGs-Rev1-E.pdf.

Factors controlling the spatial distribution of sediment yield and area-specific sediment yield on large scale: example of Morocco

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Abstract

Morocco ranks among countries with the greatest achievements in the field of dams in Africa, but affected by sedimentation phenomenon due to soil erosion. However, the assessment of soil erosion and sedimentation remains a global challenge, practically in Morocco characterized by a great morphological, climatic and biological diversity. We collected and analyzed an extensive data of 42 catchments of the biggest and important dams of Morocco, the mean observed sedimentation (SY) found was 1.96 $Mt \cdot yr^{-1}$ and the Suspended Sediment Yield (SSY) was 6.40 $t \cdot ha^{-1} \cdot yr^{-1}$. In order to produce a model able to assess SSY and SY; Correlation analysis, Agglomerative Hierarchical Clustering, the Principal Component Analysis and Classification and Regression Tree model (CART) were used. The elaborated statistical analysis show that SY is more related to the catchment area and drainage network length, on the other hand the variation of SSY is more related to soil organic content stock, Rainfall and Clay fraction, the CART model using this variables gives very good satisfactory results in predicting the SSY (NSE=0.80, R^2=0.79; RMSE=6.21 $t \cdot ha^{-1} \cdot yr^{-1}$). The proposed approach is a very simple approach that can present a real key-solution to the difficulty of the comprehension and assessment of SSY across the world.

Keywords: Soil erosion, Sediment yield, Area-specific sediment yield, Morocco, Statistical approach

Introduction, scope and main objectives

Morocco is one of the African countries with the highest number of dams (Cole *et al.,* 2014) experiencing the growing necessity for dams to satisfy the increasing water and energy needs, population growth and climatic changes (e.g. Alhassan, 2009; Wisser *et al.,* 2013). Despite this fact, there is a major lack of studies and necessary data aiming the assessment and study of sedimentation due soil erosion mean factor major deteriorating factor affecting dams, furthermore, understanding the sediment delivery process at the catchment scale remains a real challenge in erosion and sedimentation research (e.g. Walling, 1984; Milliman and Farnsworth, 2011).

Dealing with these challenges, researchers and policymakers face the question of which model is most effective and efficient to predict sediment yield and area-specific sediment yield. However, conceptual, traditional physics-based and empirical or regression models didn't show the ability to define these processes due to unfeasible required data and insufficient systems knowledge. In the light of this concerns, we used some building statistical models and Remote sensing coupled with

Geographic Information System technique to: i) the proposition of a simple approach able to predict SSY and SY ii) determine the spatial distribution of sediment yield and SSY and factors.

Methodology

In order to understand factors controlling the suspended sediment yield SSY ($t \cdot ha^{-1} \cdot year^{-1}$) and sediment yields SY ($t \cdot year^{-1}$) in Morocco and produce a model able to predict them, the study approach consisted of five main steps: (1) estimation of the observed SY and SSY on the basis of the bathymetric surveys of the studied check dams (2) the collection of the most important parameters characterizing the catchments of the considered dams (3) introduction of all information collected in statistical approaches (4) The selection and exploitation of those variables with close relation to SSY and SY and introduction exploitation, (5) processing and validation of models able to predict SY and SSY.

The database used consists of:

-Vegetation: NDVI;

-Soil data: clay fraction, silt fraction, sand fraction, coarse fragment volumetric, deep to bed-rock up to 200 cm, absolute deep to bed-rock, soil organic carbon stock;

-Climate: aridity index, precipitations;

-Morphology: altitude, slope;

-Hydrology: catchment area, drainage network length, drainage density;

-RUSLE factors: C-Factor, R-Factor, K-Factor, LS-Factor, A the result.

Results

Spatial distribution of sediment yield SY and area-specific sediment yield SSY

The distribution map of SY ($Mt^3 \cdot year^{-1}$) and SSY ($t \cdot ha^{-1} \cdot year^{-1}$) was illustrated in Figure 1A. Results show a mean SY of 1.96 $Mt \cdot year^{-1}$, recording as a highest value of SY 15.08 $Mt^3 \cdot year^{-1}$, the lowest value recorded is 0.04 $Mt^3 \cdot year^{-1}$. The average SSY is 6.40 $t \cdot ha^{-1} \cdot year^{-1}$, the lowest value is 1.02 $t \cdot ha^{-1} \cdot yr^{-1}$, and the highest value is 55.25 $t \cdot ha^{-1} \cdot year^{-1}$. The majority of watershed experiencing high SSY are located in the North, these watersheds are generally characterized by a Mediterranean climate, dense vegetation and located in the north, the presence of the friable lithology in these areas induces spectacular gully soil erosion as mentioned by many authors (Gourfi *et al.,* 2018).

Correlation test analysis

The correlation matrix between Area-Specific Sediment Yield, Sediment Yield and catchment properties shows information about relations existing between some variables, most relevant remain the existing relation between rainfall and soil organic carbon stock (r=0.88), the observed sediment yield and catchment area (r=0.74), the estimated soil erosion using RUSLE model and slope (r=0.73), silt content and NDVI (r=0.78).

A set of founded high correlations between some variables indicated collinearity between them. For example, Rainfall, C-RUSLE factor, Soil organic carbon stock and NDVI are strongly correlated, and also, catchment area, drainage network length and drainage density.

Only a few variables are significantly correlated with sediment yield, the most important explanatory variables for SY are catchment area and stream length, with respectively a correlation coefficient of 0.74 and 0.73. The SSY shows as a most important positive correlation with the NDVI and SOCS respectively 0.56 and 0.53, a moderate negative correlation is also observed between SSY and C-RUSLE factor, drainage density, drainage network, catchment area and K-RUSLE factor respectively -0.57, -0.55, -0.53, -0.52 and -0.52.

Major groups of watersheds in Morocco

The application of the Principal Component Analysis (PCA) decorticates the watershed in Morocco into four major categories, each category is characterized by a vegetation cover, a climate and a geography. The PCA allowed also the understanding of variables having close relation with this groups (Figure 1B).

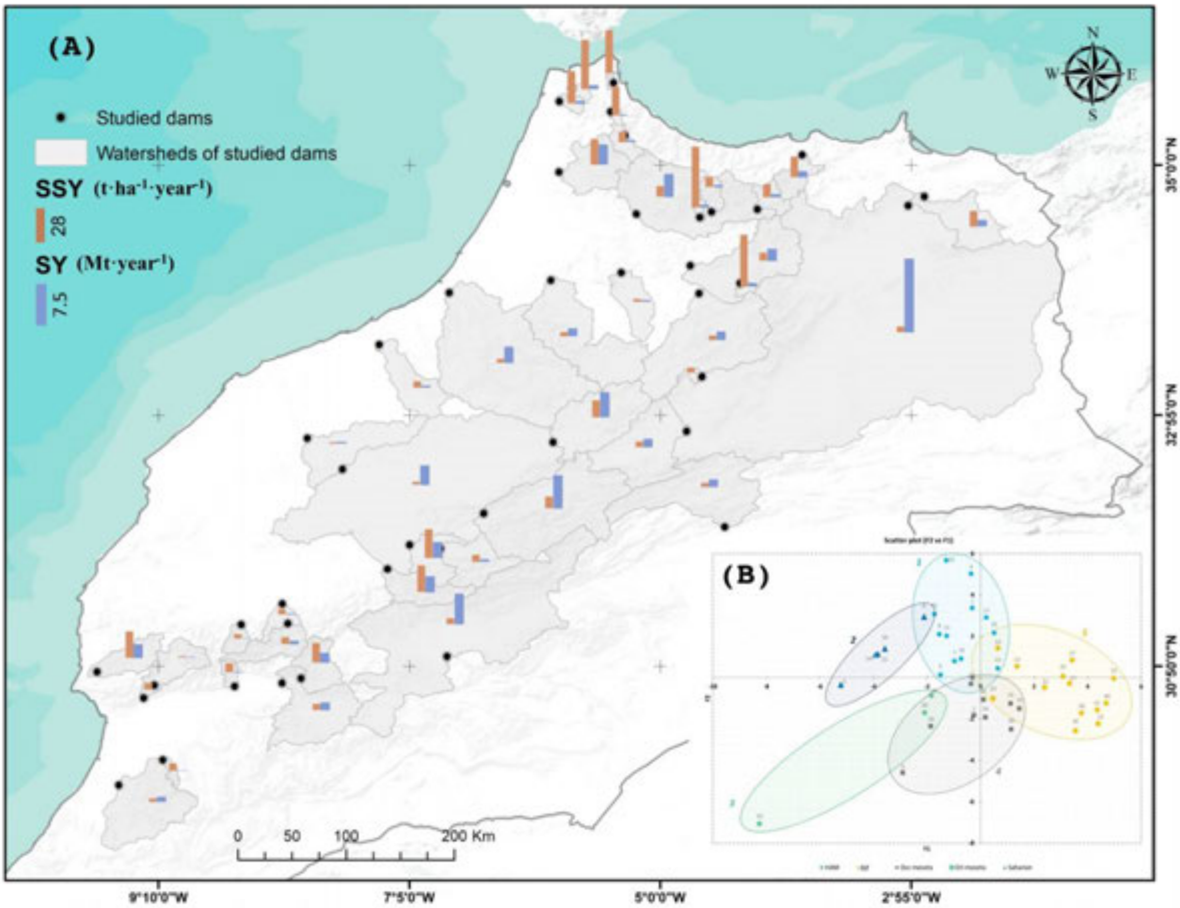

Figure 1: A: Factors controlling SSY and SY, B: Major watersheds groups

The Agglomerative Hierarchical Clustering (AHC) is a statistical model performed in order to detect similarities between area-specific sediment yield, sediment yield and the other studied parameters (Figure 2A). The displayed result show that SY is more related to the catchment area and drainage network length, it is this two parameters that have taken into consideration in the PLS model (Partial Least Squares Regression) in order to produce an equation able to estimate SY, the obtained results reveals a very satisfactory predictions models with a Nash criterion of NSE=0.82, R^2=0.82; RMSE=1.17 $Mt^3 \cdot yr^{-1}$; p value<0.0001; n=42. Clay, Bulk density, Silt, Rainfall, Aridity index, R factor, Soil organic carbon stock and NDVI are the factors having the closest variation with SSY, these variables were taken as input parameters to the Classification and Regression Tree model (CART), this last, selected only three parameters considered according to the model as most useful in describing the given SSY data set, the final tree structure is illustrated in Figure 2B. The SOCS variable located at the upper parts of the tree structure, Rainfall variable at the middle, while variables of SOCS and Clay were located in the lower parts of the tree, the applied classification and regression tree model is a very good predictor model, with NSE=0.80, R^2=0.79; RMSE=6.21 $t \cdot ha^{-1} \cdot year^{-1}$; p value < 0.0001; n=42.

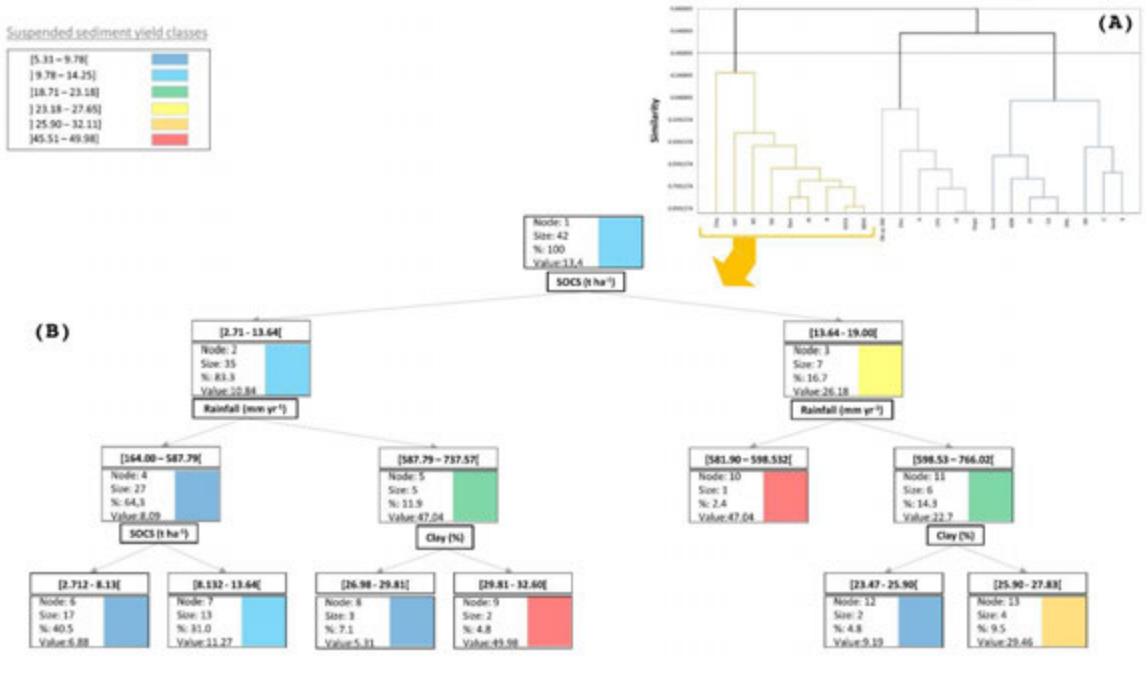

Figure 2: A: The Agglomerative Hierarchical Clustering (AHC), B: Resulting classification and regression trees map

Discussion

Conceptual, traditional physics-based and empirical or regression models didn't show the ability to define these processes due to unfeasible required data and insufficient systems knowledge. Therefore, the applicability of these models at the basin scale is troublesome. Generally, most empirical models are based on the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.,* 1997), developed to predict soil losses generated by sheet and rill erosion. As sediment deposition is not considered (Wischmeier, 1976; Boardman, 2006), not either permanent gullies and landslides (Verstraeten *et al.,* 2003); such models cannot be used to predict catchment SSY (De Vente *et al.,* 2013; Gourfi *et al.,* 2018). Gully erosion and landslides remain one of the most important forms of soil degradation and have long been neglected because of the difficulty to study and to predict (Valentin *et al.*, 2005). Furthermore, gullies and landslides can be a substantial proportion (10–80%) of total erosion (Boardman *et al.,* 2006). At the Mediterranean regions, only gully erosion may produce a rate of erosion from 1.1 to 455 $t \cdot ha^{-1} \cdot yr^{-1}$ (Poesen *et al.,* 2006). Thus, to model valid sediment fluxes and to create valid practical tools for watershed management, it is fundamental to introduce all types of land degradation. However, it took a large amount of data difficult to have, particularly for a developing Mediterranean country such as Morocco, suffering from a lack of studies. This work proposes a simple approach able to estimate SSY and SY, the approach result can give satisfactory results and can give a vision of haw factors controlling SSY are spatially distributed. The used approach will not be only a benchmark indicator on SSY in Morocco and areas with various environments, more comprehensive and accurate than those derived in previous assessments, but also, build a solid dataset for decision makers and regional policy wishing to make studies and relative characterization related to reservoirs sedimentation and land degradation by water.

Conclusions

(i) A database of annual values of sediment yield and area specific sediment yield was constructed for most important Moroccan dams catchments.

(ii) Highlighted the good linear relation found between catchment size and SY.

(iii) Emphasize the main factors parameters having a close relation with area-specific sediment yield and sediment yield.

(iv) The application of a simple approach able to asses SSY in the light of the difficulty to estimate the last one in a country know by a great morphological, climatic and biological diversity.

References

Alhassan, H.S. 2009. Viewpoint — butterflies vs. hydropower: reflections on large dams in contemporary Africa. *Water Altern.*, 2: 148–160.

Boardman, J. & Poesen, J. 2006. Soil erosion in Europe: major processes, causes and consequences. Soil Erosion in Europe. Wiley, Chichester., 479–487.

Cole, M.A., Elliott, R.J.R. & Strobl, E. 2014. Climate change, hydro-dependency, and the African dam boom. *World Development*, 84-98

de Vente, J., Poesen, J., Verstraeten, G., Govers, G., Vanmaercke, M., Van Rompaey, A., Arabkehdri, M. & Boix-Fayos, C. 2013. Predicting soil erosion and sediment yield at regional scales: where do we stand? *Earth Sci. Rev.,* 127: 16–29.

Gourfi, A., Daoudi, L. & Shi, Z. 2018. The assessment of soil erosion risk, sediment yield and their controlling factors on a large scale: Example of Morocco. *Journal of African Earth Sciences*, 147: 281–299.

Milliman, J.D. & Farnsworth, K.L. 2011. River Discharge to the Coastal Ocean: A Global Synthesis. Cambridge University Press, Cambridge, United Kingdom, (384 pp.).

Poesen, J., Vanwalleghem, T., De Vente, J., Knapen, A., Verstraeten, G. & Martinez-Casasnova, J.A. 2006. Gully erosion in Europe. In: Boardman, J., Poesen, J. (Eds.), Soil Erosion in Europe. Wiley: Chichester, 515-536.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. & Yoder, D.C. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised universal soil loss equation (RUSLE). USDA agricultural handbook 703.

Valentin, C., Poesen, J. & Yong, L. 2005. Gully erosion: impacts, factors and control. *Catena*, 63: 132–153.

Verstraeten, G., Poesen, J., de Vente, J. & Koninckx, X. 2003. Sediment yield variability in Spain: a quantitative and semiqualitative analysis using reservoir sedimentation rates. *Geomorphology*, 50(4): 327-348.

Walling, D.E. 1984. The sediment yields of African rivers. In: Walling, D.E., Foster, S.S.D., Wurzel, P. (Eds.), Harare symposium, challenges in African hydrology and water resources. IAHS Publication, 144: 265–283.

Wischmeier, W.H. 1976. Use and misuse of Universal Soil Loss Equation. *J. Soil Water Conserv.*, 39: 105–107.

Wisser, D., Frolking, S., Hagen, S. & Bierkens, M.F.P. 2013. Beyond peak reservoir storage? A global estimate of declining water storage capacity in large reservoirs. *Water Resour. Res.,* 49: 5732–5739.

Using fingerprint methods to implement effective strategies for management, sustainable use and conservation of the Brazilian Atlantic Forest ecosystems

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Abstract

Guapi-Macacu River Basin has great socioeconomic importance, being responsible for supplying water of about 2.5 million inhabitants. The basin has been subjected to intense processes of physical alteration to introduce small urban centers focused on agriculture and livestock activities in the last 100 years. In addition, a petrochemical complex (COMPERJ) is being built in this area. Aiming to contribute to the strengthening of soil and water conservation strategies at the landscape level in natural and agricultural ecosystems from Atlantic Forest Biome, Compound-Specific Stable Isotope (CSSI) and Diffuse Reflectance Fourier-Transform Mid-Infrared Spectroscopy (DRIFT-MIRS) techniques were used to identify hotspots of soil erosion in this basin. For soil apportionment assessment, a mixing model based on a Bayesian inference framework was used (CSSIAR v.2.0). The results indicated that main sediment sources that are silting the mangroves in the Guapimirim APA and damaging its water quality are mainly from pasture and sugarcane activities and river bank erosions. Activities of extracting sand also need to be revised and adjusted to avoid the Macacu River siltation.

Keywords: soil erosion process, landscape level, fingerprinting, soil apportionment, CSSIAR, soil and water conservation strategies

Introduction

About half the Brazilian population live in the Atlantic Forest biome, whose way of life directly affects its hinterland and coastal environments. The incorporation of modern human societies and their needs for forest resources has greatly reduced the Atlantic Forest in size. Almost 88 % of the original forest habitat has been degraded by human-modified landscapes, including pastures, croplands, and industrial/urban areas. This reinforces the urgent need to implement more effective strategies for management, sustainable use and conservation of the Brazilian Atlantic Forest ecosystems.

The identification of critical areas prone to erosion can assist this task to better target soil conservation efforts. Investigations at the watershed level can provide the information required to understand the spatial patterns and complexity of sediment fluxes and sediment sinks and thus the efficiency of sediment delivery to the stream network and to link downstream sediment fluxes with upstream sediment sources (Gibbs, 2008; Bravo-Linares *et al.*, 2018). Soil conservation measures should target the major runoff and sediment source areas. These critical source areas may represent only a small fraction of the total surface area of a watershed and targeting these areas can result in significant cost savings when implementing soil conservation measures. Identification of key sediment source areas and sediment delivery pathways at the watershed level will enable planners to optimize land use according to both the risk and the potential associated with individual areas within the watershed (Gibbs, 2008).

The objective of this work is therefore to use fingerprinting techniques to obtain accurate and up-to-date quantitative information on the spatial distribution of the main sediment sources that are contributing to the Atlantic Forest degradation in the Southeastern Brazil.

Methodology

Study area

The Guapi-Macacu River Basin (GMRB) is located on the eastern part of the Guanabara Bay, Rio de Janeiro, ranging from 22°20'00" S to 22°40'00" S and from 43°05' 00" W to 42°30'00" W (Figure 1A). The basin has a drainage area of 1 256 km², being formed mainly by the rivers Macacu and Guapiaçu. The climate is subtropical. The annual mean temperature ranges from 18°C to 23°C. The mean annual precipitation varies from 2 500 mm (on the steep slopes of the mountain range) to 1 500 mm (on the lowest areas), with relative air moisture around 83 %. The main characteristics of the land use can be found on Figure 1C.

Sample collection

The chosen area covers around 50 km^2, encompassing the Guapimirim APA entrance, Imunana dam, COMPERJ's construction sites and the main agricultural, livestock, urban, industrial and reforestation areas located along the Guapiaçu and Macacu rivers (yellow rectangle on Figure 1A).

Figure 1B shows 30 sampling sites inside the 50 km^2 area, from which soil and sediments samples were collected, representing the main soil degradation sources and sediment accumulation point in the basin, respectively. As potential soil erosion sources, areas from riparian forest, pasture, sugar cane, crop rotation (corn, manioc, beet, okra etc.), river bank erosion, artificial drains, roads and access routes to COMPERJ were selected. As sediment accumulation (sink) samples, several points were chosen in the Guapiçu and Macacu rivers. Boundary sediment samples were used as soil erosion sources from outside the 50 km^2 sampling area.

Fingerprint methods

DRIFT-MIRS analysis was carried out at LARA. Wavelength spectra were obtained from a Praying Mantis Diffuse Reflection Accessory (Harrick Co.) coupled to Tensor II Fourier transform spectrometer (Bruker Optik GmbH, Ettlingen, Germany) equipped with a potassium bromide (KBr) beam splitter and a RT-DLaTGS detector. The spectra were obtained in triplicate in the mid-infrared range (4000 - 400 cm^{-1}) by combining 16 individual scans at a resolution of 4 cm^{-1} recorded in absorbance units [log(1/Reflectance)]. All spectra were averaged and baseline corrected. Additionally, the background CO_2 region (2400 to 2300 cm^{-1}) and spectrum edges (> 3900 and < 700 cm^{-1}) were excluded (Demyan *et al.*, 2012). Isotope analyses of $\delta^{13}C$ (bulk and fat acids - FA) were performed at UC Davis Stable Isotope Facility (USA). For the application of the mixing model, the CSSIAR v.2.00 software was used (los Santos-Villalobos *et al.*, 2017).

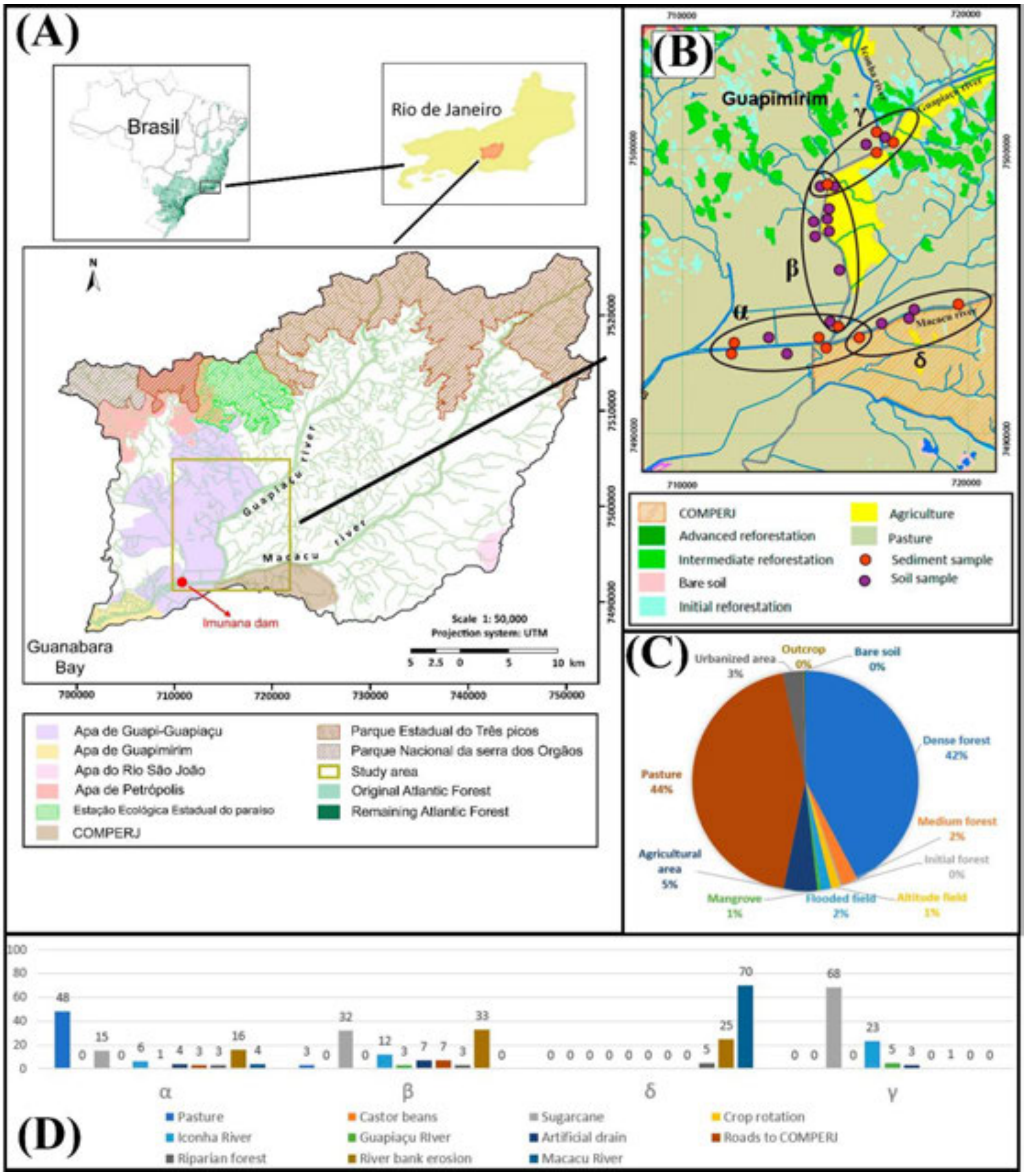

Figure 1: A) Localization of the Guapi-Macacu River basin and study area; B) Sampling sites. Modified from Pedreira *et al.* (2009). The regions delimited by α, β, δ and γ represent the four sectors in which CSSIAR modelling was applied to generate the spatial distributions of sediments from erosive processes; C) Main characteristics of the land use; D) Sediment apportionment from soil/sediment samples. Error bars represent the standard deviation obtained by different iterations from the mixed model.

Results

Sediment source discrimination based on fingerprint methods was performed applying the DRIFT-MIRS and CSSI techniques in soil/sediment samples from Guapi-Macacu River Basin.

Using the unsupervised multivariate cluster analysis of soil and sediment was possible to reorganize the DRIFT-MIRS spectra in order to discriminate the main soil constituents.

In turn, the spectral peaks can be related to the main soil constituents: quartz (Qz), organic compounds (OC), and soil clay minerals (SCM – kaolinite [Kt], smectite [Sm], mica [Mc], hydroxy-interlayered vermiculite [HIV], gibbsite [Gb]) (Demyan *et al.*, 2012). The $\delta^{13}C$ bulk from the total organic carbon and their respective $\delta^{13}C$ - FA for the sediment sources werw used to determine the sediment apportionment (Figure 1D).

Discussion

The spatial variability was performed by estimating the soil proportion ratios. Around upper part of Sector γ (Figure 1D), the main sediment sources are expected to come from erosion processes related to the activities of sugarcane and castor bean cultivations, pasture and artificial drainages. Using the CSSIAR approach, it was found that the sediments are produced mainly by the sugarcane cultivation. Specifically, CSSIAR suggests that the erosion process from sugarcane cultivation contributes 68 ± 11 % of the sediments, Iconha River with 23 ± 11 %, and Guapiaçu River with 5 ± 3 %. The contribution from artificial drains with only 3 ± 2% and the pastures and castor bean cultivation are negligible.

From the intersection between Sectors γ and β, it is possible to evaluate the sediment transport from Sector γ (Figure 1D). Along this sector, crop field activities, pastures, riparian forests, bank erosions on the Guapiaçu River, and the construction of a road to COMPERJ are observed. The mixed model calculations indicate that the main sediment source is originated from the bank erosion present on the elevated sides of the Guapiaçu River (33 ± 6 %), when compared to the road to COMPERJ (7 ± 2 %), pasture (3 ± 1 %) and riparian forest (3 ± 1 %). On the other hand, it is also observed that the sediments generated around upper part of Sector γ run through this sector, entering Sector β, since sugarcane cultivation contributes 32 ± 5 % of the sediments in the Sector γ, artificial drains with 7 ± 2 %, Iconha River with 12 ± 5 %, and Guapiaçu River with 3 ± 2 %.

Analyzing now the upper part of Sector δ, the sediment samples collected in the Macacu river bed represents the reservoir of the all sediment sources from upstream of the Macacu river. Activities of sediment extraction from the river to be used as building material, bank erosion, guava cultivation, and pasture areas are observed in the upstream. It was found that the highest amount of sediment in the Sector δ comes from the upper part of the Macacu River (70 ± 2 %). The river bank erosion contributes with 25 ± 2 %, and riparian forest with only 5 ± 2%. No contribution of sediment sources from the pastures and COMPERJ areas was observed by using CSSIAR modeling.

Sector α is characterized by a large area of pasture without riparian forest, and the few existing ones were very spaced. Therefore, this sector shows little environmental protection on the banks of the Macacu River. According to Figure 1D, the sediments from Sector δ have a low influence on the sediment accumulation in the Immunana dam. Sector δ disclose as an area of sediment transit and trapping. Most of the 70 ± 2 % of the sediments originated in the upper part of the Sector δ are retained on this sector. Only 4 ± 1 % of them reach the Immunana dam. The main sediment source apportionments in this dam are from the local pasture soil (48 ± 7 %) and river bank erosion (16 ± 1 %). The other influences on the Immunana dam come from Sector β: sugarcane (15 ± 2 %), Iconha River (6 ± 2 %), Guapiaçu River (1 ± 1 %), artificial drains (4 ± 1 %), road to COMPERJ (3 ± 1 %), and riparian forest (3 ± 1 %).

The DRIFT-MIRS analysis indicated that the study area consists of argisols (Group 1), latosols (Group 2) and cambisols (Groups 3). These results agree with the Brazilian Soil Map from the Brazilian Institute of Geography and Statistics (IBGE, 2014). In addition, it was observed that Sector α (Immunana dam) receives the influence of sediment sources originating mainly of argisols (Group 1) and cambisols

(Groups 3). This finding corroborates the CSSIAR modelling, since the sediment source apportionment from the construction of a road to COMPERJ (Group 2, latosols) is very low (3 ± 1 %) on the Sector α.

Conclusions

The findings suggest that some sectors already use a few effective strategies for management, sustainable use and conservation of the Guapi-Macacu River Basin. Other sectors still need to implement more effective strategies of soil and water conservation. For instance, the activities of extracting sand (upper part of Sector δ) need to be revised and adjusted to avoid the Macacu River siltation. Riparian forests should be introduced in sugarcane (Sector γ) and pasture (Sector α) areas, comparable to those in Sector δ. Burning activities should be eliminated. The river bank erosions present in the Sectors α, β, and δ should be recovered.

There are several plant species that are economically valuable, well adapted to the Atlantic Forest ecosystems and can be used successfully for the recovery of riparian forest and river bank erosions. They allow financial counterbalancing the reduction of the area of planting to protect the river banks. In addition, the agricultural producer will have financial gains by reducing the fertilizer use.

Acknowledgements

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References

Bravo-Linares, C., Schuller, P., Castillo, A., Ovando-Fuentealba, L., Muñoz-Arcos, E., Alarcón, O., de los Santos-Villalobos, S., Cardoso, R., Muniz, M., Meigikos dos Anjos, R., Bustamante-Ortega, R. & Dercon, G. 2018. First use of a compound-specific stable isotope (CSSI) technique to trace sediment transport in upland forest catchments of Chile. *Science of The Total Environment*, 618: 1114–1124. https://doi.org/10.1016/j.scitotenv.2017.09.163.

de los Santos-Villalobos, S., Bravo-Linares, C., dos Anjos Roberto, M., Cardoso, R., Gibbs, M., Andrew, S., Mabit, L. & Dercon, G. 2017. The CSSIAR v.1.00 Software: A new tool based on SIAR to assess soil redistribution using Compound Specific Stable Isotopes. *SoftwareX*, 6: 13–18. https://doi.org/10.1016/J.SOFTX.2016.12.005.

de los Santos-Villalobos, S., Bravo-Linares, C., dos Anjos Roberto, M., Cardoso, R., Gibbs, M., Andrew, S., Mabit, L. & Dercon, G. 2017. The CSSIAR v.1.00 Software: A new tool based on SIAR to assess soil redistribution using Compound Specific.

Gibbs, M. 2008. Identifying source soils in contemporary estuarine sediments: A new compound-specific isotope method. *Estuaries and Coasts*, 31: 344-359.

Quantifying erosion using 137Cs in cultivated soil in the Sbaihia watershed-Zagouane, Tunisia

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Abstract

Soil erosion is a prime cause of loss of productivity of land. Decline in land productivity in most cases triggers the conversion of natural forests into agricultural land. The severe soil erosion in the highlands of Tunisia is believed to be a result of agricultural conversion.

The objective of the present study was to evaluate the applicability of the ^{137}Cs technique to assess soil redistribution rates for different management's types of watershed of Zaghouan in the north of Tunisia with an area of 355 ha. For this purpose tow crop fields of the land were selected. One soil is preserved with banquet and the second without. It has an average annual rainfall of 440 mm. The management actions represent 35 % of the area. As for the types of land use most often found in the watershed area, there are annual crops (cereal crops), forests, scrublands and bare soil. The spatial distribution of the soil redistribution rates obtained by the ^{137}Cs method using Mass Balance Model II for the tow plots of land (managed and non-managed soil) has significant variations. The ^{137}Cs estimates of soil movement and redistribution were related to slope, land use, and conservation practices. The ^{137}Cs inventories of the tow plots were compared to the reference inventory value 1322 (Bq/m^2) with CV 28 %, for the reference site (non-disturbed and a forest site). The mean annual erosion rates found using MBM II in managed soil is 21 t ha^{-1} year^{-1}. The mean annual erosion rates were obtained to be 38 t ha^{-1} year^{-1}, respectively in the non-managed soil.

Key Words: Caesium-137, fallout radionuclide tracer technique, reference inventory, soil erosion, Mass Balance Model

Introduction

Several quantitative and qualitative techniques have been developed and used to estimate soil erosion and deposition throughout the world. However, most of them do not produce the spatial patterns of soil movements and redeposition of eroded particles within the fields to understand soil loss. Use of nuclear techniques in erosion monitoring and especially for qualification of soil loss has offered a fast and economical tool to estimate erosion rate starting with ^{137}Cs in 1970s (Ritchie and McHenry, 1990). ^{137}Cs techniques have been used extensively to quantify erosion-induced soil losses over the 35– 40 years (McIntyre, 1987; Walling *et al.*, 1995; Walling and He, 1999; Ritchie and Rasmussen, 2000; Theocharoploulos *et al.*, 2002; Ugur *et al.*, 2003a, 2003b, 2004; Sac, 2003). Fallout of this artificial radionuclide from the atmospheric testing of nuclear weapons began in 1954 and reached a peak in 1963, the year of international test ban treaty, after which it declined sharply.

The ^{137}Cs levels in soils of reference site, managed soil and non-managed soil were determined to be 2–16 Bq kg^{-1}, 0.7–11 Bq kg^{-1} and 0.7–4 Bq kg^{-1}, respectively. ^{137}Cs (half-life of 30.2 years) deposited on land became tightly sorbed to soil particles and was concentrated in the surface layer of undisturbed soils. At the field level deposition of ^{137}Cs appears to have been relatively uniform.

The advantages of using the ^{137}Cs technique to study soil erosion are that it (a) requires a single sampling trip to the field; (b) provides results quickly; (c) allows retrospective assessment of soil erosion rates (average losses for 35–40 year period thus is less influenced by extreme events); (d) provides estimates of soil erosion rates, deposition rates, and export rates and (e) allows a sampling strategy to provide any spatial resolution required (Nouira *et al.*, 2003)

The studied site is a Watershed (small basin) located in the northern part of Zaghouane in Northern Tunisia. Tow crop fields were chosen to be studied, one preserved soil with benches the other not preserved. The shoulder slopes of the hills with typical range 5–17% were selected for sampling (Figure 1). The climate is typically Mediterranean with a mean annual rainfall of 440 mm, most of which is concentrated during the period extending from December to April.

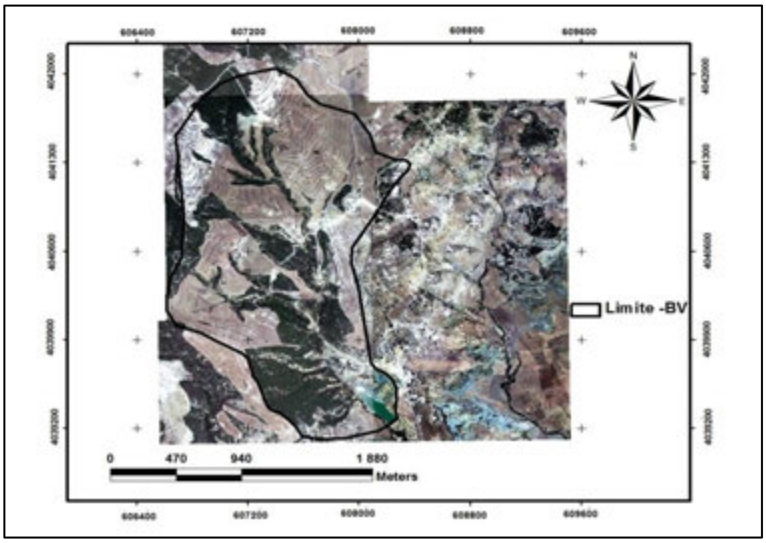

Figure 1: Map of the study site

Methodology

The Tunisian work consists on the Cs-137 fallout to test the efficiency of different agricultural soil management practices in Tunisia. We have chosen a watershed suffering from high erosion in the north of the country to perform the study. The sampling strategy (determination and sampling in the reference site and in the cultivated areas) and data treatment.

The sampling has then been performed (220 soil samples) and Cs-137 was measured in all these samples. The activity concentrations of Cs-137 were then used to obtain the Cs-137 inventories which were used with specific conversion models softwares to estimate the soil redistribution in our studied watershed.

In general, tow transects were established for each studied sites with the spacing of sample points ranging from 20 m. Typically, between 16 and 28 bulk samples were obtained at each site. Depending on the soil properties, different soil corers were used. Larger core (diameter: 10 cm) was used on cultivated areas. Soil samples from different depths were collected in order to obtain information on local reference inventory and the depth distribution of ^{137}Cs in the soil profiles. Reference cores were sampled to a depth of 30 cm. The highest and the lowest cores for each transect were sectioned (2 cm resolution), the profile distribution of the tow sectioned cores are chosen. To estimate the ^{137}Cs reference inventory, reference sites were chosen near each study field on a flat area with a minimal intervention, located at some altitude with respect to the study field and also not affected by soil erosion or sedimentation and exhibiting a full grass and shrub cover during the whole year. All samples were oven dried at 105 °C for 48 h, disaggregated and sieved to separate the <2 mm fraction. They were packed into a 1000 ml (1 kg) plastic Marinelli beaker for the bulk and in cylindrical container of sectioned cores for measurement of ^{137}Cs activity. The samples were analysed for ^{137}Cs by direct gamma ray spectrometry system, Ortec HPGe coaxial germanium detectors (FWHM: 0.85 keV at 122 keV, FWHM: 1.85 keV at 1.33 MeV), respectively 35 % relative efficiency for bulk sample and 80 % relative efficiency for cylindrical caintainer. The detectors were calibrated with Standard Mixed Source Reference.

Results

^{137}Cs distribution profile within the soil in reference site was of exponential type (Figure 2). This was in accordance with other results for the undisturbed soils (Walling and Quine, 1995). Tow sectioned cores from reference site are chosen for measuring the activities variation of Cs-137 in core01 and core02 (Figure 2) The total inventory for the sectioned core 01 and sectioned core 02 are respectively, 1 431 and 1 455 (Bq/m^2). We conclude that 90 % of total ^{137}Cs is in the 10 cm upper the soil. The mean inventory for the reference site is: 1 322 ± 28 (%) Bq/m^2**,** this value is coherent with the measured one using the software established by Pr Dess Walling; at 450 mm precipitation expected Cs inventory is 1 200 Bq/m^2.

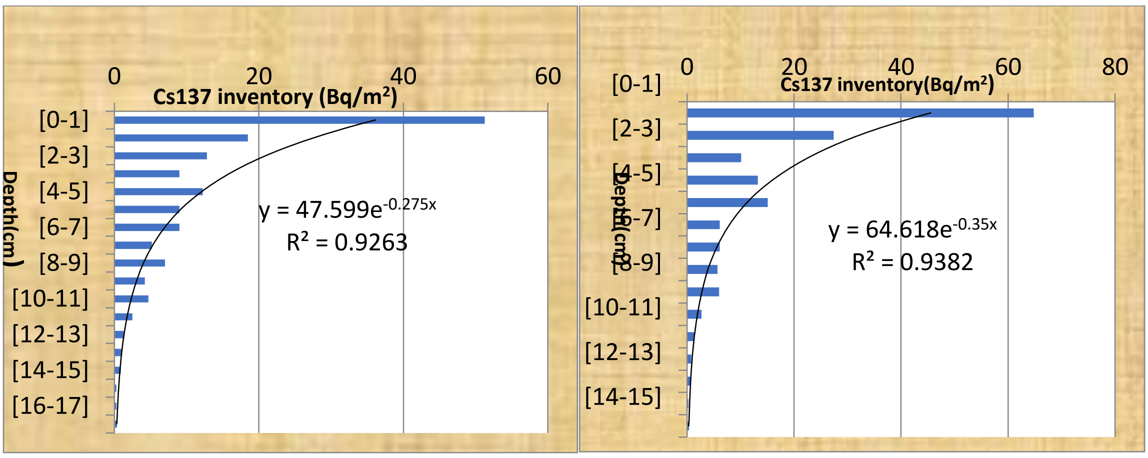

Figure 2: ^{137}Cs profile distribution in reference site

The mean^{137}Cs inventory measured in cultivated soils for the tow studied sites, for the preserved site and non preserved site are respectively, 200 to 2 300 Bq.m^2 and 200 to ± 1 400 Bqm^2. The mean erosion rate in the preserved site is estimated to be 8.5 t ha $^{-1}$ year^{-1} and in the non-managed soil is estimated to 27.5 by applying the proportional model whereas by using the simplified mass balance model2 it was as 16 t ha $^{-1}$ year^{-1} and 38 t ha $^{-1}$ year^{-1} respectively for the managed soil and non-managed soil.

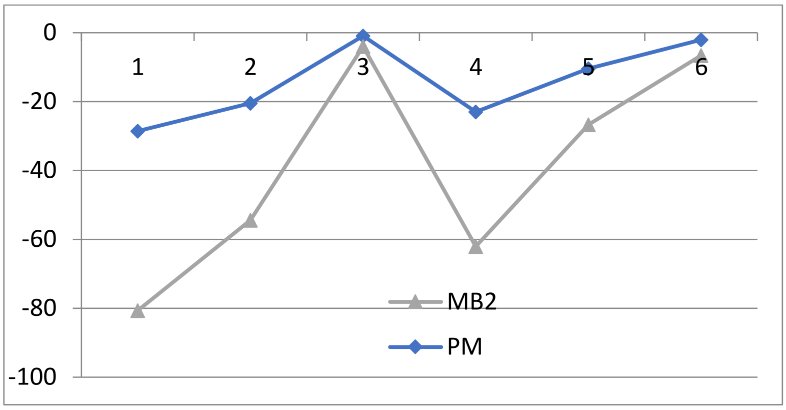

Figure 3: The erosion rates estimated using MBM2 and PM for preserved site

In general the difference between the two models becomes more important for the high soil erosion rates. The erosion rates derived from the proportional model (PM) remain always lower than those predicted with the simplified mass balance model2 (MBM2). It is because, in contrary with PM, MBM2 takes into account the effect of surfaced Models used for erosion rates from ^{137}Cs measurements.

Table 1: The average annual erosion rates derived using different models in study sites

Sampling sites	PM (t ha $^{-1}$ year^{-1})	MBM2 (t ha $^{-1}$ year^{-1})
Managed soil (preserved)	11.5	24.0
Non-managed soil	30.5	39

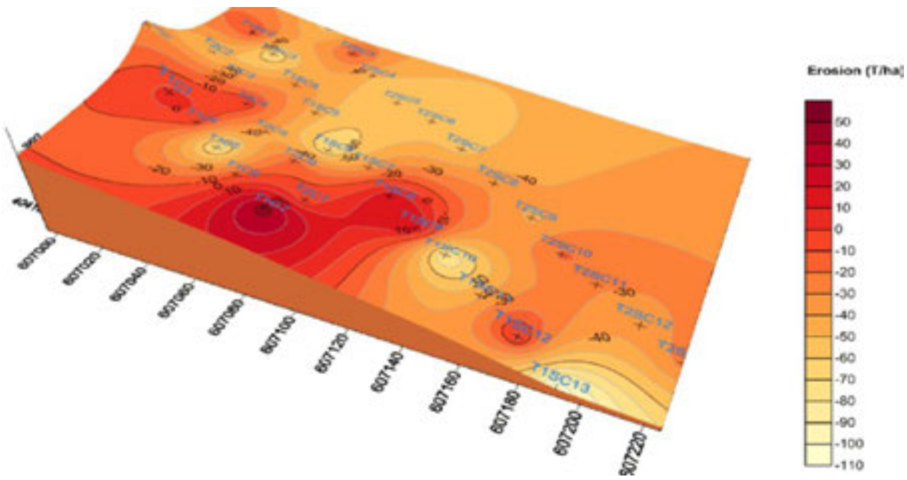

Figure 4: Distribution of soil redistribution rates estimated using Cs-137 in managed and non-managed soil

The mean erosion for managed soil is 18 t ha $^{-1}$ year^{-1} and 35 t ha $^{-1}$ year^{-1}, we can conclude that there are preservation soil at 44 % using the benches in the managed site. The management procedure seems to protect the soil at a certain level in this work, the preservation soil using benches it's not sufficient to have a good result using FRNs models. That is why MBM2 approach would be more suitable for water affected erosion studies in the tow cultivated sites and it is more important for non managed (preserved) site.

References

Ritchie, J. C., & McHenry, J. R. 1990. Application of radioactive fallout cesium-137 for measuring soil erosion and sediment accumulation rates and patterns: A review. *Journal of Environmental Quality*, 19: 215–233.

Ritchie, J. C., & Rasmussen, P. E. 2000. Application of cesium-137 to erosion rates for understanding soil carbon loss on long-term experiments at Pendleton, Oregon. *Land Degradation and Development*, 11: 75–81.

McIntyre, S. C., Lance, J. C., Campell, B. L., & Miller, R. L. 1987. Using ^{137}Cs to estimate soil erosion on a clearcut hillside. *Journal of Soil and Water Conservation*, 42: 117–120.

Walling, D. E. & He, Q. 1999. Improved models for estimating soil erosion rates from cesium-137 measurements. *Journal of Environmental Quality*, 28: 611–622.

Walling, D. E., He, Q., & Quine, T. A. 1995. Use of Caesium- 137 and Lead-210 as Tracers in Soil Erosion Investigations. Tracer Technologies for hydrological Systems, IAHS Publ. No.229.

Oztas, T. 1993. Assessment of erosion rates and patterns from spatial variability of cesium-137. PhD thesis, Nebraska University, Lincoln, Nebraska, USA.

Estimation of Soil Erosion Deforestation-induced Using Nuclear Techniques (Case study: Golestan Province, Iran)

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Abstract

Hyrcanian Forests (HF), the most important ecosystem along the south of Caspian Sea in the North of Iran, experienced extensive deforestation. Golestan Province that covers the East part of the HF, has mainly cleared cut because of land use policy and increasing demand for crop lands since 1965. Dry-lands farm especially wheat farms contributed to sediment delivery to the sink areas. The present research is the first regional study aimed to estimate on-site impacts of deforestation in the East of HF using nuclear techniques. Results emphasized on accuracy of site selection based on similarity in soil texture of loess deposits and rainfall range. Accordingly, the mean rate of 32.27 t ha^{-1} yr^{-1} has been obtained for Hyrcanian Forests. Our data suggest that soil from dry-land farms will be eroded with the mean rate of 0.2 cm y^{-1} under the mean rainfall of 700-1000 mm per year. Our data provide key information for the decision makers to carry out conservation practices in this ecologically important region of Iran.

Keywords: Hyrcanian Forests, Golestan Province, Nuclear Technique, Soil Erosion, Deforestation, Dry-land farm

Introduction

Land use changes including clear cutting of forests play an important role in soil degradation in catchment areas worldwide (Gharibreza *et al.*, 2013a, 2013b). Hyrcanian Forests (HF) are well known forests which are located along the South of the Caspian Sea, in the North of Iran. Rapid increase in population accompanying with development of wood industries resulted in extensive deforestation and decline in coverage of HF (8.4 million ha) between 1942 and 2005 years. Development of croplands was one of important reasons of deforestation. Accordingly, two representative transects were selected from West of the province in Azadshahr area which have uniform slope of 22 % with the Southeast and Southwest directions and 350 m and 350 m length, respectively. Another representative transect at the East of Golestan Province, Galikesh area with 1000 m length, slope of 20 % and North-east direction. The study area has a semi-humid climate with maximum rainfall occurring in October and minimum in July. The mean annual precipitation in the study area ranges between 700 mm to 1000 mm and the mean temperature is 16.4°C. During the last decades, on-site and off-site impacts of land degradation encouraged researchers to study soil redistribution through application of nuclear techniques (Du and Walling, 2011; Porto *et al.*, 2016; Zhang, 2003). In this context, application of Cesium-137 (half-life = ca. 30 years) proved to be very useful as a tracer to estimate soil redistribution.

The objective of this research was to determine the soil redistribution pattern induced by deforestation along the representative transects.

Methodology

The research method designated to apply nuclear techniques and fallout radionuclides (^{137}Cs) to estimate soil redistribution. Analytical methods and models for estimating soil erosion using ^{137}Cs have remarkably improved over the last four decades (IAEA, 1998; Poreba, 2006; Porto *et al.*, 2003; Robbins *et al.*, 1978). The setting-up of a proper sampling strategy is critical in soil erosion estimation using radioisotopes. This strategy further, depends on deforestation and tillage commencement dates, the lithology of parent rocks, and the intrinsic ^{137}Cs inventory and site accessibility in any area. Sampling in the study area consisted of 56 bulk samples collected from three transects following different directions in two specific areas. In this case, a core sampler of 11-cm diameter was used to a depth of 35 cm. Also, one sample from mobilized sediment at the catchment outlet (where deposition occurred) was collected to gain information on particle size factor. Incremental depth sampling was carried out in both locations. A scraper plate with a cutting edge and having a rectangular metal frame (surface area = 1292.71 cm^2) served to collect 2 sectioned cores samples (one for each site) at 2-cm intervals to a total depth of 45 cm. The samples were preliminarily dried at 105˚C, weighed and finely ground (less than 2 mm) before analysis. Sediment sub-samples were packed in special containers of 250 g capacity and analyzed for ^{137}Cs content. The ^{137}Cs specific activities were measured using a well calibrated gamma-spectrometry based on high-purity germanium (HPGe) detectors in the laboratories of Nuclear Science & Technology Research Institute (NSTRI), Atomic energy organization of Iran. The PC-compatible Excel-Add that is developed by Walling *et al.* (2007) was used to apply improved models to estimate erosion and deposition rates in the study area. Comparison of conversion models showed the Mass Balance II is the most compatible model to estimate soil redistribution of deforested lands.

Results

The ^{137}Cs depth distribution of the two sectioned cores collected from the two reference sites (one for each location) represents an exponential decline with depth. The shape of these profiles conforms to what can be expected for an undisturbed location, showing ca 70-80 % of the ^{137}Cs inventory present in the top 12 cm. The ^{137}Cs inventory obtained in the reference sites of Azahshahr and Galikesh were 3 849 and 4 062 Bq m^{-2}, respectively. The ^{137}Cs measurements obtained in the two transects of Azadshahr area provided a mean ^{137}Cs inventory of ca. 1 421.77 Bq m^{-2} with single values ranging from 271.2 Bq m^{-2} to 2896.4 Bq m^{-2} and a CV equal to ca. 61 %. The ^{137}Cs measurements obtained in the representative transect of Galikesh area indicates a mean ^{137}Cs inventory of ca. 1 600.91 Bq m^{-2} with single values ranging from 833.6 Bq m^{-2} to 2 340.4 Bq m^{-2} and a CV equal to ca. 31 %. Results showed that clay, silt and sand size components of soil samples have average contents of 33±2, 60±3, and 6±3 %, respectively. Silty clay loam is the dominant soil texture along the studied transects which are characterized by loess deposits in the North-East of Iran.

Results showed that soil erosion was the dominant process since beginning ^{137}Cs fallout in the mid-1950s. Maximum, minimum and mean values of soil erosion along the AZ-Southeast direction transect were 81.25, 7.63 and 35.86 t ha^{-1} yr^{-1}, respectively, while the corresponding values for the AZ-Southwest direction transect were 69.68, 8.66 and 34.87 t ha^{-1} yr^{-1}, respectively. The maximum, minimum and mean values of soil erosion along the Galikesh-Northwest direction transect were 48.4, 15.8 and 29.19 t ha^{-1} yr^{-1}. Our study suggests that net erosion rate of dry-land farms of the East and West of Golestan Province were 35.36 t ha^{-1} yr^{-1} and 29.19 t ha^{-1} yr^{-1} (Table 1) and the mean rate of soil erosion for the whole province and loess soil type was 32.27 t ha^{-1} yr^{-1}. According to the mean rate of soil loss along the Azadshahr transects (64.24 % and 60.24 %), the mean bulk density of 1400 kg m^{-3}

and the tillage depth of 250 kg m^{-2}, the results indicate that ca. 153.1 kg m^{-2} (or ca. 10.93 cm) and ca. 150.0 kg m^{-2} (or ca. 10.71 cm) of soil has been eroded from the AZ-Southwest and AZ-Southeast transects, respectively. Considering the elapsed time (54 years) between deforestation and present research, the soil erosion along these transects occurred with the rate of 0.20 cm y^{-1}, 0.19 cm y^{-1} respectively. Based on the mean rate of soil loss along the Galikesh transect (60.59 %) and the mean bulk density of 1430 kg m^{-3} and the tillage depth of 250 kg m^{-2}, the results suggested 151.47 kg m^{-2} (or ca. 10.59 cm) eroded from the North-west direction transect. Considering the elapsed time (54 years) between deforestation and present research, the soil erosion along this transect occurred at the rate of 0.19 cm y^{-1}.

Table 1: Net erosion rate along the representative transects of Azadshar and Galikesh areas

Westward Direction, Azadshahr			*Eastward Direction, Azadshahr*			*Northward, Galikesh*		
Sample ID	Soil Lost %	Soil Erosion	Sample ID	Soil Lost %	Soil Erosion	Sample ID	Soil Lost %	Soil Erosion
AZ1-1	-90.74	-69.68	AZ2-1	-92.95	-81.272	Gali1-1	-72.32	-38.499
AZ1-2	-90.78	-69.54	AZ2-2	-91.22	-73.591	Gali1-2	-79.48	-48.397
AZ1-3	-90.27	-65.39	AZ2-3	-92.28	-78.072	Gali1-3	-72.98	-39.278
AZ1-4	-89.05	-63.349	AZ2-4	-74.05	-38.279	Gali1-4	-78.83	-47.337
AZ1-5	-88.42	-56.648	AZ2-5	-25.01	-7.72	Gali1-5	-62.55	-28.88
AZ1-6	-85.70	-53.958	AZ2-6	-26.13	-8.13	Gali1-6	-76.97	-44.528
AZ1-7	-84.52	-55.018	AZ2-7	-24.91	-7.69	Gali1-7	-44.34	-16.82
AZ1-8	-73.30	-38.349	AZ2-8	-24.75	-7.63	Gali1-8	-47.48	-18.55
AZ1-9	-67.48	-30.44	AZ2-9	-61.37	-26.4	Gali1-9	-61.94	-28.38
AZ1-10	-71.77	-34.879	AZ2-10	-90.53	-70.971	Gali1-10	-60.91	-27.55
AZ1-11	-57.95	-24.76	AZ2-11	-88.01	-62.989	Gali1-11	-50.27	-20.19
AZ1-12	-51.93	-21.39	AZ2-12	-78.49	-44.078	Gali1-12	-49.76	-19.88
AZ1-13	-41.87	-14.05	AZ2-13	-37.63	-12.78	Gali1-13	-54.70	-23.01
AZ1-14	-42.85	-15.15	AZ2-14	-37.64	-12.78	Gali1-14	-45.14	-17.25
AZ1-15	-46.23	-17.17	AZ2-15	-40.20	-13.95	Gali1-15	-68.06	-33.899
AZ1-16	-28.16	-8.66	AZ2-16	-27.57	-8.67	Gali1-16	-54.91	-23.15
AZ1-17	-52.18	-20.52	AZ2-17	-77.30	-42.41	Gali1-17	-51.49	-20.94
AZ1-18	-56.48	-23.49	AZ2-18	-54.86	-21.89	Gali1-18	-55.53	-23.58
AZ1-19	-50.77	-19.86	AZ2-19	-86.17	-58.24	Gali1-19	-63.52	-29.7
AZ1-20	-53.71	-17.14	AZ2-20	-78.19	-43.65	Gali1-20	-78.79	-47.277
AZ1-21	-35.62	-12.73	AZ2-21	-55.79	-22.49	Gali1-21	-42.38	-15.8
Net Erosion	***-64.28***	***-34.87***	AZ2-22	-68.57	-32.49	***Net Erosion***	***60.59***	***-29.19***
			AZ2-23	-77.24	-42.33			
			AZ2-24	-77.09	-42.12			
			Net Erosion	***-60.24***	***-35.86***			

Discussion

Hyrcanian Forests especially in the Golestan Province experienced two intensive periods of deforestation, while some shorter periods of deforestation for harvesting timbers occurred. The first important period started in 1965 (Bobek, 2005), when maximum FRNs received in the Northern hemisphere. Deforestation occurred during this period in Azadshar and Galikesh areas, when local people were allowed and authorized by the government to have their own cultivated lands. Therefore, the elapsed time of 54 years between the commencement tillage or deforestation and the present study was verified. Present study accurately explained the effects of deforestation and land use changes to specific crops of wheat in the North-East of the Hyrcanian Forest. Results emphasized on accuracy of site selection based on similarity in background soil texture and rainfall range and accordingly representation of the mean rate of 32.27 t $ha^{-1}yr^{-1}$ for the west of Hyrcanian Forests. Our research suggests that soil from dry-lands farm is likely to be eroded with the mean rate of 0.2 cm y^{-1} under the mean rainfall of 700-1 000 mm per year.

Conclusions

For the first time in Iran, we measured soil redistribution following conversion of original forests to crop lands in the East of Hyrcanian Forest. The original assumption based on which conversion to crop lands was tested with the help of ^{137}Cs measurements. Soil erosion rate (32.27 t ha^{-1} yr^{-1}) obtained in Golestan Province resulted much higher than the national rate of land degradation (16 t ha^{-1} yr^{-1}), suggesting that rainfall amount and type of soil are crucial in erosion processes in this area. The results obtained in this study contributed in knowledge in terms of highlighting sensitivity of soil erosion in such ecological important region of Iran and providing key information for decision makers to implement conservation practices.

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References

Bobek, H. 2005. Historical View of Natural Forests and Iran's Trees (Vol. 1). Tehran: Geographic Organization of the Armed Forces.

Du, P. & Walling, D. E. 2011. Using Cs-137 measurements to investigate the influence of erosion and soil redistribution on soil properties. *Applied Radiation and Isotopes*, 69: 717-726.

Gharibreza, M., Raj, J. K., Yusoff, I., Ashraf, M.A., Othman, Z., & Tahir, W.Z.W.M. 2013. Effects of agricultural projects on nutrient levels in Lake Bera (Tasek Bera), Peninsular Malaysia. *Agriculture, Ecosystems & Environment*, 165: 19-27. doi: https://doi.org/10.1016/j.agee.2012.12.004

Gharibreza, M., Raj, J.K., Yusoff, I., Othman, Z., Tahir, W.Z.W.M. & Ashraf, M.A. 2013. Land use changes and soil redistribution estimation using ^{137}Cs in the tropical Bera Lake catchment, Malaysia. *Soil and Tillage Research*, 131: 1-10. doi: https://doi.org/10.1016/j.still.2013.02.010

IAEA. 1998. Use of Cs137 in the study of Soil Erosion and Sedimentation TECDOC-0828 (Vol. 1028). Vienna: International Atomic Energy Agency.

Poreba, G., J. 2006. Cesium-137 As a Soil Erosion Treacer: A Review. *Journal on methods and applications of Absolut Chronology,* 25: 37-46.

Porto P., Walling D.E., La Spada C. & Callegari, G. 2016. Validating the use of ^{137}Cs measurements to derive the slope component of the sediment budget of a small catchment in southern Italy. *Land Degradation & Development*, 27: 798-810.

Porto, P., Walling, D.E., Ferro, V. & Di Stefano, C. 2003. Validating erosion rate estimates by caesium-137 measurements for two small forested catchments in Calabria, Southern Italy. *Land Degradation and Development*, 14: 389-408.

Robbins, J.A., Edgington, D.N., Kemp, A.L.W. 1978. Comparative ^{210}Pb, ^{137}Cs, and pollen geochronologies of sediments from Lakes Ontario and Erie Quaternary Research, 10(2): 256-278.

Walling, D.E., Zhang, Y. & He, Q. 2007. Models for Converting Measurements of Environmental Radionuclide Inventories (^{137}Cs, Excess ^{210}Pb, and ^{7}Be) to Estimates of Soil Erosion and Deposition Rates (Including Software for Model Implementation). Exeter: University of Exeter.

Zhang, Y., Yang, H., Du, M., Tang, X., Zhang, H. & Peng, B. 2003. Soil Erosion Study on Hillside in Southern Jiangsu Province Using the Cesium-137 Tracer Technique. *Journal of Soil Science and Plant Nutrition*, 49: 85-92.

Dynamic Erosion Model and Monitoring System (DEMIS) at the National Scale in Turkey

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Abstract

The Report on Status of the World's Soil Resources (SWSR) indicates minimizing soil erosion is one of the most significant objectives for Sustainable Soil Management (SSM). As rapid assessment of erosion is becoming supportive planning tool for decision making and policy development in Turkey, a Dynamic Erosion Model and Monitoring System (DEMIS) is accordingly established to monitor soil erosion in 25 river-basins, based on RUSLE technology and technically reinforced by RS and GIS.

Countrywide soil loss by the DEMIS is 642 million ton ha^{-1} y^{-1}, and 24 % of this delivers to streams. Erosion severity also revealed 79.41 % of Turkey is under the influence of either very low or low erosion although 20.60 % under moderate erosion, severe and very severe erosion. Once sorted by land use types, severe and very severe erosion rates alarm for pastures and agricultural land. When further partitioned for the weight of each model parameter on total loss, the topographic effect on overland flow processes took a lead with rational efficiency of 47.55 %, followed by crop management, erosivity, and erodibility with percentages of 34.82, 14.26 and 3.36, respectively. Thus, DEMIS already performs successfully to delineate erosion risk for SSM techniques to minimize soil erosion at different scales in Turkey.

Keywords: DEMIS, SSM, erosion

Introduction, Scope and Main Objectives

Soil erosion is one of the most important means that threatens the sustainable use of soil resources in the catchments of Turkey (FAO and ITPS, 2015). Also, varying with climate, soil, topography and land cover and management, sediment amounts transported into water reservoirs by different erosion processes cause harmful consequences for energy and agricultural water use in the semi-arid ecosystems of Anatolia in Turkey. Therefore, a nationwide evaluation of erosion risk became a pressing priority for natural resource managers and soil erosion scientists to have to contain this threat, and a RUSLE model-based project was initiated by the General Directorate of Combating Desertification and Erosion (ÇEM) under the Ministry of Agriculture and Forestry (MAF).

Indeed, studies of assessing erosion risk by USLE/RUSLE technology have been for a long time used at the scale of small watersheds in Turkey.

Also, some researchers have made of the RUSLE-based erosion assessments in order to design rehabilitative practices of Sustainable Land Management (SLM) at small dam watersheds, using the product of crop management and support practice factors as decision criterion. Most recently, a Water Erosion Atlas has been published to give statistical data on soil erosion in 25 river-basins of Turkey along with their maps (Erpul *et al.*, 2018).

This paper introduces "Dynamic Erosion Model and Monitoring System (DEMIS)" developed by the Ministry of Agriculture and Forestry, General Directorate of Combating Desertification and Erosion to support decision and policy making in Turkey given close intertwinement of soil ecosystem functions and services with climate change, land degradation and desertification and significance of conserving soil resources to ensure food security.

Methodology

Study Area and Material

The "Dynamic Erosion Model and Monitoring System (DEMIS)" estimates potential and actual erosion rates for all river basins at the national scale in Turkey using the RUSLE erosion model (Wischmeier and Smith, 1978; Renard *et al.*, 1997). Model parameters are calculated by Remote Sensing (RS) and GIS techniques along with spatial statistical methodologies, and the digital databases (raster and vector) with which the model systematically associate are:

- Topographical maps (1:25 000)
- Digital elevation models (1:25 000)
- Soil maps (1:25 000)
- Land use data (CORINE, 2012)
- Catchment and river network data (General Directorate of State Hydraulic Works)
- River sediment data (E.İ.E.İ)
- Erosivity map and Automatic Meteorological Observation Stations Data (Turkish State Meteorological Service)
- National Water Erosion Atlas (Erpul *et al.*, 2018).

Operation Method

General workflow scheme of DEMIS is given in Figure 1, which depicts it is based upon the Revised Universal Soil Loss Equation (RUSLE) (Wishcmeier and Smith, 1978; Renard *et al.* 1997), distinctively given by (Eq.1):

A = R x K x LS x C x P [1]

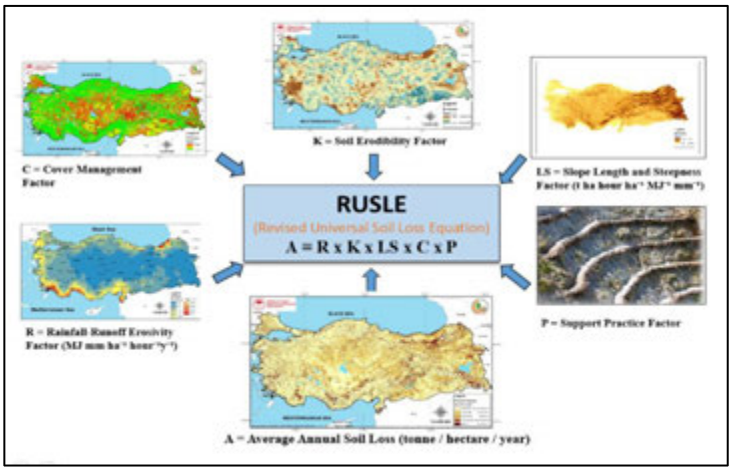

Figure 1: A Workflow Scheme of the Dynamic Erosion Model and Monitoring System (DEMIS)

DEMIS uses an existing map of R-factor of Turkey, which is layered by using 357 minute-data of the Automatic Meteorological Observation Station and calculated as a result of the annual total energy of rainstorm (E, MJ $ha^{-1}y^{-1}$) and the maximum 30-min intensity (I_{30}, mm h^{-1}) ($E \times I_{30}$) (Wischmeier and Smith 1978; Renard *et al.* 1997; Erpul *et al*., 2016)

DEMIS computes soil erodibility factor from 23 thousands of geo-referenced soil samples distributed over Turkey. Dependent upon presence of germane soil parameters required to estimate erodibility, the equations of nomograph (Wischmeier *et al.*, 1971), Torri *et al.* (1997, 2002) and Römkens *et al.* (1986, 1997) were utilized to assess K factor after regression analyses to express best possible relations among three different K values.

The topographic factor of DEMIS is interactively calculated by slope length factor (L) and steepness factor (S) along with flow accumulation (Moore and Bruch, 1986a, b; Ogawa *et al.,* 1997) (Eq. 2).

$$LS = \left(\frac{x\eta}{22{,}13}\right)^{0{,}4} \left(\frac{\sin\theta}{0{,}0896}\right)^{1{,}3} \qquad [2]$$

Where χ is the flow accumulation and is obtained from DEM using a GIS accumulation algorithm, which employs the watershed delineation tool of Arc view 10.2 (Lee, 2004), η is the cell size, and θ is the slope steepness in degrees.

DEMIS consumes 44 classes of CORINE land cover (CORINE, 2012) as a base map for the RUSLE-C together with correspondent values determined by Panagos *et al.* (2015). Furthermore, additional adaptive corrections were performed combinatorially using the National Forest Map of Turkey given semi-arid specificities of forest types and vegetative covers.

As well, DEMIS could be run to predict soil losses and to assess water erosion risk at the micro-catchment level considering support practice factors along with effects of existent dams and lakes on the erosional transport processes, and has a sufficient capability to be integrated with the Sediment Delivery Ratio (Eq. 3 and 4) to compute sediment amounts reaching outlet of each micro-catchments. Its calibration and validation works have been in progress by comparing with the suspended sediment loads directly measured at monitoring stations of the state.

$$Q_T = \{\textstyle\sum_{i=1}^{n} ECA_i \times A_i\} \times SDR \qquad [3]$$

$$Q_T = \{\textstyle\sum_{i=1}^{n} ECA_i \times (R.K.L.S.C.P)_i\} \times SDR \qquad [4]$$

Q_T, Total sediment arriving to the dam reservoir (ton y^{-1}); *ECA*, Erosion Class Area (ha); A_i [$(R.K.L.S.C.P)_i$], Soil loss (ton ha^{-1} y^{-1}), *SDR*, sediment delivery ratio (%).

Results and Discussion

One - minute detailed rainfall data recordings by the state meteorological stations distributed over different climatic regions of the country provided the system with exhaustive calculations for both rainfall intensities and energy fluxes, portraying climatic severity for erosion.

Moreover, tapped into were soil data as extensive as possible all over the country for having a map for soil susceptibility to water erosion.

Based on the RUSLE technology methodologically reinforced by RS and GIS for estimating model parameters at the national scale, which are readily compatible with possible scale-ups for watersheds, regional, and national purposes, DEMIS resulted in a Water Erosion Atlas (Erpul *et al.*, 2018) to give statistical data on soil erosion (Table 1) in 25 river-basins of Turkey along with their detailed maps for severity assessment (Figure 2).

Total countrywide soil loss predicted by the DEMIS is 642 million ton ha^{-1} y^{-1}, and 24 percent of this annual loss delivers to the streams. Magnitude of the predicted annual soil losses showed that 79.41 % of Turkey is under the influence of either very low (60.28 %) or low erosion (19.13 %) although 20.60 % under the influence of either moderate erosion (7.93 %) or severe (5.97 %) and very severe erosion (6.7 %). Also, these amounts calculated for each river basins (Table 1).

Table 1: National statistics of DEMIS sorted out by 25 River Basins on soil erosion severity and soil loss rates (tone $year^{-1}$) of different land use types

	Soil Loss (%)					Amount of Erosion	Erosion in Grassland Areas	Erosion in Forest	Erosion in Agricultural Areas	Erosion in Other Areas
	0 - 1	1 - 5	5 - 10	10 - 20	20 - +					
Basin Name	**Very Low**	**Low**	**Moderate**	**Severe**	**Very Severe**	**tone $year^{-1}$**	**tone $year^{-1}$**	**tone $year^{-1}$**	**tone $year^{-1}$**	**tone $year^{-1}$**
Akarçay	60,58	20,95	8,58	5,22	4,67	4.803.394,68	2.942.856,75	124.601,12	1.618.646,32	117.290,49
Antalya	75,39	11,58	4,08	3,33	5,61	15.373.556,15	7.477.986,04	1.377.224,64	6.004.857,62	513.487,85
Aras	41,15	28,03	12,11	9,13	9,58	29.456.085,13	22.172.090,87	96.944,12	6.902.238,86	284.811,28
Asi	65,03	12,95	5,14	5,39	11,49	10.800.877,22	1.629.480,14	508.110,55	8.457.453,27	205.833,26
Batı Akdeniz	67,50	16,26	3,79	3,36	9,10	28.721.544,25	11.111.828,06	1.749.919,22	9.263.244,73	6.596.552,24
Batı Karadeniz	76,41	9,26	4,98	4,91	4,44	15.151.093,02	1.404.945,89	1.960.229,64	11.414.555,68	371.361,81
Burdur	70,12	15,19	5,89	3,97	4,83	3.644.525,70	2.156.494,65	223.751,97	1.203.910,01	60.369,07
Büyük Menderes	69,29	12,03	5,91	5,10	7,66	25.437.415,87	5.411.148,72	1.194.831,04	16.905.950,49	1.925.485,62
Ceyhan	60,86	18,27	7,85	6,76	6,26	15.429.686,09	6.716.129,21	800.240,95	7.631.105,98	282.209,95
Çoruh	43,57	18,19	9,64	8,84	19,75	52.848.848,78	45.180.341,26	872.526,46	6.402.981,79	392.999,27
Dicle-Fırat	52,75	22,37	9,56	6,98	8,34	159.832.719,65	121.178.327,61	3.331.647,99	32.938.556,44	2.384.187,61
Doğu Akdeniz	67,54	9,57	4,73	5,47	12,69	33.237.078,42	20.393.209,54	1.280.821,83	10.602.448,75	960.598,30
Doğu Karadeniz	42,01	25,66	12,75	10,15	9,42	26.517.468,22	12.761.467,04	1.923.627,55	11.827.101,39	5.272,24
Gediz	69,01	10,25	7,89	6,89	5,97	11.468.942,37	2.159.779,27	759.949,48	8.219.961,29	329.252,33
Kızılırmak	53,92	27,66	9,15	5,56	3,71	45.496.277,22	18.530.132,50	1.893.783,67	24.477.144,26	595.216,79
Konya Kapalı	70,86	17,43	5,23	3,24	3,23	23.211.147,68	14.616.611,82	570.592,76	7.100.886,66	923.056,44
Kuzey Ege	67,57	7,58	6,19	7,01	11,65	13.388.428,93	1.550.819,34	490.945,48	10.103.043,97	1.243.620,14
Küçük Menderes	68,17	11,02	5,42	5,80	9,60	7.576.292,14	1.530.695,79	366.066,31	5.011.660,34	667.869,70
Marmara	78,70	5,73	4,26	4,76	6,54	15.637.948,72	685.647,19	1.279.196,51	12.552.037,20	1.121.067,82
Meriç Ergene	58,38	18,40	9,41	7,68	6,13	10.337.920,51	680.343,82	292.100,90	9.092.113,68	273.362,11
Sakarya	63,02	22,67	7,54	4,39	2,38	26.524.638,92	9.156.326,71	2.044.084,88	14.576.100,21	748.127,12
Seyhan	67,98	14,30	5,83	5,14	6,74	18.174.922,94	12.415.406,76	745.757,01	4.425.382,13	588.377,04
Susurluk	72,64	11,20	7,48	5,79	2,89	10.821.938,74	888.545,87	1.306.496,82	7.985.891,62	641.004,43
Van Gölü	56,28	20,30	9,04	7,56	6,81	13.229.460,68	10.050.573,16	18.218,52	2.525.045,51	635.623,49
Yeşilırmak	58,72	21,53	9,10	5,97	4,69	25.086.331,57	11.814.405,41	1.600.355,85	11.372.018,29	299.552,02
TOTAL	**60,28**	**19,13**	**7,93**	**5,97**	**6,70**	**642.208.543,60**	**344.615.593,42**	**26.812.025,27**	**248.614.336,49**	**22.166.588,42**

Once sorted out over different land use types, severe and very severe erosion rates are alarming for semi-arid pastures (approximately 50 %), having the percentages of 35 % and 4.0 % for agricultural land and forest, respectively (Table 1).

When we further partitioned the weight of each model parameter on total soil loss, the topographic effect on overland flow processes (LS) took the lead with the rational efficiency of 47.55 %, respectively followed by crop management (C), rainfall erosivity (R), and erodibility (K) with the percentages of 34.82, 14.26 and 3.36.

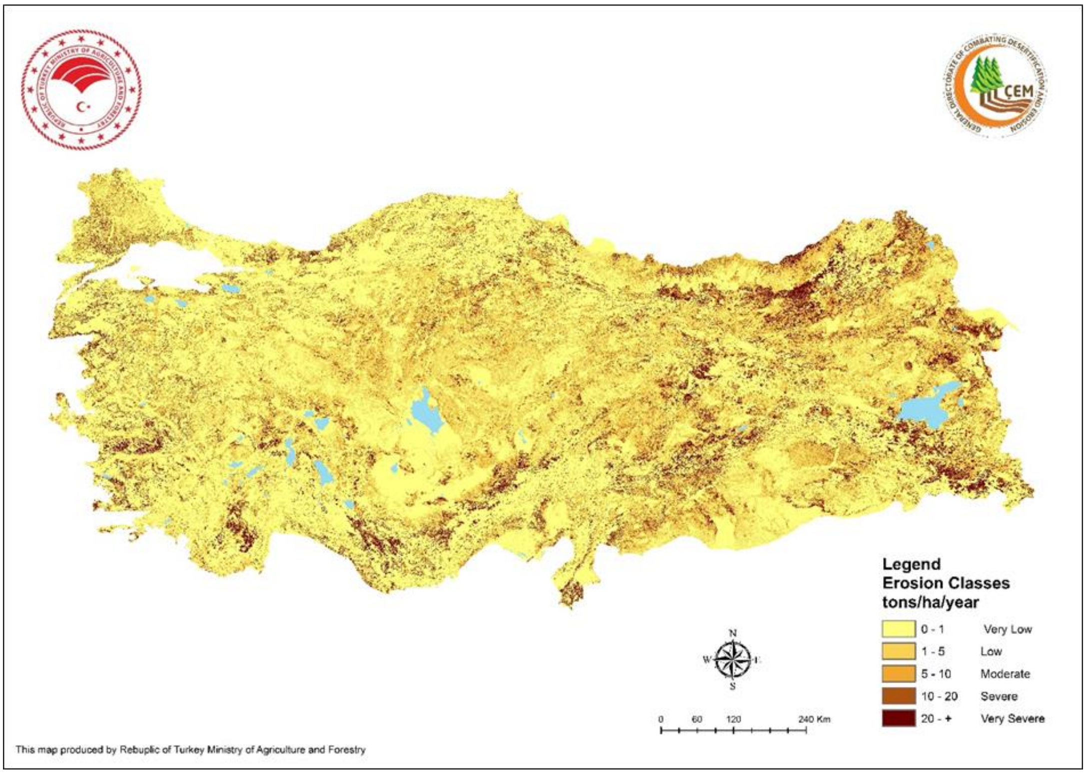

Figure 2: Erosion Map of Turkey

Conclusions

Maps of the predicted soil losses together with soil erosion risk classes at different scales ranging from small watersheds up to big river basins in Turkey have been produced by using the RUSLE methodology after a Dynamic Erosion Model and Monitoring System (DEMIS) was set up. It continuously generates temporal and spatial statistics on when and where human-induced erosion rates alarmingly threaten soil resources.

Given the fact that soil erosion is a threat causing significant loss of ecosystem services and biodiversity and critical indicator for land degradation under the changing semi-arid climate in Turkey, DEMIS as a supportive prediction tool and system would have a high potentiality and provide opportunities for decision-makers and policy developers not only to minimize soil erosion aimed at by for Sustainable Soil Management (SSM) but also to ensure sustainability of land resources by hierarchically avoiding, reducing and reversing land degradation.

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References

Bayramin, I., Basaran, M., Erpul, G., & Canga, M. R. 2008. Assessing the effects of land use changes on soil sensitivity to erosion in a highland ecosystem of semi-arid Turkey*. Environmental Monitoring and Assessment*, 140: 249–265.

Erdogan, E.H., Erpul, G. & Bayramin, I. 2007. Use of USLE/GIS Methodology for Predicting Soil Loss in a Semiarid Agricultural Watershed. *Environ. Monit. Assess.,* 131: 153–161.

Erpul, G., Şahin, S., Akgöz, R., İnce K., Güden, A. & Çetin, E. 2016. Türkiye Yağışlarının Özellikleri ve Yenilenmiş Evrensel Toprak Kayıpları Eşitliği (YETKE) R Faktörü. Çölleşme ve Erozyonla Mücadele Genel Müdürlüğü Yayınları. ISBN:978-605-4610-93-8.

Erpul, G., Şahin, S., İnce, K., Küçümen, A., Akdağ, M.A., Demirtaş, İ. & Çetin, E. 2018. Türkiye Su Erozyonu Atlası. Çölleşme ve Erozyonla Mücadele Genel Müdürlüğü Yayınları (ISBN: 978-605-9550-23-9). Ankara.

FAO & ITPS. 2015. Status of the World's Soil Resources – Technical Summary. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

Lee, S. 2004. Soil erosion assessment and its verification using the universal soil loss equation and geographic information system: a case study at Boun, Korea. *Environ Geol*, 45: 457-465.

Moore, I.D. & Burch, G. J. 1986a. Modelling erosion and deposition. *Topographic effects Trans Am Soc Agric Eng*, 29: 1624–1630 1640.

Moore, I.D. & Burch, G.J. 1986b. Physical basis of the length-slope factor in the universal soil loss equation. *Soil Sci Soc Am J*, 50: 1294– 1298.

Ogawa, S., Saito, G., Mino, N., Uch Da, S., Khan, N.M. & Shafiq, M. 1997. Estimation of soil erosion using USLE and Landsat TM in Pakistan, GIS development. Net, ACRS, pp 1–5.

Panagos, P. *et al.* 2015. The new assessment of soil loss by water erosion in Europe. *Environ. Sci. Policy,* 54: 438–447.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. 1997. Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation RUSLE (p. 404). U. S. Department of Agriculture, Agriculture Handbook 703, Government Printing Office, SSOP, Washington, D.C., ISBN 0-16-048938-5.

Römkens, M. J. M., Young, R.A., Poesen, J., McCool, D.K., El-Swaify, S.A. & Bradford, J.M. 1997. Soil erodibility factor (K). In Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE) 65-99. K. G. Renard *et al.*, eds. Washington, D.C.: USDA.

Römkens, M. J. M., Prasad, S.N. & Poesen, J. 1986. Soil erodibility and properties. In Proc. of the 13th Congress of theIntl. *Soil Science Society,* 5: 492-504.

Saygin, S.D., Ozcan, A.U., Basaran, M. *et al.* 2014. The combined RUSLE/SDR approach integrated with GIS and geostatistics to estimate annual sediment flux rates in the semi-arid catchment, Turkey. *Environ Earth Sci*, 71: 1605-1618.

Topçu, P. & Erpul, G. 2017. Climate Change and Sustainable Soil Management (SSM). Türk Coğrafya Kurumu (TCK) 75. Yıl Uluslararası Kongresi, 654-660.

Torri, D., Poesen, J. & Borselli, L. 1997. Predictability and uncertainty of the soil erodibility factor using a global dataset. *Catena*, 31: 1–22.

Torri, D., Poesen, J. & Borselli, L. 2002. Corrigendum to ''Predictability and uncertainty of the soil erodibility factor using a global dataset'' [Catena 31(1997): 1–22] and to ''Erratum to Predictability and uncertainty of the soil erodibility factor using a global dataset. [Catena 32(1998):307–308]''. *Catena*, 46: 309–310.

Wischmeier, W.H. Johnson, C.B. & Cross, B.V. 1971. A soil Erodibility nomograph for farmland and construction sites. *J Soil Sci Water Conserv*, 26(5): 189–193.

Wischmeier, W.H. & Smith, D.D. 1978. Predicting rainfall erosion losses–a guide for conservation planning. USDA, Agricultural Handbook, U.S. Government Printing Office, Washington, DC., pp. 537.

Simulation and evaluation of global sediment runoff and soil organic carbon removal by erosion in maize fields under varying field management

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Abstract

The removal of soil organic carbon (SOC) due to erosion of the topsoil is a threat to global agriculture and the focus of many studies. Varying soil and crop management around the world plays a major role in quantifying SOC displacement but have not been sufficiently considered in previous studies. Furthermore, validating simulated sediment runoff on a global scale remains a challenge. In this study, we use a global gridded version of the Environmental Policy Integrated Climate (EPIC) crop model to simulate the impact of water erosion on soil sediment and SOC mobilization off maize cropland, while accounting for different intensities in field management and off-season soil cover. Water erosion sediment was estimated on a daily time step from 1980-2010 and evaluated using long-term soil loss measurements by ^{137}Cs method. We estimated an annual flux of SOC in eroded sediment of 0.02 Pg and a median SOC loss rate of 68.2 kg/ha with the highest rates in tropical regions. Due to the high sensitivity of simulated soil loss to tillage intensity and soil cover, the field measurements were useful as a first indicator to evaluate the robustness of our simulation results under different field management scenarios.

Keywords: Water erosion, global soil organic carbon removal, crop model, maize, Cs-137, field management

Introduction, scope and main objectives

Recent years have seen an increasing number of global soil erosion modelling studies ranging from theoretic erosion potential to crop-specific estimates based on gridded climate, topography, and soil data (e.g. Doetterl *et al.*, 2012; Borrelli *et al.*, 2017). Global assessments can provide vital information to identify soil erosion hotspots to be the target for management interventions and policy-making or to quantify the global state of agricultural soil erosion and its drivers. Yet, two aspects were commonly not considered in past studies: (a) the evaluation of modelled erosion estimates based on reported ground data, and (b) the consideration of contrasting crop management strategies and their impacts on soil displacement including associated soil organic carbon (SOC) and nutrient losses. Both are vital for assessing spatially the robustness of erosion estimates and identifying the most effective soil erosion control measures.

Vice versa, soil erosion is typically not considered in global gridded crop model (GGCM) studies as models have relevant processes most often not implemented or soil erosion cannot be properly evaluated due to lack of ground data. However, the importance of such models for climate change impact assessments and as providers of input data for agro-economic models renders the inclusion of soil degradation processes highly relevant to provide integrated impact estimates across various dimensions of environmental change. Also, climate change mitigation and adaptation options can rely substantially on soil functions such as water holding capacity or carbon sequestration potential, both of which depend on SOC stocks and fluxes (Lal *et al.*, 2004; Quinton *et al.*, 2010). A recent study estimates a terrestrial C flux of 0.3–1.0 Pg C yr^{-1} in eroded sediment, which contributes significantly to the total C balance and may change the sign of regional SOC budgets (Chappell *et al.*, 2015).

In this study, we use a global gridded crop model based on the field-scale agronomic model Environmental Policy Integrated Climate (EPIC; Williams, 1990) to simulate soil erosion from cropland under various crop management scenarios. Embedded in a spatial simulation framework, the model runs for about 100 000 simulation units globally ranging from a resolution of 5-30 arc minutes, considering soil, topography, climate, and crop management. In a first assessment, maize is simulated as a model crop due to its global importance as food and fodder, its cultivation across all significant climate and soil regions and because it contributes substantially to soil erosion from cultivated land due to its poor soil conserving efficiency and large acreage.

Specific objectives of this study are to:

(a) Estimate global and regional SOC potentially removed with sediment runoff and its spatial pattern;

(b) Evaluate simulated sediment losses due to water erosion from cropland against a newly compiled database of reported erosion rates based on ^{137}Cs measurements;

(c) Assess simulated erosion estimates for contrasting crop management scenarios covering reduced and conventional tillage systems and bare or green fallows outside the main cropping season.

Methodology

A global gridded version of the EPIC crop model, EPIC-IIASA (Balkovic *et al.*, 2014), was used to simulate the daily growth of maize from 1980-2010 under rainfed and irrigated conditions accounting for sediment and SOC loss with runoff. EPIC has a detailed representation of organic carbon, nutrient and water dynamics as well as a wide range of field management options, including tillage operations and crop rotations (Williams 1990; Izaurralde *et al.*, 2006). Water erosion was simulated with a modified version of the Universal Soil Loss Equation adjusted for small watersheds (MUSS) implemented in EPIC.

The gridded crop model requires input data on daily climate, soil, and topography. The basic spatial resolution of the model is 5’ x 5’ (about 8 km x 8 km near the equator) at which soil and topographic data are provided. These are aggregated to homogenous response units based on classification and further intersected with a 30’ x 30’ climate grid, the resolution at which global gridded climate data are available. This results in a total, of about 100’000 simulation units with a spatial resolution of 5’ to 30’. Global daily weather data were adopted from the AgMERRA dataset for the years 1980-2010 (Ruane *et al.*, 2015). Soil information and initial organic carbon stocks were obtained from the Harmonized World Soil Database (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2009). Topography was acquired from USGS GTOPO30.

Crop management was based on reported growing seasons (Sacks *et al.*, 2010) and fertilizer application rates combined with a range of tillage and cover crop scenarios. Spatially explicit nitrogen and phosphorus fertilizer application rates are based on a dataset by Mueller *et al.* (2012). The simulations were carried under two tillage (conventional, reduced) and two cover crop scenarios (bare fallow, green fallow), to analyse the impact of contrasting field management on simulated sediment runoff and SOC loss. A business-as-usual baseline scenario (termed “MIX” below) combines these scenarios spatially based on climatic and economic indicators.

To evaluate model outputs, simulated soil loss was compared with soil loss measured in the field using ^{137}Cs as radioactive tracer. The data were compiled from a literature review and comprise 364 data points globally covering most agro-environmental conditions relevant for maize cultivation. In the further text, this database is referred to as ^{137}Cs.

Results and Discussion

For the business-as-usual scenario, the global median rate of SOC loss from maize fields with sediment runoff is 68.2 kg ha^{-1} yr^{-1} with a mean of 349.9 kg ha^{-1} yr^{-1}. The total annual loss of SOC from land cultivated with maize is 0.02 Pg. The magnitude of SOC loss varies in different parts of the world with the highest values in tropical regions (Figure). Those regions include Melanesia, South-Eastern Asia, Central America and the Caribbean where SOC loss is 3 to 17-fold the world median. Southern and Western Europe, Eastern Africa, South America and Western Asia exceed the world median of SOC loss as well. Regions with lower SOC loss include a large share of flat and dry land where low water erosion is simulated.

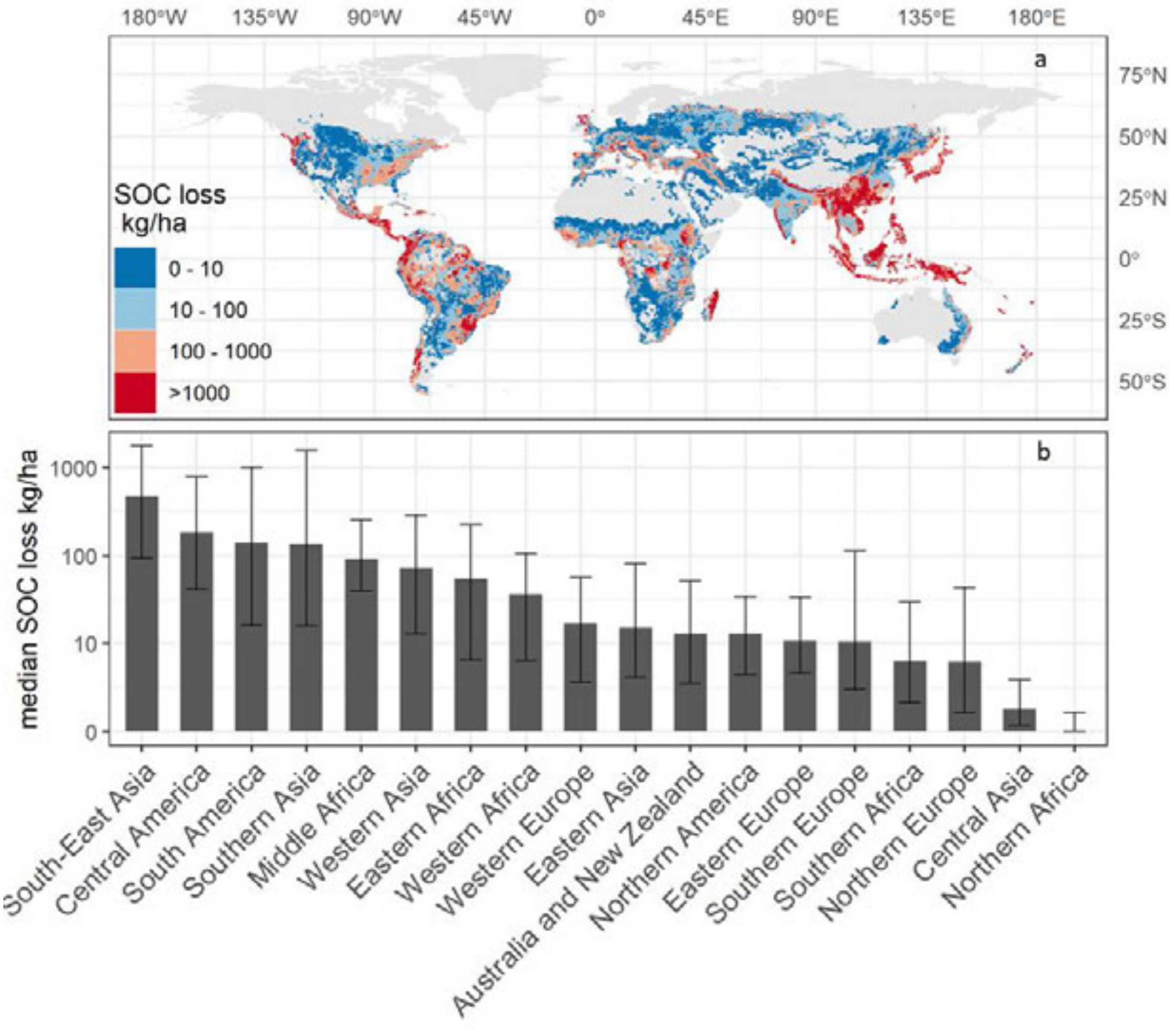

Figure 1: Simulated annual loss of SOC in sediment runoff of maize fields (1980 – 2010) in the baseline tillage scenario "MIX". a: Annual loss of SOC simulated for more than 100 000 grids, where daily growth of maize and water erosion is simulated. b: Median and error bars with first quartiles and third quartiles of simulated annual SOC loss in sediments for major world regions.

The evaluation against field measurements shows that most of the water erosion rates simulated with the business-as-usual scenario (MIX) are in the range of the field data (Figure). Under conventional tillage management (CON) with bare or green fallow, the simulation of water erosion increases with a large portion of values exceeding the range of the field data, which indicates an overestimation of global water erosion and SOC loss if this management is assumed globally. The simulation of water erosion under reduced tillage with bare soil in between maize seasons results in a large number of values exceeding field data, whereas reduced tillage with green fallow results in water erosion values mostly lower than those measured in the field.

Simulated water erosion and SOC loss are significantly sensitive to field management scenarios. While the evaluation against reported data provides a first indication of the robustness of results, the meta data accompanying the field measurements do presently not allow for detailed benchmarking with respect to specific management in place. All erosion measurements provide geographic coordinates allowing for overlay with climate data and regional allocation. Yet, data on slope inclination is often missing, soil types or texture classes are only provided for a limited set of data points (n=244, 66 % of samples) and information on crop types and tillage systems implemented over time are provided only for few points. To facilitate in-depth evaluation of erosion models across scales, it will be crucial to provide such information in field erosion measurements.

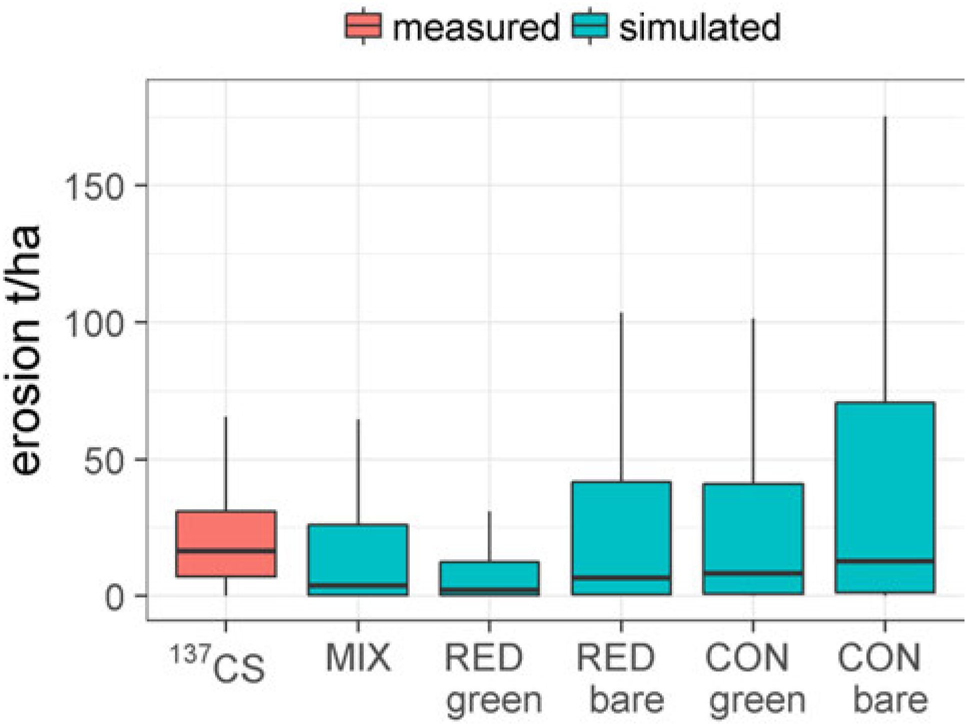

Figure 2: Comparison of water erosion measured in agricultural fields (n=364) and water erosion simulated for maize with spatially attributed intensities of tillage and fallow greening (MIX), or uniformly reduced (RED) or conventional tillage (CON) combined with bare and green fallow. Outliers are defined as values with a greater distance than 1.5 times the interquartile range and have been removed from the figure to improve the visual comparison between the boxplots.

Conclusions and outlook

With an estimated loss of SOC associated with maize production of 0.02 Pg yr^{-1} globally and regional variability in SOC loss rates ranging from 1 170 kg ha^{-1} yr^{-1} in Melanesia to 2.7 kg ha^{-1} yr^{-1} in Central Asia, soil erosion is an important externality of maize production systems. It hence needs to be a target of policy and management interventions to protect soil productivity and will also need to be considered in global efforts for climate change mitigation such as the 4 per mil initiative. To develop a full picture of sediment, SOC, and plant nutrient mobilization as a next step of our study, further crops with different growth properties will be included to cover water erosion estimates for major global crop cultivation systems.

Comparing simulated water erosion under different crop management scenarios to the reported ground data showed that a large portion of water erosion rates simulated under conventional tillage management with a bare fallow are substantially higher than benchmark data. Conversely, with reduced tillage and off-season green fallow management, the estimated soil loss is closer to the field data range. This underpins that the consideration of contrasting crop management strategies is vital for identifying the most effective measures for soil erosion control.

The meta data accompanying the field measurements, crucial for assessing the robustness of erosion estimates, do presently not allow for detailed benchmarking due to lack of information on crop types, tillage systems, and in part slope classes in a large number of samples. While our estimates are within the range of erosion measurements covering all relevant agro-environmental conditions for maize cultivation, only further detail will allow for evaluations by tillage systems, soil classes, and topography.

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References

Balkovič, J., van der Velde, M., Skalský, R., Xiong, W., Folberth, C., Khabarov, N., Smirnov, A., Mueller, N.D. & Obersteiner, M. 2014. Global wheat production potentials and management flexibility under the representative concentration pathways. *Global and Planetary Change*, 122: 107–121. https://doi.org/10.1016/J.GLOPLACHA.2014.08.010.

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K. Van, Montanarella, L. & Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8(1): 2013. https://doi.org/10.1038/s41467-017-02142-7.

Chappell, A., Baldock, J. & Sanderman, J. 2016. The global significance of omitting soil erosion from soil organic carbon cycling schemes. *Nature Climate Change*, 6(2): 187–191. https://doi.org/10.1038/nclimate2829.

Doetterl, S., Van Oost, K. & Six, J. 2012. Towards constraining the magnitude of global agricultural sediment and soil organic carbon fluxes. *Earth Surface Processes and Landforms*, 37(6): 642–655. https://doi.org/10.1002/esp.3198.

FAO/IIASA/ISRIC/ISS-CAS/JRC. 2009. Harmonized World Soil Database (version 1.2). FAO, Rome.

Izaurralde, R.C., Williams, J.R., McGill, W.B., Rosenberg, N.J. & Jakas, M.C.Q. 2006. Simulating soil C dynamics with EPIC: Model description and testing against long-term data. *Ecological Modelling*, 192(3–4): 362–384. https://doi.org/10.1016/J.ECOLMODEL.2005.07.010.

Lal, R., Griffin, W.M., Apt, J., Lave, L. & Morgan, M.G. 2004. Managing Soil Carbon. *Science*, 304(5669): 393. https://doi.org/10.1126/science.1093079.

Mueller, N.D., Gerber, J.S., Johnston, M., Ray, D.K., Ramankutty, N. & Foley, J.A. 2012. Closing yield gaps through nutrient and water management. *Nature*, 490, 254–257.

Quinton, J.N., Govers, G., Van Oost, K. & Bardgett, R.D. 2010. The impact of agricultural soil erosion on biogeochemical cycling. *Nature Geoscience*, 3(5): 311–314. https://doi.org/10.1038/ngeo838.

Ruane, A.C. et al. 2015. Climate forcing datasets for agricultural modelling: merged products for gap-filling and historical climate series estimation. *Agric. Forest Meteorol.*, 200: 233–248, http://dx.doi.org/10.1016/j.agrformet.2014.09.016

Sacks, W.J., Deryng, D., Foley, J.A. & Ramankutty, N. 2010. Crop planting dates: an analysis of global patterns. *Global Ecology and Biogeography*, 19(5). https://doi.org/10.1111/j.1466-8238.2010.00551.x.

Williams, J.R. 1990. The Erosion-Productivity Impact Calculator (EPIC) Model: A Case History. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 329(1255): 421–428.

Downscale LS derived from 1-arc SRTM in Global Soil Erosion Assessment

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Abstract

The accuracy of slope length and steepness factor (LS) is influenced by resolution of input DEM dataset. In this paper, the difference between LS derived from 1-arc Shuttle Radar Topography Mission (1arc-SRTM) and from 5m DEMs was quantified in 4 typical areas and a downscale method was given in order to make the LS derived from 1-arc SRTM more suitable to be used in global soil erosion assessment. A frame of sampling strategy was given for further global down scale of LS. The result showed comparing with 5m DEMs, using 1-arc SRTM as base dataset, LS would be underestimated in hilly areas with detailed terrain structures where LS value changing was dominated by slope. And it would be overestimated in general structures dominated terrain types with slope length influenced LS to greater extent. The down scale process will improve the accuracy of LS by 15 % in mountain areas and around 10% in hilly areas, not much improvement showed in flat areas. This paper suggested a downscale process of terrain parameters in the modelling of global soil erosion and a global LS downscaling strategy has been proposed.

Keywords: 1-arc SRTM, LS, Downscale, Global Soil Erosion Assessment

Introduction

The slope length and steepness factor (LS) is one of key parameters in erosion models such as USLE (Wischmeier and Smith, 1978), RUSLE (Renard, 1997) and CSLE (Liu *et al.,* 2002) which has been widely used (Panagos, 2015; Borrelli, 2017; USDA, 2018; Yin 2018). 1-arc SRTM is one of the most widely used DSM datasets in erosion modelling (Borrelli, 2017) which could be easily obtained in most areas of the world. However, LS calculated based on 1-arc SRTM was not accurate enough for erosion modelling because of the relatively lower resolution. Research on the influence of resolution of input DEM to terrain parameters shows that slope gradient decrease with resolution becomes coarser, while slope length increase (Wolock and Price, 1994; Wang and Yin, 1998; Yin and Wang, 1999, Zhang *et al.*, 1999; Wolock and McCabe, 2000, Wu *et al.*, 2008; Yang *et al.*, 2008, Vaze *et al.*, 2010). LS changing with resolution may varies in different areas. The method of "Histogram matching" (Yang *et al.*, 2008) is useful and suitable for downscale terrain parameters. In this paper, the different laws of scale effect for both slope, slope length and LS were analysed in hilly, mountain and flat areas. A frame of global LS downscale was given for future global LS calculation in order to offer more accurate LS dataset for global soil erosion mapping.

Methodology

Study area and base data

This research involved 4 terrain types, 2 watersheds was carefully chosen for model establishment and model calibration separately in each terrain area. The area of each watershed is around 20 km^2. The 4 terrain types Hilly area, (C1), Relatively flat area (C2), mountain area (U1) and another Hilly area (U1). The base dataset includes 1-arc SRTM DSM dataset, 5m DEM built based on 1:10000 topo-map by Chinese government for C1 and C2 and 1/9 arc Lidar dataset for U1 and U2 (https://viewer.nationalmap.gov/basic). The 1/9 arc Lidar dataset was resampled to 5m and 1-arc SRTM DSM dataset was resampled to 30m in grid cell size.

Method

LS calculation

LS was calculated based on elevation datasets above using software LS-Tools (Zhang *et al.*, 2013; Zhang *et al.*, 2017). The LS algorithm presented by McCool D.K. (McCool *et al.*, 1987) was used for flat area with slope less than 10° and for those greater than 10° algorithm presented by Liu Baoyuan (Liu *et al.*, 1994)

Down scaling method

The method of rescaling the slope, slope length and LS of the coarser ones by matching histograms of their frequency curves (Yang *et al.*, 2008).

Model calibration method

In this paper, HI (Histogram Intersection) between histograms of LS based on 5m DEM and 1-arc SRTM was calculated in 4 calibration watersheds.

$$\mathrm{HI}(X, Y) = \sum_i \min(x_i, y_i)$$

Where X and Y refers to histograms of 5m LS and downscaled 1-arc SRTM LS; xi and yi refers to values of frequencies of 5m LS and downscaled 1-arc SRTM LS at LS of i. The down-scaling model is better is the value of HI larger.

Results

Scaling effect of LS

With resolution becomes coarser from 5m to 30m, mean slope gradient decreased and mean slope length increased in all areas, while mean LS value decreased in C1 and U2 and increased in C2 and USA1. In study area C1 and U2, slope is the most significant parameter that changing with resolution, while in C2 and U1 slope length dominants the process. With resolution become coarser from 5 m to 30 m, mean LS value in C1 and U2 decreased a little less than 30 %, in C2 it is slightly increased by 3.7 %, in U1 it increased 43.8 %. Slope gradient decreased most in C1 and least in C2. Slope length increased most in U1 and least in C2. The HI values shows similar trends.

Downscale analysis

Table 1 shows the 1-arc SRTM, 5 m, and downscaled 1-arc SRTM surfaces for slope, slope length and LS at 4 calibration watersheds. After downscaling, mean values for slope, slope length and LS in 4 areas are more close to finer resolution. And Histogram Intersection (HI) values between 5m and downscaled 1-arc SRTM are all higher than 88% for slope and higher than 80 % for slope length, higher than 80 % for LS. The improvement after downscale for LS is greater in U1 and less in C2.

Table 1: Mean value and HI in the 4 calibration watersheds

Sample	resolution	Mean value			Histogram intersection value between each dataset and 5m resolution dataset /%		
		Slope /°	Slope length/m	LS	HI (Slope)	HI (Slope length)	HI (LS)
C1	30m	14.54	185.59	11.66	49.7 %	58.1 %	82.1 %
	5m	27.67	127.09	16.05	100 %	100 %	100 %
	Downscaled 30m	28.57	123.57	15.41	93.8 %	81.2 %	91.3 %
C2	30m	1.85	323.56	1.13	92.0 %	65.3 %	79.0 %
	5m	2.02	257.05	1.09	100 %	100 %	100 %
	Downscaled 30m	2.01	268.55	1.06	95.1 %	80.3 %	82.2 %
U1	30m	21.40	425.97	29.26	90.8 %	48.8 %	78.3 %
	5m	23.80	198.35	20.35	100 %	100 %	100 %
	Downscaled 30m	23.87	172.3	19.84	99.9 %	89.9 %	93.0 %
U2	30m	6.11	177.62	3.98	0.654 %	58.0 %	84.7 %
	5m	9.85	114.55	5.57	100 %	100 %	100 %
	Downscaled 30m	9.23	111.27	5.35	91.0 %	90.8 %	90.0 %

Sampling Strategy for global LS downscale

According to scale effect and downscale result, a worldwide strategy for global LS downscaling method has been detected. 125 samples locate at different terrain types has been chosen as downscaling model building. As the result shows above, if mean slope in a certain terrain region is lower than 2° there will be no downscaling process in this region. Otherwise the downscale model will be built and used for both slope gradient and slope length.

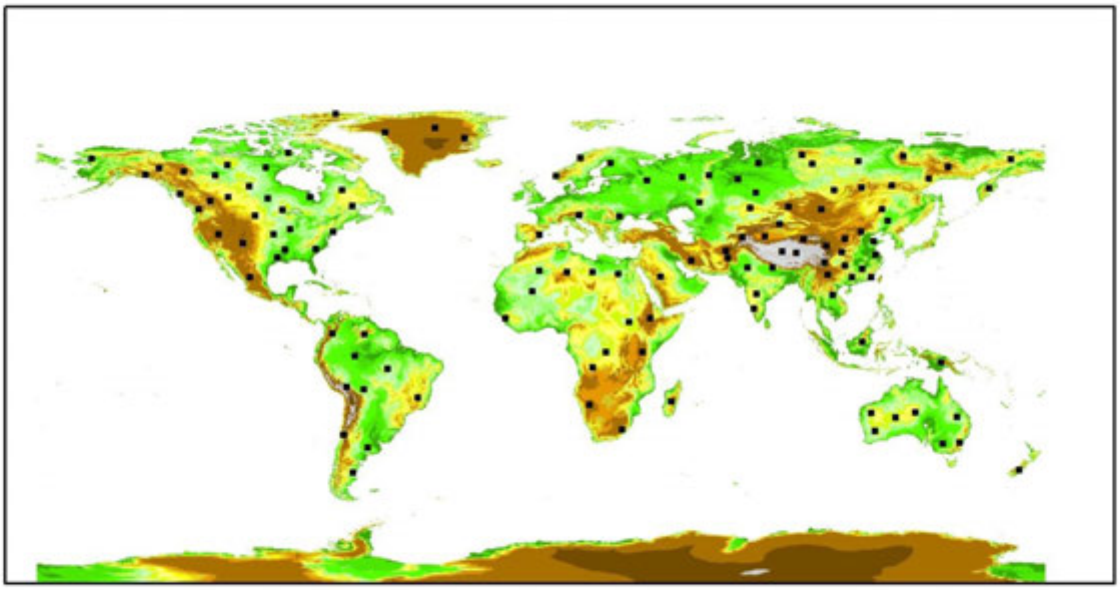

Figure 1: Sampling Strategy for global LS downscale

Discussion

The result of this works show the different scale law could be divided in too two types, slope gradient dominated area and slope length dominated area. With the input DEM resolution becomes coarser, LS would decrease for the former type and increase for the latter type.

The high resolution DEM dataset used in this paper varied which may influence the result to some extent. The influence should be quantified in the further study since we have to use varied types of high resolution elevation datasets in the study of global LS downscaling.

Conclusions

(1) In different terrain types, LS derived from 1-arc SRTM can underestimate in some areas (such as hilly area in C1 and U2) or overestimate in some other areas(such as mountain area U1), in flat area the LS result did not show much different comparing with that from 5m DEMs.

(2) The downscale method used in this paper can improve the accuracy of LS about 15 % in mountain areas and 10% in hilly areas.

(3) A global LS downscaling frame has been proposed in this paper. We suggest in the global soil erosion assessment in model such as USLE/ RUSLE/CSLE, a downscale process of LS should be carried out.

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References

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K. Van, Montanarella, L. & Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*. https://doi.org/10.1038/s41467-017-02142-7

Liu, B., Nearing, M.A. & Risse, L.M. 1994. Slope gradient effects on soil loss for steep slopes. *Transactions of the ASAE*, 37(6): 1835-1840.

Liu, B.Y., Zhang K.L. & Xie, Y. 2002. A empirical soil loss equation. Proc of 12th ISCO. Beijing, Tsinghua press: 143-149.

McCool, D.K., Brown, L.C. & Foster, G.R. 1987. Revised slope steepness factor for the Universal Soil Loss Equation. *Transactions of the ASAE-American Society of Agricultural*, 30(5): 1387-1396.

Panagos, P. 2015. The new assessment of soil loss by water erosion in Europe. *Environ. Sci. Policy*, 54.

Renard, K.G., Foster, R.R., Weesies, G.A. et al. 1997. Predicting rainfall eosion by Water: A Guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE).

USDA. 2018. Summary Report: 2015 National Resources Inventory, Natural Resources Conservation Service, Washington, DC, and Center for Survey Statistics and Methodology, Iowa State University, Ames, Iowa. http://www.nrcs.usda.gov/technical/nri/15summary.

Vaze, J., Teng J. & Spencer, G. 2010. Impact of DEM accuracy and resolution on topographic indices. Environmental Modelling & Software, 1086–1098.

Wang, X. and Yin, Z.Y. 1998. A comparison of drainage networks derived from digital elevation models at two scales. *Journal of Hydrology*, 210(1-4): 221-241.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting Rainfall Erosion Losses, A Guide to Conservation Planning. Agricultural Handbook no. 537. Washington, DC, US Department of Agriculture.

Wolock, D.M. and McCabe, G.J. 2000. Differences in topographic characteristics computed from 100- and 1000-m resolution digital elevation model data. *Hydrological processes*, 14(6): 987-1002.

Wolock, D.M. and Price, C.V. 1994. Effects of digital elevation model map scale and data resolution on a topography-based watershed model. *Water Resources Research*, 30(11): 3041-3052.

Wu, S., Li, J. & Huang, G.H. 2008. A study on DEM-derived primary topographic attributes for hydrologic applications: Sensitivity to elevation data resolution. *Applied Geography*, 28(3): 210-223.

Yang, Q. K., David, J., Li, R. & Liang, W. 2008. Re-scaling lower resolution slope by histogram matching. Advances in Digital Terrain Analysis. Q. Zhou, B. G. Lees and G. A. Tang. New York, USA, Springer: 193-210.

Yin, S. Zhu, Q., Wang, Z. Y. et al. 2018. Regional soil erosion assessment based on a sample survey and geostatistics. *Hydrology and Earth System Sciences*, 22(3): 1695-1712.

Yin, Z.Y. and Wang, X. 1999. A cross-scale comparison of drainage basin characteristics derived from digital elevation models. Earth surface processes and landforms, 24(6): 557-562.

Zhang, H., Wei, J. & Yang, Q., et al. 2017. An improved method for calculating slope length (lambda) and the LS parameters of the Revised Universal Soil Loss Equation for large watersheds. *Geoderma*, 308: 36-45.

Zhang, H., Yang, Q., Li, R. et al. 2013. Extension of a GIS procedure for calculating the RUSLE equation LS factor. *Computers & Geosciences*, 52: 177-188.

Zhang, X.Y., Drake, N. A., Wainwright, J. et al. 1999. Comparison of slope estimates from low resolution DEMs: Scaling issues and a fractal method for their solution. *Earth Surface Processes and Landforms,* 24(9): 763-779.

Soil erosion intensity and SOM dynamics: traditional cultivation *vs*. perennial cover crop

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Abstract

Soil erosion in a conditions of intensive agricultural production systems, like vineyards and orchards on inclined terrains, is a serious form of land degradation. The processes of soil erosion are additionally accelerated, with the negative impact of climate change, especially in arid and sub arid regions.

Main objective of this study was to estimate the influence of certain adaptive measures on soil erosion, in order to improve or replace the traditional cultivation practices. In a period of 4 vegetation seasons the influence of perennial grass cover on soil erosion and soil loss, as a replacement to the traditional cultivation, was monitored. Soil erosion experimental fields has been established on two locations on an inclined terrain. Soil sediment has been collected and monitored on a weekly base or immediately after rainfall events.

Soil sediment loss in all four years of monitoring vary in a broad rages of 0.6 up to 35.4 t/ha in variant OC in Skopje experimental site. Ration of eroded sediment among the variants in Skopje site is approx. 1:100, while in Negotino experimental site is only 1:7. The lost organic matter in variant 1 OC in Skopje site is almost 2 t/ha for a 4 year period, while with cover crops is only 19 kg/ha. The influence of cover crops on SOM content in top soil is evident. In Skopje experimental site the SOM content in variant PG increased for 2.71 % or almost double, while in Negotino site for about 0.21 %.

Keywords: soil sediment, SOM, soil erosion, cover crops

Introduction, scope and main objectives

Soil erosion is considered to be the dominant process of land degradation, especially in intensive systems of agricultural production, affecting big areas of agricultural land (Wysocka-Czubacheck *et al.*, 2014). Areas affected with soil erosion, rapidly and inevitably lose the fertile top soil, soil nutrients, and water holding capacity. In the same, the eroded sediment pollute surface water courses, accumulate over fertile soils in the valleys and threatens the infrastructural facilities.

Central and south –eastern part of the R. of Macedonia are under influence of sub-arid climate conditions with hot and dry summer, mining that an intensive agricultural production is almost impossible without intensive irrigation. In such climatic conditions, soils usually have low soil organic matter content, with loose and unstable soil structure.

In such conditions, cultivation practises are of particular importance for efficient control of soil erosion processes. In many cases as a result of the relief specifics or the shape of the parcel, cultivation is performed downslope, which can cause severe process of soil erosion.

This problem is very intensive in the driest central part and south-eastern part of the country where the majority of vine production is situated.

Main objective of this research was to evaluate the influence of a simple and easy to use adaptive practices, as a tool for reduction of the intensity of soil erosion processes, in vine production regions. To compare the efficiency of the proposed measures under different soil and climatic conditions and to monitor the influence of the proposed adaptive measures on soil properties, especially soil organic matter content. Another objective of this research, was to demonstrate the tested measures to the farmers in order to present its efficiency in practice.

Methodology

Experimental sites were situated on two locations with different soil and climatic conditions. First site (Negotino site) was located in the central part of the country in a vineyard on an inclination of 11.5 %. The experimental site was located on Humic calcaric regosol with a visible signs of erosion of its topsoil, which was mostly eroded. The rows of the vineyards, were situated downslope and all cultivation practices including furrow irrigation have been performed downslope. The second experimental site (Butel) was located in the northern part in the vicinity of the capitol Skopje, on a Chromic luvisol on saprolite (WRB), on a sloppy terrain with approx. 11 % inclination.

The influence of two different methods of cultivation on soil erosion intensity, were tested, on both location: ordinary cultivation and perennial grass used as a cover crop.

Both experimental sites consisted of two variants in three replications, or in total six replications. Each of the replications consisted of two vineyard rows, where each row was 22, 1 m long and 1.87 m width ((Whichmaer and Smith, 1978).

Each replication was fenced with thin-sheet tin to enable streaming of the run-off and the sediment to the outlets at the end of the parcel. The influence of the both cultivation systems on soil erosion was monitored trough collection of soil sediment in a special containers installed at the outlet of the experimental parcels.

In autumn, the tin fences were partially moved to enable deep ploughing in variant one. In spring, the tin fences were mounted again.

Before setting up of the experimental sites in order to have an initial overview of soil quality at the initial stage, soil samples from both localities were collected for laboratory analysis of soil chemical properties, e.g.: pH in KCl and H_2O, SOC etc. In the next stages of the monitoring period, soil samples for soil chemical analysis were collected from each experimental plot every year at the end of vegetative season. Special attention is payed to the dynamics of soil organic carbon and nutrients: nitrogen, phosphorus and potassium. In all years of the monitoring period, soil sediment has been collected on a weekly base or day after intensive rainfall events. The weight of collected soil sediment was measured and laboratory tested for the quantity of soil organic matter and nutrients. Soil samples from the top soil from all replications from both variants were collected at the end of each vegetative season in order to monitor the dynamics of SOM in top soil.

Results

Negotino experimental site was located on Humic calcaric regosol, while the second experimental site (Butel) was located on Chromic luvisol on saprolite (WRB) Soil profiles has been excavated before setting of the experimental fields and soil samples were collected and analyzed. Data regarding basic soil chemical and mechanical properties are presented in Table 1 and 2.

Out of the data, presented in Table 1 it can be seen that soil in Butel experimental have fine texture with domination of clay particles and fine sand. Clay content increases in the lower part of the soil horizon, with a maximum content of 56.2 % in (B)/C. Fine sand fraction has its highest content in the surface (Ap) horizon and subsurface horizon (B). Low content of coarse sand and skeleton fraction from 8.7 % in hor. Ap up to 3.3 % in C, indicates low infiltration rate of the top soil and possible high coefficient of erodibility. As for the Negotino site, the soil has much lighter texture with domination of fine sand especially in the surface layer which gradually decreases in hor. AC and C. Silt and clay contents are very close and the only difference is that clay slightly increases in depth of the soil horizon. High skeleton content is notable, which coupled with high content of fine sand indicates a good infiltration rate of this soils.

Table 1: Texture of soils in Skopje and Negotino experimental sites

Soil horizon	Depth (cm)	Skeleton (> 2 mm)	particle size distribution %				Texture
			Coarse sand (2-0.2 mm)	Fine sand (0.2-0.02 mm)	Silt (0.02-0.002 mm)	Clay (<0.002 mm)	
Chromic luvisol on saprolite – Butel experimental site							
Ap	0-23	8.78	8.7	35.2	16.4	39.7	Clay loam
(B)	23-65	9.46	6.0	41.3	11.1	41.6	Sandy clay
(B)/C	65-89	6.24	3.5	27.7	12.6	56.2	Clay
C	89-123	6.34	3.3	28.4	14.2	54.1	Clay
Humic calcaric regosol – Negotino experimental site							
Ap	0-15	32.54	14.02	44.15	21.67	20.16	Sandy clay loam
A	15-48	30.36	11.53	39.15	23.97	25.35	Sandy clay loam
AC	48-78	21.56	8.93	33.23	28.14	29.70	Clay loam
C	78-115	18.48	14.34	32.15	22.35	31.16	Sandy clay loam

Data from the 4 year monitoring program for the total quantities of eroded sediment, and the quantities of lost organic matter are presented in Table 2. There are a significant differences in collected sediment in all four years of the monitoring program, which vary in a rages of 0.6 up to 35.4 t/ha in variant OC in Skopje experimental site. Big differences in the eroded sediment is identified between the variants on both locations, which in Skopje site is approx. 1:100, while in Negotino experimental site is only 1:7.

The chemical properties of the eroded sediment were monitored as well. Out of the data in Table 2 it can be seen that the lost organic matter in Skopje site with ordinary cultivation is almost 2 t/ha for a 4 year period, while with perennial grass as a cover crop, is only 19 kg/ha. The positive influence of cover crops (perennial grass) on SOM content in the top soil on both locations, is evident. In Skopje experimental site the SOM content in variant PG increased for 2.71 % or almost double, while in Negotino site this increasing is only 0.21 %.

Table 2: Sediment loss and SOM loss and dynamics in the top soil

Para-me-ter	Soil sediment loss kg ha^{-1}				SOM loss with erosion kg/ha				Top soil SOM content dynamics, %			
Loca-tion	Exp. site Butel		Exp. site Negotino		Exp. site Butel		Exp. site Negotino		Exp. site Butel		Exp. site Negotino	
Vari-ant	OC	PG	OC	PG	OC	PG	OC	PG	OC	PG	OC	PG
2013	604.6	181.4	8 539.4	3 143.7	35.1	7.0	117.0	60.7	2.3	2.6	1.6	1.8
2014	7 850.7	116.0	5 802.6	812.6	366.6	4.4	75.4	13.8	2.1	2.6	1.4	1.8
2015	11 863.0	11.5	4 830.0	515.0	430.6	0.7	53.1	10.6	1.8	5.1	1.1	1.9
2016	35 423.0	111.0	2 390.0	490.0	1 115.8	7.0	25.1	10.5	1.1	5.3	1.1	2.0
Total	55 741.3	419.9	21 562.1	4 961.3	1 948.2	19.1	270.7	95.6	(-1,183)	(+ 2.717)	(-0.500)	(+0.21)

Discussion

The intensity of soil erosion is highly related to the geomorphology of the terrain and soil properties. Some authors (Sahoo *et al.*, 2016) reports significant increase (17 %) in annual runoff due to increase in slope. In such circumstances, the effects of different cultivation practices (Quinton and Catt, 2004; Stevens *et al.*, 2009) and cropping systems becomes of crucial importance in the process of reduction of this type of degradation.

In the four years of monitoring campaign, particular interest has been payed to the quantity of eroded soil sediment under two different cultivation practices: ordinary cultivation and perennial cover crop, on the intensity of soil erosion processes.

This alteration on intensive plantations on inclined terrains, resulted with significant reduction of sediment loss, which is obvious from the presented data. Beside this, there are significant differences in the yearly production of soil sediment within the variants, as a result of the hydrological specifics in some years, due to what the sediment loss in Variant 1 (OC) in Skopje, ranges from 0.6 t/ha/y in the extremely dry 2013 up to 35.4 t/ha/y in year 2016 when several extreme rainfall events occurred. Similar variations among each monitoring year can be noted in Negotino site as well, with less variations in the quantities of the eroded soil sediment, which is due to the more balanced hydrological cycles. Another factor influencing the intensity of soil erosion are, the soil properties of the examined locations. The heavier texture and higher erodibility of the Chromic luvisol in comparison to the lighter texture of the Negotino soils, are one of the factors which coupled with the weather extremes, influence the intensity of soil erosion processes in Skopje experimental site.

The SOM content significantly changes depending of the system of applied cultivation practices. There are significant increase of almost 50% of top soil SOM in Varian 2 (PG) in Skopje experimental site. This increase is much lower in the top soil of Negotino soil, which is result to the drier climate of Negotino area and the lower biomass productivity of the cover crop.

Conclusions

The intensity of soil erosion on agricultural land is highly dependent to the applied system of cultivation, relief and soil conditions, and climate specifics,

There are significant differences in production of sediment, between ordinary cultivation and perennial grass as a cover crop in perennial plantations, Hydrological conditions can significantly influence the intensity of soil erosion,

The dynamics of, Soil Organic Matter contents in the top soil, is highly dependent to the cultivation system applied, as well as to the intensity of soil erosion

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References

Kisic, I., Bashic, F., Nestroy, M., Mesic, M. & Butirac, A. 2002. Soil erosion under different tillage methods in central Croatia. *Die Bodencultur*, 53(4): 199-206.

Sahoo, C.D., Madhu, G.M., Bosu, S.S & Khola, S.P.O. 2016. Farming methods impact on soil and water conservation efficiency under tea [Camellia sinensis (L.)] plantation in Nilgiris of South India. *International Soil and Water Conservation Research*, 195–198.

Stevens, C.J., Quinton, J.N., Bailey, A.P., Deasy, C., Silgram, M., Jackson, D.R. 2009. The effects of minimal tillage, contour cultivation and in-field vegetative barriers on soil erosion and phosphorus loss *Soil and Tillage Research*, 106: 2121-2130

Wischmeier, W.H. & Smith D.D. 1978. A Universal soil-loss equation to guide conservation farm planning. Int. Congr. Soil Sci.,Trans., 7 Int. Soc. Soil Sci., Madison, 418–425.

Wysocka-Czubaszek, A. & Czubaszek, R. 2014. Tillage erosion: The principles, controlling factors and main implications for future research. *Journal of Ecological Engineering*, 15(4): 150–159.

Quinton, J.N. & Catt, J.A. 2004. The effects of minimal tillage and contour cultivation on surface runoff, soil loss and crop yield in the long-term Woburn Erosion Reference Experiment on sandy soil at Woburn, England. *Soil Use and Management*, 20: 343–349.

An investigation of the relationship between flow characteristics and soil erosion indices

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Abstract

This study aimed to examine the relationship between different soil erosion indices and different flow characteristics for five contrasting soil samples at the laboratory condition. The soil samples include two surface cultivated soils, a saline-sodic marl, a well aggregated forest soil, and a fluvial sand. A uniform bed of 2.5 m long, 5 cm width with 5 cm depth of each sample was formed, and soil erosion and flow characteristics were determined under six flow rates on a 2 % slope. The changes with time of sediment concentration and erosion rate indicated the possibility of changing soil erosion system from transport-limited to detachment-limited for higher flow rates. A linear regression analysis was performed between flow characteristics and soil erosion indices. While there were not considerable differences among selected flow characteristics, different soil erosion indices including sediment concentration, soil erosion rate, and total soil loss were differently correlated with flow characteristics.

Keywords: Flow shear stress, Streampower, Rill erosion, Sediment concentration, Soil erosion rate

Introduction

Soil erosion is a serious environmental problem threatening the future development of agriculture and society. Increased attention to the problem has led to improve soil conservation measures, which is based on the knowledge of soil erosion mechanisms and with the assistance of soil erosion models (Lei *et al.,* 2008). Process-based soil erosion models are very important in this case. A process-based model for soil erosion prediction is a group of mathematical functions based on soil erosion processes (Lei *et al.,* 2008). An equation for evaluating the sediment transport capacity of overland flow is a necessary part of a physically based soil erosion model describing sediment detachment and transport as distributed processes (Vito, 1998). In general, transport capacity is a function of the flow hydraulics and the sediment characteristics (Polyakov and Nearing, 2003).

For modeling purposes, soil erosion by water is commonly divided into rill and interrill components, depending on the source of eroded sediment (Meyer and Wischmeier, 1969). Several different flow characteristics have been used to quantify soil detachment in rills, including flow discharge rate (Meyer and Wischmeier, 1969), hydraulic shear stress (Nearing *et al.,* 1989), streampower (Hairsine and Rose, 1992; Nearing *et al.,* 1997), and unit streampower (Morgan *et al.,* 1998). On the other hand, in soil erosion modeling, various indices have been used to quantify soil erosion/loss including mass sediment concentration (Hairsine and Rose, 1992), volume sediment concentration (Morgan *et al.,* 1998), and mass of soil loss per unit area per unit time (Flanagan *et al.,* 2001). There are also different time scales, i.e. average annual, event based, steady state condition and continuous dynamic for soil erosion modeling. It is still questionable which index on what time scale is proper to quantify soil erosion/loss. This study was aimed to test the relationship between different soil erosion indices and different flow characteristics for five contrasting soil samples at the laboratory condition.

Methodology

Five contrasting soil samples were used in the study to provide a range of particle size distribution, density and cohesion. The soil samples include two surface cultivated soils, a saline-sodic marl, a well aggregated forest soil, and a fluvial sand. The range of sand OM, MWD, and calcium carbonate equivalent were 17-95 %, 0.0-5.7 %, 1.03-3.62 mm, and 2-22 %, respectively. A solid base tilting flume with runon facility was used to carry out the experiments (For the details see Asadi *et al.,* 2011). A uniform bed of 2.5 m long, 5 cm width with 5 cm depth of each sample was formed before being saturated for one night with tap water. Six flow rates were tested including 0.03, 0.05, 0.075, 0.1, 0.15 and 0.2 L s-1 on a 2 % slope. Sediment concentration was determined at times 1, 2, 3, 4, 5, 7, 10, 20, 30 and 40 minutes from the commencement of the experiment. Flow velocity was measured by colorimetric method with three replications. The depth of flow was measured with a special bathometer at three points along soil bed with three replications during the experiment.

Results and Discussion

Dynamic changes of sediment concentration and soil erosion rate, total soil loss

As many previous studies (e.g. Fox and Bryan, 1999; Asadi *et al.,* 2007, 2011; Zhang *et al.,* 2010), sediment concentration was high at the beginning but decreased and approached an approximately a constant value. Time of approach to an approximately constant value was somewhat different for different soil types, but it was generally longer for higher flow streampowers than low streampowers. As shown in Figure 1 (as an example for the marl sample), early unsteady sediment concentration is higher for higher flow streampower, however surprisingly it is more or less the same for all streampowers at final steady condition, even it is lower for higher streampowers than lower ones in some cases. This contradictory result needs some explanation, and could be discussed in part by the concepts of “transport limit” and “detachment limit”. On the other hand, it is also may dictated that sediment concentration is not a good index to differentiate among the treatments.

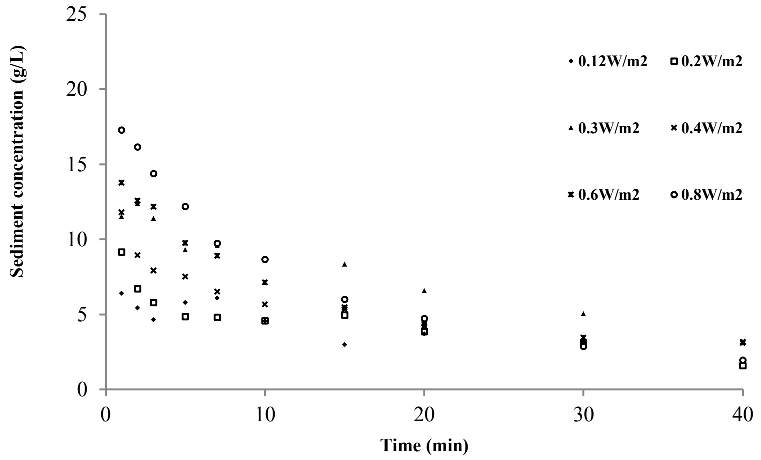

Figure 1: Dynamic changes of sediment concentration at different streampowers for the marl sample.

In the laboratory conditions like the present study, in addition to the natural background, the sampling and preparation of the soil are the main processes of supplying a quantity of detached easily transportable material. This material usually puts the flow at the transport limit on the commencement of erosion. At this stage sediment concentration is high and the differences among flow rates/streampowers are noticeable (Figure 1) because of the difference among their transport capacities. Previous studies (Asadi *et al.,* 2007, 2011) have shown that the early outflow sediment mainly consists of very fine particles. When the erosion proceeds, the amount of already detached material decreases which gradually puts the flow at the detachment limit. Soil detachment rate may also be limited by the deposited layer of coarse sediment developed during time, which protects the bed from detachment forces of the flow (Haisine and Rose, 1992). These stages happen sooner for the higher flow rates/streampowers than the lower ones. Accordingly, at the apparent steady condition (Figure 1, times 20 minutes upward), flow regime likely is still at transport limiting phase for low rates/streampowers while it is at detachment limiting phase for higher flow rates/streampowers.

To test if soil erosion rate is a better index of erosion severity, the changes with time in soil erosion rate was calculated and compared to sediment concentration. The compression showed that while erosion rate has a similar trend as sediment concentration, but in this case the difference among flow rates/streampowers was clearer especially on the first unsteady 20 minutes for all soils and even all the time for the marl sample, forest soil and fluvial sand. In other words, as we expected the higher flow rate/streampower, the higher erosion severity, this can be shown by erosion rate better than sediment concentration for three soils, but there was still problem with two soils.

To give more insight into the results, total soil loss was calculated for each experiment. The results showed that total soil loss increases significantly with increasing streampower. The soil loss in highest streampower was more than 13 times of that of the lower streampower. Expressed amount of erosion, in terms of sediment concentration and erosion rates may resulted a mislead view in some cases. This could be one of the reasons for lower performance of the models estimating soil erosion rates in terms of sediment concentration.

The relationship between soil erosion and flow characteristics

To quantify soil erosion five indices were used including; steady state sediment concentration, time-averaged sediment concentration, steady state erosion rate, time-averaged erosion rate and total soil loss. These soil erosion indices were plotted against different flow characteristics (including flow streampower, shear stress, flow velocity, the fifth and sixth powers of flow velocity) for the five tested soil samples. The results (Table 1) indicated that:

(i) Considering all soils, flow streampower showed the best and worst linear relationship with total soil loss (R^2 ranged from 0.89-0.98) and steady state sediment concentration, respectively. But excluding one of the soil samples (i.e. a calcareous cultivated soil), the best linear relationship was observed between flow streampower and steady state erosion rate (R^2 ranged from 0.92-0.98).

(ii) Considering all soils, flow shear stress showed the best linear relationship with total soil loss (R^2 ranged from 0.89-0.96) and time-averaged erosion rate (R^2=0.87-0.98). The worst linear correlation was again for steady state sediment concentration. But excluding the calcareous cultivated soil, the linear relationship between flow shear stress and steady state erosion rate was also strong (R^2=0.93-0.96).

(iii) The fifth and sixth powers of flow velocity showed strong linear relationships with time average erosion rate and total soil loss. Though the relationships between sediment concentrations with flow velocity of different powers were quite better than those with flow shear stress and streampower, but they were not also reasonable for all soil samples.

Table 1: Coefficient determination of linear equation between flow characteristics and soil erosion indices

Soil sample	SSER-Ω	TSL-Ω	SSER-τ	TAER-τ	TSL-τ	TAER-Q^5	TAER-Q^6	TSL-Q^6
Cultivated 1	0.353	0.936	0.416	0.984	0.957	0.742	0.730	0.922
Cultivated 2	0.975	0.945	0.953	0.866	0.894	0.787	0.836	0.859
Marl	0.934	0.971	0.938	0.953	0.958	0.987	0.990	0.975
Forest	0.924	0.887	0.924	0.891	0.887	0.924	0.943	0.942
Fluvial sand	0.976	0.982	0.964	0.895	0.942	0.986	0.983	0.931

SSER, steady state erosion rate (g m^{-2} s^{-1}); TSL, total soil loss (g $event^{-1}$); TAER, time- averaged erosion rate (g m^{-2} s^{-1}); Ω, stream power (W m^{-2}); τ, flow shear stress (Pa); Q, flow velocity (m s^{-1})

Conclusions

Proper modeling of soil erosion needs the knowledge of relationship between soil erosion and flow characteristics. In this case not only the choice of flow characteristics is important, it is important to know the proper index for quantifying soil erosion. In this laboratory study under flow induced erosion, flow shear stress and time-averaged erosion rate and total soil loss were recognized as the proper flow and soil erosion characteristics for modeling purposes.

References

Asadi, H., Ghadiri, H., Rouhipour, H. & Rose, C.W. 2007. Interrill soil erosion processes and their interaction in low slopes. *Earth Surface Processes and Landform*, 32(5): 711-724.

Asadi, H., Moussavi, S.A., Ghadiri, H. & Rose, C.W. 2011. Flow-driven soil erosion processes and the size selectivity of sediment. *Journal of Hydrology*, 406: 73-81.

Flanagan, D.C., Ascough, J.C., Nearing, M.A. & Laflen, J.M. 2001. The Water Erosion Prediction Project (WEPP) model. In: Harmon RS, Doe WW (eds), *Landscape Erosion and Evolution Modelling*, New York: Kluwer Academic, pp. 145–199.

Fox, D.M. & Bryan, R.B. 1999. The relationship of soil loss by interrill erosion to slope gradient. *Catena*, 38: 211–222.

Hairsine, P.B. & Rose, C.W. 1992. Modeling water erosion due to overland flow using physical principals, 2. Rill flow. *Water Resource Research*, 28(1): 245-250.

Lei, T.W., Zhang, Q.W., Yan, L.J., Zhao, J. & Pan, Y.H. 2008. A rational method for estimating erodibility and critical shear stress of an eroding rill. *Geoderma*, 144: 628–633.

Meyer, L.D. & Wischmeier, W.H. 1969. Mathematical simulation of the process of soil erosion by water. *Transactions of the ASAE*, 12: 754–758, 762.

Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D. & Styczen, M.E. 1998. The European Soil Erosion Model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surface Processes and Landforms*, 23: 527-544.

Nearing, M.A., Foster, G.R., Lane, L.J. & Finkner, S.C. 1989. A process-based soil erosion model for USDA-Water Erosion Prediction Project Technology. *Transactions of the ASAE*, 32(5): 1587-1593.

Nearing, M.A., Norton, L.D., Bulgakov, D.A., Larionov, G.A., West, L.T. & Dontsova, K.M. 1997. Hydraulics and erosion in eroding rills. *Water Resource Research*, 33(4): 865–876.

Polyakov, V.O. & Nearing, M.A. 2003. Sediment transport in rill flow under deposition and detachment conditions. *Catena*, 51: 33-43.

Vito, F. 1998. Evaluating overland flow sediment transport capacity. *Hydrological Processes*, 12: 1895-1910.

Zhang, W., Yu, D., Shi, X., Tan, M. & Liu, L. 2010. Variation of sediment concentration and its drivers under different soil management systems. *Pedosphere*, 20: 578–585.

Evaluation of soil erosion risk and identification of soil cover and management factor (C) for RUSLE in European vineyards with different soil management

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Abstract

Vineyards present some of the largest erosion rates reported in agricultural areas in Europe, although there is a large variability in reported rates. This is because under the same land use, erosional processes are highly affected by climate, soil, topography and by the adopted soil management practices (SMP). The choice of SMP to be adopted is the main way for farmers to control soil erosion and at the same time to increase other ecosystem services in vineyards.

The Revised Universal Soil Loss Equation (RUSLE) is commonly adopted to estimate rates of water erosion on cropland under different forms of land use and management. The identification of a proper value of the soil cover and management (C) factor is essential to obtain a reliable evaluation of soil erosion rates in a given area and for a specific land use. This paper presents the preliminary version of the analysis of erosion risk in vineyards, using ORUSCAL, which is a simplified erosion prediction model that is designed to calibrate RUSLE for a range of management conditions in vineyards with limited datasets. The analysis has been carried out in three wine-growing areas in Spain, Italy and Austria. The aim was to provide estimations of C-values and to explore the erosion risk under different SMP in wine-growing areas across Europe.

Keywords: vineyard, erosion, soil management, RUSLE, model, Italy, Spain, Austria

Introduction, scope and main objectives

Vineyards represents one of the land uses for which very high rates of runoff and sediment losses has been observed in European agricultural areas (Cerdan *et al.*, 2010), although the reported erosion rates in vineyards across Europe present a large variability (Prosdocimi *et al.*, 2016). Under the same land use and similar conditions for climate, topography and soil texture, the soil management practice (SMP) adopted in the vineyard's inter-rows highly affects soil erosion risk in a given area. Moreover, soil management practices classified within the same category change in subtle but relevant details in different regions in Europe (Bauer *et al.*, 2017). The choice of SMP to be adopted is the main way for farmers to control soil erosion and at the same time to increase other ecosystem services in vineyards (Winter *et al.*, 2018). Therefore, it is very important to provide to farmers and stakeholders a reliable evaluation of the erosion risk associated to the use of different SMP in order to support their choices, for instance by using soil erosion simulation models, such as the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 2017), which is one of the most widely used and validated erosion tool (Dabney *et al.*, 2012). Despite its relative simplicity, a proper RUSLE calibration is required for conditions outside of those widely covered in the USA.

This communication presents the preliminary results of the implementation of a simplified soil erosion prediction model in three wine-growing areas in Europe, and aimed to (i) identify values for the cover management factors and to (ii) evaluate soil erosion risk, considering the most adopted SMP.

Methodology

ORUSCAL is a simplified erosion prediction model based on RUSLE, which was designed and built as an Excel tool to allow the calibration of the Revised Universal Soil Loss Equation (RUSLE) for a broad range of management conditions in vineyards with limited datasets (Gómez *et al.*, 2016). In the ORUSCAL tool, each of the factors of RUSLE is calculated in one Excel sheet, or in several ones from each of the corresponding sub-factors. The model and different calibration strategies, for C and K parameters, were previously evaluated using a long-term experiment dataset (Biddoccu *et al.*, 2016) from a vineyard in Northern Italy (Gómez *et al.*, 2017). In this study ORUSCAL was implemented in three regions: Spain (D.O. Montilla-Moriles), Italy (Monferrato area, Piedmont region), and Austria (Carnuntum and Leithaberg region) (Figure 1). ORUSCAL was fully calibrated for the D.O. Montilla-Moriles using 16 consecutive years: the C-factor for different soil management practices (SMP) was determined and its variability analysed as a preliminary evaluation of the approach to be implemented in other study areas. The topographic, soil, cover and management information required for calibration of ORUSCAL was taken from field survey in two of the study regions of the VineDivers project (www.vinedivers.eu). At each study region 16 vineyards were sampled. These vineyards were chosen to have 8 of the two most common soil management techniques in the region (low or high intensity in terms of encouraging ground cover in the alleys or not, respectively). Climate data were taken from nearby weather stations and rainfall erosivity (R factor) from Ballabio *et al.* (2016) to prevent bias in R determination across regions.

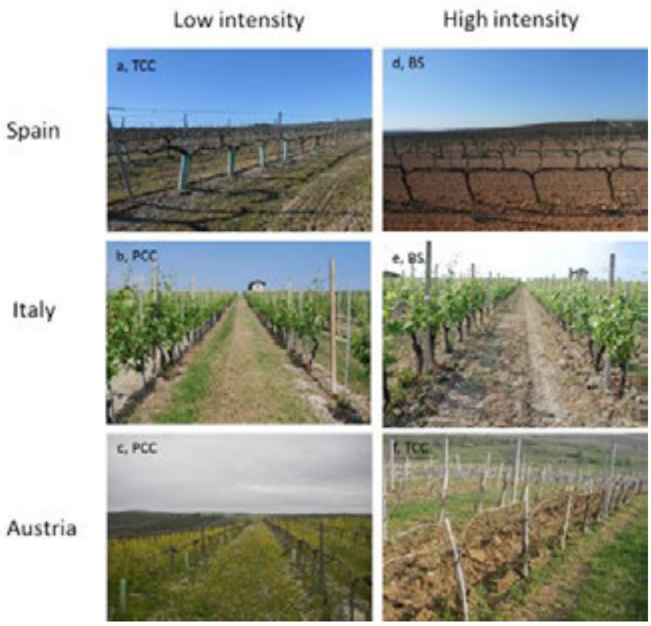

Figure 1: Example of the considered SMP, in the study areas in Spain, Italy and Austria. Low intensity management: a) TCC, temporary cover (only in fall and winter), b) and c) PCC, permanent cover crop. High intensity management: d) and e) bare soil by tillage or herbicide (BS), e) TCC, temporary cover crop (TCC), obtained vegetation cover every second lane, the other one tilled.

Results

C-factor values were obtained as a result of the ORUSCAL calibration in the three areas, for vineyards with different cover and management practices (Table 1). Values obtained for bare soil (BS), obtained by tillage or herbicides, ranged from 0.17 to 0.27, representing for all location the worst condition in terms of soil protection. Temporary cover crop (TCC) was differently applied in Spain (ground cover only in fall and winter) and in Austria (vegetation cover every second lane, the other one tilled) and resulted in at least 48% reduction of the C-factor values. The adoption of the lowest intensity soil management by using permanent vegetation cover (at least in the vineyard inter-rows) dramatically decreased the C-factor values that were lower than 0.04, thus not more than 15% of the C-value obtained for BS in the same area.

The soil erosion risk was evaluated in each area by means of the average annual soil loss (SL), calculated by ORUSCAL for the different SMP (Table 1). In Spain and Austria the TCC management resulted in 54% and 24% predicted SL, respectively, compared to vineyards managed with bare soil. In all study areas, the PCC management allowed a substantial reduction (more than 90%) of the predicted soil losses, with respect to the BS management.

Table 1: Results of the ORUSCAL implementation for the three study areas: C-factors obtained after calibration (C) and predicted annual average soil loss (SL, t ha^{-1} $year^{-1}$)

	Spain		Italy		Austria	
	C	**SL**	**C**	**SL**	**C**	**SL**
BS	0.27	17.5	0.17	8.5	0.27	19.4
std	0.03	14.8	0.05	6.3	-	12.4
TCC	0.13	9.5	-	-	0.14	4.7
std	0.07	4.5	-	-	-	2.8
PCC	0.04	1.6	0.01	0.6	0.04	1.4
std	0.00	1.4	0.01	0.4	-	0.8

Discussion

The determination of C-factor by means of proper calibration values for the three selected areas allows to obtain accurate values for different SMP currently adopted in European vineyards. The values seem to be relatively homogeneous across locations, and assume values spanning from 0.01 to 0.27, which are lower values than the general values indicated by Panagos *et al.* (2015) for European vineyards, ranging approximately from 0.15 to 0.45. The preliminary results of this study show the importance of performing RUSLE calibration, especially for the C-factor, when predicting soil losses for a land use as viticulture, in which erosion risk is highly affected by the adopted SMP. It also suggests the need for a further validation against long-term datasets at representative scales (e.g. Gómez *et al.*, 2008). The application of the simplified model allowed the evaluation of the soil erosion risk in vineyards with different intensity of soil management, highlighting the importance of selecting the most appropriate SMP to be adopted in each area, in order to protect soil from erosion.

Conclusions

The preliminary results of this work suggests the effectiveness of using ORUSCAL to perform soil loss prediction with limited datasets, both for calibration purposes such as the identification of site-specific values for C-factor and for the evaluation of soil erosion risk under different intensities of soil management. It highlights the need for a thorough validation of erosion predictions. The implementation of ORUSCAL and deep analysis of results obtained in other wine-growing regions across Europe will allow to identify the C-factor and assess the erosion risk for the most common SMP. This enables a reliable application of RUSLE prediction to stakeholders for selecting the most appropriate management for a given location.

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References

Ballabio, C., Borrelli, P., Spinoni, J., Meusburger, K., Michaelides, S., Beguería, S., Klik, A., Petan, S., Janeček, M., Olsen, P., Aalto, J., Lakatos, M., Rymszewicz, A., Dumitrescu, A., Tadić, M.P., Diodato, N., Kostalova, J., Rousseva, S., Banasik, K., Alewell, C. & Panagos, P. 2017. Mapping monthly rainfall erosivity in Europe. *Science of The Total Environment*, 579: 1298–1315. https://doi.org/10.1016/J.SCITOTENV.2016.11.123.

Bauer, T., Strauss, P., Kumpan, M., Guzmán, G., Gómez, J.A., Stiper, K., Popescou, D., Guernion, M., Nicolai, A., Winter, S. & Zaller, J. 2017. Effects of inter row management intensity on soil physical properties in European vineyards. *Geophysical Research Abstracts Vol. 19*, EGU2017-2218.

Biddoccu, M., Ferrari, S., Opsi, F. & Cavallo, E. 2016. Long-term monitoring of soil management effects on runoff and soil erosion in sloping vineyards in Alto Monferrato (North–West Italy). *Soil Till. Res.,* 155: 176-189.

Cerdan, O., Govers, G., Le Bissonnais, Y., Van Oost, K., Poesen, J., Saby, N., Gobin, A., Vacca, A., Quinton, J., Auerswald, K., Klik, A., Kwaad, F.J.P.M., Raclot, D., Ionita, I., Rejman, J., Rousseva, S., Muxart, T., Roxo, M.J. & Dostal, T. 2010. Rates and spatial variations of soil erosion in Europe: A study based on erosion plot data. *Geomorphology*, 122(1–2): 167–177. https://doi.org/10.1016/J.GEOMORPH.2010.06.011.

Dabney, S.M., Yoder, D.C. & Vieira, D.A.N. 2012. The application of the Revised Universal Soil Loss Equation, Version 2, to evaluate the impacts of alternative climate change scenarios on runoff and sediment yield. *J. Soil Water Conserv.*, 67: 343-353.

Gómez, J.A., Biddoccu, M., Guzmán, G., Bauer, T., Strauss, P., Winter, S., Zaller, J. & Cavallo, E. 2017. A proposal for soil cover and management factor (C) for RUSLE in vineyards with different soil management across Europe. *Geophysical Research Abstracts Vol. 19*, EGU2017-3845.

Gómez, J.A., Biddoccu, M., Guzmán, G. & Cavallo, E. 2016. A simplified Excel tool for implementation of RUSLE2 in vineyards for stakeholders with limited dataset. *Geophysical Research Abstracts Vol. 18*, EGU2016-51427.

Gómez, J.A., Giráldez, J.V. & Vanwalleghem, T. 2008. Rapid communication: Comments on "Is soil erosion in olive groves as bad as often claimed?" by L. Fleskens and L. Stroosnijder. *Geoderma,* 147: 1-2.

Panagos, P., Borrelli, P., Meusburger, C., Alewell, C., Lugato, E. & Montanarella, L. 2015. Estimating the soil erosion cover-management factor at European scale. *Land Use Policy*, 48: 38-50. DOI:10.1016/j.landusepol.2015.05.021.

Prosdocimi, M., Cerdà, A. & Tarolli, P. 2016. Soil water erosion on Mediterranean vineyards: A review. *Catena*, 141: 1-21.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. & Yoder, D.C. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). In: U.S. Department of Agriculture*, Agricultural Handbook,* 703.

Winter, S., Bauer, T., Strauss, P., Kratschmer, S., Paredes, D., Popescu, D., Landa, B., Guzmán, G., Gómez, J.A., Guernion, M., Zaller, J.G. & Batáry, P. 2018. Effects of vegetation management intensity on biodiversity and ecosystem services in vineyards: A meta-analysis. *Journal of Applied Ecology*, 55(5): 2484–2495. https://doi.org/10.1111/1365-2664.13124.

Models erosion as methodical basis combating its manifestations in Ukraine

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Abstract

The main approaches to investigating water erosion and degradation due to this influence of land resources were considered. It is shown that the most objective methods for evaluating the manifestations of erosion phenomena are field research, data of remote sensing of the Earth and modeling. For the conditions of Ukraine, it was found that the estimation of the number of eroded lands on the basis of existing official cartographic data may not be accurate due to their general aging status. The second problem is the inadequate coverage of soil investigations of the territory. The approaches we use, in particular predicative modeling of soil cover, give an expanded estimation of the distribution of eroded soils according to the official data. Disadvantages of this approach are described. It is shown that a more precise picture of the manifestation of erosion processes gives the use of the model of water erosion-deposition SIMWE. The described approaches are tested on an example of a typical region for Ukraine and it is concluded that this method is scalable for the entire territory of Ukraine and may be recommended for a more accurate assessment of the risks of erosion.

Keywords: erosion, estimation of erosion, modeling, DEM, forecast, SIMWE, GRASS GIS

Introduction, scope and main objectives

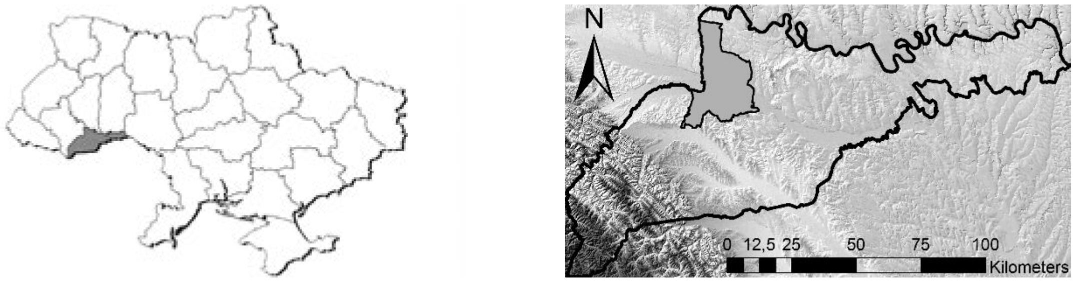
Soil is a self-sustaining organ-mineral natural body that arose over a long period of time in the surface layer of the Earth's lithosphere as a result of the long-term effects of biotic and abiotic factors and has such a uniqueness as fertility. The water and wind erosion heading the list of destructive phenomena concerning of the soils. A detailed analysis carried out by soil scientists in Ukraine has shown that the combination of negative factors has a positive dynamic (Baljuk *et al.*, 2010). Emphasis on modern methods of diagnosis, monitoring and modeling of erosion phenomena is practically the only way out of the current situation (Aiello *et al.*, 2015). Accuracy of the predicted erosion processes and their propagation areas will be determined by the basic model, the form of which should be best suited to the applied tasks of land management. An urgent requirement for the model is its relative simplicity and speed of processing of data, which is extremely important for practice (Dmytruk and Cherlinka, 2012). In researches of water erosion of soils and degradation due to this influence of land resources, relief in general plays an important role. Therefore, in this field, the numerous of the physical and mathematical models of both empirical and theoretical nature was developed (Mitas and Mitasova, 1998; Schmidt, 2000).

Methodology

Data processing was carried out with the use of GIS GRASS. As object of research, a fragment of the territory of Ukraine (Figure 1a) was selected, in particular the Kitsman district of the Chernivtsi region (Figure 1b), is confined to the Dniester-Prut watershed with contrasting geomorphological conditions (Figure 1c). This area has a varied economic use, and, with its choice, typical problems that often arise in Ukraine at work of this field were resolved (Cherlinka and Dmytruk, 2014; Cherlinka, 2017a).

Therefore, for non-explored areas was constructed predicative soil maps using the methods described in the literature (Malone *et al.*, 2016).

With DEM (1arcsec SRTM resampled to a resolution of 25 m (NASA JPL, 2013) we have identified a number of morphometric characteristics of the relief, which were provided as predictors. To create simulation models of soil cover, we used the Cherlinka script (2017b) written on the R-statistic, which includes a number of adaptations for solving set tasks and implements 14 basic types of predicative algorithms. This work used implementation Random Forests in the R ranger package (Wright and Ziegler, 2017).



a) b)

Figure 1: Geographical location of the research area within Ukraine (a), Kitsman district in Chernivtsi region (b), based on SRTM (NASA JPL, 2013)

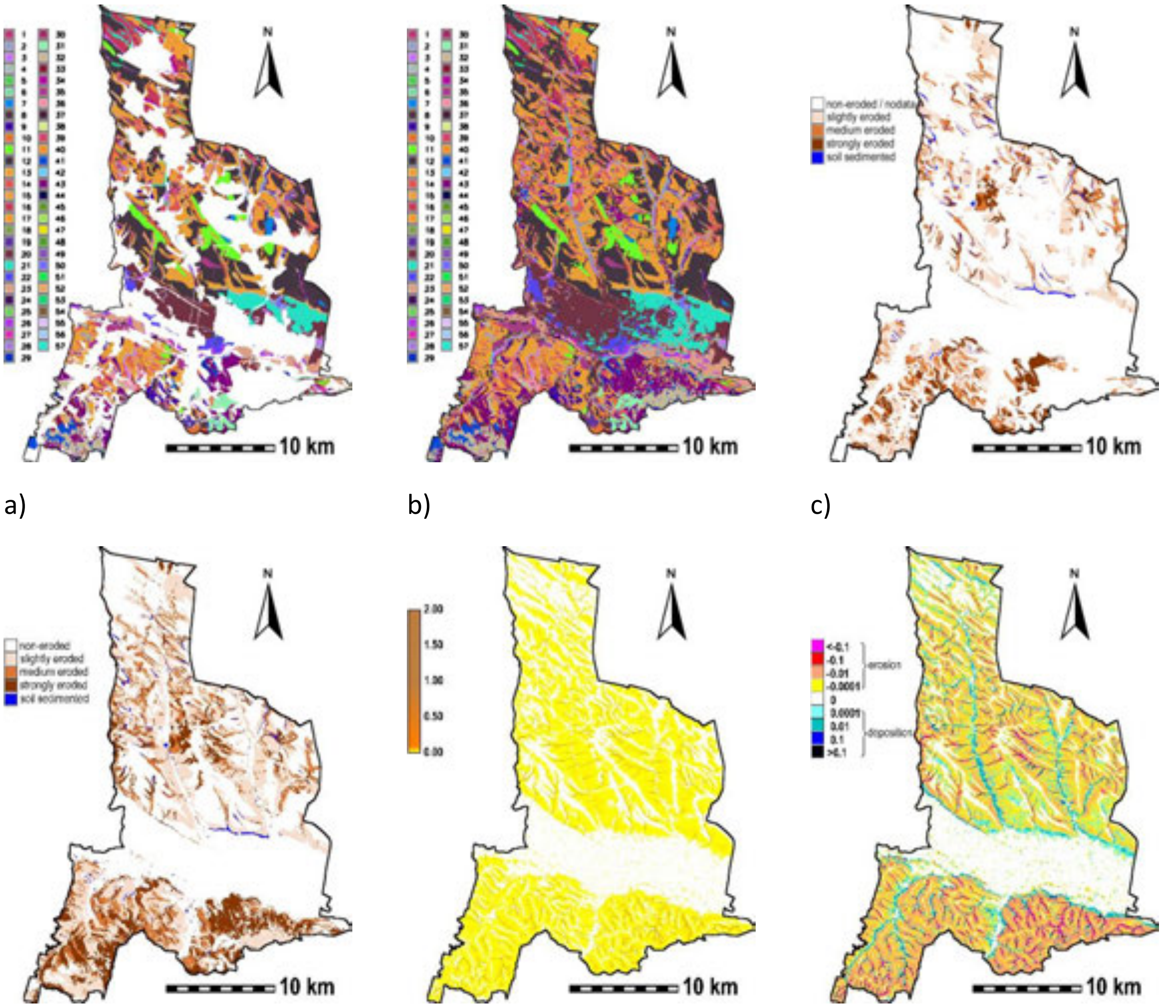
In order to evaluate the quality of the models obtained, we used the Coehens kappa index κ (Malone *et al.*, 2016). We simulated and evaluated the potential risks of erosion phenomena using the SIMWE model (Mitas and Mitasova, 1998; Hofierka *et al.*, 2002).

Results

According to Kanash (2013) only 66 % of the territory of Ukraine (40 million hectares) was surveyed. The data on soils were reduced to maps of agro-industrial groups of soils, which combine the soil with similar agronomic properties. At presents, these data are the basis of statistical reports on the prevalence of erosion of soils in Ukraine. Correspondingly, anti-erosion measures, which are planned, are based on these incomplete data. As was shown, the data of this surveys, have a large number of errors (Cherlinka and Lobova, 2018). For comparing we are given by erosion modeling on the example of the typical region of Ukraine, which is average for all parameters. As we see (Figure 2a, Table 1), only 60.3 % of its territory is covered by soil surveys.

Table 1: Differences between official and model data on soil erosion

No	Erosion level	Official data		Modelled data		Growing, %
		ha	%	ha	%	
1	no data	24230	39.7	-	-	-
2	non-eroded	20438	33.5	32956	54.0	161.2
3	slightly eroded	8803	14.4	15180	24.9	172.4
4	medium eroded	3625	5.9	5773	9.5	159.3
5	strongly eroded	3434	5.6	6621	10.8	192.8
6	soil sedimented	499	0.8	499	0.8	0.0
7	Total observed	36799	60.3	61029	100.0	-
8	Total	61029	100.0	61029	100.0	-



a) b) c)

d) e) f)

Figure 2: Soil resources of the region of research: map of agro-industrial groups of soil (a); predicative soil map (b); eroded soils according to official data (c); eroded soils according to the predicative map (d); sediment flow rate map from SIMWE, $kg{\cdot}m^{-1}{\cdot}s^{-1}$ (e); erosion-deposition map from SIMWE, $kg{\cdot}m^{-2}{\cdot}s^{-1}$ (f)

To fill the gaps, we obtained a predicative soil map with κ = 87.4 % (Figure 2b). This allowed us to use these predictive data for the expansion of the official assessment of the territory's erosion. If we calculate erosion only according to official data (we recall that the data are 60-30 years old), then in general it is 15862 ha or 26 % of the area of the district (Figure 2c, Table 1).

If we estimate the erosivity of the soil to give a predicative soil map, then we see that the erosivity increases by 224 %, with strongly eroded soils occupying almost 2 times more areas (Figure 2d, Table 1). The area of the sedimented soils remained at the previous level.

In contrast to the previous approach the definition of the number of eroded areas, the next approach is based on a mathematical model experiment. Simulation of water erosion based on SIMWE model showed interesting results. First of all, it is clearly observed that erosion processes are timed to the relief of the territory. Sedimentary flows increase their capacity on steep slopes (Figure 2e), which, with further simulation, allowed to obtain a complete picture of erosion hazard (Figure 2f). This Figure shows that the location of eroded soils on the official maps do not really have the necessary precision, since they do not take into account many of the moments associated with the progress of real erosion processes.

Discussion

Comparison of the obtained data makes it possible to draw preliminary conclusions about the fact that the assessment of eroding by official data does not give its full picture. This is due to the age of data, which does not cover the whole territory of the study.

Therefore, predicative modeling of soil cover is one of the possible ways of evaluating potentially dangerous territories. However, even this method has disadvantages. In particular, problems it is based on old data, as well as the high probability of the existence of errors in determining the soils in them. This leads to the fact that learning the model on inaccurate data gives us in the last case also inaccurate results.

Therefore, the most reliable way to detect and combat soil erosion is to simulate and verify these data in field conditions. It will give an opportunity to really assess the pace of manifestation of erosive processes and, on the basis of simulation with different parameters, create different scenarios of combating them.

Another way to improve the diagnostics of erosion processes is to use the data of remote sensing of the Earth. In general, the combination of the last two approaches can give the most reasonable estimate of erosion and the basis for further combat the manifestations of erosion.

Conclusions

It has been shown that the existing data on the development of soil erodibility in Ukraine are outdated, incomplete and have numerous errors. An advanced version of the evaluation of this data, i.e. filling gaps in researches through predicative soil modeling, although possible, but can't be too precise due to incomplete reliability of the source data. Our research confirms the effectiveness of using GRASS GIS and the model of water erosion-deposition SIMWE for a more correct assessment of the phenomenon of erosion. This is a prerequisite for the development of a system of anti-erosion measures at a qualitatively higher level. It also allows assessing different scenarios and strategies to combat the manifestations of erosion processes. Such an approach is scalable for the entire territory of Ukraine and may be recommended for a more accurate assessment of the risks of erosion.

References

Aiello, A., Adamo, M. & Canora, F. 2015. Remote sensing and GIS to assess soil erosion with RUSLE3D and USPED at river basin scale in southern Italy. *Catena,* 131: 174–185.

Baljuk, S.A., Medvjedjev, V.V., Tarariko, O.H., Hrekov, V.O. & Balajev, A.D. (Eds.). 2010. *Nacionaljna dopovidj «Pro stan rodjuchosti ghruntiv Ukrajiny»*. MAPU, Centrderzhrodjuchistj, NAANU, NNC IGhA, NUBiP, Kyjiv.

Cherlinka, V.R. 2017a. Using Geostatistics, DEM and Remote Sensing to Clarify Soil Cover Maps of Ukraine. In: Dent, D., Dmytruk, Y. (Eds.), *Soil Science Working for a Living: Applications of soil science to present-day problems*. Springer-Verlag GmbH, Cham, Switzerland, Ch. 7, pp. 89–100.

Cherlinka, V.R. 2017b. *Morfometrychni parametry reljjefu jak bazys dlja predykatyvnogho modeljuvannja prostorovogho poshyrennja gruntovykh vidmin*. In: Aghrokhimija i gruntoznavstvo. Mizhvid. tem. nauk. zb. — Vyp. 86. TOV «Smughasta typoghrafija», Kharkiv, pp. 5–16, in ukrainian.

Cherlinka, V.R. & Dmytruk, Y.M. 2014. Problems of creation, georectification and use of large-scale digital elevation models. *Heopolytyka y ekoheodynamyka rehyonov*, 10(1): 239–244, in ukrainian.

Cherlinka, V.R. & Lobova, O.V. 2018. Metodychni pidkhody do uzghodzhennja gruntovykh kartoghrafichnykh materialiv na mezhakh administratyvnykh utvorenj. *Naukovi dopovidi NUBIP Ukrajiny*, 6(76): 1–15, in ukrainian.

Cutler, A., Cutler, D.R. & Stevens, J.R. 2012. *Random Forests*. Springer US, Boston, MA, pp. 157–175.

Dmytruk, Y.M. & Cherlinka, V.R. 2012. Vykorystannja modelej vodnoji eroziji pry rozv'jazanni prykladnykh zavdanj zemleustroju: gheoinformacijnyj pidkhid. *Zemleustrij i kadastr*, (1): 12–18, (in ukrainian).

Hofierka, J., Mitasova, H. & Mitas, L.. 2002. GRASS and modeling landscape processes using duality between particles and fields. In: *Proceedings of the Open Source GIS-GRASS users conference*. Trento, Italy. pp. 11–13.

Kanash, O.P. 2013. Grunty — providna skladova zemeljnykh resursiv. *Zemleustrij i kadastr*, (2): 68–76, in ukrainian.

Malone, B.P., Minasny, B. & McBratney, A.B. 2016. *Using R for Digital Soil Mapping*. Progress in Soil Science. Springer International Publishing.

Mitas, L. & Mitasova, H. 1998. Distributed soil erosion simulation for effective erosion prevention. *Water Resources Research*, 34(3): 505–516.

NASA JPL. 2013. *NASA Shuttle Radar Topography Mission Global 1 arc second*. 2013, distributed by NASA EOSDIS Land Processes DAAC.

Schmidt, J. (Ed.). 2000. *Soil Erosion: Application of physically based models*. Springer Science & Business Media.

Wright, M.N. & Ziegler, A. 2017. Ranger: a fast implementation of random forests for high dimensional data in C++ and R. *arXiv preprint arXiv:1508.04409*, 77(1): 1–17.

Soil erosion as a source of sediment and phosphorus in Vltava River basin

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Abstract

The article presents the results of determination of sediment and phosphorus transport for the entire catchment area of the Vltava River and a more detailed analysis of the results on the Želivka basin (the basin of the Švihov Reservoir). The whole watershed area was modelled by WaTEM/SEDEM, adapted for modelling phosphorus transport using Sharpley's approach. WaTEM/SEDEM offers an approach that allows us to target on spatially focused outputs that can easily be implemented in the decision-making process for effective watershed control. Švihov Reservoir is the most important source of drinking water in the Czech Republic, the key for supplying of Prague and Central Bohemia region. Nevertheless, in the basin of the Vltava River Švihov Reservoir is the tank with the highest specific transport of sediment within the entire catchment area. The average long-term area specific soil loss in the basin, according to a calculation exceeds the value of 6 t/ha/year. The total average annual entry into the reservoir is close to 48 000 t/year. Phosphorus transported by water erosion is an important element in the balances of phosphorus sources in basins.

Keywords: Vltava Basin, sediment transport, soil erosion by water, Švihov Reservoir

Introduction, scope and main objectives

The Water Framework Directive (2000/60/ES) is a potentially effective long-term tool for enhancing the sustainability of surface water quality in the EU. In the Czech Republic, the River Basin Management Plans, as implemented in two recent planning periods of the Water Framework Directive, were mostly focused on point pollution sources (sewage treatment). Control of non-point pollution sources was generally based only on the Nitrate Directive limits (EC-Europa, 2018), e.g. control of fertilizers. The Water Framework Directive link to sediment transport protection is based on phosphorus concentration limits to reduce eutrophication. In the Czech Republic, however, phosphorus and suspended solids are monitored only in large rivers, and sampling is performed monthly (Beránková *et al.*, 2010). For this reason, only a very small number of erosion sediment transport events have been documented. Moreover, unlike the limits for total phosphorus concentration (150 $\mu g.l^{-1}$), suspended solids and sediments are not considered in environmental objectives for surface waters (Government Decree No 61/2003 Coll.).

It is known that phosphorus transported by erosion does not directly cause eutrophication, since it is mostly bound to particles (Kopáček *et al.*, 2005). Eutrophication is mostly triggered by dissolved phosphorus from sewage waters (Jachymova and Krasa, 2017). However, erosion is a major phosphorus driver for the total phosphorus mass balance in most agricultural watersheds. There is a lack of phosphorus in the fields, but the reservoirs are loaded with it, leading to the associated risks of desorption (Jan *et al.*, 2013). Sediment transport from the agricultural landscape and the resulting siltation of rivers and reservoirs also cause problems with other transported particle-bound pollutants (mainly metals), and with the sediment load, leading to functional problems (loss of water storage capacity, water transport problems, changes in the ecosystem, etc.).

The Vltava Rives State Enterprise initiated a project called "Preparation designs of A-type measures of for localities of agricultural pollution for in River Basin Management Plans”. We assume that coupling off-site impacts in terminal reservoirs with sediment source areas is a suitable approach for functional landscape planning and water protection.

Methodology

The study field area is entire Vltava River Basin, ca 1/3 of the Czech Republic area. Vltava is the longest river in the Czech Republic. Major reservoirs of the Czech Republic are located within the Basin, including historical fishpond areas, and most important drinking water sources.

For the Czech Republic, the RUSLE-based WaTEM/SEDEM model (Van Oost *et al.*, 2000; Van Rompaey *et al.*, 2001; Verstraeten *et al.*, 2002) has been verified and used in large-scale studies (Krasa *et al.*, 2019). To model phosphorus transports using WaTEM/SEDEM, the ratio of soil enrichment by phosphorus was implemented into the structure of the model. That way the original K factor dataset is replaced by the K_p dataset, which reflects both the soil erodibility and the soil enrichment ratio (Sharpley, 1985). The method is described in detail in (Jachymova and Krasa, 2017).

Raster-based GIS input data on topography and land use in 10 m spatial resolution were prepared. The river network corresponds with the 1:10 000 scale of other inputs. Reservoirs have to be linked to appropriate river segments both in the input links (through-flow-tanks) and in the output links (all tanks). The topology must be accurate, in order to route the sediment correctly through the complex river systems. Finally, the reservoir trap efficiency has to be estimated for each reservoir in the river system (Brune, 1953).

On the basis of the entire topological network of rivers and reservoirs with their trapping efficiencies, we were able to prepare a recursive script (in python) analyzing the river networks from target reservoirs upstream. By this approach, the total transport efficiency applied to the sediment routed from the stream unit to the target reservoir can be determined for each stream unit in the river topology network. A direct assessment can then be made of the volume of the sediment generated within the sub-watershed of the stream unit that reaches the target reservoir. In this way, the proposed measures can be directly targeted to locations that contribute most to the sediment load into the terminal reservoir.

For allocating the measures, the sediment/phosphorus values were transformed into indices and combined with sub-surface nutrient flows modeled by other team of the study.

Results

After building complex river topology schemes and estimating the trap efficiencies in all reservoirs in the river networks, we are able to estimate the total transport efficiency for each river unit for any outlet point (terminal reservoir). Then, even for entire Vltava River basin, we are able to define the most highly contributing sources of sediment (phosphorus) at single parcel scale. In the river data system of the study area, the average length of a river segment was 300 m. The contribution of each sub-watershed of that river segment is computed.

The results can be upscaled to entire Czech Republic Area. Based on that, total soil loss in the Czech Republic would reach 33.4 million of tons per year. About 9.2 tons are transported out of agricultural fields. Sediment inflow into the river systems in the Czech Republic can reach from 3.2 up to 5.4 million of tons per year. One of the most endangered reservoirs is Švihov (sediment deposition of 46 444 $t.y^{-1}$) and several reservoirs in its watershed area (Trnávka, Sedlice, Němčice). Švihov is the biggest drinking water source in the Czech Republic, supplying water to more than 1 million inhabitants.

The biggest reservoirs and the biggest sediment sinks of the Vltava River are Orlík (sediment deposition of 189 923 $t.y^{-1}$) and Slapy (sediment deposition of 54 006 $t.y^{-1}$). These watersheds have much larger contributing areas. Švihov Reservoir with much smaller basin area is therefore characterized by much higher area specific soil loss (6 $t.ha^{-1}.y^{-1}$) and sediment yield.

Discussion

There are estimated to be about 24 000 real reservoirs and fishponds (Pavelková *et al.*, 2016) in the Czech Republic. Parametrizing the reservoirs for trap efficiency and including them in the WaTEM/SEDEM river topology is a complex and difficult task. To validate the model and for a further analysis of the variation of the sediment yields predicted by WaTEM/SEDEM in the Czech Republic, measured data from reservoirs were collected (Krasa *et al.*, 2019).

On the basis of our results and available studies, we cannot state that WaTEM/SEDEM produces perfect results. The available data shows rather high uncertainty of the predicted sediment yields. There is another issue related to the modeling and validation risks. The estimated deposited volume is also influenced by the predicted trap efficiency of each reservoir (Brune, 1953). The dataset includes thousands of reservoirs of highly variable sizes, dam types, and basin sizes. The actual trap efficiencies may therefore differ substantially from those estimated by the Brune curve. But generally the model performs reliably. For decision support, a map output can be compiled that provides the user with all spatially distributed results. For watershed conservation purposes, the results serve to provide summaries at watershed level.

Conclusions

After building complex river topology schemes and estimating the trap efficiencies in all reservoirs in the river networks, we are able to estimate the total transport efficiency for each river unit for any outlet point (terminal reservoir). Then, even for large watersheds in the Czech Republic, we are able to define the most highly contributing sources of sediment (phosphorus) at single parcel scale. The contribution of the sub-watershed of that river segment is computed. The modeled fluxes cannot be taken as absolute volumes, but for appropriate input data they visualize the most highly contributing sources, down to the level of a single parcel.

Acknowledgements

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References

Beránková, T., Vogel, R.M., Fiala, D. & Rosendorf, P. 2010. Estimation of phosphorus loads with sparse data for agricultural watersheds in the Czech Republic. *Hydrological Sciences Journal*, 55: 1417–1426. https://doi.org/10.1080/02626667.2010.528418.

Brune, G.M. 1953. Trap efficiency of reservoirs. *Transactions, American Geophysical Union*, 34: 407. https://doi.org/10.1029/TR034i003p00407.

EC-Europa, 2018. Czech Republic - Environment - European Commission [WWW Document]. URL http://ec.europa.eu/environment/water/participation/map_mc/countries/czech_en.htm (accessed 4.30.18).

Jachymova, B. & Krasa, J. 2017. A new method for modeling dissolved phosphorus transport with the use of WaTEM/SEDEM. *Environmental Monitoring and Assessment*, 189: 365. https://doi.org/10.1007/s10661-017-6082-4.

Jan, J., Borovec, J., Kopáček, J. & Hejzlar, J. 2013. What do results of common sequential fractionation and single-step extractions tell us about P binding with Fe and Al compounds in non-calcareous sediments? *Water research*, 47: 547–57. https://doi.org/10.1016/j.watres.2012.10.053.

Kopáček, J., Borovec, J., Hejzlar, J., Ulrich, K.U., Norton, S.A. & Amirbahman, A. 2005. Aluminum control of phosphorus sorption by lake sediments. *Environmental Science and Technology*, 39: 8784–8789. https://doi.org/10.1021/es050916b.

Krasa, J., Dostal, T., Jachymova, B., Bauer, M. & Devaty, J. 2019. Soil erosion as a source of sediment and phosphorus in rivers and reservoirs – Watershed analyses using WaTEM/SEDEM. *Environmental Research*, 171: 470–483. https://doi.org/10.1016/J.ENVRES.2019.01.044.

Pavelková, R., Frajer, J., Havlíček, M., Netopil, P., Rozkošný, M., David, V., Dzuráková, M. & Šarapatka, B. 2016. Historical ponds of the Czech Republic: an example of the interpretation of historic maps. *Journal of Maps,* 12: 551–559. https://doi.org/10.1080/17445647.2016.1203830.

Sharpley, A.N. 1985. The selective erosion of plant nutrients in runoff. *Soil Science Society of America Journal,* 49: 1527–1534. https://doi.org/10.2136/sssaj1985.03615995004900060039x.

Van Oost, K., Govers, G. & Desmet, P. 2000. Evaluating the effects of changes in landscape structure on soil erosion by water and tillage. *Landscape Ecology*, 15: 577–589. https://doi.org/10.1023/A:1008198215674.

Van Rompaey, A., Verstraeten, G., Van Oost, K., Govers, G. & Poesen, J. 2001. Modelling mean annual sediment yield using a distributed approach. *Earth Surface Processes and Landforms*, 26: 1221–1236. https://doi.org/10.1002/esp.275.

Verstraeten, G., Van Oost, K., Van Rompaey, A., Poesen, J. & Govers, G. 2002. Evaluating an integrated approach to catchment management to reduce soil loss and sediment pollution through modelling. *Soil Use and Management*, 18: 386–394. https://doi.org/10.1079/SUM2002150.

Soil Erosion Risk in the Rainy Mountainous Area of Eastern Mediterranean

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Abstract

The study conducted in a rainy mountainous area of eastern Mediterranean west of Syria in order to produce a soil erosion risk map based on the COoRdination of Information on the Environment (CORINE) model for. The indexes of Soil Erodibility (SE), Erosivity Index (EI) and Slop Index were used to extract the map of Potential Soil Erosion Risk (PSER). A risk map of soil erosion was prepared from information on land cover and potential risk erosion classes obtained previously. The results showed that 18.56 % of 110.56 km^2 that located in complex relief of southwest and north of the area in high-risk soil erosion areas, 3.98 % in moderate risk areas, and 77.46 % in low-risk areas. There was an obvious positive effect of land cover that reduces the high potential soil erosion risk area by 58.27 %.

Keywords: CORINE, Erosion, Mediterranean, Syria

Introduction, scope and main objectives

Soil erosion is one of the most serious agriculture problems, causes negative consequences on soil quality and land productivity, due to soil fertility deterioration even in some cases totally removal of the soil which is a medium for plant growth (Hauck, 1985; Morgan, 1995; Zhang *et al.*, 2009). Mountainous areas of Mediterranean are probably the most accessible regions to water erosion (CEC, 1992). Due to its natural conditions, such as steep and long slopes, shallow soil cover, a long dry summer season that is inappropriate for the accumulation of organic matter, high winter rainfall average (800- 1 500 mm) (Kbibo and Nesafi, 1997) and frequent rainstorms cause gullying, mass movements and flooding (CEC, 1992). Van-Camp *et al.* (2004) showed that only small soil losses are tolerable on shallow soils on steep slopes. Land use further affects erosion processes in several ways, e.g. by soil displacement by tillage practices, overgrazing (Poesen and Hooke, 1997). Soil erosion is strongly contributing to desertification that is a serious problem in eastern Mediterranean countries, i.e. 10 % of all land area in Syria is affected by desertification (Ilawi *et al.*, 1992). In Syria about 18 % of arable lands is submitted to water erosion with a different degree (85 % slight, 12 % moderate, while 3 % severe erosion) (ACSAD, 2007) and eroded soil in some coastal area acceded 100 t/ha/y (FAO and UNEP, 2009).

The objective is to characterize the spatial distribution of soil erosion risk in the eastern Mediterranean wet mountainous area of Syria, within two major dominated ecosystems: forest and arable lands that will help prioritize critical areas for adopting suitable soil erosion prevention measures.

Methodology

Study area

The study conducted on an area of wet mountainous eco-systems in the eastern Mediterranean of Syria. The geographical area is approximately 598.15 km^2, situated between 36°.39.3.76-36°.19.16.17 E longitude and 35°.13.55.06-34°.53.6.12 N latitude with an elevation ranging from 240 to 1 140 m above sea level that (Figure 1).

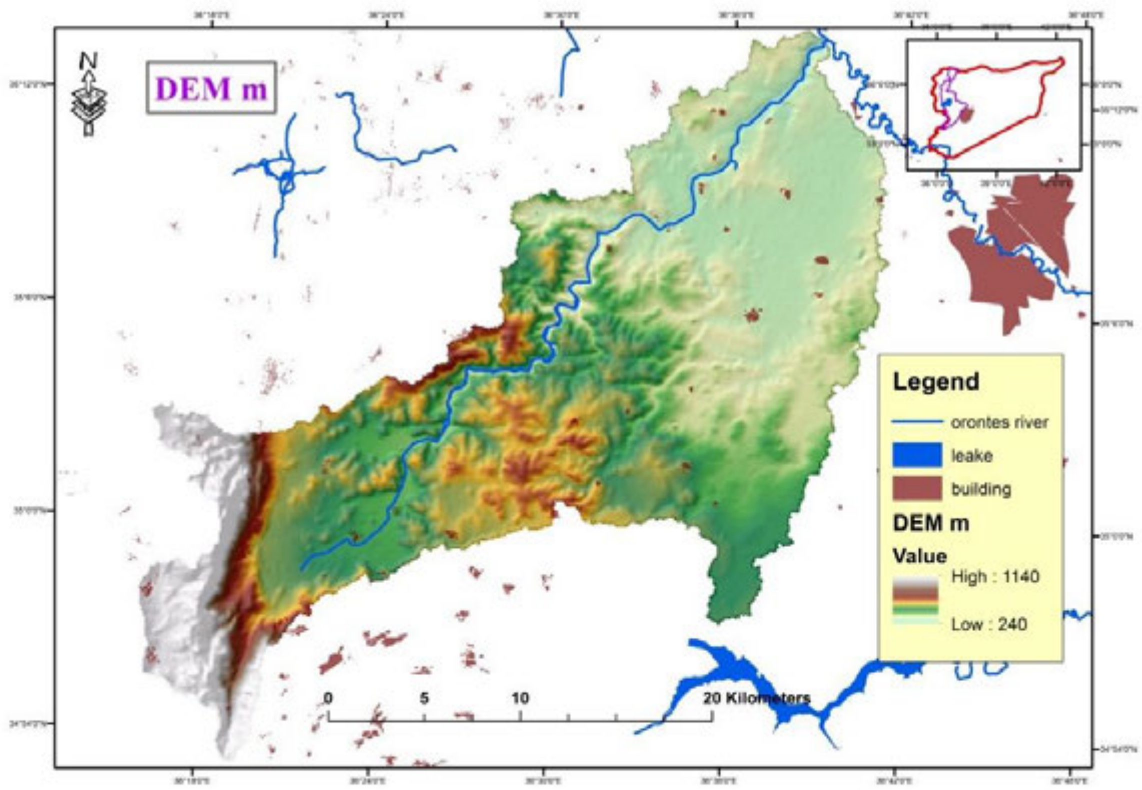

Figure 1: Location and Digital Elevation Model (DEM) of the study area.

The area receives an average annual between 300 mm in the east, to 1 500 mm, during the rainy season (October-May). The region composed of very complicated, rocky and sloppy reliefs, with relatively shallow soil except for the flat plain area. Soil erosion is prevalent in the area partly due to the rolling topography and improper agricultural management practices.

The soil erosion map was produced flowing the procedures of the COoRdination of Information on the Environment (CORINE) model. The parameters are represented as four separate indices.

-SE index includes surface rockiness, texture and depth was extracted from soil map of Orontes basin (Al Siddik *et al.*, 2015), then reclassify according to the hydrologic conductivity (Brakensiek *et al.*, 1986), and for CORINE erodibilty index (Aydin and Tecimen, 2010), table 1.

Table 1: SE classes.

Class	Surface rockiness	Soil texture	Soil depth	Soil erodibilty index	Soil erodibilty
0	-	Bare rock	-	0	-
1	<10%	Clay, Sandy Clay, Silty Clay	>75	0-3	Low
2	>10%	Sandy Clay Loam, Clay Loam, Silty Clay Loam, Loamy Sand, Sand	25-75	3-6	Moderatly
3	-	Loam, Silt Loam, Silt, Sandy Loam	<25	>6	High

- EI was calculated as a monthly of precipitation and temperature by combining two climatic indexes: Modified Fournier index (MFI) and Bagnouls-Gaussen aridity index (BGI). The MFI is computed depending on total precipitation in a month (Pi) and total mean annual precipitation (Pa) as follows (Arnolds, 1980):

$$\mathrm{MFI} = \sum_{i=1}^{12} \frac{\mathrm{Pi}^2}{\mathrm{Pa}}$$

where Pi the amount of monthly precipitation in (mm), Pa total annual rainfall in (mm).

The BGI is defined as follows (Arnolds, 1980; CORINE, 1992):

$$\mathrm{BGI} = \sum_{i=1}^{12} (2t_i\text{-}P_i)\,\mathrm{ki}$$

where ti is the mean temperature for the month, Pi is the total precipitation for the month, and ki is a factor was calculated (Ki = 2ti-pi) when 2ti-pi> 0 and neglect If this ratio is < 0.

The FI index has divided into five classes, whereas the BGI to four classes and the EI to thee classes (Aydin and Tecimen, 2010). Table 2.

Table 2: FI index, BGI and EI index classes.

Class	FI	Description	BGI	Description	EI	Description
1	< 60	Very low	0	Humid	<4	Low
2	60- 90	Low	0- 50	Moist	4 -8	Moderate
3	90-120	Moderate	50 -130	Dry	>8	High
4	120-160	High	>130	Very Dry		-
5	>160	Very High	-	-	-	-

- Slope index (SI) drifted from Digital Elevation Model (DEM) that generated from topographic maps with a scale of 1:50 000. Table 3.

Table 3: Slope gradient and e classes according to CORINE model.

Class	Slope gradient	Description
1	5 >	Very gentle
2	5-15	Gentle
3	15-30	Steep
4	>30	Very Steep

- PSER was generated from the equation:

PSER = SEI. EI. SI

where *SEI* is soil erodibilty index, *EI* erosivity index; *SI* slope index.

- Vegetation cover mapped from tow Landsat images ETM+ (Path 174-Row 35, 36) and divided into two classes: a fully protected area (forest, permanent pasture, and dense scrub) and not fully protected (cultivated or bare land).

Actual Soil Erosion Risk (ASER) was calculated for each point of the soil samples by overlapping the PSER with land use land cover layer using “Raster Calculator” tool in the “Spatial Analyst” extension of ArcGIS to generate actual soil erosion risk map. Actual soil erosion risk map is classified into three classes; (1) low, (2) moderate, and (3) high.

Results

The soil map of the area Figure 2-A, showed five classes, 1-Loamy sand, very shallow (10 cm) and somewhat excessively drained. 2-Clay loam, shallow (10-25 cm) and well-drained 3- Silty Clay somewhat deep (25-50 cm) moderately well drained. 4-Clayey, somewhat deep (25-50 cm) and somewhat poorly drained. 5-Clayey, deep (50-75 cm) and poorly drained. As such, low soil erodibilty area account for 22.4 % (clayey, somewhat deep, clayey, deep soil and silty clay somewhat deep soil) corresponds to 2.8 erodibilty index. Moderately soil erodibilty account for 30.3 % (clay loam shallow soil) corresponds to 5.3 erodibilty index. The rest 47.3 % of the area (Loamy sand very shallow soil) corresponds to 6.7 erodibilty index of high soil erodibilty.

EI expressed by isohyet map, Figure 2-B and by Fournier and Bagnold-Gawsn indexes that showed an average of 148.4 Fournier index, the maximum is 192.66 and the minimum is 109.02. Average of Bagnold-Gawsn index is 264.76, the maximum is 1 220.07 and the minimum is 219.11. The high erosivity area account for 88.9 % corresponding to 12.4 (EI), the moderate is 9.11 % corresponding to 9.11 EI and the rest of the area 1.99 % corresponding to 2.1 (EI) is low erosivity.

Slope index showed 73.9 % of the area is very gentle slope, 18.8 % is gentle slope and 7.3 % is steep slope, Figure 2-C

Land Cover particularly canopy cover, is considered a major factor in protecting soil aggregates against the kinetic energy of raindrops. The model shows that most rainfall periods are uncovered (there is no vegetarian growth). The index was drifted from digital Land use Land cover (LuLc) map that consists of 8 classes Building, Water bodies, Tree cropland (olive and fruits), Pasture, Irrigated land (vegetables), Rain-fed land (winter wheat), Shrubs and Forest, Figure 2-D. The land cover index of fully protected area account for 23.7 % and the rest of 76.3 % is not fully protected area.

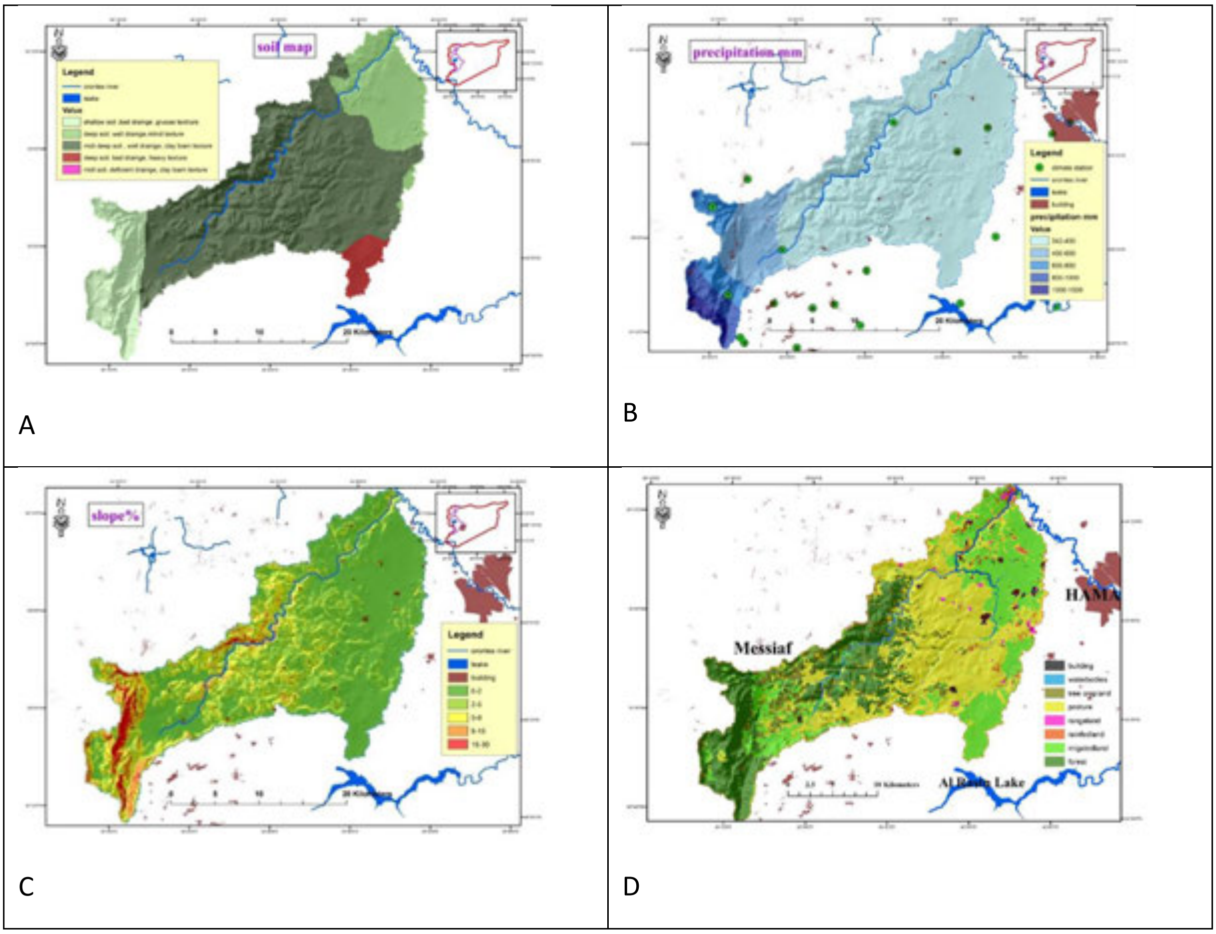

Figure 2: Parameters of the study area: A soil, B perception, C slope, D land cover.

The ASER map, which derived from the LuLc map and the PSER map showed that 18.56 % of 110.56 km^2 of the area located in southwest and north of the area in high risk, 3.98 % in moderate risk, and 77.46 % in low risk.

Discussion

SE that refers to the susceptibility of the soil to erosion depends primarily on soil ability to adsorb rainfall and its stability to resists the direct effect of rainfall. Soil properties such as texture, organic matter, and structure influence both water storage and resistance to sediment detachment, and erodibility. PSER map that was generated by overlapping of SE, EI, and SL, shows that 31.85 % of the area in southeastern and mid-north is subjected to high potential risk, 4.61% is subjected to moderate potential risk and 63.54 % is subjected to low potential risk. When the LuLc map and the PSER map combined to produce the ASER map that showed variation of risk due to the role of land cover that protects soil from direct effect of rainfall and reducing the risk of soil erosion. Thus, the low risk area increased from 63.54 % to 77.46 %, the moderate potential risk area decreased from 4.61 % to 3.98 % and the high potential risk area decreased from 31.85 % to 18.56 % of 110.56 km^2 that located in complex relief of southwest and north of the area.

Conclusions

The use of GIS and CORINE model is very well suited, low cost and time saving for erosion prediction at region scale, beside provides a vision of the effect of each factor independently of each other in this area. The area characteristic by highly erodible soils. It is possible that natural vegetation from forests and shrubs would have covered the area before it was replaced with olives and other fruit orchards at the beginning of the 20th century, thus increasing erosion risk. In complexes, elevated area the soil depth has reduced to a depth less 10 cm. Even more, water erosion exposing the bare rock in many places, the process could be irreversible within a few dictates. There was an obvious positive effect of land cover that reduces the high potential soil erosion risk area by 58.27 % (from 31.85 % to 18.55 %). Although the model did not intend to estimate the amount of soil eroded but provides erosion risk map for decision makers that assist in conservation and protection actions.

References

ACSAD. 2007. *Soil Degradation in Syria*. Damascus.

Arnolds, H.M. 1980. An approximation of the rainfall factor in the Universal Soil Loss Equation. En: De Boodt M., and Gabriels D. (eds) Assessment of erosion. John Wiley and Sons, Inc. Chichester, West Sussex, UK; pp. 127-132.

Aydin, A. & Tecimen, H.B. 2010. Temporal soil erosion risk evaluation: a CORINE methodology application at Elmalı dam watershed, Istanbul. *Environ. Earth Sci.*, 61: 1457–1465.

Brakensiek, D. L., Rawls, W. J., & Stephenson, G. R. 1986. Determining the Saturated Hydraulic Conductivity of a Soil Containing Rock Fragments 1. SSSAJ, *50*(3): 834-835.

CEC. 1992. *CORINE:* Soil erosion risk and important land resources in the southern regions of the European Community, Luxembourg.

CORINE. 1992. Soil Erosion Risk and Important Land Resources in the Southeastern Regions of the European Community. EUR 13233, Luxembourg, BELGIUM; pp. 32-48.

FAO-UNEP & Beneficiaries–Lot, F. C. 2009. Delegation of the E.C. to Syria.

Hauck, F.W. Soil erosion and its control in developing countries. Soil erosion and conservation. SSSA, Ankeny. 1985: 718-728.

Ilawi, M., Abdelgawad, G. & Jabour, E. 1992. Human-induced soil degradation map of Syria in World Atlas of Desertification. UNEP.

Kbibo, I. & Nesafi, I. 1997. Water erosion and impacts on the coastal area in the Syrian Arab Republic. *Tishreen University J. St. Scie. Res.*, 18: 59-76.

Mohamed, A b. Al –Siddik, Hussam H. M. Husein, Mouhiddine K. & Yousef, M. 2015. Mapping Agro Climate Zoning (ACZ) in Orontes Basin Using Geographic Information Systems (GIS)**.** *Research Journal of Aleppo University,* Engineering Science Series 114.

Morgan, R. 1995. *Soil Erosion and Conservation*, second ed., Essex, New York.

Poesen, J.W.A. & Hooke, J.M. 1997. Erosion, flooding and channel management in Mediterranean environments of southern Europe. *Prog. Phys. Geog.*, 21: 157–199.

Van Camp, L. Bujarrabal, B., Gentile, A.R., Jones, R.J.A., Montanarella, L., Olazabal, C. & Selvaradjou, S-K. 2004. Reports of the Technical Working Groups established under the Thematic Strategy for Soil Protection. Vol.-II: European Communities, Luxembourg.

Zhang, Y., Degroote, J., Wolter, C. & Sugumaran, R. 2009. Integration of modified universal soil loss equation (MUSLE) into a gis framework to assess soil erosion risk. *Land Degradation & Development*, 20(1): 84–91. https://doi.org/10.1002/ldr.893.

A contribution to the analysis of urban erosion in Kinshasa, DRC.

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Abstract

This study contributes to improve the understanding of the erosion process in an urban context. It proposes a visual interpretation key of the gullies, be they active or not, on a very high resolution satellite image. While the gullies are delineated, the urban context is analyzed on the image to identify the origin of each gully. These results are confronted with an exhaustive ground survey achieved by DGPS.

Keywords: gullies, urban, remote sensing, very high resolution, visual interpretation.

Introduction, scope and main objectives

The phenomenon of erosion is a mechanism that has been studied at length in the past. In fact, there are many publications dealing with the loss of the surface part of soils by various bioclimatic agents, mainly on arable land. However, few articles report the problem in urban areas.

The city of Kinshasa, a megacity and capital of the Democratic Republic of Congo, has been experiencing unprecedented urban growth since the early 1950s. The intense development of its lands, without any real control by the planning authorities, as well as the lack of knowledge by the latter of the effective actions that can be taken against the degradation of soils by regressive gully, do not currently aggravate the situation of instability and danger in the hilly region.

Thus, the objective of this work is defined through a satellite remote sensing method with a very high resolution for a visual interpretation identifier, but also for the identifier of the origin of the different ravines. Then, an inventory of the active gullies by differential GPS with objective not interpreted visual but especially deepened with the understanding of the causes of the intra-urban erosion.

The two objectives of this study are to improve the understanding of erosion in urban areas. The first aims not only to identify the parameters of visual interpretation of the ravines, active and inactive, on a satellite image with very high spatial resolution, but also of power by visual interpretation of the urban context, to identify the origin of the different ravines. The second is to trace the history and evolution of all the ravines in the Funa River watershed and the various factors responsible for their formation.

Methodology

Pretreatment

In order to minimize observation and measurement errors in the visual interpretation of panchromatic and multi spectral images, they have undergone a geometric correction via the Geomatica 10.1 computer program. The X and Y coordinates of 12 calibration points were recorded in the field using differential GPS.

To improve the detailed visual interpretation of the ravines and their features, the panchromatic image of a resolution of 0.6 m has been merged with the blue, green, red and near infrared bands of the multi-spectral 2.4 m resolution image using the Pan-sharpening command from ArcMap 9.2©. This step assumes perfect co-registration of the images. The visual interpretation of the ravines was performed on a colorful composition in true colors and a false color infrared.

Next, the area to be interpreted was limited to the steepest slopes within the Funa River watershed. Van Caillie (1983), in his research on soil erosion in the Democratic Republic of Congo, says that the vast majority of ravines are located for the city of Kinshasa on slopes estimated at 10, 15, or even 20 % at most.

Finally, the ridges of the Funa River watershed have been delineated on the basis of the digital terrain model using the "Basin" function of ArcMap 9.2©. This function is based on the preliminary calculation of the flow direction of the water.

Visual interpretation

The visual interpretation parameters of the ravines were analyzed on the THRS images and were organized in an interpretive key

DGPS surveys

The data recorded by the receiver used in the field and by the base were extracted via "Terrasync". Subsequently, all of the data collected has been differentially corrected using the "Pathfinder" program.

Study site.

Figure 1: Location of the Funa River watershed, Lemba commune, Kinshasa.

Figure 2: Ravine appeared following the completion of a collector (a) Terraced urban development on an erosion-sensitive site (b)

Results

Visual interpretation of the THRS imagery results in an original interpretive key that brings together the essential criteria for interpreting the ravines (Table 1). The limitation of the area to be interpreted thanks to the mask of the steep slopes and the Funa basin has proved very effective. Slope thresholding at 10% did not lead to the omission of ravines; however, the mask could have been expanded to eliminate small areas.

Table 1: Visual interpretation key useful for gully detection, scale 1/3000.

Form		**Texture (in panchromatic)**		**Color**			
				Fusion of images			
				True colors		**IR False colors**	
2D	**Shadow and deviation**	**Active ravine**	**Ravine inactive**	**Active**	**Inactive**	**Active**	**Inactive**
Lying in the direction of the slope. Winds along the slope.	In hollow. In "V" or "U". Bottom line visible and parallel to the	Heterogeneous Grenue composed of elements of variable size. Presence of grass trees and bare soil.	Homogeneous Fine and grainy.	Yellow clear associated with sand.	Green.	Bare ground. Turquoise and white. Sometimes presence of trees.	Herbaceous vegetation. Slopes with very dark green shade. Green exposed slopes with

	edge of the ravine.					Presence of red spots.	red highlights. Bright Red Trees.

On the other hand, the context is very useful for identifying the origin of the ravines (Table 2). The origin of the ravines was interpreted systematically on the study area from the satellite image and commented on using the knowledge accumulated during the field mission. Indeed, the proximity of a macadamized road makes it possible to assume that the gutters along the road are no longer operational and are probably broken upstream of the erosion head.

Table 2: Origin and activity of the different ravines (Realization: T. Wouters, 2008).

Ravines	Active / Inactive	Origin	Additional remarks
1	A	Breakdown of a "lost well"	
2	A	End of a pipeline	The water coming out of the pipe continued along the slope.
3	A	End of a collector	The construction of the collector to the middle of the slope (1992). The water continues to the bottom of the basin.
4	A	Rupture of one of the two pipes connected to one of the lost wells of the ISTEM (Higher School).	The water no longer accumulating in the well flows on the soil with low vegetation cover. Recent Ravine (2006-2007).
5	I	Breakdown of a lost well	A new sink was built next to the previous one, allowing the ravine to stabilize with vegetation.
6	I	Rupture of a retention basin	
7	I	Rupture of a retention basin	Ravine formed during the overflow of water contained in the retention basin.
8	I	Rupture of a retention basin	Overflow of a retention basin responsible for the formation of ravines 10 and 11.
9	A	Break of a collector	The collector built, after backfilling the basin in 1970, was undermined by surface runoff. The latter was likely to harvest water from the university hospital upstream. The resumption of erosion is linked to the cultivation of the bottom of the ravine.
10	I	Rupture of a retention basin	

Discussion

It appears on the colored composition in true colors, that the vegetation is strongly present within the inactive ravines on slope not or not urbanized. It therefore seems possible, thanks to this parameter, to directly identify the stabilized gullies by their very pronounced green color; sand, of a light yellow hue, not present at the level of the latter, constitutes, for its part, a criterion in favor of the activity.

The color composition in false-color infrared, for its part, confirmed the importance of the vegetation cover observed in the stabilized gullies, the active ravines being characterized by a turquoise or even white color reflecting the absence of vegetation.

The structure, corresponding to the association of objects with respect to each other, does not seem very useful here. Indeed, as the origin of the ravines depends exclusively on the action of man on his environment, especially by the construction of infrastructures such as collectors or roads, it seems very difficult to define a generalizable structure to the all of the catchment areas of the hilly region.

Conclusions

The useful interpretation parameters have been gathered in a key to interpretation of active and inactive gullies on sandy soil. Indeed, the shape and the radial deviation visible on the panchromatic image make it possible to locate the ravines, to trace their outlines and their bottom line. The texture on the panchromatic image and color on true color compositions or false color infrared supports the discrimination between active and inactive gullies. The context authorizes the expert in intra-urban erosion to identify the causes of the gully.

The cause of gullies can be for each ravine deduced from a contextual analysis of the THRS image and commented on using a field analysis. The causes are confirmed by the comprehensive gully survey by DGPS survey. In the study area, there are four main causes of gully erosion: overflow of retention basins, collector failure, trails created in the direction of the slope, and silting and then breaking up of lost wells. Many infrastructure much have not supported the erosive nature of precipitation and the instability of the superficial soils called sandy. The lack of maintenance and the lack of sites that can accommodate the various filth of the population of Kinshasa have also played a role in the failure to fight against the gully.

However, the research carried out in this field, aimed at breaking the helplessness around the problem, is every day to new innovations leading. The control techniques developed attempt to develop more efficient infrastructures, mainly through a judicious combination of experience gained in the past and recent knowledge on the subject.

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References

Antoine, P. 1991. Croissance urbaine et insertion des migrants dans les villes africaines. L'exemple de Dakar, in *Pratiques sociales et travail en milieu urbain*, *Les Cahiers n° 16*, Orstom/Sud, Paris, 16 p.

Barnes, E.M. & Baker, M.G. 2000. Multispectral data for mapping soil texture: possibilities and limitations. *Applied Engineering in Agriculture, 16*(6) : 731-741.

Delbart V. & Wolff E. 2002. Extension urbaine et densité de la population à Kinshasa : contribution de la télédétection satellitaire. *Belgeo, 3*(1): 45-59.

Delis, P. & Girard, C. 1985. L'immobilisation privée du sol à Kinshasa. *Les Annales de la recherche urbaine, 25*, 20 p.

Fitzjohn, C., Ternan, J.L. & Williams, A.G. 1998. Soil moisture variability in semi-arid gully catchment: implication for runoff and erosion. Control. *Catena, 32* : 55-70.

Gay, M., Cheret, V., Denux, J-P. 2002. Apport de la télédétection dans l'identification du risque d'érosion. *La Houille Blanche,* 1, pp. 81-86.

Kirkby, M.J. & Morgan, R.P.C. 1980. *Soil erosion*, John Wiley et Sons, Chichester, 316 p.

Morgan, R.P.C. 2005. *Soil Erosion and Conservation*, Blackwell Publishing, 3e édition, Oxford, 304 p.

Pedersen, H.S. & Hasholt, B. 1995. Influence of wind speed on rainsplash erosion, *Catena, 24:* 39-54.

Tho, N. 2008. Erosion and Nutrient Loss on Sloping Land under Intense Cultivation in Southern Vietnam. *Geographical Re search, 46*(1): 4-16.

Van Caillie, X.D. 1976-78, 1987. *Notice de présentation de la carte géomorphologique et géotechnique de Kinshasa au 1/20 000,* Bureau d'étude d'aménagement urbain, 17 p.

Vigneau, J-P. 2000. *Géoclimatologie,* Ellipses Edition Marketing S.A., Paris, 288 p.

Comparison of RUSLE model and UAV-GIS methodology to assess the effectiveness of temporary ditches in reducing soil erosion

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Abstract

Good Agronomic and Environmental Conditions (GAEC), refer to a set of European Union standards with a view to sustainable agriculture. This work shows the results of monitoring performed on a hilly farm in Italy to verify the effectiveness of standard 5 (temporary ditches) in the reduction of soil erosion. This standard prescribes the realization of temporary ditches spaced-out at 80 meters. Monitoring has compared the erosion measured by a UAV-GIS technology with RUSLE predictions, with (Factual) and without (Counterfactual) temporary ditches. This comparison is crucial to evaluate the RUSLE, chosen by the European Evaluation Network for Rural Development Programs (RDPs) as a forecasting tool for the quantification of the Common Indicator 'soil erosion by water'.

The results of surveys in two years of observations have shown that temporary ditches were effective in decreasing erosion, on average, by 62.5 %, from 44.75 t ha^{-1}to 16.78 t ha^{-1}during the monitoring period. Results can be considered very satisfactory since temporary ditches were tested for their capacity to reduce erosion under severe rainfall conditions. We also suggest coupling measures to prevent soil erosion with additional management practices that while enhancing soil organic carbon content, improve soil structure and decrease soil vulnerability to erosion.

Keywords: Cross-compliance, rural development, soil erosion, temporary ditches, rill erosion, runoff, Unmanned Aerial Vehicles

Introduction, scope and main objectives

The European Cross-Compliance mechanism set up within the CAP provides support payments to farmers under the condition that specific Standards for Good Agricultural and Environmental Conditions (GAECs) are respected, as first established by Council Regulation (EC) 1782/2003 and more recently by Council Regulation (EC) 1306/2013. GAEC standard 5 - minimum land management reflecting site specific conditions to limit erosion - addresses specific requirements to limit soil loss by erosion in arable crops and requires the beneficiary of the payment to comply with the "Realization of temporary ditches" in sloping lands affected by soil erosion. In the absence of specific rules established by the Italian Regions, this standard prescribes the realization of temporary ditches spaced-out at 80 meters (Bazzoffi 2015). Farmer's obligation consists in: "The realization of temporary drainage ditches, so that the collected rainwater maintains a speed not compromising the function of the ditch itself and is carried away into the permanent channels and natural impluvia along the field border. This obligation applies to sloping land showing erosive phenomena indicated by the presence of extensive rills in the absence of land set-up systems for soil and water conservation".

Monitoring the effect of temporary ditches on soil erosion is necessary for two purposes:

- evaluation of the environmental effectiveness of actions applied by farmers through this cross-compliance Standard;

- calibrate and validate the soil erosion prediction models commonly adopted in the scenario analysis, that constitute the premise to the formulation of Rural Development Programs (RDPs). The RUSLE (Renard *et al.*, 1997) was chosen by the European Evaluation Network for Rural Development (ENRD 2013) as a forecasting tool to quantify, at the regional scale, the Common Indicator 'Soil erosion by water'. Calibration and validation of the RUSLE is therefore crucial for evaluating RDPs. Photogrammetry acquired by Unmanned Aerial Vehicles (UAV), integrated by postprocessing, is a promising methodology in terms of speed of data acquisition, data processing and cost-effectiveness. The main advantage is the generation of high-resolution Digital Elevation Models (DEMs) from the images.

Methodology

Monitoring was made at Tor Mancina research farm (Monterotondo, Rome). The WGS84 coordinates of farm centroid are: N 42° 05' 43.09''; E 12° 38' 04.83", at 43 m a.s.l. Soils derive from pedogenized stratified volcanic tuff with lapilli, cinerites and Pleistocene leucitic scorias, classified as Typic Argixeroll (Soil Survey Staff, 2014). The survey was performed with a UAV Falcon 8 (Astec, Germany), equipped with 8 rotors, a remote pilotage MGS (Mobile Ground Station) and a high-resolution camera. Georeferenced Ground Control Points were used to derive the DEM after creating an orthomosaic from the UAV images with Photoscan Pro. The total volume of rills was determined in ESri ArcGis 10.0, and Plan Curvature analysis and Focal Statistics analysis.

In the farm the monitored parameters were:

- Erosion measured with UAV-GIS methodology (Bazzoffi 2015) and estimated erosion with RUSLE in conditions of implementation of the Standard (Factual) and in conditions of non-implementation (counterfactual); with land sown with wheat (Figure 1).

- Rill erosion as volume of rills (m^3).

Two types of field surveys were performed.

Basin comparisons. Two theses have been compared during two cropping years (2012-2013/2013-2014) as follows: 1) Factual (with temporary ditches and soil chiselling); 2) Counterfactual thesis (without temporary ditches and ordinary ploughing).

Plot comparisons. During the same two cropping years, simultaneously with the basins survey, two plots were monitored to determine soil erosion and crop yield.

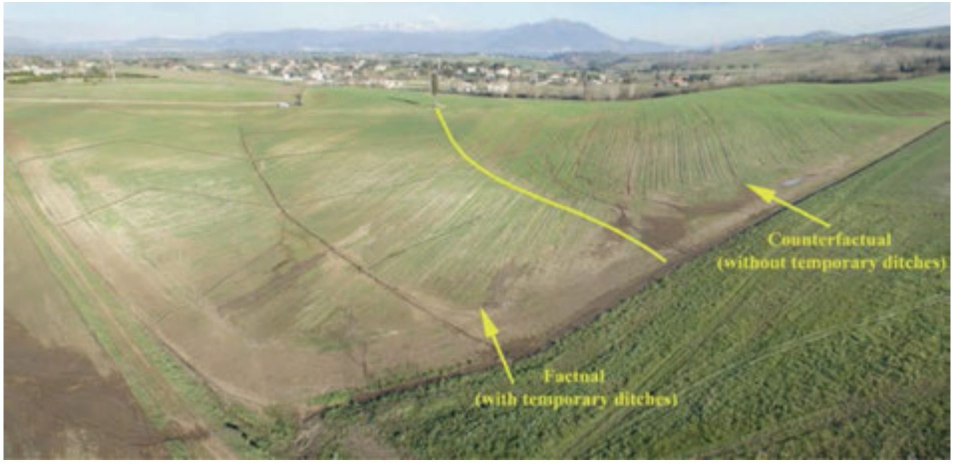

Figure 1: Soil erosion in Tor Mancina farm (Italy) (Bazzoffi, 2015)

Results

Table 1 shows the summary of soil erosion (t ha^{-1} $period^{-1}$) measured on monitoring sites by using the UAV-GIS methodology (Bazzoffi, 2015). Period represents the time elapsed between the date of execution temporary ditches (immediately after wheat sowing) and the date of the survey with UAV. Table 1 also shows the characteristics of monitoring sites, the amount of rainfall during the observation period, the volume of rills (m^3) and the RUSLE factors applied through GIS. The last column on the right shows the RUSLE estimates by using resampled DEMs with cell size of 20 meters (the original cell size of DEM is 4,7cm).

Figure 1 shows the effectiveness of the temporary ditches to intercept runoff and to decrease the formation of rills down the ditch. Conversely, shows the catastrophic effect of concentration of runoff and the ineffectiveness of temporary ditches where they are not able to fulfill their function due to undersizing.

Comparing the UAV-GIS methodology (27.34 t ha^{-1} $period^{-1}$) and the RUSLE in GIS it was possible to validate the predictive RUSLE model (36.83 t ha^{-1} $period^{-1}$). Mean values showed no significant difference between the observed the predicted values with the RUSLE model. Despite the limited observations the performance of the RUSLE resulted satisfactory as shown by the linear regression (y=1.0346x-3.0593, R^2 = 0.947).

Table 1: Soil erosion by UAV-GIS methodology on the monitoring sites. Rainfall, RUSLE factors and estimated soil erosion by RUSLE model (Bazzoffi, 2015).

Tratment	Observation start	Observation end	Period (months)	Slope (%)	Slope length (m)	Plot area (ha)	rills (m^3)	t ha^{-1} $period^{-1}$	Period rainfall (mm)	RUSLE Factors				RUSLE_GIS on DEM 20 meters (t ha^{-1} $period^{-1}$)
										R	K	C	P	
Counter-factual Basin13	16 Nov. 2012	27 Feb. 2013	3.4	15.4	136.1	1.58	103.75	87.6	372.8	6 580.82	0.054	1.00	1.00	79.38
Factual Basin13	16 Nov. 2012	28 Feb. 2013	3.5	13.8	147.7	1.72	60.56	43.9	372.8	6 580.82	0.054	1.00	1.00	57.22
Factual Basin14	19 Sep. 2014	23 Nov. 2014	2.2	13.2	142.1	2.50	5.57	2.8	210.9	9 486.20	0.054	1.00	1.00	3.12
Counter-factual Basin14	19 Sep. 2014	23 Nov. 2014	2.2	13.8	218.9	2.45	24.27	12.4	210.9	9 486.20	0.054	1.00	1.00	13.9
Factual Plot13	16 Nov. 2012	27 Feb. 2013	3.4	12.4	123.7	0.13	0.65	6.4	372.8	6 580.82	0.054	1.00	1.00	n.a.
Counter-factual Plot13	16 Nov. 2012	28 Feb. 2013	3.5	13.5	126.0	0.11	3.01	34.0	372.8	6 580.82	0.054	1.00	1.00	n.a.
Factual Plot14	19 Sep. 2014	23 Nov. 2014	2.2	12.4	123.7	0.18	2.08	140	210.9	9 486.20	0.054	1.00	1.00	n.a.
Counter-factual Plot14	19 Sep. 2014	23 Nov. 2014	2.2	13.5	126.0	0.12	4.19	45.0	210.9	9 486.20	0.054	1.00	1.00	n.a.

n.a., not applicable due to the small plot size

Discussion

Results of the UAV-GIS methodology on a monitoring hilly farm and in two years of observations have shown that temporary ditches were effective in decreasing erosion, on average, by 62.5 %, passing from 44.75 t ha^{-1} to 16.78 t ha^{-1} during the monitoring period. This result is above the limit of tolerable erosion (6 t ha^{-1} $year^{-1}$) set by the OECD (OECD, 2008) but can be considered very satisfactory when considering that the monitoring period was characterized by abundant and quite intense rainfall that occurred in a few months, in the autumn-winter period. Therefore, temporary ditches were tested for their capacity to reduce erosion under severe rainfall conditions, having had to cope with considerable runoff volumes. These results confirm what has been found in a previous trial conducted in Guiglia (Modena, northern Italy) on small basins planted with corn (Chisci and Boschi, 1988), where ditches significantly decreased soil erosion by 94 %, from 14.4 t ha^{-1} $year^{-1}$ to 0.8 t ha^{-1} $year^{-1}$. Overall, the reduction in the erosion following the application of the GAEC Standard observed in the present monitoring and in the previous research at Guiglia ranges between 48 % and 94 %. From the results of soil erosion acquired through the application of the methodology UAV-GIS and application of the RUSLE model in GIS (Table 1) it was possible to validate the predictive RUSLE model. Despite the few observations at disposition the performance of the RUSLE model resulted quite satisfactory.

Conclusions

Soil erosion, principally by water and to a lesser extent wind, is considered to be the highest priority soil quality issue for some European countries. The effect of soil erosion is particularly relevant in areas with seasonally contrasted climate conditions, with summer drought and heavy rainfall in winter when the soil is not fully covered by vegetation and is more prone to erosion. Recently, the risk of soil erosion has been exacerbated by the extreme rainfall events alternating with periods of drought, affecting land degradation processes, particularly in areas where soils are structurally more vulnerable such as the Mediterranean basin. In these areas concerns about soil erosion and its consequences emerged mainly with the cultivation of steep slopes in hilly areas where intense erosion processes are widespread, particularly sheet erosion, rilling, gullying, shallow land sliding and the development of active badlands both in sub–humid and semi–arid areas. Erosion processes are influenced by different factors, including soil erodibility determined by soil physical, chemical and biological properties, rainfall erosivity, slope characteristics, gradient, length and form, land cover use and management adopted. Therefore, the adoption of Best Management Practice (BMPs) in arable lands can help decreasing soil losses by erosion. Additional management practices such as maintaining a soil cover all year-round, crop residues incorporation or mulching, cover cropping, green manure crops, the improvement of crop rotation with legume crops, and the adoption of conservation agriculture (minimum or no-tillage) can enhance soil organic carbon content, thus improving soil structure and decreasing soil vulnerability to erosion.

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References

Bazzoffi, P. 2015. Measurement of rill erosion through a new UAV-GIS methodology. *Italian Journal of Agronomy*, 10 (Suppl.1): 708.

Chisci, G. & Boschi, V. 1988. Runoff and erosion control with hill farming in the sub-coastal Apennines climate. *Soil &Tillage Research*, 12: 105-120.

ENRD (European Evaluation Network for Rural development). 2013. Approaches in using common Rural Development indicators in regional RDPs. Workshop Specific challenges in using common RD indicators at regional level, Rome, Italy. Available at: https://enrd.ec.europa.eu/en/evaluation/evaluation-expert-network.

OECD. 2008. Environmental Performance of Agriculture in OECD countries since 1990, Paris, France. Available at: www.oecd.org/tad/env/indicators.

Renard, K.G., Foster, G.R., Wessies, G.A., McCool, D.K. & Yoder, D.C. 1997.Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook 703, U.S. Department of Agriculture.

Soil Survey Staff. 2014. Keys to soil taxonomy, 12th ed. USDA-Natural Resources Conservation Service, Washington, DC.

(R)USLE factors obtained in standard plots: a critical analysis, opportunities and challenges related to the database in Brazil

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Abstract

This study aimed to compile literature records of the factors involved in the erosive process using the (Revised) Universal Soil Loss Equation - (R) USLE models. The factors: R (rainfall-runoff erosivity), K (soil erodibility), LS (topography), C (cover management) and P (conservation practices) are multiplied with each other to obtain soil loss values. The database was acquired from the literature in the main indexing databases, consisting of 616 data entries, corresponding to a period of 37 years. The values of R factor for Brazil are oscillating between 1.672 and 22.452 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}. The K factor values ranged from 0.0004 (Acrisol) to 0.0840 (Cambisol) Mg.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}, with an average value of 0.0185 Mg.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}. For corn crop, C factor ranged from 0.007 (no-tillage) to 0.156 (conventional tillage). This mean values of the C factor for native pastures and forests were 0.1142 and 0.0295, respectively. For the P factor, the study suggests cumulative values in the order of 0.75 (contour planting), 0.50 (terraces) and 0.01 (mulch). There is a need for a more comprehensive database for the North and Central-West regions of Brazil.

Keywords: water erosion, erosivity, erodibility, cover, topography, conservation practices

Introduction

Brazil is one of the most important food, fiber and fuel producers in the world. The expansion of cultivated areas and incorrectly managed pastures can lead to increased rates of soil erosion. Studies conducted by Guerra *et al.* (2014) concluded that quantitative data on soil erosion rates are scarce, and Brazil is one of the "hotspots" of global erosion. According to the same authors because of the very diverse environmental and management conditions, it is very difficult to produce reliable average estimates of soil losses for the entire country, requiring an integrated program of research, monitoring and modelling.

One way to diagnose, monitor, predict critical events and control soil degradation by soil erosion is through the use of modelling. Among the various models of erosion prediction, the most widely used in Brazil is the Universal Soil Loss Equation (USLE), originally developed by Wischmeier and Smith (1978), and its revised version which was developed by Renard *et al.* (1997), called the Revised Universal Soil Loss Equation (RUSLE), which means the product of the factors R (rainfall erosivity), K (soil erodibility), LS (topography) C (cover management) and P (conservation practices) to estimate soil losses. A meta-analysis of the (R)USLE factors for Brazil was interpreted for rainfall erosivity (Silva 2004, Oliveira *et al.* 2012, Mello *et al.,* 2013), a critical review of the topographic factor was performed by Oliveira *et al.* (2013) and a compilation of directly obtained erodibility data, was published by Marques *et al.* (1997a) and Silva *et al.* (2000). For the other factors there are no publications.

Meta-analysis studies on soil losses by water erosion in experimental plots under natural rainfall were conducted by Anache *et al.* (2017) where average annual soil loss ranged from 0.1 $Mg.ha.yr^{-1}$ (pasture) to 136.0 $Mg.ha.y^{-1}$ (cultivated soils). A large-scale modelling study in Brazil, using the (R)USLE model was developed by several authors (Lu *et al.,* 2004; Didoné *et al.;* 2015, Batista *et al.;* 2017, Cunha *et al.,* 2017; Gomes *et al.,* 2017) and to the world with inferences for Brazil was developed by Borrelli *et al.* (2017).

It is intended in this study to present a meta-analysis study using a compilation of literature records of the factors involved in the erosive process using the (R)USLE model conducted in experimental plots in Brazil, evaluating the trends, challenges and opportunities for implementation of it in large scale in the country.

Methodology

Survey on soil erosion database was investigated from articles published in national and international journals, theses, dissertations and scientific documents in the bases of Web of Science, Scopus, SciELO and Google Scholar. The studies were organized into a database consisting of 627 data entries, in the year 2019, encompassing more than 30 years of research. The methodology involved the storage, in a dimensional database, specifically structured for this purpose, of spatial and bibliometric information. Statistical indicators were calculated, and the geography of the research was mapped.

Results and Discussion

In soil erosion modelling, it is essential to know the basic characteristics of the rainfall and runoff, and the erosive potential called rainfall erosivity (R-factor). The climate differences inherent to the several geographic situations can cause great variations in the results and in Brazil there are relatively few meteorological stations such data for use in studies of water erosion. Major advances in this area can be obtained with the implantation of automated stations, soil moisture sensors, with remote data transmission. According to the research data, the values of rainfall erosivity for Brazil are oscillating between 1.672 and 22.452 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$, considered low and very high, respectively.

Soils present a different capacity to resist water erosion, termed soil erodibility (K-Factor), being related to their intrinsic attributes. As such, soil erodibility is best estimated by performing direct measurements in field plots. Databases about the erodibility factor obtained directly, were generated in the last decades, contemplating 61 soils, except for Gleysols, Histosols, Chernozems and soils with strong human influence (Anthrosols and Technosols), according to IUSS/WRB (2015). The values showed a range of 0.0004 to 0.0840 $Mg.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$, for Acrisols and Cambisols, respectively, with the mean value being 0.0185 $Mg.\ ha.h.ha^{-1}.MJ^{-1}.mm^{-1}$. However, information about this factor is needed for the other various soil types.

In Brazil, for indirect estimation of erodibility there are models for soils with argic horizon (Marques *et al.,* 1997b), for less weathered soils (Wischmeier *et al.,* 1971) and for more weathered soils, notably Ferralsols (Silva *et al.* 1999). Although the high clay content of Ferralsols they present microaggregation characteristics (Uehara and Gillman, 1981) that favour high permeability to the water and consequently low values of soil erodibility (Silva *et al.,* 1999).

The topography factor (LS-factor) involves declivity and ramp length. Its determination, in a digital environment, allows systematization, large-scale study and methodological standardization, considering the effects of topography complexity, reproducing with high fidelity the preferential water flow in the drainage networks and in the rill erosion (Oliveira *et al.,* 2013).

The cover management (C-factor) is dimensionless and the value one corresponds to bare soil. In this study, it was observed that the corn crop presented values ranging from 0.007 to 0.156, for no-tillage systems and conventional cultivation, respectively. The average value for pasture is 0.1142, and for native forests, the average value is 0.0295. The measurements of remote sensing, through sensors that determine the vegetation index by normalized difference, can be used to obtain the vegetation cover factor in the modelling of soil erosion.

Another important factor is the conservationist practice (P-factor), which is considered to be the most uncertain and difficult to determine, due to high cost and time-consuming in experimental plots, in many cases involving long-term and large-scale experiments. Values in the order of 0.75 for planting and preparation of the soil in level, when associated to terraces (0.50) and when considering the maintenance of mulch of previous crop in the surface of the soil (0.01).

The analysed data of soil losses by water erosion in Brazil presented maximum values in the order of 494 $Mg.ha^{-1}.yr^{-1}$ for bare soil and water losses (superficial runoff) in the order of 50 % of the total rainfall. Considering that some regions have suffered substantial water deficits in recent years, the loss of water by erosion is of major importance.

Conclusions

Brazil has invested a significant effort in collecting information to parameterise the R(USLE). More information is available for the R and K factors than the C and P factors. Although the coverage of this information is discontinuous in time and space. Major challenges remain in extrapolating the results to areas with little or no data to constrain the model output. There is a need for greater agility in obtaining these factors, and potential for developing automating technologies in data collection. There is also a need to increase the network of automated rainfall and sedimentological stations, notably in the North and Central-West regions of Brazil.

Evaluating the performance of the R(USLE) in different environments within Brazil will be an important step in understanding the reliability of soil erosion predictions. Connectivity studies between soil erosion and river sedimentation, such as the use of source indicators and sediment deposition, can elucidate the processes that govern the transfer of sediments from erosion in terrestrial systems to the aquatic systems in watersheds.

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References

Anache, J.A.A., Wendland, E.C., Oliveira, P.T.S., Flanagan, D.C. & Nearing, M.A. 2017. Runoff and soil erosion plot-scale studies under natural rainfall: A meta-analysis of the Brazilian experience. *Catena*, 152: 29-39.

Batista, P.V.G., Silva, M.L.N., Silva, B.P.C., Curi, N., Bueno, I.T., Júnior, F.W.A., Davies, J. & Quinton, J.N. 2017. Modelling spatially distributed soil losses and sediment yield in the upper Grande River Basin – Brazil. *Catena,* 157: 139-150.

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K.V., Montanarella, L. & Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8(1): 2013.

Cunha, E.R., Bacani, V.M. & Panachuki, E. 2017. Modeling soil erosion using RUSLE and GIS in a watershed occupied by rural settlement in the Brazilian Cerrado. *Natural Hazards,* 85: 851-868.

Didoné, E.J., Minella, J.P.G. & Merten, G.H. 2015. Quantifying soil erosion and sediment yield in a catchment in southern Brazil and implications for land conservation. *Journal Soils Sediments*, 15: 2334-2346.

Gomes, L., Simões, S.J.C., Forti, M.C., Ometto, J.P.H.B. & Nora, E.L.D. 2017. Using Geotechnology to Estimate Annual Soil Loss Rate in the Brazilian Cerrado. *Journal of Geographic Information System*, 9: 420-439.

Guerra, A.J.T., Fullen, M.A., Jorge, C.O.M. & Alexandre, S.T. 2014. Soil Erosion and Conservation in Brazil. *Anuário do Instituto de Geociências,* 37(1): 81-91.

IUSS/WRB. 2015. World Reference Base for Soil Resources 2014, update 2015, International soil classification system for naming soils and creating legends for soil maps. *FAO World Soil Resources Reports 106*. Rome: FAO, 192pp.

Lu, D., Li, G., Valladares, G.S. & Batistella, M. 2004. Mapping soil erosion risk in Rondônia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. *Land Degradation & Development*, 15: 499-512.

Marques, J.J.G.S.M., Curi, N., Ferreira, M.M., Lima, J.M., Silva, M.L.N. & Carolino de Sá, M.A. 1997a. Adequação de métodos indiretos para estimativa da erodibilidade de solos com horizonte B textural no Brasil. *Revista Brasileira de Ciência do Solo*, 21: 447-456.

Marques, J.J.G.S.M., Curi, N., Lima, J.M., Ferreira, M.M., Silva, M.L.N. & Ferreira, D.F. 1997b. Estimativa da erodibilidade a partir de atributos de solos com horizonte B textural no Brasil. *Revista Brasileira de Ciência do Solo*, 21: 457-465.

Mello, C.R., Viola, M.R., Beskow, S. & Norton, L.D. 2013. Multivariate models for annual rainfall erosivity in Brazil. *Geoderma*, 202–203: 88-102.

Oliveira, A.H., Silva, M.A., Silva, M.L.N., Curi, N., Klinke Neto, G. & Freitas, D.A.F. 2013. Development of topographic factor modeling for application in soil erosion models. *Soil Processes and Current Trends in Quality Assessment*. 4: 111-138pp.

Oliveira, P.T.S., Wendland, E. & Nearing, M.A. 2012. Rainfall erosivity in Brazil: A review. *Catena* 100:139-147.

Renard, K.G., Foster, G.R., Weessies, G.A. & McCool, D.K. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Yoder C (Ed.), U.S. Department of Agriculture, Agriculture Handbook 703.

Silva, A.M. 2004. Rainfall erosivity map for Brazil. *Catena,* 57: 251-259.

Silva, M.L.N., Curi, N., Ferreira, M.M., Lima, J.M. & Ferreira, D.F. 1999. Proposição de modelos para estimativa da erodibilidade de Latossolos Brasileiros. *Pesquisa Agropecuária Brasileira*, 34: 2287-2298.

Silva, M.L.N., Curi, N., Lima, J.M. & Ferreira, M.M. 2000. Avaliação de métodos indiretos de determinação da erodibilidade de Latossolos Brasileiros. *Pesquisa Agropecuária Brasileira*, 35: 1207-1220.

Uehara, G. & Gillman, G. 1971. *The mineralogy, chemistry and physics of tropical soils with variable charge clays*. Boulder: Westview, 170pp.

Wischmeier, W., Johnson, C. & Cross, B. 1971. A soil erodibility nomograph for farmland and construction sites. *Journal Soil and Water Conservation*, 26(3): 189-193.

Wischmeier, W. & Smith, D. 1978. Predicting rainfall erosion losses: a guide to conservation planning. *Agricultural Handbook 537*, Washington: US Department of Agriculture, 62pp.

Application of the EUROSEM model in drainage basins in areas of the Valencian Community, Spain

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Abstract

The results of the application of the EUROSEM model are compared in different drainage basins in the Spanish provinces of Valencia and Alicante (Vall d'Ebo, Sierra de la Murta and La Casella). The goal is to study erosion problems by evaluating soil losses -due to erosion in the current situation- and study the effect of the change of conditions and its repercussions in order to apply palliative techniques.

The aim of this study is to evaluate the erosive phenomena using the EUROSEM model GIS. In addition, the tool, MDT, is used to represent the topography of the area. A generalized drainage model is constructed by calculating the flow direction, and identifying homogeneous units depending on various parameters evaluated (slope, geology, soils, and vegetative coverage), thus obtaining a schematic representation of the basin with different units / EUROSEM elements. For this purpose, soil samples were analyzed with a detailed study of vegetation, mulch, stoniness, grooves, roughness, and so forth. As well as considering the precipitation data obtained from an automated weather station in the basin.

In the application of the model and making modifications of the parameters, important differences are obtained in values such as infiltration, run-off, and erosion/sedimentation. These sites are located in zones with major risk of erosion and in zones of major concentration of superficial flow which are a consequence of the hydrological connectivity and the effect of heavy rain. The results show the effects of rain on the loss of soil by erosion in the zones studied, showing that the tons of eroded soil would triple. These results indicate how a change in weather conditions can increase the values of soil loss by erosion in drainage basins.

Keywords: Soil erosion, EUROSEM model, drainage basin

Introduction

The European Soil Erosion Model (EUROSEM 2010) is a dynamic distribution model (Borselli and Torri, 2010), capable of simulating erosion, sediment transport and deposition on the surface for small watersheds. Compared with other soil erosion models, EUROSEM considers flow in furrows and the effects of rocky and vegetation cover on the interception of precipitations on infiltration. Its application in small basins that are divided into a network of homogeneous slope planes and channel elements arranged in a cascading sequence allows to facilitate the circulation of the sediments on the surface of the Earth (Quinton *et al.*, 2010).

The model EUROSEM allows to obtain predictions of the loss of soil by erosion of watersheds modifying the conditions of the scenarios as are some spatial characteristics peculiar to the territory because of human actions, or an increase of the intensity of rainfall. Through various simulations, we can relate the modifications made on the hydrological behavior of the sub-basin, detect, a priori, areas with erosion problems and make recommendations for the sustainable management of the Territory. The objective of this study is to evaluate soil loss by erosion in different drainage subwatersheds in mountainous zones of the provinces of Valencia and Alicante (Spain) (Vall d´Ebo, La Murta, Casella) and identify the critical points where these are manifested using the model EuroSEM. This simulates a scenario based on the characteristics of the territory and identifies critical areas with hydrological and erosive risks.

Methodology

The limits of the study area and the digital representation of the topography of the area have been defined using GIS and MDT tools. From this information, a generalized model of drainage has been constructed and identifying the areas of greater slope and the floodable zones, together with their hydromorphological characteristics. The flow direction calculation has been carried out, thus defining the boundaries of the Valleys of the Vall d´Ebo, La Murta, and Casella Basins and their drainage subwatersheds. Within these sub-basins, through GIS treatment of the available layers of information, homogeneous units have been identified in terms of slope, geology, soils, and plant cover. The study was completed by integrating field and laboratory results from soil sampling conducted in the selected area. Thus, it has obtained a first schematic representation of the basin with the units/elements EuroSEM.

In some zones, two climatic scenarios were simulated: an episode of intensity and duration of "real rain" using intervals of 5 minutes, and another episode or "Theoretical Rain" that supposes an increase of 25% in the intensity following the predictions indicated By the InterGovernmental Group of Experts on Climate Change (IPCC). This episode of Theoretical Rain was constructed from the data of the real rain, modifying the total period of the event and reducing the reading intervals of the same (Salvador *et al.*, 2008; De Baets *et al.*, 2008). Three scenarios were used with different precipitation data (scenario 1), real precipitation (another theoretical precipitation (scenario 2), and finally torrential precipitation (scenario 3).

Soil samples were taken to perform the required analyses in the model and at the same time a detailed study of the vegetation (both in type and shape), plant cover, rocky, number of furrows, roughness, etc., all parameters necessary to be able to run the model. In relation to rainfall data, real data have been used for an automated meteorological station located in the central part of the valley, this has been used data of three intensities of low rainfall (I30 6 mm/h), moderate (I30 12 mm/h) and high (I30 55.4 mm/h), and finally simulated with a fictitious torrential rain of 206 mm/h.

Using the Integrated Earth Units (ITU) Method, it shows the polygons representing geographical units, delineated by integrating overlapping thematic maps such as lithology, land use, orientation, and slopes. Common features or traits at the intersection of entries are written to the output shape. These units or geographical spaces express characteristics homogeneous among themselves, peculiarities or traits of depth or texture of the soil, lithology or type of geological formation, landscapes, and typical properties of each one of them.

Results

The topographical representation of the terrain carried out through the Geographic Information System (GIS) for the three zones has allowed the digital quantitative representation of the topographical surface of the terrain shown in Figure 1 to be obtained. The altitudes of the watersheds range from 150 m. to 525 m in the Murta and 630 m in La Casella, and between 300 and 750 m in the Vall d´Ebo. The Lithologic map differentiates areas of limestone and loam lithology in both zones located on the slopes and fillings of the valley.

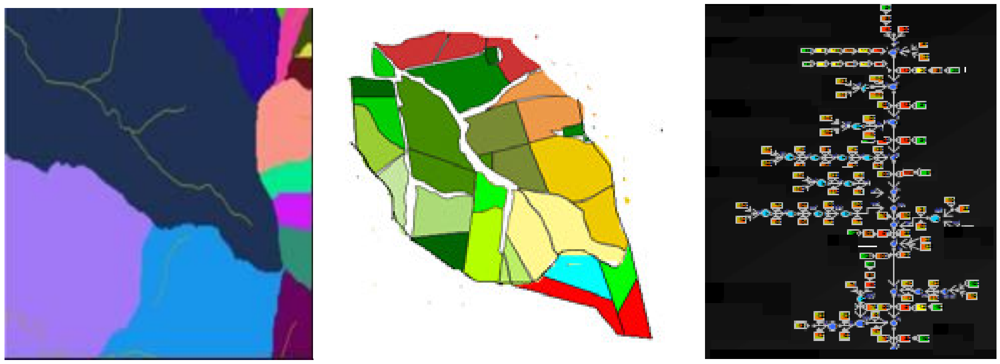

Figure 1: Raster of the Digital Elevation Model (DEM) of the Vall of Murta (Valencia). Units Map. Connectivity units

In the results obtained in the analysis of soils carried out are some contents of organic matter and high structural stability, are well-structured soils, so they have a good capacity of infiltration and low loss of soil by Erosion.

In the Murta zone scenario 1 with a relatively weak rain event, the infiltration is high and very low moisture content. The polygons located in the central part of the basin have high infiltration and very low erosion/sedimentation values due to the low displacement of solid particles. In scenario 2, the erosion occurs in the upper part of the North slope and the central part of the South slope. In the North slope are the units of soil with higher average slope, (values around 30 %), and with a low infiltration capacity. In the lower part of the Northern slope, as a result of the decrease in slope, all the eroded material is deposited that comes from the higher units of the slope. In this area, the soil is deeper, and the use of soil is part agricultural. These units are characterized by a very low average slope (4 % average), a high infiltration capacity and low content in rocks and vegetation cover. In the area located in the middle-lower part of the hillside, we also found similar levels of deposition. While on the Southern slope, (in areas with higher slope and low plant cover and infiltration capacity.) High erosion occurs.

As for the behavior of runoff in scenario 3, the topography marks the depth of soil. In the Northern Slope, the polygons located in the middle and high slopes of the hillside have the highest values of runoff, given the low values of infiltration, high cohesion, and humidity, an abundance of rocks and coarse texture. On the Southern slope, the runoff originates in the middle part coinciding with the units with higher slope and less vegetation cover (Soriano *et al.*, 2015).

Table 1: Values of total runoff results in scenarios 1 and 3 in some basin units.

Element	Contribution Area (m^2)	Total Runoff (m^3) Stage 1	Total Runoff (m^3) Scenario 3
32	225.991	62.003	151.523
45	45.493	6.340	12.611
94	146.901	12.001	23.198
136	126.327	9.300	11.432
152	62.873	2.215	3.456
32	225.991	62.003	151.523
45	45.493	6.340	12.611

Table 1 shows some examples of the results of total runoff in scenarios 1 and 3, produced by changing the intensity of the rain. The contribution area is specified for different elements resulting from the study. In all cases, the runoff collected by the element in question when considering elevated rainfall intended values is considerably altered. Runoff volume increases are observed 3 times higher for some units considering the same contribution area. In the area of the Murta soil erosion losses are represented in ranges ranging from light erosion with values lower than < 1 t/ha, low and moderate erosion with ranges up to-8 t/ha, high of 8-12 t/ha and very-high higher than 12 t/ha. 65 % of the zone corresponds to low erosion ranges favored in most cases by high plant cover values and located on the northern slopes and in low sediment deposition areas (basin center) 26% of the area corresponds to areas of moderate and high erosion and the rest to areas of very high erosion.

Conclusions

Hydrological in the form of homogeneous planes interconnected by flow channels, where water and sediments experience a downward movement without lateral movements.

The simulation with heavy rainfall results in an increased risk of erosion. The identification of areas where soil loss predominates, transport areas and areas where sedimentation occurs makes it possible to highlight the points where erosive phenomena are critical. This information is of great relevance when it comes to individualizing practices of prevention, correction or mitigation in the plans that require intervention.

References

Benavides-Solorio, J. & MacDonald, L. 2005. Measurement and prediction of post-fire erosion at the hillslope scale, *Colorado Front Range International Journal of Wildland Fire*, 14(4): 457–474.

Cerdá, A. & Doerr, F. 2005. Influence of vegetation recovery on soil hydrology and erodibility following fire: an 11-year investigation. *International Journal of Wildland Fire*, 14: 423 – 437.

De Baets, S., Torri, D., Poesen, J., Salvador, M.P. & Meersmans, J. 2008. Modelling increased soil cohesion due to roots with EUROSEM. *Earth Surface Processes and Landforms*, Wiley, 33: 1948-1963.

Doerr, S. & Cerdá, A. 2005. Fire effects on soil system functioning: new insights and future challenges. *International Journal of Wildland Fire*, 14(4): 339 – 342.

Elliot, W.J. 2004. WEPP internet interfaces for forest erosion prediction. *Journal of the American Water Resources Association,* 40: 299–309.

Quinton, I., Govers, G., Van Oost, K. & Richard D. 2010. The impact of agricultural soil erosion on biogeochemical cycling. *Bardgett Nature Geoscience*, 3: 311–314.

Salvador, M.P., Torri, D., Borselli, L. & Poesen, J. 2008. Climate Effects on Soil Erodibility. *Earth Surface Processes and Landforms*, 33(7): 1082–1097.

Soriano, M.D., Lahiguera, A., García-España, L. & Salvador, P. 2015. Aplication ot the EUROSEM model in drainage basins after severe wildfire. VI Reunión Internacional Fuegored, 88-91 pp.

Use of geochemical fingerprints to trace sediment sources in an agriculture catchment of Argentina

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Abstract

This research focuses on the identification of suitable soil tracers from hot spots of land degradation and sediment fate in an agricultural catchment of central Argentina with erodible loess soils. Using Energy Dispersive X-Ray Fluorescence (EDXRF) for geochemical characterization, element concentrations were used as soil tracers.

Tracers were identify using two artificial mixtures composed of known proportions of soil sources collected in different sites with distinctive soil uses. Phosphorus, iron, calcium, barium, and titanium were identified for obtaining a best suitable reconstruction of the source proportions in the artificial mixtures. Then, these elements as well as the total organic carbon were applied for identifying critical hot spots of erosion in the catchment. Feedlots were identified to be the main source of sediments, river banks and dirt roads together are the second most important source. This case study provides key information for improving soil conservation strategies and selecting land management practices and land uses that do not contribute considerably to sediment redistribution.

Keywords: fingerprinting, geochemical elements, energy dispersive X-ray fluorescence, soil erosion, mixing models

Introduction, scope and main objectives

Soil erosion reduces significantly cropland productivity and contributes to the pollution of water-courses, wetlands, and lakes. This natural process becomes even more critical in arid and semi-arid zones (as the west-central of Argentina) due to two main reasons: (i) agricultural areas were expanded at expenses of native forest cover disturbing the hydrological balance, and (ii) associated with climate change, precipitations show a tendency to increase, with a higher frequency of extreme rainfall events (Manyevere *et al.,* 2016; Giménez *et al.,* 2016; Barros *et al.,* 2015). Therefore, in order to implement effective strategies for controlling excessive flow of sediment, it is necessary to determine both the nature and location of the main sources of sediments at the watershed scale. Sediment geochemistry has been widely used to identify the spatial sources of sediments delivered to watercourses (Hardy *et al.,* 2010). Fingerprint techniques allow identification and quantification of transported sediment from different sources. The geochemical concentrations of eroded sediments are mainly conditioned by the type of soils and the geological substratum from which they originate (Blake *et al.,* 2012). Applying mixing models (MM) is possible to infer the relative contributions of different sources to the sediment mixtures in the fate places.

Mass concentration of geochemical element of soil can be assessed by energy dispersive X-ray fluorescence (EDXRF) spectroscopy (see Melquiades *et al.,* 2013).

The two major objectives of this investigation were: (a) to identify the most efficient set of fingerprint elements using artificial soil mixtures and (b) to use these suitable soil tracers to describe the temporal sediment apportionment in different locations of the river of an Argentinian agricultural catchment located 23 km north-east of San Luis.

Methodology

The sampling procedure involved removing the leaves and plant material that was found in the place before taking a soil layer of 20 cm^2 and 2 cm thick of exposed soil using a stainless-steel flat spatula. At each location, multiple subsamples from an area of about 100–200 m^2 were collected in a plastic bucket to obtain a composite sample representative of that land use (source samples). Samples were taken during three different periods: (a) end of rainy season (b) end of dry season, and (c) middle of rainy season. Sediment samples (mixture samples in the river courses) were collected at the top 20 mm of the accumulation zones on little floodplains where deposition process was observed. Four of the source samples i.e. S1, S2, S3, and S4 were used to create two artificial mixtures (MIX 1 and MIX 2) with the proportions showed in Figure 1. The proportions were selected to represent the possible distributions of sediment origin, including the end members of sediment contribution and to ensure as well that the model testing gets results outside the uncertainty margins of the model. For EDXRF spectrometry analysis, the samples were ground into fine powder and pressed pellets of 25 mm diameter and 2.5 g weight were produced. These pellets were measured at the IAEA Nuclear Science and Instrumentation Laboratory using a heavy-duty, fully software-controlled EDXRF spectrometer utilizing five secondary targets (SPECTRO X-LAB 2000). The concentration of more than 40 elements for each sample was obtained. A three steps procedure was applied for fingerprints selection, i.e. Kruskal Wallis H test, Discriminant Function Analisis and Bi-plots examination (Torres Astorga *et al.,* 2018). The resulting elements were validated using the two artificial mixtures in two MM: CSSIAR v2.00 (de los Santos Villalobos *et al.,* 2013) and IsoSource (Phillips and Gregg, 2003). After validation, CSSIAR v2.00 was applied for identifying critical hot spots of erosion using the selected geochemical elements and total organic carbon (TOC) data as fingerprints in the collected mixture samples.

Results

After applying the statistical tests and the bi-plot examination, phosphorus (P), iron (Fe), calcium (Ca), barium (Ba), and titanium (Ti) were selected as fingerprints. The concentrations of these five elements were used in CSSIAR v2.00 to reconstruct the two artificial mixtures into their original soil sources. The Figure 1 presents the calculated proportions. The bank's contribution to the mixture is in accordance with the actual proportions in both mixtures; in MIX 1, the difference between the calculated and the actual value is only 4%, while in MIX 2 this difference is 1.7 %. Furthermore, for feedlot source apportion, the result is close to the actual value; in MIX 1, the absolute difference between the calculated and the actual proportion is 6%, and in MIX 2 only 2 %.

Then, the selected elements (P, Ca, Fe, Ti and Ba) were used as tracers in the catchment to identify the main sediment sources. TOC was used as the sixth tracer to improve the accuracy of the results without changing the resulting proportions.

Results on sediment apportionment in channel mixtures are reported in Figure 2.

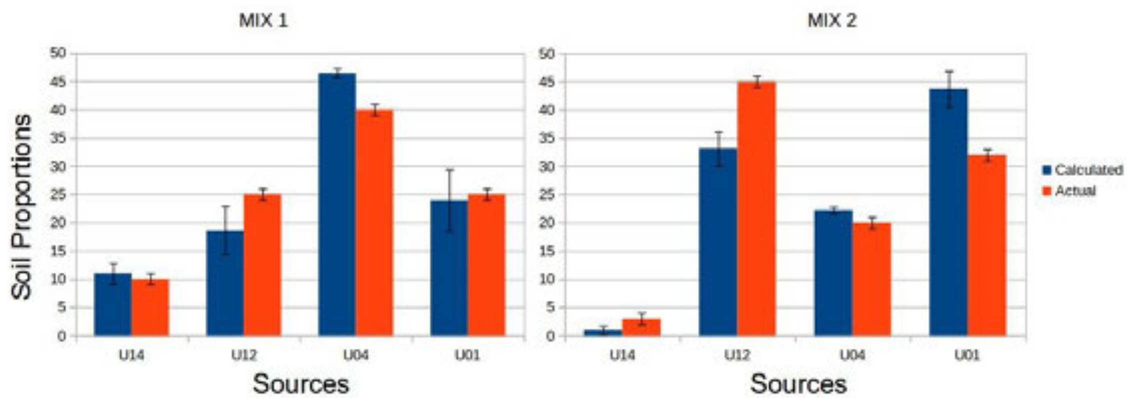

Figure 1: Comparison between actual and calculated soil proportion in the artificial mixed samples. The error bars represent the associated uncertainty when preparing the artificial mixtures. For the calculated soil proportions the standard deviation provided by the mixing model was represented (Adapted from Torres Astorga *et al.,* 2018).

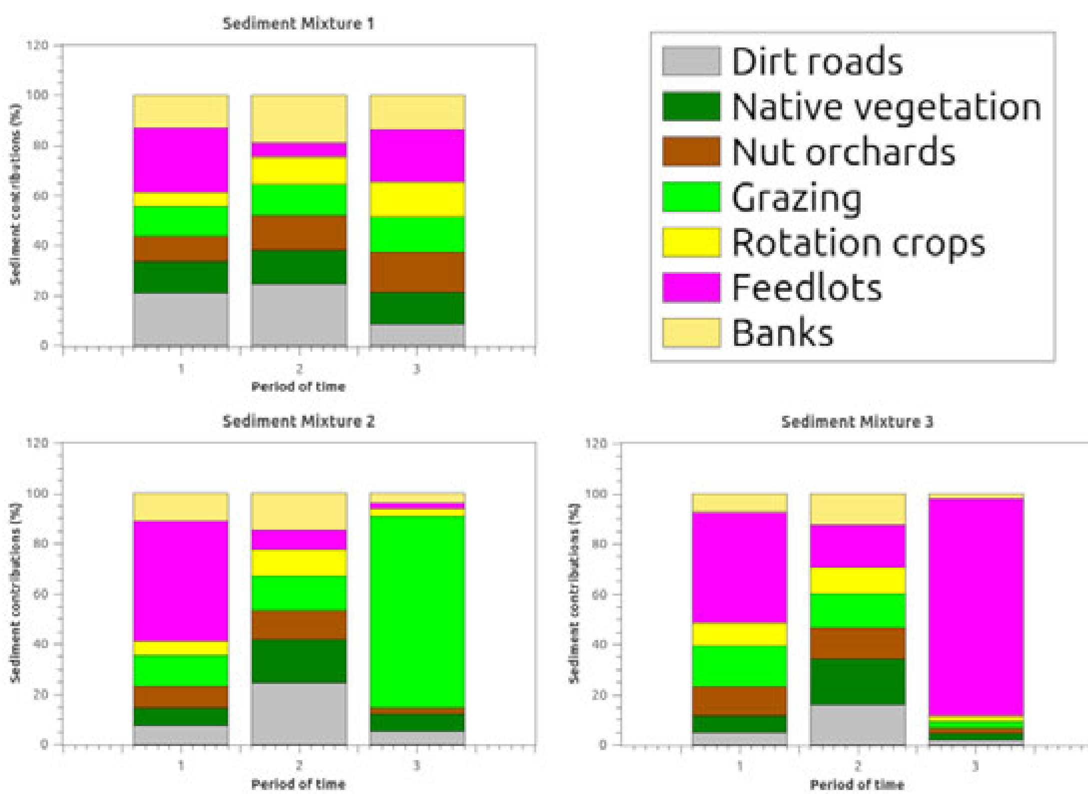

Figure 2: Sediment mixtures collected in three channels of the catchment at (1) the end of rainy season, after harvesting; (2) the end of dry season; (3) middle of rainy season.

Discussion

The selected elemental tracers can be used as suitable fingerprints due to the particular features of the land uses in the study area. Calcium content is lower in the topsoil of the agricultural fields as compared to the soil from the stream banks and native vegetation soils without human intervention. Its content is high also in the feedlot soil. Iron shows different concentrations as well. The lower content of Fe may be related to the constant application of fresh manure in the feedlot soils. It is expected a lower Fe content in the trees topsoil (walnuts) than in the native vegetation and grassland top soils. Phosphorus is expected to have highest content in the feedlot due to the cattle manure. An increased P content in the agricultural fields might be due to the use of fertilizers. Titanium content could be inherited from the parent material and its variability may show differences because of the origin of the loess materials. This would explain the variability in Ti comparing cultivated and uncultivated areas, as banks, dirt roads and native vegetation lands. From the analysis, *feedlots* were identified to be one of the main sources of the sediments produced. *River banks* and *dirt roads* together are the second most important source of sediments particularly at the end of the dry season (period 2). Both sources jointly, which consist of subsoil material, are the main source of sediments in all three downstream mixtures at the end of dry season. In some cases, rangelands and pasturelands (treated as *grazing*) are considered as main source in two channel sediment mixtures. Moreover, where *grazing* is the major contributor the proportions are high (76 % and 60 %). This might be explained by a larger number of animals living in that area and their proximity to the water channel. Other important outcome is the low contribution of the sources *native vegetation* and *nut orchards*. This behaviour is expected as there is no soil removal in these zones.

Conclusions

- P, Ca, Fe, Ti and Ba allow to determine effectively the source proportions of the sources in the artificial mixtures;
- Feedlots were identified to be the main source of sediments in most of the channel sediment mixtures analysed;
- Together river banks and dirt roads are the second most important source of sediments. Indeed, the limited vegetation cover during every dry season favours sediment movement;
- Rangelands and pasturelands can be a relevant source of sediments;
- The area of native vegetation presents one of the lowest contributions to soil erosion.

Results of this investigation provide key information for improving soil conservation strategies and selecting land management practices and land uses that do not contribute much to sediment redistribution.

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References

Barros, V.R., Boninsegna, J.A., Camilloni, I.A., Chidiak, M., Magrín, G.O. & Rusticucci, M. 2015. Climate change in Argentina: trends, projections, impacts and adaptation. *Wiley Interdiscip Rev Clim Chang.,* 6: 151–169. https://doi.org/10.1002/wcc.316.

Blake, W.H., Ficken, K.J., Taylor, P., Russell, M.A. & Walling, D.E. 2012. Tracing crop-specific sediment sources in agricultural catchments. *Geomorphology,* 139–140: 322–329. https://doi.org/10.1016/j.geomorph.2011.10.036.

de los Santos-Villalobos, S., Bravo-Linares, C., Meigikos dos Anjos, R., Cardoso, R., Gibbs, M., Swales, A., Mabit, L. & Dercon, G. 2017. The CSSIAR v.1.00 Software: A new tool based on SIAR to assess soil redistribution using compound specific stable isotopes. *SoftwareX,* 6: 13–18. https://doi.org/10.1016/j.softx.2016.12.005.

Giménez, R., Mercau, J., Nosetto, M., Páez, R. & Jobbágy, E. 2016. The ecohydrological imprint of deforestation in the semiarid Chaco: in- sights from the last forest remnants of a highly cultivated landscape. *Hydrol Process.,* 30: 2603–2616. https://doi.org/10.1002/hyp.10901.

Hardy, F., Bariteau, L., Lorrain, S., Thériault, I., Gagnon, G., Messier, D. & Rougerie, J.F. 2010. Geochemical tracing and spatial evolution of the sediment bed load of the Romaine River, Québec, Canada. *Catena,* 81: 66–76. https://doi.org/10.1016/j.catena.2010.01.005.

Manyevere, A., Muchaonyerwa, P., Mnkeni, P.N.S. & Laker, M.C. 2016. Examination of soil and slope factors as erosion controlling vari- ables under varying climatic conditions. *Catena,* 147: 245–257. https://doi.org/10.1016/j.catena.2016.06.035.

Melquiades, F.L., Andreoni, L.F.S. & Thomaz, E.L. 2013. Discrimination of land-use types in a catchment by energy dispersive X-ray fluores- cence and principal component analysis. *Appl Radiat Isot.,* 77: 27–31. https://doi.org/10.1016/j.apradiso.2013.02.015.

Phillips, D.L. & Gregg, J.W. 2003. Source partitioning using stable isotopes: coping with too many sources. *Oecologia,* 136: 261–269. https://doi.org/10.1007/s00442-003-1218-3.

Torres Astorga, R., de los Santos Villalobos, S., Velasco, H., Dominguez-Quintero, O., Pereira Cardoso, R., Meigikos dos Anjos, R., Diawara, Y., Dercon, G. & Mabit, L. 2018. Exploring innovative techniques for identifying geochemical elements as fingerprints of sediment sources in an agricultural catchment of Argentina affected by soil erosion. *Environmental Science and Pollution Research*, 25(21): 20868–20879. https://doi.org/10.1007/s11356-018-2154-4.

Rainfall Erosivity in China

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Abstract

Rainfall erosivity is one of variables for empirical models of the USLE or CSLE. Its original index EI_{30}, the product of the total kinetic energy and maximum 30-min intensity, requires high resolution rainfall data, which are often unavailable. To develop equations for event, daily, seasonal, and annual rainfall erosivity based on commonly available rainfall data, one-minute resolution rainfall process data from 18 weather stations during years of 1961/1971- 2000 in the eastern monsoon climate region of China, where water erosion dominated, was collected. Data from 11 stations was for model development, and the other for model calibrations. The results showed that the combined index of both rainfall amount and maximum period rainfall intensity had the higher accuracy for any specific resolution data than that only using rainfall amount. It is acceptable to estimate rainfall erosivity using only rainfall amount when the maximum period of rainfall intensity is unavailable. Comparing with EI_{30}, the symmetric mean absolute percentage errors of event equations were 13.9 %, 11.0 %, and 4.7 % for individual, monthly, and annual erosivity respectively, 38.1-67.8 %, 15.5-31.2 %, and 5.9-13.0 % for daily, monthly, and annual erosivity with daily equations, 22.9-41.5 % and 16.0-29.4 % for monthly and annual erosivity with monthly equations, and 15.4-25.6 % for annual erosivity with yearly equations.

Keywords: Rainfall erosivity, EI_{30}, Maximum period rainfall intensity, Event rainfall erosivity, daily rainfall erosivity, Seasonal rainfall erosivity, Annual rainfall erosivity

Introduction, scope and main objectives

Empirical soil erosion models such as Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978) and Chinese Soil Loss Equation (CSLE, Lu *et al.,* 2001) have been applied for regional soil erosion survey for soil conservation plan and effects assessment (Schnepf and Flanagan, 2016; Liu *et al.*, 2013). Model variables have to be calibrated based on observation data for the empirical models. In addition, rainfall erosiviey index EI_{30}, the product of the total kinetic energy and maximum 30-min intensity, requires high resolution rainfall data both in temporary and spatial scales, which are hardly available. Many estimation equations using easily available and different resolution rainfall data were developed (Richardson *et al.*, 1983; Renard and Freimund, 1994). China has diverse climate types, especially in water erosion region dominated by monsoon. The estimation equations for EI_{30} should reflect great variability both in rainfall amount and intensity. To predict precise soil loss, seasonal erosivity distributions, ratio of half-month or month erosivity to annual values, and average annual erosivity are needed. The objective of this study is to develop a series of erosivity estimation equations in four scales data availability cases, event and daily erosivity for evaluating impact of extreme rainfall events, seasonal erosivity for estimating influences of vegetation cover variations on soil loss, and annual erosivity for predicting annual soil loss.

Methodology

Data

One-minute resolution rainfall process data from eighteen weather stations distributed over the eastern water-erosion region of China was collected (Figure 1). The periods of record for 16 stations were 1961 through 2000, and those for Wuzhai and Yangcheng in Shanxi province were 1971 through 2000. The data was obtained by siphon, self-recording rain gauge observations (Wang *et al.*, 2004). For the eight stations in the northern part of China, only the period from May to September was used because the siphon, self-recording rain gauges were not available in winter for freeze damage. Data of the whole year was used for the remaining ten stations located in the southern part of China. Data from eleven stations was used to develop models, and data from the other seven stations was used to evaluate the models (Figure 1).

Figure 1: Locations of the 18 stations with one-minute resolution rainfall data. Eleven stations marked with dots were used to calibrate 21 models. The other seven stations marked with triangles were used to validate models and conduct comparisons with previous research.

Calculations of EI_{30} at different time scales

The erosivity for event, daily, month, and annual scales was calculated based on the one-minute resolution rainfall data. EI_{30} (MJ mm ha^{-1} h^{-1}) is the rainfall erosivity index for a rainfall event, where E and I_{30} were the total rainfall kinetic energy and the maximum contiguous 30-minute intensity during an event (Wischmeier and Smith, 1978). An individual rainfall event was defined as a period of rainfall with at least six preceding and six succeeding non-precipitation hours (Wischmeier and Smith, 1978). Daily rainfall erosivity was calculated under three conditions of only one event within one day, more than two events within one day, and one event lasting in two or more than two days. Event EI_{30} and sum of event EI_{30} equaled to the daily erosivity for the first and second situations respectively. For the last condition, the same maximum 30-minute rainfall erosivity was used for days the rainfall event spanning, and daily rainfall energy for each day was the part of the whole event rainfall energy. The summation of event EI_{30} in one half-month or one month reflected seasonal erosivity distribution, and the year EI_{30} was summed from event EI_{30} in one year.

Since not all rainfall causes soil erosion, the mimimum rainfall of 12 mm was used as the erosive rainfall standard. If daily rainfalls only equaling to or more than 12 mm were used for calculating EI_{30}, the results would be underestimated because of one event lasting two or more days. Under the assumption that the annual erosivity of summing erosive events EI_{30} in one year should be the same as that of summing daily EI_{30} above some threshold, the threshold of daily erosive rainfall could be determined as 10 mm (Xie *et al.*, 2016).

Model development and validations

Based on the availability of rainfall data from weather stations in China, two types of estimators for daily, monthly, and yearly erosivity by using easily available data were chosen. One was the combining estimations of rainfall amount and the maximum period rainfall amount, and the other was only the rainfall amount. For event erosivity, PI_{30} was used for estimation, where P was event rainfall, easily available comparing with process data for calculating of E. For daily erosivity, P_{day}, $P_{day}I_{10d}$, and $P_{day}I_{60d}$ were used for estimation, where P_{day} was daily rainfall equaling to or more than 10 mm, I_{10d} and I_{60d} were daily maximum 10-minute and 60-minute rainfall intensity in $mm \cdot h^{-1}$respectively. Half-month erosivity was summed for daily erosivity. For monthly erosivity, $P_{m\text{-}ave}$, $P_{m\text{-}ave}(P_{60})_{m\text{-}max}$, and $P_{m\text{-}ave}(P_d)_{m\text{-}max}$ were used for estimation, where $P_{m\text{-}ave}$ was average monthly rainfall amount, $(P_{60})_{m\text{-}max}$ and $(P_d)_{m\text{-}max}$ were the largest values of monthly maximum 60-minute and daily (1440-minute) rainfall amount in mm respectively. For yearly erosivity, $P_{y\text{-}ave}$, $P_{y\text{-}ave}$ $(P_{60})_{y\text{-}max}$, and $P_{y\text{-}ave}(P_d)_{y\text{-}ave}$ were used for estimation, where $P_{y\text{-}ave}$ was average annual rainfall amount, $(P_{60})_{y\text{-}max}$ and $(P_d)_{y\text{-}ave}$ were the largest values of yearly maximum 60-minute and the average value of yearly maximum daily (1440-minute) rainfall amount in mm respectively. One-minute rainfall data was transformed into above estimators, and these estimators in four scales of event, daily, monthly, and yearly were regressed to EI_{30} values in corresponding time scales.

The performances for these regressive models were assessed with two parameters of the symmetric mean absolute percentage error ($MAPE_{sym}$) and the Nash-Sutcliffe model efficiency coefficient (NE) by using one-minute rainfall data from seven validation stations to calculate EI_{30} and estimators for four scales.

Results

The finer the temporal resolution of the rainfall data, the better the models performed for a given erosivity timescale. Models used the product of maximum period rainfall intensity and rainfall amount had better results than those with only rainfall amount (Table 1).

Table 1: Regressive Models and their performances by using the MAPEsym and the ME (Yin *et al.*, 2015; Xie *et al.*, 2016)

Time Scales	Regressive Models	$MAPE_{sym}$(%)			NE	
		Event/Daily	Month	Annual	Event/Daily	Month
Event	$R_{event} = 0.1592\ P_{event}I_{30}\quad I_{30} < 15mm/h$ $R_{event} = 0.2394\ P_{event}I_{30}\quad I_{30} \geq 15mm/h$	13.9	11.0	4.7	0.97	0.99
Daily	$R_{day} = 0.1661\ P_{day}(I_{10})_{day}$	38.1	20.4	11.7	0.90	0.96
	$R_{day} = 0.3488\ P_{day}(P_{60})_{day}$	38.4	15.5	5.9	0.93	0.98
	$R_{day} = 0.3846\ P_{day}^{1.7394}$ May-Sept. $R_{day} = 0.3156\ P_{day}^{1.7394}$ Oct.-Apr.	67.8	31.2	13.0	0.57	0.88
Monthly	$R_{ave\_month} = 0.0755\ P_{ave\_month}^{1.8430}$	--	41.5	29.4	--	-0.44
	$R_{ave\_month} = 0.0877\ P_{ave\_month}(P_{60})_{month\_max}$	--	22.9	16.0	--	0.82
	$R_{ave\_month} = 0.0410\ P_{ave\_month}(P_{1440})_{month\_max}$	--	29.8	20.6	--	0.72
Yearly	$R_{annual} = 1.2718\ P_{annual}^{1.1801}$	--	--	25.6	--	--
	$R_{annual} = 0.0584\ P_{annual}(P_{60})_{year\_max}$	--	--	15.4	--	--
	$R_{annual} = 0.0492\ P_{annual}\overline{(P_{1440})_{annual}}$	--	--	17.0	--	--

MAPEsym, the symmetric mean absolute percentage errors, was calculated as (Armstrong, 1985)

$$MAPE_{sym} = \frac{100}{m}\sum_{k=1}^{m}\left|\frac{R_{sim}(k)-R_{obs}(k)}{(R_{sim}(k)+R_{obs}(k))/2}\right|$$

NE, the Nash-Sutcliffe model efficiencies, was calculated as (Nash and Sutcliffe, 1970)

$$NE = 1-\frac{\sum_{k}^{m}[R_{sim}(k)-R_{obs}(k)]^2}{\sum_{k}^{m}[R_{obs}(k)-\overline{R_{obs}}(k)]^2}$$

--, null

Discussion

The results of this study provide a multitude of options for dealing with the problem of variations in available temporal resolutions of rainfall data, and a series of equations for estimating erosivity at event, daily, monthly, and annual scales. To obtain more accurate erosivity, the finer resolution rainfall data would be necessary. For the same resolution data, the maximum period rainfall erosivity would improve the predicting results comparing with only using rainfall amount.

Conclusions

One-minute resolution rainfall process data from 11 weather stations was collected to develop estimated equations for event, daily, monthly, and annual erosivity, and data from other 7 stations was used to evaluate the equations. The finer the temporal resolution of the rainfall data, the better the models performed. For the same resolution data, the product of rainfall amount and the maximum period rainfall intensity was better than that only using rainfall amount comparing observed EI_{30} values. The symmetric mean absolute percentage errors of event equations were 13.9 %, 11.0 %, and 4.7 % for individual, monthly, and annual erosivity respectively, 38.1-67.8 %, 15.5-31.2 %, and 5.9-13.0 % for daily, monthly, and annual erosivity with daily equations, 22.9-41.5 % and 16.0-29.4 % for monthly and annual erosivity with monthly equations, and 15.4-25.6 % for annual erosivity with yearly equations.

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References

Armstrong, J.S. 1985. *Long-range forecasting: From crystal ball to computer (*2nd Ed.). New York: Wiley.

Liu, B., Guo, S., Li, Z., Xie, Y., Zhang, K. & Liu, X. 2013. Sampling water erosion survey of China. *Soil and water conservation in China*, 10: 26-34.

Liu, B., Zhang, K. & Xie, Y. 2002. An empirical soil loss equation. In: *Proceedings-Process of soil erosion and its environment effect.* 12th international soil conservation organization conference. Beijing: Tsinghua University Press, pp. 21-25.

Nash, J.E. & Sutcliffe, J.V. 1970. River flow forecasting through conceptual models, Part 1: A discussion of principles. *J. Hydrol.*, 10: 282–290.

Renard, K.G. & Freimund, J.R. 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. *J. Hydrol.*, 157: 287–306.

Richardson, C.W., Foster, G.R. & Wright, D.A. 1983. Estimation of erosion index from daily rainfall amount. *T. ASAE.,* 26 (1): 153–156.

Yin. S., Xie, Y., Liu, B. & Nearing, M.A. 2015. Rainfall erosivity estimation based on rainfall data collected over a range of temporal resolutions. *Hydrol. Earth Syst. Sci.*, 19: 4113–4126.

Schnepf, M. & Flanagan, P. 2016. A History of Natural Resource Inventories Conducted by the USDA's Soil Conservation Service and Natural Resources Conservation Service. *A Special Report by the Soil and Water Conservation Society*. Available at: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1212208.pdf.

Wang, B.M., Lu, Y.P. & Zhang, Q. 2004. The color scanning digitizing processing system of precipitation autographic record paper. *J. Appl. Meteor. Sci.*, 15: 737–744.

Wischmeier, W.H. & Smith, D.D. 1978. Predicting rainfall erosion losses: A guide to conservation planning. U.S. Dep. Agric., *Agric. Handbook No.537.* Washington, D.C.

Xie, Y., Liu, B. & Nearing, M.A. 2002. Practical Thresholds for Separating Erosive and Non-Erosive Storms. *Transactions of the ASAE,* 45(6): 1843-1847.

Xie, Y., Yin, S., Liu, B., Nearing, M.A. & Zhao, Y. 2016. Models for estimating daily rainfall erosivity in China. *Journal of Hydrology*, 535: 547–558.

Theme 2: Policies and practices to address soil erosion

Zeolite effects on soil organic carbon and structure against erosion in vineyards

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Abstract

Zeolites are considered as an environmental-friendly soil conditioner able to improve physical and chemical properties of agricultural soils. In this experimentation, the response of some chemical, biochemical and physical indicators of soil quality to different doses (0, 5 and 10 t ha^{-1}) of zeolite (mainly clinoptilolite) has been studied in a vineyard soil after one year from treatments. A stimulation of microbial processes involved in soil organic matter degradation by applying zeolite was showed. Indeed, an increase in dehydrogenase activity and a decrease in soil organic carbon was observed in zeolite treated soils. The ability of zeolite to affect nutrient availability, by increasing cation exchange capacity, can be the reason of this trend. The maintenance of glomalin content, which is mainly formed by recalcitrant aromatic carbon compounds, suggested that organic carbon degradation affected the more labile fraction of organic matter. Further studies about zeolite application in combination with a source of organic matter available at the farm, such as winery waste, are being carried out in order to optimize the fertilizer use efficiency and preserve soil organic matter and aggregate stability.

Keywords: Zeolite, Clinoptilolite, ion exchange, slow-release fertilizer, ammonium retention, soil organic carbon, glomalin, aggregate stability

Introduction, scope and main objectives

Attempts to control water erosion and limit soil degradation in cultivated lands has become of paramount importance during the last century. Among the cultivated lands, vineyards deserve a particular attention because the form of agricultural use causes one of the highest soil losses. In particular, Mediterranean vineyards are exposed to severe risk of erosion due to their topographic, edaphic and climatic conditions. In intensive viticulture, continuous working practices with heavy machinery and inappropriate tillage addressed to reduce water and nutrients competition among vines and other plants are responsible for increasing soil erosion rates which in turn, may rise CO_2 emission and organic carbon loss (Cerdà *et al.*, 2017). In addition, in order to counteract fertility decrease and maintain appropriate plant vigor, conventional vineyards are usually treated with massive inputs of agrochemicals, producing mid and long-term decrease of soil structural stability and leading to pollutants release into soil and water bodies (Chevigny *et al.*, 2014).

Zeolites are considered to be the most widely used natural inorganic soil conditioners enhancing relevant soil properties such as infiltration rates, water holding capacity, cation exchange capacity and nutrient retention (Chmielewska, 2014). According to Englert and Rubio (2005) they are crystalline hydrated aluminosilicates with both high specific surface area (SSA) ranging from 200 $m^2\ g^{-1}$ (external SSA by N_2 sorption) to 500 $m^2\ g^{-1}$ (total SSA by water sorption) and cation exchange capacity (CEC). Natural zeolite has also been investigated for its contribution to soil organic matter and structure stability. Mirzaei *et al.* (2015) observed an increase in soil organic carbon (SOC) and water stability of aggregates (WSA) in soils amended with natural zeolite and plant residues.

In this paper we investigate the effect of different doses of natural zeolite applied to an Italian soil under vineyard cultivation with the objective to record eventual soil organic carbon, glomalin and structure stability alteration with respect to the untreated soil.

Methodology

The study area is located in Tuscany (Italy) with a semiarid climate (annual precipitation 859 mm, annual temperature 14.3° C). The soil was classified as Calcixerept (Soil Survey Staff, 2014) with a sandy clay loam texture.

A vineyard cultivated with *Trebbiano* variety was selected; the vineyard area of 1.5 ha was divided into three plots (0.50 ha each), where zeolite (mainly clinoptilolite) at the rates 0 t ha^{-1} (control, C), 5 t ha^{-1} (5) and 10 t ha^{-1} (10) was applied. After one year, three composite representative soil samples were taken from each treatment and separately analyzed (Table 1). Soil aggregate stability was determined according to Kemper and Rosenau (1986). Soil pH and electrical conductivity (EC) were analyzed in 1:2.5 w/v (Forster, 1995). Soil organic carbon (SOC) was performed by the dichromate oxidation method and total soil nitrogen (N_T) was determined with the Kjeldhal method (ISRI, 2002). Glomalin related soil protein (GRSP) was extracted following Rillig (2004). Glomalin concentration was quantified by the Bradford method (Bradford, 1976). Dehydrogenase activity was assayed using the method of Masciandaro *et al.* (2000).

Figure 11: Zeolite application and incorporation into soil at 30 cm depth

Results

The vineyard soil showed moderately alkaline pH (7.92-8.08) and was not saline (electrical conductivity 0.13-0.17 dS m^{-1}). CEC values increased with increasing zeolite doses and the same did N_T values. Instead SOC decreased from control to increasing zeolite treatments. Values of GRSP resulted very low with respect to SOC and they were no significantly different in zeolite treatments with respect to control soil. However, higher values of dehydrogenase enzyme activity were found in zeolite treatments. Finally, fluctuating values were obtained in the two aggregate classes (Table 1).

Table 1: Relevant properties in the vineyard soil treated with zeolite at the doses 0, 5 and 10 t ha^{-1}. Different letters indicate significant differences according to Tukey's HSD test (α=0.05).

SOIL	CEC	N_T	SOC	GRSP	Dh-ase	$WSA_{0.25-2}$	$WSA_{2-5.6}$
C	12.35	1.20	5.50	0.56	0,76	91.80	41.73
	±1.68b	±0.09b	0.02a	±0.15a	±0,06b	±0.88a	±13.00a
5	16.41	1,31	2.80	0.65	0,80	88.18	83.76
	±1.89ab	±0.06b	±0.06b	±0.04a	±0,12b	±1.04a	±0.97b
10	21.45	1.40	2.90	0.59	0,95	81.29	25.09
	±3.12a	±0.01a	±0.13b	±0.11a	±0,09a	±9.87a	±17.65a

C: control soil; 5 and 10: treatments with 5 and 10 t h^{-1} of zeolite. CEC: cation exchange capacity (Cmol kg^{-1}); N_T: total nitrogen (g kg^{-1}); SOC: soil organic carbon (g kg^{-1}); GRSP: glomalin related soil protein (g kg^{-1}); Dh-ase: dehydrogenase activity (mgINTF kg^{-1} h^{-1}); $WSA_{(0.25-2)}$: soil aggregates in 0-25-2 mm fraction (%); $WSA_{(2-5.6)}$: soil aggregates in 2-5.6 mm fraction (%).

Discussion

Results depicted a clear effect of zeolite on important soil properties. In the selected vineyard soil, CEC increased significantly by 33 % with 5 t ha^{-1} and by 74% with 10 t ha^{-1} respectively when compared to control soil (Table 1). Douglas and Dixon (1987) reported CEC values up to 165 Cmol kg^{-1} of pure clinoptilolite. The higher CEC values after zeolite treatments are therefore realistic and corroborate the positive effect of zeolite on soil ion exchange ability. Total nitrogen also increased with treatments and may be related to a major ability of treated soil to retain NH_4^+ nitrogen form. Surprisingly, significant decrease of SOC was observed after treatments. On average SOC decreased by 53%. This decrease can be attributed to dehydrogenase activity increase, strictly related to microbial population growth, and thus, to accelerated SOM microbial mineralization processes.

Even though GRSP values did not show significant variability, a slight increase was observed with 5 t ha^{-1} (+16 %) and 10 t ha^{-1} (+5 %) treatments (Table 1). As GRSP is a glycoprotein containing organic carbon composed of aromatic compounds (Gispert *et al.*, 2018) it may be postulated that SOC degradation after treatment may theoretically affect more labile organic compounds thus producing a comparative increase of recalcitrant organic compounds as GRSP is part of SOC.

In terms of absolute values the 0.25-2 mm aggregate fraction showed more homogenous values though WSA slightly decrease with 5 t ha^{-1} and 10 t ha^{-1} zeolite (3.62 % and 11.44 % respectively). By contrast, WSA in the 2-5.6 mm fraction increased by 50 % with 5 t ha^{-1} but decreased by 40 % with 10 t ha^{-1}. These results may suggest that a larger aggregate stability is maintained in the lower aggregate fraction which seems reasonable considering that smaller aggregate may better conserve architectural frame (Rillig, 2004).

Conclusions

Application of different doses of zeolite has proved to increase ion exchange properties with respect to untreated soil under vineyard cultivation. At this regard ion exchange capacity was even postulated by NH_4^+ retention and storage for later release for plant requirements. Conversely, zeolite produced soil organic carbon consumption through mineralization enhanced by microbial activity (dehydrogenase activity). The metabolic acceleration favored by the presence of zeolite in the soil determines a consumption of the available substrates, indicating the need to integrate an organic matter reserve that meets the demands of the increased microbial activity. Minor quantities of organic carbon can lead to a lower stability of the aggregates, especially with larger granulometries (2-5.6 mm). Further studies on the stability of micro-aggregates developed in an environment enhanced by the presence of zeolite and conditioned by an organic matter source will be the next stage in the development of a process that enhances the structural capabilities of the vineyard soils.

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References

Bradford, M.M. 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical Biochemistry*, 72: 248–254.

Cerdà, A., Keesstra, S.D., Rodrigo-Comino, J., Novara, A., Pereira, P., Brevik, E., Giménez-Morera, A., Fernández-Raga, M., Pulido, M., di Prima, S. & Jordán, A. 2017. Runoff initiation, soil detachment and connectivity are enhanced as a consequence of vineyards plantations. *Journal of Environmental Management*, 202: 268-275.

Chevigny, E., Quiquerez, A., Petit, C. & Curmi, P. 2014. Lithology, landscape structure and management practice changes: Key factors patterning vineyard soil erosion at metre-scale spatial resolution. *Catena*, 121: 354-364.

Chmielewska, E. 2014. Zeolitic adsorption in course of pollutants mitigation and environmental control. *Journal of Radioanalytical and Nuclear Chemistry*, 299: 255-260.

Doni, S., Gispert, M., Peruzzi, E., Macci, C., Mattii, G.B., Manzi, D., Masini, C.M. & Masciandaro, G. 2019. Impact of natural zeolite on agronomic properties of vineyard soils. *Catena*, under revision.

Douglas, W. & Dixon, J.B. 1987. Quantitative determination of clinoptilolite in soils by a cation exchange capacity method. *Clays and Clay Minerals*, 35: 463-468.

Englert, A.H. & Rubio, J. 2005. Characterization and environmental application of a Chilean natural zeolite. *International Journal of Mineral Processing*, 75: 21-29.

Forster, J.C. 1995. Soil physical analysis. In: K. Alef and P. Nannipieri (eds), *Methods in Soil Microbiology and Biochemistry*. London: Academic Press, pp. 79–87.

Gispert, M., Pardini, G., Emran, M., Doni, S. & Masciandaro, G. 2018. Seasonal evolution of soil organic matter, glomalin and enzymes and potential for carbon storage after land abandonment and renaturalization processes in soils of NE Spain. *Catena*, 162: 402-413.

ISRI. 2002. Procedures for soil analysis. Technical paper 6. International Soil Reference and Information Center- FAO.

Keith, H. & Wong, S.C. 2006. Measurement of soil CO_2 efflux using soda lime absorption: both quantitative and reliable. *Soil Biology and Biochemistry*, 38: 1121–1131.

Kemper, W.D. & Rosenau, R.C. 1986. Aggregate stability and size distribution, In: A. Klute (ed), *Methods of Soil Analysis, Part 1, 2nd edition*. Madison: Agronomy Monograph No. 9, ASA and SSSA, pp. 425–441.

Masciandaro, G., Ceccanti, B., Ronchi, V. & Bauer, C. 2000. Kinetic parameters of dehydrogenase in the assessment of the response of soil to vermicompost and inorganic fertilisers. Biology *and Fertility of Soils*, 32: 479-483.

Mirzaei, M., Akbar, A. & Mohsen, S. 2015. Aggregation stability and organic carbon fraction in a soil amended with some plant residues, nanozeolite and natural zeolite. *International Journal of Recycling of Organic Waste Agriculture*, 4:11–22.

Rillig, M.C. 2004. Arbuscular mycorrhizae, glomalin, and soil aggregation. *Canadian Journal of Soil Science*, 84: 355–363.

Soil Survey Staff. 2014. *Keys to Soil Taxonomy*. Natural Resources Conservation Service, United States Department of Agriculture, 525 pp.

Effects of biochar on soil properties and erosion potential in a degraded sandy soil

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Abstract

Degraded soils in humid tropics are characterized by low fertility and high soil erosion potential. Hence, field experiments were conducted during 2017 and 2018 cropping seasons on an Alfisol at Owo in the forest-savanna transition zone of southwest Nigeria to evaluate the effects of application of biochar (B) produced from waste wood of trees on changes of physicochemical characteristics and erosion potential. Four treatments considered were control (no biochar application), 10 t ha^{-1}B, 20 t ha^{-1}B and 30 t ha^{-1}B). The treatments were laid out in a randomized complete block design with three replications. Results indicated that biochar application significantly improved soil chemical properties, and reduced bulk density and penetration resistance, and increased porosity, moisture content, hydraulic conductivity and the mean weight diameter (MWD) of soil aggregates. Incorporating biochar into the soil significantly reduced soil loss by 31 %, 58 % and 82 % at 10, 20 and 30 t ha^{-1} application rates, respectively, compared with the control. The formation of macroaggregates in the biochar-amended soils is the critical factor to improve soil erosion potential. Therefore, application rate of 30 t ha^{-1} biochar is considered as suitable for severely degraded soil because this application rate efficiently improves soil properties and reduces soil loss.

Keywords: Biochar, soil erosion, soil properties, sandy soil, Alfisol, Nigeria

Introduction

Intensive, long-term cultivation of sandy soils often results in their degradation, which includes soil acidification, soil organic matter (SOM) depletion and severe soil erosion and leaching. According to Tejada and Gonzalez (2007), the decrease in soil organic carbon (SOC) caused by long-term cultivation decreases the aggregate stability of the soil and increases its erosion potential. Therefore, the effective maintenance of SOM in degraded soils can help preserve soil fertility and reduce erosion susceptibility by promoting soil aggregation stability, and improving hydraulic conductivity and water retention ability (Tejada and Gonzalez, 2007). Although application of organic matters (i.e. manure, mulches, and composts) have frequently been shown to increase soil fertility, the benefits are generally short-lived due to rapid decomposition of organic matter under the hot, humid tropical environment (Glaser *et al.*, 2002). This has made the practice expensive and therefore, the farmers refrain from organic matter addition to crops, often. An alternative to this practice could be the use of more stable compounds such as biochar, instead of the ordinary degradable organic manures.

Biochar, a carbon-rich material obtained from heating organic biomass under limited oxygen conditions appears to be a more stable source of carbon and it remains in the soil for hundreds or even thousands of years. The beneficial effects of biochar on soil properties have been reported by many researchers and includes physical (Chan *et al.*, 2008), chemical (Jien and Wang, 2013), and biological changes in soil (Rondon *et al.*, 2007). Biochar was also found to effectively maintain SOM levels, increase fertilizer-use efficiency and increase crop production, particularly for long-term cultivated soils in subtropical and tropical regions (Chan *et al.*, 2007, 2008). Few studies have examined the benefits of biochar application on the soil properties and erosion recalcitrant of soil. However, most of the biochar studies were either conducted on clayey soils or characterized by wide range of biochar mixing rates and plant responses (Glaser *et al.*, 2002). Some mixing rates used in early studies; for instance, 135.2 t ha^{-1} (Lehmann *et al.*, 2003), 200 t ha^{-1} (Rondon *et al.*, 2007), and 100 t ha^{-1} (Chan *et al.*, 2007), may not be feasible in regions where feedstock availability is limited such as in sandy dryland areas. Furthermore, little research has been conducted on the effects of biochar on physico-chemical properties of sandy soil and potential to erosion control. Where such studies were performed, they were pot experiments in a greenhouse and not field experiment. Glaser *et al.* (2002) suggested that future research need to focus on testing biochar amendments in experimental plots and under field conditions and achieving a better understanding of the physical and chemical properties of biochar surfaces. Hence, the objectives of this study were (1) to evaluate the effects of wood biochar on the physicochemical properties and erosion potential of a degraded sandy soil, and (2) to assess the relationships between soil properties and soil erosion potential.

Materials and methods

Field experiment was carried out at Owo (Lat 7°12ʹN and long 5°35’E) in the forest-savanna transition zone of southwest Nigeria during 2017 and 2018 cropping seasons. The experiments were conducted to evaluate the effects of application of biochar produced from waste wood of trees on changes of physicochemical characteristics and erosion potential. The experiment was laid out in a randomized complete block design with three replications. The treatments were four biochar rates; 0, 10, 20 and 30 t ha^{-1}. Each plot size was 5 m x 4 m. Blocks were 3 m apart and plots were 1 m apart. Disking of soil was followed by initial manual clearing with cutlass. The biochar was incorporated into the soil to the depth of approximately 10 cm with a hand held hoe on 21 April 2017 and 18 April 2018 and then left in the soil for 9 months in each year. Before the commencement of the experiment in 2017, soil samples were taken from 0-15 cm depth for physical and chemical analysis (Table 1). The wood biochar used for the experiment was also analysed to determine its chemical composition (Table 1). In 2017 and 2018 at 9 months after biochar incorporation, composite soil samples were also collected on plot basis for physical and chemical analysis. Physical properties measured include bulk density, porosity, penetration resistance, moisture content, saturated hydraulic conductivity, aggregate stability and soil losses. Soil chemical properties also determined were pH, OC, N, P, K, Ca and Mg. Data collected from each experiment were subjected to mean separation analysis using the 1-way ANOVA test at a significance of $p = 0.05$. The differences between mean values were identified using Duncan's multiple range test.

Results

Properties of the studied soil and the biochar

The physical and chemical properties of the soil before the start of the experiment in 2017 and the biochar are presented in Table 1. The soil was sandy soil in texture, slightly acidic, and had high bulk density and low levels of organic carbon (OC), total N, K, very low level of available P, but had adequate levels of exchangeable Ca and Mg. The biochar had high pH of 7.62 and a liming potential on acid soils. Organic C, exchangeable K, Ca and Mg, and N were much higher in the biochar than in the soil of the experimental site. Biochar also has extremely high C:N ratio of 800.5.

Table 1: Basic properties of the experimental site prior to experimentation in 2017 and the biochar

Properties	Soil	Biochar
Sand (%)	92.4	ND
Silt (%)	2.8	ND
Clay (%)	4.8	ND
Textural class	Sand	ND
Bulk density (Mg m^{-3})	1.58	0.60
pH (water)	5.6	7.62
Ash (%)	ND	0.028
Organic carbon (%)	0.74	520.3
Total N (%)	0.10	0.65
C/N	7.4	800.5
Available P (mg kg^{-1})	2.68	36.4
Exchangeable K (cmol kg^{-1})	0.12	1.75
Exchangeable Ca (cmol kg^{-1})	3.1	4.51
Exchangeable Mg (cmol kg^{-1})	0.98	0.78
Copper (%)	ND	0.013
Manganese (%)	ND	0.068
Sulphur (%)	ND	0.091
Zinc (%)	ND	0.008
Sodium (%)	ND	0.21

ND; not determined

Changes in soil physical properties after biochar application

The effect of the applications of biochar on soil physical properties on pooled data of 2017 and 2018 (after 9 months of application in each year) are shown in Table 2. Relative to the control, biochar-amended soils significantly reduced bulk density, penetration resistance, and increased porosity, moisture content, saturated hydraulic conductivity (Ksat) and mean weight diameter (MWD) of soil aggregate. Furthermore, the significant decrease in bulk density and penetration resistance decreased with increasing rate of biochar application. Likewise, increased porosity, moisture content, saturated hydraulic conductivity (Ksat) and mean weight diameter (MWD) of soil aggregate increased with increasing biochar application rate. Table 2 shows the soil loss after 9 months of biochar application in each year. The highest soil loss (324.9 kg ha^{-1}) occurred in the control, and the lowest soil loss (57.2 kg ha^{-1}) occurred in the amended plots with the highest application rate (30 t ha^{-1}). The soil loss significantly decreased as the biochar application rate increased, indicating that biochar largely ameliorated soil erosion potential in degraded sandy soils.

Table 2: The physical properties of biochar-amended soil at the end of application time (pooled data of 2017 and 2018

Biochar ($t\ ha^{-1}$)	Bd ($Mg\ m^{-3}$)	Porosity (%)	PR ($kg\ cm^{-2}$)	MC (%)	Ksat ($cm\ day^{-1}$)	MWD (mm)	SL (cm)	SL ($kg\ ha^{-1}$)
0	1.54a	41.9d	16.5a	11.3d	1.64d	1.16d	2.11	324.9
10	1.41b	46.8c	11.2b	13.3c	2.05c	1.53c	1.58	222.8
20	1.28c	51.7b	6.7c	16.1b	2.81b	1.80b	1.06	135.7
30	1.06d	60.0a	2.8d	17.6a	3.56a	2.09a	0.54	57.2

Bd: bulk density; PR: penetration resistance; MC: moisture content; Ksat: saturated hydraulic conductivity; MWD: mean weight diameter of soil aggregate; SL: soil loss.

Values followed by similar letters under the same column are not significantly different at p = 0.05 according to Duncan's multiple range test.

Discussion

Results showed that the site was low in OC, N, P, K, and slightly acidic with high bulk density. These conditions are the characteristics of soils in humid tropical regions. The low soil fertility might be the result of low organic matter content and low clay activity in the soil. The application of biochar improved soil physical properties compared with the control. Our results showed clearly that the addition of biochar significantly decreased the bulk density of the sandy soil studied (Table 1), which was attributable to the lower bulk density of the porous biochar (0.6 $Mg\ m^{-3}$) than of field soil (1.58 $Mg\ m^{-3}$) through the physical dilution effect. The decrease in penetration resistance and bulk density of the biochar-amended soils appears to have also been the result of alteration of soil aggregate sizes. This results agrees with the findings of Tejada and Gonzalez (2007) who amended soils by using organic amendments. The increase in porosity of biochar applied to soil could be related to the high porous nature of biochar. There was an increase in moisture content as a result of biochar application compared with the control. This was attributed to biochar's relatively higher surface area and higher porosity compared to other types of soil organic matter, it is suitable to improve water retention through improvement of soil texture and soil aggregation. In this current study, the moisture content of biochar amended soil at rate of 30 $t\ ha^{-1}$ was 56% higher than the moisture content of the control soil. This might be due to effects of charcoal itself and resulting higher levels of soil organic matter. Overall, biochar application can reduce bulk density and penetration resistance, suggesting the potential to improve soil structural development and stability.

The result that biochar increased soil pH, OC, P, K, Ca and Mg contents can be due to the low initial soil fertility status of the site before the commencement of the experiment. It also consistent with the chemical composition of the biochar used (Table 1). The increase in pH as a result of biochar application is due to its high liming potential (pH 7.62) and Ca content raised the pH of the sandy soil. This confirmed that biochar improved the base status of the soil to which it is applied. The increase in soil nutrients in soils amended with biochar compared with the control was attributed to the addition of nutrients contained in biochar, and through improved nutrient retention, modified soil microbial dynamics and increased decomposition of organic material in soil.

Based on our results, we deduced that the major reason for reduction of soil loss after the addition of biochar was the redistribution of the relative proportions of soil aggregate sizes. This indicated that aggregate stability and macroaggregate formation were important factors in maintaining soil porosity and in decreasing soil erosion. The unamended sandy soils were highly susceptible to water erosion because of their unstable aggregates.

Conclusions

Biochar prepared from the waste wood of trees through slow pyrolysis is an acid-neutralizing material for severely degraded soils, and is a potential source of nutrients. The persistent characteristics of the biochar ensure long-term benefits for the soils. Our field experiments showed that wood biochar not only improved the chemical properties, but also improved the physical properties of the soil, such as bulk density, porosity, penetration resistance, moisture content, hydraulic conductivity, aggregate stability, and erosion resistance. These results suggest that the addition of wood biochar effectively improved poor soil characteristics in severely degraded sandy soil, and reduced soil losses. The results of this study could be used to avoid rapid soil degradation and soil loss in subtropical and tropical regions.

References

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A. & Joseph, S. 2007. Agronomic values of greenwaste biochar as a soil amendment. *Australian Journal of Soil Research*, 45(8): 629-634.

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A., Joseph, S. 2008. Using poultry litter biochars as soil amendments. *Australian Journal of Soil Research*, 46(5): 437-444.

Glaser, B., Lehmann, J. & Zech, W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - a review. *Biology and Fertility of Soils*, 35(4): 219-230.

Jien, S-H & Wang, C-S. 2013. Effects of biochar on soil properties and erosion potential in a highly weathered soil. *Catena*, 110, 225-233.

Lehmann, J., Jr. da Silva J.P., Steiner, C., Nehls, T., Zech, W. & Glaser, B. 2003. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. *Plant and Soil*, 249(2): 343-357.

Rondon, M.A., Lehmann, J., Ramirez, J. & Hurtado, M. 2007. Biological nitrogen fixation by common beans (*Phaseolus vulgaris* L.) increases with biochar additions. *Biology and Fertility of Soils*, 43(6): 699-708.

Tejada, M., Gonzalez, J.L. 2007. Influence of organic amendments on soil structure and soil loss under simulated rain. *Soil and Tillage Research*, 93: 197-205.

Soil and water conservation technics as a mechanism to adapt to the impacts of climate change in the Maule River Basin Chile

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CONAF

Abstract

The impacts of climate change in the Maule River Hydrographic Basin are expressed in the increase of the maximum average temperature by + 0.6C ° in the last 14 years, above the world average (University of Talca, 2017), a reduction of the precipitations of the order 30 % (period 1973-2013, PASO 2013) and therefore a reduction of flows to 2025 of 16.3 % (DGA, 2011), as direct hydro-meteorological effects.

Erosion processes affect 51 % of granitics soils (cambisol FAO, xeralf 7th approximation), drought and shortage of water resources affect the quality of life of small and medium farmers / foresters. With high probability the forest fires 2016/2017, where they affected of the order of 280.106 has, constitutes the empirical evidence of an anthropic climatic change.

Adaptive measures of soil and water conservation are implemented and evaluated for erosion control such as subsoiling with infiltration ditch and ditch, associated with the reforestation of eroded soils in 18 properties. In each plot, growth and edapho-hydraulic variables are sampled. 320 sample plots are made for a comparative analysis of plantation cultivation with similar ages with and without treatments of soil and water conservation works.

The results of the evaluation indicate that the soil and water conservation treatments applied favorably influence the productivity of the forest site, where in the treatment of infiltration ditches there are increases in the diameter and height variables of 23 % and 40 %, respectively. In the treatment of subsoiling with ridges the increases in the diameter and height variables, the increases are even greater, of 122 % and 85 %, in both variables, respectively.

The results of the survey indicate that the application of adaptive measures to climate change such as soil and water conservation works, control erosion, favorably effect erosion control, hydrological performance at the hydrographic basin level and express themselves favorably in the sustainable productivity of the soil.

Methodology

In order to obtain basic information that allows the design of a methodology at a national level, it has been defined as a pilot area forest plantations in the Maule Region in the Provinces of Talca, Cauquenes and Linares, considering that the region holds surfaces planted in the order of 700 000 ha and of the order of 55 000 ha with afforestation associated with reclamation works of degraded soils nationwide. A study is carried out on the development of forest plantations of Pinus radiata, between 2 and 8 years of age, which includes a total of 18 properties of small and medium owners, distributed in 3 provinces of the Maule Region (Cauquenes, Talca and Linares), where a program of systematic sampling of 220 parcels is carried out. In each sample unit the variables of forest growth (diameter, height, volume), soil and nutritional are evaluated, to later perform comparative analysis of forest plantations of similar ages with and without soil and water conservation treatments.

Results

In the attached Figures 1, 2, 3 and 4 for stands of the province of Talca, where you can clearly see the effects of soil and water conservation treatments on the response to the growth variables and therefore the impact of the productivity of the forest site.

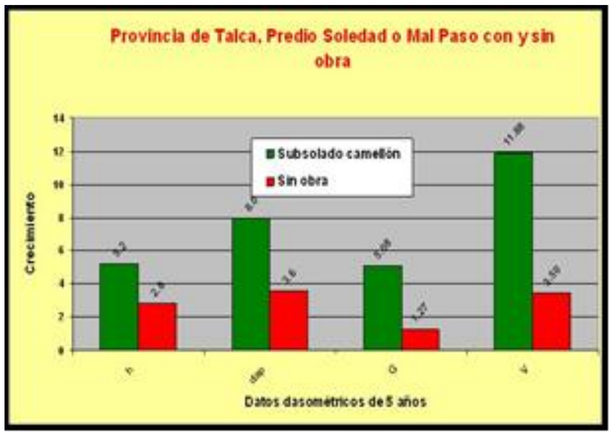


Figure 1: Comparison of growth variables in stands with subsoiling with ridge and without work.

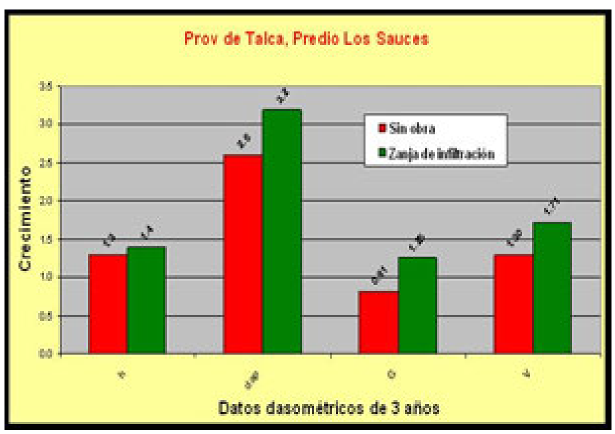


Figure 2: Comparison of growth in stands with infiltration ditch and without work.

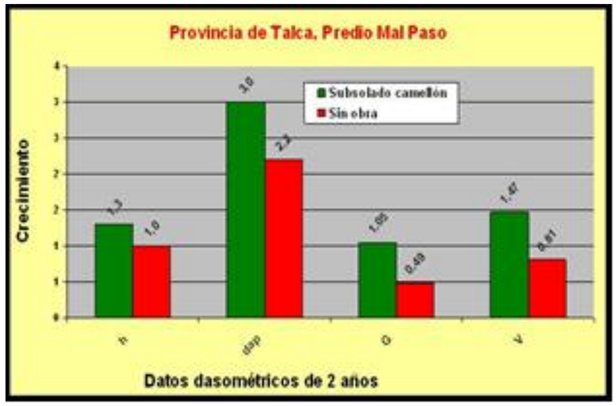


Figure 3: Comparison of growth in stands with subsoiling with ridge and without work.

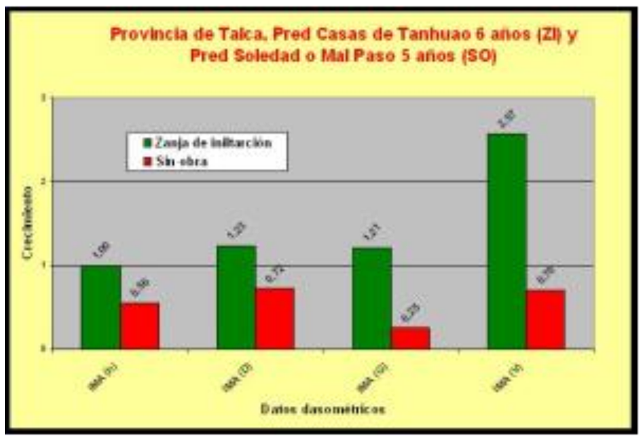
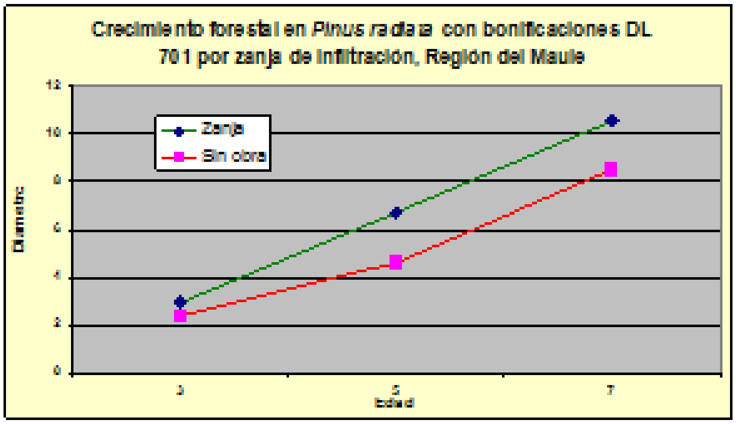


Figure 4: Comparison of growth in stands with infiltration ditch and without work.

In stands "comparable pairs" of the three provinces of the Maule region (Talca, Linares and Cauquenes) in which the response is measured with respect to the treatment of infiltration ditches, increases in diameter and height are observed up to 23 % and 40 %, respectively, in relation to plantations of similar age without application of the indicated treatment.

In stands "comparable pairs" where the response to subsoiling treatment with ridge is evaluated, increases in diameter and height of up to 122 % and 85 %, respectively, are registered in relation to plantations of similar age without application of soil conservation treatment and waters indicated.



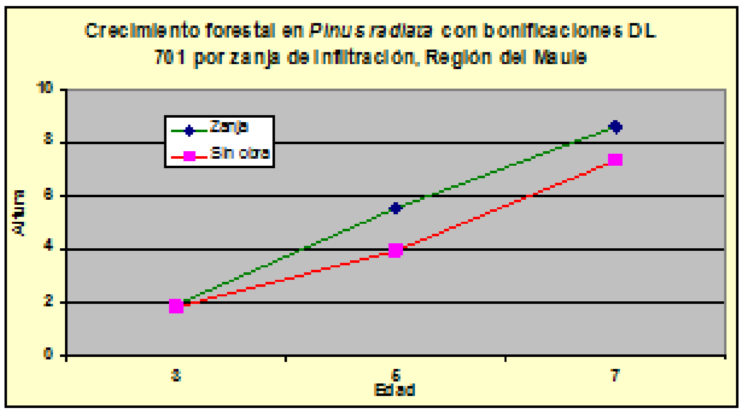
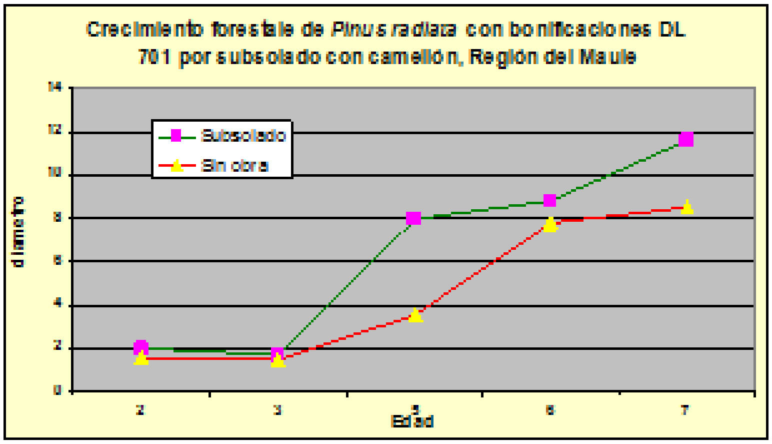


Figure 5 and 6: Growth of Pinus radiata in height and diameter with infiltration ditch and without soil conservation works



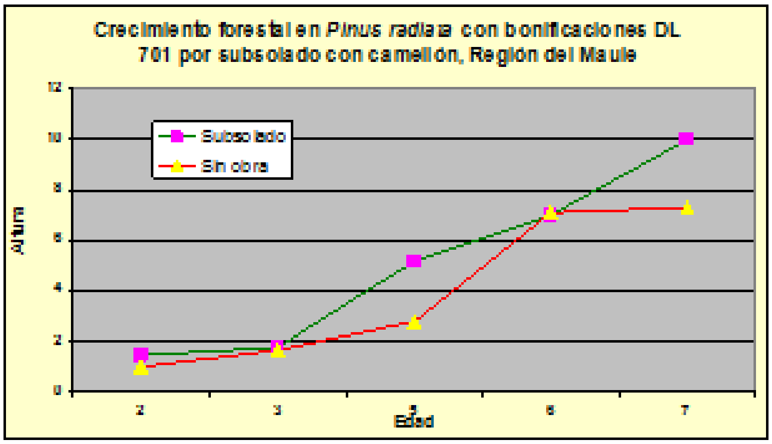


Figure 7 and 8: Growth of Pinus radiata in height and diameter with subsoiling with ridges and without soil conservation works

The evolution of the growth curves for height and diameter up to 8 years result clearly and clearly superior trends in infiltration ditches, while for subsoiling with ridges a clear tendency is observed in the variable diameter, although the variable height denotes superiority, registers greater variability depending on the period under analysis.

Discussion

At the level of the hydrographic basin, soil and water conservation treatments influence erosion control, regulate surface runoff and increase water infiltration in the soil, where higher water storage results in better water storage. forest site.

It should be borne in mind that the forest plantations of Pinus radiata (D. Don) in the study region, include stands with plantations between 2 and 8 years of age and that have a forest rotation between 22 and 24 years, in such a way as to maximize the income of the owners, so it is necessary to evaluate the projection of the increments in the variables of diameter, height and volume.

It is necessary to advance in the determination of volume increases according to type of products, based on soil and water conservation treatments and their effects on the productivity of forest sites with limiting edaphic factors.

Conclusions

The results of the evaluation indicate that the soil and water conservation treatments applied favorably influence the productivity of the forest site, where in the treatment of infiltration ditches there are increases in the diameter and height variables of 23 % and 40 % , respectively. In the treatment of subsoiling with ridges the increases in the diameter and height variables, the increases are even greater, of 122 % and 85 %, in both variables, respectively.

The valuable experience obtained recommends the joint implementation of soil preparation techniques oriented to the "plant" (for example: subsoiling with ridges) and soil and water conservation techniques oriented to the "river basin" system, (for example: ditch of infiltration), associated with afforestation or revegetation techniques in priority areas, which, incidentally, constitute the main soil and water conservation techniques, with a casuistic and integral approach.

The silvicultural recommendation is that in degraded and eroded soils, between the IV and XI regions of the country, reforestation should be carried out with or without soil preparation techniques and / or in conjunction with soil and water conservation techniques, that is to say, a sustainable forest management, where, it is possible to harmonize productivity of the soil, of the forestry site and hydric yield of the river basins.

References

Francke, S., Vargas, R., Tokugawa, M. Editions 1999, 2004 and 2009, 2017. *Erosion Control Manual*. 74 p. CONAF. JICA Basins Project, Santiago, Chile.

Francke, S. *et al.* 1999. Recovery of Degraded Soils within the framework of the new Forestry Development Law. 84p. CONAF, Santiago de Chile.

FONDEF. 2005. Practical Handbook for Management of Radiata Pine Plantations. 126 p. Concepción de Chile.

The Potential of Goji Berry Tree to Control Soil Erosion in Cameron Highlands, Malaysia

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Abstract

Agricultural activities in Cameron Highlands, Malaysia were believed to have contributed to the degradation of the highland's environment. Improper soil managements resulting from farming activities caused severe sedimentation of local rivers, dams and water reservoirs. Hence, a study was conducted at the Malaysian Agricultural Research and Development Institute (MARDI) Research Station, Cameron Highlands with the objective of intercropping Goji berry (GB) tree (*Lycium chinense*) to minimise soil erosion in vegetable farms. GB tree were cultivated according to different arrangements on the erosion study plot which was developed according to runoff plot design. Soil loss and surface runoff were quantified using stilling basin and tipping bucket systems. Results indicated higher soil loss in plot without Goji berry tree planted as compared to plot without GB, although their values were not statistically significant. In contrast, surface runoff for GB planted plots were significantly lower compared to the control. Overall results showed that cultivating GB on the flow pathway of the plot was the best treatment for reducing soil erosion and surface runoff.

Keywords: soil loss, surface runoff, Goji berry, Chinese Boxthorn

Introduction, scope and main objectives

Besides being a popular tourist destination, Cameron Highlands is also an important agricultural production area of Malaysia. Cameron Highlands alone supplies more than 90% of vegetables and flowers in the country. However, agricultural activities in Cameron Highlands were believed to have contributed to the degradation of the highland's environment. Improper soil managements resulting from farming activities caused severe sedimentation of rivers, dams and water reservoirs. Sedimentation was caused by movement of eroded soil from agricultural farms into these water bodies. The sedimentation has caused reduction in volume and flow competency of the dams. For example, a report in the local newspaper Sinar Harian (2013) indicated that the total accumulation of soil sediment at the load catchment area of Sultan Abu Bakar Hydroelectric Dam in Ringlet was 500 000 m^3 per year. This amount has reduced the reservoir's capability to store water from the original depth of 23-28 m to only 6-9 m. Deterioration of the highlands environment in Cameron Highlands was largely due to improper soil management that resulted in the sedimentation of local dams and water reservoirs. While the sedimentation caused significant loss of fertile agricultural soils, it also triggered the transportation of eroded soil into water bodies which reduced water storage and flow competency of dams. According to Waters (1995) the accelerated accumulations of sediments in aquatic ecosystems lead to a decline in surface water quality and biodiversity. Unfortunately, the soil erosion and the subsequent sedimentation of water bodies in Cameron Highlands are frequently aggravated by the excessive seasonal rainfall resulting in severe soil erosion, silting and water pollution. The situation becomes eminent because of the fragile ecosystems of steep land and mountainous terrain which can be regarded as environmentally sensitive areas. Therefore, as pointed out by Waters (1995), joint efforts by relevant authorities must be initiated to minimise land degradation specifically soil erosion caused by agricultural activities in slope lands of Cameron Highlands. Hence, a study was conducted at the MARDI Research Station, Cameron Highlands with the objective of using Goji berry tree (*Lycium chinense*) to minimise soil erosion in vegetable farm. Goji berry (GB) trees are deciduous woody perennial plants that can grow up to 3m tall. These plants are commercially grown in southern parts of China for their novelty and nutritional value. The whole fruit or “goji berry” are claimed to have numerous health benefits (Ong, 2011). The plant is extremely hardy, quick growing, drought-tolerant and resilient when pruned. Due to their extensive root systems, they were also planted to control erosion and prevent irrigated soils from desertification. Examination of these plants in Cameron Highlands confirmed their extensive and well-developed root systems (Figure 1).

Figure 1: (Top left) GB's roots close-up. (Bottom left) GB roots dug out from soil after 3 years. (Right) One year old GB’s roots. SOILS 2015 Proceedings, p.117-120

Methodology

Study plot and sampling technique

A study plot was established at the MARDI Research Station Cameron Highlands using methodology described from the book “Field measurement of soil erosion and runoff” by N. W. Hudson (Hudson, 1993). The erosion study plot consisted of 8 subplots measuring 2.5 m x 11.0 m (27.5 m^2) and subplots were separated by brick walls of 30 cm height (Figure 2). Each subplot consists of six vegetable beds and planted with cabbage. Soil is from Tanah Rata series, which has been classified as an Aeric Ultic Troaquod, which is loamy, siliceous and isothermic. The minerology is dominated by kaolinite, halloysite and gibbsite (Wan Abdullah *et al.*, 2001). It has low saturation, low CEC and acidic (Lim *et al.* 1987). Soil loss and surface runoff from the study was accounted using stilling basin and tipping bucket system, where the stilling basin will entrap the eroded soil and tipping bucket will record the amount of runoff generated from each subplot by using counter meter. Data of soil loss and surface runoff were quantified for every 10 days.

Figure 2: Erosion study plot in MARDI Cameron Highlands, Malaysia

Soil loss and runoff calculation

The concept of this system was adapted from the method used by Japan International Research Centre for Agricultural Sciences (JIRCAS, 1997) as reported by Wan Abdullah *et al.* (2003). For soil loss determination, samples of bed load and suspended load were quantified. For suspended load, the stilling basin from each subplot was cautiously stir using glass rod at 10cm depth. Water samples at 10 cm depth were collected using 25 ml pipette and transferred into small plastic container. These samples were taken to the lab and poured into empty crucible (w^0) and placed in the oven at 105 °C for 24 hours. After 24 hours has passed, the crucible weight was recorded in gram (w^1). Below is the formula to calculate the total weight of suspended load (***SL***).

$$\frac{w^0 - w^1}{25\text{mL}} = \boldsymbol{N}\ \text{gmL}^{-1}$$

$$\boldsymbol{L} = \boldsymbol{BL} + \boldsymbol{SL}$$

$$\boldsymbol{SL} = \boldsymbol{N}\ \text{gmL}^{-1} \text{ X volume of water in the stilling basin (mL)}$$

Bed load (***BL***) was collected by removing water from sediment collected in the stilling basin and weigh the whole amount. Total soil loss (***L***) from the subplot is;

Runoff from the subplot was measured using tipping bucket installed at the water outlet from the stilling basin. The tipping bucket is connected to a counter meter where every tip will raise the number in the counter meter and each tip will represent an average volume of 2.6 litre of runoff. Every sampling time, the number of tips was recorded and multiplied with the average volume of runoff.

Treatments

Treatments (Figure 3) consisted of three different types of Goji berry tree arrangements and a control (without GB). Treatment 1 was two rows of GB planted at the bottom end of the subplot perpendicular to the slope. Treatment 2 was four rows of GB planted similarly at the bottom end of the subplot. Treatment 3 was 2 rows of GB planted on flow pathways of the subplot. Treatment 4 (no GB) was only beds of cabbage without GB.

Figure 3: Top left: two rows of GB at the bottom of the plot at early stage; top middle: four rows of GB at the bottom of the plot and top right: 2 rows of GB at both sides of the plot (flow pathway). Bottom left, middle and right: Matured, ready to harvest GB shoots.

Statistical analysis

The mean values of soil loss and runoff were tested using a one-way analysis of variance (ANOVA) with a $P<0.05$ level of significance. All statistical tests were performed using SAS statistical software version 9.1. Differences of data at $p <0.05$ level were considered significant.

Results

Soil loss

Based on data collection, subplots with two rows of GB planted along both side of the edge (Treatment 3) were able to reduce soil loss about 43 %, while subplots with two (Treatment 1) and four (Treatment 2) rows of GB planted at the bottom end of the subplot were able to reduce soil loss about 30% and 28% respectively. However, when analysed using statistical analysis there was no significant different between all treatments (Figure 4).

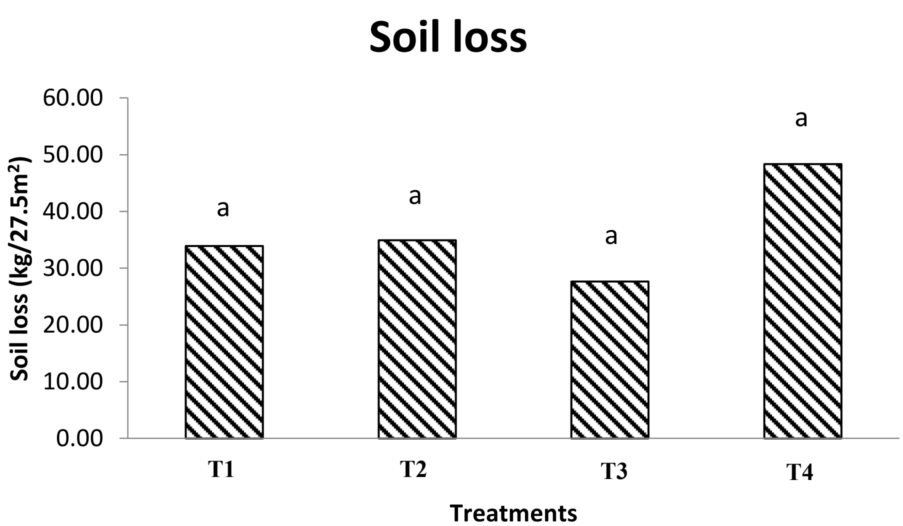

Figure 4: Mean soil loss for every treatment. Same letter over bar indicate no significant difference (P<0.05). SOILS 2015 Proceedings, p. 117-120

Surface runoff

In terms of surface runoff, there was a significant different among treatments when run through statistical analysis. Figure 5 indicates that Treatments 2 and 3 were significantly lower in terms of surface runoff compared to Treatments 1 and 4.

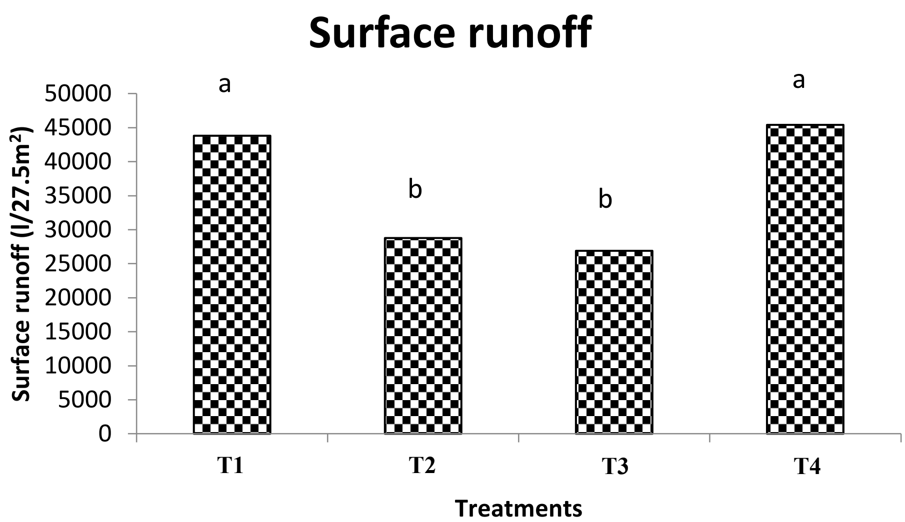

Figure 5: Means surface runoff for every treatment. Different letters over bar indicate significant difference (P<0.05). SOILS 2015 Proceedings, p. 117-120

Discussion

According to Hashim (2003) cropping system could determine the extent of soil erosion during a rainfall event. In this study, intercropping GB trees in the subplot resulted in less runoff and soil loss compared to subplot with no GB trees. In order to quantify a lesser soil lost, different arrangement of the trees must be employed. For example, by having GB trees cultivated on the flow pathways, the velocity of surface water was slower and resulted in lowest amount of soil loss. The pathways were acting as a sediment storage sites, trapping much sediments that were being transported by the runoff. Therefore, a proper arrangement of vegetation could reduce surface runoff and soil loss in sloppy agricultural lands.

Conclusions

In conclusion, it was found that Goji berry trees have the potential to reduce soil erosion on sloping farms in Cameron Highlands. However, the best planting arrangement of the tree need to be quantified so that the most effective overall reduction of soil loss and surface runoff could be achieved. A large-scale and a long-term study should be investigated. This is to observe the plant (GB) effectiveness in minimizing the soil loss and runoff in large-scale areas. As it is, our study indicated that GB tree could be used to reduce sedimentation problems in the rivers and dams in Cameron Highlands.

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Isa Ariffin, Mohd Salman Salehuddin, Gopi Managarai, Sef Belangok and Jamaludin Lan are greatly appreciated.

References

Bernama. 2013. Tasik Ringlet makin tenat, 60% dipenuhi mendapan. Available at: *http://www.sinarharian.com.my/rencana/tasik-ringlet-makin-tenat-60-dipenuhi-mendapan-1.217847*

Hashim, G. M. 2003. *Managing soil erosion and nutrient depletion*. MARDI, Serdang.

Hudson, N. W. 1993. Food and Agriculture Organization of The United Nations. Retrieved November 9, 2015, from FAO Corporate Document Repository: http://www.fao.org/docrep/t0848e/t0848e-08.htm#P877_79066.

Lim, J. S., Chan, Y. K., & Loh, K. F. 1987. Soils on Steep Land in Penisular Malaysia. Proceedings of the International Conference on Steepland Agriculture in the Humid Tropics (pp. 93-129). Kuala Lumpur: MARDI

Ong, H. C. 2011. Sayuran Khasiat Makanan & Ubatan 2. Utusan Kuala Lumpur: Publications and Distributors.

Sinar. 2013. Available at: http://www.sinarharian.com.my/rencana/tasik-ringlet-makin-tenat-60-dipenuhi-mendapan-1.217847

Wan Abdullah, W. Y., Aminuddin, B. Y., Salama, R. B., Cheah, U. B., Jamaluddin, J., & Osman, G. 2001. *Site description and project field activities in the Cameron Highlands*. Agrochemical Pollution of Water Resources (p 3-9). Canberra

Wan Abdullah, W. Y., S., A., & A.R, A. 2003. Design of Demonstration Plots and Their Equipment for Measurement of Runoff and Sediment Quantification. *Malaysian Journal of Soil Science*, 1-8.

Waters, T. F. 1995. Sediment in streams: sources, biological effects, and control. American Fisheries Society, Monograph 7, Bethesda, Maryland.

A possible approach to control soil erosion: natural farming

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Abstract

This paper reports the results of the experimental work of a comparative test between natural cultivation method and organic farming developed to evaluate the possible reduction of erosion risk of soil in the medium term. The 4-year experimental measures campaign was carried out by CREA in Central Italy. The physical and mechanical behavior of the soil was studied in both method, natural and organic gardening. The main chemical-physical characteristics of the soil were analyzed: oedometric parameters, dry bulk density, aggregate stability index, soil organic matter. The results obtained with the two cultivation methods, related to different parameters, were compared. In particular, from the processed data, the organic matter content of the soil (SOM) was higher in the natural garden, equal to 33.0 g kg^{-1}, compared to 17.0 g kg^{-1} of the organic vegetable one. The preliminary results obtained lead to affirm that the natural farming, contributing to the increase of the organic substance, protects the soil from erosion and instability and contributes to conserving water resources.

Keywords: Erosion, Natural farming, Organic agriculture, Medium-term monitoring, Sustainable soil

Introduction, scope and main objectives

Soil erosion by water and wind are most significant threat to global soils. Soil erosion causes the loss of surface soil layers containing organic and mineral nutrient pools, partial or complete loss of soil horizons and possible exposure of growth-limiting subsoil (FAO, 2017).

The last decades have been characterized by anthropic activities such as agriculture and industrial zootechny, urbanization and industrialization, land-use changes such as deforestation or improper grassland-to-cropland conversion, which have determined, in addition to climate changes, the degradation of chemical (pollutants and loss of organic substance), physical (reduction of structural stability, phenomena erosion, etc.) and microbiological (biodiversity reduction) characteristics of soils, which have had a negative impact on the quality of ecosystems. A cover of growing plants or other organic and non-organic residues that protects the soil surface from erosion should be maintained through implementation of appropriate measures. In this context, sustainable agriculture conserves, respects the environment and biodiversity and aims to develop production systems that protect and safeguard the soil from erosion and instability, helping to conserve water resources.

A loss of soil organic carbon due to inappropriate land use or the use of poor soil management or cropping practices can cause a decline in soil quality and soil structure and increase soil erosion. On the other hand, appropriate land use and soil management can lead to increased organic carbon and improved soil quality.

Soil organic matter (SOM) plays a central role in maintaining soil functions and preventing soil degradation. Soils constitute the largest organic carbon pool on Earth. In sandy soil, the interaction of organic matter with the mineral fraction increases the resistance to deformation and water retention. On the other hand, in clay and silty soil, the organic coating of mineral components reduces the formation of superficial crusts and cracks (Sposito, 1989). Soil structure and its stability play important roles in a variety of processes in the soil, such as erosion, water infiltration, root penetration, aeration, and mechanical strength. Cultivation and other tillage operations generally cause a continued decrease in the stability of aggregates, unless the organic-matter level in the soil is kept relatively high and mechanical manipulation of soil is performed at optimum moisture contents. To improve the soil structure stability of the agricultural soil, the most important treatment is the organic-matter administration (Beni *et al.*, 2012). Šimon, in 2008, studied the influence of long-term organic and mineral fertilization on soil fertility and demonstrated that agricultural management practices quantitatively and qualitatively influence soil organic matter.

It is in this context that the was born, between the end of the nineteenth century and the beginning of the twenties, of a new model of farm takes on importance, nature oriented, intended as a self-sufficient living organism, characterized by new cultivation techniques in synergyistic farming with nature. It was thanks to these principles that in the 80s the concept of synergistic cultivation and natural farming was born, elaborated by the naturalist Emilia Hazelip, developed this method based on agronomic practices mainly aimed at the fertility of soil and the consequent better health of the whole soil-microorganism-plant system, rather than the increase in productivity. Just like organic agriculture, but with more incisive measures, which are based on the lack of the techniques of agricultural land work and on the association of plants at least three different families (Hazelip, 2014; Beni *et al.*, 2018).

Methodology

The experimental research was conducted in farm located in central Italy, in Lazio region about 30 km North of Rome. The cultivation was carried out on raised beds, and as provided by synergistic agriculture, at least three botanical families were considered, in fact the system is based on the concept of soil self-fertility. At the fourth year of life of the synergistic garden, a comparison test was set up between the synergistic cultivation method and the organic farming.

In the natural farming, by arranging them in a completely randomized way, the following a polycultural rotation was carried out with the following species of vegetable plants have been associated: tomato, roman lettuce, savoy cabbage, parsley, red beetroot and courgette. The same crops were planted in the organic garden, placing them in specialized rows. The experimental period was carried out for 4 years. The plants were purchased in the nursery and then transplanted on the synergistic raised beds and on the organic farming at the beginning of the experiment. The studies were carried out considering, in each of the two vegetable gardens, nine plants for each species taken randomly. The results obtained with the two cultivation methods, related to different parameters, were compared.

The texture of soil is classified as Loam (USDA, 2017) and characterized by medium contents of organic matter and total N. After 4 years tests were carried out to evaluate the effect of the two different types of agronomic management. In particular, at the beginning of the experiment a chemical characterization of the soil was carried out (MIPAF, 1999). Physical tests have been carried out to. Soil organic matter (SOM) was calculated by multiplying the organic carbon content by the factor 1.724.

Monoaxial compression test on soil (Lambe and Whitman, 1969) was detected with an oedometer apparatus (Controls, mod. T302) under vertical loads (10 and 200 daN) for evaluating the plastic soil deformation during a 24-h test. Dry bulk density was measured by collecting samples of soil with a corer (100-cm^3 sample ring; internal diameter 5.0 cm, length 5.1 cm and wall thickness of 0.15 cm) at a depth of 0.05–0.10 m. These samples were dried until reaching a constant weight.

Moreover, structural stability index (SSI) was calculated by means of humid with soil aggregates dried at 55 °C placed in water on horizontal oscillator for 1 hour and subsequent determination of the weight of the stable residual aggregates on a 2 mm sieve. Available water content (AWC) was measured with Richards' plate.

Results

In this study, after 4 years of agronomic management, the parameters were investigated, whose results are shown in tables 1 and 2.

Table 1: Main physico - chemical characteristics of the initial soil

PARAMETER	UNIT OF MEASURE	VALUE
pH		7.6
Sand	%	24.8
Silt	%	49.2
Clay	%	26.0
Texture (USDA)		Loam
Organic Carbon	g kg^{-1}	7.8
Soil Organic Matter	%	1.7
Total Nitrogen	%	0.12
C/N		6.7
K_2O exchange	mg kg^{-1}	638.0
P_2O_5 available	mg kg^{-1}	49.46
CEC	cmol kg^{-1}	31.41
Electric conducibility	µs cm^{-1}	240.0

Table 2: Main mechanical parameters of soil natural farming and organic agriculture

PARAMETER	UNIT OF MEASURE	VALUE	
		NATURAL	ORGANIC
SOM	g kg^{-1}	33.0	17.0
Monoaxial compression 10 daN	mm	7.5	10.0
Monoaxial compression 200 daN	mm	2.5	5.5
Dry bulk density	t m^{-3}	1.1	1.2
Aggregate stability index	g kg^{-1}	680.0	550.0
AWC		37.0	31.0

Discussion

The analysis of the results obtained showed that the amount of SOM present is greater in the thesis natural farming soils (33.0 g kg^{-1}) respect to those of the organic garden (17.0 g kg^{-1}), about 50 %.

The greater amount of organic matter increases the colloidal properties of the soil and consequently its binding power. This is confirmed by the structural stability index: in natural farming were observed highest result compared to organic agriculture of about 20%. The oedometric test (monoaxial compression) shows lower values in natural farming, thus confirming the major resistance to soil deformation.

Conclusions

The work present and discuss the preliminary results of an experimental research conducted over the medium term of 4 years, in Italy in the Lazio region, near the city of Rome.

The results obtained, even considering the importance of the pedoclimatic reality of the area where experimental field was carried out, show the potential of this type of agronomic technique. It is still not much known and used, and is often considered a curiosity, while the results obtained are positive. The first experimental data obtained allow to be able to affirm the effectiveness of the natural farming technique, with respect to organic agriculture, as it contributes to the increase of the organic matter and therefore is able to protect the soil by reducing the erosion and instability risks, contributing to the conservation of water resources. This agronomic management applies above all in the family farm, also in accordance with the provisions of the UN 2030 Agenda for sustainable development with its objectives.

References

Beni C., Servadio, P., Marconi, S., Neri, U., Aromolo, R. & Diana, G. 2012. Anaerobic Digestate Administration: Effect on Soil Physical and Mechanical Behavior*. Communications in Soil Science and Plant Analysis.*

Beni, C., Socciarelli, S., Fontana, C., Neri, U. & Prado, R.P. 2018. *Synergistic Agriculture Vs Organic Farming. First Results*. Atti XLVII Convegno SIA L'Agronomia nelle nuove Agriculturae.

Hazelip, E. 2014. *Agricoltura sinergica*. Terra Nuova. Firenze.

FAO. 2017. *Voluntary Guidelines for Sustainable Soil Management*. Food and Agriculture Organization of the United Nations. Rome, Italy.

Lambe, T.W. & Whitman, R.V. 1969. *Soil mechanics*. New York: John Wiley & Sons.

MIPAF (Italian Ministry of Agricultural Policies). 1999. *Metodi ufficiali di analisi chimica del suolo*. D. M. del 13/09/1999, Gazzetta Ufficiale n. 248, 21/101999 supplemento ordinario n. 185.

Šimon, T. 2008. The influence of long-term organic and mineral fertilization on soil organic matter. *Soil and Water Research*, 3(2): 41–51.

Sposito, G. 1989. *The chemistry of soils*. Oxford: Oxford University Press.

USDA - Soil Science Division Staff. 2017. *Soil survey manual*. C. Ditzler, K. Scheffe, and H.C. Monger (eds.). USDA Handbook 18. Government Printing Office, Washington, D.C.

Conservation practices to reduce soil erosion in hillsides cultivated with plantain (*Musa* AAB)

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AGROSAVIA

Abstract

Hillside soils cultivated by plantain producers in the department of Cundinamarca (Colombia) have a high susceptibility to water erosion. Considering the above, in the municipalities of La Vega and Viotá (Cundinamarca) the following conservation practices were validated: 1. Tracing furrows with level curves; 2. Planting maize and beans as living coverage; 3. Incorporating organic matter (OM), and 4. Using biofertilizers. The previous practices allowed reducing in threefold the loss of soil compared to farms without conservation practices. The level curves contributed to decreasing soil loss due to its opposition effect to the movement of runoff water. Further, coverage plantation and management protects from the direct impact of raindrops, decreasing the speed of runoff water favoring water infiltration. Soil planted with plant cover (beans or maize) showed high microbial activity and improved physical properties such as bulk density and hydraulic conductivity, in contrast to traditionally managed soil by producers. Therefore, these practices are shown as an alternative to conventional management, promoting an improvement in the physical and biological soil conditions.

Keywords: living coverages, rain erosion, level curves, organic matter, biofertilizers

Introduction

Soil degradation processes are dynamic, growing and cause global concern as these affect the quality of the resource, and they become one of the challenges for the sustainable management of these in the short and medium terms (Torres *et al.,* 2015). In this sense, 40 % (equivalent to 45 379 058 ha) of the continental and insular surface of Colombia shows some degree of soil degradation due to erosion (IDEAM and UDCA, 2015). Among the soil practices proposed to reduce erosion, tracing furrows with level curves is employed; this is a simple practice where other regular tasks carried out to the crop such as cleaning and fertilization are done in the same direction of the furrows, so these oppose to the passage of rain that does not infiltrate the soil, decreasing its speed, and soil and nutrient drag (FHIA, 2011). Likewise, planting live coverage such as intercropping with plantains avoids competition from weeds or unwanted plants for nutrients, and improves the physical soil conditions (Ruiz and Molina, 2014). Crop rotation, management of crop residues and the type of crop used are some of the practices that must be taken into account in order to promote changes in the most sensitive OM constituent fractions. Nonetheless, to establish the microbial soil activity (MSA) becomes a fundamental function to estimate the biological activity of agroecosystems. Respiration is one of the measures used to estimate the MSA, therefore, it is very common to use this index to evaluate changes in biomass and the influence these have on the MSA, regarding both the edaphoclimatic conditions and the activities of anthropic origin for the management of productive systems (Zagal *et al.*, 2002).

Plantain producers in the municipalities of La Vega and Viotá (Cundinamarca, Colombia) have little information on the implementation of soil conservation practices as a complement to crop management, and therefore, are unaware of their benefits. Based on the above, the aim of this research was to validate with farmers, soil conservation practices in hillsides planted with plantain through a productive and sustainable vision including social, economic and environmental conditions.

Methodology

For the evaluation of different soil conservation practices, two plots cultivated with plantain were established in the department of Cundinamarca (Colombia), one in the municipality of Viotá located at 4°26'30.62" N and 74°28'11.32" W, altitude of 1,225 meters above sea level, average temperature of 25 °C, 1 473 mm of annual precipitation and 80% of relative humidity; and the second plot was established in the municipality of La Vega located at 5º2'14.00" N and 74º18'2.60" W, altitude of 1 699 meters above sea level, average temperature of 20.1 °C and cumulative rainfall of 735 mm. In both plots, reference controls were established (T0), which consisted in carrying out practices traditionally used by farmers (planting with herbicide applications and without level curves or biological and organic fertilization) to be contrasting with the following conservation practices (T1):

1. **Establishment of the crop with level curves and triangle planting** by using a type "A" level or gantry level built in the productive unit (Guzmán, 2012).
2. **Application of organic matter**. 2 kg plant^{-1} of OM was applicated in planting, six and twelve months after planting (MAP).
3. **Use of biofertilizers**. 20 g of commercial arbuscular mycorrhizal fungi (AMF) was incorporated into the soil (>230 spores g-^{1} of the genera *Glomus, Acaulospora, Scutellospora,* and *Entrophospora*). Nine MAP, root samples were taken in both treatments to identify colonization percentage.
4. **Plant cover management and conservation plan**. Sowing of a secondary crop between plantain row: A) La Vega, a row of common shrub bean (*Phaseolus vulgaris*) of the variety Calima was scythed and arranged as a cover. B) Viotá, maize (*Zea mays*) of the variety ICA V305; three rows with 0.30 meters between plants.

Runoff plots

The evaluation of soil loss was carried out in a period of three months (September to November/2017), using the methodology of "Runoff plots" in treatment 0 and 1. Both treatments had an area of 2 010 m^2 and a slope of 55 %. After heavy precipitation occurred (> 12.5 mm), sampling was carried out. Each sample was transferred to a 1 000 cm^3 beaker. 95 percent of sulfuric acid (one drop per 50 mL suspension) was added. It was allowed to settle for 24 hours. Subsequently, the excess water was discarded until a minimum was left with the sediments flocculated in the bottom of the beaker. The excess water was separated from the sediments by filtration. The sediments in the filter paper were taken to an oven at 105 °C for 24 hours for drying. The sediments were weighed and with the volume (850 cm^3) of each sample, the density of suspended sediments (g cm^{-3}) was established. The soil collected in the collector channel was submitted to a temperature of 105 °C for 24 hours. Subsequently, it was weighed and the corresponding calculations using the following equation were carried out:

$$E = 1x10^{-4} \, x \, A \, x \, Ps + (Ds \, xVs)$$

Where: E = Soil loss; A = Plot area in m^2 = 12 m^2. Ps = Soil weight coming from the gutter in g; Ds = Sediment density in the can (g cm^{-3}); Vs = Volume of the runoff in the can (cm^3).

Microbiological soil activity (MSA)

100 grams of soil were taken at field capacity at a depth of 20 cm per sample in three different plots (Figure 1). Sample processing was carried out employing the methodology of Anderson (1982).

Figure 1: Plots for the evaluation of microbial activity: **Fallow** (top left); **T1,** conservation practice (top right) and **T0**, traditional management carried out by producers (bottom)

Physical parameters

Soil samples were taken with the "known volume ring" method to establish bulk density, hydraulic conductivity, and moisture retention. Likewise, a disturbed sample per treatment was taken to determine stability index (SI), mean weighted diameter (MWD), mean geometric diameter (MGD), and fine (FA) and extreme aggregates (EA).

Results

From the results obtained from the runoff plots, it was possible to identify a higher average soil loss in T0 (0.12 t ha^{-1}) compared to T1 (0.04 t ha^{-1}), evidencing the positive effect of soil conservation practices on the decrease of soil loss by runoff. Moreover, it had a higher colonization percentage of AMF in T1 (29.3 %) vs T0 (5 %).

The scenario that showed the highest C-CO_2 mineralized was the fallow plot with an average of 2256.10 µg C-CO_2 gss^{-1} followed by T1 with an average of 1 863.42 µg C-CO_2 gss^{-1}. In the scenario under T0, the lowest MSA values (930.73 µg C-CO_2 gss^{-1}) were found.

Greater bulk density was found in the soil of T0 in comparation with T0 and therefore, less movement of the subsurface water of the soil (T1= 2.05 vs T0= 18.7 cm h^{-1}), considered moderate if it is compared with the rapid mobility of water in treatment 1. The physical parameters estimated in the soil of both treatments can be observed on table 1.

Table 1: Indices to characterize structural stability and percentage of mesopores and micropores

Parameter	T1	T0
Stabilization index (SI)	90.31	55.89
Fine aggregates (FA)	33.61	18.81
Extreme aggregates (EA)	52.55	64.14
Mean weighed diameter (MWD)	1.32	1.91
Mean geometric diameter (MGD)	0.73	1.32
Mesopores	8.90	7.50
Micropores	30.80	39.60

Discussion

Soil physical properties showed favorable values in T1 in comparation with T0 in parameters as loss of soil, aggregate stability, porous space and hydraulic conductivity; these results are agreeing with it reported by Lozano *et al.* (2010), who mentions that these practices improve moisture retention capacity in the root zone, releasing water and nutrients to the roots of the plant.

The MSA results in fallow are possibly due to the resting time underwent (five years without intervention). Additionally, during the sampling in the fallow area the presence of *Eisenia foetida* was evidenced, an organism that accelerates the decomposition of organic waste, making nutrients more available and improving physical properties of the soil (Zapata *et al.,* 2016). In La Vega plot where bean was sowed (a legume that is associated with bacteria of the genus *Rhizobium* spp.), MSA increased (Yáñez *et al.*, 2017), in contrast to the production scenario that showed a decrease in MSA. This occurred because the superficial soil layers were exposed to the adverse climatic conditions because they do not have any type of coverage, tending to show nutrient loss processes due to washing and/or some type of water or wind erosion (Sanclemente, 2009). Similar results were obtained in the samples from the plot in Viotá, where the microbial activity measured as respiration, was higher for the scenario with conservation practices with 255 µg C-CO_2 gss^{-1} compared with the conventional management scenario, where the activity was 45 µg C-CO_2 g^{-1}.

In relation to the use of mycorrhizae, the roots colonized by these fungi increased their capacity to absorb certain mineral nutrients, being specifically effective in the assimilation of phosphorus. The colonization of the mycorrhizae produces physical, biochemical and physiological changes in the colonized roots that lead to a better general state of the plant, and contributes to alleviating situations of abiotic and biotic stress (Barea *et al.*, 1997).

Conclusions

Soil conservation practices in hillsides cultivated with plantain allowed reducing soil erosion by 300%, increasing its microbial activity, improving its physical properties, and allowing a greater water movement and better aeration of the root system.

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References

Anderson, J.P. 1982. Soil respiration. p. 831-871. Number 9. In A.L. Page, R H. Miller and D.R. Keeney (eds.), *Methods of soil analysis, Part 2. Chemical and microbiological properties.* 2nd ed. Soil Science Society of America, Madison, Wisconsin, USA.

Barea, J., Azcón, C. & Azcón, R. 1997. Interactions between mycorrihizal fungi and rhizosphere microoganisms within the context of sustainable soil-plant systems. In: AC Gange and VK Brown. (Eds), *Multitrophic interactions in terrestrial systems.* Oxford: Blackwell Science, pp. 65-67.

FHIA (Fundación Hondureña de Investigación Agrícola). 2011. *Guía sobre prácticas de conservación de suelos.* La Lima, Cortes, Honduras: FHIA. Available at: http://www.fhia.org.hn/dowloads/guia_conservacion_de_suelos.pdf.

Guzmán, G. 2012. *Conservación de suelos: Cómo trazar curvas a nivel.* MAG. Available at: http://www.mag.go.cr/bibliotecavirtual/AV-1226.pdf.

IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales), U.D.C.A (Universidad de Ciencias Aplicadas y Ambientales). 2015. *Síntesis del estudio nacional de la degradación de suelos por erosión en Colombia.* Bogotá. IDEAM-MADS. Available at: http://documentacion.ideam.gov.co/openbiblio/bvirtual/023648/Sintesis.pdf.

Lozano, Z., Romero, H. & Bravo C. 2010. Influencia de los cultivos de cobertura y el pastoreo sobre las propiedades físicas de un suelo de sabana. *Agrociencia, 44*: 135-146.

Ruiz, E. & Molina, D. 2014. Beneficios asociados al uso de coberturas leguminosas en palma de aceite y otros cultivos permanentes: una revisión de literatura. *Palmas*, *35*(1): 53-64.

Sanclemente, Ó. 2009. *Efecto del cultivo de cobertura: Mucuna pruriens, en algunas propiedades físicas, químicas y biológicas de un suelo Typic Haplustalfs, cultivado con maíz (Zea mays L.) en zona de ladera del municipio de Palmira, Valle.* (PhD tesis, Universidad Nacional de Colombia, Sede Palmira).

Tórres, O., Sánchez, R., Otero, J., Cocomá, N. & Gómez, C. 2015. *Protocolo para la identificación y evaluación de la degradación de los suelos por erosión.* Bogotá: IDEAM-U.D.C.A. Available at: http://www.andi.com.co/Ambiental/Documents/Protocolo-erosion.pdf.

Yáñez, A., Gallegos, G., Medina, D. & Galindo, M. 2017. *Recuperación de Rhizobacterias del Cultivo de Frijol (Phaseolus vulgaris)* (Linneo) *de San Andrés Tlalamac, Estado de México.* Mexico.

Zagal, E., Rodríguez, N., Vidal, I. & Quezada, L. 2002. Actividad microbiana en un suelo de origen volcánico bajo distinto manejo agronómico. *Agricultura Técnica, 62*(2): 297-309.

Zapata, I., Martínez, L., Posada, E., Gonzales, M. & Saldarriaga, J. 2016. *Efectos de la lombriz roja californiana (Eisenia foetida), sobre el crecimiento de microorganismos en suelos contaminados con mercurio de Segovia, Antioquia.* Available at: https://revistas.unimilitar.edu.co.

How is soil erosion evaluated in the land capability systems used in Brazil?

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Abstract

In order to advise farmers on the importance of soil erosion control it is relevant to evaluate soil erosion risks and to recommend the proper conservation practices. In Brazil two systems are used to evaluate land capability or agricultural suitability, commonly resulting in different interpretations. The objective of this work is to compare those systems, and their approaches to evaluate soil erosion, and to advise on a policy to be used by Brazil toward implementing regulations to reduce soil erosion. The two systems were compared as to the attributes taken in consideration to evaluate soil erosion, agriculture conservation practices, and the application of each system. As main findings, it is clear that both are relevant tools for land planning and recommendation of practices for controlling of soil erosion. However, they are based mainly on a subjective interpretation of qualitative attributes of soils and landscape features. Brazil should define a system and normative to be applied nationwide and according to the survey objective; at small scales for regional planning or at the level of watersheds and rural properties. Plus, a national data base on soil erosion, according to the practices adopted in each region, is required to validate the recommendations.

Keywords: Land capability, agricultural suitability, SAAAT, soil attributes, intensive agriculture, land usage

Introduction, scope and main objectives

Land capability systems are generally developed to integrate the main factors affecting the potential of soils and landscapes for agricultural usage. In Brazil, two main systems are used. The most commonly adopted is the System for Evaluation of Land Capability for Agriculture (in Portuguese represented as SAAAT), and it was developed by Ramalho and Beek (1995), with the first edition in 1978. The SAAAT had as main objective to support the interpretation of soil surveys, at a small scale, for regional and national planning and development of agriculture. In order to rating the agricultural conditions of the soils and landscapes, the following limiting factors were considered: deficiency of fertility, deficiency of water, excess of water, susceptibility to erosion, and potential of usage for agriculture machinery. Three levels of land management are considered in this system, based on economic and technological investments by the farmers, identified as A – low, B – medium, and C – high.

The second system is an adaptation to the Soil conservation survey handbook (Norton, 1939) and Land capability classification (Klingebiel and Montgomery, 1961), and the latest edition of the "Manual for utilitarian land evaluation and classification according to the usage capability system" was published in 2015 by Lepsch *et al.* This system also takes in consideration soil erosion as an important factor, however the farmer is presumed as having an advanced technological level.

The objective of this work is to compare those systems, and their approaches to evaluate soil erosion, and to advise on a policy to be used by Brazil toward implementing regulations to reduce soil erosion and, consequently, losses of agricultural productivity.

Methodology

The conceptual rules and methods of each system were compared as to the attributes taken in consideration to evaluate soil erosion, agriculture conservation practices recommended to the farmers, and a short historical background and application of each system. Tables were elaborated from the descriptive attributes used in the SAAAT to evaluate soil erosion susceptibility (Table 1), as well as the main conservation practices listed in the system (Table 2). The main concepts of the utilitarian land capability system are highlighted.

Results

The SAAAT started to be used more intensively in the 1970 - 1980s, with the advance of soil surveys of Brazilian States, which had a low level of detail, usually at scales around 1:750.000 or smaller. The attributes used to evaluate soil erosion are mainly qualitative, and associated to climate, soil properties and relief, where the slope classes are semi-quantitative. They are summarized at table 1.

Table 1: Attributes used to evaluate soil erosion in the SAAAT, Ramalho and Beek (1995)

Climate	Soils	Relief	Slope classes (%)
Amount of precipitation	Texture classes and gradient B/A	Plain to mountainous	0-3
	Structure		3 – 8
	Soil permeability	Extension and form of slopes	8 – 13
Annual rainfall distribution	Soil depth		13 – 20
	Water retention capacity	Microrelief	20 – 45
	Limiting layers, stony		Above 45

The erosion control methods recommended to farmers according to the technological levels (B or C) are also broadly stated in the SAAAT (Table 2).

Table 2: Erosion control methods recommended to farmers according to the technological level (B – medium; C - high) and degree of limitation, in the SAAAT (Ramalho and Beek, 1995).

Class 1 – Level B and C	Class 2 – Only Level C
Minimum tillage	Terracing (level, graded, bench)
Mulching or bundles of crop residues	Runoff channels, trenches
Level and contour plowing	Individual basins
Alternating weed removal	Deep ploughing, subsoiling, superficial disc harrowing
Cover crops, grass strips	Permanent vegetation breaks
Contour bunding, buffer strips	Gully control practices
Crop rotation, strip cropping, intercropping	No-tillage

In the SAAAT the land is also classified according to levels of conservation practices required, from C1 to C4. For the first level (C1), simple vegetative practices (Class 1, Table 2) are sufficient and the erosion susceptibility is defined as null to slightly. The intensity of practices increases progressively and at C3, the limitation is moderate to strong and mechanical practices are required (Class 2, Table 2). In the last level, C4, there are no practices recommended and the land should be left for preservation of flora and fauna.

The utilitarian land capability system was established by Lepsch *et al.* (2015) as a technical and interpretative classification, based on potentialities and limitations of the land, with emphasis in the susceptibility to erosion and conservation practices required for agricultural usage. Reproducing the concepts in the original publications - Soil conservation survey handbook (Norton, 1939) and Land capability classification (Klingebiel and Montgomery, 1961), Lepsch *et al.* (2015) adopted the classification in three groups (A, B, C); eight classes (I to VIII); and four subclasses (*e, s, a, c*), where "*e*" is used to represent erosion risks. The group A includes classes I to IV and the land is considered proper for agriculture usage, with the limitations and requirement of conservation increasing progressively toward more complex practices, until perennial crops should be the only usage for class IV lands. Group B includes land not suitable for crops and recommended for pasture, silviculture, and preservation of fauna and flora; and the risk of erosion is one of the main factors to define the classes VI and VII. The last group (C) has only one class (VIII) and is defined as - land not suitable for agriculture, pasture or silviculture and only useful for fauna and flora conservation or recreation.

The erosion factor is evaluated by the attributes: slope (length and degree), textural abrupt change among surface and subsurface horizons, low permeability, sandy textures, type of hydric erosion occurring on the land (sheet, rill, interril and gully), and wind erosion.

Discussion

The SAAAT was mainly used to support interpretation of reconnaissance soil surveys of various states of Brazil, done primarily by the National Service of Soil Survey and Conservation (identified as SNLCS), current Embrapa Soils. Thus, due to the small scale of the survey the maps produced using this system were also less detailed, and in many areas of Brazil, such as in the Cerrado region, a biome with a highly intensive grain production, the interpretation of the agriculture potential using SAAAT is deficient. Plus, the system requires upgrading in terms of the new technologies available to the farmers in the country. For instance, the Cerrado is one of the areas where the zero-tillage conservation agriculture (ZT/CA) and the integrated crop-livestock-forest (iCLF) systems increased enormously since the end of the last century, largely due to the advancements of Brazilian agriculture. These technologies are efficient as conservation practices to control soil erosion, among other benefits, and they are not taken in account in the SAAAT system. On another hand, practices such as deep ploughing and subsoiling are the subject of critics due to the intense modification on soil properties, affecting soil biodiversity, and in many cases not proven to be effective in a long term.

The utilitarian land capability system adapted by Lepsch *et al.* (2015) is recommended when detailed soil surveys are available (maps with scales larger than 1:50 000), in order to produce maps that could be useful for the planning and management of the land at the farmer level. Conservation practices are divided in three groups, vegetative, edaphic and mechanical, with the last being more complex and requiring detailed information, such as topographic maps with scales of 1:5 000 or higher. As a consequence, only a few states of Brazil adopted this system as the base for utilization and planning of land for agriculture and incorporated the system into laws. As an example, the São Paulo State Decree no 41 719, of 16th April of

1997, specifies "*the concepts and technical criteria that will direct the works of evaluation of* ***land capability classes of soil usage*** *and elaboration of projects to define technologies for conservation of agricultural soils …*". As in the SAAAT the decision on limitations, including erosion risks, are mainly subjective, and they are not validated by experimental results upon the implementing of the conservation practices recommended.

Since there is no common policy on which system should be adopted nationwide, different sectors of the federal and state governments may use one or another method for interpretation of soil surveys and establishment of programs toward soil sustainability, and soil erosion control. Even, some states developed their own adaptations of the agricultural suitability systems, such as in Santa Catarina State. The results in a non-unified data base all over the country.

Conclusions

The SAAAT and the Utilitarian land capability systems provide a convenient framework for assessing the soil attributes and landscape features, in order to plan the various land usage types and to recommend conservation practices for controlling of soil erosion. However, both result mainly in a subjective and qualitative interpretation, depending strongly on the knowledge of the surveyor.

As police to advance in the subject of soil erosion control, Brazil should define criteria and norms to be applied nationwide and according to the objective of the survey. That is at a small scale for regional planning or at the level of watersheds and rural properties.

In both cases, a national data base on soil erosion, according to the practices adopted in each region, should be implemented in order to validate the technologies recommended for each land capability or agricultural suitability classes.

Acknowledgements

Federal Rural University of Rio de Janeiro, Soils Department. Embrapa Soils. Lepsch, I.

References

Assembleia Legislativa do Estado de São Paulo. 1997. *Decreto Nº 41.719, de 16 de abril de 1997.* Available at: https://www.al.sp.gov.br/repositorio/legislacao/decreto/1997/decreto-41719-16.04.1997.html [accessed 09.03.19].

Klingebiel, A.A. & Montgomery, P.H. 1961. *Land capability classification*. USDA, Handbook 210, U.S. Government Printer Office, Washington D.C.

Lepsch, I.F., Espindola, C.R, Vischi Filho, O.J. & Siqueira, L.C.H.D.S. 2015. *Manual para levantamento utilitário e classificação de terras no sistema de capacidade de uso*. Brazilian Soil Science Society, SBCS, 170pp.

Norton, E.A. 1939. *Soil conservation survey handbook*. USDA, Soil Conservation Servce, Miscellaneous Publication No. 352. U.S. Government Printing Office, Washington, D.C.

Ramalho Filho, A. & Beek, K.J. 1995. *Sistema de avaliação da aptidão agrícola das terras.* 3. ed. rev. Rio de Janeiro: Embrapa-CNPS, 65 pp.

Effectiveness Analysis of Agricultural BMPs by SWAT Model for Appropriate Control of Sediment Yield on the Kalaya Catchment in the North of Morocco

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Keywords: SWAT model, agricultural BMPs, sediment yield, Kalaya catchment, North of Morocco

Introduction

Soil erosion is a worldwide challenge for sustainability of agriculture (Kumar and Pani, 2013). It can decrease rooting depth, soil fertility and organic matter in the soil and plant available waterreserves (Lal, 1987). The methods for reducing sediment loading to streams in agricultural landscapes have been studied extensively (Jang *et al.*, 2013). As a result, agricultural conservation practices, which often are called best management practices (BMPs) (Logan, 1993), are effective ways to reduce erosion, nutrients, pesticides, animal waste, and other pollutant loadings from their source area to receiving water bodies within the complex processes (Wu *et al.*, 2014). However, soil loss and sediment discharge to waterbodies can be prevented and mitigated by best management practices (BMPs). To reduce the soil erosion intensity, it is required to clarify the sources zones of sediment yield where soil conservation works have to focus on. The model selected for this work is the Soil and Water Assessment Tool (SWAT) which is one of many models widely used to assess soil erosion risk and simulate conservation measures efficiency. In fact, the objective of this work is to evaluate the effects of different agricultural BMPs on sediments using SWAT model in the Kalaya river basin in order to recommend the most appropriate one.

Methods

Our study focused on the Kalaya catchment (3838 ha) situated in the North of Morocco (Briak *et al.*, 2016a), which characterized by sub-humid Mediterranean climate, a wet winter and a dry summer. The agriculture is the primary land use of the watershed, accounting for approximately 77 % of the available acres. In fact, agricultural BMPs implementation and source reduction in various combinations were tested using the SWAT model to investigate various sediment load reduction strategies in the basin. The model wascalibrated and validated using observed data; the performance of the model was evaluated using statistical methods and the total soil erosion rate was estimated by this model in the study area (Briak *et al.*, 2016b). However, we concentrated on the representation of three interesting and most usable practices by the SWAT model: contouring, strip-cropping and terracing (Briak *et al.*, 2019). The general parameters of the model have been modified to reflect the implementation of three different BMPs. The modification of these parameters was based on previous research and modeling efforts conducted in watersheds and presented in Neitsch *et al.* (2005) and Arabi *et al.* (2007). Finally, the efficiency of different agriculture management practices to decrease soil erosion was evaluated.

Results & discussion

Resulting sediment yield (Briak *et al.*, 2019) were compared with the result of simulation of the baseline scenario (existing conditions) (Briak *et al.*, 2016b). In fact, effective measures to reduce sediment losses at the watershed level are organized according to their effectiveness, and these are terracing (28 % reduction and the value is 15t/ha/yr) and strip-cropping (9 % reduction and the value is 9 t/ha/yr). On the other hand, measurements performed by the contouring are inappropriate for the study area because they have contributed to increasing the soil erosion (more than 31% of losses and the value is 17 t/ha/yr more than existing conditions). The mean annual values of sediment yields obtained for scenarios with and without BMPs were compared to assess the effectiveness of BMPs (Figure 1). Among all other practices, terracing were the most effectiveBMPs for reducing sediments (Briak *et al.*, 2019). This indicates that the use of terracing on agricultural land can potentially make improvements marked the control and limitation of soil erosion which is consistent with previous research (Bracmort *et al.*, 2006; Arabi, *et al.*, 2007). These results would provide useful information for targeted management to implement the most effective BMPs within the watershed and/or in other similar watersheds.

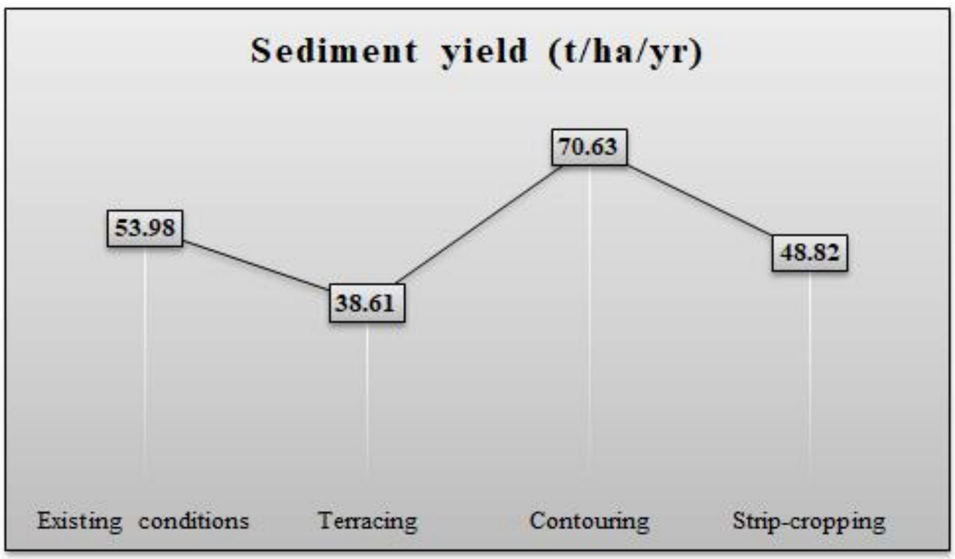

Figure 1: Average annual sediment yield simulated for each treatment (Briak *et al.*, 2019)

Conclusion

Different soil conservation scenarios were simulated and tested with respect to sediment yield using SWAT model. The demonstration study revealed that terracing operation is efficient to decrease soil erosion and the implementation of this soil conservation measures would significantly reduce sediment yields at the outlets of the watershed.

References

Arabi, M., Frankenberger, J.R., Engel, B.A. & Arnold, J.G. 2007. Representation of agricultural conservation practices with SWAT. *Hydrological Processes*, 22(16): 3042-3055.

Bracmort, K.S., Arabi, M., Frankenberger, J.R., Engel, B.A. & Arnold, J.G. 2006. Modelling long-term water quality impact of structural BMPs. *Transactions of the ASAE,* 49(2): 367–374.

Briak, H., Moussadek, R., Derradji, A., Aboumaria, K. & Mrabet, R. 2016a. Effect of vegetation types on highway erosion in Kalaya basin (North Morocco). *J. Mater. Environ. Sci.*, 7(2): 605-612.

Briak, H., Moussadek, R., Aboumaria, K., Mrabet, R. 2016b. Assessing sediment yield in Kalaya gauged watershed (Northern Morocco) using GIS and SWAT model. *International Soil and Water Conservation Research,* 4: 177–185.

Briak, H., Mrabet, R., Moussadek, R. & Aboumaria, K. 2019. Use of a calibrated SWAT model to evaluate the effects of agricultural BMPs on sediments of the Kalaya river basin (North of Morocco). *International Soil and Water Conservation Research.*

Jang, T., Vellidis, G., Hyman, JB., Brooks, E., Kurkalova, LA., Boll, J. & Cho, J. 2013. Model for prioritizing best management practice implementation: sediment load reduction. *Environ. Manage*., 51:209 –224.

Kumar, H. & Pani, P. 2013. Effects of Soil Erosion on Agricultural Productivity in a Semi-Arid Region: The Case of Lower Chambal Valley. *Journal of Rural Development,* 32(2): 165–184.

Lal, R. 1987. Effects of soil erosion on crop productivity. *CRC Crit. Rev. Plant Sci*., 5: 303– 367.

Logan, T.J. 1993. Agricultural best management-practices for water-pollution control - Current issues. *Agriculture Ecosystems & Environment*, 46(1-4): 223-231.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R., & King, K. W. 2005.Soil and water assessment tool theoretical documentation—version (2005). *Soil and water research laboratory, agricultural research service. Temple: US Department of Agriculture*.

Wu, H., Liu, Y., Liu J., Zhu, A. 2014. Representation of Agricultural Best Management Practices in a Fully Distributed Hydrologic Model : A Case Study in the Luoyugou Watershed. *Journal of Resources and Ecology*, 5(2): 179-184.

Role of biochar to counteract degradation in acid soils

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Abstract

The effect of biocarbon added to acid soils was evaluated together with organic fertilizers in the nursery phase of Morera (Morus sp). To accomplish it, two phases were worked on. In phase one, the biocarbon levels to be used in phase two were defined with Morera plants

(according to response surface) under a completely random design with Factorial 4X3 array where four teatments were evaluated (factor 1: without fertilization -SF-, with vermicompost -LC-, with effluent from biodigester -E- and vermicompost with effluent -LC + B) and three levels of biocarbon -B- (factor 2: biocarbon level 0, 4 and 6 %), with 5 repetitions.

The variables with significant response ($P < 0.05$) under treatment, level, and the interaction with mulberry were leaf weight when using biodigester effluent alone (B6E with 12.05 g) and in association with vermicompost (B6LC + E with 5.61 g). For the branch weight variable a highly significant difference was obtained ($P < 0.01$) with higher responses in treatments B6E and B6LC + E with 3.78 and 1.86 respectively, both results with the highest inclusion of biocarbon (6%).

Keywords: biochar, biomass energy, mulberry, conditioner

Introduction, scope and main objectives

As a major step in the agenda led by the United Nations (UN), world leaders adopted a set of global objectives to eradicate poverty, protect the planet, and ensure prosperity for all as part of a new initiative called Objectives of Sustainable Development (OSD); among them, OSD15 directly attacks desertification and biodiversity loss. A problem which directly affects the productive conditions of soils whose purpose is to guarantee food for the world's population.

The indiscriminate use of synthetic fertilizers has generated the degradation of soils mainly due to the impact on their structure and composition affecting processes such as cation exchange which consequently leads to acidification which induces soil decay and limits plants to access nutrients.

Biocarbon has been used as a soil conditioner (Major *et al.*, 2010; Rodriguez *et al.*, 2009), bioremediator in soils contaminated with hydrocarbons (Beesley *et al.*, 2011), prebiotic in ruminants (Phuong *et al.*, 2019), carbon capture (Bejarano and Aguilar, 2017); the biocarbon addition in acid soils allows to correct the pH achieving a greater availability of nutrients for the plant and a better proportion of the porosity, where the water and air manage to contribute to the productivity of the soil, both, with the growth of the microbiota important in the decomposition and mineralization of organic matter, counteracting the degradation processes that occurs due to an inadequate management of fertilizers and a deficient use of agricultural machinery.

This research evaluated the effect of biochar and organic fertilizers on the development of mulberry stakes (*Morus sp*) at nursery stage under conditions of acid soils in tropical dry forest.

Biochar was produced by micro gasification stove and the fertilizers used were vermicompost and digester effluent.

Methodology

In tropical dry forest conditions with acid soils of pH 4.2 an experiment was set with a completely randomized model with a Factorial 4X3 array. The development of mulberry stakes was evaluated with four treatments: without fertilizer (SF), vermicompost (LC), effluent as nitrogen fertilizer (E) and vermicompost with effluent (LC + E) and three levels of biocarbon 0, 4 and 6% (according to response surfaces of the bioassay) with 5 repetitions.

Optimal biochar levels were determined by mathematical modeling with the Curve Expert 1.4 program (2010).

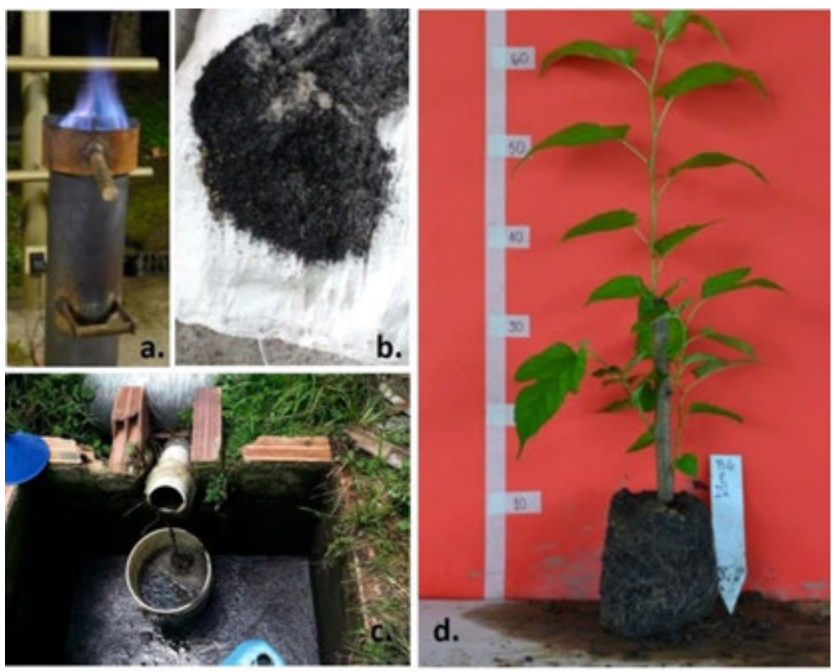

Figure 1: a) Upflow microgasification stove. b) Biochar of rice husk. c) Collection of biodigester effluents. d) Morus sp

The variables measured during five weeks were: plant height, number of shoots, number of branches, branch length, number of leaves per branch, branch diameter, growth rate, survival, arrest, incidence of pests and diseases. As in experiment 1, the data was subjected to a mathematical modeling to define the functional response against the treatments. During this week a destructive evaluation of mulberry was also carried out to determine root length and weight and weight of leaves and stem.

The soil was prepared accordingly to treatments, taken to nursery and located according to the field map. Mulberry stakes 30 cm long with 3-4 knots and diameters of 2-3 cm were planted. 200 g of vermicompost was applied at the beginning of the sowing and the corresponding treatments were fertilized with 270 cc of biodigester effluent, divided in 3 applications of 90 cc each starting the second week of the established trial, which provided 214 mg of N per 2 kg bag as recommended by Boschini and Vargas (2009) for mulberry fertilization; humidity was maintained at field capacity.

Soil samples were taken for each treatment to measure pH and assess the presence of aerobic mesophilic microorganisms, molds and yeasts by means of a logarithmic conversion of the data and the statistical program SAS was used for treatment and biochar level.

Results

At the end of the trial the response of the mulberry stakes to the application of fertilizers and biochar was positive and significant (P <0.01) for treatment, level and interaction, in the variables weight of leaves and branches (Table 1).

In order to precisely define the response in the leaf weight variable, a mathematical modeling was carried out by calculating the functions that would explain the answer, based on the definition of the derivative, where the response surface for SF treatment was at level 4.2 to 4.3 % of biocarbon, for LC the best response was at level 2.9 to 3.0 % of biocarbon, in treatment E the best level of production was presented in 1.9 to 2.0 % inclusion of biochar and for LC + E the response had an ascending behavior as the percentage of biochar increased.

In laboratory tests carried out to assess the changes in soil microbiology, it could be established that there was no significant difference (P> 0.05) in the mesophilic population although for the B0LC treatment the results show a high content of these microorganisms probably generated by bacteria from the vermicompost. On the other hand, for molds and yeasts, significant differences were found (P <0.05) for treatments, with the B0LC treatment being the most frequent.

Table 1: Response to the application of biochar and fertilizers on performance indicators of harvest of mulberry stakes

TREATMENT	LEVEL BIOCHAR		LONG ROOT (cm)	WEIGHT ROOT (g)	BRANCHES (#)	WEIGHT LEAVES (g)	WEIGHT BRANCH (g)
WITHOUT FERTILIZER	0	Mean	15.65	0.80	4.00	0.79	0.31
		SE	11.07	0.56	2.83	0.35	0.14
	4	Mean	24.08	4.29	4.25	2.38	0.66
		SE	12.04	2.15	2.13	1.06	0.30
	6	Mean	14.95	1.09	3.00	1.97	0.65
		SE	10.57	0.77	2.12	0.88	0.29
WITH VERMI-COMPOST	0	Mean	18.75	2.53	3.00	1.06	0.62
		SE	13.26	1.79	2.12	0.47	0.28
	4	Mean	14.90	2.17	3.67	2.81	0.55
		SE	8.60	1.25	2.12	1.26	0.25
	6	Mean	31.60	3.16	4.00	1.03	0.63

		SE	31.60	3.16	4.00	0.51	0.31
WITH EFFLUENT	0	Mean	13.13	1.28	3.25	2.07	0.55
		SE	6.56	0.64	1.63	0.93	0.25
	4	Mean	21.20	4.07	6.00	2.23	1.01
		SE	21.20	4.07	6.00	1.00	0.45
	6	Mean	22.25	8.14	5.50	12.05	3.78
		SE	11.13	4.07	2.75	6.03	1.89
WITH VERMI-COMPOST + EFFLUENT	0	Mean	32.35	4.44	6.50	3.87	1.37
		SE	22.87	3.14	4.60	1.94	0.69
	4	Mean	25.10	6.25	5.00	4.92	1.59
		SE	14.49	3.61	2.89	2.20	0.71
	6	Mean	24.63	4.46	4.33	5.61	1.86
		SE	14.22	2.57	2.50	2.51	0.83
P	TREAT-MENT		0.1928	0.0656	0.0711	0.0003	<0.0001
	LEVEL		0.7238	0.1398	0.6352	0.0033	0.0005
	T X L		0.3000	0.0674	0.1391	0.0008	0.0004

SE: standard error

Discussion

The pH variations in the treated soils respond to the effect that the biochar has as an alkalizing agent added to the organic fertilizers that once stabilized have a close to neutral pH, thus managing to counteract the effects that the acidic pH has on the availability of the nutrients for plants.

Once the mathematical modeling was carried out, by calculating the functions that would explain the response, the different response behaviors that include biochar were identified.

Although in this experiment there was no significant response in microorganism populations, fungi and bacteria populations reacted differently to pH. Bacteria tended to increase with higher pH values (around 7), while fungi did not not show any change in total biomass nor drastically reduced their growth potential at higher pH (Rousk *et al.*, 2009).

Conclusions

The application of biochar and organic fertilizers to acidic soils produced a better response in the aerial portion of the mulberry stakes especially when there is a combination of fertilizers. Regardless of treatment, biochar presence between the range of 4 and 6 % favors a significant response for mulberry.

The organic amendments used in this trial allowed a visual improvement of physical soil parameters related to moisture retention and increased porosity.

The biodigester effluent as a powerful nitrogen fertilizer alone and with vermicompost allowed the best development of mulberry plants thanks to the contribution of N showing higher growth when compared to the other treatments.

It is important to note that changes in the composition of the microbial community of the soil and / or the activity induced by the biochar can not only affect the nutrient cycles and plant growth, but also the cycle of the organic matter in soils which increases productivity. Therefore more specific microbiological tests are to be carried out.

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References

Beesley, L., Moreno-Jiménez, E., Gomez-Eyles, J., Harris, E., Robinson, B. & Sizmur, T. 2011. A review of biochars' potential role in the remediation, revegetation and restoration of contaminated soils. *Environmental Pollution*, 159: 3269–3282.

Bejarano, L. & Aguilar, P. 2017. Evaluación del biochar e hidrochar como medio para captura de carbono en el suelo. Available at: http://repository.lasalle.edu.co/bitstream/handle/10185/22399/41121007_2017.pdf?sequence=1&isAllowed=y [Accessed 07.03.2019].

Boschini, C. & Vargas, F. 2009. Rendimiento y calidad de la morera (Morus alba) fertilizada con Nitrógeno, Fósforo y Potasio. *Agronomía Mesoamericana*, 20(2): 285-296. ISSN: 1021-7444.

Major, J., Rondon, M., Molina, D., Riha, S. & Lehmann, J. 2010. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil*, 333(1-2): 117-128.

Phuong, L.T.B, Preston, T.R, Van, N.H & Dung, D.V. 2019. Effect of additives (brewer's grains and biochar) and cassava variety (sweet *versus* bitter) on nitrogen retention, thiocyanate excretion and methane production by Bach Thao goats. *Livestock Research for Rural Development,* 31.

Rodríguez, L., Salazar, P. & Preston, T.R. 2009. Effect of biochar and biodigester effluent on growth of maize in acid soils. *Livestock Research for Rural Development,* 21.

Rousk, J., Brookes, P. & Bååth, E. 2009. Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. *Applied and Environmental Microbiology,* 75: 1589 -1596.

Assessing Soil Health Following the Adoption of Conservation Agriculture in East Africa

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Abstract

The Canadian Foodgrains Bank's *Scaling up Conservation Agriculture (CA) in East Africa* project aims to improve food security and build a more resilient soil. Practices such as keeping the soil covered with mulch or intercropping with legumes can protect the soil from erosion during heavy rains, while also providing cover to decrease moisture loss by evaporation. A simple-to-use, in-field soil health assessment protocol was developed to document the impact of CA on soil health, including soil structure. Preliminary results indicate that the soil structure improves even after early adoption of CA practices. Further improvement is expected as the practice of CA continues over time.

Keywords: Conservation Agriculture, Soil Structure, East Africa

Introduction

Conservation Agriculture (CA) is a farming system designed to improve food security of smallholder farms. It is based primarily on three principles: minimal mechanical soil disturbance through reduced or zero tillage, maintaining permanent soil cover using cover crops or mulches, and diversified crop rotations (FAO, 2017). Two major advantages of the CA system are to conserve moisture and reduce soil erosion. The use of mulch not only decreases evaporation losses from the soil surface, but also protects the soil from water erosion during heavy rain events. The CA practice in general also builds and maintains soil structure, allowing more water to infiltrate during rainfall, thus decreasing erosion and conserving moisture.

The project *Scaling up Conservation Agriculture in East Africa* is an initiative of the Canadian Foodgrains Bank (CFGB) to expand the number of farms practicing CA in Ethiopia, Kenya and Tanzania. Part of the project is to collect farm-level data on the impact of CA on soil, to document not just the benefit to food security, but the long-term changes to soil health as well.

Methodology

A soil health assessment protocol has been developed to determine changes to the soil with the implementation of CA practices. The assessment includes categories of soil pH, soil colour, microbial respiration, crop assessment (nutrient deficiencies, root growth, crop yield) and general field observations on the evidence of water erosion and ponding/pooling of water. The categories also include soil physical characteristics (soil structure, crusting, tilth and compaction) and are a key factor in determining the soil's resilience to erosion. The assessment was designed to be carried out in the field, using simple, easy-to-access tools and general observation skills. Training has been provided to CFGB staff working in each of the three participating countries and they have been collecting data since 2017. Data collection will continue until the end of the project in 2020.

The protocol is based on the Cornell approach to soil health assessment (Moebius-Clune *et al*, 2016), but is focused on elements that use the 'senses' such as sight, smell and touch to rate the soil. Each category is rated on a scale of one to five, with one being the highest (or best) rating and five being the lowest (or worst) rating. For the soil physical characteristics (Table 1), the hoe test is carried out by hoeing 10 planting stations and describing the ease of hoeing and how the soil breaks up with impact. Either the CFGB staff conducting the assessment or the farmer carry out the hoe test. The soil structure assessment studies the size and proportion of soil aggregates. Soil compaction assesses for hard pan layers or difficulty in digging/hoeing the soil. The soil crusting assessment describes how the impact of rain may cause the soil to "seal off" at the surface and form a crust as the soil dries. The protocol was developed with input from the CFGB field staff to create a user-friendly approach, with descriptive language that is appropriate for the farming community and the local soil/field conditions. Samples are taken from paired CA and non-CA plots from the same farm.

Table 1: Rating Guide for Assessing Soil Physical Characteristics

Assessment Score	**Soil Structure Assessments**			
	Hoe Test	Soil Structure	Soil Compaction	Soil Crusting
1	Soil is soft and easy to hoe, no chunks of soil are observed, soil has good crumb structure.	Good crumb structure, 50% of aggregates are between 3mm and 5mm in size, soil breaks up easily leaving no clods.	Soil is loose and soft, unrestricted root penetration.	Soil maintains open/porous surface all growing season, seedling emergence not affected.
2	Soil is relatively easy to hoe, some chunks of soil may be observed, chunks break up with ease.	Soil has moderate crumb structure, aggregates are small in size (under 3mm), soil breaks up easily.	Soil is firm, no impact on root penetration.	Some surface sealing, no noticeable effect on seedling emergence.
3	Soil is firm, able to hoe to proper depth, some chunks of soil, chunks break up under moderate pressure.	Soil has moderate crumb structure, aggregates are small in size (under 2mm), some clods were observed, soil breaks apart with some pressure.	Soil is firm, root penetration somewhat restricted.	Some surface sealing, minimal effect on seedling emergence.

4	Soil is moderately hard, able to hoe to proper depth, soil comes up as large chunks that are difficult to break up.	Soil is hard, many clods were observed, soil breaks apart with considerable pressure.	Soil is firm, root penetration is restricted.	Soil surface seals easily after rain events, minimal effect on seedling emergence.
5	Soil is hard, very difficult to hoe to a proper depth (evidence of a hard pan/restrictive layer), soil comes up as large chunks.	Soil is hard, inserting the spade to dig up the soil was difficult, hard clods were removed that do not break apart OR soil breaks down into fine particles (no aggregates or aggregates are all under 1mm in size).	Hard layers, tight soil, severely restricted root penetration.	Soil surface seals easily after rain events, inhibits seedling emergence.

Results and Discussion

The preliminary soil physical assessment results from 2018 are presented in Figure 1. Data shown is for 31 paired CA and non-CA plots where CA has been practiced for a minimum of three years (Ethiopia = 5, Kenya = 16, Tanzania = 10). There is a trend for CA plots to have a better rating (lower, or closer to one) when compared to the non-CA plots. As this is a preliminary view of the data in the early stages of the project and only basic statistical analyses have been completed. The early results show an improvement in soil physical characteristics with the adoption of CA practices. Further improvement is expected as CA is practiced for a longer period of time.

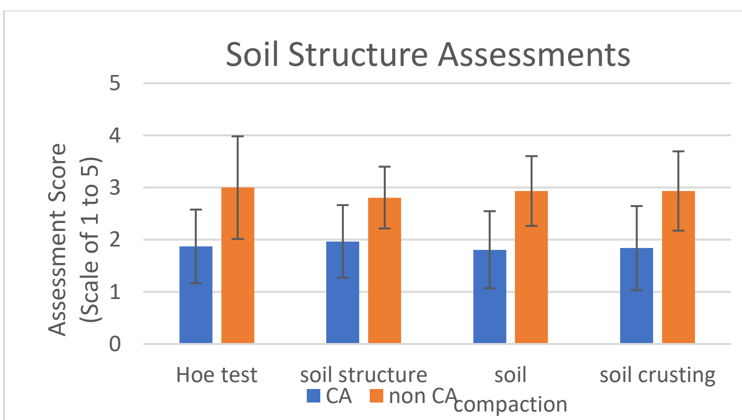

Figure 1: Soil Physical Assessment of CA and non-CA fields (31 paired plots from Ethiopia, Kenya and Tanzania)

As the project comes to a close in 2020, a more intensive assessment of the oldest CA fields will be carried out to determine the impact on reducing soil erosion and improving soil health. The preliminary data includes fields that have been under CA for a range of years – currently to be included in the assessment, a field must be in CA for at least two cropping seasons. In the final year of the program, there will be a number of fields where CA was adopted early, so assessment can focus on the oldest CA fields to gain better documentation on the long-term benefits of CA.

Conclusions

Conservation Agriculture practices have been shown to improve soil physical properties, even in the early years of adoption. Over time, this should result in a more resilient soil that can better resist the impact of erosion and flooding/drought events. Soil erosion is decreased not only by the mulch used in the CA practice acting as 'armor' to protect the soil, but that mulch also provides food for soil microorganisms to create organic matter over time. By improving soil structure and building soil organic matter, soils should be able to absorb more water, improving their water holding capacity and decreasing the amount of erosion during heavy rain events. Documentation of these changes over time, whether through soil health assessment or simple observation by farmers, should help to increase the adoption of CA in East Africa – as improvement of the land will support crop growth, increasing yields and creating food security for farmers.

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References

FAO. 2017. *Conservation Agriculture*. Available at: http://www.fao.org/3/i7480en/I7480EN.pdf [accessed 16.03.19]

Moebius-Clune, B.N., Moebius-Clune, D.J., Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., Ristow, A.J., van Es, H.M., Thies, J.E., Shayler, H.A., McBride, M.B., Wolfe, D.W. & Abawi, G.S. 2016. Comprehensive Assessment of Soil Health – The Cornell Framework Manual, Edition 3.1, Cornell University, Geneva, NY.

Soil Degradation and Erosion Processes under New Extensive Agro-Industrial Developments: Causes and Consequences

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Abstract

The last decades have seen increasing demand and high market prices for food and energy crops, mainly soybeans and palm oil, that have led to drastic and unregulated changes in the use and management of large areas of land, resulting in new and worsening problems of soil and water degradation, including erosion. These changes are mostly happening on savanna and forested lands in tropical and subtropical regions of Asia, Africa and Latin America, under the initiative of large individual producers and corporations, usually seeking short term profit, with little concern for negative environmental or social consequences. Frequently, such cropland developments are justified under an apparent use of so-called “conservation agriculture” systems, mainly based on “zero tillage” practices, supposedly leading both to improved production and to soil and water conservation, with decreased erosion and positive effects on the environment and climate change. There is clear evidence, however, that inadequate application of those “conservation agriculture” systems is increasingly degrading the soil and water resources, with negative environmental and socio-economic impacts at local and World-wide level. A new focus is required for research activities that seek solutions to soil and water conservation problems, taking into consideration the complex interactions between land use and changing social and economic conditions, leading to more sustainable policies and decisions about land use and management. Soybean production in Argentina and Brazil is analyzed as case studies.

Keywords: soil erosion, industrial agriculture, land degradation, food production, conservation agriculture

Introduction

The processes of soil erosion are closely linked through unfavourable alterations in the hydrological processes determining the soil water balance and the soil water regime, which are conditioned by the climatic conditions and by the land use and management. This will become more important under the previewed effects of global climatic changes, which supposedly will mainly affect hydrological processes in the land surface, mostly related to the field water balance (Pla, 2017).

The last decades have seen increasing demand and high market prices for food and energy crops, mainly soybeans and palm oil, that have led to drastic and unregulated changes in the use and management of large areas of land, resulting in new and worsening problems of soil and water degradation, including erosion. These changes are mostly happening on savanna and forested lands in tropical and subtropical regions of Asia, Africa and Latin America, under the initiative of large individual producers and corporations, usually seeking short term profit, with little concern for negative environmental or social consequences. The importance of those degradation processes increases if we take into consideration that the new lands incorporated into those industrial agricultural developments are part of the few remaining global land reserves, mostly with high quality soils, for the production of the food requirements of an increasing world population.

A high proportion of the land in LAC is on steep slopes, and the main limitation for its agricultural use is water erosion. However, the problems of accelerated water erosion are not confined to steep slopes, but are also widespread in agricultural areas with more gentle slopes. In general, the increasing trend of erosion in LAC is mainly due to the fast growth of the human population and to pressures put on the land by deforestation and over-grazing, and by inappropriate agricultural practices in both subsistence and large-scale high-input commercial agriculture (FAO and ITPS, 2015; Pla, 1996a).

Although there is clear evidence that large and increasing areas of land are being affected by different processes of soil erosion, most of the existing evaluations of the type, extent and intensity of soil erosion at country or regional level are not very precise or objective. Mass and landslide erosion processes are usually not differentiated from surface erosion problems, leading to an often faulty identification of the origin of erosion processes (Pla, 1997, 2011).

In LA after some initial soybean agricultural developments on the 1970-80, the land used to grow soybeans increased gradually up to the 1990-2000, when the World demand of soya beans and soya products raised dramatically. The result was a fast growing land area planted with soybeans, that in Argentina went from 6 million ha in 1999 to 20-25 million ha in 2018, and in Brazil from 11 million ha in 1999 to 35-40 million ha in 2018. In the same period new areas were planted with soybeans in Paraguay (3 million ha), Bolivia (2 million ha) and Uruguay (1,3 million ha). Although this large expansion of soybean cropping has brought many economic benefits to the countries and private producers, they are accompanied by great changes in the hydrology, loss of biodiversity and problems of soil and water degradation, including soil erosion in sloping lands, which may affect their medium and long term economic, environmental and social sustainability (Merten and Minella, 2013). Soybean agricultural developments in Argentina and Brazil are analyzed as case studies.

Soil degradation and erosion processes under agro-industrial developments

The initial agricultural developments in the 1970-80, in areas previously occupied by pastures, forests or other permanent crops like coffee, included management systems highly mechanized, using excessive plowing for seedbed preparation, wed control etc, which led to problems of soil physical degradation, los of OM, plow pans, erosion, etc (Casas and Albarracin, 2015). To control those degradation processes, there were proposed “no till” (NT), that were empirically proposed as the universal recommended soil conservation practice to control soil erosion and to control anthropogenic climate change through increased C sequestration, under any conditions without due consideration and research on the long-term effects of such management under different combinations of soils, climate, drainage, crops and herbicide use (Pla, 2014). Some short term and small scale experiments reporting positive effects of zero tillage systems with different rotations, have not been able to evaluate the effects of the way that system is really applied under field conditions in extensive industrial agricultural developments, and specially the hydrological and long term consequences. Some studies have shown that no-till is not as efficient in controlling surface runoff losses as it is in reducing soil loss (Merten *et al.*, 2015), and that the absence of soil disturbance leads to surface compaction with consequent porosity reduction (Imbellone and Alvarez, 2018). Such contradictory results are probably due to differences between materials from which soils develop, and differences in texture, hydrological and climate regime, the ways in which soil is managed (crops used in rotation, quantity, and quality of crop residues), and other factors. When NT was applied in soils already degraded, with plow-pans, from previous agriculture use and management, it was not been able to reverse the problems of physical degradation for 10-15 years after introducing NT.

Although in the initial stages, at the nineties, of application of the zero tillage system, where crop rotations (soybean-corn, soybean-wheat,..) were regularly used, together with other conservation practices as terracing and contour planting, there were observed some positive effects in soil and water conservation, this situation has been changing, driven by changes in the application of the system derived of political and economical reasons. The last 15-20 years, in the fast expanding new areas under soybeans, derived of the higher profitability of the crop products and the increasing contribution to the export income of the producing countries, the mode of production has become a highly industrialized soybean monoculture, with an intensive use of technology in very large production units. This evolution toward an increasing soybean monoculture, with very poor residue cover and shallow rooting depth, and the abandonment of other conservation practices like contour planting and terracing, which could restrict large machinery traffic (Merten *et al.*, 2015), has derived in increased problems of soil erosion, soil compaction, decrease in soil OM, cumulative negative budgets in soil nutrients (despite increasing use of fertilizers), and environmental problems derived of increasing emissions of greenhouse gases as CO_2 and N_2O.

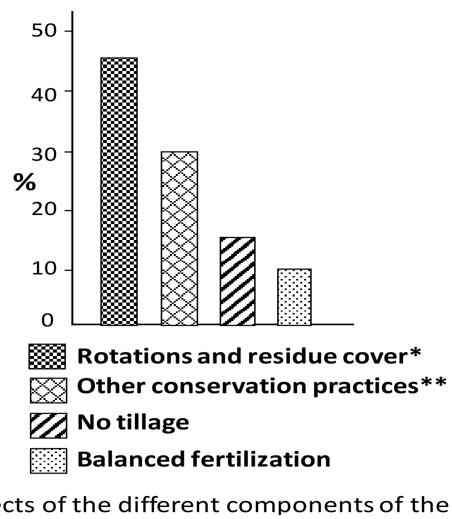

Figure 1: Relative effects of the different components of the "no tillage" soil management system (* *Intensity and diversity of rotations, residues persistence; ** Terracing, contour planting, strip planting etc*)

Using the proposed relative effects (Figure 1) for the application of the "no tillage system", the more optimistic appreciations consider that only 20-30 % of the cropland under soybeans in Argentina and Brazil would reach an accumulative effect of more than 50 %, mainly for failures in the rotations and conservation practices blocks.

Usually, in many official reports, NT is confused with "conservation agriculture" (CA), although at present the other requirements of CA, as rotations, residues cover and conservation practices (Figure 1) are not accomplished (FAO, 2001). The proportion of cropland area in LA countries under supposed CA, based on that information reported to FAO, has led to some indirect evaluations and conclusions about an estimated soil erosion reduction of 33 % in Argentina, 27 % in Paraguay, 20 % in Brazil, 20 % in Uruguay, and 10 % in

Bolivia", derived of the application of CT in the large expansion of cropland areas in those countries (Borelli *et al.*, 2017). Those conclusions do not coincide, and actually are opposite, with the real field evaluations reported for Argentina (Casas and Albarracin, 2015), which probably would also apply for other LA countries like Brazil (Merten *et al.*, 2015).

Conclusions

There are clear evidences that the new agro-industrial developments in LA, especially in the very large areas incorporated to mono-cropping of soybeans in the last decades, are leading to various problems of soil and water degradation and derived effects, including soil erosion, affecting the economic, environmental and social sustainability of such developments. The use of NT practices, without appropriate rotations, and with poor soil cover with residues, under soybean monoculture, does not meet most of the requirements of "conservation agriculture". It may be concluded that the adoption of usually considered of universal application, land conservation systems and practices, like cero tillage, without considering the specific conditions (soil, climate, drainage, crops, rotations, etc) may lead, and is leading instead to land, soil and water degradation processes, with onsite and offsite sometimes catastrophic consequences (Pla, 1996b, 2011).

The adequate selection of those sustainable practices must be based on research with a broader vision of soil conservation, where all the system components and their interactions are considered and understood with a far-sighted approach, to ensure that short term gains in one aspect or location do not induce long-term losses in other aspects or elsewhere (Pla, 2003).

In most LA countries, the application of conservation measures is limited by lack of integration between conservation and development, the lack of legislation or ways to implement it, and the shortage of basic local information, trained personnel and financial resources. There are required programs of sustainable agricultural developments that should not only meet short term economic goals but which would also take into account social interests, environmental preservation (biodiversity and water resources), and maintain national security (provision of hydropower and food) in the medium and long term. To maintain such programs, it will be necessary some incentives and subsidies for farmers to apply the appropriate soil conservation systems, which may require funding based on taxes to the exported agricultural products (Merten and Minella, 2013).

In general, the conclusion is that there are required new focus and orientation in the evaluation, research activities and solutions related with soil and water conservation problems (Pla 2003), taking into consideration the complex interactions among different factors (Figure 2), and the additional changing social and economic factors leading to policies and decisions about land use and management in each case.

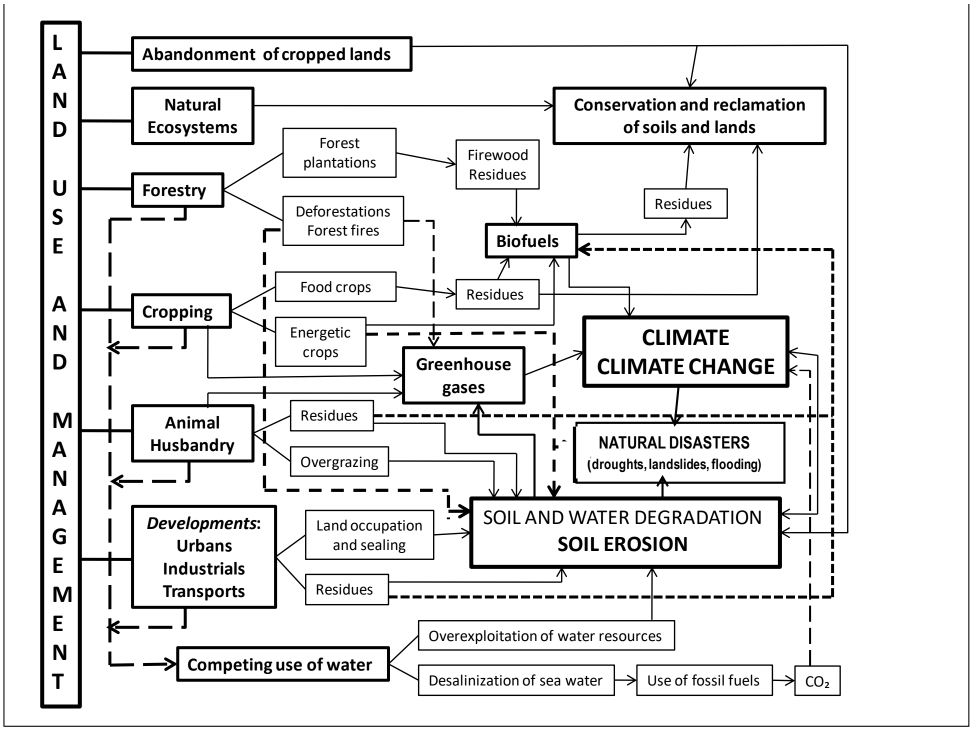

Figure 2: Relations between land use and management, climate, soil and water degradation and soil erosion (Pla, 2014)

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References

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K. Van, Montanarella, L. & Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8(1): 2013. https://doi.org/10.1038/s41467-017-02142-7.

Casas, R & Albarracín, G.F. (eds). 2015. El Deterioro del Suelo y del Ambiente en la Argentina. FECIC-PROSA. Buenos Aires, Argentina. 2Vol. 1064 pp.

FAO. 2001. Conservation agriculture. Case studies in Latin America and Africa. *FAO Soils Bulletin 78*. Rome, Italy.

FAO & ITPS. 2015. Status of the Word`s Soil Resources. Main Report. Rome, Italy.

Imbellone, P & C. Alvarez, C. (Ed). 2018. Compactaciones Naturales y Antrópicas en Suelos Argentinos. AACS. Buenos Aires, Argentina. 547 pp.

Merten, G & Minella, J. 2013. The expansion of Brazilian agriculture: Soil erosion scenarios. *International Soil and Water Conservation Research*, 1(3): 37-48.

Merten, G.H., Araújo, A.G., Biscaia, R.C.M., Barbosa, G.M.C. & Conte, O. 2015. No-till surface runoff and soil losses in southern Brazil. *Soil and Tillage Research*, 152: 85–93. https://doi.org/10.1016/J.STILL.2015.03.014.

Pla, I. 1996a. Degradación de suelos en zonas de ladera de América Latina. In: F.Bertch and C. Monreal (eds), *El Uso Sostenible del Suelo en Zonas de Ladera: El Papel Esencial de los Sistemas de Labranza Conservacionista*. FAO-MAG. San José.(Costa Rica) pp 27-49.

Pla, I. 1996b. Sistemas y prácticas de conservación de suelos y aguas. In: *Planificación y Manejo Integrado de Cuencas Hidrográficas en Zonas Áridas y Semiáridas de América Latina*. FAO-PNUMA. Santiago de Chile. (Chile) pp 131-160.

Pla, I. 1997. A soil water balance model for monitoring soil erosion processes and effects on steep lands in the tropics. *Soil Technology,* Elsevier. 11(1): 17-30.

Pla, I. 2003. Erosion research in Latin-America. In: D. Gabriels y W. Cornelius (eds), *25 Years of Assessment of Erosion.* Univ. of Gent. Gent (Bélgium) pp 19-27.

Pla, I. 2011. Evaluación y Modelización Hidrológica para el Diagnóstico y Prevención de "Desastres Naturales". *Gestión y Ambiente,* 14 (3): 17-22.

Pla, I. 2014. Advances in soil conservation research: challenges for the future. *Spanish Journal of Soil Science, SECS* 4(3): 265-282.

From Soil Erosion to Soil Accumulation: Recycling Urban Organic Waste to the Eroded Land in Sahel, West Africa

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Abstract

The authors carried out an on-site experiment, using multiple plots scattered with varying amounts of urban organic waste over ten years, to quantify the soil improvement effects of the waste scattering practice. According to the plant growth observation during 10 years, the critical amount of urban waste was at least 20 kg/m^2, approximately 2 cm thick on the ground for land restoring. The results revealed that the urban organic waste shows 8 effects of land restoring. (1) urban waste trapped wind-blown sand and organic matter, (2) preventing erosive wind and water, (3) termite build shelters over the organic matter and elevate the small grain clay and silt in the soil and mixes them with wind-blown sand, (4) termite tunnels penetrate the hard sedimentary layer which allows rainwater to infiltrate easily through the tunnels, and (5) the aggregated soil structure is porous, and allows plant roots to grow and penetrate as well as contains oxygen and moisture all necessary for plant growth. (6) Urban organic waste are slightly alkaline and neutralize the soil acidity and (7) adding nutrients to the soil. (8) Urban organic waste contains many seed of edible plant and fodder plant. These effects improve the plant growth and change the place from the soil erosion to the soil accumulation.

Keywords: land restoring, greening, termite, Harmattan wind, rainwater, land rehabilitation, desertification, Niger

Introduction

Rapid population increase, low technology in agriculture, and overgrazing are considered to be causing land degradation in the Sahel Area (Ayatunde, 2000; Mortimore and Turner, 2005; Tschakert, 2007). The farmers in Sahel claim that the proportion of cultivated fields to fallow fields increased from the mid 1980s to the present. The continuous cultivation and overgrazing accelerate the water and wind soil erosion from the farmland. In recent years, both famers and herders have experienced hunger and poverty caused by soil erosion and land degradation in the Sahel region. This has led to armed conflicts and terrorism. There is a downward spiral of land degradation, hunger and poverty, armed conflict, and terrorism occurring throughout the region. This spiral drives the mass emigration from the Sahel to Europe through Sahara Dessert and Mediterranean.

Recent research has shown that the awareness of local residents as to soil erosion and land degradation was consistent with the scientific soil information (Warren *et al.*, 2003; Oyama, 2012, 2018). When the fields become eroded, the farmers scatter livestock manure as well as household waste and sometimes urban organic waste over their cropland in southern Niger. This organic waste improves the soil quality. The authors carried out an on-site experiment, using multiple plots scattered with varying amounts of urban waste during almost twenty years, to quantify the soil improvement effects. This paper clarified the plant growth and land restoring effects of urban organic waste. We aimed to eradicate the hunger and poverty through land restoration by building the organic matter circulation between urban cities and rural area in the Sahel.

Methodology

The research area was one village in Dogondoutchi region, Republic Niger. The altitude is 240 m. The population of the village is 310 persons with 60 households in 2010. The authors aimed to elucidate greening effects of urban organic waste on the hard sedimentary layer occurring in eroded land. A fenced area of 45 m north-south by 50 m east-west kept out people and livestock in August 2008. The area was sloped east to west by 3^{o} within which five 4 m by 30 m plots were prepared (Oyama, 2012).

In November 2008, the authors began the urban waste project on each plot. No waste was scattered onto plot 1 for comparison. Plot 2 was scattered with 600 kg (5 kg/m^2), plot 3 with 1 200 kg (10 kg/m^2), plot 4 with 2 400 kg (20 kg/m^2), and plot 5 with 5 400 kg (45 kg/m^2) of urban organic waste. The urban waste contained sand with organic matter such as livestock dung and plant residue (92 %), plastic bag (6.7 %), stone (0.6 %), plastic bottle (0.2 %) and metal (0.1 %) in weight. To take into account the future use of such urban waste against land erosion, the authors left the non-organic matter in the waste (Figure 1). We could recognize the safeties of urban waste which was dumped immediately from the house yards (Oyama, 2015). We continued the monitoring on plant growth and soil profiles in 5 plots.

Results

Plant composition change

Plot 1 with no waste input showed no visible change nor plant growth in 10 years (Figure 2). Plot 4 had many plant species grow. After one year, the plot contained 35 species weighing 59 547 g (4 962 kg/ha) in total. The predominant plant species were pearl millet (*P. gluacum*) weighing 4 257 kg/ha, *Hibiscus sabdariffa* (226 kg/ha), and *B. radiata* and *B. stachydea* (166 kg/ha). *H. subdariffa* is cooked and eaten by the farmers as a side dish. Pearl millet weighed 85.8% of the total. After two years there were 17 plant species weighing 37 903 g (3 159 kg/ha) (Figure 2). The weight of pearl millet decreased to 0.6 % of the total at 18 kg/ha. The predominant plant species were *B. radiata* and *B. stachydea* (1 236 kg/ha), *H. sabdariffa* (785 kg/ha), and *Indigofera prieureana* (596 kg/ha). Five plant species, *B. aegyptiaca*, *Ipomoea vegan, Z. glochidiata,* and two unkown species newly germinated after two years. After three years, plant species counted 16 and weighed 15 674 g (1 306 kg/ha). Among these, *B. radiata* and *B. stachydea* (714 kg/ha), *Schizachyrium exile* (231 kg/ha), *I. priureana* (174 kg/ha) were predominant. Six plant species (*Cassia obtusifolia, Indigofera astragalina, Aristida mutabilis, Pennisetum pedicellatum, Gymnospria senegalensis*, one unknown) newly germinated after three years. There was no pearl millet. Most plant species on Plot 4 were favored as livestock feed.

Soil profiles

In August 2008, the soil profile of Plot 1 (0-30 cm deep), without any waste input, was packed with dull, orange-colored (7.5YR 7/4) minute sand. Absolute hardness at 5 cm from the surface was 48.0 kg/cm^2; at 15 cm, 40.0 kg/cm^2; and at 30 cm, 42.0 kg/cm^2. The hardness category was very hard. When the soil was wet, soil hardness decreased drastically. This sedimentary layer was strongly acidic at pH 4.5, EC was low at 41-88 µS/cm, contained little salts as well as little nitrogen, carbon, and phosphates. Neither physical nor chemical soil properties were suitable for plant growth. When the exposed sedimentary layer is very hard or hard, rain does not infiltrate the surface, and promotes surface runoff. Plot 1 with such hardened surface saw no plant growth. With no waste input, the surface remained very hard or hard after 7, 12, 24, and 36 months later. The sedimentary layer lied until 30 cm from the surface.

Plot 4 was scattered with a 2 cm layer of waste. Soil hardness at 5, 15, and 30 cm were all very hard, and soil color was dull orange (7.5 YR7/4). Seven months later, soil with much organic matter had accumulated for 5 cm thickness and the porous soil was slightly hard. This surface soil was neutral at pH 7.6 as was the case for plot 3. It contained much mineral salts, nitrogen, carbon, and phosphate deriving from the waste. The soil color was dull yellow orange (10YR 6/4), and contained much organic matter from the waste. “Termite sand” 5-17 cm deep to sedimentary layer 17-30 cm deep had improvement in chemical property due to the waste but limited and did not contain much nutrients. Both soils were colored dull orange (7.5YR 7/4).

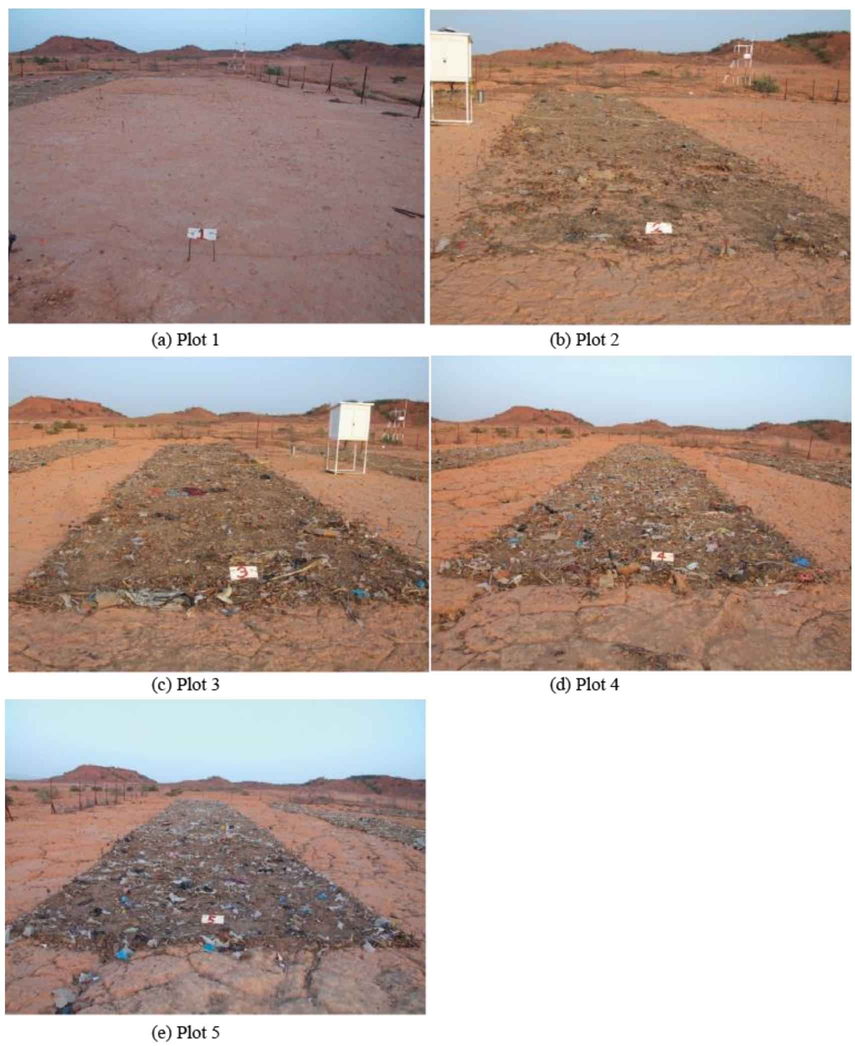
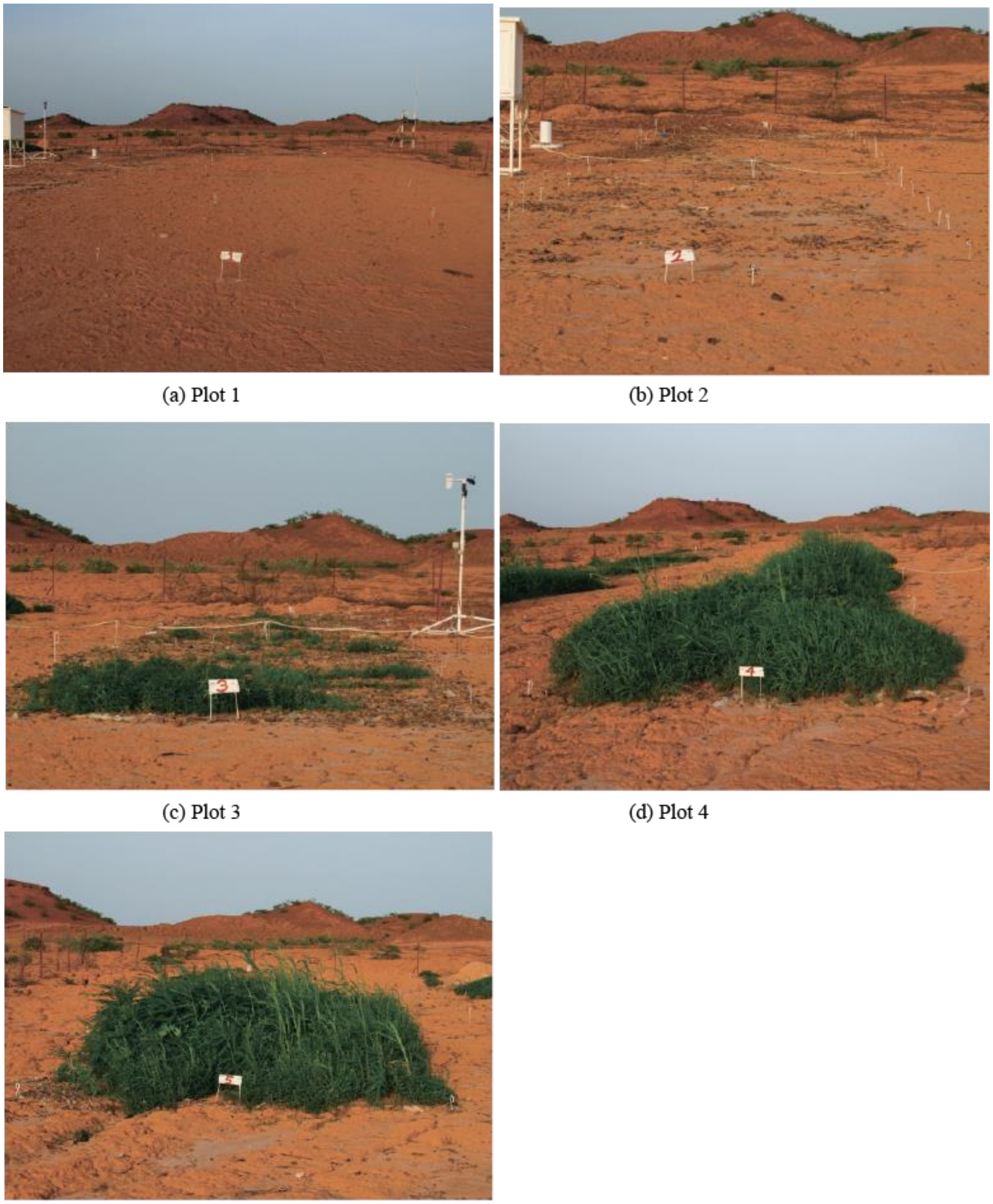


Figure 1: Five plots of urban waste input (November 2008): (a) no waste, (b) 5 kg/m^2, (c) 10 kg/m^2 (d) 20 kg/m^2, and (e) 45 kg/m^2



(a) Plot 1 (b) Plot 2

(c) Plot 3 (d) Plot 4

(e) Plot 5

Figure 2: Five plots of urban waste input (August 2010): (a) no waste, (b) 5 kg/m^2, (c) 10 kg/m^2 (d) 20 kg/m^2, and (e) 45 kg/m^2

After 24 months "manure sand" was 3 cm deep. It was loose and dull yellow orange (10YR 6/4). The effect of waste scattering was apparent. "Termite sand" was 3-13 cm deep underneath which was the sedimentary layer. Soil hardness for the former was very hard, and the latter was hard. Both were colored dull orange (7.5YR 7/4). Plant roots were found until 5 cm deep and they reached the "termite sand" through “manure sand”. After 36 months, wind-blown sand had accumulated 1 cm deep. The color was dull orange and the hardness was loose. “Manure sand” was 1-3 cm deep and dull yellow orange (10YR 6/4). The soil hardness was slightly soft. From 3-10 cm deep there were many termite tunnels. This soil was “termite sand” and slightly hard. Below 10 cm deep was the sedimentary layer, and very hard. From 12-24 months later, decomposition of the organic matter and reduction in organic and “manure sand” due to soil erosion and termite activity was found, and land degradation resumed after 24 months.

Discussion

The critical amount of urban waste was at least 20 kg/m^2, approximately 2 cm thick on the ground for land restoring. This study revealed the urban waste input on the eroded land improve plant growth through combination of 8 factors identified below (Figure 3). The soil type of Arenosols is prone to damage from water and wind erosion (Bleich and Hammer, 1996). But low mounds with intricate elevations on the flat topography in effect (1) trapped sand and organic matter blown in from the strong winds. This effect is the same that Michaels *et al.* (1995) aimed the wind erosion control using millet residue, and (2) urban waste prevents erosive wind and water.

Through this termite activity, (3) termite shelters over the organic matter have concentrated amounts of organic matter and termites elevate the small grain clay and silt in the soil and mixes them with wind-blown sand, (4) termite tunnels penetrate the sedimentary layer which allows rainwater to infiltrate easily through the tunnels, and (5) the aggregated soil structure is created as they solidify grains of sand with their saliva when termites build the mounds. According to the observation result, the aggregated soil structure is porous, and allows plant roots to grow and penetrate as well as contains oxygen and moisture all necessary for plant growth.

These all contribute to ameliorating poor nutrient content and strong acidity indicated in the high pH of the parched degraded land. Organic matter including livestock excreta contains much nitrogen, phosphate, and potassium, and the chemical properties of the soil are much improved. Urban waste and excreta are neutral to alkaline, and (6) neutralize the soil acidity (pH 4.5) of the degraded land, (7) adding nutrients to the soil. Finally, (8) urban waste contains many seeds of edible matter including pearl millet, *Hibiscus subdarefa, Balanites egyptiaca*, and plants favored as feed for livestock. These naturally germinate with the arrival of the rainy season, and the experimental plots saw their growth thanks to moisture and nutrients from the waste. The above eight effects can be combined to improve soil fertility and plant growth productivity.

Conclusions

The experiment revealed that urban organic waste is capable of preventing soil erosion and preparing grazing grassland and pearl millet fields. The urban waste may have dangerous contents such as heavy metals (Adejumo *et al.*, 2011), but we can avoid toxic substances by using the urban waste dumped immediately from house yards. In the Sahel, urban waste contains much wind-blown sand and organic content in the form of excreta and leftover food stuffs that are rich in nutrients. The land degradation in farmland and urban waste proliferation in urban areas are two sides of the same coin. The problem lies in the imbalance in the organic matter cycle between rural area and urban area. Urban organic waste is, therefore, an advantageous resource that can be used to improve depleted soils in farmland and it should be utilized for land rehabilitation.

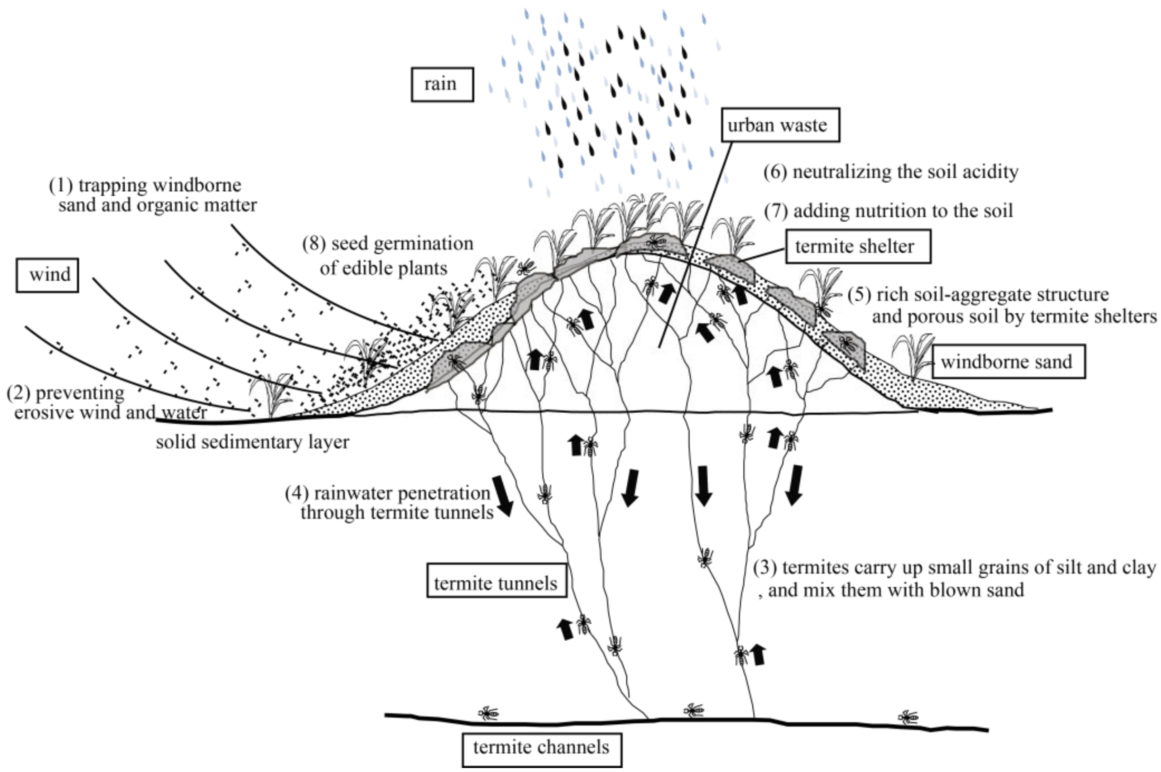


Figure 3: Eight effects of the urban organic waste input on the degraded land for combating soil erosion

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References

Adejumo, S.A., Togun, A.O., Adediran, J.A. & Ogundiran, M.B. 2011. Field assessment of progressive remediation of soil contaminated with lead-acid battery waste in response to compost application. *Pedologist*, Special Issue, 54(3): 182-193

Ayantunde, A.A. 2000. Herder's perceptions, practice, and problems of night grazing in the Sahel: Case studies from Niger. *Human Ecology*, 28: 109-130.

Bleich, K.E. & Hammer, R. 1996. *Soils of western Niger*. In: B. Buerkert, B.E. Allison and M. von Oppen (eds.) *Wind erosion in Niger: Implications and control measures in a millet based farming system*. Dordrecht: Kluwer Academic Publishers, pp. 23-32.

Michaels, K., Sivakumar, M.V.K. & Allison, B.E. 1995. Wind erosion control using crop residue II: Effects on millet establishment and yields. *Field Crops Research*, 40: 111- 118.

Mortimore, M. & Turner, B. 2005. Does the Sahelian smallholder's management of woodland, farm trees, rangeland support the hypothesis of human-induced desertification? *Journal of Arid Environments*, 63: 567-595.

Oyama, S. 2012. Land rehabilitation methods based on the refuse input: local practices of Hausa farmers and application of indigenous knowledge in the Sahelian Niger. *Pedologist,* 55: Special Issue: 466-489.

Oyama, S. 2015. Land degradation and ecological knowledge-based land rehabilitation: Hausa farmers and Fulbe herders in the Sahel region, West Africa. In: T. Reuter (ed.) *Averting a Global Environmental Collapse: The Role of Anthropology and Local Knowledge*. Cambridge: Cambridge Scholars Publishing, pp.165-185.

Oyama, S. 2018. Reverse thinking and "African Potentials"to combat desertification in the West African Sahel: Applying local greening techniques born from drought and famine in the 1970s. *African Study Monographs,* supplementary, 57: 95-120.

Tschakert, P. 2007. Views from the vulnerable: Understanding climatic and other stressors in the Sahel. *Global Environmental Change*, 17: 381-396.

Warren, A., Osbahr, H., Batterbury, S. & Chappell, A. 2003. Indigenous views of soil erosion at Fandou Béri, southwestern Niger. *Geoderma*, 111: 439-456.

Soil quality assessment by enzyme activities in an olive orchard subjected to living mulch to counteract soil erosion

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Abstract

In this study, we tested the use of soil enzyme activity as a tool to assess the effect on soil quality of different strategies of living mulch application finalized to counteract soil erosion. Seven enzyme activities (FDA hydrolysis, β-glucosidase, N-acetyl β-D glucosaminidase, acid and alkaline phosphatase, arylsulphatase, dehydrogenase) were measured in three plot of an olive orchard subjected to living mulch alone, living mulch combined with compost addition and living mulch combined with compost and microorganisms addition, in comparison with an untreated control. Organic matter and active carbon content were also measured in the soil under the different treatments. FDA hydrolysis, acid and alkaline phosphatase, N-acetyl β-D glucosaminidase and β-glucosidase activities were increased in the soil under living mulch, compost and microorganisms, likely due to higher organic content and perhaps to the additional production of enzymes by the supplied microbes. The results showed that living mulch improved soil quality, especially when combined with compost and microorganism addition, and that the effect was related to the increase in organic matter and active carbon content.

Keywords: soil enzyme activities, soil quality, organic matter, active C

Introduction, scope and main objectives

In the European Unit, about 11.4 % of the territory is estimated to be affected by soil erosion, with a total annual loss of soil of 970 million tons for water and 53 million tons for wind erosion (Panagos *et al.*, 2017). The loss of organic matter is among the main consequences of soil erosion and, in turn, among the main cause of reduced soil quality and fertility (Gregorich *et al.*, 1994).

Living mulches and compost amendment are sustainable management strategies able to reduce or mitigate soil erosion and, at the same time, to preserve or improve soil quality, in accordance with the principles of organic and regenerative agriculture. A living mulch is a ground cover of planted grass which reduces the intensity of rain drop impact and the water runoff, increases soil permeability allowing water infiltration into the soil and improves soil aggregation by root systems (Hartwig and Ammon, 2002). Both living mulches and compost amendment increase soil organic matter as well as microbial biomass and activity. Organic matter plays a key role on soil hydraulic properties and bonds soil particle into aggregates, which may be glued together by gums and mucilage produced by soil microorganisms (Hartwig and Ammon, 2002). Thus, it is likely that the combination of living mulches, compost amendment and microbial stimulation or augmentation can produce synergistic effects in combating soil erosion and the consequent loss of organic matter, with concomitant improvement of soil quality.

In order to assess the effectiveness of management strategies for soil conservation, it is crucial to identify suitable indicators. Soil enzyme activities are widely used as indicators of soil quality and they may also provide information about the effectiveness of soil erosion fight strategies, since they strongly depend on the labile fraction of soil organic matter, which is typically depleted in degraded soils (Gregorich *et al.*, 1994).

The aim of this study was to assess the effects on soil quality of three management strategies designed to counteract the soil erosion in an olive orchard in Southern Italy. For this goal, seven enzyme activities (FDA hydrolysis, acid and alkaline phosphatase, N-acetyl β-D glucosaminidase, arylsulphatase, β-glucosidase, dehydrogenase) were measured in the soil under the different treatments and correlated with soil organic matter and active carbon content.

Methodology

The study was carried out in an olive orchard at 560 m a.s.l., with South-South East exposure, located at San Mauro Cilento in the "Parco Nazionale del Cilento, Vallo di Diano e Alburni" (Province of Salerno, Campania Region, Italy). The soil is prone to erosion due to a 20-25 % slope and the lack of herbaceous cover as a consequence of intense trampling and grazing of horses. In december 2017, four plots of 150 m^2 each were delimited and the soil was subjected to living mulch by different strategies: living mulch alone (L); living mulch and compost amendment (LC); living mulch, compost amendment and microbial augmentation (LCM); untreated control (U). Living mulch was obtained sowing at 3-4 cm of depth a mixture of common wheat (*Triticum aestivum* L., 50 Kg ha^{-1}), red oats (*Avena sativa* L., 80 Kg ha^{-1}), common vetch (*Vicia sativa* L., 60 Kg ha^{-1}) and climson clover (*Trifolium incarnatum* L., 20 Kg ha^{-1}). The compost, four months old, was obtained from a mixture composed by olive pomace (65 %), bovine manure (25 %), pruning branches (10 %) and was buried (5 cm of depht) at a rate of 50 t ha^{-1} of dry matter, corresponding to 75 t ha^{-1} of wet weight. The microorganisms were obtained by a microbial accumulator, set up with a mixture of forest litter, wheat brain, sugar or molasses and water as growth media. Details on microbial accumulator preparation, as well as on microorganism extraction and application to soil, are extensively described by Mancini (2019).

Soil samples (0-10 cm depth) were collected in May 2018: five soil cores were taken from each plot and mixed to obtain a homogeneous sample *per* plot. The soil samples were sieved (2mm) and stored at 4 °C in polyethylene bags.

Seven soil enzyme activities (FDA hydrolysis, β-glucosidase, arylsulphatase, N-acetyl-β-D-glucosaminidase, acid and alkaline phosphatase, dehydrogenase) were assessed meausuring by spectrophotometry the enzymatic transformation rate of synthetic chromogenic compounds added as substrates (references of methods are reported in Scotti *et al.*, 2015). Soil organic matter content was estimated by loss on ignition (400 °C for 4 h). The soil active carbon, which represents the pool of more labile organic compounds, was measured by potassium permanganate oxidation as described by Weil *et al.* (2003). All analyses were performed in triplicate and the results are reported as mean values ± standard deviation.

In order to assess the significance of differences among treatments, data with normal distribution were processed by One Way ANOVA followed by Holm-Sidak post hoc test. The normality test failed for β–glucosidase activity and organic matter content, and they were analysed by ANOVA on Ranks, followed by Tukey post hoc test. In order to assay the significance of correlations, Pearson or Spearman tests were applied to data with normal or not normal distribution, respectively.

Results

The results are shown in table 1. All enzyme activities showed significant differences ($P<0.05$) among treatments, except for arylsulphatase and dehydrogenase activities. In particular, the soil under LCM treatment showed significantly higher values of FDA hydrolysis, β–glucosidase, N-acetyl-β-D-glucosaminidase and alkaline phosphatase in comparison with the other treatments. However, beyond the statistical analysis, all enzyme activities appeared considerably increased by living mulch, without or with compost addition (L and LC) and even more with microbial augmentation (LCM), in comparison with untreated control (U). The organic matter content showed significant differences among treatments ($P<0.05$), with higher values in LCM. By contrast, the active fraction of soil organic C was not significantly different among treatments, although it was, on average, three times higher in the plots L, LC and LCM (mean value 2.17 g Kg^{-1}), than in U.

All the enzyme activities were positively correlated with organic matter and, with a generally lower significance, with the active carbon content (Table 2).

Discussion

Soil quality has been defined as the continued capacity of a soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, maintain or enhance the quality of air and water and promote plant, animal and human health (Laishram *et al.*, 2012). Despite the wide interest in the assessment of soil quality, the choice of suitable indicators is still an open debate. Soil organic matter plays a key factor in all soil functions. However, its use as soil quality indicator is questionable, since changes can be revealed on a wide temporary scale (Laishram *et al.*, 2012). Soil enzymes, mainly produced by bacteria and fungi and, to a lesser extent, by plants and earthworms, control the dynamics of nutrients in terrestrial ecosystems. Soil enzyme activities have been extensively reported by the scientific literature as indicators of soil quality, since they quickly respond to changes in a number of environmental factors and are sensitive, easy and cheap to perform. Moreover, they were tested in relation to a variety of different environmental factors (Gregorich *et al.*, 1994). Enzyme production and accumulation in soil is enhanced by living mulch due to the increase of carbon inputs to soil and rhizodeposition, which stimulate soil microbial communities and supply plant-produced enzymes. Compost amendment also increases soil enzyme activities: it is an important source of carbon, energy and nutrients for soil microbial community, and improves the physicochemical environment for microbial growth. Iovieno *et al.* (2009) reported an increase of enzyme activity up to 2.5 times in an agricultural soil treated for three years with 15, 30 or 45 t ha^{-1} y (d.w.) of compost, showing a dose related effect. In the present study, compost amendment did not show additive effects with living mulch on soil enzyme activity: this suggests that the grass cover already expresses in itself a high potential of soil quality amelioration, which is not further increased by compost. A different effect was shown by the combined treatments with living mulch, compost and microbial augmentation: this treatment produced a relevant improvement of soil quality, translatable in an increased efficiency of organic matter breakdown and nutrient turnover. It can be supposed that the addition of microorganisms produces an awakening of the edaphic ecosystem, giving impetus to its functioning. However, the correlations of enzyme activities with organic matter and, to a lesser extend with its more labile fraction, underline the importance of these latter to explain the observed trends.

Table 1: Enzyme activities, organic matter and active carbon content (mean values ± standard deviation) in the soil from the untreated plot (U) and under different treatments (L=living mulch; LC=living mulch+compost; LCM= living mulch+compost+microorganisms. Different letters indicate significant differences (P<0.05) among treatments.

	U	L	LC	LCM
FDA hydrolysis (μg FDA g^{-1} d.w. h^{-1})	1926 ± 315 b	2916 ± 338 b	2581 ± 382 b	4856 ± 950 a
β-glucosidase (μg PNP g^{-1} d.w. h^{-1})	81 ±12 b	188 ± 38 b	171 ± 37 b	372 ± 40 a
N-acetyl β D- glucosaminidase (μg PNP g^{-1} d.w. h^{-1})	17 ± 0.5 b	41 ± 6.2 b	±58 ± 30 b	106 ± 18.2 a
Alkaline phosphatase (μg PNP g^{-1} d.w. h^{-1})	968 ± 53 b	1379 ± 137 b	1327 ± 179 b	2135 ± 278 a
Acid phosphatase (μg PNP g^{-1} p.s. h^{-1})	150 ± 7.8 b	203 ± 32 abc	180 ± 32 bc	326 ±42 a
Arylsulphatase (μg PNP g^{-1} d.w. h^{-1})	37 ± 3.8 a	105 ±47 a	105 ± 32 a	173 ± 2.8 a
Dehydrogenase (μg TPF g^{-1} d.w. h^{-1})	0.59 ± 0.13 a	1.26 ± 0.69 a	1.22 ± 0.45 a	2.32 ± 0.58 a
Organic matter (mg Kg^{-1} d.w.)	33.0 ± 1.67 a	39.0 ± 6.27 a	73.8 ± 39.8 a	172 ± 76 a
Active C (mg Kg^{-1} d.w.)	0.91 ± 0.19 a	1.91 ± 1.55 a	1.86 ± 0.58 a	2.74 ± 0.38 a

Table 2: Correlation coefficients of the seven enzyme activities with organic matter and active carbon content in soil. (*P<0.05; **P<0.01; P<0.001).

	Organic matter	Active C
FDA hydrolysis	0.748**	0.650*
β-glucosidase	0.839***	0.776**
N-acetyl β D- glucosaminidase	0.853***	0.731**
Alkaline phosphatase	0.874***	0.713**
Acid phosphatase	0.790***	0.748**
Arylsulphatase	0.825***	0.937***
Dehydrogenase	0.699*	0.727**

Conclusions

This study indicates soil enzyme activities as useful tools to assess the effect on soil quality produced by the introduction of living mulch to counteract soil erosion. The results suggest that living mulch has the potential to improve soil quality but, at least in the investigated environment, this effect is evident only when the grass sowing was implemented with compost amendment and microbial augmentation. These should be considered as preliminary results: further studies will be carried out to confirm these findings and their extensibility to different environments.

References

Hartwig, N.L. & Ammon, H.U. 2002. Cover crops and living mulches. *Weed Science*, 50:688-699.

Gregorich, E.G., Carter, M.R., Angers, D.A., C. Monreall, M. & Ellerta, B.H. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. *Canadian Journal of Soil Science*, 74(4): 367-385.

Iovieno, P., Morra, L., Leone, A., Pagano, L. & Alfani, A. 2009. Effect of organic and mineral fertilizers on soil respiration and enzyme activities of two Mediterranean horticultural soils. *Biology and fertility of soils*, 5:555–561.

Laishram, J., Saxena, K.G., Maikhuri, R.K. & Rao, K.S. 2012. Soil quality and soil health: A review. *International Journal of Ecology and Environmental Sciences,* 38(1): 19-37.

Mancini, M. 2019. *Agricoltura organica e rigenerativa*. Firenze: Terra Nuova Edizioni.

Panagos, P., Ballabio, C., Lugato, E., Jones, A. & Borrelli, P. 2017. Condition of agricultural soils: Factsheet on soil erosion, EUR 29020, Publication Office of the European Union, Luxemburg.

Scotti, R., Iovieno, P. & Zaccardelli, M. 2015. Comparative assessment of microbial activity and biomass in paired forest and agricultural soils. *Biology and Fertility of Soils*, 51(8): 1013–1019.

Weil, R.R., Islam, K.R., Stine, M.A., Gruver, J.B. & Samson-Liebig, S.E. 2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *American Journal of Alternative Agriculture*, 18: 3-17.

Influence of mosses on soil hydraulic conductivity, penetration resistance and water repellency six years after a post-fire salvage logging treatment

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Abstract

Salvage logging (SL), a common post-fire management, can seriously affect the soil properties and therefore soil hydrology. An SL treatment was carried out in a fire-affected area in Sierra de Mariola (E Spain), resulting in rill formation and the detrimental of several soil properties. Currently, six years after the disturbance, bare soils remain as a symptom of erosion in the affected area. However, the high presence of mosses may be key to increase soil stability and protect the soil from erosion after the fire. The aim of this work was to assess the medium-term effects of an SL treatment in burned soils, and the influence of mosses in soil attending to the hydraulic properties. The hydraulic conductivity, soil resistance to penetration and water repellency, as the key factors controlling the soil hydrological behaviour, were measured in bare soils and in soil covered by mosses, in both SL and control areas. Our results did not show significant detrimental consequences regarding the parameters studied due to the management practice. However, due to their protective role for soil, it is highly recommended to take mosses in to account in any post-fire plan management.

Keywords: wildfire, salvage logging, mosses, hydraulic conductivity, penetration resistance, water repellency

Introduction, scope and main objectives

Salvage logging (SL) is a common practice after a wildfire in the Mediterranean forest. Depending on the way to perform it, manually or by using heavy machinery, and also the vulnerability of soils towards erosion and degradation, this practice can be very aggressive with the soil. Wildfires often change some soil properties affecting the soil hydrology during a period after the perturbation, mainly due to the destruction on the vegetation cover and the loss of soil organic matter (Cerdà, 1998). Post-fire salvage logging in this stage can increase soil disturbance and erosion, compromising the cover and composition of recovering native vegetation, and negatively affecting many soil properties in the first topsoil centimetres (García-Orenes *et al.*, 2017). An increase in runoff rates and erosion, by reducing micro and macro porosity associated with an increase in soil compaction due to equipment traffic, have been found in SL treatments (Wagenbrenner *et al.*, 2016). On the other hand, some authors did not found any detrimental effects by SL (Fernández and Vega, 2016)

In July 2012, a forest fire of moderate severity affected 546 ha in Sierra de Mariola (Alicante, E Spain). Six months after the forest fire, salvage logging (SL) treatments, consisting on a complete extraction of the burned wood using heavy machinery, were applied. The soil is developed over marls with a low depth, very vulnerable to erosion and degradation processes. The treatment resulted in rills formations. At present, six years after, the affected soils are mostly covered by vegetation, but bare soils remain in the burned area as a symptom of erosion.

The presence of a high cover of mosses has been detected in the affected soils. There is an extended bibliography about the key roles of these organisms forming part of the biocrust (biological soil crust) in high abiotic stress systems, especially in increasing soil stability and in protect it from erosion (Belnap and Lange, 2003). Biocrust can affect infiltration by its cover and composition and therefore the roughness of the surface (Rodríguez-Caballero *et al.*, 2012), as well as increasing soil aggregation, clogging soil pores by trapping fine particles or by the hydrophobicity of some species (Chamizo *et al.*, 2015). Mosses are found to reduce runoff and enhance infiltration (Eldridge *et al.*, 2010).

We hypothesize that the presence of mosses covering the soil had a key role in recovering the soil after the fire attending to the hydraulic properties and protecting the soil from increasing erosion. In order to research the medium-term (6 years) effects of an SL treatment in soils, and the impact of mosses in them, hydraulic conductivity (K), soil resistance to penetration (PR) and water repellency (WR) were evaluated as key factors controlling the soil hydrological response.

Methodology

Study area and experimental design

The study area is located in “Sierra de Mariola Natural Park” in Alcoi, Alicante (E Spain). This area has a Mediterranean climate, with an average precipitation of 490 mm and mean temperatures of 14.8 ºC. The soil is classified as a Typic Xerorthent (Soil Survey Staff, 2014) developed over marls.

Two adjacent study areas of 50 m^2 were established, one in the SL area and the other in a similar nearby area with no treatment, the control (C). In each area, 25 random points over bare soils (BS) and 25 points over mosses (M) were distributed randomly (50 for each treatment, 100 in total).

Analysis

A Mini-Disk Infiltrometer (Decagon Devices, USA, 2007) was used for measure hydraulic conductivity (K) in each point over BS and M. Soil penetration resistance (PR), representing the pressure applied to the soil surface before it breaks, was measured in each point in 2 cm intervals in 5 pseudoreplicates, over BS and M, and under M, using a field penetrometer (Geotester Pocket Penetrometer, Italy). The same procedure was applied to measure water repellency (WR), assessed by the Water Drop Penetration Time (WDPT) test.

Non-parametric Mann-Whitney U test and Kruskal-Wallis test for the analysis of mean comparison was chosen due to the lack of normality and homoscedasticity requirements. Significant differences were determined by Kruskal-Wallis post hoc test ($P < 0.05$). All the analyses were performed with a confidence level of 95 % by using SPSS v.20.0 (SPSS Inc., Chicago, USA).

Results

The values for K did not show significant differences between the SL treatment and the control and neither between BS and M in each treatment. However there is a slight increasing trend of this parameter which can be appreciated in M values.

For PR the obtained values were low (1.2-1.5 kg/cm^2), without significant differences between BS and over and under M, and between SL and C.

Significant differences were found for the WR parameter. Mosses showed water repellency comparing to BS and soils under M, with hardly ever repellency. However, the maximum value for water repellency was 60 seconds.

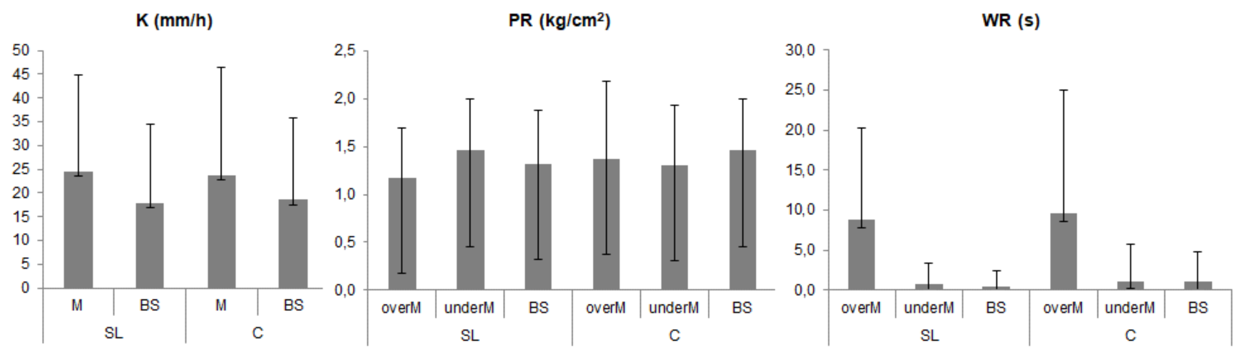

Figure 1: Hydraulic conductivity, K (mm/h); penetration resistance, PR (kg/cm^2); and water repellency, WR (s), measured in treated soils by salvage logging (SL) and control (C), over bare soils (BS) and over and under mosses (M) for PR and WR.

Discussion

Our results did not show significant differences between the treated soils with salvage logging practice and the control soils. However, although no detrimental effects were shown in this study regarding the studied parameters, a significantly higher cover of mosses was found in control soils, 58.8 % and 78.4 % (significant differences at $p<0.05$, data not published), in SL and C respectively.

According to Belnap (2006), biocrust can influence the local hydrological cycles by modifications in soil porosity, absorptivity, roughness, aggregate stability, texture, pore formation and water retention. Mosses specifically provide better protection from raindrop impact. However, as the author reports, the influence in soils also depends on the disturbance history; hence, six years since a perturbation as a wildfire and additionally aggressive post-fire management may be a short time for some parameters recovery or see any influence.

The protection of mosses against water erosion is widely accepted (Bowker *et al.*, 2008); indeed, Chamizo *et al.* (2015) reported that the highest impacts on water processes take place during the first rains after a disturbance in the biocrust. Therefore, the appearance of the biocrust would slow down the erosion processes and six years after no influence in the hydraulic conductivity would appear.

Biocrust controls water infiltration by affecting the surface penetrability (Zaady *et al.*, 2014). Higher developmental stages of the biocrust are related to higher penetration resistance. However, despite mosses cover high areas of soil, only six years after a perturbation may not be enough time to develop a complex state of the biocrust that could reach higher levels of differences between mosses and bare soils.

Hydrological processes can be affected by soil hydrophobicity, which is known to enhance runoff responses and soil erosion (Mataix-Solera and Doerr, 2004). In our study, the soils rarely showed water repellency, but the mosses did. Some authors like Williams *et al.* (2012) expose that the hydrophobic characters of the mosses may help trapping water near the soil surface. In any case, our WR results showed lower values.

Conclusions

Despite post-fire salvage logging affected in a medium-term to the percentage of soil covered by mosses, our results did not show significant detrimental consequences regarding the hydraulic conductivity, penetration resistance and water repellency parameters as a consequence of the management practice. Salvage logging was a very aggressive practice with soils over marls, but the development of vegetation like mosses forming part of a biocrust could be protecting the soil in a medium-term. We recommend to forest managers to take into account this natural recovery in order to do not affect them if any post-fire management is planned. More research is needed in order to identify if mosses are improving significantly other soil properties.

Acknowledgements

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References

Belnap, J. 2006. The potential roles of biological soil crusts in dryland hydrologic cycles. *Hydrological Processes,* 20(15): 3159–3178.

Belnap, J., & Lange, O. L. (Eds.). 2013. Biological soil crusts: structure, function, and management (Vol. 150). Springer Science & Business Media.

Bowker, M.A., Belnap, J., Chaudhary, V.B. & Johnson, N.C. 2008. Revisiting classic water erosion models in drylands: the strong impact of biological soil crusts. *Soil Biology Biochemistry*, 40: 2309–2316.

Chamizo, S., Rodríguez-Caballero, E., Cantón, Y., Asensio, C. & Domingo, F. 2015. Penetration resistance of biological soil crusts and its dynamics after crust removal: relationships with runoff and soil detachment. *Catena*, 126: 164-172.

Cerdà, A. 1998. Changes in overland flow and infiltration after a rangeland fire in a Mediterranean scrubland. *Hydrological processes*, 12(7): 1031-1042.

Eldridge, D.J., Bowker, M.A., Maestre, F.T., Alonso, P., Mau, R.L., Papadopoulos, J. & Escudero, A. 2010. Interactive effects of three ecosystem engineers on infiltration in a semi-arid Mediterranean grassland. *Ecosystems*, 13(4): 499-510.

Fernández, C. & Vega, J.A. 2016. Effects of mulching and post-fire salvage logging on soil erosion and vegetative regrowth in NW Spain. *Forest Ecology and Management*, 375: 46–54.

García-Orenes, F., Arcenegui, V., Chrenková, K., Mataix-Solera, J., Moltó, J., Jara-Navarro, A.B. & Torres, M.P. 2017. Effects of salvage logging on soil properties and vegetation recovery in a fire-affected Mediterranean forest: A two year monitoring research. *Science of the Total Environment*, 586, 1057-1065.

Mataix-Solera, J. & Doerr, S.H. 2004. Hydrophobicity and aggregate stability in calcareous topsoils from fire-affected pine forests in southeastern Spain. *Geoderma*, 118(1-2): 77-88.

Rodríguez-Caballero, E., Cantón, Y., Chamizo, S., Afana, A. & Solé-Benet, A. 2012. Effects of biological soil crusts on surface roughness and implications for runoff and erosion. *Geomorphology*, 145–146: 81–89.

Wagenbrenner, J.W., Robichaud, P.R. & Brown, R.E. 2016. Rill erosion in burned and salvage logged western montana forests: effects of logging equipment type, traffic level, and slash treatment. *Journal of Hydrology,* 541: 889–901.

Williams, A.J., Buck, B.J. & Beyene, M.A. 2012. Biological Soil Crusts in the Mojave Desert, USA: Micromorphology and Pedogenesis. *Soil Science Society of America Journal*, 75(5): 1685.

Zaady, E., Katra, I., Yizhaq, H., Kinast, S. & Ashkenazy, Y. 2014. Inferring the impact of rainfall gradient on biocrusts' developmental stage and thus on soil physical structures in sand dunes. *Aeolian Research*, 13: 81-89.

Use of perennial crop (*Arundo Donax* L.) in two degraded areas to control soil erosion and improve soil quality

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Abstract

Perennial plants can reduce soil erosion and improve soil features also providing biomass for biofuel. In this paper, we monitored during three years aboveground and belowground biomass of Giant reed (*A. donax* L) and soil concentration of organic carbon in two eroded areas in Southern Italy. Our results indicated a good adaptability of *A. donax* L. to degraded soils and good productive performance with different growth strategies. After a first naturalization period, *A. donax* L. can reach high yields and a complete soil covering in short time thus contributing to soil erosion control and improving soil quality by increasing C storage in soil, very important for climate change mitigation.

Keywords: Erosion, Giant reed, Biomass crops, Soil fertility, Carbon sequestration

Introduction, scope and main objectives

Soil erosion is one of the biggest environmental problems throughout European Union (Panagos *et al.*, 2015). Natural drivers such as climate change, steep topography and rainfall erosivity in autumn and winter seasons cause a considerable loss of soil (Kosmas *et al.*, 1997) with an increased severity due to human activities such as forest fires, road construction and soil cultivation. The best way to reduce soil erosion at all levels is using plant cover to regulate hydrological processes and increase soil fertility (Duràn-Zuazo *et al.*, 2013). It has been reported that perennial crops are associated to a lower soil lower erodibility and water runoff than annual crops, owing to soil covering for a longer time (Fernando *et al.*, 2010) as compared to annual species (Zegada-Lizarazu *et al.*, 2010). In particular, perennial plant species, such as giant reed (*A. donax* L.), might help to limit soil erosion in sloping areas and increase carbon storage in the soil, also providing lignocellulosic biomass for energy and green chemistry (Zegada-Lizarazu *et al.*, 2010). Giant reed is a rhizomatous plant, from rhizomes fibrous roots starts reaching 1 m of depth (Monti and Zatta, 2009), suitable for any type of soil, including marginal soils with poor fertility and high salinity (Pilu *et al.*, 2012).

Therefore the objectives of the present study were to evaluate the growth potential and effect on soil fertility by a perennial plant species (*A. donax* L.), known for its adaptability and soil erosion prevention (Cosentino *et al.*, 2015; Fagnano *et al.*, 2015) in two degraded lands.

Methodology

A 3-year experiment was carried out in two degraded sites in Southern Italy: an ex-landfill in a marginal plain area (Teverola) characterized by physical degradation due to soil compaction, poor fertility; a marginal hilly area (Sant'Angelo dei Lombardi; 10 % slope) where deep soil tillage performed in late summer caused a severe water erosion in autumn-winter period when rainfalls occur on soil not covered by vegetation.

A. donax L. rhizomes (local ecotype) were transplanted on spring 2014 at 10-16 cm of soil depth with a density of 2 pt m^{-2} (0.6 m x 0.8 m). Plants were grown under low agronomic inputs conditions (no irrigation and fertilization). Belowground (rhizomes and roots) and aboveground (culms and leaves) biomass was monthly collected from July 2014 together with bulk-soil (0-30 cm) at both sites (4 plants per sampling). The growth parameters evaluated were aboveground (leaves culms) and belowground (rhizomes and roots) biomass; a sub-sample of each plant tissue was washed and oven-dried at 60 °C until constant weight for dry matter determination. Total C concentration was determined in bulk samples (0-30 cm depth) at the end of each growth cycle.

Results

Plants growth

In the 1st growth cycle (2014), the aboveground maximum growth was lower at Teverola (Figure 1a) than S. Angelo site (180 g DW pt^{-1} vs 280 g DW pt^{-1} respectively) (Figure 1b). Similar to aboveground growth, belowground maximum biomass production was lower at Teverola (Figure 2a) than S. Angelo site (Figure 2b) in the first year (283 g DW pt^{-1} vs 409 g DW pt^{-1} respectively).

In 2015 (2nd growth cycle), the aboveground growth peak at Teverola site increased by 10 times (1717 g DW pt^{-1}) compared to the first year (Figure 1a) while at S. Angelo the maximum aboveground growth was almost 3 times higher (871 g DW pt^{-1}) than first year (Figure 1b). Belowground biomass in the second growth cycle showed a 6-fold increase at Teverola (Figure 2a) and a 2-fold increase at S. Angelo site (Figure 2b) compared to the first year.

In 3st (2016) growth cycle, the maximum aboveground biomass production at S. Angelo site showed a maximum value of 1315 g DW pt^{-1} (Figure 1b), while after the summer at Teverola site, the aboveground growth peak reached 2434 g DW pt^{-1} (Figure 1a). The maximum belowground biomass in the third growth cycle reported values of 1792 g DW pt^{-1} at Teverola site and 1361 g pt^{-1} at S. Angelo site. The seasonal peak of belowground biomass accumulation was reached in late winter (January) in both sites.

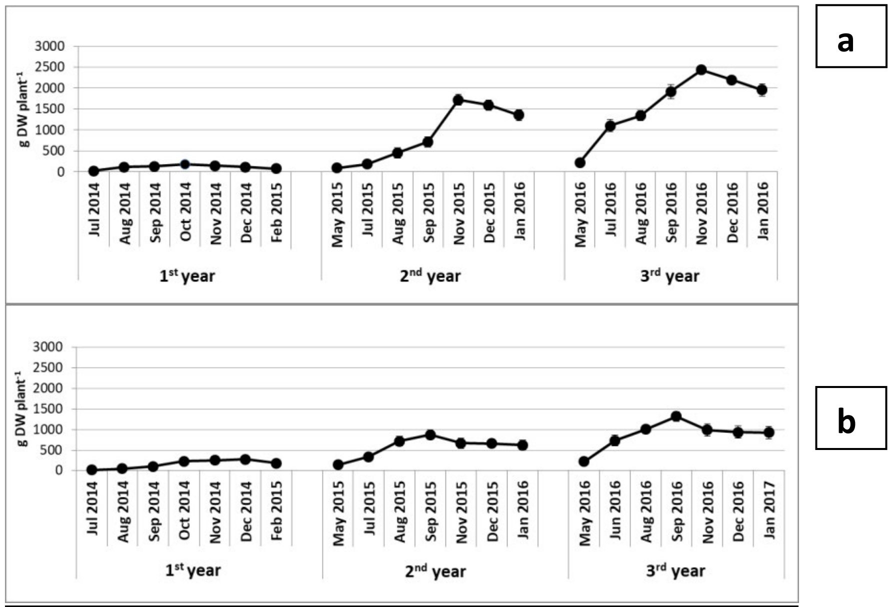

Figure 1a and 1b: Growth trend of *A. donax* aboveground biomass (dry weight) in Teverola site (a) and in S. Angelo dei Lombardi site (b). Bars indicate ± standard errors.

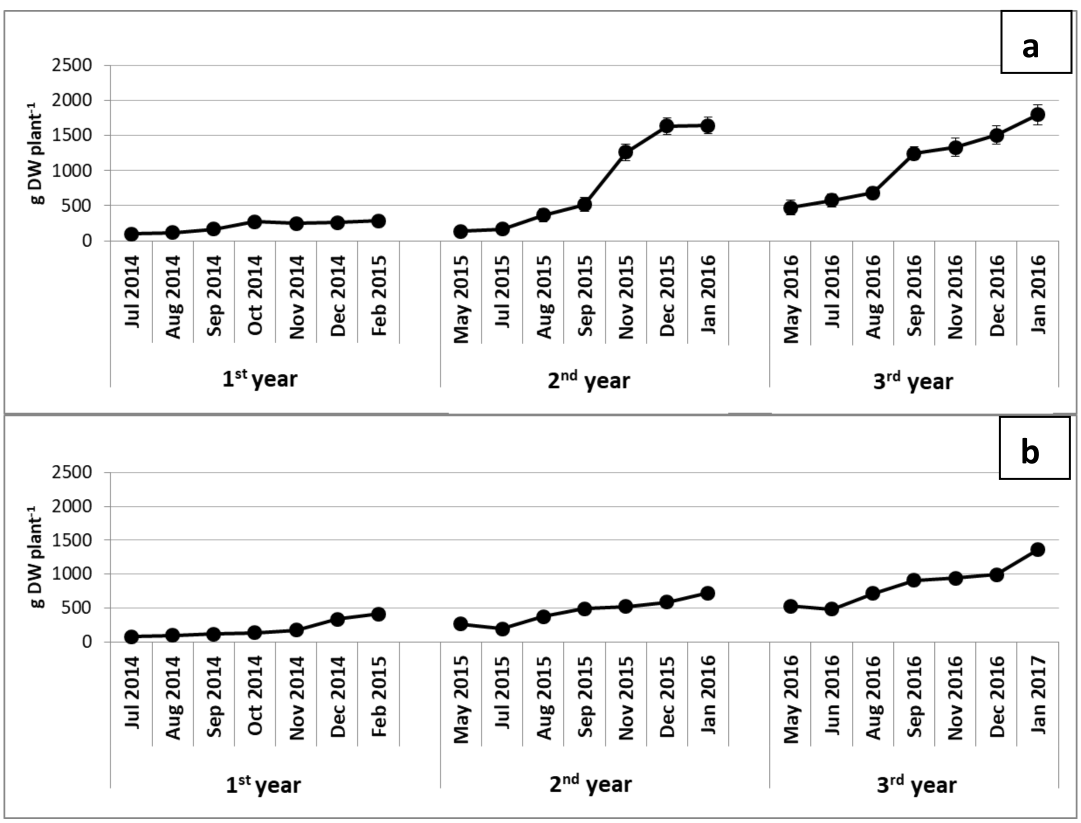

Figure 2a and 2b: Growth trend of *A. donax* belowground biomass (dry weight) in Teverola site (a) and in S. Angelo dei Lombardi site (b). Bars indicate ± standard errors.

Plant effect on soil organic carbon

The soil organic carbon content increased from 2014 to 2016 in the 0–30-cm top layer by 1.33 g kg^{-1} at Teverola site (from 11.27 to 12.60 g kg^{-1}) and by 1.16 g kg^{-1} at S. Angelo site (from 8.00 to 9.16 g kg^{-1}). This variation corresponded to a 3 years contribution of giant reed to C storage of about 4.7 Mg ha^{-1} [(12.60–11.27) kg $Mg^{-1}*10{,}000$ m^2 $Mg^{-1}*0.3$ m$*1.2$ Mg m^{-3}] at Teverola site and of about 4.1 Mg ha^{-1} [(9.16–8.007) kg $Mg^{-1}*10{,}000$ m^2 $Mg^{-1}*0.3$ m$*1.2$ Mg m^{-3}].

Discussion

In our experiment, *A. donax* L. showed a positive trend along the three years at both the site. This phase is considered a "yield increasing phase" as reported by Angelini *et al.* (2009) that tends to stabilize in the following six years. The different growth of giant reed sites could be a consequence of different temperature and soil characteristics of the two sites. In fact, according to climatic conditions, growing season of Giant reed in Teverola starts in March and ends in November, while in the hilly site (S. Angelo) growing season starts in April and ends in September confirming the growth behaviour showed by Nassi o Di Nasso *et al.* (2011) in a previous study. The mean aboveground growth at S. Angelo site was similar to that reported by Fagnano *et al.* (2015) in an eroded hilly area and was almost the double at Teverola site probably due to better climatic conditions and the longer vegetative period. Fagnano *et al.* (2015) suggested that the strongly reduced soil erosion in *A. donax* plots was due to the soil protective effect from rain erosivity and to the reduction in soil erodibility. A similar erosion reduction effect was also showed by Evers *et al.* (2013) on wind erodibility by perennial plants.

Concerning the rhizome growth, with the exception of the establishment year, the growth of the giant reed rhizome showed an initial decline until early summer; an increase until early winter and a stable phase until the following crop sprouting suggest a remobilization of resources from the rhizomes to emerging shoots as already reported by Nassi o Di Nasso *et al.* (2013). In addition rhizome growth showed an increasing trend along the three years at both sites suggesting that belowground biomass dynamics can have a positive role in C storage and soil physical features improvement (Fernando *et al.*, 2018).

In fact, the giant reed cropping system has a positive effect on the storage of C in the soil showing an increase in the third year respect to the first. This positive variation may be due to the contribution of leaf fall, root exudates and root turnover as reported by Fagnano *et al.* (2015). Furthermore, soil C was also protected by the litter effect (Fernando, 2013), and by the absence of soil tillage ensuring carbon storage in soil.

Conclusions

Results indicated a good adaptability of *A. donax* L. to degraded soils with a good growth performance due to combined growth strategies: during the first year, biomass production was limited by sites pedoclimatic conditions forcing plants to promote rhizomes growth. Instead in the second year at both sites, improved climatic conditions, raised up biomass production. After a first adaptation period, *A. donax* L. can reach a complete soil covering in short time contributing to soil erosion prevention and improving soil quality by increasing Carbon storage in soil. However, further experimentations are necessary to evaluate also biomass quality for different technologies for energy and material recovery.

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References

Angelini, L.G., Ceccarini, L., Nassi o Di Nasso, N. & Bonari, E. 2009. Comparison of Arundo donax L. and Miscanthus x giganteus in a long-term field experiment in Central Italy: Analysis of productive characteristics and energy balance. *Biomass Bioenergy,* 33: 635–643.

Cosentino, S.L., Copani, V., Scalici, G. & Scordia, D. 2015. Soil erosion mitigation by perennial species under mediterranean environment. *Bioenerg. Research*, 8: 1538-1547**.**

Durán-Zuazo, V.H., Francia-Martínez, J.R., García-Tejero, I. & Cuadros Tavira, S. 2013. Implications of land-cover types for soil erosion on semiarid mountain slopes: Towards sustainable land use in problematic landscapes. *Acta Ecologica Sinica*, 33: 272–281.

Evers, B.J., Blanco-Canqui, H., Staggenborg Scott, A. & Tatark, J. 2013. Dedicated Bioenergy Crop Impacts on Soil Wind Erodibility and Organic Carbon in Kansas**.** *Agronomy Journal*, 105: 1271–1276.

Fagnano, M., Impagliazzo, A., Mori, M. & Fiorentino, N. 2015. Agronomic and environmental impacts of giant reed (Arundo donax L.): results from a long-term field experiment in hilly areas subject to soil erosion. *Bioenergy Research,* 8: 415-422.

Fernando, A.L., Duarte, M.P., Almeida J., Boleo, S., Di Virgilio, N. & Mendes, B. 2010. The Influence of Crop Management in the Environmental Impact of Energy Crops Production. *18th European Biomass Conference and Exhibition*, 2275-2279.

Fernando, A.L. 2013. Miscanthus for a sustainable development: how much carbon is captured in the soil? *21st European Biomass Conference and Exhibition,* 1842-1843.

Fernando, A.L., Costa, J., Barbosa, B., Monti, A., Rettenmaier, N. 2018. Environmental impact assessment of perennial crops cultivation on marginal soils in the Mediterranean Region. *Biomass and Bioenergy,* 111: 174-186.

Kosmas, C., Danalatos, N., Cammeraat, L.H., Chabart, M., Diamantopoulos, J., Farand, R., Gutierrez, L., Jacob, A., Marques, H., Martínez-Fernandez, J., Mizara, A., Moustakas, N., Nicolau, J.M., Oliveros, C., Pinna, G., Puddu, R., Puigdefabregas, J., Roxo, M., Simao, A., Stamou, G., Tomasi, N., Usai, D. & Vacca, A. 1997. The effect of land use on runoff and soil erosion rates under Mediterranean conditions. *Catena,* 29: 45–59.

Monti, A. & Zatta, A. 2009. Root distribution and soil moisture retrieval perennial and annual energy crops in Northern Italy. *Agriculture Ecosystem & Environment*, 132: 252–259.

Nassi o Di Nasso, N., Roncucci, N., Triana, F., Tozzini, C. & Bonari, E. 2011. Productivity of giant reed (Arundo donax L.) and miscanthus (Miscanthus x giganteus Greef et Deuter) as energy crops: growth analysis. *Italian Journal of Agronomy,* 6: 22.

Nassi o DiNasso, N., Roncucci, N. & Bonari, E. 2013. Seasonal dynamics of aboveground and belowground biomass and nutrient accumulation and remobilization in giant reed (Arundo donax L.): a three-year study on Marginal Land. *Bioenergy Research*, 6: 725–736.

Panos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburgerb, K., Montanarella, L. & Alewel, C. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy,* 54: 438–447.

Pilu, R., Bucci, A., Badone, F.C., Landoni, M. 2012. Giant reed (*Arundo donax* L.): a weed plant or a promising energy crop?. *African J. Biotech*., 11 (38): 9163-9174.

Zegada-Lizarazu, W., Wolter Elbersen, H., Cosentino, S.L., Zatta, A., Alexopoulou, E. & Monti A. 2010**.** Agronomic aspects of future energy crops in Europe*. Biofuels Bioprod. Bioref*, 4: 674-691.

Long-term effectiveness of Sustainable Land Management practices to control runoff, soil erosion and nutrient loss in Mediterranean rainfed agroecosystems

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Abstract

During six years (2010-2016) we monitored the effects of different Sustainable Land Management (SLM) practices in wheat and almond fields on runoff, soil erosion, particle size distribution, and organic carbon and nutrient (N and P) contents under natural rainfall conditions using open plots at an experimental farm in south-eastern Spain. The implemented practices were reduced tillage (RT) in wheat fields and almond orchards, and reduced tillage combined with green manure (RTG) in the almond orchard. We specifically assessed the influence of precipitation depth and intensity on the hydrological and erosive responses. SLM practices resulted in increased organic carbon and nutrients contents in the soil, reduced runoff, erosion, and mobilization of organic carbon and nutrients in sediments. The beneficial effect of the SLM practices on soil erosion was observed within the first 18 months after their implementation and continued throughout the six years of the study. Furthermore, the effectiveness of tillage reduction with respect to erosion control and carbon and nutrients mobilization was highest during the most intense rainfall events, which are responsible for the highest erosion rates in Mediterranean areas. Our results support the key role of SLM practices under semiarid conditions as useful tools for climate change mitigation and adaptation, given the expected increase in high-intensity rainfall events in semiarid areas.

Keywords: soil conservation, reduced tillage, high-intensity rainfall, climate change mitigation, adaptation

Introduction, scope and main objectives

Sustainable Land Management (SLM) practices have the potential to reduce soil, OC, and nutrient losses by erosion (Maetens *et al.*, 2012; Almagro *et al.*, 2016). The SLM practices include a wide range of techniques, such as reduced tillage, no-tillage, cover crops, etc. These usually aim to increase plant cover (native or introduced), buffer raindrop impact, and increase soil roughness. Moreover, the incorporation of plant residues into the soil promotes the recycling of nutrients and OC, avoiding the impoverishment of agricultural soils and increasing their water retention capacity. In addition, the vegetation, together with the biological activity of the soil linked to it, favours the formation and stabilization of aggregates by means of the secretion of cementing agents (exudates, microbial secretions, etc.), making the soil more resistant to erosion. In spite of these benefits, SLM practices are not commonly adopted by farmers, because they consider that spontaneous or introduced plants can compete with crops for water and nutrients and thus require control of the vegetation cover (Gómez *et al.*, 2009). Moreover, SLM practices often do not have an immediate positive impact on the main crop yields (Gomez *et al.*, 2009; Martínez-Mena *et al.*, 2013) and there are few subsidies to help farmers to apply these techniques. Understanding the rainfall/runoff/erosion relationships and related nutrient dynamics is of great relevance in terms of soil quality, especially in soils with low organic matter content that are susceptible to erosion and degradation. Studies comparing soil, water, and nutrient loss rates in cropping systems under sustainable management practices to those under conventional management are crucial to understand the potential of the former to promote soil conservation and sustainability in the long-term. The results from such studies can guide farmers in the decision making process and help them to choose the most suitable measure to reduce soil degradation while increasing soil quality. Furthermore, this kind of information would help policy-makers to adopt decisions in relation to subsidies for soil and water conservation in the framework of the European Common Agricultural Policy (CAP).

The objective of this paper is to assess the effectiveness of reduced tillage (RT) and reduced tillage combined with green manure (RTG) in reducing runoff, erosion, and associated losses of OC and nutrients (N and P) in two Mediterranean organic rainfed systems: a wheat and an almond orchard. In addition, we evaluate how the rainfall characteristics influence the effectiveness of these SLM practices with regard to the control of runoff, erosion, and nutrient mobilization.

Methodology

In 2009, three replicate open runoff erosion plots were set up in the lower slope segment of each tillage treatment, resulting in a total of nine and six plots in the almond and wheat field, respectively. The size of the plots varied between 25 and 126 m^2 (almond) and between 44 and 265 m^2 (wheat), with the long side of each one following the direction of the maximum slope (Figure 1). The average plot slope was 10-12% in both crop fields. At the end of each plot a sediment trap (Gerlach type) was connected to two storage tanks (Figure 1). All the sediment accumulated in the Gerlach trap and five aliquots of 1 L each, from different depths in each tank, were taken. The sediment was filtered, oven-dried at 60 °C, weighed to determine the suspended sediment concentration, and stored for further analysis. The sediment concentrations were averaged and multiplied by the total runoff to calculate the total soil loss after each erosion event. The annual OC, N, and P losses by erosion (in g m^{-2} $year^{-1}$) were calculated as the sum of the net OC or nutrient export after every erosion event during one year divided by the drainage area of each erosion plot. A total of 34 erosion events occurred between 12th January 2010 and 30th December 2015 and are presented in this study. The sediment samples were analyzed per erosion event. Rainfall erosivity was estimated using rainfall data from a rain gauge connected to a data logger in the experimental farm, which recorded values every five minutes. Rainfall events greater than 1 mm were considered.

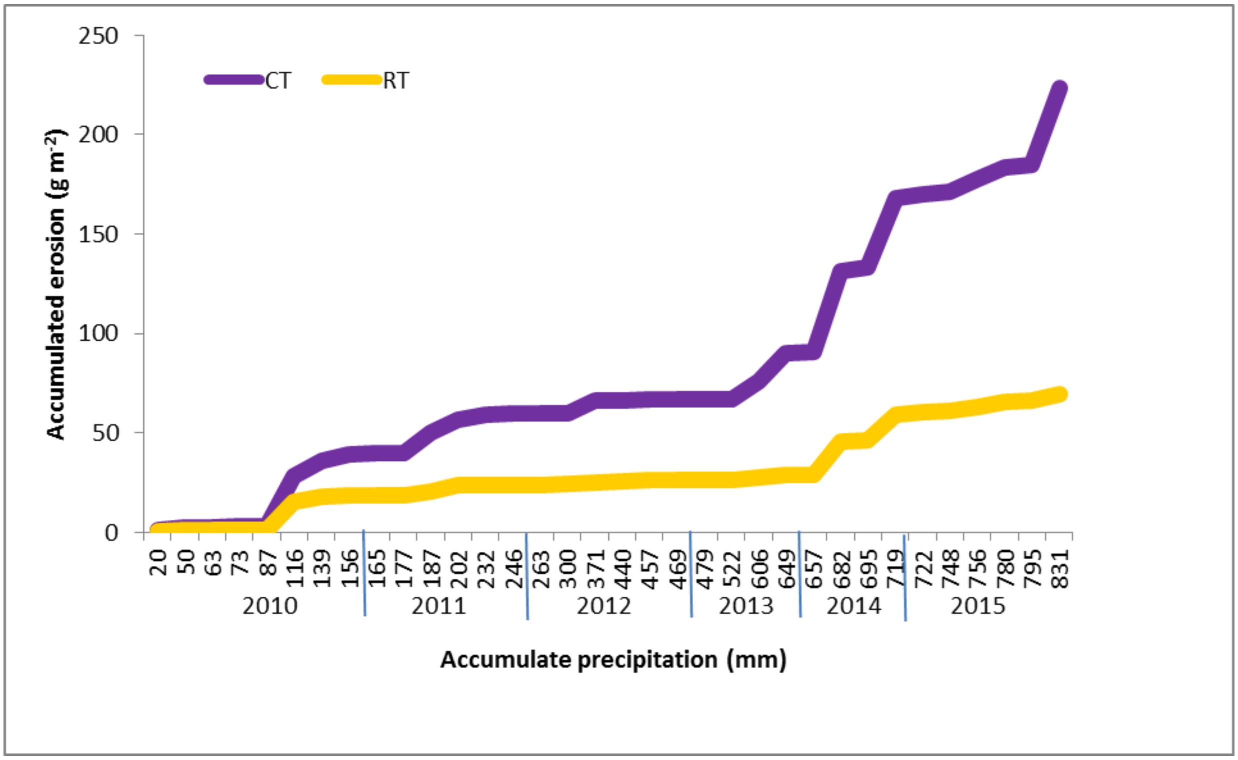
Figure 1: Location of the two experimental fields within the farm: i) wheat (down, left) and ii) almond tree orchard (above, right), and the locations of the erosion plots within each field.

Results

In the wheat field, the total annual soil erosion rates were 360 kg ha^{-1} and 110 kg ha^{-1} under CT and RT (69% decrease), respectively, while in the almond field the values were 70 kg ha^{-1}, 12 kg ha^{-1}, and 20 kg ha^{-1} under CT, RT, and RTG, respectively, the decrease being 83% for RT and 71 % for RTG (Figure 2). Six years after its implementation, reducing tillage frequency - with the subsequent development of vegetation and the incorporation into the soil of plant residues - increased the soil OC and P contents in the wheat field by 45 %. In the almond field, soil OC increased between 23 and 30 %, while soil N increased between 35% and 40 %, depending on the soil management (RT or RTG), compared to CT. In contrast, the total OC, N, and P eroded during the six year period was higher under CT (19.8, 2.8, and 0.05 kg ha^{-1} for OC, N, and P, respectively) than under RT (7.8, 1.2, and 0.02 kg ha^{-1} for OC, N, and P, respectively) in the wheat field. In the almond field, the total eroded OC, N, and P under CT (13.6, 1.2, and 0.03 kg ha^{-1} for OC, N, and P, respectively) were higher than under RT (0.9, 0.08, and 0.001 kg ha^{-1}) and RTG (4.0, 0.43, and 0.01 kg ha^{-1}). The mean values of the runoff, sediment concentration, and erosion rates increased with increasing rainfall erosivity in most of the treatments tested, in both crops. In the wheat field the greatest reduction in runoff (50 %) was found for the least erosive rainfall events, while the reduction in erosion was not dependent on the rainfall erosivity. By contrast, in the almond field the greatest reduction in runoff and erosion was found for the most erosive events. Positive correlations between climatic characteristics and those related to hydrological and erosive responses, across managements, were observed in both fields. In general, the correlations were higher in the wheat field than in the almond field, and both the erosive and hydrological responses were correlated much more closely with the rainfall intensity than with the rainfall depth. The correlations between erosion and rainfall erosivity were stronger in conventional tillage than in reduced tillage, independently of the crop (wheat: $r=0.70$ versus $r=0.33$, $p<0.001$, for conventional and reduced tillage, respectively; almond: $r=0.39$ versus $r=0.20$, $p<0.05$, for conventional and reduced tillage, respectively). For RTG in the almond field there was no significant correlation between the rainfall intensity and erosion rates.

Discussion

Reduced tillage (RT), in both crops, and green manure incorporation (RTG), in the almond tree crop, supposed a reduction in the total runoff (between 30 and 65 %) and total erosion (between 63 and 80 %) with respect to the CT, in both fields. Parallel, an improvement in some soil quality indicators (OC, N, and P concentrations) due to the management practices was also observed six years after their implementation, in both crops, suggesting that not only the vegetation cover, but also the soil quality might have an influence on controlling erosion in these areas. The higher sensitivity to the rainfall erosivity under conventional management than with SLM practices, as indicated by the lower correlations of erosion and sediment concentration with rainfall erosivity under reduced (RT and RTG) tillage, in comparison with CT suggests that these management practices are particularly useful techniques in the context of climate change adaptation, characterized by an increase in the irregularity and intensity of rainfall (Ozturk *et al*., 2015). It is interesting to note that in our study only four events represented about 60% of the total erosion that occurred during the six years of study, in both crops; precisely, these were events of greater intensity. In the same way that the SLM practices evaluated here were more effective in reducing erosion in more intense events, they also showed greater decreases in the total OC, N, and P losses in the most intense events. These results should help to increase the awareness among farmers and stakeholders of the importance of preventing soil erosion by the implementation of improved soil management practices; economic assessments incorporating the costs associated with losses of soil organic matter and nutrients (indirect costs) would help this. In both crops, the effect of the sustainable management practices on the runoff and erosion was evident before the second year of their implementation. Such short-term beneficial effects underline the interest in using these techniques in areas where erosion is a potential risk in the acceleration of soil degradation.



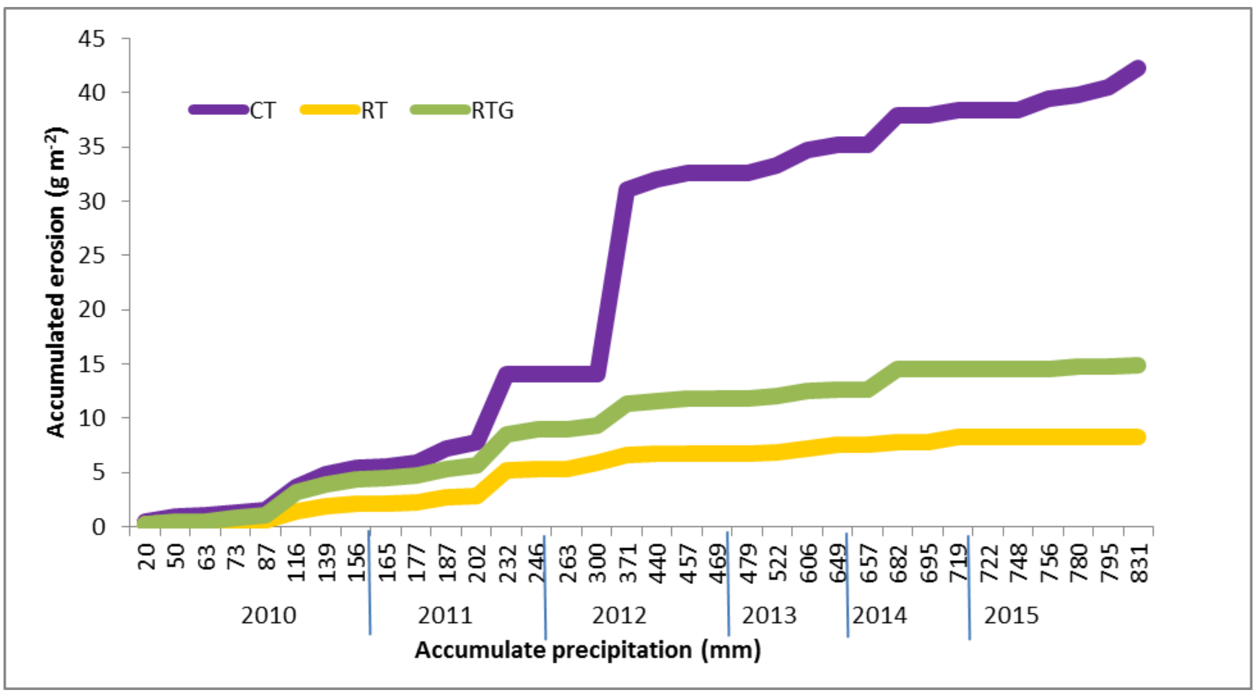


Figure 2: Accumulated erosion versus accumulated precipitation during the study period in the wheat (above) and almond (below) fields.

Conclusions

In this monitoring study, the Sustainable Land Management (SLM) practices implemented reduced runoff by between 30 and 65 % and erosion by between 65 and 85 % in wheats and almond orchards. This indicates the relevance of such management practices to the control of surface runoff and erosion.

The effectiveness of reduced tillage and green manure to control runoff, mobilization of carbon and nutrients was higher in more intense events, which are responsible for the largest erosion rates and highest total erosion volumes in Mediterranean areas. This highlights the key role of implementing these SLM practices under semiarid conditions as useful tools for climate change mitigation and adaptation given the projected increase in high-intensity rainfall events in many Mediterranean semiarid areas.

The incorporation of green manure in the almond tree orchard increased the OC stored in the soil, lowered the enrichment of OC in the sediment and also caused a higher erosion reduction under highest intensity rainfall events with respect to reduced tillage alone.

Our results show a short-term effect of the evaluated SLM practices on erosion control, making their implementation especially attractive for farmers.

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References

Almagro, M., de Vente, J., Boix-Fayos, C., García-Franco, N., Melgares de Aguilar, J., González, D., Solé-Benet, A. & Martínez-Mena, M. 2013. Sustainable land management practices as providers of several ecosystem services under rainfed Mediterranean agroecosystems. *Mitigation and Adaptation Strategies for Global Change*, 21(7): 1029–1043. https://doi.org/10.1007/s11027-013-9535-2.

Gómez, J.A., Guzmán, M.G., Giráldez, J. V. & Fereres, E. 2009. The influence of cover crops and tillage on water and sediment yield, and on nutrient, and organic matter losses in an olive orchard on a sandy loam soil. *Soil and Tillage Research*, 106(1): 137–144. https://doi.org/10.1016/J.STILL.2009.04.008.

Maetens, W., Poesen, J. & Vanmaercke, M. 2012. How effective are soil conservation techniques in reducing plot runoff and soil loss in Europe and the Mediterranean? *Earth-Science Reviews*, 115(1–2): 21–36. https://doi.org/10.1016/J.EARSCIREV.2012.08.003.

Martínez-Mena, M., Garcia-Franco, N., Almagro, M., Ruiz-Navarro, A., Albaladejo, J., de Aguilar, J.M., Gonzalez, D. & Querejeta, J.I. 2013. Decreased foliar nitrogen and crop yield in organic rainfed almond trees during transition from reduced tillage to no-tillage in a dryland farming system. *European Journal of Agronomy*, 49: 149–157. https://doi.org/10.1016/J.EJA.2013.04.006.

Ozturk, T., Ceber, Z.P., Türkeş, M. & Kurnaz, M.L. 2015. Projections of climate change in the Mediterranean Basin by using downscaled global climate model outputs. *International Journal of Climatology*, 35(14): 4276–4292. https://doi.org/10.1002/joc.4285.

Soil loss impacts on food security: a case study on LSLA in Mozambique

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Abstract

Forests play a key role in preventing soil erosion and shallow landslides, and deforestation has been recognized as one of the main causes of increased mass wasting in hillslopes undergoing land cover change. According to Land Matrix, an open-source database of reported land deals, there are currently 123 intended and confirmed land deals in Mozambique, which together account for 2.34 Mha of mainly forested lands. Between the years 2000 and 2014, the country's Licungo basin has lost nearly 160 000 ha of forest, 17 % of which occurred in areas acquired by large scale land investors. This study analyses the relationship between deforestation occurring within LSLA areas (usually for conversion to agriculture) and the likelihood of soil loss occurrence in the Licungo basin.

Keywords: landslide, Mozambique, large scale land acquisition, food security

Introduction, scope and main objectives

Forests play a key role in preventing soil erosion and shallow landslides, and deforestation has been recognized as one of the main causes of increased mass wasting in hillslopes undergoing land cover change. According to Land Matrix, an open-source database of reported land deals, there are currently 123 intended and confirmed land deals in Mozambique, which together account for 2.34 Mha of mainly forested lands. Between the years 2000 and 2014, the country's Licungo basin has lost nearly 160 000 ha of forest, 17 % of which occurred in areas acquired by large scale land investors. This study analyses the relationship between deforestation occurring within LSLA areas (usually for conversion to agriculture) and the likelihood of soil loss occurrence in the Licungo basin. In recent years vast tracts of land have been acquired by foreign investors and domestic-foreign partnerships to satisfy an increasing demand for agricultural products. As such, these large scale land acquisitions (LSLAs) – which are often granted in areas considered 'unused' or 'marginal' – often result in the conversion of forested landscapes into agricultural fields. Mozambique has been a major target of LSLAs.

Methodology

We combined information on topography, land use, and hydrological processes under four different land cover scenarios to examine the potential effects of deforestation (i.e., through the loss of cohesion provided by plant roots) and land concessions in triggering soil instability and impacting food production in the Licungo basin in Zambezia (Figure 1). The basin covers an area of about 22 600 km^2 lying between latitude 17.7S and 15.3S and longitude 35.8W and 37.5W, with high mountains located in the north in the Gurue and Milange district.

In particular, this study analyses the relationship between deforestation occurring within LSLA areas (usually for conversion to agriculture) and the likelihood of soil loss occurrence in the Licungo basin. To do this we use a spatially distributed and physically based model that couples the assessment of slope stability with hillslope scale hydrological processes and evaluates the change in slope stability associated with remotely sensed forest loss. To predict local instability, we used a grid based (30 m x 30 m) spatially distributed and physically based model (Rosso *et al.*, 2006) that couples a slope stability equation with a hill-slope hydrological model. We considered an infinite planar slope (Terzaghi *et al.*, 1996) and defined the shear strength of the soil along the slope, following the Mohr Coulomb failure law. The water level during the storm (i.e., the water content w=h/z) was calculated treating the hillslope as a flow tube of contour length b, assuming that overland flow is due to an excess of saturation and that the average void ratio e and the average degree of saturation Sr are both constant (Rosso *et al.*, 2006).

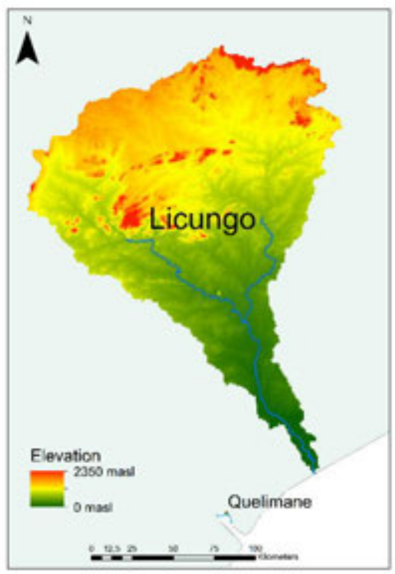

Figure 1: Licungo basin in Mozambique

Results

Zambezia is the most forested province in Mozambique with nearly half of its area (more than 6.5 Mha (Hansen *et al.*, 2013) covered in forests). In the year 2000, forests covered 38 % of the Licungo river basin. Under a 30-minute rainfall event with a 100-year return period, we estimate that 11 563 ha (0.5 % of Licungo basin) and 16465 ha (0.7 % of Licungo Basin) would become potentially unstable for internal friction angles of 40° and 35°, respectively. Relative to conditions where no human modification of land cover has occurred, we find that LSLAs have the potential to increase unstable areas by about 20% for selected storms (duration, return period), with potential implications for the food supply of local populations. Using the metric of maize equivalent, we estimate that, should all LSLAs be put under production and their crops be unavailable to local communities, the local food supply would decrease by

740 kcal cap-1 day-1, which correspond to 32.4 % drop with respect to the current per capita calorie intake in Mozambique.

Discussion

Mozambique's economy relies heavily on agriculture, with over two-thirds of its population living in rural areas and practicing subsistence farming (Benfica *et al.*, 2012). Current average diet in Mozambique include 2 282 kcal/cap day, a value much lower than the recommend limit fixed in 2 400 kcal/day cap. Cassava contribute 30 % of daily average intake, followed by maize (19 %), rice (10 %) and wheat (5 %) (Faostat, 2017). With crop production from Zambezia' harvested field, it's possible to cover only around 90% of the calories intake of the average diet in Mozambique, corresponding to about 2 000 kcal/cap day, more than half (51 %) coming from cassava. The situation will worsen if LSLA areas will be put under production, since we quantified potential enhancements of slope instability as a result of forest loss, showing how more than 10 % of instable cell are localized in cropland not acquired by foreign investors consequent to forest clearing within LSLA boundaries.

With this detailed knowledge of unstable areas and their relationship to land investments, decision-makers can develop strategies that prevent forest clearing and land use change or adopt agricultural practises that promote soil conservation (e.g. terracing, contouring or drainage systems).

Conclusion

Our study highlights the connections between land investments for agriculture, their potential consequences for mass wasting and soil degradation, and ultimately their potential indirect impacts on local food availability.

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References

Benfica, R. S. & Tschirley, D. 2012. The dynamics of agricultural market participation and performance in Central and Northern Mozambique: Evidence from a panel survey. Available at SSRN 3305062.

FAO. 2017. FAOSTAT website, FAO Statistic division, Website access on June 2017.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A. & Kommareddy, A. 2013. High-resolution global maps of 21st-century forest cover change. *Science*, *342*(6160): 850-853.

Rosso, R., Rulli, M.C. & Vannucchi, G. 2006. A physically based model for the hydrologic control on shallow landsliding. *Water Resources Research*, 42(6).

Terzaghi, K., Peck, R.B., & Mesri, G. 1996. Soil mechanics in engineering practice. John Wiley & Sons.

Soil protection from erosion on the local level in Kharkiv region, Ukraine

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Abstract

In article an example is presented describing land use structure optimization for the three typical farms of Kharkiv region, Ukraine. Research has been conducted on the basis of two methods. The first one makes use distribution into three technological groups according to the slope angle. Second method has been presented with mathematical modeling of potential soil erosion in different land use conditions. The simulation was carried out according to the model of Ts. Myrtshulawa from using Digital Elevation Model (DEM) in ArcGIS software. Using GIS to simulate and visualize the results allowed us to identify the most erosion dangerous areas and implement individual selection of crop rotation for each farm. As a result of the potential erosion threat (soil loss modelling), the second method had measurable advantages and can be used for soil loss prevention through organizational and agronomic measures that require the minimum of economic costs.

Keywords: soil erosion, modelling, digital elevation model (DEM), crop rotation

Introduction, scope and main objectives

The cessation and reversing (return to initial state) of land degradation processes is one of the main objectives of sustainable human development as defined in the program document "Transforming our world: the 2030 Agenda for Sustainable Development", adopted by the UN General Assembly on September 25, 2015 year (FAO, 2015). Land degradation, as a complex process of degradation of land resources, is largely due to soil degradation processes, among which wind and water soil erosion occupy the main place in the world (FAO, 2016).

In Ukraine, the problem of soil erosion is also acute – up to 40 % of the area of arable land is erosion-hazardous and requires additional anti-erosion measures (Resolution of CMU, 2017). Since the second half of the 20th century, Ukraine has accumulated a huge and successful scientific experience of systematic solving the problem of rational land use and soil conservation under conditions of a potentially high level of erosion. Unfortunately, this experience has been gained in the conditions of strict centralized management inherent in socialist Soviet society and state ownership of land. It is based on a systematic approach, which includes a set of interrelated activities that are applied within catchment basins area.

After the collapse of the USSR, as a result of changes in the state system and land reform, in Ukraine more than 80.0% of the land fund of the state is transferred to private ownership. Citizens have allocated more than 6.9 million land plots (shares) with an average size of 4.0 ha. As a result, modern agrarian production in Ukraine is characterized by a mosaic structure of land use, which is associated with the specifics of small-scale land degradation with the subsequent transfer of individual shares to agricultural producers. According to (Statistical report..., 2017), the average size of a modern agricultural enterprise in Ukraine is

112 hectares, of which arable land is 100 hectares, that is, over 97 %. In this case, the land of individual farms, as a rule, is not a solid mass, but a few isolated, often quite distant from each other, plots.

Large objects of the soil protection system, such as shelterbelts, hydrotechnical structures, land reclamation systems, remained after reform in state and communal ownership. Thus, in recent years, the function of the soil protection system from erosion has been impacted due to the destruction of anti-erosion facilities and age-related changes in afforestation system and as a result of the changed structure of land use. Land users in such conditions could not manage the anti-erosion objects and control their functioning. As a result of negligence towards the anti-erosion protection of the territory there is a direct and indirect harm from the occurrence of erosion processes. Under these conditions the system of protection of soil from erosion include: application of agrotechnical and organizational activities consisting of selected crop rotation techniques with anti-erosion effect; directions and methods of cultivation for each working area, considering parameters of the relief and soil properties. In addition, the shape and size of the work areas should also be adjusted according to erosion safety requirements. Active development of anti-erosion measures system for each particular farm should take into account the impact of these factors: shape and size of the working sites, their orographic position, use and properties of soils. Our experience shows that the implementation of this approach is most effective in conditions of complicated relief.

Methodology

For the basis of calculations were taken vectorized topographic maps of scale 1: 10 000, mappings of soil cover 1: 25 000 scale. The anti-erosion network was verified according to high-resolution satellite imagery using the Google Earth materials. Information processing was carried out in ArcGIS.

Modeling of erosion processes and calculation of potential soil faults were conducted according to the current Ukrainian State Standard (SSU) 7 905 (SSU, 2016). Following these requirements, the calculation of potential soil losses is carried out according to Hydrodynamic Model of Water Erosion (HMWE) by Ts. Mirtskhlava. Recommendations on placement of crops and crop rotation were based on current legislative documents of Ukraine. Three agricultural farms with an area of 316 (Farm 1 Location – Derhachivskyi region), 414 (Farm 2 Location – Krasnohradskyi region) and 252 (Farm 3 Location –Chuhuivskyi region) ha were selected for research. The basis for the selection of land was the domination in the territory of each of the main agricultural soils of the Kharkiv oblast. Farm 1 – chernozem podzolized, Farm 2 – chernozem ordinary and Farm 3 - chernozem typical.

All investigated areas are used in conventional intensive agricultural production. Field studies conducted on the territory of all three farms revealed the occurrence of accelerated erosion of soils - ravines in fields, cones of removal soil outside shelterbelts borders. As a rule, these forest shelterbelts are the borders of existing land fields, therefore, in the form of land management projects, their inviolability is a prerequisite.

Results

In Ukraine the requirements for restrictions on the use of soils depend on the steepness of the field surface (Order *et al.*, 2013). These requirements are primarily aimed at preventing the development of water erosion. Depending on the angle of inclination of the surface, agricultural land should be divided into III technological groups with different requirements for land use (I – up to 3^{o}, II – 3-5 $(7)^{o}$, III – 5(7) ^{o} and more). When conducting research on anti-erosion optimization of the land use structure of farms in the first stage, we evaluated the compliance of land use with restrictions on the relief parameters.

All fields of investigated farms were divided on areas of technological groups. With a help of DEM, the angle of inclination (tilt angle) for each of the fields was determined, so as the distribution of land by the technological groups I-III. As we have found, most of the existing fields are heterogeneous in accordance to the relief parameters. The greatest deviation from the normative requirements for safe use was found for field No. 6 and No. 7 of the Farm 1, field №1, №2, №4 and №7 Farm 2 and № 10, № 11, № 12 of the Farm 3. In process of conducting field research, the major number of water erosion process was observed exactly on their territory.

Discussion

The possible solution to the problem is to isolate the most dangerous areas into a special soil protection crop rotation (growing perennial grasses and other erosion-resistant crops). The main criterion for choosing grown crops besides anti-erosion efficiency is the economic feasibility of their cultivation.

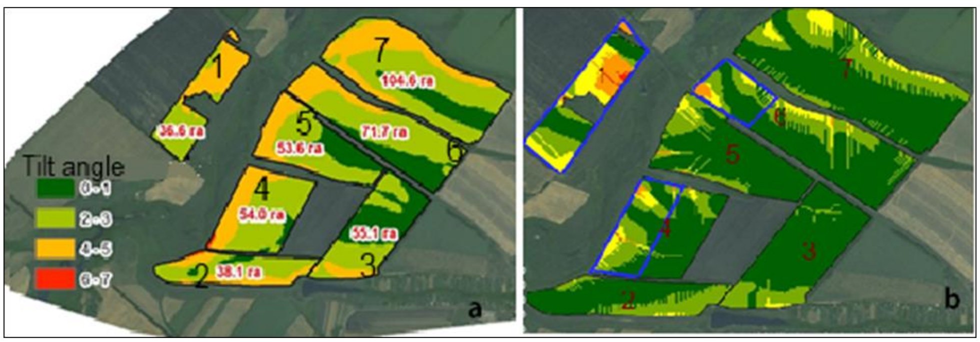

Figure 12: Example of cartograms for Farm 2: a – tilt angle, ^{o}; b – forming a soil protective crop rotation due to potential soil losses (blue color).

As we know, the angle of inclination is an important, but not always correct and only criterion for anti-erosion land management (Figure 1a). Yet, other important parameters are not taken into account here: length and shape of the slope, protective effect of shelterbelts. More reliable is the allocation of erosion-hazardous sites based on the results of mathematical modeling of erosion processes.

In Figure 1b shows the cartogram of potential soil losses, built on the results of soil loss simulation for HMWE. The use of such cartograms makes it possible to identify the most dangerous areas and allocate them for soil protection crop rotation. In Figure 1b the field recommended for removal under soil protection crop rotation is highlighted in blue, this is entirely the whole field number 1 and parts of field No. 4 and No. 6.

The next stage of soil protection is the selection of crops whose protective action is adequate to erosion hazards. In Ukraine the digital monthly values of anti-erosion efficiency are used (Morgun *et al.* 1986). It is desirable to achieve the value of estimated soil losses below 1.5 t/ha.

Certain restrictions stipulated by the legislative document relate to the terms of return of culture to the same field and the specific percentage of some crops in the structure of sown areas. On average, a set of crops for crop rotation without technological limitations reduces soil losses by 25-40 %, for soil protection crop rotation by 65-75%. Figure 2 shows a comparison of soil losses in all fields of investigated farms before and after anti-erosion optimization of land use.

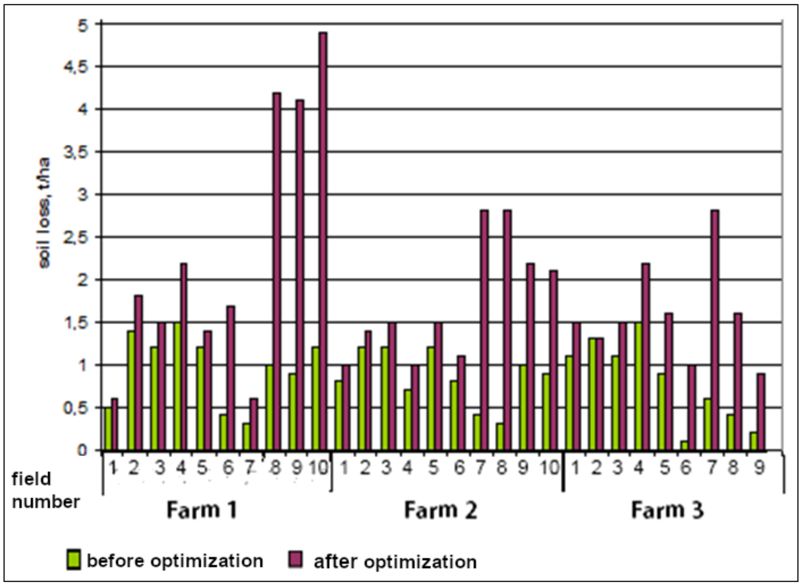

Figure 2: Calculated soil loss before and after optimization on example of cartograms for Farm 2: a – tilt angle, ^{o}; b – forming a soil protective crop rotation due to potential soil

Potential soil losses were calculated for HMWE taking into account the protective effect of crops. Implementation of the updated crop rotation structure reduces the potential soil loss to a safe level for all studied fields. Soil-protected crop rotations at the most erosional hazardous sites provide for the exclusion of crop rotations and fallow with further growing on part of crop rotation areas of perennial grasses.

Conclusions

Using modeling of erosion processes in GIS allows us to itemize and visualize the spatial position of erosion-hazardous areas and to select crops for each field, taking into account the requirements of erosion safety and economic viability. As our studies have shown, carrying out a complex of measures on anti-erosion optimization of land use area avails reaching the allowable values of soil runoff in all fields of investigated farms. At the same time, soil losses decreased from 10 % on slopes to 3 %, and up to 4.2 times on complicated slopes of the territory.

Correction of the land use based on the results of mathematical modeling of erosion and does not require fundamental changes in land use and significant investment, so can be positively perceived by farmers and implemented in the shortest possible terms. This specified way of combating water erosion in modern conditions of Ukraine we consider the most realistic.

References

FAO. 2015. A/RES/70/1. Transforming our world: the 2030 Agenda for Sustainable Development, Agenda items 15 and 116 of UN Seventieth session. FAO, 21 October 2015. Available at: https://sustainabledevelopment.un.org/post2015/transformingourworld [accessed 05.02.19].

FAO. 2016. Land degradation neutrality target setting programme. Land degradation neutrality target setting – a technical guide. FAO, May, 2016 Available at: https://knowledge.unccd.int/sites/default/files/2018-08/LDN%20TS%20Technical%20Guide_Draft_English.pdf [accessed 07.02.19].

Morgun, F.T., Shykula, M.K. & Tarariko, A.G. 1988. Pochvozashitnoe zemledelie. Kyiv: «Urozhai», 256 pp.

Order of State Agency of Land Resources of Ukraine. 2013. № 396. https://zemres.com/files/admin/2_10_2013396.pdf [accessed 05.02.19].

Resolution of the Cabinet of Ministers of Ukraine. 2017. № 413. Available at: https://www.kmu.gov.ua/ua/npas/250068882 [accessed 05.02.19].

SSU 7904. 2015. Soil Quality. Determination of the potential threat of erosion under the influence of rain. [Exist from 2016-07-01]. Kyiv, 2016. 12 p.

UKR STAT. 2017. Statistical report. The number of agricultural enterprises and the area of agricultural land in their use by regions on November 1, 2017. Available at: http://www.ukrstat.gov.ua/operativ/operativ2016/sg/ksgp/ksgp_u/ksgp_11_2017u.htm [accessed 11.11.2017].

Environmental assessment of land management interventions, Atlantic Morocco

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Abstract

Land degradation is the form of desertification that most affects the plains and Atlantic plateaus. But if the mechanisms that trigger it and the processes through which it unfolds are known and widely studied, the aspects relating to conservation are rarely subject to evaluation. That is why we try in this article to contribute to highlight the most promising techniques and practices in terms of improvement of the surface states, allowing to regulate the hydrological functioning, the increase of the yields, the fodder potentialities and the conservation of biodiversity.

Keywords: Land degradation, environmental assessment, soil and land management

Introduction, scope and main objectives

In Morocco, traditional techniques of soil and water conservation are still widely practiced, especially in the rugged relief areas and regions with an arid tendency (Laouina, 2010).

In the Sehoul commune (Figure 1), the object of our study, despite the extent and age of erosive phenomena, the anti-erosion practices developed by local populations remain modest and insufficient. It seems that the dominance of pastoral activity has largely encouraged peasants to keep their fields open, allowing animals to move from one field to another without hindrance. It is also clear that the absence of rocky outcrops allowing the construction of cords, thresholds and strong walls well used in the works of SWC in Morocco, can explain in some way the absence of apparent and effective works.

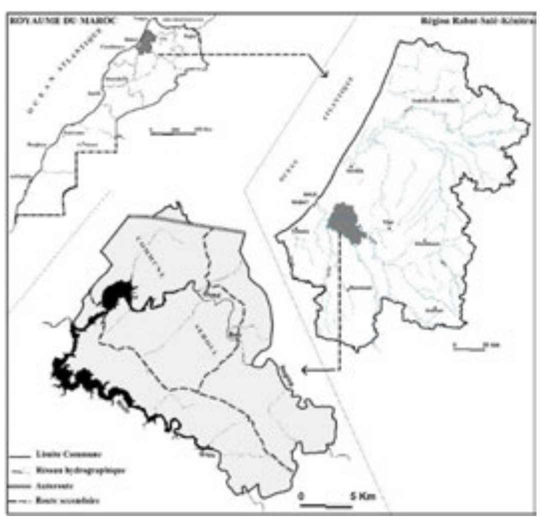

Figure 1: The study site localisation

Despite the many efforts made to improve the well-being of the population of the Sehoul commune, particularly in the context of the rainfed lands enhancement project (2002-2005) and the Horticulture Plan as part of the green Morocco plan, the land continues to deteriorate, both in the pastures lands and in the crops lands.

Thus, in this article, we proceed to the environmental assessment of the different soil and water conservation techniques existing in the study area as well as those set up by our research team. An attempt will be made to study the hydrological functioning of land management interventions and to demonstrate, through the use of a multidisciplinary methodology, the capabilities and limitations of various techniques adopted to contribute to the reversal of the desertification process in the region.

The results of this research aim to enable decision-makers and local actors to identify the practices and techniques allowing the establishment of land management and the sustainable development of the Sehoul commune.

Methodology

In order to carry out this evaluation, we used the Wocat tool "World Overview of Conservation Approaches and Technologies" (WOCAT, 2007), adopted today at the international level.

The assessment carried out with the Wocat tool, included interviews with the farmers and technicians and field measurements of the efficiency in terms of WSC (quantitative measures of the vegetation, in particular the cover and phytomass of herbaceous, shrub and tree layers, floristic biodiversity, rainfall simulations, runoff and infiltration measurements, and measurements of soil surface conditions including soil moisture, soil cohesion, resistance to penetration and rate of pebbles , as well as measurements in the laboratory (determination of forage production of vegetation, fertility and stability of soil structure), and economic and social results. These measurements were made in the cork oak forest, pasture lands and cropland.

Results

Some new techniques introduced during the last decades of the 20th century by some farmers were identified, by the stakeholders who participated to the field interviews and to the workshop, as potential strategies for WSC approach. The field work has the objective of monitoring some samples of these techniques and approaches in order to evaluate their efficiency, both in term of land degradation mitigation and farm's yield increase.

Assessment of existing CES techniques and practices in the area

- ***Assisted regeneration of cork oak (forest land)***

Facing the degradation of the forest, forest services were quick to take emergency measures, in particular the intensification of the works of assisted cork oak regeneration in areas where this noble species can reproduce.

Assisted regeneration of cork oak has several advantages on the environmental level:

- Increase cover rate of herbaceous vegetation and increasing the degree of soil protection
- Increase rate of perennial herbaceous cover
- Improving the forage quality of herbaceous cover
- Decrease the cover rate of invasive shrubs (Cistus)
- Increase the biodiversity

- Increase of vegetable biomass
- Improvement of soil surface
- Improved soil fertility
- Reduction of soil loss

Direct measurements in the forests show that the setting in defence of the oak cork supports its regeneration. The signs of degradation disappear. There is an enrichment of organic matter, the improvement of the structure of the soil, the reduction of the crust, and thus a better infiltration. Assisted regeneration made it possible to increase by 3 times the number of the herbaceous species per m2, undoubtedly by with the setting in defence.

- ***Crop rotation Cereal / leguminous in the rainfed cultivation***

Crop rotation is part of the agronomic techniques that can be summarized in the improvement of the cropping system by adopting a biennial and / or triennial rotation that allows the use of food and forage legumes, as previous crops for cereals

The tendency is for the rotation of cultivations, both to improve the fertility of the soils and to diversify the yield in order to prevent the problems of water scarcity during any of the seasons. The winter cereals (barley and wheat) are more and more mixed with fodder plants, beans and corn.

The results of the environmental assessment show that Crop rotation Cereal / Leguminous are several advantages:

- Increased soil protection by providing better cover
- Maintaining and improving soil fertility
- Improving soil structure and its structural stability
- Increased soil moisture

If these parameters are taken into account, the impact of the rotation can be considered positive for the restoration of land equilibrium and water management.

- ***Rainfed fruit tree plantation associated with annual cultivations (example olive tree)***

This technique has several advantages:

- Improved soil surface condition: the moisture content exceeds the rate recorded in cereals.
- Improved soil structure: the highest level of organic matter (4.31 %), thus exceeding the rate recorded for cereal plots and legumes.
- Reduction of runoff and improvement of infiltration: In the oat plot runoff started in the first 10 minutes, while the olive plot did not flowing after 60 minutes of simulation.

- ***Crop rotations cereals / forage legumes, example of lupine***

There are several environmental benefits to growing lupine:

- Greater cover: rate of cover vegetation reaches 65 %, while it does not exceed 49 % in the one-year fallow period, 38 % in the 10-year fallow and only 24 % in the matorral.

- Increased organic matter content in the soil: the rate of organic matter reaches 1.46% higher than the rate recorded in fallow, oats and barley.
- Increased fodder production: we registered in the atriplex plot, the largest herbaceous phytomass 34 275 Kg/ha of green phytomass, while only 18 583 Kg/ha is recorded in the barley plot.
- Reduction of runoff: The results of measurements on plot under natural rain show that for the same rainy events the cultivated plot of lupine flow much less than the plots of wheat and fallow.

Assessment of experimental WSC devices

The results were presented at the actors within the framework of two workshops. The first one was organized with technicians who delivered their opinion on the procedure of evaluation and discussed the validity of the results. The participative approach of the evaluation and the choice of technologies to be adopted was followed during the second workshop with the farmers, the local technicians, the elected officials and associations.

Two techniques were selected and implemented in an experimentation device, and a follow-up methodology was established over the course of 3 years from 2008-09 to 2010-11:

- The first is the rehabilitation of fragile lands in the process of desertification by the process of gullying, through the planting of fodder shrubs on a half-hectare ravined plot
- The second is aimed at better management of marginal, unproductive cereal lands threatened with the beginning of a process of desertification, through the practice of mulching associated with minimum tillage.

- ***Gullies restoration by planting atriplex fodder shrubs***

The results of the monitoring during 2 years show that the protection the slope affected by gillies and rills by fencing and fodder shrubs plantation has several advantages:

- Increase of the covering rate by herbaceous plants from 57 % in the gullied field to 87% in the restored plot, during spring.
- improvement of the quality of the herbaceous vegetation, with a 3 times increase of the permanent species, after one year
- Improvement of the floristic biodiversity: In the restored plot the number of plant species is two times more than the non protected slopes
- Increase of the vegetation biomass: the total palatable biomass has increased from 360 kg/ha to 1235 after management
- Increase of the fodder production: from 127 fodder units per ha to 694, wich represent a rate of 72%
- Improvement of the soil surface: in the atriplex plot is recorded a higher soil moisiture than in the non protected slopes, and a weaker resistance to penetration as well as a lower cohesion.

- ***Mulching and minimum tillage***

The aim is the conservation of sloping cereal lands by improving the techniques of their management, with stubble conservation in summer (mulch) and the reduction of tillage. The experimental protocol was based on the monitoring of two contiguous fields, within the same fenced plot, on a slope exposed to the SE.

The field putting in defense retains a protective plant cover all summer; in autumn, the first rains give more infiltration in the field and more runoff in the grazed fields. This explains the rapid plant growth in the mulch field and therefore a better vegetation cover, observed in December, before the arrival of the winter rains. Improved cultivation practice, with direct seeding after herbicide treatment and use of an animal coupling seeder, explains the positive result in terms of soil moisture and recovery of its organic stability

Discussion

The management of water and soil in the area of Sehoul is conditioned by the various relationships between land and natural resources in a continuously changing social context. The implementation of agricultural techniques does not have everywhere a positive impact on restoring the balance of the land.

Conclusions

The study has as main objective, to identify existing and new strategies, capable to prevent or mitigate land degradation and to experiment those strategies with some required techniques of measurement, in order to be able, after some years of experimentation to assure for these successful strategies a high and fast rate of dissemination among local stakeholders.

The field work programmed for the monitoring of these techniques and approaches to determine their efficiency, in term of land degradation mitigation, social benefits and farm's yield increase gives successful results.

The stakeholders meetings showed the importance of bringing solutions to this degradation trend which threats both the environment and the farmers' income. The choice for more integration between croplands and pastures represents the less costly and the most profitable option.

References

Gobin, A., Jones, R., Kirkby, M., Campling, P., Govers, G., Kosmas, C. & Gentile A.R. 2004. Indicators for pan-European assessment and monitoring of soil erosion by water. *Environmental Science & Policy,* 7: 25–38.

John, W. D. 2002. Soil health and global sustainability: translating science into practice. *Agriculture, Ecosystems and Environment,* 88: 119–127.

Kirubel, M. & Gebreyesus, B.T. 2011. Impact assessment of soil and water conservation measures at Medego watershed in Tigray, northern Ethiopia. *Maejo Int. J. Sci. Technol,* 5(03): 312-330.

Laouina, A. 2010. Conservation des eaux et des sols au Maroc, la prise en compte de la diversité géographique. *Norois*, 214: 85-99.

WOCAT. 2007. Where the land is greener, case studies and analysis of soil and water conservation initiatives worldwide. Liniger HP, Critchley W, Associate Editors:Gurtner M, Schwilch G, Mekdaschi Studer R.CTA, FAO,UNEP and CDE, Bern.

Termite footprints in restored versus degraded agrosystems in southwestern Niger

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Abstract

Effective soil restoration practices are keys to achieving sustainable development goals. Advances in research showed the effectiveness of restoration practices where termites play a major role. However, information on termites' species and functional groups in the community, and the evaluation of richness and abundance is still poor. We compared the footprints of termite community assemblages in two agrosystems under farmer practices: restored (zaï +mulching) and in unrestored (control) over a 2-year period in semi-arid Niger. We used a rapid assessment protocol based on the transect protocol of termites to assess termite communities. Our results showed that termite abundance, richness, and diversity were (15% to 45%) higher in the restored agrosystems than in the degraded ones. The evenness of termites did not augment in the restored habitats what might result from the changes in soil properties triggered by clearcutting. Moreover, higher abundances of termites had positive effects (r= 0.81) on soil moisture, water infiltration, phosphorus, carbon, nitrogen, sodium and potassium contents. A higher termite diversity and abundance are important factors underlying positive changes in soil properties. Furthermore, because of their diversity, high abundance, and sensitivity to changing environmental conditions, termites may be useful key organisms to monitor and evaluate restoration processes.

Keywords: termites, taxonomic richness, soil properties, agrosystems restoration, bio indicators

Introduction

Tropical soils have less than 10 g kg^{-1} of organic matter because of climatic conditions and to land use (Lal, 2015). This is particularly true for the Plinthosoils prevalent in Southwest Niger. The challenge is to restore soil organic matter so as to improve and maintain the productivity of these soils. Enhancement of soil organic matter is essential for crop growth as it activates the development of soil microorganisms important for decomposition and delivery of nutrients to soil (Govorushko, 2018). Several interventions can be applied to restore soil nutrients. In Southwest Niger, there is an increasing interest in the application of traditional soil restoration practices as a coping strategy of small scale farmers to high cost of inorganic fertilizer and agrochemicals. Among the practices used by farmers to sustainably produce in the changing climate, is the traditional zaï technique combined with crop residues mulching. The litter used in this practice attracts termites (Isoptera).

Termites are among the most influential 'ecosystem engineers' (De Bruyn, 1990) whose biogenic structures modify the availability of resources for other organisms. Their role in ecosystems has been reviewed by several authors (Verma, 2016). In arid and semiarid regions, termites are the key soil turbators all year round, strongly influencing SOM turnover and soil structure in agrosystems (Lal, 2015). By constructing networks of foraging tunnels they alter soil water infiltration and soil aeration (Lal, 2015). Better soil aggregation may have significant impacts on soil quality. They influence the decomposition of litter by enhancing populations of bacteria and fungi, thereby affecting SOM turnover (Govorushko, 2018). In this regard, termites can be used to sustain nutrient accessibility to crop growth and recovery from drought (Lal, 2015). Such field studies have provided more information on soil processes (Govorushko, 2018). But only a few quantitative data are available to evaluate the exploitation of termites on soil functioning, in particular to nutrient cycling, and their reaction on changing environmental parameters.

The assessment of termite communities could indicate the state of the agrosystems regarding the restoration goals and the effectiveness of the restoration interventions. A two year study was carried out to quantify the colonization rates of termites on marginal soils and in agrosystems with ongoing restoration efforts, as well as determine their footprints on soil characteristics and on environmental variables (soil temperature, soil water content and water infiltration). We therefore, hypothesized that the practice of zai + mulching can have important impacts on termite's community indices and have complex effects on ecosystem process. Moreover, manipulation of termite abundances under zaï + mulching could be an optimistic approach to improve soil properties such as nutrient contents, which are indeed pre-eminent for the ecological restoration of marginal soils in arid and semi-arid areas.

Methodology

We used a rapid assessment protocol used by Dorkas (2017) to assess the termite communities in three study sites. The sites are Kollo (524 mn), Baleyara (398 mm) and Simiri (343 mm) where degraded farms were selected to represent a decreasing rainfall gradient. The soils are Plinthosols with OC content, acidic and low nutrient content. In each of the three study sites, we collected termites on plots treated with Zaï + millet stover mulching versus untreated adjacent plot (control). A 50 m Adjusted Belt Transect consisting of 10 contiguous sections of 5 x 2 m was used.

Per study site, we had six transects. In each section of the transect, we first searched for termites in different microhabitats. Then, after removing the litter layer, we randomly take eight soil samples, each 0.12 x 0.12 m and 0.15 m deep. Priority was given to finding soldiers, as they are the easiest to identify, but workers were collected as well. The sampling time per section was one person-hour stopping rules applied if less or no microhabitats could be found resulting in a shorter sampling time. The sampling was done during the early morning since termite activity decrease later during the day (Colloff *et al.*, 2010). All collected specimens were stored in labeled vials containing 90% ethanol and taken to the laboratory for species identification. The termites were identified to the level of species based on their morphological characteristics (mandible, form and size) and as described by Mathot (1965).

Composite soil samples were also taken at 0 to 0.2 m depth from the soil scrapes where termites had been sampled. The soil samples were first labelled and transported to the pedological laboratory of iEES-Paris where they were stored at laboratory conditions before analyses. These samples were analyzed using standard methods for pH, CEC, (P), (C), (N), (Na), and (K) contents.

Results

Ecological indices across study sites

In the three study sites, four hundred and sixty one (461) specimens belonging to nine species (09) were recorded (Table 1). Six (06) of these species could be identified to the species level, and the three other could be identified to the level of morphospecies only. The fungus-growing *Odontotermes* sp1 was the most abundant in all sites (19.7 %), followed by the fungus-growing *Microtermes* sp1 and the wood-feeding species *Microcerotermes aff parvus* had the least abundance. The two most abundant species were widespread in all sites. The composition of the termite communities and their abundances differed significantly across the different study sites (P < 0.05). Furthermore, the number of species decreased with rainfall from 25 species in the highest rainfed to 17 in the less rainfed. We collected 189 specimens in Kollo representing eight species, 95 specimens from 5 species in Simiri, and 176 specimens from 7 species in the Baleyara sites.

Compared to the degraded habitats, a significant variation in richness was found in the restoration sites. The Shannon index indicated a higher termite diversity in Kollo than in Simiri and Baleyara (Table 1).

Regardless of rainfall regime, Zai + MSM positively impacted the termite species abundance. The average number of speciemen recorded in un treated plots is six times less than the average number obtained on treated plots.

Table 1: Number of specimens per termite species and relative frequency in restored (Z+MSM) and unrestored (Control) ecosystems recorded from three sites in Niger

Species	**Relative frequency**	**Simiri**		**Baleyara**		**Kollo**	
		Z + MSM	Control	Z + MSM	Control	Z + MSM	Control
Amitermes evuncifer	9.3	3	0	21	0	3	3
Amitermes aff. Guineensis	6	0	0	0	0	23	5
Microtermes sp	15.8	22	4	23	5	15	4
Microcerotermes aff. Parvus	1	0	0	0	0	4	0
Macrotermes bellicosus	14.9	21	5	14	3	24	2
Ondototermes sp 1	19.7	13	4	28	1	36	6
Ondototermes sp2	16.4	19	4	13	4	32	5
Trinervitermes geminatus	9.3	0	0	26	5	12	0
Ancistrotermes aff. Cavithorax	7.1	0	0	32	1	0	0
Total		78	17	157	19	149	25

Relationship between termite ecological diversity indices and soil characteristics

Pearson correlation showed that termites ecological diversity indices (abundance, richness and diversity) were significantly correlated with clay and silt content ($r > 0.5$, $P < 0.05$) (Figure 1). Furthermore, these indices were associated with key soil properties (C, N, P and K^{+} contents) ($r > 0.90$, $P < 0.05$). In contrast, the termites ecological indices were negatively correlated to the concentrations of Mg^{2+}, Ca^{2+}, pH, CEC, soil temperature and sand particles.

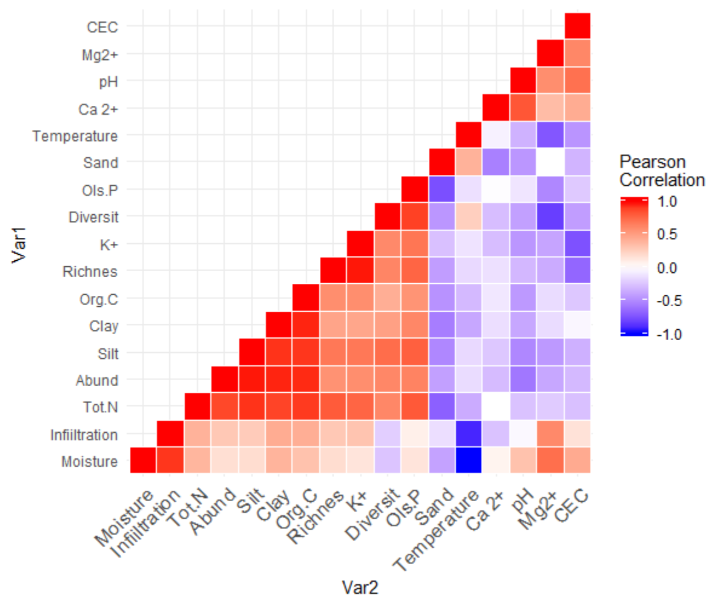

Figure 1: Relationships between termites' composition and soil properties across the restored sites. Nb: correlation coefficient of 0.60–0.79 is significant, and from 0.80 to 1 is very significant.

Discussion

Overall termites' indices were high in site of Kollo, an area with high pluviometry that enhanced termites' blooming. These findings support studies by Frouz (2018) where it was shown that termites were abundant, rich and diverse in higher rainfall areas. It is important to note that these changes can be useful for evaluating changes related to soil properties (Dorkas, 2017).

Multiple studies have documented how restored agrosystems promote soil fauna (Jones, 1994). However, zaï + mulching will be a useful strategy for augmenting termites' communities where they are not present. This was mainly a consequence of the presence of substrate upon which termites feed and reproduce (Garba *et al.*, 2011).

As regard to the effect on soil texture, in general, soil clay is positively correlated with carbon content, which in turn could affect soil aggregation Jones, (1994) and could physically protect organic matter from decomposition (Bottinelli, 2014). Furthermore, Frouz, (2018) determined that soil with a high fauna has the best soil structure.

The present study showed that termites' assemblages respond to soil restoration, both in functional and taxonomic terms.

Conclusions

This study showed that regardless of rainfall regime and soil characteristics, soil moisture mobilization conservation structures such as zaï + MSM have the potential to enhance soil quality and soil fauna ecological diversity, especially termites in terms of population and biomass. After a 2 year study, our results indicated the possibility of recovery of soil chemical and physical properties lost due to degradation. In addition, this is to be partially attributed to termite activities. Based on this, we can conclude that any changes in termites' community composition are likely to have impacts on agrosystems, influencing a wide range of ecosystem processes and services.

Acknowledgements

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References

Bottinelli, N., Jouquet, P., Capowiez, Y., Podwojewski, P., Grimaldi, M. & Peng, X. 2014. Why is the influence of soil macrofauna on soil structure only considered by soil ecologists? *Soil & Tillage Research*, 1–7.

Colloff, M.J., Pullen, K.R. & Cunningham, S.A. 2010. Restoration of an Ecosystem Function to Revegetation Communities. *Restoration Ecology*, *18*: 65–72.

De Bruyn, L.A.L. 1990. Conacher, A.J. The role of termites and ants in soil modification: A review. *Australian Journal of Soil Research*, *28*: 55–93.

Dorkas, K., Michel, L., Souleymane, K. & Karl, E. 2017. Ecosystem services of termites (Blattoidea : Termitoidae) in the traditional soil restoration and cropping system Zaï in northern Burkina Faso. *Agriculture, Ecosystems and Environment*, *236*: 198–211.

Frouz, J. 2018. Effects of soil macro- and mesofauna on litter decomposition and soil organic matter stabilization. *Geoderma*, 332: 161–172.

Govorushko, S. 2018. Economic and ecological importance of termites: A global review. *Entomological Science*, 1–15.

Jones, C.G., Lawton, J.H. & Shachak, M. 1994. Organisms as Ecosystem Engineers. *Oikos*, *69*, 373.

Lal, R. 2015. Restoring Soil Quality to Mitigate Soil Degradation, 5875–5895.

Mathot, A.B.G. 1965. *Quel est ce termite Africain ?* Leopoldville, Belgian Congo: Ed. de l'Université.

Verma, M.K. 2016. Efficacy of antagonistic soil bacteria in management of subterranean termites.

Soil carbon storage in Mediterranean forest stands: implications in the restoration of eroded soils

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Abstract

Soils with degraded structure are often subject to loss of organic carbon, which plays a key role in the resistance to soil erosion. Afforestation of degraded land can reverse some degradation processes through the storage of carbon in the soil and phytomass. Also different management practices in forest areas can lead to changes in the soil organic carbon content (SOC) and cause, in the long time, erosion phenomena.

In this study, we reported SOC values in forest 15-cm topsoil from six Mediterranean forest stands affected by different agro-forest managements (i.e. abandoned coppices after coppicing, undisturbed coppices, coppice with grazing and coppice subject to tourism exploitation). The results showed that 15-cm topsoil carbon content ranging from 82 to 217 Mg ha^{-1}. These differences are probably due to both the type of vegetation and site conditions affecting the chemical characteristics of litter and soil as well as to the different agro-forest managements.

The case studies showed SOC values in forest stands subjected to different agro-forest managements.

Keywords: soil organic carbon, soil erosion, forest management, Mediterranean forest soil

Introduction, scope and main objectives

The forest environment protects the soil from erosive phenomena both for mechanical actions (e.g., the roots' ability to retain the soil and those of the vegetation cover to weaken the impact force on the ground of rainwater) and for its high concentration of SOC compared to other scenarios of land use.

The soil organic matter content (SOM) relates very well with many aspects of productivity, sustainability and environmental integrity in agricultural and forest systems (Smith *et al.,* 1999). Yet, the soil organic carbon stock (SOC) maintains soil physical (Rehana-Rasool *et al.,* 2008) and biochemical quality (Benbi and Chand, 2007). Forest soil represent a relevant reservoir in which atmospheric CO_2 is stored and several studies have highlighted its contribution in the mitigation of climate change and soil degradative phenomena (Di Matteo *et al.,* 2014; Lorenz and Lal, 2014; Peichl *et al.,* 2012; Lal, 2005). In forest conditions, surface runoff and soil erosion are generally low because of the protection exerted by litterfall. This is why litterfall and understorey both help break the kinetic energy of raindrops, reducing the erosive phenomena of the soil caused by splashes of rain. Moreover, herbs, shrubs and trees in the forests represent important vegetation layers to prevent soil erosion and stabilize the soil by root systems. The absence of vegetation in forest areas or a depletion of the forest resources also related to soil over-exploitation are due to severe perturbations they are experienced such as fires, unplanned silvicultural practices, forest abandonment, excessive grazing, land-use change and in general the over-exploitation of forest resources (Prăvălie, 2018; Wiesmeier *et al.,* 2009). This could cause increased soil erosion phenomena, particularly when the forest canopy is high and there is no understorey vegetation.

The SOC stock varied significantly with land use and soil depth. The SOC in eroded topsoils was lower than in less disturbed grassland, cultivated and forest soils (Saha *et al.,* 2014). The total SOC stock in the 1.05-m soil profile was in the order of forest>grassland>cultivated>eroded lands. Because SOM is concentrated in the topsoil, accelerated erosion leads to its progressive depletion. Soil erosion involves preferential removal and redistribution of the light soil fractions, comprising SOM and clay contents (Olson *et al.,* 2016; Rasool *et al.,* 2008).

The management of soil and vegetation with proper (silvi)cultural practices has long been recognized as the most efficient and effective way to reduce the extent of soil loss, thus influencing the soil erosion control (Guillaume *et al.,* 2015; Labrière *et al.,* 2015; Reis *et al.,* 2007). Moreover, the afforestation of agricultural soils and correct management of forest plantations are useful practices to enhance SOC stock through C sequestration (Paul *et al.,* 2002).

This study aims to compare the capacity of some forest soils subjected to different land use in storing atmospheric CO_2 in SOC. The study rationale is to use the information from these case studies to highlight the risk in the long time of soil erosion due to a reduction of SOC.

Methodology

We compared soil C storage values in six forest soils subjected to different agro-forest managements in central Italy (Tuscany and Latium regions) (Table 1). In Tuscany, Caselli (CA, Pisa municipality) and Poggio Pievano (PP, Grosseto municipality) forests are typical abandoned Turkey oak (*Quercus cerris* L.) stands managed under the coppice system until 1960s. The remaining four forest soils were located in Latium region. Two unperturbed forest areas located in the natural reserve of Vico Lake (Cimini Mountains, Viterbo municipality). These forests differed since populated by different species, i.e. *Fagus sylvatica* L. (MF, Monte Fogliano) and *Quercus cerris* L. (MV, Monte Venere). One area affected by grazing perturbation located in Tolfa Mountains (TM, Viterbo municipality) and the last forest area was affected by touristic perturbations located in the National Park of Abruzzo (NPA, L'Aquila municipality).

Soil sampling was carried out by taken cylindrical soil cores (10 soil sample per site) sized diameter 8 cm, length 15 cm, and core volume 750 cm^3 to get soil bulk density and consequently soil mass was determined by soil weight-to-sampling volume ratio.

Fifteen-centimeter topsoil samples were sieved to 2 mm to separate out root component. A solution of 10 % hydrochloric acid (HCl) was used to eliminate carbonates from soil samples. Total soil organic carbon (TOC %) was measured by an Elemental Analyzer (Thermo Fisher Scientific, model FlashEA 1112 NC Analyzers, Bath, UK). Soil carbon content (SOC) was calculated by multiplying soil mass to total organic carbon concentration.

Table 1: Summary of the agro-forest managements carried out in the six agro-forest areas

Site	Species	Management
CA	*Quercus cerris* L.	abandoned coppice after coppicing
PP	*Quercus cerris* L.	abandoned coppice after coppicing
MF	*Fagus sylvatica* L.	unperturbed
MV	*Quercus cerris* L.	unperturbed
TM	*Fagus sylvatica* L.	coppiced and pastored
NPA	*Quercus spp.*	touristic use

Results and discussion

Table 2: Total soil organic carbon (%) and soil carbon content (Mg ha^{-1}) values in the six agro-forest areas

Site	TOC (%)	SOC (Mg ha^{-1})
CA	4.22	82.29
PP	4.65	90.67
MF	12.10	217.80
MV	6.40	115.20
TM	9.50	185.25
NPA	6.40	115.20

TOC and SOC ranging from 4.2 -12.10 and 82.3 - 217.8 Mg ha^{-1} respectively (Table 2). The unperturbed forests (MF and MV) showed contrasting results, i.e. higher TOC and SOC values for MF compared to both MV and the rest of case studies. These differences are probably due to both the type of vegetation cover and species that could influence the chemical characteristics of the litter and of the soil itself (Lawson and Michler, 2014; Woodall *et al.,* 2011; Cortez *et al.,* 1996). CA and PP sites showed lower TOC and SOC values compared to the rest of sites. Here, intra-differences between CA and PP in SOC values are due to age and soil fertility (Di Matteo *et al.,* 2014).

In coppiced and pastured area (TM), the SOC value was probably influenced by high input rates of fresh substrate (leaves and cattle manure), which would determine additional supply of organic material to the soil. NPA site showed intermediate TOC (6.40 %) and SOC (155.2 Mg ha^{-1}) values. It is a site subjected to a constant anthropic disturbance, this could lead to a greater compaction of the soil, even if no substantial differences in soil bulk density compared to the rest of sites have been observed (data not reported).

The SOC values found in the case studies showed high level of SOC, typical of forest stands, thus they did not indicate a risk of soil alteration due to erosive processes.

We should note that some limitations in the study could have affect the interpretation of SOC values due to the fact that we do not take into account the effect of forest age, soil fertility, climatic conditions and forest cover on SOC. This was because the study objective was specifically limited to SOC values comparison in different forest soils in order to evaluate the risk of soil carbon depletion.

Conclusions

Afforestation plans are a valid tool for the restoration of degraded soils, the recovery of soil organic matter and nutrients and the prevention of soil erosion.

The success of the afforestation is based on the deep knowledge of the silvicultural and pedoclimatic history of the area. In this study it was highlighted that the considered different forest managements could be applied in afforested areas without negative effects, in the long time, on SOC.

Further studies are needed to analyze in the long time the changes in SOC following afforestation and the positive function of this practice in mitigating erosion processes.

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References

Benbi, D.K. & Chand, M. 2007. Quantifying the effect of soil organic matter on indigenous soil N supply and wheat productivity in semiarid sub-tropical India. *Nutrient Cycling in Agroecosystems,* 79: 103–112.

Cortez, J., Demard, J.M., Bottner, P. & Jocteur Monrozier, L. 1996. Decomposition of mediterranean leaf litters: a microcosm experiment investigating relationships between decomposition rates and litter quality. *Soil Biology & Biochemistry*, 28: 443-452.

Di Matteo, G., Tunno, I., Nardi, P., De Angelis, P., Bertini, G. & Fabbio, G. 2014. C and N concentrations in different compartments of outgrown oak coppice forests under different site conditions in Central Italy. *Annals of Forest Science*, 71(8): 885-895.

Guillaume, T., Damris, M. & Kuzyakov Y. 2015. Losses of soil carbon by converting tropical forest to plantations: erosion and decomposition estimated by $\delta^{13}C$. *Global Change Biology*, *21*(9): 3548-3560.

Labrière, N., Locatelli, B., Laumonier, Y., Freycon, V. & Bernoux, M. 2015. Soil erosion in the humid tropics: A systematic quantitative review. *Agriculture, Ecosystems & Environment,* 203: 127-139.

Lal, R. 2005. Forest soils and carbon sequestration. *Forest Ecology and Management,* 220(1-3): 242-258.

Lawson, S.S. & Michler, C.H. 2014. Afforestation, restoration and regeneration - Not all trees are created equal. *Journal of Forestry Research,* 25(1): 3-20.

Lorenz, K. & Lal, R. 2014. Soil organic carbon sequestration in agroforestry systems. A review. *Agronomy for Sustainable Development,* 34(2): 443-454.

Olson, K.R., Al-Kaisi, M., Lal, R. & Cihacek, L. 2016. Impact of soil erosion on soil organic carbon stocks. J*ournal of Soil and Water Conservation*, *71*(3): 61A-67A.

Paul, K.I., Polglase, P.J., Nyakuengama, J.G. & Khanna, P.K. 2002. Change in soil carbon following afforestation. *Forest Ecology and Management,* 168: 241–257.

Peichl, M., Leava, N.A. & Kiely, G. 2012. Above-and belowground ecosystem biomass, carbon and nitrogen allocation in recently afforested grassland and adjacent intensively managed grassland. *Plant and Soil,* 350(1-2): 281-296.

Prăvălie, R. 2018. Major perturbations in the Earth's forest ecosystems. Possible implications for global warming. *Earth-Science Reviews,* 185: 544-571.

Rasool, R., Kukal, S.S. & Hira, G.S. 2008. Soil organic carbon and physical properties as affected by long-term application of FYM and inorganic fertilizers in maize–wheat system. *Soil and Tillage Research,* 101(1-2): 31-36.

Rehana-Rasool, Kukal, S.S. & Hira, G.S. 2008. Soil organic carbon and physical properties as affected by long term application of FYM and inorganic fertilizers in maize–wheat system. *Soil and Tillage Research,* 101: 31–36.

Reis, M., Yüksel, A., Erdaş, O., Tonguç, F. & Akay, A.E. 2007. Afforestation practices in preventing erosion in watersheds of Turkey. In *International Congress on River Basin Management*, Vol. 1, pp. 115-120.

Smith, O.H., Petrsen, G.W. & Needelman, B.A. 1999. Environmental indicators of agroecosystems. *Advances in Agronomy,* 69: 75-97.

Saha, D., Kukal, S.S. & Bawa, S.S. 2014. Soil organic carbon stock and fractions in relation to land use and soil depth in the degraded Shiwaliks hills of lower Himalayas. *Land Degradation and Development,* 25(5): 407-416.

Wiesmeier, M., Dick, D.P., Rumpel, C., Dalmolin, R.S.D., Hilscher, A. & Knicker, H. 2009. Depletion of soil organic carbon and nitrogen under *Pinus taeda* plantations in Southern Brazilian grasslands (Campos). *European Journal of Soil Science*, 60(3): 347-359.

Woodall, C.W., D'Amato, A.W., Bradford, J.B. & Finley, A.O. 2011. Effects of stand and inter-specific stocking on maximizing standing tree carbon stocks in the eastern United States. *Forest Science,* 57(5): 365–378.

Assessing the effectiveness of Sustainable Land Management for large-scale climate change adaptation

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Abstract

Climate change will strongly affect essential ecosystem services, like the provision of freshwater, food production, soil erosion and flood control. Sustainable Land Management (SLM) practices are increasingly promoted to contribute to climate change adaptation, but there is lack of evidence at scales most relevant for policymaking. We evaluated the effectiveness of SLM in a large Mediterranean catchment where climate change is projected to significantly reduce water security. We show that the on-site and off-site impacts of climate change are almost entirely reversed by the large-scale implementation of SLM under moderate climate change conditions, characterized by limited reductions in annual precipitation but significant increased precipitation intensity. Under more extreme reductions of annual precipitation, SLM implementation reduces the impacts on water security, but cannot prevent significant increased plant water stress and reduced water availability. Under these conditions, additional adaptation measures are required considering their interactions and trade-offs regarding water security and soil erosion.

Keywords: sustainability, rainfed agriculture, soil erosion, extreme events, water security

Introduction, scope and main objectives

In the coming decades, climate change will strongly affect global socio-ecological systems by altering the hydrological cycle, agricultural production potential and essential ecosystem services. For many areas worldwide, climate projections foresee less rainfall and more extreme weather events, causing decreased water availability and food production, and increased soil erosion and flood frequency (Eekhout *et al.*, 2018a). To prevent devastating impacts for human well-being and help prepare society achieve the Sustainable Development Goals, climate change mitigation and adaptation are major priorities for the coming decades. Recent scientific studies and policy initiatives suggest that Sustainable Land Management (SLM) practices can contribute significantly to climate change adaptation and mitigation. SLM refers to a range of technologies, policies and activities aiming for integrated management of soil, water, vegetation, and biodiversity to support long-term productive ecosystems by integrating biophysical, socio-cultural and economic needs and values.

In this research we quantify the on-site and off-site impacts of SLM based climate change adaptation on soil and water resources and related ecosystem services. We applied a coupled hydrology-soil erosion model to a large Mediterranean study area, where climate change is expected to have a significant negative impact on water security in the coming century (Eekhout *et al.*, 2018a). We evaluated the effectiveness of SLM with on-site (hillslope erosion and plant water stress) and off-site (reservoir inflow, flood discharge and reservoir sediment yield) water security indicators. The results aim to increase insight in the effectiveness of SLM to alleviate the on-site and off-site impacts from drought and extreme weather at regional scales, most relevant for policy makers.

Methodology

This study is performed in the Segura River catchment in the southeast of Spain, covering an area of 15,978 km^2. Catchment-averaged annual rainfall amounts to 361 mm (1981-2000). The climate is Mediterranean in the headwaters (19 %) and semi-arid in the rest of the catchment (81 %). The dominant landuse types are shrubland (28 %), forest (26 %), cereals (14 %) and almond orchards (9 %). Agriculture covers 44 % of the catchment. There are 33 reservoirs in the catchment (total capacity 1230 Hm^3) for irrigation, electricity supply and flood prevention.

We applied the SPHY-MMF model (Eekhout *et al.*, 2018), a spatially distributed hydrological model, fully coupled with a soil erosion model, and runs with a daily time step. The model simulates the most relevant hydrological (e.g. interception, evapotranspiration, surface runoff) and soil erosion processes (e.g. soil detachment by raindrop impact and runoff, sediment routing, sediment deposition) and incorporates a dynamic vegetation model.

We identified realistic SLM practices for the study catchment based on a review of previous local stakeholder consultation processes and scientific literature reporting on the impacts of SLM practices obtained from field experiments (Almagro *et al.*, 2016). Low-cost practices were identified as most promising and feasible SLM options providing benefits for soil quality, erosion reduction and soil water retention. We applied two types of SLM, i.e. reduced tillage (RT) for cereals, and reduced tillage in combination with green manure (RT+GM) for tree crops and vineyards, which account for 38% of the total catchment area. Green manure is a SLM technique where a mixture of cereals and leguminous cover crops (*Vicia sativa*) are seeded in autumn and ploughed into the soil in early spring.

We applied four different future climate scenarios, divided over two future periods and two Representative Concentration Pathways (RCPs). We have indicated the scenarios as follows: S1 (RCP4.5, 2031-2050), S2 (RCP4.5, 2081-2100), S3 (RCP4.5, 2031-2050) and S4 (RCP4.5, 2081-2100). We compare results for these future scenarios with a reference scenario (1981-2000).

Results

Impact of Climate Change

Climate change leads to a significant increase of plant water stress throughout the catchment. In scenarios S1-3 a moderate average on-site increase of plant water stress is projected of around 5.3-5.9%, while for S4 a more severe increase of 13.4 % is projected (Table 1). In scenarios S1-3 catchment total reservoir inflow (24-29 %) and catchment-average flood discharge (25.2-29.8 %) increase significantly. However, in scenario S4 a significant 25.0-60.3 % decrease of flood discharge is projected in 6 headwater subcatchments. Hillslope erosion is projected to increase for all scenarios between 33.7 % to 55.0 % in almost the entire catchment. Reservoir sediment yield also increases in scenarios S1-S3, but significant changes are only observed in S4 with a decrease of 29.2 %.

Adaptation with SLM

Large-scale implementation of SLM mitigates the increased plant water stress under climate change in scenarios S1-3, for which only a small but non-significant catchment-average increase of 0.8-1.6 % is projected. However, also after implementation of SLM, plant water stress still significantly increases with 9.5% in scenario S4. Catchment total reservoir inflow still increases in scenarios S1-3 with 8-11 %, while in scenario S4 a decrease of reservoir inflow of 9 % is projected. Similar results are obtained for flood discharge. With SLM, hillslope erosion is projected to decrease with 5.3-18.8 %. A decreased catchment total reservoir sediment yield is projected for all future climate scenarios (S1-4), with significant changes for scenario S4 (-41.4 %).

Table 1: Average on-site and off-site impacts of water security indicators. Values for the reference scenario without SLM are the absolute values. All other values are differences with respect to the reference without SLM and are accompanied with percentages in parentheses. Values marked in bolt are significantly different ($p < 0.05$). Adapted from Eekhout and de Vente (2019).

	On-site indicators		Off-site indicators		
Scenario	Plant water stress (-)	Hillslope erosion (Mg km^{-2} yr^{-1})	Reservoir inflow (Hm3)	Flood discharge (m^3 s^{-1})	Sediment yield (Gg yr^{-1})
ref.	0.64	3.6	815.4	6.3	1301
ref. + SLM	-0.03 (-4.2)	-1.5 (-40.9)	-119.5 (-14.7)	-0.8 (-12.2)	-90.9 (-7.0)
S1	**0.04 (5.5)**	**1.7 (46.5)**	**199.3 (24.4)**	**1.9 (29.6)**	96.9 (7.5)
S2	**0.03 (5.3)**	**1.9 (53.1)**	**240.4 (29.5)**	**1.6 (25.2)**	39.4 (3.0)
S3	**0.04 (5.9)**	**2.0 (55.0)**	**234.6 (28.8)**	**1.9 (29.8)**	45.4 (3.5)
S4	**0.09 (13.4)**	1.2 (33.7)	53.0 (6.5)	0.0 (0.4)	**-436.6 (-33.6)**
S1 + SLM	0.01 (1.6)	-0.4 (-11.2)	66.3 (8.1)	0.8 (13.6)	-23.0 (-1.8)
S2 + SLM	0.01 (0.8)	-0.4 (-11.2)	93.3 (11.4)	0.5 (7.7)	-84.8 (-6.5)
S3 + SLM	0.01 (1.3)	-0.2 (-5.3)	88.6 (10.9)	0.8 (13.0)	-82.4 (-6.3)
S4 + SLM	**0.06 (9.5)**	-0.7 (-18.8)	-76.3 (-9.4)	-1.0 (-15.5)	**-538.8 (-41.4)**

Discussion

Our results show that climate change significantly affects hydrology, soil erosion and water security in a large catchment, representative for many Mediterranean climate regions. The most important climate change signal in the study area is an increase of extreme precipitation and frequency of dry spells. The annual precipitation sum is projected to change only slightly for scenarios S1-S3, but more severely for scenario S4, with a catchment average reduction of 18 %. The change in precipitation frequency and intensity causes a redistribution of water, defined by a significant increase of surface runoff and decrease of soil moisture content (Figure 1, middle panel). On-site, this leads to significantly increased plant water stress and hillslope erosion. The off-site impacts include increased reservoir sediment yield (n.s.) and a significant increase of reservoir inflow and flood discharge for most subcatchments in scenarios S1-S3. For the most extreme climate scenario (S4), we found no significant changes for reservoir inflow though due to the stronger decrease in precipitation sum.

Considering the potential of SLM for climate change adaptation, our results demonstrate that SLM significantly reduces both the on-site and the off-site impacts of climate change on soil erosion and water security. Under moderate climate change conditions (scenarios S1-S3), SLM can entirely reverse the climate change impacts or leads to non-significant changes with respect to the reference scenario, with a minor increased plant water stress (n.s.) and a decrease of hillslope erosion (n.s.) compared to the reference scenario without SLM. Furthermore, a non-significant increase of reservoir inflow and flood discharge is projected, while reservoir sediment yield slightly decreases (n.s.).

Under the more extreme climate change scenario (S4), implementation of SLM also strongly reduces the severity of impacts, however, it does not take them away entirely and still results in a significant negative impact for crucial water security indicators (Table 1). While plant water stress still increases significantly, flood discharge, hillslope erosion and sediment yield reduce, which is the combined effect of strongly reduced annual precipitation and implementation of SLM resulting in soil water retention and erosion prevention. The consequence of these findings is that current rainfed and irrigated agriculture as well as natural vegetation will suffer from increased water shortage and may become unsustainable under future extreme climate conditions (Leon-Sanchez *et al.*, 2018). Hence, additional (SLM) measures are required to adapt to these extreme climate conditions.

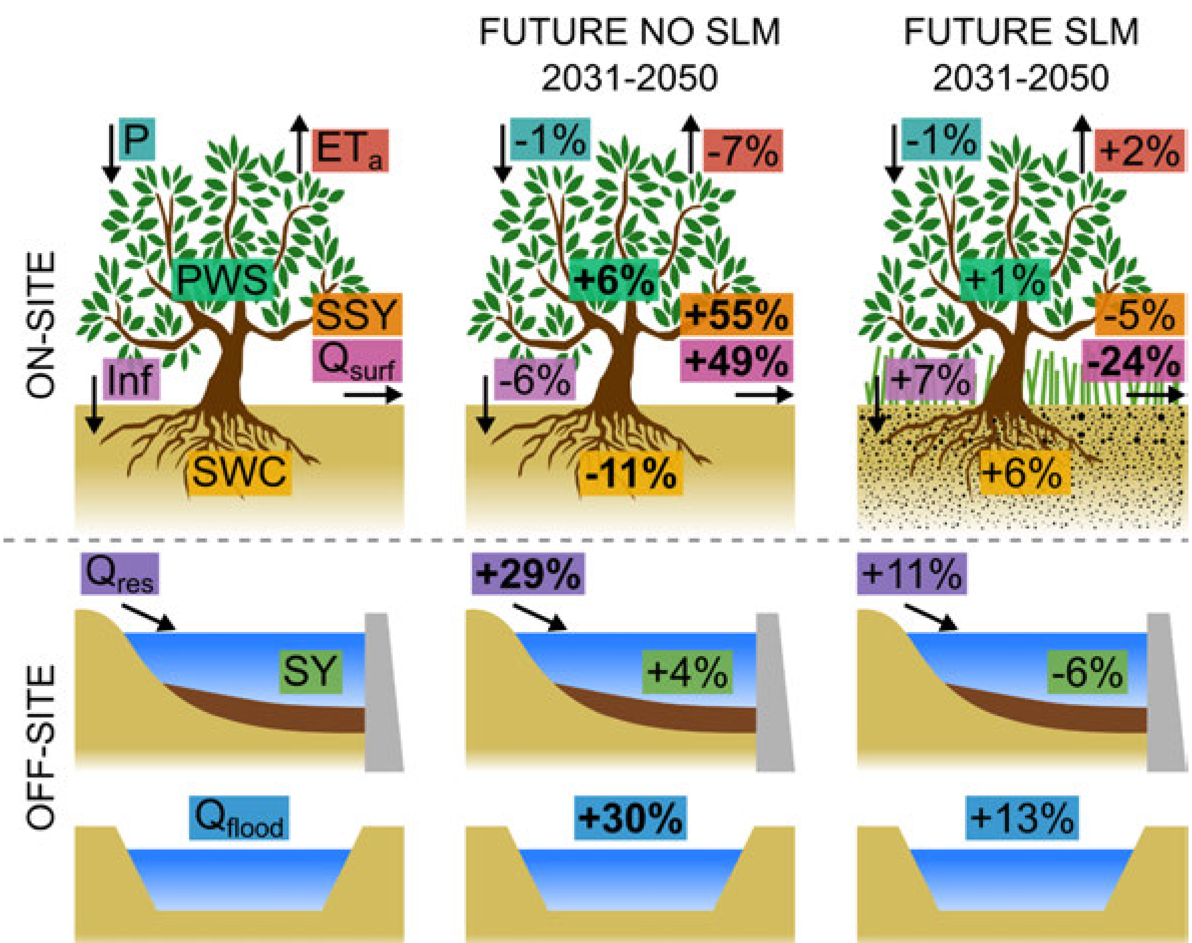

Figure 1: The on-site and off-site impacts of climate change and implementation of SLM. The left panel defines the indicators: precipitation (P), actual evapotranspiration (ET_a), plant water stress (PWS), infiltration (Inf), hillslope erosion (SSY), surface runoff (Q_{surf}), soil water content (SWC), reservoir inflow (Q_{res}), reservoir sediment yield (SY) and flood discharge (Q_{flood}). Adapted from Eekhout and de Vente (2019).

Conclusions

Large-scale implementation of SLM in agricultural lands can significantly reduce the on-site and off-site impacts of climate change on soil erosion and water security. Implementation of SLM in rainfed farming systems almost entirely reverses the on-site and off-site impacts of climate change under moderate climate conditions. Under more extreme reductions of annual precipitation, SLM implementation counteracts negative impacts on soil erosion and reduces the impacts on water security but cannot prevent significant increased plant water stress and reduced water availability. These extreme conditions require additional adaptation measures, considering their interactions and trade-offs regarding water security.

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References

Almagro, M., de Vente, J., Boix-Fayos, C., García-Franco, N., Melgares de Aguilar, J., González, D., Solé-Benet, A. & Martínez-Mena, M. 2016. Sustainable land management practices as providers of several ecosystem services under rainfed Mediterranean agroecosystems. *Mitigation and Adaptation Strategies for Global Change*, 21(7): 1029-1043.

Eekhout, J.P.C., Terink, W. & de Vente, J. 2018. Assessing the large-scale impacts of environmental change using a coupled hydrology and soil erosion model. *Earth Surface Dynamics*, 6(3): 687-703.

Eekhout, J.P.C., Hunink, J.E., Terink, W. & de Vente, J. 2018a. Why increased extreme precipitation under climate change negatively affects water security. *Hydrology and Earth System Sciences*, 22(11): 5935-5946.

Eekhout, J.P.C. & de Vente, J. 2019. Assessing the effectiveness of Sustainable Land Management for large-scale climate change adaptation. *Science of the Total Environment*, 654: 85-93.

León-Sánchez, L., Nicolás, E., Goberna, M., Prieto, I., Maestre, F.T. & Querejeta, J.I. 2018. Poor plant performance under simulated climate change is linked to mycorrhizal responses in a semi-arid shrubland. *Journal of Ecology*, 160(3): 960-976.

Using 'No-tillage' farming technique as an assessment tool in soil erosion control study on highly acidic soils formed from the volcanic origin, common in Micronesia

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Abstract

The soils of southern Guam are formed from very deep; well-drained Saprolite derived from volcanic based tuff and tuff breccias. These soils suffer from severe erosion as the result of rapid overland flow due to intensive rain events typical of islands of Micronesia. An integrated approach to control the accelerated soil erosion was designed to include; conservation tillage practices such as no-till, crop rotation with leguminous plant, and residue management for soil surface cover. Soil quality indicators and changes were monitored and measured. Our data showed that, the infiltration rate as a runoff control parameter remained relatively high for the NT treatment during the entire 60-minute of simulated rain event. However, the infiltration rate decreased gradually for the CT plots. The infiltration rate for the RT, on the other hand, remained high throughout the rainfall events On the CT plots rotated with leguminous Sunn hemp (CT/SH), the infiltration rate was also high during the rainfall event and remained comparable to the infiltration rate of the NT treatment. In this paper, we will present up-to-date data analysis and detailed methodology that was applied for reducing runoff, hence controlling soil erosion by water.

Keywords: Conservation agriculture, No-Tillage system, Volcanic soils, Micronesia, Guam

Introduction

Accelerated soil erosion, not only degrades the soil resource but also negatively impacts the downstream environment in Guam and the other islands of Micronesia. These threats are manifested most seriously in the southern part of the island where the soils are more acidic (Lewis, 1999). The challenge facing soil and agricultural scientists and policy makers is, therefore, to develop and adopt soil conservation strategies that restore the health and resilience of these soil, and improve soil quality for a sustainable crop production as well as maintaining the integrity of the environment.

This research, therefore, assesses the effectiveness of various conservation techniques adoptable for the region for controlling runoff and reducing soil erosion on these highly degraded volcanic soils of southern Guam and the neighboring islands of Micronesia. These include soil management systems such as conservation tillage (no-tillage and reduced-tillage), as well as crop rotations with leguminous sunn hemp (*Crotalaria juncea*) with maize (*Zea mays*).

The principal method of controlling rapid surface runoff thus, controlling water erosion is to maintain adequate vegetative and/or crop residue cover on the soil surface at all times (Hargrove, 1985; NeSmith *et al.*, 1987). On the other hand, rapid surface runoff due to inadequate surface cover with the conventional farming practices which involves frequent plowing and tilling have shown to be highly susceptible to soil erosion, hence reducing the soil's long term production capacity (Dumanski and Peiretti, 2013).

On the other hand, and as reported (Radcliffe *et al.*, 1988; Golabi *et al.*, 1995; Golabi *et al.*, 2016; El-Swaify, 2001), under no-tillage farming systems, soil disturbance is virtually eliminated. The adoptability of the procedures however, may differ from place to place based on the climate as well as other ecosystem conditions. As our data showed, no-tillage may not be adoptable to the farming systems practiced in Guam and the other island in Micronesia. Among the disadvantages that may be associated with the no-tillage, include higher herbicide application for weed management (Blevins *et al.*, 1993) which is a major issue in this region. Also, for imperfectly drained soils common in the region, no-tillage may aggravate the drainage problem preponderance with soils of volcanic origin common in Guam and the neighboring island. However, other conservation techniques such as reduced tillage which was studied, proved to be adoptable for the climate conditions common among the islands of Micronesia. Furthermore, incorporating Sunn hemp as a rotating crop, also showed promising effect for restoring the severely eroded soils and for improving their quality, as a required component to a sustainable agricultural system in the islands of Micronesia.

The objectives of this study were to; 1) evaluate the use of crop rotation and tillage management for improving the overall quality of severely eroded soils, 2) assess the effect of conservation practices on yield and crop productivity of these eroded soils, 3) assess the effects of conservation techniques including no-tillage systems on water runoff and infiltration.

Material and Methods:

The soil under investigation is located at the University of Guam's research station in the Ija region of southern Guam. This soil is; 'a very fine, kaolinitic, isohyperthermic Oxic Haplustalfs' (Young, F. J. 1988). These soils are formed from weathered volcanic rocks where depth to bedrock is 50–100 cm. Being formed from volcanic rock, they contain considerable amounts of aluminum (Al) and iron (Fe) oxides, and are very acidic, with measured pH as low as 4.2, in their natural condition (Young, F. J. 1988).

Field Experiment

A group of 12 field plots (each 9 m×11 m) were set up to evaluate soil management techniques for reducing the impact of soil erosion on crop productivity. Initial chemical and physical properties of soil samples were determined prior to first planting of corn (*Maize*) in 2013. An attempt was made to plant irrigated corn during the dry season and Sunn hemp (*Crotalaria juncea*) during the wet season.

The experiment included corn plantings under four conditions, conducted on different plots: 1) Conventionally tilled (CT) were used as control plots. 2) Conventionally tilled rotated with Sunn hemp (CT/SH), 3) Reduced tillage (RT), and 4) the No-tillage (NT) treatment plots were among the techniques practiced in these studies. All plots/treatments were randomly assigned and replicated three times.

Sunn hemp (*Crotalaria juncea*) is a leguminous cover crop adapted to tropical or subtropical areas that generate much biomass, and produces 150 to 165 kg/ha of N under favorable conditions (Koon-Hui Wang *et al.*, 2011). When incorporated into the soil, Sunn hemp amendments also enhance the abundance of free-living microorganisms that play important roles in nutrient cycling, and result in higher soil nutrient content, organic matter, especially on these soils with low organic matter.

Treatments

The Conventional tillage (CT) treatments consisted of plowing, tilling, and disking before planting. The plots were tilled again immediately after harvest with a roller tiller in order to incorporate the plant residue into the soil surface.

In the Conventional treatment, rotated with Sunn hemp (CT/SH), the leguminous Sunn hemp was grown between successive main crops (maize). The Sunn hemp was then bush cut and incorporated into the soil with a tiller, and then plowed and disked just before planting the subsequent main crop.

In the No-till (NT) plots, the field was never tilled or plowed, and the soil surface remained undisturbed at all times. For this treatment (NT) corn seeds were drilled directly into the soil with the existing plant residue from the proceeding crop and/or vegetation. In the NT plots, however, the standing residue from the previous crop was maintained while the growing weeds were killed using appropriate herbicides a week prior to planting.

In the Reduced-tillage (RT) plots however, the soil surface was left undisturbed after the harvest with the remaining crop residue on the soil surface. The plots were only plowed and tilled for seeding preparation just before the subsequent planting of the main crop (maize).

Yields of the corn crop (*maize*) were measured after the harvest, and soil samples were also collected and analyzed for soil-property evaluation.

Infiltration Measurements

In order to assess the effect of different conservation techniques on infiltration rates, a portable rainfall simulator was used to measure runoff. Hence a sixty-minute rain event was conducted on each treatment plot for this purpose. The rainfall simulation was performed using high-pressure spray nozzles mounted on a frame five meters above the 1 m^2 subplots (enclosure). The runoff was collected within 10 minute intervals for a total of sixty minutes. The collected runoff was then measured using a graduated cylinder for calculating the infiltration rate during each rainfall event. The collected runoff was also used to determine the sedimentation rate during each rain event.

Results and Discussion

Soil quality indicators and changes were measured. Organic matter increased in the NT, RT, as well as the CT/SH treatments compared to CT treatments. Bulk density, on the other hand, increased slightly under NT (data not shown), indicating compaction of the No-till soil during the experiment.

The yield data showed overall low crop productivity due to the inherent poor fertility conditions of the soils under study. However, RT and CT/SH treatments produced the highest yield throughout the study, followed by the CT treatment (Figure 1). As shown in Figure 1, the NT treatment produced the lowest yields during the entire study period.

The higher yields in the CT plots (Figure 1) were attributed to the absence of weeds (due to frequent plowing and tilling), and to better aeration. On the other hand, the low yield from the NT treatment was due to lower aeration, higher compaction (as indicated by the increased bulk density), and also due to the aggressive weed growth typical of the tropical areas where high rain and high temperature favors aggressive vegetation growth.

Our data also showed that, the infiltration rate remained relatively high for the NT plots during the entire 60-minute simulated rain event (Figure 2). This was because residue from previous crops intercepted the rain, hence protecting soil aggregates and eliminating soil particle detachment thus preventing surface crusting and runoff. However, the infiltration rate decreased gradually for the CT plots after about 10 minutes of continuous rainfall (Figure 2), producing much runoff during the event. This gradual decrease in infiltration was attributed to soil particle detachment and crust formation as the rain impacted on the bare soil surface of the CT plots (Golabi *et al.*, 1995). Consequently, the falling rainwater turned into overland flow with little or no infiltration below the soil surface in the CT plots. The overland flow, washed away the detached soil particles causing soil erosion as was indicated by the murky runoff collected from the CT plots during the 60 minutes' rainfall event.

The infiltration rate for the RT, on the other hand, remained high throughout the rainfall events (Figure 2). This was possible because the remaining residue from the previously harvested crop intercepted the rain and reduced its impact on soil particle detachment. Furthermore, less tillage on the RT plot allowed the remaining roots and residue from the previous crop to protect the soil aggregates and resist crust formation. In addition, the RT plots were less compacted and hence more aerated as compared to the NT plots.

On the Conventional plots rotated with leguminous Sunn hemp (CT/SH), the infiltration rate was also high during the simulated rainfall event and remained comparable to the infiltration rate on the NT plots (Figure 2). This was contributed to the higher organic matter content of the soil due to the incorporation of the Sunn-hemp into the soil as green manure before the subsequent main crop (maize) was planted.

Conclusions

The reduced-till, as well as the no-tillage practices, proved to be effective techniques for controlling runoff, as indicated by the measured infiltration rates. However, yields on the no-tillage treatment plots were lower than any other treatments evaluated in this study (Figure 1). This indicates that, unless no-tillage is practiced for longer periods of time thereby allowing the system to stabilize (Isro Ismail *et al.*, 2014) and develop the benefits of improved soil conditions (Lal, 2014), they will not be attractive to farmers in the Micronesian islands who have to deal with inherently poor quality soils. On the other hand, due to high soil acidity and poor fertility conditions inherited from the volcanic parent material in this region, practicing no-tillage farming on these soils prove to be a major challenge for traditional farmers in this region. A useful compromise, however, was the reduced-tillage, which produced higher yield than NT (Figure1), but also was quite effective in increasing infiltration rates which resulted in reduced runoff and less erosion by reducing overland flow rates. Conventional tillage rotated with leguminous Sunn hemp (CT/SH) also produced higher yields (Figure 1) as well as reduced the runoff hence produced less soil erosion. This was as the result of Sunn hemp acting as a green manure thus, improving the organic matter content and soil quality which in turn help resist soil loss due to less erosion.

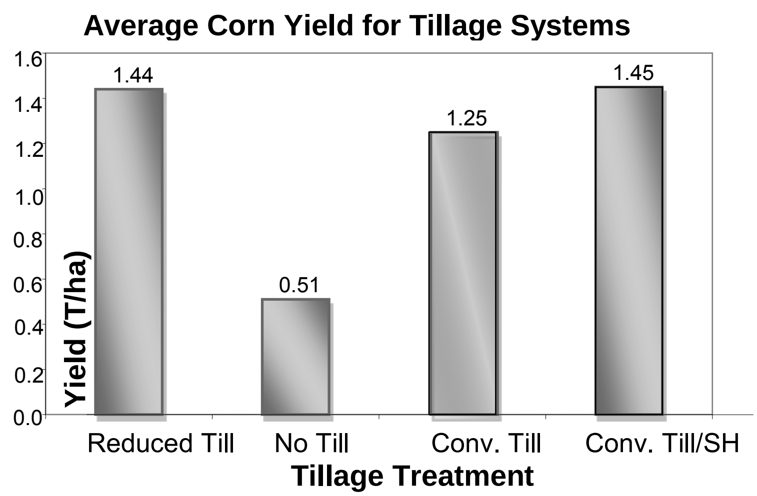

Figure 1: Corn yields. Bars represent treatment means based on Fisher's t-test. Treatments did not differ significantly at the 0.05 levels.

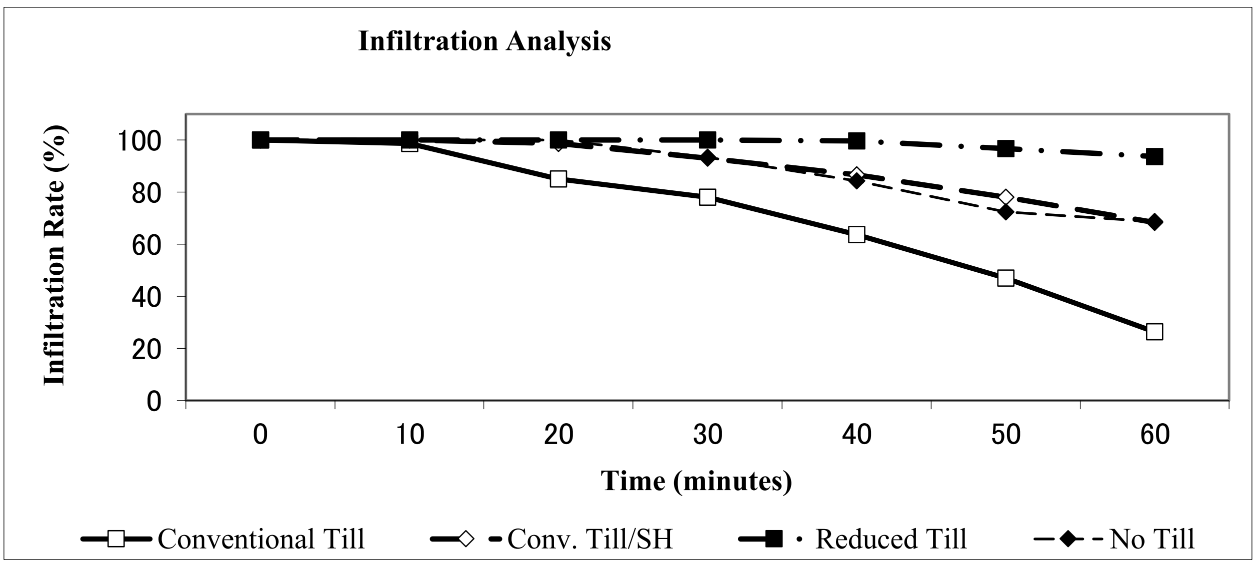

Figure 2: Infiltration (%) measured under different tillage treatments during a one-hour simulated rain event.

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References

Blevins, R. L. & Frye, W.W. 1993. Conservation tillage: an ecological approach to soil management. *Advances in Agronomy,* 51: 32–79.

Dumanski, J. & Peiretti, R. 2013. Modern concept of soil conservation. *International Soil and Water Conservation Research*, 1(1): 19-23.

El-Swaify, S. A. 2001. Impact of erosion and restoration on water and nutrient use efficiency in Hawaii oxisol. *Comm. Soil Sci. Plant Anal.*, 32: 1187–1201.

Golabi, M.H., Denny, P. & Iyekar, C. 2006. Composting of Disposal Organic Wastes: Resource Recovery for Agricultural Sustainability. *The Chinese Journal of Process Engineering*, publication of Chinese Academy of Sciences, 6(4).

Golabi, M.H., Radcliffe, S.E., Hargrove, W.L. & Tollner, E.W. 1995. Macropore effects in conventional tillage and no-tillage soils. *J. Soil Water Conserv*, 50: 205–210.

Hargrove, W.L. 1985. Influence of tillage on nutrient uptake and yield of corn. *Agron. J.*, 77: 763–768.

Isro Ismail, R., Blevins, L. & Frye, W.W. 2014. Long-Term No-tillage Effects on Soil Properties and Continuous Corn Yields. Alliance of Crop, Soil and Environmental Science Societies. Available at: https://dl.sciencesocieties.org/publications/sssaj/abstracts/58/1/SS0580010193

Koon-Hui W., Sipes, B.S., Hooks, C.R.R. & Leary, J. 2011. Improving the Status of Sunn hemp as a Cover Crop for Soil Health and Pest Management. Hānai'Ai. The Food Provider. Available at : http://www.ctahr.hawaii.edu/sustainag/news/articles/V8-Wang-sunnhemp.pdf

Lal, R. 2014. No-tillage Effects on Soil Properties under Different Crops in Western Nigeria. Alliance of Crop, *Soil and Environmental Science Societies*. Available at: https://dl.sciencesocieties.org/publications/sssaj/abstracts/40/5/SS0400050762

NeSmith, D.S., Hargrove, W.L., Radcliffe, D.E., Tollner, E.W. & Arioglu, H.H. 1987. Tillage and residue management effects on properties of an ultisol and double-cropped soybean production. *Agron. J.,* 79: 570–576.

Radcliffe, D.E., Tollner, E.W., Hargrove, W.L., Clark, R.L. & Golabi, M.H. 1988. Effects of tillage practices on infiltration and soil strength of a typic hapludult soil after ten years. *Soil Sci. Soc. Am. J.,* 52: 798–804.

Young, F.J. 1988. *Soil Survey of Territory of Guam.* U.S. Department of Agriculture, Soil Conservation Services, Washington, D.C.

No-till effect on soil erosion in mid-slope cropping through soil aggregates stability and fallout radionuclides

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Abstract

This work deals with the effect of no-till, as a component of conservation agriculture, on the soil erosion using two indicators. Our study site is a one hectare experiment plot of four years of no-tillage system on cereals-legume rotation. We compared the impact of the no-till plot to a conventional tillage one under same environment and management practices. We used the test on soil aggregates' stability developed by Le Bissonnais, along with the fallout radionucleides (FRN) ^{7}Be and ^{137}Cs as soil erosion tracers. For each of the radionucleides, we sampled a stable reference site using grid sampling and the two study sites using a one-dimensional point transect sampling. For the study sites, we collected five samples with a regular sampling distance of 10 m. The aggregates' stability test resulted into a mean weighted diameter (MWD) of 2.18 for the no-till plot and 2.02 for the conventional tillage, meaning a reduced soil detachability under the no-till system. Concerning FRN results, the ^{7}Be activity tests showed that the no-till plot retained 74.6 % of the reference site activity, against 58.1 % for the conventional tillage one, while the ^{137}Cs activity tests showed that the no-till plot retained 20.7 % of the reference site activity, against 18.5 % for the conventional tillage one. The mass balance conversion models showed that no-till system generated 5.4 % less soil erosion rate than conventional tillage.

Keywords: Soil erosion, structural stability, fallout radionuclide, Morocco

Introduction, scope and main objectives

Moroccan soils are generally of poor organic matter contents and thus lowly resistant to water erosion. This can partially be explained by the dominant actual intensive cropping systems and management practices, especially tillage. As an alternative, the no-till system, as a part of conservation agriculture, is recommended by several researchers as a mean to enhance physical soil properties such as soil organic matter content, structural stability and erodibility (Moussadek *et al*., 2011).

Soil structural stability is an important physical parameter that reflects soil erodibility. It indicates the soil particles' capacity to conserve proper arrangement when faced to splash or humectation phenomena (Le Bissonnais, 1996). The same author states that a low structural stability leads to particle detachment and transport.

Another soil erosion indicator is the flux of fallout radioneclides (FRN). In fact, three FRNs are used as tracers of soil erosion/accumulation: ^{137}Cs, ^{7}Be and $^{210}Pb_{ex}$ (Walling *et al.*, 1995; Mabit *et al.*, 2008; IAEA, 2014). These FRNs have half-lifes running from 40 days for ^{7}Be to 100 years for $^{210}Pb_{ex}$, allowing soil erosion and accumulation assessment within time scales from that of a rainfall event using ^{7}Be to that of more than a century using $^{210}Pb_{ex}$. Several researches used FRNs based techniques for soil erosion quantification. He and Walling (1997) studied the distribution of FRNs in assessing soil erosion in cultivated/uncultivated soils. Gaspar (2012) used ^{137}Cs for soil erosion assessment is several bare and cultivated Mediterranean soils. In Central Morocco, Benmansour *et al*. (2012) correlated FRNs based results to RUSLE model on a vertisol.

In this study, we approached soil erosion in a mid-slop Vertic Regosol (WRBSR, 2006) using structural stability and two FRNs (^{137}Cs and ^{7}Be) on two sites with two cropping systems (no-till and conventional tillage).

Methodology

The experimentation is located in the Tetouan region, in the undulating hilly environment of North-West of Morocco. The area is under Mediterranean sub-humid climate with a mean annual temperature of 17 °C and an average annual precipitation of 500 mm. The experiment site is a one hectare plot with a four years no-till system on cereals-legumes rotation. It located in the Dar Chaoui village (25 Km West of the city of Tetouan; 5°39'57''W; 35°35'20''N). The plot is a Vertic Regosol on a limy schist parent material and a mean slope gradient of 5 %.

The cropping system is a cereals-legumes rotation with a no-till (NT) system. We tested the effect of four years no-till with an adjacent plot under conventional tillage (CT) using two indicators: (i) agregates' structural stability as developed by Le Bissonnais (1996) and (ii) the flux of two fallout radionuclides (^{137}Cs and ^{7}Be).

For the structural stability test, we took three undisturbed samples from each plot (NT and CT) to calculate the mean weighted diameter (MWD) resulting from three stability tests for the 2-5 mm soil fractions: (i) rapid humectation test by immersion in water, simulating the effect of intense rain events (ii) slow rehumectation using water, simulating soil behavior under moderate rainfall after dry periods and (iii) desagregation test using ethanol, testing soil particles cohesion. After the three tests, seven aggregate classes are differentiated based on the particle diameters, using a dry sieving with a column of six sieves of decreasing sizes: >2 mm, 1 to 2 mm, 0.5 to 1 mm, 0.2 to 0.5 mm, 0.1 to 0.2 mm, 0.05 to 0.l mm and <0,05mm. The MWD is then calculated as the sum of the aggregate weigh on each sieve multiplied by the average size of the two surrounding sieves. High MWD values indicate a high aggregate stability. The MDW is defined by this equation:

$$MWD = ((3.5 \times [\% > 2\ mm]) + (1.5 \times [\%\ 1\ to\ 2\ mm]) + (0.75 \times [\%\ 0.5\ to\ 1\ mm]) + (0.35 \times [\%\ 0.2\ to\ 0.5\ mm]) + (0.15 \times [\%\ 0.1\ to\ 0.2\ mm]) + (0.075 \times [\%\ 0.05\ to\ 0.1\ mm]) + (0.025 \times [\% < 0.05 mm]))/100$$

Concerning the FRN flux, we compared ^{137}Cs and ^{7}Be activities along the two study sites to their activity in a stable reference site. The reference site for the ^{137}Cs is a neighboring forest, while that of ^{7}Be is a neighboring unexploited site. For both reference sites, we used a grid sampling of nine samples to the depth of 1m for ^{137}Cs and 40 cm for ^{7}Be. These depths are the maximum reached by the elements, where we can identify the radionuclide's general activity and profile distribution. For each of the study sites, we used a transect approach of five samples and 10 m sampling distance. The FRN activities were identified using Gamma HPGe spectrometry, and then mass balance conversion models were used to convert activites to soil loss rates.

Results

The calculated MDW for the three structural stability tests on the two plots are shown on the Figure 1, while the Figure 2 shows results obtained using ^{137}Cs and ^{7}Be flux. The average MWD is of 2.18 mm for the NT plot and 2.02 mm for the CT plot. This indicates a higher soil aggregates stability and thus reduced particle detachability under no-till system. The FRN flux shows a similar pattern, where ^{7}Be activity showed that the NT plot retained 74.6 % of the reference site activity, while the CT plot retained 58.1 %. As for the ^{137}Cs, the NT plot retained 20.7 % of the reference site activity while the CT one retained 18.5 %. We used the mass balance II conversion model for the resulted activities. The conversion model showed that the NT plot generated 5.4 % less soil loss rate compared to the CT one. This indicates that the no-till system is helping creating better soil particle cohesion and thus reducing soil erosion in this mid-slope cropping environment.

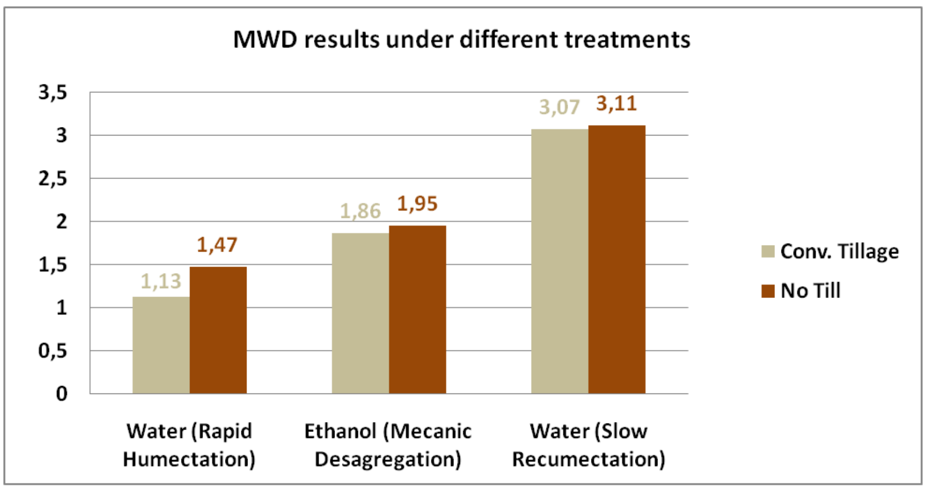

Figure 1: MDW for the three stability tests and the two plots

7Be and 137Cs activities for the study sites samples

Sample	7Be Activity (Bq/m²)		137Cs Activity (Bq/m²)	
	Conv. Tillage	No Till	Conv. Tillage	No Till
1	133	237	232	183
2	193	280	192	246
3	170	114	156	101
4	127	182	120	95
5	168	203	839	1100
Avg.	**158**	**203**	**308**	**344**

Ref. inventories: 7Be: 272 Bq/m² ; 137Cs: 1661 Bq/m²

Figure 2: FRN results for the two plots

Conclusions

This study attests of the effectiveness of the no-till system and conservation agriculture as a package for enhancing soil aggregates' stability and reducing soil erosion impact in mid-slop cropping.

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References

Benmansour, M., Mabit, L., Nouira, A., Moussadek, R., Bouksirate, H., Duchemin, M. & Benkdad, A. 2012. Assessment of soil erosion and deposition rates in a Moroccan agricultural field using fallout ^{137}Cs and ^{210}Pbex. *Journal of Environmental Radioactivity*, 115: 97-106.

FAO. 2006. World reference base for soil resources. ISBN 92-5-105511-4.

Gaspar, L. & Ana Navas, A. 2012. Vertical and lateral distributions of ^{137}Cs in cultivated and uncultivated soils on Mediterranean hillslopes. *Geoderma*, 207-208: 131–143.

He Q. & Walling D.E. 1997. The Distribution of Fallout ^{137}Cs and ^{210}Pb in undisturbed and cultivated soils. *Appl. Radiat. lsot*., 48(5): 677-69.

IAEA. 2014. Guidelines for using fallout radionuclides to assess erosion and effectiveness of soil conservation strategies. ISBN 978–92–0–105414–2. 226 p.

Le Bissonnais, Y & Le Souder, C. 1995. Mesurer la stabiité structurale des sols pour évaluer leur sensibilité à la battance et à l'érosion. *Etude et Gestion des Sols*, 2(1): 43-56.

Le Bissonnais, Y. 1996. Aggregate stability and assessment of soil crustability and erodibility: theory and methodology. *European Journal of Soil Science*, 47: 425-437.

Mabit, L., Benmansour, M. & Walling, D.E. 2008. Comparative advantages and limitations of the fallout radionuclides 137Cs, 210Pbex and 7Be for assessing soil erosion and sedimentation. *Journal of Environmental Radioactivity*, 99: 1799–1807.

Moussadek, R., Mrabet, R., Zante, P., Lamachere, J-M., Pepin, Y., Le Bissonnais, Y., Verdoodt, A. & Van Ranst, E. 2011. Effet du travail de sol et des résidus de culture sur les propriétés du sol et sur l'érosion hydrique d'un Vertisol Méditerranéen. *Can. J. Soil Sci*., 91: 627-635.

Roose, E. 1994. *Introduction à la GCES*. Bulletin pédologique FAO, 70. 420pp.

Roose, E. 1996. Méthodes de mesure des états de surface du sol, de la rugosité et des autres caractéristiques qui peuvent aider au diagnostic de terrain des risques de ruissellement et d'érosion, en particulier sur les versants cultivés des montagnes. *Bull. Réseau Erosion,* 16: 87-97.

Walling, D.E., He, Q. & Quinte, T.A. 1995. Use of caesium-137 and lead-210 as tracers in soil erosion investigations. *Tracer Technologies for Hydrological Systems (Proceedings of a Boulder Symposium, July 1995)*. IAHS Publ., 229.

Novel biotechnological methods of soil erosion control to achieve sustainable development goals: economic growth, food self-sufficiency, and clean water

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Abstract

Soil erosion that reduces agricultural productivity and pollutes environment due to removal of nutrients and humus can be controlled using conventional biotechnical methods that are based on the planting of appropriate species. The novel biotechnological methods are based on the microbially-mediated aggregation of soil particles and formation of the soil crust. Most feasible approaches are different types of calcium-based bioaggregation of the soil surface particles using biocement and/or microbial polysaccharides, cultivation of cyanobacteria for soil crust formation, irrigation of soil surface with calcium bicarbonate solution, and formation of the biocemented microbial barriers on the slopes. The results of these biotechnologies are diminishing of water- and wind-caused movement of the fine soil particles, humus, and plant nutrients, as well as control of water flows on soil surface. For example, the bioaggregation of soil made at the dosage of bioprecipitated calcium 64 kg/ha with the cost of about US$150/ha, suppressed the movement of the fine particles and soil pollutants by 61 – 74 % and the dosage of 156 kg of bioprecipitated calcium/ha supressed the soil erosion and the release of the pollutants by 99 %.

Keywords: soil erosion control, soil bioaggregation, soil biocrust, dust control

Introduction, scope and main objectives

Soil erosion can cause losses of fertile topsoil, reduction of agricultural productivity due to removal of nutrients and humus, as well as pollution of natural water bodies. It is estimated that soil erosion for the globe and for the conventional plowing fields is about 0.38 mm/yr and 1 mm/yr, respectively (Yang *et al.,* 2003; Montgomery, 2007). Runoff from soil surface contains nutrients, pesticides, and biopollutants from the cattle or chicken manure fertilizers polluting surface and ground waters (Jamieson *et al.* 2002; Ramos *et al.,* 2006; Gilley *et al.,* 2012; Sepehrni *et al.,* 2017). Agricultural, mechanical and chemical techniques are used to control soil erosion, for example conservation tillage (Blevins *et al.,* 2018) or chemical stabilization using anionic polyacrylamides (Levy and Warrington, 2015). All known methods of chemical stabilization of soil and binding reagents to control soil erosion either negatively affect plants or are relatively expensive and environmentally harmful.

Microorganisms and their polysaccharides are playing important role in stabilization of soil due to aggregation of soil particles and formation of soil crust (Gupta and Germida, 2015; Ivanov and Stabnikov, 2017a). Therefore, the most environmentally friendly and feasible approach to stabilize agricultural soil could be microbially-induced aggregation of soil particles and formation of strong soil crust. The scope of this study was comparative analysis of the methods for microbial biostabilization of soil. The objective of the study was recommendation of the biotechnological methods to control soil erosion.

Methodology

Microorganisms

Isolated strains of bacteria were identified using 16S rRNA gene sequencing and used for soil particles bioaggregation and, if neccessary, for the formation of strong soil crust. Soil-aggregating bacteria were *Sporosarcina pasteurii (Bacillus pasteurii*), micrococci Y*aniella* sp. VS8, *Bacillus ginsengi* strain VSA1, and *Staphylococcus saprophyticus* AU1.

Cultivation

Microorganisms were cultivated aerobically at 25 ^{o}C in rich sterile medium of the following composition: Tryptic Soya Broth DIFCO™, 20 g; urea, 2 g; NaCl, 20 g, $NiCl_2 \cdot 6H_20$, 24 mg, phenol red, 10 mg, distilled water 1 L, pH 8.2. Treatment of bacterial cells Y*aniella* sp. VS8 to produce crude urease was done by addition of 0.5 % (w/v) sodium dodecyl sulfate (SDS) for 960 min.

Soil treatment

The soil treatment was done by one or several times spaying of calcium solution with urea, when needed, and bacterial suspension. Typical dosages of bacterial suspension were from 0.02 to 0.1 L/L of soil-aggregating solution.

Measurements

Urease activity was determined as the amount of ammonium produced from 1 M solution of urea per minute. Calcium concentrations in the liquid before and after biogrouting were determined using standard ethylene diaminetetraacetate titrimetric method 2 340 C with Eriochrome Black T indicator (APHA, 1999). Concentration of ammonium in effluent after treatment was measured by the APHA standard 4500-NH_3 F Phenate method (APHA, 1999). All control and experiments, as well as chemical analysis have been done in triplicate.

Results

Comparative analysis of potential methods for soil stabilization

Soil bioaggregating composition is a mixture of at least three components: 1) a major inorganic component producing binding matter, 2) a component that changes pH and produces carbonate, phosphate, sulphide, or hydroxylic groups for the precipitation of a binder; and 3) either enzyme, or live microbial cells, or dead but enzymatically active microbial biomass which catalyze reaction caused the pH changes or other biochemical reactions. There are many different types of potential soil bioaggregating materials and processes shown in the Table 1.

Table 1: Diversity of soil bioaggregation processes and their applicability for soil erosion control

Soil bioaggregation process and the major chemical equation	Pros and cons for soil erosion control
Crystallization of calcium carbonate due to hydrolysis of urea: $Ca^{2+} + (NH_2)_2CO + 2\ H_2O \rightarrow \mathbf{CaCO_3}\downarrow + 2\ NH_4^+$	Pro: fast and strong soil crusting. Con: release of ammonia and increase of pH
Crystallization of calcium carbonate due to aerobic microbial oxidation of calcium (and magnesium) formate or calcium (and magnesium) acetate: $(CH_3COO)_2Ca + 4\ O_2 \rightarrow \mathbf{CaCO_3}\downarrow + 3\ CO_2\uparrow + 3\ H_2O$ $(CH_3COO)_2Ca + (CH_3COO)_2Mg + 8\ O_2 \rightarrow \mathbf{CaCO_3}\downarrow + \mathbf{MgCO_3}\downarrow + 6\ CO_2\uparrow + 6\ H_2O$	Pro: environmentally-friendly method, no release of ammonia and increase of pH. Con: addition of nutrients for growth of bacteria in soil
Crystallization of calcium carbonate due to decay of calcium bicarbonate and drying: $Ca(HCO_3)_2 \rightarrow \mathbf{CaCO_3}\downarrow + CO_2\uparrow + H_2O$	Pro: environmentally-friendly method. Con: low concentration of dissolved calcium
Formation of soil biocrust based on the production of biomass and polysaccharides on soil surface by phototrophic bacteria: light + $CO_2 + H_2O \rightarrow \mathbf{CH_2O}$ (biomass) + O_2	Pro: environmentally-friendly method Con: requires high humidity and content of nutrients in soil for growth of cyanobacteria
Crystallization of calcium phosphate (hydroxyapatite) due to the increase of the pH by urease: $10\ Ca^{2+} + 6\ H_2PO_4^- + 14\ OH^- \rightarrow \mathbf{Ca_{10}(PO_4)_6(OH)_2}\downarrow + 12\ H_2O$	Pro: environmentally-friendly method + material could be produced from waste bones after meat-processing. Con: probably, it is more expensive technology than methods based on calcium carbonate precipitation
Crystallization of calcium and magnesium carbonates due to hydrolysis of urea at molar ratio (Ca + Mg): urea = 0.5 – 2.0: $Ca^{2+} + Mg^{2+} + CO(NH_2)$ + UPB $\rightarrow \mathbf{CaMg(CO_3)}\downarrow + 2\ NH_4^+$	Pro: material could be produced from waste cement powder or dolomite. Con: release of ammonia and increase of pH

So, depending on the availability and cost of the raw materials, different kinds of soil aggregating compositions can be produced and used in agricultural practice to control soil erosion. The most prospective processes for the formation of soil crust are: 1) crystallization of calcium (and magnesium) carbonate due to aerobic microbial oxidation of calcium (and magnesium) formate or calcium (and magnesium) acetate; 2) crystallization of calcium carbonate due to decay of calcium bicarbonate and drying; 3) artificial formation of cyanobacterial soil crust. The raw materials for soil-aggregating compositions could be limestone, dolomite, or cement powder, which are dissolved using acetic, formic, or carbonic acids. In last case there could be a cement powder, a waste of the cement plant, dissolved in water saturated with carbon dioxide released on the same cement plant.

Data on soil stabilization using bioprecipitation of calcium carbonate

Biotreatment of soil with calcium chloride, urea and urease-producing bacteria, or with calcium acetate and acetate-oxidizing bacteria can decrease the seepage rate to very low values, for example from 1×10^{-4}

ms^{-1} to 1×10^{-8} ms^{-1} due to formation of almost impermeable and strong soil crust. To produce maximum effect the content of precipitated calcium carbonate should be on the level of 20 % (w/w) (Ivanov and Stabnikov, 2017b). However, to bind the soil particles to eradicate water erosion of soil the content of precipitated calcium carbonate in 1 mm layer of soil should be about 1 % (w/w), i.e. dosage of precipitated calcium as calcium carbonate per ha must be about 160 kg/ha.

Experimental data showed that at the dosage of precipitated calcium 64 kg/ha with the evaluated cost of about US$150/ha and linear velocity of water flow 0.17 cm/s the erosion rate of fine sand was decreased from 66 to 20 kg/m^2d, the maximum size of 90 % of the soil particles was increased from 40 to 80 µm, and the releases of the model soil pollutants such as phenanthrene, lead , and cells of *Bacillus megaterium* were diminished by 70, 70, and 90 %, respectively. Similar results were obtained for wind erosion of soil, when the dosage of precipitated calcium about 156 kg Ca/ha suppressed the release of fine sand dust by 99.8 %, increased the maximum size of 90 % of the sand dust particles from 29 µm to 181 µm, and diminished the releases of the model soil pollutants such as phenanthrene, lead, and cells of *Bacillus megaterium* by 92.7, 94.4, and 99.8 %, respectively.

Conclusions

Bioaggregation treatment of the soil surface could be useful method to prevent soil erosion and the release of soil-associated chemical and bacteriological pollutants in water and air. Such biotechnologies as crystallization of calcium carbonate due to aerobic microbial oxidation of calcium formate or calcium acetate and crystallization of calcium carbonate due to decay of calcium bicarbonate and drying could be recommended for pilot-scale testing of the soil erosion control for different types of agricultural soils. It is recommended for soil-aggregating solutions such raw materials as limestone, dolomite, cement powder, which must be dissolved by acetic, formic, or carbonic acids. Most prospective material is the cement powder dissolved in water saturated with carbon dioxide, both are the wastes of the cement plants.

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References

APHA. 1999. *Standard Methods for the Examination of Water and Wastewater*. 20th Edition, American Public Health Association, Washington DC.

Blevins, R.L., Lal, R., Doran, J.W., Langdale, G.W. & Frye, W.W. 2018. Conservation tillage for erosion control and soil quality. In: Advances in Soil and Water Conservation FJ Pierce, ed. New York, Routledge: e-published https://doi.org/10.1201/9781315136912.

Gilley, J.E., Vogel, J.R., Eigenberg, R.A., Marx, D.B. & Woodbury, B.L. 2012. Nutrient losses in runoff from feedlot surfaces as affected by unconsolidated surface materials. *Journal of Soil and Water Conservation*, 67(3): 211-217.

Gupta, V.V.S.R. & Germida, J.J. 2015. Soil aggregation: Influence on microbial biomass and implications for biological processes. *Soil Biology and Biochemistry*, 80(1): A3-A9.

Ivanov, V. & Stabnikov, V. 2017a. Soil surface biotreatment. In: *Construction Biotechnology: Biogeochemistry, Microbiology and Biotechnology of Construction Materials and Processes*. Ivanov V., Stabnikov V., eds. Springer, p.179-197.

Ivanov, V. & Stabnikov, V. 2017b. Bioclogging and biogrouts. In: *Construction Biotechnology: Biogeochemistry, Microbiology and Biotechnology of Construction Materials and Processes*. V. Ivanov and V. Stabnikov, eds. Springer, p. 139 -178.

Jamieson, R.C., Gordon, R.J., Sharples, K.E., Stratton, G.W. & Madani, A. 2002. Movement and persistence of fecal bacteria in agricultural soils and subsurface drainage water: A review. *Canadian Biosystems Engineering*, 44: 1.1-1.9.

Levy, G.J. & Warrington, D.N. 2015. Polyacrylamide addition to soils: impacts on soil structure and stability. In: *Functional Polymers in Food Science: From Technology to Biology, Volume 2*. G. Cirillo, U.G. Spizzirri, F. Iemma, eds. John Wiley & Sons, Inc. Hoboken, New Jersey: pp. 9-32.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. *PNAS*, 104(33): 13268-13272.

Ramos, M.C., Quinton, J.N. & Tyrrel, S.F. 2006. Effects of cattle manure on erosion rates and runoff water pollution by faecal coliforms. *Journal of Environmental Management*, 78(1): 97-101.

Yang, D., Kanae, S., Oki, T., Koike, T. & Musiake, K. 2003. Global potential soil erosion with reference to land use and climate changes. *Hydrological Processes*, 17(14): 2913-2928.

Conservation and Traditional Agriculture Impacts on Soil in the Peruvian's highlands

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Abstract

The main economic activity of most people from Peruvian´s highlands is crop production, which is carried out through practices of traditional agriculture (TA) that degrades soil. Contrarily, practices of conservation agriculture (CA) are suitable techniques for improving soil and crops yields and to reduce soil erosion. A field experiment with corn crop was set up for compering both agricultural systems and specifically the soil erosion. A completely randomized design with 3 replications of 50 erosion pins and LSD test with 10 replications of corn grain yield and 20 replications of bulk density (D_b) and volumetric moisture (θ_v) at two soil depths were designed. Soil wild weed cover significantly reduced almost half TA soil erosion. CA soil D_b was constant in the first layer. CA soil θ_v was significantly higher than TA at the first layer. Corn grain yield was higher in CA soil than TA. Results showed that CA practices are more economically profit and friendly with natural resources than TA.

Keywords: Erosion, volumetric moisture, bulk density, corn grain yield

Introduction, scope and main objectives

The 49.8 % of the Junín rural population has as main economic activity the agrarian item (INEI, 2018), most of them produce crops through TA practice on 202 184 ha (DRA JUNIN, 2017), which present severe soil erosion. The main trouble of the agricultural production in the Peruvian´s highlands is soil erosion, 60 % of soils are severely eroded (Brack and Mendiola, 2006). Intensive tillage and vegetables residues burning causes soil deterioration (Kirk and Olk, 2000). CA is characterized minimum mechanical soil disturbance, permanent organic soil cover and crops rotation, which led to reduction of soil erosion and increase soil water storage. TA practices encourage soil structure degradation, causing higher soil erosion and run off (Benites and Bot, 2014). CA practices storage more water inside soil than TA soil, also they physically protect soil, decreasing soil erosion (Ghosh *et al.,* 2015).

The main objectives of this experiment were determinate and compare the soil erosion, D_b, θ_v and corn grain yield between CA and TA.

Methodology

The experiment was carried out in Junín, 12°02'28" S and 75°19'14" W, at 3211 m.a.s.l. and cold climate. The soil has loam texture with great amount of pebbles, pH moderately alkaline, D_b 1.28 g cm^{-3} and a 16 % slope.

Cumulative rainfall and evapotranspiration were 432.5 and 235.05 mm, respectively, during the 94 days that soil erosion was evaluated.

Experimental plot had 6724 m^2 with radish as soil cover, the plot was divided in two parts, 1200 y 5524 m^2 for CA and TA, respectively. In the first plot, shallow cut on soil were done for depositing seed and fertilizers, then they were earthed up with soil and a non-selective herbicide was sprinkled. In the second, soil was tilled through draught animal power, radish was burned and furrows were done. Corn sowing (under rainfed conditions) was done at a row distance of 0.75 m and plant distance of 0.30 m, with 3 seed in each hole, for a density of 133 333.3 plants/ha. Fertilizers doses was 50 N- 50 P_2O_5- 10 K_2O.

Soil erosion was determined by erosion pin method. Iron pins of 35 cm of length and 2.4 mm of diameter were used. The pins were marked in the middle, which indicates soil surface position, they were collocated since corn sowing. Distance between each pin was 40 cm. A completely randomized design with 3 replications of erosion pins groups (5 x 10) were set up in soil to the same soil slope direction under CA and TA. Algebraic sum of erosion (+) and sedimentation (-) was done at 94 days after of sowing (d.a.s.). Erosion was calculated multiplying eroded height (mm) by D_b and by 10.

D_b was determined through cylinder method (3.70 cm diameter and 5.98 cm height), 20 samples from each plot were collected at 0 – 10 and 10 -20 cm depths in two opportunities at 30 and 53 d.a.s., registering soil moisture weights. Samples were dried in an oven at 105 °C for 24 hours (Brady N.C. and Weil R.R. 2016).

D_b and θ_v were determined by next formulas:

$$\mathrm{Db} = \frac{dried\ soil\ mass\ (g)}{total\ volume\ (cm3)} \qquad \theta\mathrm{v} = \frac{moist\ weight\ (g) - dried\ weight\ (g)}{dried\ weight\ (g)}\ x\ Db\ x 1000$$

CA and TA plots, the number of plants, grain weight on 5 m of sowing line, with 10 randomized replications were registered and adjusted to hectare.

Values obtained of evaluated variables were further processed using ANOVA. The averages were compared by $LSD_{0.05}$ test and soil erosion values were compared by Tukey's HSD test ($p < 0.05$).

Results

Results of D_b, θ_v, erosion and corn yield under CA and TA principles are summarized in Table 1.

Table 1: Averages of the Db, θv and erosion under the AC and AT

Variables	**Depth (cm)**	**CA**	**TA**			**CA**	**TA**		
		Days after of sowing (d.a.s.)							
		30		CV(%)	$LSD_{0.05}$	53		CV(%)	$LSD_{0.05}$
D_b (g cm^{-3})	0 – 10	1.280	1.23	4.80	0.049	1.28	1.200	8.30	0.082
	10 – 20	1.420	1.29	7.20	0.060	1.48	1.360	7.20	0.071
θ_v (m^3 ha^{-1})	0 – 10	192.0	155.9	17.4	21.11	227.1	189.8	22.2	36.71
	10 – 20	233.3	195.4	13.1	18.02	255.8	280.5	22.9	52.24
		CA			**TA**				$LSD_{0.05}$
Corn grain yield (kg ha^{-1})			1311.12			701.1			425.09

D_b: bulk density. θ_v: volumetric moisture. TA: traditional agriculture. CA: conservation agriculture.

TA soil D_b in both soil depths and sampling days were significantly less than CA, exception of D_b at 0 – 10 cm depth at 53 d.a.s. (Table 1), simultaneously, all D_b at 10 – 20 cm depth were higher than upper layers D_b. TA and CA D_b of lower layers showed an increase at 53 d.a.s. CA and TA soil D_b of upper layers were constant and decreased, respectively (Table 1).

CA soil θ_v at 0 – 10 cm depth at 30 and 53 d.a.s. were 36.1 and 37.3 m^3 ha^{-1} of water more than TA soil, respectively (Table 1), representing a 23.07 and 19.54 % more water than TA and according to LSD test, CA soil θ_v at 0 – 10 cm depth is significantly greater than TA.

CA soil erosion at 94 d.a.s. was 35.82 t ha^{-1}, which represented 30.71 t ha^{-1} of soil less than TA (Figure 1) and according Tukey´s HSD test ($p < 0.05$). TA soil loss was significantly higher than CA.

CA grain yield was 87 % higher than TA.

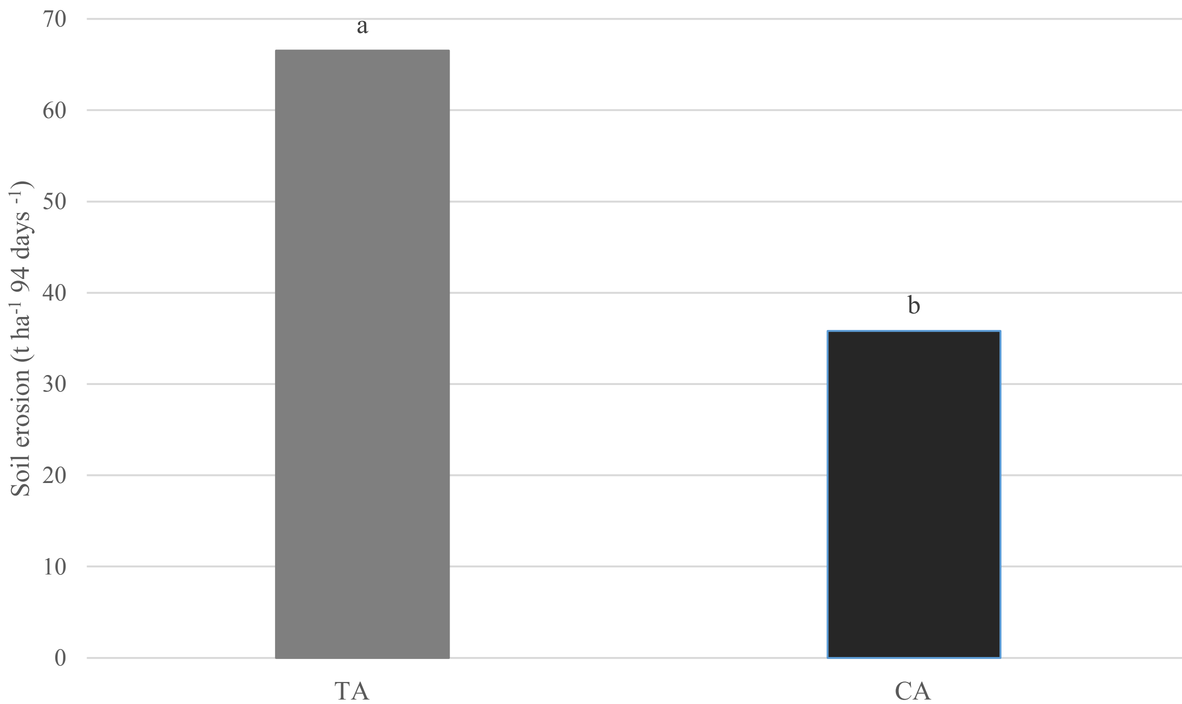

Figure 1: Effect of CA and TA on soil erosion with corn sowing. TA: Traditional agriculture. CA: conservation agriculture. a, b: Values of erosion are significantly different for Tukey's HSD test ($p < 0.05$).

Discussion

Initial soil D_b was 1.28 g cm^{-3}, it was not ideal value for a loam texture, but it does not restrict roots growth (Álvaro – Fuentes *et al.*, 2019). CA soil D_b was constant at 0-10 cm depth, perhaps due to abundant pebbles and no-tilled soil. Analogously, in a natural structure soils, pebbles significantly conserved D_b in different soil textures (Rücknagel *et al.*, 2013).

TA soil θ_v at 10- 20 cm depth was higher than CA, maybe because a tillage floor was developed below depth at which soil was tilled and it often has smooth surfaces with filled porous, due to tillage degradant action (Benites and Bot, 2014), which could decrease water infiltration, storing more amount of water and decreasing oxygen diffusion (Mehra *et al.*, 2018), causing plant yellowing and growth less of corn plants on TA plot, resulting a minor corn grain yield. The higher θ_v either could be because tilled soils D_b increase and macropores decrease, affecting negatively water infiltration, while CA soil D_b is constant and macropores percentage is the double than tilled soils (Gassen D.N. and Gassen F.R., 1996).

The CA soil erosion with a 16 % slope was similar to erosion of 22 microcatchments of Peruvian's highlands with slopes that ranged from 17 to 40 %, with native vegetation and no-tilled soil, 45.04 t $ha^{-1}año^{-1}$ (Vásquez and Tapia, 2011). Despite CA soil erosion was less than TA, it is high and would decrease with next sowings, applying CA principles (Izaurralde *et al.*, 2007). A soil with a 2 % slope and applying CA with corn sowing, soil erosion was 3.5 t ha^{-1}, it was less than half of TA (Ghosh *et al.*, 2015). In CA and TA soils, erosions were 7 and 68 t ha^{-1}, respectively (Gassen D.N. and Gassen F.R., 1996). Wheat sowing on CA soil and flat slope, soil erosion was null, while under reduced tillage the erosion was 62 t ha^{-1} $año^{-1}$ (Yao, 2004).

CA corn grain yield was higher than TA perhaps because CA soil θ_v in the first layer was higher than TA, corn plants supported better water stress on days of rains shortage.

Conclusions

CA soil D_b was constant without need to till soil as TA. CA soil θ_v presumably with a suitable water infiltration was higher than in TA, being that a goodness for crop for eventual days of water shortage.

CA soil erosion was far less than TA and it will be probably even less due to greater cover crop in next sowings.

The results demonstrated CA potential for conserving natural resources, to increase crop yield and CA application is feasible in conditions of minifundium of the Peruvian's highlands.

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References

Álvaro–Fuentes, J., Lóczy, D., Thiele–Bruhn, S. & Zornoza, R. 2019. *Handbook of Plant and Soil Analysis for Agricultual Systems*. Cartagena – Spain: Crai upct Editions, 389 pp.

Brack Egg, A. & Mendiola Vargas, C. 2006. Lima Peru: *Ecology of Peru*. Ed. Bruño, 196 pp.

Benites, J.R. & Bot, A. 2014. *Agricultura de Conservación. Una práctica Innovadora con beneficios económicos y medioambientales*. Lima – Perú: Letera Gráfica SAC, 344 pp.

Brady, N.C. & Weil, R.R. 2016. *The Nature and Properties of Soils*. Columbus. USA: 15° edition, Macmillan Publishing Company, 1084 pp.

DRA JUNIN (Dirección Regional de Agricultura de Junin). 2017. Junín: *Compendio Estadístico Agropecuario* 1997 – 2016. Huancayo. Available at: https://drive.google.com/file/d/0B6teYThL_oDqX2hBazIwVmlZbFk/view [accessed 01.03.19].

Gassen, D.N. & Gassen, F.R. 1996. *Plantio direto*. Passo Fundo RG: Aldeia Sul Editora, 206 pp.

Ghosh, B.N., Pradeep, D., Sharma, N.K., Ranjan, B. & Mishra, P.K. 2015. Conservation agriculture impact for soil conservation in maize–wheat cropping system in the Indian sub-Himalayas. *International Soil and Water Conservation Research*, 3: 112–118.

INEI (Instituto Nacional de Estadística e Informática). 2018. Junín Resultados Definitivos *Población Económicamente Activa* Tomo II. Available at : https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1617/ [accessed 04.03.19].

Izaurralde, R.C., Williams, J.R., Post, W.M., Thomson, A.M., McGill, W.B., Owens, L.B. & Lal, R. 2007. Long-term modeling of soil C erosion and sequestration at the small watershed scale. *Climate Change*, 80: 73–90.

Mehra, P., Baker, J., Sojka, R.E., Bolan, N., Desbiolles, J., Kirkham, M.B, Ross, C. & Gupta, R. 2018. A Review of Tillage Practices and their Potential to Impact the Soil Carbon Dynamics. *Advances in Agronomy*, 3: 1-47.

Rücknagel, J., Götze, P., Hofmann, B., Christen, O. & Marschall, K. 2013. The influence of soil gravel content on compaction behaviour and pre-compression stress. *Geoderma*, 209: 226–232.

Vásquez, A. & Tapia, M. 2011. Cuantificación de la erosión hídrica superficial en las laderas semiáridas de la Sierra Peruana. *Revista INGENIERÍA UC*, 18(3): 42-50.

Yao, Y., Schiettecatte, W., Lu, J., Wang, Y., Hu, H., Jin, K., Cai, D., Gabriels, D., Hartman, R., Cornelis, W., Baert, M. & Buysse, T. 2004. Influence of tillage practices on yield, water conservation and soil loss: results of field experiments in the Eastern Loess Plateau (Henan province, China). ISCO - *13th International Soil Conservation Organization Conference*. Brisbane 233, pp 1-5.

Zhou, W., Lv, T.F., Chen, Y., Westby, A.P. & Ren, W.J. 2014. Soil physicochemical and biological properties of paddy-upland rotation: a review. *The Scientific World Journal*, 1: 24 – 31.

Erosion-induced soil toxicity undermined maize-bean responses to sustainable land management practices on Mount Wanale in eastern Uganda

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Abstract

This study was informed by the poor crop performance observed under a World Bank (WB)-supported sustainable land management (SLM) project to restore Mt Wanale ecosystem in eastern Uganda blighted by decades of accelerated soil erosion. The study was aimed at identifying cause(s) for the observed poor crop performance beyond the explanation from implementers of the SLM project, that farmers' soils were nonresponsive'. We hypothesized that poor crop performance was due to soil toxicity induced by decades of unabated accelerated soil erosion. To test this hypothesis, we collected and analysed bulk soil samples for physico-chemical properties using standard protocols. Data collected were checked for conformity with the conditions for conducting ANOVA and analysed using the Genstat statistical package 12th edition. The soils were severely acidic (pH 3.25$\pm$0.58 to 4.85$\pm$0.58) and soil organic matter (SOM) also ranged from 0.40$\pm$0.69 to 2.05$\pm$0.69 which was in the very low to low range, respectively. These pH and SOM levels are in the range known to induce Fe^{3+}, Al^{3+} and Mn^{2+} toxicity to plants and were the cause of poor crop performance under the WB SLM project. Sustained liming with wood ash and municipal solid waste applications to raise soil pH to ≥5.0 and SOM to ≥ 2.8, respectively should have preceded investment in the costly SLM practices.

Keywords: Accelerated water erosion, Mt Wanale, poor crop performance, sustainable land management, soil toxicity, World Bank, zero tillage

Introduction, scope and main objectives

Mountainous ecosystems are very fragile and delicate with endangered species yet, they are densely populated worldwide. Land use/land cover changes can have profound negative effects on such ecosystems, disturbing the delicate ecological balance and thus, triggering a cascade of environmental catastrophes (Olupot *et al.*, 2017). Mt. Wanale had previously been gazetted as an ecotourism centre in the early 1980s shortly before it was encroached on. Ensuing deforestation and a shift away from the traditional banana-coffee-and montane forest ecosystem resulted in loss of over 90 % of the carbon sequestered in forest biomass alone in 27 years from the encroachment (Buyinza *et al.*, 2014; Olupot *et al.*, 2017), triggering catastrophic soil erosion on bare landscapes (Figure 1).

Soil erosion is the major contributor to soil nutrient mining and depletion in mountainous areas (Olupot *et al.*, 2019), necessitating reliance on fertilizers. Soil erosion also reduces rooting depth and causes water loss and overall reduction in soil productivity. It reduces land quality and value, silts reservoirs, rivers, navigable waterways and natural drainage systems; pollutes water; increases severity and frequency of flooding and reduces power generation and aquatic ecosystems productivity. Erosion selectively removes

SOM and associated exchangeable bases. Soil pH below 5.0 induces Al^{3+}, Fe^{3+} and Mn^{2+} toxicity to plants (USDA, 2006; Yang *et al.*, 2009; Gerard, 2016), necessitating a range of soil management strategies. Rebuilding damaged ecosystems requires smart step by step approaches and practices (Guobin, 2016) including: crop rotation, reduced tillage, mulching, legume cover cropping, fallowing, fertiliser application, terracing, trenches and contours (FAO, 2017; Karidjo *et al.*, 2018). We conducted this study to identify the cause(s) of the poor crop performance we observed on World Bank (WB)-supported sustainable land management (SLM) project on Mt Wanale. We hypothesized that poor crop performance was due to erosion-induced soil toxicity.

Methodology

Site characterisation

This study was conducted in Wangasa village, Bunatsoma parish, Wanale Sub-County, Mbale district in eastern Uganda. Wanale is located about 6.8 km to the south east of Mbale Municipality at $1^0$03'14.2"N and $34^0$14'24.9"E at an elevation of 2092 meters above sea level with slopes of steepness 30 – 60% (Figure 1). It is a source of streams which supply Mbale and join to compose rivers: Manafwa, Sironko, and Namatala, which drain into the flood plains and Albert Nile via Lake Kyoga and River Mpologoma (www.mbale Wikipedia.go.ug). For detailed information about climate, soils, vegetation, population and land use (NEMA, 1996; Mboga, 2012).

Study design and data collection

The WB SLM project field trials were toured with the farmers guided by the field extension officer after a brief informal meeting. We observed that the study area had a total of 19 treatments allocated on nine blocks in a completely randomized block design with blocks separated from one another by a contour (Figure 1). We collected data from seven blocks and 15 treatments under the experiment (Table 1). The control (Cont) involved conventional tillage (CT) with traditional planting method whereas slushing and spraying with herbicides was applied for zero tillage (ZT). Planting basins (B) measured 0.3 m x 0.3 m each with three bean plants or five maize plants (the test crops) with beans either inoculated (R) or not. Fertiliser NPK (17:17:17) was applied at 300 kg nutrient ha^{-1} and compost at 20 t ha^{-1}.

We collected and analysed bulk soil samples for physico-chemical properties including pH (H_2O), SOM, N, P and K, texture and hydrological properties using standard protocols in Okalebo *et al.* (2002). The data collected were checked for conformity with the conditions for conducting ANOVA prior to analyses using the Genstat statistical package 12th edition. Significantly different means ($P<0.05$) were separated using Fischer's protected LSD.

Results

The soils were severely acidic, pH ranged from 3.3±0.58 under Bean+ZT+Compost+R treatment to 4.85±0.58 under maize+ZT+ NPK treatment (Table 1). The SOM and N were also below critical limits but plant-available P and exchangeable K exceeded critical limits (Table 1). Soil textural class was silt clay loam, ranging from 26 ± 2.46 to 31 ± 2.46 (%clay), 32 ± 5.01 to 42 ± 5.01% (%silt) and 32 ± 2.80 to 37 ± 2.80% (%sand) (Table 1). Soil water ranged from 0.29 ± 0.02 g cm^{-3} to 0.31 ± 0.02 g cm^{-3} (field capacity, FC) and 0.17 ± 0.02 g cm^{-3} to 0.17 ± 0.02 g cm^{-3} (permanent wilting point, PWP) (Table 1).

Figure 1: Location of Mt Wanale (top left), very steep landscape (top middle) and red soils with miserable maize (top right) contrary to vigorous bananas and climbing beans on farmers' own plot which had been used as a pen for zero-grazing dairy cattle (extreme left of middle row) and total maize failure in one of the 'best' SLM practices (middle of middle row). Contour cultivation (extreme right of middle row) as one of the interventions to combat water erosion. Notice vigorous bananas+beans+ maize and maize+finger millet+banana intercrops with yams in the Dokho flood plain (left and middle bottom row) where eroded soils are deposited and compost from one of the windrows due for sieving at the Mbale Municipal Solid Waste Composting Plant.

Discussion

Our soil pH values were below the 5.5 – 6.5 range considered optimum for normal plant growth (Okalebo *et al.*, 2002) and in the pH range for Al^{3+}, Fe^{3+} and Mn^{2+} toxicity (USDA, 2006; Gerard, 2016) evidenced by the red soils (Figure 1). Accelerated water erosion selectively removes SOM and its associated clay (organo-mineral complexes) hence, the low to very low range of SOM (Broquen *et al.*, 2005) in our study. Associated loss of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) induces soil acidity and Al^{3+}, Fe^{3+} and Mn^{2+} toxicity to plants (Yang *et al.*, 2009). The red colour of the supposed-to-be Andosols on Mt Wanale and miserable crops especially in the World Bank SLM project site contrasted strikingly with the vigorous performance of bananas (*Mussa sp*), beans and maize intercropped with finger millet (*Elucine coracana*) on dark sediment eroded down the Dokho flood plain (Figure 1).

The unexpected high levels of plant-available P and exchangeable K could be from high fertiliser rates (300 kg nutrient ha^{-1}). But the low to very low soil N (Galantini and Rosell, 2006) could be due to volatilisation. During soil sampling, we observed granules of fertilisers still on the soil surface two months after application, a predisposing factor to N volatilisation. The silt-clay-loam textural class points to susceptibility of the soil to erosion. Although the ranges and averages of water contents of the soil at FC and PWP are within those modeled for similar soils elsewhere (Mohanty *et al.*, 2015), accelerated water erosion has altered the water properties of soils on Mt Wanale negatively.

Table 1: Mean soil physico-chemical properties under selected soil conservation practices from the World Bank sustainable land management project on Mt Wanale, eastern Uganda as of June, 2016.

	pH	SOM	N	P	K	Clay	Silt	Sand	FC	PWP
Treatment		(%)	(mg kg^{-1})		(cmol kg^{-1})	(%)			(g cm^{-3})	
Bean CT	3.5	1.52	0.12	14.2	0.61	28	39	33	0.31	0.17
Bean CT+Comp	4.1	1.42	0.08	14.7	1.65	29	38	33	0.30	0.16
Bean CT+Comp+R	3.3	1.85	0.13	14.2	0.75	27	41	32	0.30	0.15
Bean ZT+R	3.7	0.40	0.08	18.6	1.51	28	40	32	0.30	0.16
Bean ZT+R+B	3.6	0.79	0.02	12.7	1.05	31	33	36	0.31	0.17
Maize CT	3.8	1.44	0.10	59.8	1.02	29	36	36	0.30	0.16
Maize CT+Comp	3.9	1.69	0.10	13.7	2.11	29	38	33	0.31	0.17
Maize CT+NPK	4.2	2.05	0.11	42.1	0.92	31	32	37	0.30	0.17
Maize CT+NPK+Comp	3.4	1.98	0.14	12.7	1.12	26	41	33	0.29	0.15
Maize ZT+Comp	3.6	1.62	0.13	18.1	0.96	26	42	32	0.29	0.15
Maize ZT+Comp+B	4.6	1.12	0.09	20.6	1.86	27	39	34	0.29	0.15
Maize ZT+NPK	4.9	0.86	0.08	21.6	1.32	28	39	33	0.29	0.15
Maize ZT+NPK+B	4.3	1.78	0.08	25.5	1.44	30	36	34	0.31	0.17
Maize ZT+Comp+NPK	4.9	0.86	0.08	21.6	1.32	28	39	33	0.30	0.16
Maize ZT+Comp+NPK+B	3.7	1.06	0.06	21.1	1.51	28	38	34	0.30	0.16
P-value	0.206	0.51	0.100	0.977	<.001	0.279	0.746	0.815	0.598	0.354
L. S.d	1.197	0.68	0.063	75.05	0.963	5.074	4.929	5.764	0.018	0.025
S.e	0.58	0.69	0.031	36.43	0.468	2.46	5.01	2.8	0.009	0.012
Critical values	5.5	3.0*	0.25*	15*	0.4**					

Key: conventional tillage (CT), compost (Comp), rhizobia (R), zero tillage (ZT), planting basins (B)

Conclusions

The soil pH of the study site is in the range of Al^{3+}, Fe^{3+} and Mn^{2+} toxicity to plants and together with the low levels of SOM, could be the reasons for poor crop responses to the SLM practices on Mt Wanale. Raising the soil pH to ≥ 5.0% and SOM to ≥ 3.0 % using locally available amendments such as wood ash and municipal solid waste compost (pH ≥ 9.0) (Plate 1 bottom right) should have preceded investment in the costly SLM practices, paving a way towards restoring the landscape to its original ecosystem prior to encroachment.

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References

Broquen, P., Lobartini, J.C., Candan, F. & Falbo, G. 2005. Allophane, aluminum, and organic matter accumulation across a bioclimatic sequence of volcanic ash soils of Argentina. Geoderma, 129(3-4): 167–177.

Buyinza, J., Tumwebaze, S.B., Namaalwa, J. & Byakagaba, P. 2014. Above-ground biomass and carbon stocks of different land cover types in Mt. Elgon, Eastern Uganda. *International Journal of Research on Land-use Sustainability*, 1: 51-61.

FAO. 2017. Voluntary Guidelines for Sustainable Soil Management. Available at: *www.fao.org/3/a-bl813e.pdf* [Accessed 09/03/19].

Galantini & Rosell, R. 2006. Long-term fertilization effects on soil organic matter quality and dynamics under different production systems in semiarid Pampean Soils. *Soil and Tillage Research*, 87(1): 72–79.

Gérard, F. 2016. Clay minerals, iron/aluminum oxides, and their contribution to phosphate sorption in soils: A myth revisited. *Geoderma*, 262: 213–226.

Guobin, L. 2016. Royal Swedish Academy of Sciences Soil Conservation and Sustainable Agriculture on the Loess Plateau: challenges and soil conservation and sustainable agriculture on the Loess Plateau: challenges and prospects. *Royal Swedish academy of Sciences*, 28(8). Retrieved from www.jstor.org/stable/4314979.

Karidjo, B.Y., Wang, Z., Boubacar, Y. & Wei, C. 2018. Factors influencing farmers' adoption of soil and water conservation technology (SWCT) in Keita valley, a semi-arid area of Niger. https://doi.org/10.3390/su10020288.

Mbogga, M. 2012. Climate profiles and climate change vulnerability for the Mbale region of Uganda. Available at :

https://www.google.com/search?ei=v9SHXJP2L5CY1fAPs9WxsAY&q=michael+mbogga+study+on+mt+wanale+2012&oq=michael+mbogga+study+on+mt+wanale+2012&gs_l=psy-ab.12...16390.24692..27929...0.0..0.1200.9478.2-1j6j6j4j1j1......0....1..gws-wiz.40QWinDo7kE.

Mohanty, M., Sinha, N.K., Painuli, D.K., Bandyopadhyay, K.K., Hati, K., Reddy, K.S. & Chaudhay, R.S. 2015. Modeling soil water contents at field capacity and permanent wilting point using artificial neural networks for Indian soils. *National Academy of Science Letters*, 38(5): 373-377.

NEMA. 1996. State of Environment Report for Uganda.

Okalebo, J.R., Gathua, K.W. & Woomer, P.L. 2002 Laboratory methods of soil and plant analysis: a working manual of soil (eds). TSBF/UNESCO/ROSTA, Nairobi, Kenya.

Olupot, G., Otukei, J.R., Muwanika, V.B., Esaete, J. & Tabuti, J.R.S. 2017. Conversion of Native Vegetation in Protected Areas Fuels CO_2-equivalent Losses. In Uganda. In S.A. Mukul and A.Z.M. Manzoor Rashid (eds), Protected Areas: Policies, Management and Future Directions. New York: Nova Publishers, pp 179 – 202.

Olupot, G., Twaha, A.A.B., Ebanyat, P., Musinguzi, P., Opolot, E., Amoding, A.K., Bekunda, M.A. & Singh, B.R. 2019. (In Press). Making Sense Out of Soil Nutrient Mining and Depletion in Sub-Saharan Africa. Book Chapter (3), in Soil Degradation and Restoration in Africa. Advances in Soil Science.

USDA. 2006. Soil quality institute. Natural Resource Conservation Services. Available at http:/soils.usda.gov/sql/.

Yang, Z.B., You, J.F., Xu, M.Y. & Yang, Z.M. 2009. Interaction between aluminium toxicity and manganes toxicity in soybean (*Glycine max*). *Plant Soil*, 319: 277–289.

Surface creep, saltation and suspension with large and medium aggregates: a wind tunnel experiment

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Abstract

A wind tunnel experiment was settled to elucidate the effect of two aggregate sizes (8 and 4.8 mm) on surface creep, saltation and suspension on a sandy loam typic Torriorthent soil from a farm located in La Rioja, Argentina. The experiment used three different treatments: 1) a smooth soil surface with no aggregates (Bare soil); 2) an alternate spatial arrangement of aggregates of 8 mm on soil surface (Ag8) and 3) the same spatial arrangement with aggregates of 4.8 mm (Ag4.8). The sediment was captured in traps at 0, 6, 14 and 20 cm height, with full capture of suspension in a water tray at the end. The sediment captured in traps were sieved in three size classes: a) 1 to 0.5 mm; b) 0.5 to 0.25 mm and c) smaller than 0.25 mm. The suspension was dried at 60 ˚C and weighed. We observe that Ag8 treatment was only effective against surface creep, reducing particles from 1 to 0.5 mm. Moreover, Ag4.8 resulted substantially better for controlling saltation and suspension, hence no relation was observed between wind erosion control and aggregate size. Our findings confirm that wind erosion is an intricate process related to multiple interaction factors.

Keywords: Aggregates, sediment transportation, suspension, spring tine harrow, surface creep control, management practices

Introduction, scope and main objectives

In agroecosystems of wind erosion-affected regions, the condition of soil surface plays a very important role in soil sustainability and in control of erosive processes. Argentina hold almost 75% of the country with arid and semi-arid conditions, with an estimated soil loss from 10 to 50 Mg ha^{-1} year^{-1} due to intensive use or improper management system. The replacement of natural covert, acting as a trigger of wind erosion processes were observed in all the region (Maggi and Bargiella, 2019). This situation exposes the aggregates in soil surface to the erosive agents and the inappropriate management decreases the possibility of developing a strong aggregation status. In general, soils from these regions are highly erodible because they dry quickly, present very low aggregate stability and contain a great part of particles in the most erodible fraction (particles from 0.080 to 0.200 mm in diameter) (Buschiazzo and Funk, 2015). In addition, the critical soil depth affected for wind erosion is in fact the first centimeters in depth as confirmed in wind tunnel experiments (Xing and Guo, 2009; Kohake *et al.,* 2010; Asensio *et al.,* 2016). These aspects of wind erosion determine an active interest in developing strategies to increase soil cover or surface roughness to reduce soil loss. One older farmer's management practice in areas with very low natural cover consist in using a spring tine harrow to bring large aggregates up to the soil surface and increase soil roughness. However, the possible efficiency of such a practice is highly unknown. Under the assumption that the soil losses largely depend on the aggregate size that such a field practice could determine, an experiment was settle in a wind tunnel in laboratory. The effect of two different aggregate sizes in soil surface (8 and 4.8 mm in size) were tested, comparing the results with an untreated bare soil. The objective was to analyze the effect of both aggregate sizes in soil surface on the mobilized particles captured at different height over the ground.

Methodology

The samples used in this study were taken from the first 5 cm of soil depth of a sandy loam typic Torriorthent very common in the semiarid region of La Rioja province, Argentina **(29°24'39.8'' S 66°51'2.4'' W**). Soil aggregates of 8 (Ag8) and 4.8 mm in size (Ag4.8) were obtained from the whole samples by sieving. The wind tunnel used for the experiment is an open circuit system (Figure 1 Left), which consist of an electric fan for producing a constant wind (Malhknecht, 2004). A velocity 5 m sec^{-1} was selected for this comparison. The samples were placed 1 m apart from the source in a tray of 0.5 x 0.5 x 0.06 m. The collector traps were placed at 1 m apart from the tray at 4 different height (0.2, 0.14, 0.06 and 0 m). The height was selected to capture sediment from saltation and surface creep processes. The material that remain in suspension were collected at the end of the wind tunnel in a water-container trap. In order to create a consistent result, the aggregates of both sizes were subject to the same spatial geometric design, an alternate row and column with the same distance (0.025 m) between them (Figure 1 Right). A metallic grid (0.445 x 0.445 m) was used as a guidance. The control tray (Bare soil) presents only a smooth surface with no aggregates. After 1 hr. of exposed to the wind, the material collected in the different traps were sieved in classes of 1to 0.5, 0.5 to 0.25 and smaller than 0.25 mm size. The suspension material captured in the water container was dried at 60˚C and weighed. Data were analyzed in an ANOVA procedure in a 3 x3 random block design with n = 9 and Tuckey test between groups.

Figure 1: Details of the experiment. Left: Laboratory wind tunnel. Right: Soil sample tray showing the alternate spatial arrangement of aggregates of 8 mm in size

Results

Table 1: Particles of different sizes measured at different height in the wind tunnel for the control (Bare soil) and both treatments, aggregates of 8 mm (Ag8) and aggregates of 4.8 mm in size (Ag 4.8). Suspension material was collected at the end of the wind tunnel in a water-container trap. Data expressed in mass (g)

Sediment trap	Particles from 1 to 0.5 mm			Particles from 0.5 to 0.25 mm			Particles smaller than 0.25 mm		
	Control	Ag 4.8	Ag 8	Control	Ag 4.8	Ag 8	Control	Ag 4.8	Ag 8
H=20 cm	0.00	0.000	0.000	0.030a	0.000b	0.010c	1.010a	0.560b	1.340c
H=14 cm	0.010a	0.000	0.000	0.010a	0.000b	0.010a	0.980a	0.545b	1.045a
H= 6 cm	0.010a	0.000	0.000	0.010a	0.005b	0.025c	1.820a	1.100b	1.680a
H =0 cm	0.400a	0.360a	0.075b	0.750a	0.550b	0.335c	13.210a	9.525b	12.465c
Suspension	2.870a			1.080b			2.580a		
Abbreviations: Different letter in the same row represent significant differences with p<0.05.									

In the Table 1 were displayed the results of the experiments carry on in the wind tunnel with bare soil and both aggregate sizes. For better understanding, the results were arrangement in function of the sediment sizes that were captured at different height from the ground. As expected, the large particles (1 to 0.5 mm) were not captured in the elevated traps but at zero height level (ground level). Ag8 produce the large reduction in surface creep or rolling, while Ag4.8 present no differences with Bare soil. The next particle-size class (0.5 to 0.25 mm) shows differences ($p<0.05$) among all the treatments including at different height levels. Ag4.8 were more effective than Ag8 to reduce the movement of this particles size at 6, 14 and 20 cm in height, but the effect of Ag8 was more important at zero level. The effectiveness of the treatments was notorious on the mobilization of particles smaller than 0.25 mm in size and Ag4.8 determines better control than Ag8 at all levels over the ground. Notably, Ag8 determine no differences with Bare soil at 14 cm height and mobilize more particles than bare soil at 20 cm height. Moreover, notice that only Ag4.8 determines a significant reduction on particles in suspension (Table 1).

Discussion

The preliminary results observed in this study could help to understand several issues of wind erosion, especially when management practices involved soil aggregates in surface. From early studies of Chepil is known that by modifying the first centimeter of soil surface the wind erosion consequences would be altered. However, our findings are showing that the process of saltation, surface creep and suspension are following different pathways, depending on particles size and the height measured and the aggregate size located on the soil surface. As expected, with Ag8 the surface creep that involve particles from 1 to 0.5 mm size was substantially reduced, likely because they are the biggest obstacle acting as a ridge. Liu *et al.* (2006) found that a ridge reduced the total mass of wind erosion at 4 and at 20 cm in height. Our data are showing that the effect of an obstacle (Ag8) strongly depend on the particle size considered and the height evaluated. For example, the pattern observed in particles from 0.5 to 0.25 mm mobilized for saltation were different between Bare soil and Ag8 at 0, 6 and 20 cm height but Ag4.8 were completely different from the others. The poor effectiveness of the Ag8 treatment could be explained by considering its large surface exposed to the wind and a possible weak stability. This could be the reason for the large mass of particles smaller than 0.25 mm found in this treatment and the low efficiency to control particles in suspension. Alfaro (2008) mentioned that this could be the source of dust even when their presence in a free state in soils is very low. However, why the Ag4.8 treatment resulted very successful to control saltation at any height level have no clear explanation, because the only variable analyzed was the aggregate size, i.e., the soil is the same for all the treatments. These findings support the statement of Alfaro (2008) in the sense of that the nature of aggregation and particles density could play an important role in the uncertainty associate with the wind erosion processes.

Conclusions

In general terms, the old practice to bring large aggregates up to the soil surface for controlling wind erosion was found relatively successful when comparing with a bare soil, but present inconsistencies likely associated with the aggregate stability and other unknown variables that prevent a definitive recommendation. We could not find evidence of a positive correlation between aggregate size and particle size mobilization, especially for controlling saltation and suspension processes. The consistency in the behavior of the aggregates of 4.8 mm in size for controlling saltation and suspension processes have no clear explanation and deserve more research, especially with different soil textures and stability condition.

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References

Alfaro, S.C. 2008. Influence of soil texture on the binding energies of fine mineral dust particles potentially released by wind erosion. *Geomorphology*, 93: 157–167.

Asensio, C., Lozano, F.J., Gallardo, P. & Gimenez, A. 2016. Soil wind erosion in ecological olive trees in the Tabernas desert (southeastern Spain): a wind tunnel experiment. *Solid Earth*, 7(4): 1233-1242.

Buschiazzo, D.E. & Funk, R. 2015. Wind Erosion of Agricultural Soils and the Carbon Cycle. In: Banwart SA, Noellemeyer, E. and E. Milne (eds). *Soil Carbon: Science, Management and Policy for Multiple Benefits* CAB International. p. 161-168.

Chepil, W.S. 1958 Soil conditions that influence wind erosion. Unites States Department of Agriculture. Technical Bulletin N° 1185: 5-6.

Kohake, D.J., Hagen, L.J. & Skidmore, E.L. 2010. Wind Erodibility of Organic Soils. *Soil Science Society of America Journal*, 74(1): 250-257.

Liu, M.X., Wang, J.A., Yan, P., Liu, L.Y., Ge, Y.Q., Li, X.Y., Hua, X., Song, Y & Wang, L. 2006. Wind tunnel simulation of ridge-tillage effects on soil erosion from cropland. *Soil & Tillage Research*, 90: 242–249

Malhknecht, F.E. 2004 Efecto de la cobertura y del uso de una sustancia agregante sobre el movimiento de partículas por acción del viento. Tesis para optar al título de Ingeniero Agrónomo. Facultad de Agronomía UBA Buenos Aires, Argentina.

Maggi A. & Bargiela M. 2019. Evaluación de la degradación de tierras a nivel local: Valles áridos. *En*: Almut T., M.L. Corso, M. Stamati, C. Bottero, P. Lizana y V. Pietragalla (Eds) *Síntesis de Resultados de la Evaluación de la Degradación de Tierras: 2012-2017*. Observatorio Nacional de la Degradación de Tierras y Desertificación. *In press (ISSBN pending)*.

Rienzi, E.A., Marchi, A. & Rodriguez, G. 2018 Aggregate size, particulate and total organic carbon in different land uses on a sandy loam soil exposed to wind erosion. *Advances in Agricultural Science*, 6(3): 95-111

Xing, M. & Guo, L.J. 2009. The dust emission law in the wind erosion process on soil surface. *Science in China Series G-Physics Mechanics & Astronomy,* 52(2): 258-269.

Increasing soil chemical properties through the application of rock fines in tropical soils in west Cameroon, Africa

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Abstract

Rock fines from basalt, trachyte and volcanic pyroclastic materials in addition to limestone and gneiss were applied as fertilizers in several localities of west Cameroon. Control soils samples in addition to soils after treatment were collected and analyzed to assess the variation of textural and chemical compositions of soils. These soils show clayey with loamy to loamy sandy structures. After treatment, there is a general and slight increase of pH in all samples. However, a sample with the application of fines from pyroclastic materials showed a remarkable pH increase from 5.9 to 6.9. After treatment, there is also a slight increase of the organic carbon and organic matter as well. Mg and Ca remains slightly constant with some highest values (= 45.8 and 24.0) and (= 9.1 and 10.2), respectively. The highest available phosphorus (P) values of 96.0 ppm was found on the treatment with trachyte fines. Other higher values of P (50.9 and 51.5 ppm) are encountered on treatments with limestone and basalt fines, respectively. Then, this suggests that the application of fines from rocks such as trachyte, limestone, gneiss and basalt increase phosphorus in soils.

Keywords: control, treatment, soil chemicals, acidic, pH, Magnesium, Calcium and Phosphorus

Introduction, scope and main objectives

Soil erosion is a process acting over millions of years. It is known as “geologic” or natural, according to Bennett and Chapline (1928) when caused by factors such as climate, soil type and topography. In addition, Human also induced soil erosion through activities such as overgrazing, deforestation and agriculture (Mostafa and Osama, 1992) which are the major factors of the soil erosion accounting for 92 % of all activities destroying the soil structure (Mostafa and Osama, 1992). In fact, soil productivity depends on a number of physical, chemical and biological soil properties. The chemical fertility depends on the amount of available nutrients in a soil which is governed by the soil pH, organic matter content and other characteristics. Then, soil erosion leads to the decrease of the chemical fertility through the leaching of some nutrients and the loss of agricultural productivity. This also leads to the economic damage of the income of farmers.

In fact the economic damage of soil erosion is alarming in sub-Sahara Africa. In Zimbabwe alone, it is estimated that farmers loose three times more nitrogen and phosphorus by erosion than they apply to their fields. Then soil erosion is a burden for agricultural productivity and has rendered soils depleted in essential nutrients necessary for crop growth in Africa. According to Smaling *et al.* (1996), the average N, P and K balances for Africa in 1983 were -22, -2.5 and -15 Kg ha^{-1} yr^{-1}, respectively. In fact, these nutrients were lost through exported harvested products and erosive processes such as water runoff and wide spread eroding sediments that caused negative balances. Then, adding NPK chemical fertilizers is the common method used by farmers in sub-Sahara Africa to solve the problem of soil depletion in these chemicals. This focuses an alternative to the use of chemical fertilizers to combat chemical loss in soils. This method is based on the application of fines from different types of rocks to increase chemicals in soils.

Methodology

Soil samples were collected from 06 experimental plots made up of 06 different localities namely Befang (06°20'18"N, 10°02'47"E), Foumbot (05°32'25"N, 10°35'30"E), Batibo (05°45'10"N, 09°45'35"E), Kalong (04°47'30"N, 11°03'53"E), Bonadale (04°09"36"N, 09°34'34"E) and Santa (05°47'58"N, 10°09'46"E) in west Cameroon. Each experimental plot was made up of several experimental microplots made up of 3 to 5 treatments replicated at least twice. Fresh rock samples locally collected were crushed into smaller fragments then ground several times into fines and sieved with a 1x1 mm mesh sieve and used as fertilizers. These rocks are volcanic rocks such as basalt, trachyte and volcanic pyroclastic materials in addition to limestone and gneiss. Poultry manure or cow dump were also added to some treatments. The test crops were chosen based on the potentially of a plant to rapidly grow on a specific site and were mostly maize. However cabbage, potatoes and carrots were also used as test crops in some sites.

The experimental trials were made up of the control and treatment soils. Soil samples were collected after harvesting test crops on 06 different spots of microplots and within 0- 25 cm of depth, mixed, dried and stored in clean plastic bags and taken for further description and analysis in the Laboratory of Soil Sciences, Faculty of Agronomy, University of Dschang, Cameroon. In the laboratory, the soil samples were air-dried at room temperature for one week and passed through a 2-mm polyethylene sieve to remove plant debris and pebbles. Afterwards, they were lightly crushed in an agate mortar into fine powder and passed through a 0.149-mm nylon sieve then stored in glass containers then preserved under ambient conditions pending analysis. The soil samples were subjected to physiological analysis using a standard laboratory procedure for soil analyses (AFNOR). Soil reaction was determined in soil water suspension 1:2.5 using a glass electrode. Organic matter was determined by wet digestion according to Walkley and Black (1934). Total nitrogen was analyzed by the method of Kjeldahl (1883) modified. Exchangeable cations and exchange capacity (CEC) were determined by percolation with 1 M ammonium acetate, and the determination of Ca, Mg, K and Na using a flame photometer and Mg with an atomic absorption spectrophotometer. And pH_{water} (Peech, 1965) was measured with a pH meter at 1:2.5 soil/water.

Results

They are made up of texture and chemical compositions of control and treated soils and presented on the Table. The texture composition was determined based on the percentage composition of each soil sample in sand, silt and clay. Parameters such as pH, OM and OC (%), N (g/Kg), Ca, Mg, Na and K (meq/100 g) and P (ppm) were determined for the chemical compositions.

Control soils

Control soils show textures belonging to the fields of loamy sand (T01 and T02) to clay (T03) passing through clay loam (T06) and silty clay (T05). The pH values vary between 7.1 and 4.6 and organic matter between 7.2 – 0.95 % for CO, 9.3-1.64 % for MO and 4.6 – 0.06 g/Kg for N. For the exchangeable cations, Ca exhibits highest values of 3.8 meq/100 g while lowest values belong to Na with 0.00 meq/100g. K and

Mg exhibit values between 3.2 – 0.0 meq/100g. Available phosphorus (P) values are between 26.5 and 6.8 ppm for these controls.

Treated soils

The textures of different treated soil samples were plotted on the field of sandy loam (T12, T22 and T62) and clay (T13, T23 and T45). However, some treated samples presented properties of clay loam (T26 and T46) and laomy sand (T41). The highest (= 7.2) and lowest (4.8) pH belong to T41 and T15, respectively. The organic matter vary between 7.0 – 0.2 % for CO, 12.1 – 0.4 % for MO and 5.5 – 0.1 for N (g/Kg). For the exchangeable cations, the highest values (= 45.8 - 24.0) and (= 10.2 – 0.9) belong to Mg and Ca, respectively. Lowest values (= 0.1 - 0.0) are those of Na. K also exhibits low values (= 1.8 – 0.0). The higher (= 48.9) and lower (= 8.8) capacity of cationic exchange (meq/100 g) were found on T23 and T25, T35 and T45, respectively. The highest available phosphorus (P) values of 96.0 ppm was found on sample T46. Other higher values of P are encountered on T62, T22, T23 and T24 with 50.9, 51.5, 32.7, and 30.1, respectively.

Discussion

Most control soils in this work are moderately to slightly acidic. However, a pH value of 4.6 indicates the acidic nature of T05.

There is a broad slight variation of pH values after treatment except samples (T04 to T24) with a remarkable pH variation from pH = 5.9 to pH = 6.9. Since this treatment is made up of basaltic fines, these variations may suggest that the soil pH increase with the application of the basaltic fines. There is a slight increase of OM for some samples. However, samples T04 and T24 exhibit an increase of OM from 4.5 to 9.1%, and sample T01 and T41 indicates an increase from 9.3 to 11.3 %. These treatments also were treated with basalt fines. Then, this may also suggest that basalt fines also increase OM contents in different treatments. N contents remained very weak except high values of more than 2.8 g/Kg for sample T41, T15 and T45. These samples got treatment made up of basalt fines and poultry or green manure. Then, added N came from manure. After different treatments with rock fines, Na remains unchanged and K values slightly increase to 0.8 - 1.1 meq/100g. However, there are remarkable high values of Mg and Ca on some samples with treatment of basalt and trachyte fines. This suggest these rocks as a source of Ca and Mg in soils. For P, there is a general increase in relation to the controls in most soil samples after treatment (Figure). The highest values of 96.0, 51.5 and 50.9 ppm were found on soils treated mostly with trachyte and limestone, respectively. Higher P contents of 32.7 and 30.1 came from treatments with fines of gneiss and volcanic pyroclastic materials. This suggests that application of fines from rocks such as trachyte, limestone, gneiss and basalt as a potential source of phosphorus in soils.

Table 1: Variation of chemical properties of controls (T01, T02, T03, T04, T05 and T06) and different treatments (T41- T46) of soils collected in different localities in Cameroon.

	T01	T02	T03	T04	T05	T06	T41	T12	T22	T62	T13	T23	T24	T15	T45	T26	T46
	Control soils						Treated soils										
Texture																	
Sand	86.0	82.5	18.0		5.0	40.0	83.0	75.0	70.0	77.5	27.0	38.0		5.0	4.0	40.0	39.0
silt	10.0	5.0	24.0		40.0	28.0	13.0	10.0	20.0	15.0	28.0	34.0		40.0	36.0	25.0	27.0
Clay	4.0	12.5	58.0		55.0	32.0	4.0	15.0	10.0	7.5	45.0	43.0		55.0	60.0	36.0	34.0
	LS	LS	C		SC	CL	LS	SL	SL	SL	C	C		SC	C	CL	CL
Soil reaction																	
pHw	7.1	6.4	5.6	5.9	4.6	5.8	7.2	6.0	6.6	6.5	5.7	6.4	6.9	4.8	4.8	5.2	6.1
Organic matter																	
OC %	5.5	1.3	1.0	2.3	3.8	7.2	6.4	0.2	0.3	2.1	1.6	2.1	6.8	3.2	3.8	7.0	6.7
OM %	9.3	2.2	1.6	4.0	6.6	12.5	11.3	0.4	0.6	3.5	2.7	4.1	9.1	5.5	6.6	12.1	11.6
N (g/Kg)	4.6	0.6	0.1		3.1	0.2	5.5	1.0	0.7	0.9	0.1	0.3		2.9	2.8	0.1	0.2
C/N	11.6	23.0	15.0		12.0		11.6	2.0	5.0	24.0	11.0	9.0		11.0	14.0		
Exchangeable Cations (meq/100g)																	
Ca	1.8	1.6	3.8	0.9	2.5	3.2	2.0	1.9	3.0	2.4	6.6	9.1	1.7	2.6	2.5	10.2	3.2
Mg	0.9	0.8	2.3	0.3	0.5	3.2	1.0	0.4	0.4	0.2	3.7	4.3	1.0	0.0	0.4	45.8	24.0
K	0.7	0.8	0.7		0.1	0.0	1.1	0.8	0.2	0.6	0.7	0.7		0.1	0.1	0.0	0.0
Na	0.0	0.0	0.1		0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1		0.0	0.0	0.0	0.0
Sum of exchangeable bases (meq/100g)	3.4	3.3	6.9	1.9	3.1		4.1	3.2	3.6	3.4	11.1	14.1	3.6	3.1	3.0	56.0	27.2
Capacity of cationic exchange (meq/100g)	7.4	15.0	15.3	22.0	8.8	20.4	8.8	15.2	13.6	14.2	33.2	48.9	28.0	10.7	8.8	24.2	21.2
Phosphore Assimilable (ppm) Bray II	6.8	7.8	26.5	19.6	20.5	19.1	7.2	26.7	51.5	50.9	28.0	32.7	30.1	23.6	18.5	24.3	96.0

T01, T02, T03, T04, T05 and T06 are control soils collected in the localities of Foumbot, Bonandale, Kalong, Befang, Santa and Batibo in Cameroon, respectively. T41 = T01 + 600g basalt fines + 600g poultry manure; T12 = T02 + 2Kg basalt fines ; T22 = T02 + 2Kg limestone fines ; T62 = T02 + 1Kg limestone ; T13 = T03 + 3Kg basalt fines ; T23 = T03 + 3Kg gneiss fines ; T24 = T04 + 200g fines from volcanic pyroclastic materials (basaltic in composition); T15 = T05 + 1Kg basalt fines ; T45 = T05 + 1Kg basalt fines + 0.5Kg green manure (Tithonia) ; T26 = T06 + 2Kg basat fines + 0.75Kg green manure (Tithonia) ; T46 = T06 + 2Kg trachyte fines + 0.75Kg green manure (Tithonia). Abbreviations: LS = Loamy sand; C = Clay; SC = Silty clay; CL = Clay loam; SL = Silty laom. pHw = pH water

Table: Physico-chemical properties of control and treated soils collected in different localities in Cameroon.

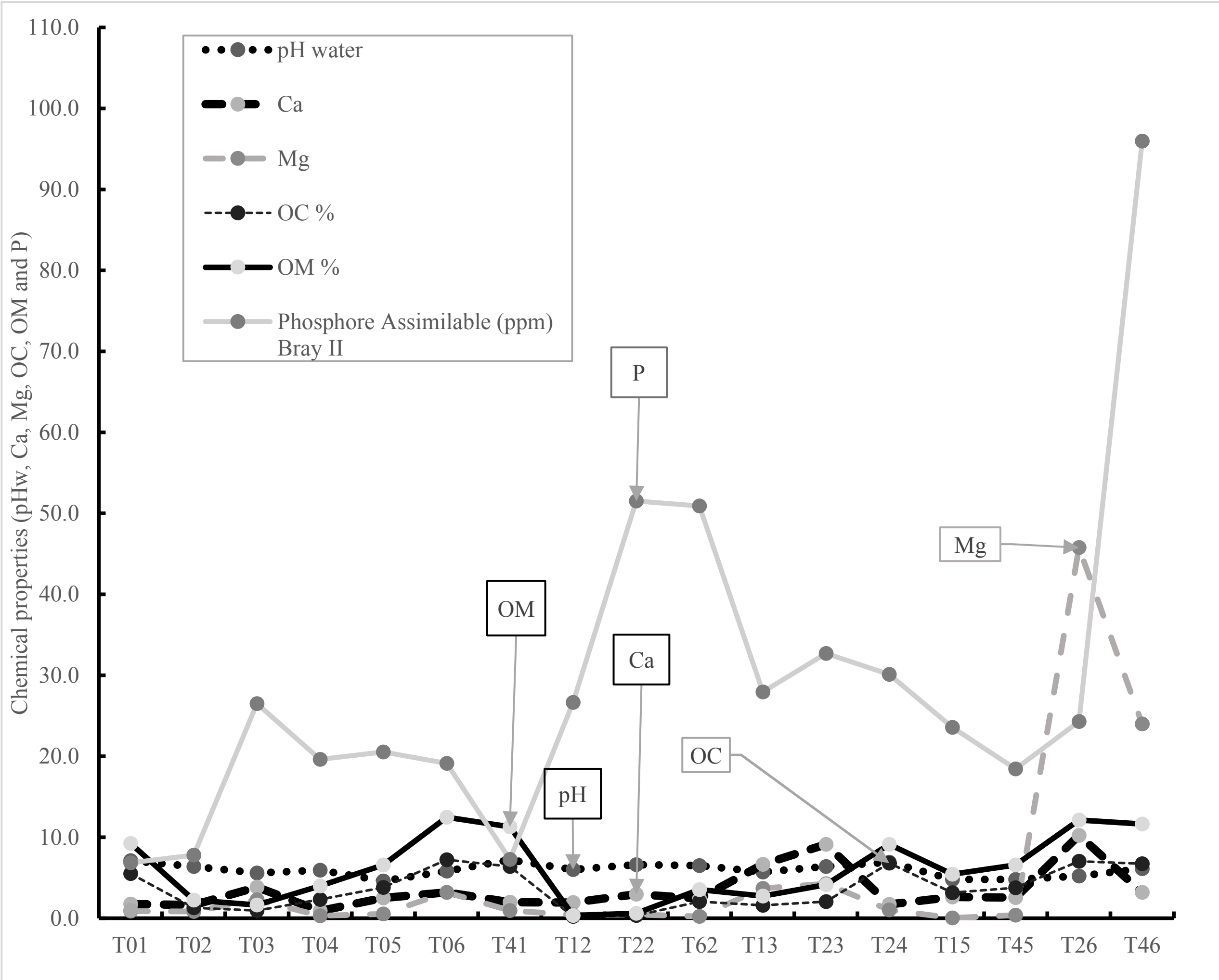

Figure 1: Variation of chemical properties of controls (T01, T02, T03, T04, T05 and T06) and different treatments (T41- T46) of soils collected in different localities in Cameroon.

Conclusions

Rock fines from basalt, trachyte and volcanic pyroclastic materials in addition to limestone and gneiss were applied as fertilizers in several localities of west Cameroon. After treatment, there is a slight increase of pH in all samples. However there is a remarkable pH increase in a treatment with basalt fines. Then the application of the fines from these rocks may be used to manage the soil acidity. These basalt fines also increase significantly the soil content in Mg and Ca. The higher values of P suggests the application of fines from rocks such as trachyte, limestone, volcanic pyroclastic materials and basalt as a source of phosphorus in soils.

Acknowledgements

Our appreciation goes to all small scale local farmers that accepted to carry out these field trials on their land in the localities of Befang, Santa, Batibo, Foumbot, Bonandale and Kalong in west Cameroon. We also thank all local agricultural technicians or any villagers who assisted us during field works.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

References

Bennett, H.H. & Chapline, W.R. 1928. Soil erosion a national menace. US Dep. Agric., Circ. 33.

Kjeldahl, J. 1883. Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern (New method for the determination of nitrogen in organic substances). *Zeitschrift für analytische Chemie*, 22(1): 366-383.

Euroconsult. 1989. Agricultural compendium for rural development in the tropics and the subtropics, Elsevier Amsterdam, pp.778.

Mostafa, K.T. & Osama, A.E.K. (eds.). 1992. The world environment 1972-1992. Two decades of challenge. Chapman and Hall, London, England.

Peech, M. 1965. Hydrogen-ion activity In C.A. Black *et al.*, Eds., Methods of Soil Analysis. Part 2. American Society of Agronomy, Madison, WI; pp. 914–926.

Smaling, E.M.A., Nandwa, S.M. & Janssen, B.H. 1997. Soil Fertility Is at Stake, in Replenishing Soil Fertility in Sub-Saharan Africa. In: Buresh, R., Sanchez, P.A. and Calhoun, F., Eds., *American Society of Agronomy and Soil Science Society of America*, Madison Wisconsin, 47-61.

Walkley, A.J. & Black, I.A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Sci.,* 37: 29-38.

Building a solid foundation for erosion control: resilience-based stewardship in Burundi

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Abstract

This paper describes the results and impact of an inclusive bottom-up intervention approach: the PIP approach. This Integrated Farm Planning approach was applied in Burundi, and aims to build a foundation of resilience-based stewardship among farmers, which triggers them to invest in a more resilient household and in more diverse land management practices to control erosion and increase soil fertility levels. The survey for this study covered 202 farmers from four different PIP generations, from the first farmers trained by the project until PIP farmers in adjacent villages, as well as a control group. The study finds that integrated farming practices are rapidly adopted by Burundian farmers, and lead to more sustainable land management and less erosion. Motivation to invest in the land is a key driver of this change, because by means of the PIP approach farmers become empowered and can make the change towards resilience-based stewardship. When this process is further triggered by other rural development organisations in Burundi, widespread and visible impact can be expected in combating soil erosion, based on this solid foundation of motivated land stewards.

Keywords: PIP approach, stewardship, soil erosion, resilience, integrated farming, Burundi

Introduction, scope and main objectives

With 90% of the population depending on agriculture, subsistence farming is on small fragmented farms (with an average size of less than 0.2 hectares) is very common in Burundi. This intensive land use and farming on ever-more marginal soils – such as steep slopes – to cope with the increasing food demand (Baumont-Keita *et al.*, 2011), has resulted in high erosion rates and soils becoming increasingly unproductive. Next to the intensive use of the land, high intensity rainfall and erodible soils contribute to high erosion rates (Paridaens *et al.*, 2012). The amount of lost soil by erosion per year is estimated around 4 tons ha^{-1} in the Eastern part of the country, 18 tons ha^{-1} in Central and Western Burundi, and more than 100 tons ha^{-1} in the Highlands (Minagrie, 2012). Coping with soil erosion is a major challenge in Burundi, however, the cost associated to investments in conservation practices often remains a limitation for farmers (Ndagijimana *et al.,* 2018). Programmes to stimulate sustainable land management such as trenches on the contour-lines and tree planting, were therefore mainly undertaken through incentive-based projects, using cash- or food-for-work strategies. However, these projects have not been able to reverse the trend of land degradation, with farmers not being empowered and motivated to manage their land more sustainably. This paper describes the results and impact of a different kind of intervention approach, the PIP approach, or Integrated Farm Planning approach, which is currently being applied in Burundi. The PIP approach aims at building a foundation of resilience-based stewardship among farmers, which triggers their intrinsic motivation to invest in a more resilient household and in more diverse land management practices to control erosion and increase soil fertility levels.

Methodology

At the core of the PIP approach lies the Integrated Farm Plan: the PIP, which consists of two drawings that visualize the current farm situation and the family's desired future situation. It is made by each farmer family, and covers a diverse set of activities, with sound soil fertility management and erosion control being paramount – including measures such as compost use, green manure, erosion control, crop diversification and good crop rotations. Knowledge on these practices is transferred from farmer-to-farmer, with farmer-trainers who teach next generations of PIP farmers how to create a PIP, and how to apply better practices.

This paper is based on the results of an impact assessment study that was carried out three years after the start of the project, and focuses on the changes in motivation and land management in 5 different generations of PIP farmers. Generation 1 are Farmer Innovators (Paysans Innovateurs in French, or PIs) who were trained by the project staff. Generation 2 are farmers trained by the PIs by means of farmer-to-farmer training during a first PIP competition, and Generation 3 farmers are those trained indistinctly by either 1st or 2nd generation PIP farmers, also during a competition. Generation 4 are PIP farmers in adjacent villages, who were trained during the scaling-up phase of the project by already experienced PIP-trainers (farmers) and the extension service. During the time of the survey, most of the 4th Generation PIP farmers had only recently been trained (about one year ago). Finally, the no-PIP (control group) farmers are from other villages who had never been in contact with the project villages. In total 202 farmers were surveyed, more or less evenly distributed over the 5 PIP generations.

Results

The impact assessment analysed to what extent the Integrated Farm Plan drawn by the farmer families was translated into concrete measures to improve the health of the land (i.e. its physical, chemical and biological quality), and how this was related to farmers' motivation. Huge changes were measured in the diversity of practices that farmers apply after having started with the PIP approach, which is crucial because integration and diversity of practices is key in sustainable land management. Furthermore, farmers' knowledge concerning these practices had increased as well, which is the basis for sustainable change. In this paper we highlight specific results for soil erosion control practices, with an example shown in Figure 1 for changes in the use of contour lines with vegetation (i.e. trenches on the contour line or slow-forming terraces) and mulching. Figure 1 presents the changes in the use of these two measures between the 5 Generations over the past 3 years. It shows two rather different situations. For the contour lines with vegetation, earlier generations of PIP farmers adopted this practice more often than later generations. This evidences that constructing contour lines is time and labour consuming, and that it is therefore generally not among the first practices that a PIP farmer will implement. These contour lines have been widely promoted by past projects, but their adoption rate has always been low: this changed drastically after farmers started to work with the PIP approach.

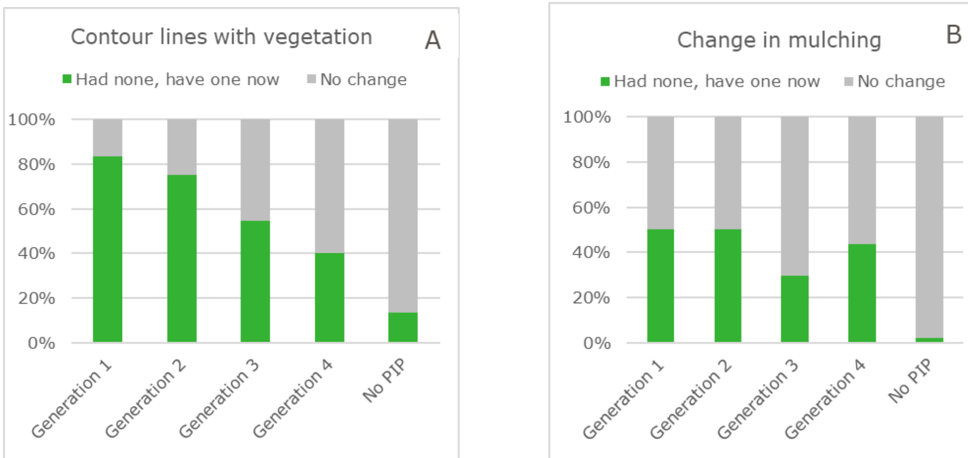

Figure 1: Change in use of contour lines with vegetation (A) and change in use of mulching compared to three years ago (B).

For mulching the picture is different, with smaller differences between the PIP generations because this practice was only quite recently promoted by the project. About 40% of the farmers was already doing this practice before PIP started, but now another 40-50% has adopted mulching thanks to the PIP approach, and is thus aware of its effect in reducing the impact of drought and heavy rains. Furthermore, it is interesting to see that the 4th generation picks-up this less labour demanding NRM practice more quickly than the 3rd generation.

The correlation between Motivation and Healthy land (i.e. investments in land management) is presented in Figure 2. It shows that families who are more motivated for (sustainable) farming also invest more in best practices to improve the quality of their land, with an R^2 of 0.55, meaning a moderate correlation. A closer look on Figure 2 and the differences between the PIP generations, shows that most of the no-PIP farmers are in the lower-left corner, while the PIP farmers are further up on the right. Figure 2 confirms that the PIP approach actually works very well to build a solid foundation of motivated people that invest in natural resources management; in this case expressed as healthy land.

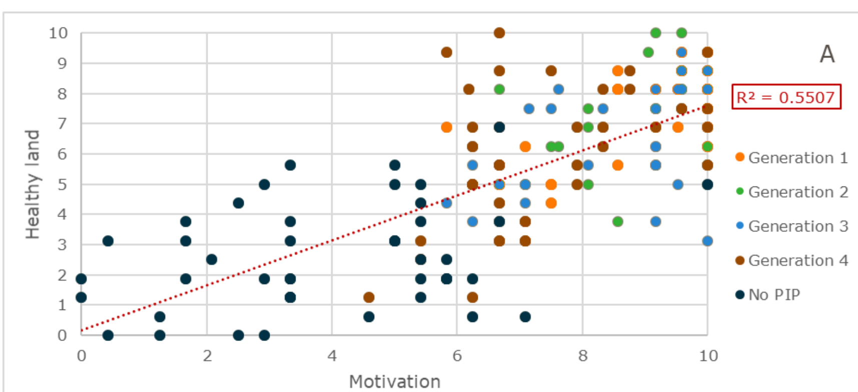

Figure 2: Motivation versus Healthy land for the different PIP generations

Discussion

This study shows that knowledge transfer from farmer-to-farmer works in the PIP approach. Knowledge concerns not only "how to create a PIP", but also concerns best practices: the ones promoted by the project, but also many others, often based on tacit knowledge of farmers, who are proud of what they know and like to share this with others. Also in the adjacent villages farmers have rapidly taken-over knowledge about better practices, with the 4th generation PIP farmers participating on their own initiative – driven only by their intrinsic motivation. The whole PIP process has been much more spontaneous here, and even so, often within a year, changes have occurred. We see a high uptake of the less labour demanding practices (such as compost pits and mulching) in these adjacent villages, but also construction of the contour lines (the trenches) that reduce runoff and erosion. This integration of practices on the farm is essential to really advance towards resilience-based stewardship and erosion control; this message is quickly understood, thanks to the exchange visits between the project villages, and the promotion from farmer to farmer of PIP creation and best practices.

Both motivation and healthy land have been strengthened by the PIP approach and mutually reinforce each other, with their correlation being significant for all PIP generations. More motivation triggers investments in healthy land, and healthier land triggers farmers' motivation to continue and invest even more in their land and farm. This is a positive upward spiral, with more and diverse (cash) crops, more investments in the farm (crops and livestock), and eventually more resilience. This attitude, this intrinsic motivation to learn, experiment and do better is one of the pillars of sustainable change, rooted in the mind-set of the people. Hence, in order to combat soil erosion, an integrated approach such as the PIP approach is crucial, as it empowers farmers to be part of the solution and invest in their land, and because it tackles the problem of land degradation from the bottom-up: based on a solid foundation of motivated land stewards with the knowledge and capacity needed for sustainable change.

Conclusions

This study evidences that an inclusive bottom-up approach such as the PIP approach applied in Burundi, is essential to tackle the root causes of soil erosion and empowers farmers to undertake action. More motivated farmers take more diverse practices, and integrate these practices better on their farms. These investments rapidly strengthen their natural resource base, increase food security, and improve farm resilience. Being a better and motivated steward of the land is therefore a precondition for being able to tackle land degradation. Given the urgency to tackle soil erosion in Burundi, fast scaling-up by means of farmer-to-farmer training and knowledge transfer is paramount. The final conclusion of this study is therefore a crucial message for all rural developments programmes: investing in motivation and land health - by means of the three PIP principles "empowerment-integration-collaboration" - actually works, and will lead to more resilient farming systems and sustainable local development.

References

Baumont-Keita, C., Linzatti, R., Ferreras, E., Kromer, J., Murara, J., Hassane, M. & Kinane, M. 2011. Burundi: *Document de Strategie Pays 2012-2016*. Available at : https://www.afdb.org/fileadmin.

MINAGRIE. 2012. *Plan National d'Investissement Agricole (PNIA).* Bujumbura, Burundi.

Ndagijimana, M., Kessler, A. & Van Asseldonk, M. 2018. Understanding farmers' investments in sustainable land management in Burundi: A case-study in the provinces of Gitega and Muyinga. *Land Degradation & Development,* 30: 417-425. https://doi.org/10.1002/ldr.3231.

Paridaens, A.M., Belotti, L., Régi, S., Mahwane, J. & Zoem, J.P. 2012. *Analyse des données secondaire de la sécurité animentaire, vulnérabilité et nutrition au Burundi.* Burundi. Avaliable at: https://documents.wfp.org/stellent/groups/public/documents/wfp253438.pdf.

Reinforce Water and Climate Co-benefits in Actions to Control Soil Erosion

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Abstract

Soil erosion resulted from human activity and related land use and climate change threaten our societal and economic thriving. A major policy response has been putting in place to mitigate the effects of soil erosion, such as in Europe and Asia. The main objective of this work is to assess the impacts of the policy response in China – the implementation of the Grain for Green Program – on ecosystem services, including carbon sequestration and water supply. A combination of bottom-up and top-down approaches is applied to highlight the critical linkages in soil conservation measures of the Grain for Green Program for managing the trade-off among ecosystem services. Lack of sustainable forest management is the primary driver of the intensified water crisis, particularly in drylands. A holistic understanding of the interconnected characters of soil conservation, water supply, and carbon sequestration is vital for developing a policy response to soil erosion. Land evaluation and trade-off analysis can facilitate the identification of the critical intervention point to reinforce the water and climate co-benefits in actions to address soil erosion.

Keywords: Soil erosion, the Grain for Green Program, land use management, Soil-Water-Climate Nexus, incentive mechanism

Introduction, scope and main objectives

Soils are one of the most precious natural resources as they feed us and help our societies and economies to thrive. The global soils not only produce more food to support a prosperous population growth by 2050 but also have an essential role in supporting the provision of primary ecosystem services. Accelerated soil erosion, resulted from human activity and related land use and climate change, deteriorates soil health and lowers the quality and capacity of soils to produce goods and services, thus hinders the national and regional implementation of sustainable development goals (SDGs). A major policy response has been putting in place to mitigate the effects of soil erosion, such as in Europe and Asia. However, the interconnected characters of soils to other natural resources and nexus to ecosystem services are often not fully considered in mitigating actions of the policy response to soil erosion. By using the policy response – the Grain for Green Program (GGP) – in China as an example, the main objectives of this work are to (i) assess the impacts of GGP and highlight the overlooked critical interlinkage to pursue synergy of ecosystem services and (ii) propose recommendations to reinforce co-benefits and mitigate tradeoffs in the actions to address soil erosion.

Methodology

The Grain for Green Program (GGP), initiated in 1999, is the worldwide largest policy response to control soil erosion through increasing land covers, such as the establishment of plantation forests and grasslands on erosion-prone locations, implemented in central and western China. Based on the scientific evidence that the large-scale vegetation restoration has reduced soil erosion and sediment yield in large rivers to a significant extent and increased carbon sequestration in biomass and soils after implementing the GGP, we analysed the effects of GGP on the water resources and related ecosystem services across multiple spatial scales.

At the field scale, the effects of implementing GGP on water availability, in this context of established forestland and grassland, are assessed using process-based data, including precipitation, interception, throughfall, evapotranspiration (soil evaporation + plant transpiration), and infiltration (Schwärzel *et al.*, 2018). Grassland ecosystem is used as a baseline to compare with the effects of the forest ecosystem. At the watershed/landscape scale, the long-term consequence of implementing GGP on off-site water availability is quantified, and their responses to climate change scenarios are projected (Zhang *et al.*, 2015). The bottom-up approach helps to clarify the functions of soil and impacts of GGP in supporting the delivery of primary water ecosystem services, while the top-down approach demonstrates the potential risks of intensified water scarcity in dryland if no proper or improved land management is included in the GGP to mitigate soil erosion.

Results and Discussion

GGP has positive impacts on mitigating soil erosion and enhancing above- and underground carbon sequestration. However, GGP's measure to increase forest cover for reducing soil erosion removes a large proportion of water from the soil to atmosphere and results in a decline of on-site and off-site water availability due to the high water use of forests (Zhang and Schwärzel, 2017). This will progressively dry up the soil and deteriorate soil health thus further cause soil erosion in the long run, in addition to a water crisis. The critical linkage to mitigate the trade-off between ecosystem services in GGP is sustainable forest management. Lack of suitable incentive scheme and Payment for Ecosystem Services (PES) discourages stakeholders from managing forests sustainably, resulting in a multi-layer structure and associated increased water loss.

Conclusions

A holistic understanding of the interconnected characters of soil-water-climate and the dynamic interactions among ecosystem services are vital for developing a viable policy response to control soil erosion. National policymakers, international development organizations, and stakeholders can use land evaluation to identify the critical intervention points to reinforce the water and climate co-benefits in actions to address soil erosion. A multi-dimensional and -scale tradeoff analysis can facilitate decisions of sustainable soil erosion control practices to avoid risks of losing other ecosystem services, while incentive schemes are helpful to elevate the public motivation for sustainable land management.

Acknowledgements

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References

Schwärzel, K., Zhang, L., Strecker, A. & Podlasly, C. 2018. Improved Water Consumption Estimates of Black Locust Plantations in China's Loess Plateau. *Forests*, 9(4): 1-21.

Zhang, L., Feger, K-H., Schwärzel, K., Podlasly, C. & Wang, Y.H. 2015. Different Land Management Measures and Climate Change Impacts on the Runoff: A Simple Empirical Method Derived in a Mesoscale Catchment on the Loess Plateau. *Journal of Arid Environments*, 120: 42-50.

Zhang, L. & Schwärzel, K. 2017. *Multifunctional Land-Use Systems for Managing the Nexus of Environmental Resources*. Cham: Springer International Publishing, 148 pp.

Agricultural defense of Sao Paulo: Twelve years of soil preservation and rehabilitation at the Rio do Peixe watershed, promoting conservation agriculture

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Abstract

The Secretariat of Agriculture of São Paulo (SAA), responsible for applying the Soil Conservation Law, has been doing this work for 20 years, working on 772 000 ha, with 19 846 rehabilitated agricultural properties. At the work carried out in Rio do Peixe Watershed, degradation agriculture was transformed into conservation agriculture. In 2019, it completed twelve years of inspection in Watershed. From 2007 to 2017, 14 076 ha were inspected in Vera Cruz, which 94 farms were assessed, that were turned from degraded into agricultural companies. In Ocauçu, 82 properties were assessed in 8 125 ha. In Marília, ADC Innovative Methodology was used and 20 properties were inspected across 27 000 ha. These inspections have received technical recovery projects and in all cases, the projects have already been implemented. Property with degraded pasture was transformed into agriculture with a No-tillage system. Pastures were recovered with Integrated Crop-Livestock Systems, where it was possible to increase the occupancy rate by 31 % in relation to the original situation. It has been a big work that brings benefits to watershed farmers and the region population who benefit from this work, including improvement of the water quality that supplies Marília. It is SAA "Caring for the welfare of the Society".

Keywords: conservation agriculture, Integrated Crop-Livestock Systems, erosion, degradation, water quality

Introduction

In order to monitor and discipline the soil use and conservation, to fight erosion, the Secretary of Agriculture of São Paulo State (SAA), through Agricultural Defense Coordination (ADC), is responsible for applying the Law n° 6,171/88, Use and Conservation of Agricultural Soil (São Paulo, 1988), and has been carrying out this work for 20 years with very positive results, mainly in the inspections carried out in Watershed. The area of the state occupied with Crop-Livestock, is approximately 18,000 hectares, with 330,000 farms. During that period, 772 000 ha were worked, 19 846 agricultural properties were assessed and rehabilitated agro-ecologically.

Inspection consists of the stages of the preliminary survey, the visit to the properties, the presentation of technical conservation projects for each property and ends with the agro-environmental rehabilitation of all properties visited and assessed. The beginning of activities, in Rio do Peixe watershed using the old methodology, was in June 2007, ending in December 2011 where 14 076 ha were evaluated. From 2011-

2015, 8 175 ha were evaluated, making a total of 22 251 ha, 216 ha per month because the work was done by a team of four Agronomist Engineers who worked one week a month for 103 months.

The ADC diagnosis methodology was developed in 1999 by a team of Agronomist Engineers, published in 2003 and improved in 2017, which was called Innovative ADC Diagnostic Methodology (IADCM). This arose because strategies of action needed to be created to expedite all this demand. Technological innovations were tested, including of an aeromodel and a helicopter, but the results were only favorable when a new working method was developed. The pilot project of IADCM was carried out in Rio do Peixe Watershed, in 53,000 hectare section, located in the municipalities of Vera Cruz, Ocauçu and Marília (Vischi Filho *et al.* 2018). At this work of the inspection of Watershed, the type of intervention aimed at the transformation of degrading agriculture into Conservation Agriculture, with the implementation of conservationist projects that contemplated this new release. Conservation Agriculture is a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance or No-tillage, and diversification of plant species, that enhances biodiversity, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production.

On June 15, 2019, twelve years of monitoring activities will be completed for the use and conservation of the soil at watershed, in the stretches located in the three municipalities. This is a great work of SAA that is "Taking care of the well-being of society", bringing benefits to farmers whose properties make up the Watershed and especially to the entire population of this region that has been benefited from the development of this work, including the improvement of the water quality that supplies the cities, mainly Marília and Presidente Prudente that get water from Rio do Peixe for public supply.

Methodology

The inspection work of soil use and conservation is carried out in all agricultural land areas located in São Paulo State, Brazil. For applying the use and conservation law, a diagnosis is made that consists of delimitation of Watershed and visits all the properties of this watershed. This procedure is called a preliminary survey and has a high cost to be realized, in addition to being very time-consuming. The diagnosis is made with aerial Google Earth® images and surveys "in loco" by ADC staff. After the inspections, the owner who is not complying with the legislation is notified and presents a technical project of soil conservation to recover that degraded area, respecting the class of land use capacity. After implementing the project, the area is recovered with the erosions are controlled, adopting conservation practices that transform the management of the soil and make it conservationist.

The present work deals with the control in Rio do Peixe Watershed, located between the coordinates S 22°15’05.0”, W 49°45’24.3” and S 22°18’49.9, W 50°04’47.3”, stretches of Vera Cruz, Ocauçu and Marília, corresponding to 53 000 hectares. With the difficulty of covering the 330 000 agricultural properties in the state of São Paulo, a new methodology was adopted for the inspection that was Innovated ADC Methodology. The methodology consists in the use of Rural Environmental Registry database (CAR), the Animal and Plant Defense Management System (GEDAVE) and Google Earth® Pro Aerial Imagery, promoting an interface of these databases, performing the diagnosis and inspection by remote sensing. After this step the data obtained with the work done in Google Earth are checked in the field and the inspection and consequent agro-environmental rehabilitation are finalized (Vischi Filho *et al.*, 2018).

The results evaluation obtained with soil conservation, through the improvement of vegetation cover and resulting from the changes in soil management practices were confirmed by an evaluation of aerial images prior to the work (the year 2002) and, after the implementation of the works foreseen in the technical projects of soil conservation (year 2013). The measurement of soil losses and sediment input to the river were evaluated by the water quality indicators evaluated by Turbidity, Suspended Solids, Phosphorus and Organic Carbon, which were measured by means of periodic water's analyzes.

Results

In the period from 2007-2018, 14 076 ha were inspected in Vera Cruz, 8 125 ha in Ocauçu and approximately 27 775 ha in Marília. In the municipality of Vera Cruz 94 agricultural properties were notified (total of 176 properties). It should be stressed that these agricultural properties were rehabilitated, changing from degraded to true agricultural enterprises, fulfilling their social function (Figure 1).

In Ocauçu, 82 farms were rehabilitated. In the Marília section, using the IADCM (Vischi Filho *et al.*, 2018), 20 large farms were inspected. From January 2017 to November 2017, were diagnosed and evaluated 27 775 ha, or 3 065 ha per month, these activities were carried out by four Agronomic Engineers during a one-week monthly in nine months of work. This methodology allows the strategy to evaluate, in detail, an area that by the old methodology would take 103 months (8 years and 7 months) to be carried out, in only nine months the work was done generating a saving of time and cost, a yield of 1 418 % favorable to IADCM Methodology.

These inspections have already received the necessary technical projects to recover the areas and in some of them, these projects have already been implemented. An example of this was the transformation of an agricultural property, located in Ocauçu, with a degraded pasture area of 500 ha, which has been transformed into an agricultural area with No-tillage System, destined to crops of annual cycle with crop rotation.

Another example is the pasture areas recovered with the adoption of the Integrated Crop-Livestock Systems (ICLS), where the management of these pastures was changed, replacing the grass variety and providing pasture with good vegetal mass during the periods of drought. This led to an occupation rate of five livestock units per hectare, as evidenced by the evaluation of 14 properties, wherein 10 of them there was an average increase of 31 % in the occupation rate, in relation to the original situation, fact it is important not only for the soil and water preservation, but also for the rural producer to make more money from their activity (Table 1).

The results obtained with the changes in soil and water management practices regarding the improvement of the vegetation cover were confirmed by an evaluation of aerial images before the work was carried out (year 2002) and after the work was done (year 2013) (Figure 1).

The improvement of the water quality due to the minimization of erosion and the sediments carried to the watercourse were confirmed by the water quality indicators: Turbidity which fell from more than 200, before the work was done, to less than 100 UNT, post work. Suspended Solids, Phosphorus and Organic Carbon, also had reduction of the levels present in the water, evidencing the lower contribution of sediments in the water course. This is verified by analyzing the graphs representing the results of these water's analyses (Figure 2).

Two workshops were held in partnership with the University of Marília, that to carry out experiments aimed evaluation of grass varieties for that microclimate and soil predominant in the place, classified as Argisol Red-Yellow, corresponding in the American Soil Classification as Udalf.

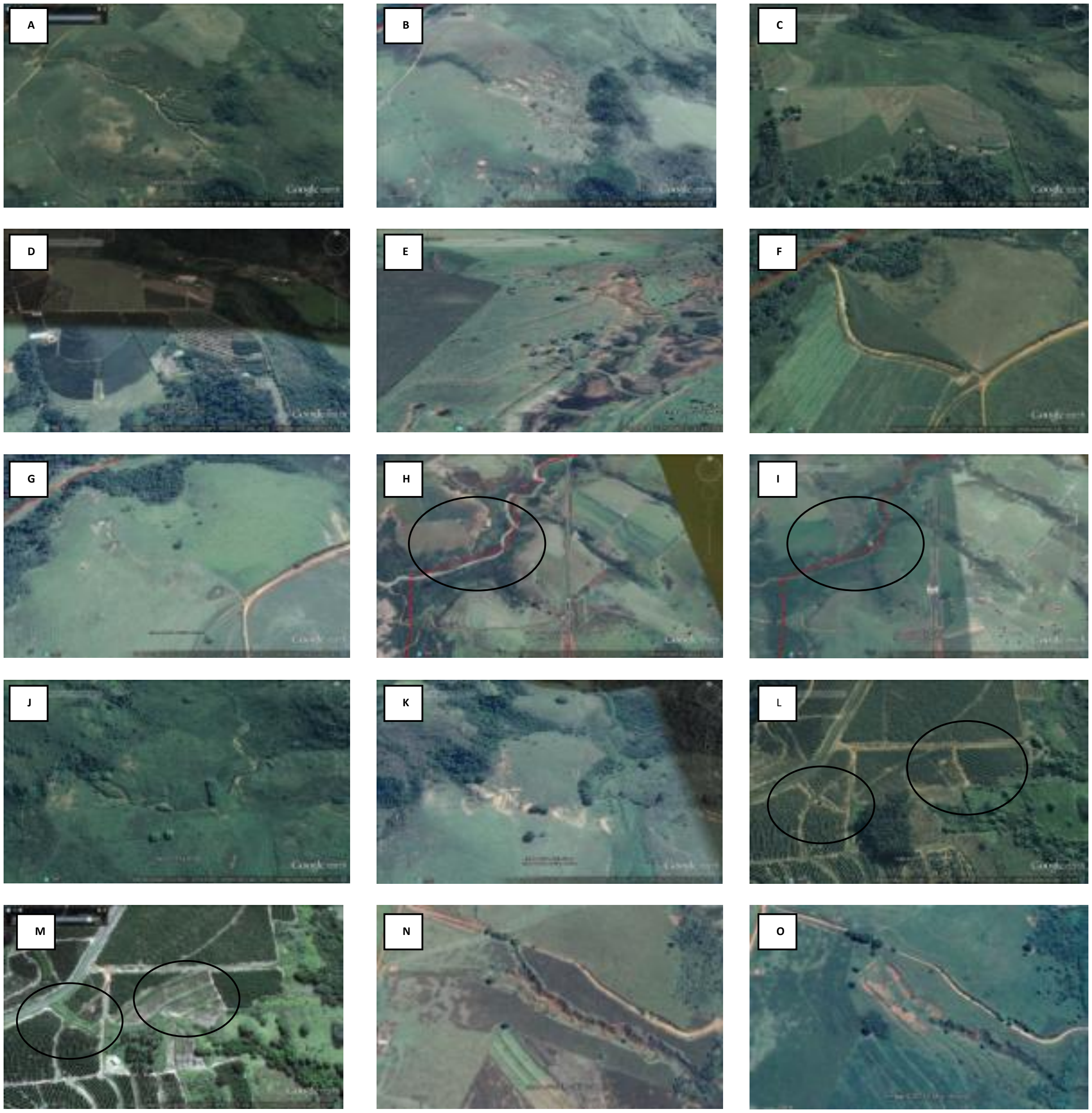
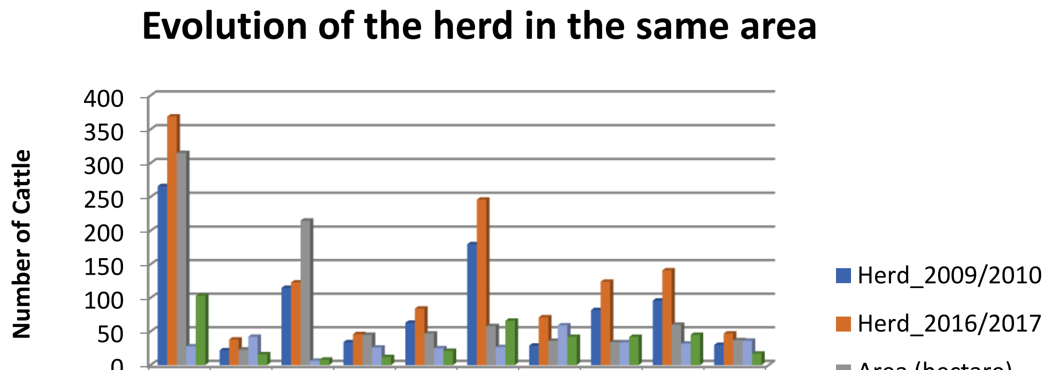


Figure 1: Images of the study area before the project implementation (A, C, F, H, J, L, N - images of 12/05/2002 Google Earth®) and after the implementation of soil conservation practices (B, D, E, G, I, M, O, 16/08/2013). A, erosion in a very deep furrow (gully); B, erosion controlled with the construction of containment boxes; C, incorrect management of coffee crop; D, with the change of management, transformation of the landscape; E, erosion controlled with construction of containment boxes; F, erosion in very deep furrow (gully); G, transformation of the landscape, with gully control; H, erosion and silted river; I, landscape transformation, by crop management change that decreases the river silting (detail); J, erosion in very deep furrow (gully); K, erosion control with construction of containment boxes; L, incorrect management of coffee crop, with several erosion (detail); M, control of gullies with the change of coffee management (detail). N, Large erosion gully. O, gully controlled with the construction of terraces. (Adapted from Vischi Filho *et al.*, 2016).

Figure 2: Turbidity (A, B, Conama 100 UNT standard), suspended solids (C, D), phosphorus (E, F, Cetesb standard 0.025 mg L) and organic carbon (G, H) in water collected in Rio do Peixe, considering the years 2000-2007 (before), and subsequent to the implementation of the project from 2008-2016 (after) (Adapted from Vischi Filho *et al.*, 2016).

Table 1: Cattle herd evolution in Rio do Peixe Watershed. 2009/2010 prior to the work completion. 2016/2017 after pastures recovery.



Properties livestock	1	2	3	4	5	6	7	8	9	10
Herd_2009/2010	266	22	115	34	63	180	29	82	96	30
Herd_2016/2017	369	38	123	46	84	246	71	124	141	47
Area (hectare)	315	23	215	45	47	58	36	34	60	37
%	28	42	7	26	25	27	59	34	32	36
Increase	103	16	8	12	21	66	42	42	45	17

Conclusions

After 20 years of applying the soil conservation legislation, 772 000 hectares have already been worked, with 19 846 agricultural properties that were assessed and rehabilitated agro-ecologically.

The monitoring of Rio do Peixe Watershed, carried out from 2007-2018, with surveys, diagnoses and rehabilitation of agricultural-livestock properties, is transforming them into conservationists, preserving the soil and water, taking care of the well-being of the local society.

Implementation of the ICLS, with the change in soil and pasture management, has increased the occupation rate of pasture areas by 31 %.

The Methodology IADCM presents a positive yield of 1 418 % compared to the conventional ADC Methodology, saving capital and ADC staff.

In these twelve years of work at Watershed, new technologies for the site have been developed: Bioengineering, No-tillage and ICLS, a fact that has changed the habit of treating natural resources of most of the farmers in the region.

The methodology IADCM of monitoring and agro-environmental rehabilitation is feasible and can contribute to the management of watershed.

Acknowledgements

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References

São Paulo. 1988. Lei n° 6.171 de 04 de julho de 1988. Dispõe sobre o uso, conservação e preservação do solo agrícola. Diário Oficial Estado de São Paulo, São Paulo, 5 jul. 1988.

Filho, O.J.V., Corsato, L.G., Quiessi, J.A., Kanno, O.Y., Penteado, R.B., Arabori, R.M., Belorte, L.C.C., Lima, M.E. de, Filho, O.J.V., Corsato, L.G., Quiessi, J.A., Kanno, O.Y., Penteado, R.B., Arabori, R.M., Belorte, L.C.C. & Lima, M.E. de. 2016. Diagnóstico e reabilitação agroambiental de trecho de bacia hidrográfica por sensoriamento remoto e turbidez da água. *Pesquisa Agropecuária Brasileira*, 51(9): 1099–1109. https://doi.org/10.1590/s0100-204x2016000900009.

Vischi Filho, *et al.* 2018. Comparation between diagnostic Metodology CDA versus Methodology CDA Innovated aiming to transform degraded areas into conservation agriculture areas. In: 21st World Congress of Soil Science. Rio de Janeiro, Brazil. August 2018.

Soil erosion policy in Switzerland

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Abstract

In Switzerland, the problem of soil erosion by water persists despite numerous studies and significant improvements. Erosion in the typical mixed crop-livestock farming systems in the hilly Midlands are causing on-site as well as off-site damages. The effect of these damages involves economic and ecological costs for society. Within the environmental policy the tolerable level of soil erosion is set to 2 or 4 t/ha and year, respectively, depending on soil depth (<70 or >70 cm); values that are often exceeded. The Swiss agricultural policy system is based on a system of direct payments (subsidies) to compensate farmers for the different types of services they deliver to society. This system supports prevention of soil erosion indirectly, e.g. by defining a minimal crop rotation or an optimal soil coverage. Furthermore, financial support is given to farmers applying conservation tillage. In the context of a new enforcement of erosion protection, payments are cut for farmers who experience recurrent soil erosion and do not cope by developing a site-specific action plan and taking adequate prevention measures. In Switzerland, agro-environmental policies are the result of negotiation and compromise rather than optimal expert determination. Despite their comprehensiveness, inconsistencies remain, leading to an ineffective implementation.

Keywords: Switzerland, on- and off-site erosion, long-term monitoring, enforcement of erosion protection, policy

Introduction

Soil erosion by water is one of the major soil threats in Switzerland (Stolte *et al.,* 2016; FOEN, 2017). Despite numerous studies and significant improvements, the problem persists, compromising the fertility of Swiss agricultural lands in the long term. Even more, beyond the provision of food, the multitude of services provided by soil is affected, leading to impacts for the society as a whole. As in many other countries, the quality and multi-functionality of soils is still insufficiently acknowledged among land users, planners and policy makers. Explicit evaluation of soil quality with respect to specific soil threats, soil functions and ecosystem services has rarely been implemented (Bünemann *et al.*, 2018). However, ecosystem services specifically related to soil have recently become increasingly important to justify and support sustainable soil management for the mitigation or prevention of soil threats (Schwilch *et al.*, 2018). This goes in line with the fact that in many countries including Switzerland, off-site effects of soil erosion – besides on-site effects – gain importance in research as well as in targeting mitigation measures.

In the typical mixed crop-livestock farming systems in the hilly Midlands of Switzerland, sheet, rill and ephemeral gully erosion, are causing on-site as well as off-site damages related to the deposition of eroded material downslope (e.g. water contamination and damages on public and private infrastructure). Long-term field studies of soil erosion on cropland in different parts of Switzerland have shown that off-site effects are considerable (Ledermann *et al.*, 2010).

Within the environmental policy, the Soil Pollution Ordinance (SoilPO) sets the tolerable level of soil erosion to 2 or 4 t/ha and year, respectively, depending on soil depth (<70 or >70 cm); values that are often exceeded (FOEN, 2017). An erosion risk map in a 2x2-metre grid (ERM2), covering the agricultural area of Switzerland (Prasuhn *et al.*, 2013), is used to support enforcement of the laws to prevent soil erosion (FOEN and FOAG, 2013). The Swiss agricultural policy system is based on a complex system of direct payments (subsidies) to compensate farmers for the different types of services they deliver to the society (e.g. food security, landscape protection, etc.). This system of direct payments supports prevention of soil erosion indirectly, e.g. by defining a minimal crop rotation or an optimal soil coverage. Furthermore, financial support is given to farmers applying conservation tillage. Despite this comprehensive legal framework, after 20 years of implementation, observers conclude that the results of these efforts to reduce soil degradation remain disappointing (Derungs, 2018). In the context of a new enforcement of erosion protection (started in 2017), payments are cut for farmers who experience recurrent soil erosion and do not cope by developing a site-specific action plan and taking adequate prevention measures.

Methodology

This work is compiled from several studies as well as experiences from the national and cantonal administration. The methodology of these studies include long-term field monitoring of soil erosion conducted on arable land in the Swiss midlands as well as an ethnographic survey.

Since late 1997, the national agricultural research institution Agroscope conducts a long term monitoring in the region of Frienisberg in the canton of Bern. Family farms, which predominate in the area, apply mixed farming methods of growing crops and keeping livestock. Winter intercrops are widespread and crop rotations mostly include a high proportion of temporary grass-clover mixtures. Prasuhn (2011) investigated 203 arable fields in the region with a total area of 265 ha, reporting a mean slope gradient of 6.5% (range 1–25%) and a mean slope length of 68m (range 15–210 m). All visible erosion features were continuously mapped and quantified over 20 years. The eroded soil volume associated with linear erosion features was calculated by measuring the length and cross-sectional area in rills at representative positions and the extent of interrill erosion was estimated.

An interdisciplinary study by Derungs (2018) combining natural, political and social sciences focused on the sustainable management of agricultural soils. It tackled Swiss environmental and agricultural policies for qualitative soil protection and the accompanying measures to limit water erosion. The study conducted ethnographic fieldwork and interviews with farmers, agricultural advisers, public servants in cantonal and federal administrations and scientists, and analysed existing national and international reports. In the end, 67 interviews and 15 field observations were carried out, and hundreds of articles and reports were consulted.

Results

The assessed soil loss values are highly variable, especially from year to year, as they strongly depend on the weather and the land management. Averaged across the first 10 study years, one-third (32.2 %) of the fields exhibited erosion. With 0.75 t ha^{-1} yr^{-1} (mean) and 0.56 t ha^{-1} yr^{-1} (median), the average annual soil loss of the region was relatively small. The year-to-year variation in soil loss of the region was great and ranged from 0.16 to 1.83 t ha^{-1} yr^{-1}. The maximum annual soil erosion in a single field was 58 t ha^{-1} yr^{-1}, thus demonstrating that only a few erosion events on a few fields may decisively contribute to the total extent of soil erosion in a region. The value for long-term tolerable soil erosion according to SoilPO was exceeded in 14 fields. 88 % of soil erosion took place on plough tilled land (PT), 9 % on non-ploughed land with less than 30 % surface residue cover (RT), 1 % on mulch-tilled land with more than 30 % surface residue cover (MT), and 2 % in non-tilled or strip-tilled land with >30 % soil cover (NT). At 0.07 and 0.12 t ha^{-1} $year^{-1}$, respectively, the mean soil loss in MT and NT fields was more than an order of magnitude lower than that under PT (1.24 t ha^{-1} $year^{-1}$) (Prasuhn, 2012). Wheel tracks, furrows, headlands, and slope depressions were important on-site accelerators of erosion. Run-on from adjacent upslope areas was an important trigger of erosion. Of the soil moved by erosion, 52 % was deposited within the field of origin. A high proportion (72 %) of the linear erosion features caused off-site damage. Part of the total eroded soil (20 %) was transported into surface water.

The largest soil losses in the hilly case study area are found on potato fields (Prasuhn *et al.*, 2017). Over 10 years, a total of 521 t of soil was eroded from these potato fields at an average of 2.87 t ha^{-1} $year^{-1}$. This corresponds to 26 % of total soil erosion in the region, despite potato fields only covering 7 % of the total agricultural area. Promising measures such as a device digging holes into the bottom of the furrows between the potato ridges showed how soil surface structure can be changed and infiltration increased, thereby reducing soil erosion and preventing waterlogging (Lemann *et al.,* 2018).

Comparing the first 10 years with the second decade of observation showed that the overall soil loss reduced from 200 t/y to 59 t/y (Fig 1). Also the number of high erosion loss features has been reduced.

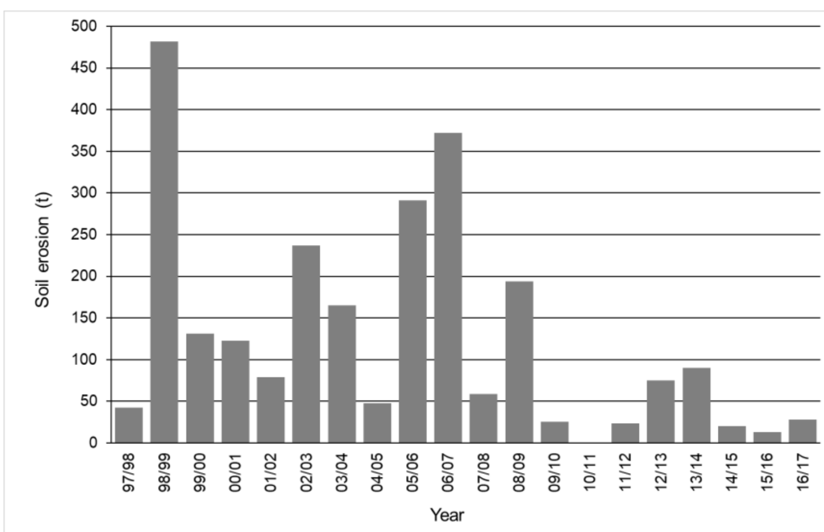

Figure 1: Development of annual soil erosion in a 265-hectare study area northwest of Bern (OFEV, 2017; data by Prasuhn)

The new enforcement of erosion protection within the Direct Payment Directive started in 2017. This implies that the cantonal administration has to take risk-based erosion controls on farmers' fields. The renewed erosion risk map is supporting the identification of high-risk areas, and combined with the intensity of rainfall events, provides an opportunity to concentrate on problem areas. If there is an erosion event taking place, the farmer has to design a site-specific action plan, either on his own or with support from the agricultural advisors. The action plan includes adequate prevention measures of his/her own choice, adapted to the local environmental but also socio-economic circumstances, providing more room for own solutions rather than prescribed measures. The action plan is elaborated for 6 years and includes concrete measures for each field. Only if the same farmer experiences recurrent soil erosion, he/she is punished by cutting direct payments.

The central role of technical experts at national and cantonal level and from research institutes such as Agroscope who function as spokespersons and moral entrepreneur for soil policy, has been a constant throughout the history of combatting soil erosion. This leading role can be seen as a strength and weakness. These experts succeeded in creating the first legal framework around qualitative soil protection in Europe. However, by confining the problem of soil erosion to an agronomic on-site problem and leaving it to technical expert circles, it became a top-down expert-based approach. In addition, the process of defining agro-environmental policies led to significant inconsistencies, such as the disconnection between quantitative (surface) and qualitative (fertility) soil protection measures, the lack of a coherent policy for the management of organic matter, the lack of guidelines around off-site erosion, etc. Furthermore, due to lack of human, financial, political and cognitive resources in environmental administration and to resistance with respect to sustainable management measures, the implementation of the SoilPO was incomplete. The analysis presented here demonstrates how points of consensus reached after long negotiations are constantly being called into question, sending confusing signals to all actors involved.

Discussion

The success of the soil erosion reduction in the Frienisberg area is probably mainly due to the financial support for conservation agriculture measures. The share of conservation agriculture practices increased from an average of 6 % in the first 10 years to 60% in the following 10 years as a result of participation in cantonal (2010-2015) and state subsidy programmes (2014-2017), and was 75 % of the arable land in the study area in 2017. The sensitisation of farmers by agricultural advisors as well as the scientific activities likely had a significant influence. In overall Switzerland, the proportion of conservation tillage methods in 2017 was only 23 %. This study thus shows that erosion control is possible and successful under real-life conditions. With its policy change after 2017, subsidy for the reduction of plant protection products became higher than for conservation agriculture, which lead to a re-increase of ploughed fields. Whether more erosion will take place due to this has to be seen in the coming years.

The environmental problem of soil degradation is not so much a technical as an expert, social, political and democratic problem. First, scientific research around soil erosion has mainly focused on a risk-based approach aiming at developing technical innovations. From this point of view, the efficiency of agri-environmental schemes depends on the participation of farmers. The lack of sociological expertise made soil degradation a depoliticized issue hardly understandable for lay people. Second, the unequal budgets and legitimacy as between environmental and agricultural administrations, as well as the influence of lobbies and the food industry, weigh heavily during the development, the implementation and the evaluation of agri-environmental policies. Trying to make soil degradation a social concern may improve balancing these power relationships.

Conclusions

Long-term monitoring in the field made it possible to draw conclusions with regard to extent, causes, spatial distribution, and off-site damage of soil erosion as well as the efficiency of mitigation measures. The approach taken in Switzerland may serve as input for similar considerations in other countries. However, experiences from the new enforcement are still lacking and although technical and agronomic innovations are essential, experts must bear in mind that soil erosion is a complex socio-environmental problem.

References

Bünemann, E.K., Bongiorno, G., Bai, Z., Creamer, R.E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T.W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J.W. & Brussaard, L. 2018. Soil quality – A critical review. *Soil Biology and Biochemistry*, 120: 105–125. https://doi.org/10.1016/j.soilbio.2018.01.030.

FOEN. 2017. Swiss Soils. State and Evolution.

FOEN & FOAG. 2013. Implementation guide environmental protection in agriculture. Module soil protection in agriculture.

Derungs, N. 2018. La gestion durable des sols agricoles : sécuriser les démarches ou légitimer les controverses ? L'exemple des politiques agroenvironnementales autour de l'érosion hydrique des sols arables en Suisse. These de doctorat, Université Neuchâtel.

Engel-Di Mauro, S. 2014. Ecology, Soils and the Left: An Ecosocial Approach. Basingstoke: Palgrave McMillan.

Ledermann, T., Herweg, K., Liniger, H.P., Schneider, F., Hurni, H. & Prasuhn, V. 2010. Applying erosion damage mapping to assess and quantify off-site effects of soil erosion in Switzerland. *Land Degrad. Dev.,* 21: 353–366. https://doi.org/10.1002/ldr.1008.

Lemann, T., Sprafke, T., Bachmann, F., Prasuhn, V. & Schwilch, G. 2018. The effect of the Dyker on infiltration, soil erosion, and waterlogging on conventionally farmed potato fields in the Swiss Plateau. *Catena*, 174: 130-141. https://doi.org/10.1016/j.catena.2018.10.038.

Prasuhn, V. 2011. Soil erosion in the Swiss midlands: results of a 10-year field survey. *Geomorphology*, 126: 32–41. https://doi.org/10.1016/j.geomorph.2010.10.023.

Prasuhn, V. 2012. On-farm effects of tillage and crops on soil erosion measured over 10 years in Switzerland. *Soil Tillage Res.*, 120, 137–146. https://doi.org/10.1016/j.still.2012.01.002.

Prasuhn, V., Liniger, H., Gisler, S., Herweg, K., Candinas, A. & Clément, J-P. 2013. A high resolution soil erosion risk map of Switzerland as strategic policy support system. *Land Use Policy*, 32: 281–291. https://doi.org/10.1016/J.LANDUSEPOL.2012.11.006.

Prasuhn, V., Lemann, T., Schwilch, G., Bachmann, F., Bandi, M., Jaunin, V. & Burgos, S. 2017. Der Einfluss von Lochstern und Querdammhäufler auf Erosion und Staunässe im Kartoffelanbau. Bodenkundliche Gesellschaft der Schweiz, Bulletin 38.

Schwilch, G., Lemann, T., Berglund, Ö., Camarotto, C., Cerdà, A., Daliakopoulos, I.N., Kohnová, S., Krzeminska, D., Marañón, T., Hessel, R. ***et al.*** 2018. Assessing Impacts of Soil Management Measures on Ecosystem Services. *Sustainability*, 10: 4416. https://doi.org/10.3390/su10124416.

Stolte, J., Tesfai, M., Øygarden, L., Kvaernø, S., Keizer, J., Verheijen, F., Panagos, P., Ballabio, C., Hessel, R. & Wur, A. 2016. Soil Threats in Europe.

The conceptual model for natural resources conservation in forest areas

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Abstract

Evaluation of environmental acts of Iran, highlights the gap that soil conservation and impacts of deforestation and guidelines for stockholders of forest areas have not been presented properly. Therefore, the work aimed to develop a conceptual model for stating the problems raised by deforestation and to present practical approaches and to define conservation levels to achieve sustainable land use. The conceptual model emphasized on watershed scale to prevent scatter practices and focused on conflicts between land users and desirability and proportionality of current land uses. The conceptual model presents the framework in which forestry activities has classified in three levels of the conservation, protection and preservation. The lowest level of conservation has authorized stockholders to change forest to specific land uses with regarding to environmental considerations. Further, based on ecological potential of forest, other activities such as tourism, fishery, cattle ranching, settlement and mining allowed to develop under certain scale of time and space. In protection level, involved and authorized companies will be guided to carry out restoration practices. In addition, forestry activities will be focused on limited areas especially to improve quality of forests. Preservation as the highest level of conservation, provides stepwise practices for involving organizations to preserve natural resources without land development. The forest breathing with certain time scale is one of the outcomes of preservation level. The conceptual model presents remarkably the practical road map for decision makers around the world to reach sustainable land use plan in watershed scale with considering human demands.

Keywords: Hyrcanian Forests, Conceptual Model, Soil Erosion, Deforestation, Conservation levels

Introduction

Land degradation is one of on-site impact of deforestation that is threatening the natural resources and food security. There is the long history for harvesting of timberlands in Iran especially from Hyrcanian Forest in the North of Iran (Bobek, 2005). The pre and post 1 950 wood harvesting regardless of soil conservation have mainly controlled with great events such as wars, construction of main roads, settlements of population and authorized companies. Nowadays, there are 103 catchments in the North of Iran in which 50 authorized companies are harvesting timberland. The annual rate of wood harvesting by such companies has been 2.3 million m-3 between 1976 and 1991. Afterward, this rate was decreased to 300 000 m-3 per year. While, privates are responsible to harvest 3 million m-3 per year without defined plan. Based on FAO (FAO, 1990, 2015) reports, the area of Hyrcanian forests has been increased from 1 771 000 ha in 1990 to 1 939 494 ha in 2015. Existence of 6 million cattle and mining activities in 100 000 ha and more than 40 places of landfills and development of several access roads through the forest regardless of the conservation rules, have been made the complicated situation in the North of Iran. Accordingly, several rules and environmental acts have been released by The Parliament of Islamic Republic of Iran (Act 41, 1962; Act 52, 1973; Act 59, 1980; Act 71, 1992; Act 89, 2010; Act 93, 2014). These regulations included comprehensive laws, strategies, policies and practices for different involved ministries, organizations, companies and end users. Lack of integrity between duties of stockholders was the big gap in such acts. In addition, weakness in structure of monitoring of the practices and undefined spatial planning of practices are other gaps for achieving of the rules goals. Therefore, the research aimed to define conceptual models to estimate impacts of deforestation especially on-site soil erosion and to present policies and an action plan for land development regarding to the conservation considerations. This objective was defined as one of the main outcomes of the technical cooperation project (IRA5013) between Iran and International Atomic Energy Agency that implemented from 2016 to 2019 in the North of Iran.

Methodology

The research method was mainly defined based on evaluation of rules and regulations that mentioned above in terms of approaches, methods, road maps and outcomes. Formulation of methods was made to presents conceptual models for assessing on-site and off-site deforestation impacts, to identify drivers, impacts, pressures, states and responses, to define watershed as geographical scale for implementation of practices, to suggest three approaches of the conservation, development and integrity to achieve an action plan under three levels of conservations for activities. Synthesizing of conceptual models was carried out regarding to conflicts and coverage in land uses, desirability and proportionate of land uses, training and awareness of stockholders, and monitoring plan.

Results

Results highlighted a high variety in impacts of deforestation and afforestation on soil redistribution in the North of Iran. The synthesized model is presented (Figure 1) with some supportive steps regarding to previous rules and guidelines. The model primarily points to classification of the deforestation periods and events based on socio-economic purposes and common methods of deforestation. Despite to mentioned acts, this step considered comprehensively impacts based on cause and effects approach. In the second step, DPSIR model (OECD, 1961) as a causal framework is suggested to describe the interactions between society and the environment. One of the main states in DPSIR model is rate of soil erosion that has been estimated using fallout radionuclides (^{137}Cs) methods for representative sites. Strategies for conservation of the human, biological and non-biological resources will be released in format of integrated watershed management (IWM). The conceptual model has focused on three approaches of the conservation, development and integrity to make the basic structure for achieving the action plan. These concept means that IWM will consider all aspects of activities and spatial planning in order to evaluate current land uses and programmed lands for developing and lands needed for conservation based on demands of stockholders and end users. Accordingly, current land uses have classified to two groups of the desirable, proportional lands and undesirable, disproportionate lands. Training and awareness program is suggested to enhance knowledge about approaches and to increase their contribution in implementation of practices. Experiences on implementation of the previous rules and guidelines showed that contribution of end users is vital in successfulness of each action plan. Accordingly, scale of contribution and effectiveness of important organizations and local users should be determined. In addition, terms and condition of conflicts and coverage of present and programmed land uses should be evaluated to find out solutions and to enhance their contribution in conducting of practices. Outputs of this step should be combine with results of desirability and proportionality of current land uses to find out priority in land use. Multi criteria decision making models will be useful to reach priority in land uses. In addition, the conceptual model suggested to use the decision support system to introduce desirable spatial planning of land uses and practices.

Classification of all forestry activities in three conservation levels of the conservation, protection and preservation is the model outcome. Conservation approach has let to land users (Authorized and privates) to change forest to specific land uses with regards to environmental considerations. In addition, other activities such as tourism, fishery, cattle ranching, settlements and mining should be implemented through an integrated program without conflict, undesirability, maximum proportionality. In protection level, wood harvesting would be limited and restoration practices should be implemented. Preservation implies to practices without any changes in forest areas and to achieve situation with limited soil erosion. The forest breathing which is newly (2016) proved in Iran for implementing in time scale of 10 years is output of preservation practices. Framework of evaluation and monitoring with certain indicators, time scale and supervisor is suggested. Supervisor for monitoring would be selected from the most important organizations involved in the study area, therefore, they would be responsible for bias and variation in planned states.

Discussion

This model has considered all previous rules and guidelines of development and conservation of Iran and presents comprehensive programme to manage current and programmed land use to solve conflict and undesirability. Suggested steps increases the ability of managers to implement conservation practices in forestry areas, where there are un-sustainability in land uses. In addition, the model has introduced the development approach in which land use changes will be implemented under conservation considerations. For instance, development projects should be conducted biological and mechanical practices to mitigate soil erosion and sediment transport to lakes and lagoons. Integrity approaches make a convergence in policies and activities of organizations who are involving in harvesting the forest and conserving the natural resources. Comparison of present conceptual model with previous models (Kaimowitz, 1998; Aukland, 2003; Tejaswi, 2007; Feng *et al.*, 2014; Indarto, 2016) showed that this model like previous ones has considered comprehensively purposes, methods and impacts of deforestation. Further, this model has several privileges in terms of methods, approaches, level of conservations and supportive sub-models for spatial planning, programming of action plan, management practices, and evaluation and monitoring.

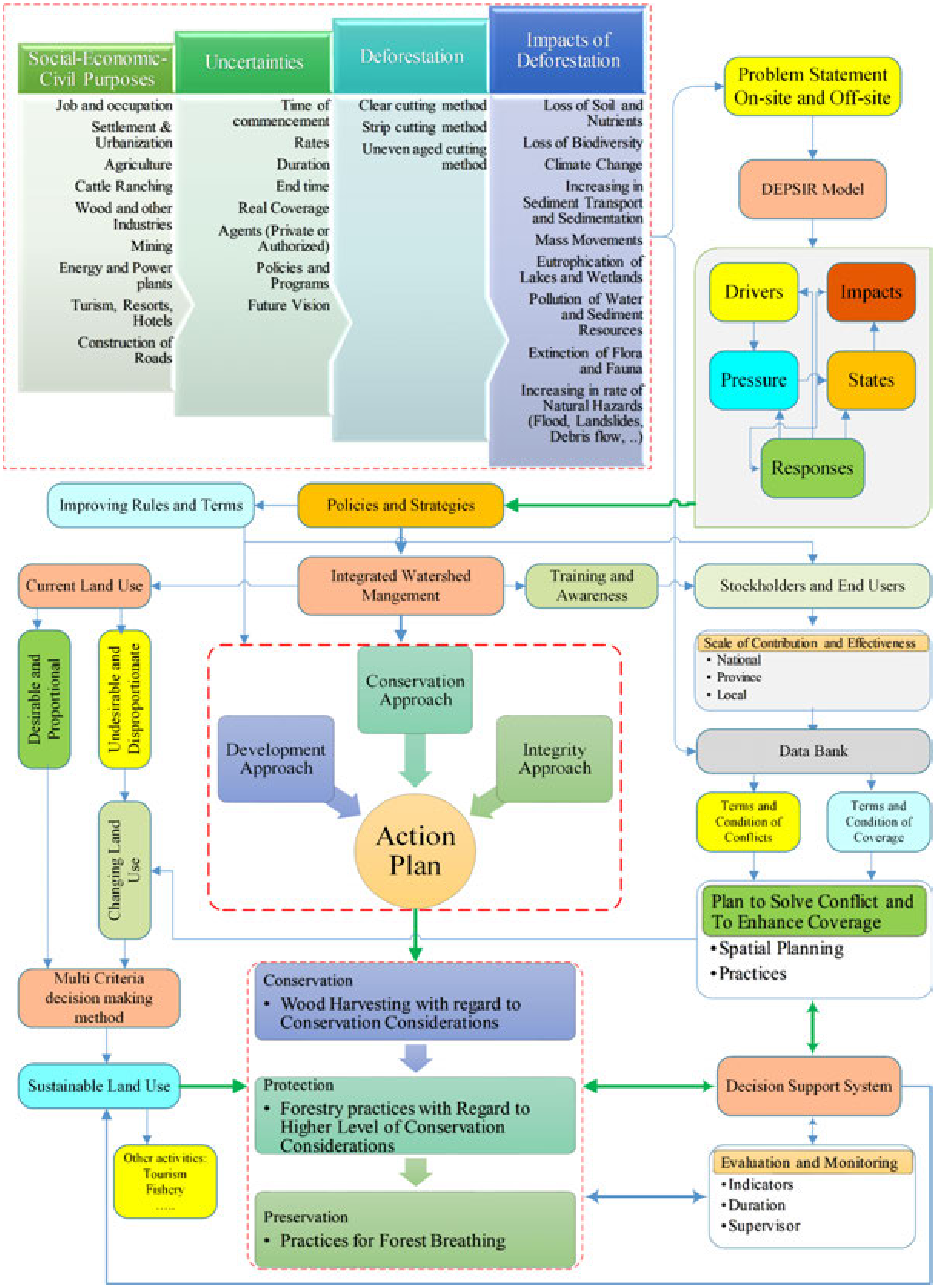

Figure 1: the conceptual model for management of deforestation and conservation of soil resources

Conclusions

Present work has concluded the high capability of nuclear techniques to quantify impacts of the deforestation and to support management models. The model designed how to state the problems raised by deforestation via DPSIR model and to define approaches and conservation levels and to response human demands. Accordingly, present model will be greatly useful for Iranian and international decision makers to choose desirable and proportional land uses without conflict among stockholders. Action plan in watershed scale prevents local and un-effectiveness practices while policies and strategies will be evaluated and monitored by supervisor to reach the sustainable land use.

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References

Act 41. 1962. Forest and rangelands nationalization law. In: Forests, R.a.W.M.O. (Ed.). The national parliament of Iran, Tehran, p. 3

Act 52. 1973. The law of preserving and expanding green space and preventing the cutting of the trees. In: Municipalities (Ed.). The national parliament of Iran, Tehran, p. 3

Act 59. 1980. Law of Transferring and Reclamation of lands. In: Forests, R.a.W.M.O. (Ed.). The Parliament of Islamic Republic of Iran, Tehran, p. 13

Act 71. 1992. The Law on Conservation and Protection of Natural Resources and Forest Resources of the Country. In: Forests, R.a.W.M.O. (Ed.). The Parliament of Islamic Republic of Iran, Tehran, p. 5

Act 89. 2010. The Law on Increasing the Productivity of the Agricultural and Natural Resources. In: Ministry, A. (Ed.). The Parliament of Islamic Republic of Iran, Tehran, p. 11

Act 93. 2014. Optimization program for monitoring, conservation, exploitation and management of forests of the country. In: Forests, R.a.W.M.O. (Ed.). The Parliament of Islamic Republic of Iran, Tehran, p. 5

Aukland, L., Costa, P. M. & Brown, S. 2003. A conceptual framework and its application for addressing leakage: the case of avoided deforestation. *Climate Policy*, 3: 123-136

Bobek, H. 2005. Historical View of Natural Forests and Iran's Trees. Geographic Organization of the Armed Forces, Tehran.

FAO. 1990. Global Forest Resources Assessment. Food and Agriculture Organization of the United Nations, Rome.

FAO. 2015. Global Forest Resources Assessment. Food and Agriculture Organization of the United Nations, Rome, p. 253.

Feng, H., Lim, C.W., Chen, L., Zhou, X., Zhou, C. & Lin, Y. 2014. Sustainable deforestation evaluation model and system dynamics analysis. *The Scientific World Journal*, 106209-106209.

Indarto, J. & Mutaqin, D. J. 2016. An Overview of Theoretical and Empirical Studies on Deforestation. *Journal of International Development and Cooperation*, 22: 107-120

Kaimowitz, D. & Angelsen, A. 1998. Economic Models of Tropical Deforestation A Review. Center for International Forestry Research, Bogor, Indonesia, p. 153

OECD. 1961. DPSIR Model. The Organisation for Economic Co-operation and Development, Paris, France

Tejaswi, G. 2007. Manual on Deforestation, Degradation, and Fragmentation Using Remote Sensing and GIS. Forestry Department, Food and Agriculture Organization of the United Nations Rome, p. 49

Challenges and Opportunities: Enabling Effective Soil Erosion Control through Land Degradation Neutrality

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Abstract

Soil erosion is a major process of land degradation and desertification. This contribution revisits soil erosion as the inherent component in the concept of desertification/land degradation and highlights the importance of addressing soil erosion induced land degradation to the achievement of Land Degradation Neutrality (LDN). Setting LDN targets and planning interventions require assessments of land potential, land degradation status and resilience, all of which are impacted by erosion. On this basis, a gap analysis is made on the needs of policy makers and land users with respect to the preliminary assessments LDN with particular consideration of the fact that erosion leads to the displacement of soil over, at times, great distances. This analysis is coupled with recognizing the opportunities to further meet 1) political commitments to SDG 13, SDG 15 and SDGs 2, 3, 6 as well as to LDN voluntary targets, 2) improved but remaining gaps in scientific understanding and public awareness on the role of soil and land-based solutions in environmental problem solving, 3) development of innovative technologies for enhancing the land degradation assessment and knowledge transferring and learning, and 4) accumulated successful cases and practices on sustainable land management (SLM) and erosion control. Recommendations, with the aim of identifying how LDN can offer a framework for controlling soil erosion, are provided with special focus on 1) how soil erosion science, technology and knowledge may contribute to the LDN preliminary assessments and 2) how new technologies can be used to establish an interactive platform for facilitating accessibility of decision makers and land users to the data necessary for integrated land use planning (ILUP), integrated landscape management (ILM) and SLM.

Keywords: Soil erosion, Land Degradation Neutrality (LDN), innovative technology, preliminary assessment, sustainable land management, incentives

Vulnerability assessment of soil erosion affected by climate change

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Abstract

Water erosion is one of main concerns to manage agricultural sustainability in Korea in which annual rainfall ranged 726 mm and 1 702 mm with regions. The nationwide soil loss of Korea was approximately 50 million MT yr^{-1} and the risk was various with land use types; the soil erosion potential was the greatest value of 41.0 MT ha^{-1} yr^{-1} for upland crop fields and followed by 11.1 for orchards and 1.0 for rice paddy fields. The potential risk of soil erosion in Korea even tended to increase influenced by climate changes. The rainfall erosivity was, on average, 3,988 MJ mm ha^{-1} yr^{-1} hr^{-1} for 1981~1990, 4,085 MJ mm ha^{-1} yr^{-1} hr^{-1} for 1991~2000, and 4,370 MJ mm ha^{-1} yr^{-1} hr^{-1} for 2001~2010 due to increased torrential rain events. It implies that the current conservation program may not be sufficient to sustain soil productivity. Therefore, the vulnerability assessment has been carried out through (i) establishing monitoring sites to analyze climate changes and their effects on soil erosion, and (ii) evaluating soil erosion reduction supported by soil conservation programs. In addition, practical action programs have been developed continuously to facilitate practices of farmers in the fields.

Keywords: soil erosion, climate change, rainfall erosivity, conservation program

Introduction, scope and main objectives

Korean peninsula is located in the Asian monsoon zone with temperature humid climate and torrential rains in summer season. The annual precipitation, on average, ranged 726 mm and 1,702 mm due to regional variation and approximately two thirds of rainfall occurred between June and October (Park *et al.*, 2011). With the rainfall pattern, soil erosion by water is one of main concerns to manage agricultural sustainability and the nationwide soil loss of Korea was assessed approximately 50 million MT yr^{-1} (Jung *et al.*, 2004; Jung *et al.*, 2005). The risk of soil erosion, however, is different among land use types. Paddy rice fields were mostly situated in plain land with A (0~2 %) and B slope (2~6 %) while upland crop fields and orchards were usually found in slope areas; the average slope gradient was 12.7 % in upland crop fields (NIAST, 1992). The soil erosion potential was the greatest value of 37.7~41.0 MT ha^{-1} yr^{-1} for upland crop fields and followed by 11.1 for orchards and 1.0 for rice paddy fields; the soil erosion potential of orchards was prominently lower than that in upland crop fields because orchards were covered by grass on most surface (Jung *et al.*, 2004; Jung *et al.*, 2005). A variety of soil conservation practices, especially for upland crop fields, have been developed and applied to manage soil loss below the tolerable level.

A number of studies presented that rainfall pattern has changed as a part of climate change (NIMS, 2018). Considering that water erosion was a crucial threat inducing soil degradation in Korea, assessing impacts of climate changes on soil erosion is necessary to apply appropriate soil conservation practices and support soil conservation programs. If rainfall erosivity has increased over time, soil conservation programs should be reinforced while political support for soil conservation should be reduced in the inverse case.

Methodology

The data of each rainfall event were collected from 60 meteorological stations between 1981 and 2010 and rainfall erosivity was calculated for both annual and seasonal unit with RUSLE method (Renard *et al.*, 1996); 60-min maximum intensity was used though. Ten-year average for each station was determined for 1981~1990, 1991~2000, and 2001~2010. The annual and seasonal erosivity data were transformed to spatial data using the inverse distance weight method based on 1 km spatial unit TM coordinates and presented as maps with GIS.

Results

Changes in seasonal variation of rainfall patterns

Precipitation, on annual average, increased gradually for last 30 decade, which was mainly affected by increasing rainfall in spring and summer season; precipitation in fall, however, trended to decrease (Table 1). Precipitation in summer occupied 53.3~55.8 % of annual precipitation and increased 4.9 % comparing values of ’01~10 to ’81~’90. Increasing tendency was clear in rainfall erosivity than that in precipitation. The rainfall erosivity was, on average, 3,988 MJ mm ha^{-1} yr^{-1} hr^{-1} for 1981~1990, 4,085 MJ mm ha^{-1} yr^{-1} hr^{-1} for 1991~2000, and 4,370 MJ mm ha^{-1} yr^{-1} hr^{-1} for 2001~2010 due to increased torrential rain events. Annual and summerly rainfall erosivity increased 9.6% and 16.4% for 20 years; rainfall erosivity in summer season occupied 69.8~74.2 % of annual sum.

Table 1: Decadal changes in precipitation and rainfall erosivity for annual and seasonal unit

Period	Precipitation (mm)			Rainfall erosivity (MJ mm ha^{-1} hr^{-1})		
	’81~’90	’91~’00	’01~’10	’81~’90	’91~’00	’01~’10
Spring	233	254	265	340	361	369
Summer	712	737	782	2,785	3,009	3,241
Fall	294	260	252	787	654	717
Winter	96	87	101	76	62	42
Year	1,335	1,339	1,401	3,988	4,085	4,370

* The table was quoted from Park *et al.* (2011)

Changes in regional variation of rainfall erosivity

Rainfall erosivity was greater in southern and north-western coastal regions while south-eastern inland areas had the lowest erosivity; Geoje and Namhae stations in southern coast presented more than 7,000 MJ mm ha^{-1} yr^{-1} hr^{-1} of erosivity (Figure 1). With an increasing trend of erosivity over time, deviation between regions became more distinct reflecting greater increment of erosivity in north and south parts of Korea.

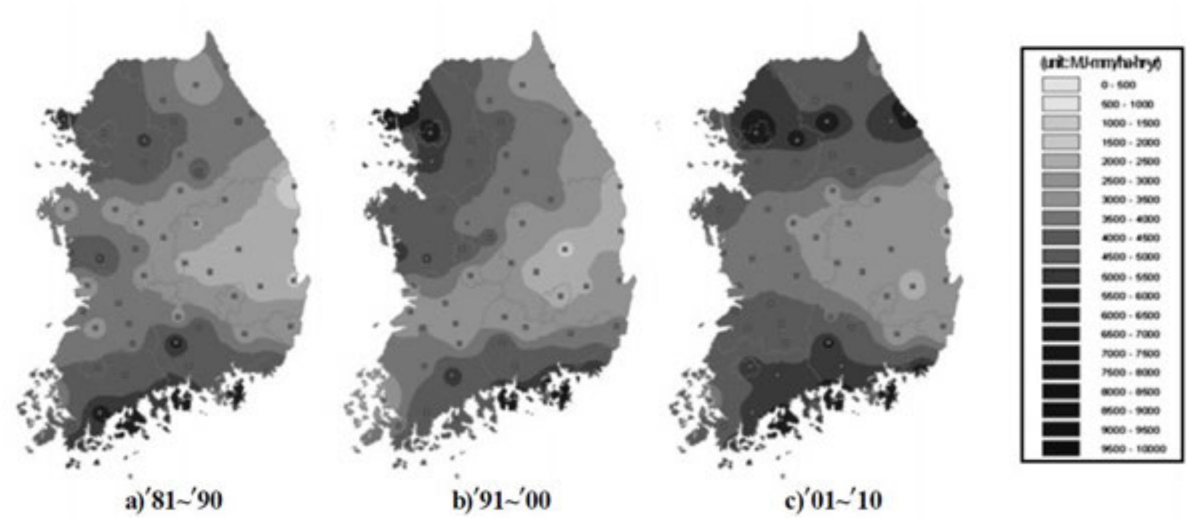

Figure 1: Changes in annual erosivity with decadal periods between 1981~2010

* The Figure was quoted from Park *et al.* (2011)

Discussion

Vulnerability of current conservation programs

Soil conservation programs in Korea were supported by several Acts including the Soil Environment Conservation Act, the Environmentally Friendly Agriculture Promotion Act, and the Agricultural Land Act. As soil is a natural body formed in a long-term scale, policy makers sometimes dealt with soils as an invariable or hardly variable factor. Climate change, however, possibly accelerates a certain pedogenic process and artificial activities may accelerate changes in soil characteristics (Lal. 2014). In Korea, water erosion could be the certain pedogenic process. With data presented in this study, rainfall erosivity increased by 9.6 % for 20 years, which means that soil erosion potential would have increased by the same portion without changes in other factors; considering the soil erosion potential of upland crop fields was approximately 40 MT ha^{-1} yr^{-1}, an expected increment of erosion potential was about 4 MT ha^{-1} yr^{-1}(Jung *et al.* 2004; Jung *et al.* 2005). It implies that the current conservation programs might not be sufficient to sustain soil productivity and the programs should be reinforced; a number of practical action programs have been developed continuously to facilitate practices of farmers in the fields though. In addition, political support was suggested to be supplemented for southern and north-western coastal regions based on our results; soil conservation programs mainly focused on the upper watersheds of four major rivers in eastern mountainous regions so far.

Revision of soil erosion potential assessment

Soil erosion potential in Korea has been assessed with USLE evaluating annual soil loss; R, K, and LS factors were determined with RUSLE guideline while C factor was applied as annual average (Jung *et al.*, 2004; Jung *et al.*, 2005; ME, 2015). The present study, however, indicated that seasonal and regional variation of erosivity became greater and proposed that cover management be weighted to allow seasonal variation with strengthening impacts of summer practices. Rural development administration in Korea, therefore, (i) established three monitoring sites to analyze cover management factors: a north-eastern site, a southern inland site, and a south coastal site in 2017 and (ii) would evaluate soil erosion reduction supported by soil conservation programs (RDA, 2016).

Conclusions

Rainfall erosivity had increased for last three decades over time, which requested that current soil conservation programs be reinforced reflecting increased soil erosion potential as well as seasonal variation. Practical action programs would be developed allowing for regional farming features. With data from monitoring sites, cover management factors would be established with a short period or season and the ordinance of Acts assessing soil erosion potential would be suggested to be revised.

Acknowledgement

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References

Jung, K.H., Kim, W.T., Hur, S.O., Ha, S.K., Jung, P.K. & Jung, Y.S. 2004, USLE/RUSLE factors for national scale soil loss estimation based on the digital detailed soil map. *Korean J. Soil Sci. Fert.*, 37(4): 199-206.

Jung, K.H., Hur, S.H., Ha, S.K., Hong, S.K. & Sonn, Y.K. 2005. Assessment of soil erosion potential in Korea. National Institute of Agricultural Science and Technology, Suwon, Korea.

Lal, R. 2014. Soil conservation and ecosystem services. *International Soil and Water Conservation Research*, 2(3): 36-47.

Ministry of Environment (ME). 2015. Notification on investigation of erosion status of topsoil. Ministry of Environment.

NIAST. 1992. General remarks of Korean soils. National Institute of Agricultural Science and Technology, Suwon, Korea.

NIMS. 2018. Korean 100-year climate change report 2018. National Institute of Meteorological Sciences.

Park, C.W., Sonn, Y.K., Hyun, B.K., Song, K.C., Chun, H.C., Moon, Y.H. & Yun, S.G. 2011. The redetermination of USLE rainfall erosion factor for estimation of soil loss at Korea. *Korean J. Soil Sci. Fert.,* 44(6): 977-982.

RDA. 2016. Notification on survey and assessment of impact/vulnerability in agricultural sector on climate change. Rural Development Administration.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. & Yoder, D.C. 1996, Predicting soil erosion by water: A guide to conservation planning with the revised Universal Soil Loss Equation (RUSLE). USDA.

Soil conservation knowledge governance in Mexico

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Abstract

Top-down and centralized soil conservation programs have translated into low adoption of soil conservation practices. The adoption of these practices is a multistage and adaptive process that relies on the management of local knowledge. The results of 61 surveys were analyzed in order to systematize experiences of soil knowledge governance involving social organizations and farmers. Soil knowledge governance was done mainly through the sharing of experiences among farmers. This path resulted both in the strengthening of existing institutions and in the creation of new associative forms and rules. The incentives for farmers to maintain soil conservation practices went beyond the financial ones and reflected the diversity of their views and expectations: eating healthy food, diversifying agricultural production and improving their social position in the community.

The increased adoption of soil conservation practices that resulted from this approach led us to think the need of polycentric governance systems based on public policies that should be flexible, bottom-up and adaptable to different environmental, social and institutional conditions, and that incorporate local knowledge.

Keywords: soil knowledge governance, sustainable land management, soil erosion public policy

Introduction

Soil erosion is a challenging issue not only because it causes yield loss and has environmental impacts, but also because it is closely linked to rural poverty (Ruben *et al.,* 2004).

During decades, the soil conservation governmental programs were characterized by the unilateral transfer of specific technologies to farmers, without incorporating their demands, culture, experiences and expectations (Manuel-Navarrete and Gallopin, 2012), and without considering site-specific biophysical conditions, the type of agriculture (irrigated or rain-fed) or livestock production (intensive or extensive), or land extension, thus, tended to have a simplistic view of rural issues. Such top-down, unilateral mechanisms seem to explain why the conservation initiatives undertaken have faced low rates of adoption of practices by farmers (Helin and Haigh, 2002; Ward *et al.,* 2018).

Incorporating the knowledge built over decades to centuries into conservation initiatives requires knowledge governance, understood as “a fluid and historical processes of co-evolution between agents, organizations and institutional arrangements, and the knowledge they help to create and reproduce” (Manuel-Navarrete and Gallopin, 2012).

In Mexico, soil erosion affects 60% of the land, and for 48.6% of the agricultural production units, loss of soil fertility was mentioned as the main obstacle to the development of farming activities (INEGI, 2012).

The problem of soil erosion in Mexico has been addressed through the creation of public programs promoting technology packages that have not been discussed or agreed with farmers, nor adapted to the large social, environmental and cultural differences of a megadiverse country (Turrent *et al.* 2014; Cotler *et al.*, 2016).

This study sought to systematize experiences of soil knowledge governance involving social organizations and farmers or ranchers, with the aim of incorporating soil conservation practices and promoting sustainable land management. Emphasis was placed on: (i) mechanisms for building knowledge governance; (ii) the implementation of sustainable land management according to local socio-environmental conditions and (iii) institutions promoting and adopting soil conservation practices. The results of this study lead us to rethink the kind of public policies that would better help soil conservation in Mexico.

Methodology

The study was conducted in three phases. The first one consisted in a compilation of case studies from social organizations working on farming issues at the national level. In the second phase, we selected the case studies with an ongoing dialog between NGOs and farmers and knowledge governance over 3 to 5 years; and the incorporation of soil conservation practices and implementation of sustainable land management. For these case studies a survey was conducted including both open- and closed-ended questions. The survey was conducted by various means: (i) through a website; (ii) by email; and (iii) on site, for farmers without internet access.

The following four main topics were addressed:

I. Selection of soil conservation practices as the result of a knowledge governance process involving social organizations and farmers;

II. The local context (social, institutional and ecological) surrounding the implementation of soil conservation practices;

III. New institutions promoting and adopting soil conservation practices; and

Results

A total of 61 survey responses were obtained from farmers, ranchers and technicians working for social organizations. The completed surveys covered 20 out of the 32 Mexican states. Of the 61 case studies, 36 related to agriculture and 25, to livestock production distributed along the country (Figure 1). The agricultural systems were mostly based on maize, which forms the basis of the Mexican diet and has deep cultural roots. These systems were small-scale, consisting of 1 to 3 ha that used mainly family labor (52 %); the production was for self-consumption with the sale of surplus (76 %). Also we interviewed farmers with more than 20 ha which production is sold in both regional and international markets.

Forty-five percent of the soil conservation practices were designed specifically for each site's environmental and social conditions by social organizations and farmers; 24 % of these practices were already known by the farmers; 17 % were promoted through subsidies from a government program; and the remaining 14 %, unknown by the farmers at first, were introduced by the social organizations following a socialization and acceptance process.

The new soil conservation practices were incorporated gradually and led to radical changes in the whole production systems. Thus, the dialog and consensus built from knowledge governance allowed not only isolated practices to be incorporated, but conventional systems to be converted into sustainably managed ones.

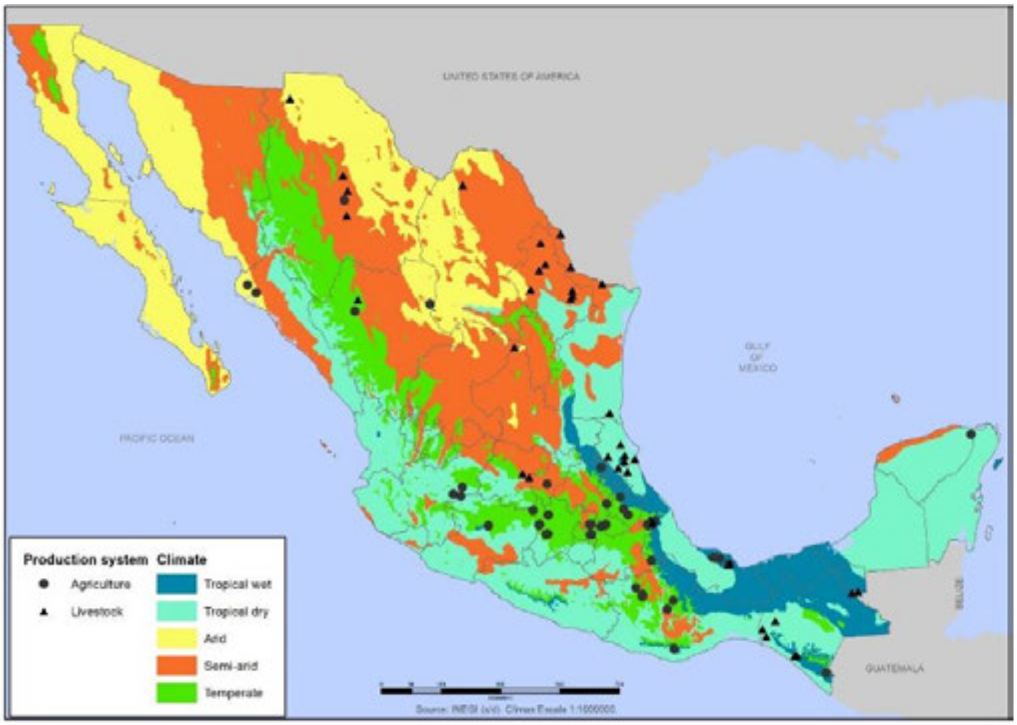

Figure 1: Sites covered by the survey of soil conservation practices and associated production systems and climates in Mexico

In over 90 % of the cases, social organization played an important role in reducing costs, sharing knowledge, expanding networks and contacts, and communicating risks.

Regarding the agricultural systems, respondents mentioned that the creation of groups of neighbors, producer associations and local committees proved to be useful, as they allowed inputs like compost, *bocashi* (compost activator) and organic pesticides to be produced jointly.

The incentives for farmers to maintain soil conservation practices were very diverse. Among the main ones, the following were mentioned: (i) eating healthy food (grown without agrochemicals), particularly in the case of agriculture for self-consumption; (ii) diversifying crops, in order to have products to sell all year round; (iii) reducing soil erosion, which threatened the integrity of their property; and (iv) improving their social position in the community by being seen as innovative people, with the possibility of teaching and seeing their family united around a new project (thus reducing the migration of young people).

Most of the time, soil conservation activities are not incorporated into traditional production systems and, as such, may represent extra work. The respondents to the survey identified different barriers to carrying them out (Figure 2).

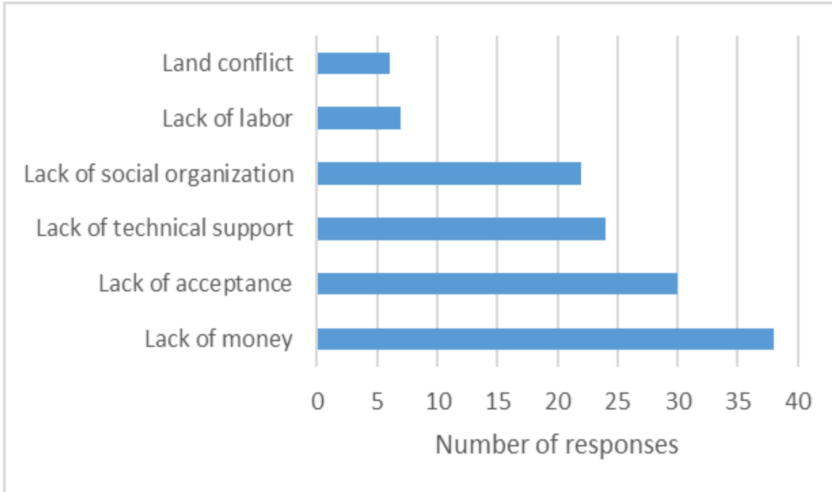

Figure 2: Main barriers to implementing soil conservation practices in agricultural and agroforestry systems as identified according to the survey

Discussion

This study shows that an important step towards adopting soil conservation practices was having them designed by several social organizations and farmers through soil knowledge governance, considering the environmental, social, institutional and economic conditions specific to each site. Thus, there seems to be a departure from the current paradigm of government programs for soil conservation, which are often managed by a centralized administration in a top-down manner, without taking environmental and social differences into account.

The literature on soil conservation has tended to emphasize the importance of financial incentives in adopting practices (Lapar and Pandey 1999). Although such incentives are, indeed, important in a poor rural context, they do not meet the diversity of views, concerns and values of this population. This study shows that in the case of agriculture for self-consumption, important incentives also include improving the ecological diversification, playing a leading role in the community, and improving the quality of their food. This contrasts with large regional and international producers, for which "money is the best incentive".

In Mexico, as in other Latin American countries, decades of intense rural–urban migration have caused the abandonment of agricultural activities, the breakdown of local knowledge, and a weakening of social organization. Incorporating young people into a process of soil knowledge governance may thus provide them with a means of valorizing their biological and cultural heritage (Maffi 2001).

In the production systems analyzed, soil knowledge governance focused mainly on the joint implementation of practices and alternative land management, based on the farmers' knowledge and expectations. The methods for assessing the practices and the system, however, are to be strengthened. The monitoring of works and evaluation of acceptability would transform soil conservation into a learning process that would gradually increase the confidence of the farmers in its efficiency.

Conclusions

Up to now, Mexican government programs for soil conservation have been implemented in a top-down manner. Specific technologies have been unilaterally transferred to farmers without incorporating their demands, experiences and expectations, and without adapting the practices to the different environmental, social and institutional conditions. This has led to a very low adoption rate of soil conservation practices.

In recent years, a consensus has emerged that the identification and implementation of soil conservation practices jointly with farmers is key to redesigning new agroecosystems that are both resilient and sustainable (Stringer *et al.* 2014; Altieri *et al.* 2015).

In the cases analyzed here, the polycentric governance of soil knowledge allowed agroecological alternatives to be developed jointly with NGOs, academic, government organizations, and farmers.

Despite several years of working together in a framework of soil knowledge governance, the agroecosystems analyzed remain fragile and vulnerable, notably to changes in the political and economic priorities of the government and NGOs. For this reason, polycentric governance systems should be based on public policies that are flexible, bottom-up and adaptable to different environmental, social and institutional conditions, and that incorporate local knowledge. What is required for the upcoming soil conservation programs is both vertical scale-up (institutionalization) and horizontal scale-up (expansion of the practices), with multi-level decision-making and a long-term, flexible funding that will allow a learning process to take place.

References

Altieri M.A., Nicholls, C., Henao, A. & Lana, A.M. 2015. Agroecology and the design of climate change-resilient farming systems. *Agron.Sustain.Dev*., 35: 869-890.

Carlisle, L. 2016. Factors influencing farmer adoption of soil health practices in the United States: a narrative review. *Agroecology and Sustainable Food Systems,* 40(6): 583-613.

Cotler, H., Martinez, M. & Etchevers, J. 2016. The conservation of organic carbon in agricultural soils of Mexico. Contributions of the research and its relation with public policies [in Spanish]. *Terra Internacional,* 43(1): 125-138.

Helin, J. & Haigh, M.H. 2002. Better land husbandry in Honduras: towards the new paradigm in conserving soil, water and productivity. *Land Degradation & Development,* 13, 233–250.

INEGI. 2012. Encuesta Nacional Agropecuaria [In Spanish], Mexico. Available at : http://www.inegi.org.mx/est/contenidos/proyectos/encuestas/agropecuarias/ena/ena2012/.

Lapar, A.M.L. & Pandey, S. 1999. Adoption of soil conservation: the case of the Philippine uplands. *Agricultural Economics,* 21: 241–256.

Maffi, L. 2001. *On biocultural diversity: linking language, knowledge and the environment*. Smithsonian Institution Press, Washington.

Manuel-Navarrete, D. & Gallopın, C.G. 2012. Feeding the world sustainably: knowledge governance and sustainable agriculture in the Argentine Pampas. *Environ Dev Sustain,* 14: 321–333.

Ruben, R., Pender, J. & Kuyvenhoven, A. 2004. Editorial: Development strategies for less-favoured areas. *Food Policy,* 29: 295-302.

Stringer, C.L., Fleskens, L., Reed, S.M., de Vente, J. & Zengin, M. 2014. Participatory Evaluation of Monitoring and Modeling of Sustainable Land Management Technologies in Areas Prone to Land Degradation. *Environmental Management,* 54: 1022–1042.

Turrent, A., Espinosa, A., Cortes, J.I., Mejia, H. 2014. Strategy analysis MasAgro –maiz [in spanish]. *Revista Mexicana de Ciencias Agrícolas* 5(8): 1531-1547.

Ward, S.P., Bell, A.R., Droppelmann, K. & Benton, G.T. 2018. Early adoption of conservation agriculture practices: understanding partial compliance in programs with multiple adoption decisions. *Land Use Policy,* 70: 27-37.

Using the SedNetNZ model as a policy planning tool in the Hawke's Bay region of New Zealand

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Abstract

Erosion and sediment in rivers is a major issue in many regions across New Zealand but particularly in the Hawke's Bay region due to extensive hill country clearance, soft rock geology and active tectonic processes. Hawke's Bay Regional Council (HBRC) is tackling the erosion/sediment issue through a series of policy and plan changes across the region. These policy changes are being informed by the SedNetNZ model with regard to erosion and sediment production. An example of where and how the SedNetNZ model was used in conjunction with policy decision making is described here. How it was used to provide estimates of spatial variation in sediment load (t a^{-1}) and yield (t km^{-2} a^{-1}) across an area referred to as the TANK catchments is discussed. The model also provided data on riverbank erosion, types of erosion taking place on flat land and hill country and each erosion type's contribution. The TANK stakeholder group was largely made up of non-scientists but this example of presenting scientific data in a simple way shows the importance of communication in science and also the benefits of providing easily accessible science to decision makers that may not have a science background.

Keywords: SedNetNZ, Sediment, Hawke's Bay, Erosion, HBRC

Introduction, scope and main objectives

Hawkes Bay is a region of New Zealand located on the east coast of the North Island. It covers an area of 1.4 million hectares (14 000 km^2) and has a population of approximately 150 000 people. The region's economy is largely based on horticulture (apples, stone fruit and vegetables), wine (vineyards and wineries) and tourism. A great deal of the hill country has been cleared for sheep (and beef) farming while the steeper country is used for production forestry or has been reserved as conservation areas.

Erosion and sediment in rivers is a major issue in many regions across New Zealand but particularly in the Hawke's Bay region due to extensive hill country clearance, soft rock geology and active tectonic processes. The region is also prone to heavy seasonal rain events that exacerbate the erosion processes. Hawke's Bay Regional Council (HBRC) is currently tackling the erosion/sediment issue through a series of policy and plan changes across the region. These changes are informed by the SedNetNZ model. This paper will look at one such area in Hawke's Bay where Hawke's Bay Regional Council (HBRC) is tackling the sediment problem and how the SedNetNZ model was used as a support tool. The area is made up of four catchments called Tutaekuri, Ahuriri, Ngaruroro and Karamu (referred to collectively as the TANK catchment). The TANK catchment is a 350 000 ha area situated in the central part of the region. The SedNetNZ modelling was used as a basis for identifying high risk areas of erosion and sediment production.

Methodology

SedNetNZ is based on the original Australian SedNet model (Wilkinson *et al.* 2004), modified to account for erosion processes that occur in the New Zealand environment (Dymond *et al.* 2016). SedNetNZ is a spatially distributed, time-averaged (decadal) model that routes sediment through the river network, based on a physical representation of hillslope and channel processes at the stream link scale and takes into account deposition on floodplains, lakes and in river channels.

The basic element in this model is the stream link, typically several hundred meters in length. Each link has an internal catchment area (subcatchment) that drains runoff and delivers sediment to that link. The river Environment Classification 2 (REC2) (NIWA 2015) data are used to define the stream link-subcatchment network.

The main outputs from the model are predictions of mean annual suspended sediment yields (t km^{-2} a^{-1}) and loads (t a^{-1}) in each stream link throughout the river network. Because source erosion is spatially linked to sediment loads, it is also possible to examine the proportionate contribution that any area of land makes to downstream export of sediment. By adjusting input data and model parameters it is possible to simulate river loads for natural (pre-human) conditions and examine the consequences of future land-use scenarios or erosion mitigations.

SedNetNZ has a number of key components:

(1) Definition of river and stream link network (REC-2)

(2) a hydrological submodel

(3) Erosion process models to calculate sediment yields and loads

(4) Data compilation for catchment and river link network, and

(5) Application of mitigation scenarios.

The SedNetNZ model was used to provide estimates of spatial variation in sediment load (t a-1) and yield (t km-2 a-1) across the TANK catchments. The model could also provide data on riverbank erosion, types of erosion taking place on flat land and hill country and each erosion type’s contribution. Different scenarios could also be modelled.

Outputs and scenarios

Output from SedNetNZ was intersected with farm boundaries from AgriBase (Assure Quality 2011), a farm spatial database, to estimate the potential sediment reduction through adoption of soil conservation farm plans, assuming a 70 % reduction in sediment where farm plans were fully implemented. This methodology was used to calculate the potential reduction in sediment generation by focusing on farms that have the largest areas of highly erodible land as identified by SedNetNZ.

The SedNetNZ model was further used to calculate stream and river bank erosion from bank height, mean annual flood, and bank migration rate. Bank erosion was summed across stream links (small hydrologically connected subcatchments) to provide overall stream bank erosion. The potential reduction in bank erosion from stock exclusion and fencing in the riparian area was also calculated assuming a reduction in stream bank erosion of 80 percent where fencing or stock exclusion was present. HBRC provided information on the current status of fencing and potential stock exclusion from stream and river riparian margins across the

TANK catchments. An analysis was undertaken to estimate stream bank erosion with current fencing and where an additional 25 %, 50 %, and 100 % of streams were assumed to be fenced on both sides of the river or stream.

Pre human versus current state was also modelled using SedNetNZ. This gave the stakeholder group an idea of the anthropogenic influence within the catchment.

The information provided by SedNetNZ was the basis for discussion through a collaborative approach with stakeholders in the TANK catchment regarding sediment and erosion in the area. The stakeholder group was made up of representatives from many parts of the community such as local industry, local Iwi (Ngāti Kahungunu), Department of Conservation, Dairy sector, commercial forestry, fruit growers, winegrowers and other farming groups, Fish and Game, Forest and Bird and local government (regional and district councils).

Results

SedNetNZ is capable of presenting several different aspects of erosion and each aspect proved to be helpful to the TANK stakeholder group. The TANK group was presented spatial information regarding yield and load of erosion/sediment. For the TANK catchment SedNetNZ predicts that the highest sediment yields of over 1000 t km^{-2} a^{-1} generally occur along the river margins and to the north east of the catchment (Figure 1).

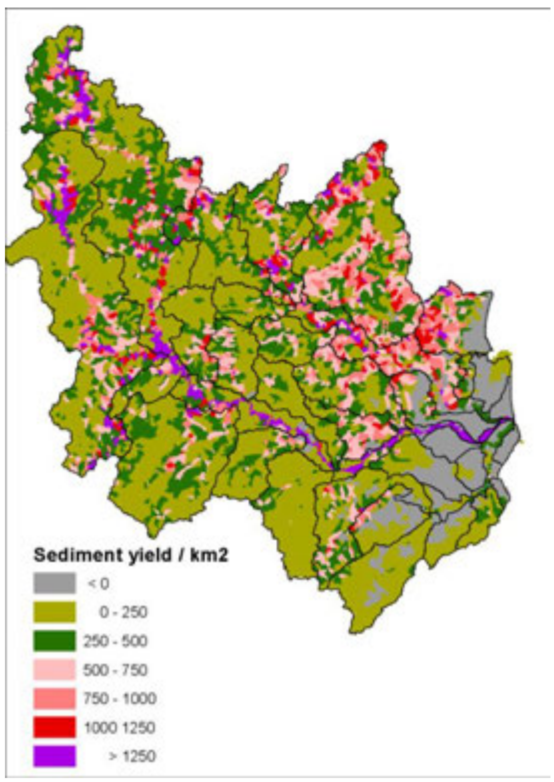

Figure 1: The TANK catchment sediment yields as predicted by SedNetNZ

Also information regarding different riparian protection scenarios was provided to the group ranging from current status where the model predicts losses of 222.425 t a^{-1} to 50.916 t a^{-1} with 100 % protection. Of course 100 % riparian protection is impossible to achieve but given here only as an example. Other scenarios with different percentage amounts of protection can be calculated. It was also interesting to compare pre-human predictions of erosion versus current erosion values. The model predicted that before human occupation the TANK catchment's sediment load would have been approximately 26 % of the current sediment load.

The model also allowed us to identify with Stakeholder members what areas may be priority sub-catchments within The TANK catchment where erosion mitigation work could be targeted first and have the biggest and earliest impact on catchment sediment reduction (see Figure 2).

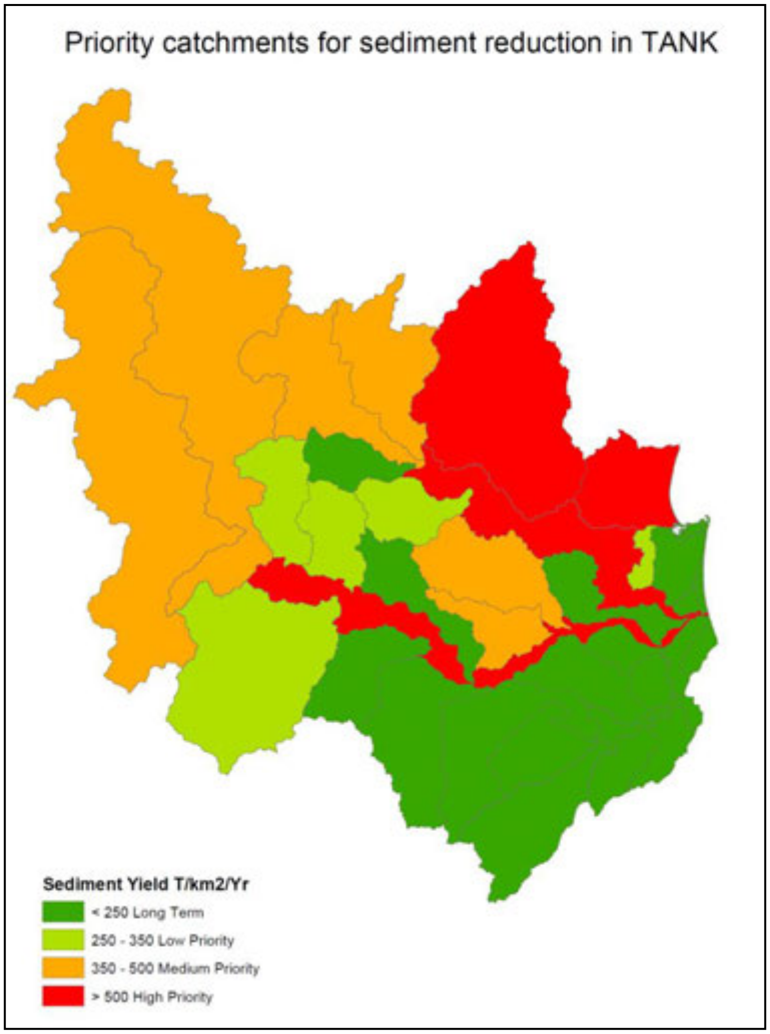

Figure 2: Priority sub-catchments as predicted by SedNetNZ

Discussion

The collaborative approach towards policy change is complex but can be greatly assisted by having as much detailed available information as possible around all aspects of the policy to be introduced. The more information that the stakeholders have the more informed they will be which in turn would hopefully lead to a better outcome for all parties. More information such as that supplied by the SedNetNZ model also makes the stakeholders more comfortable and confident that any decisions they make will be the correct ones which can speed the whole process up. SedNetNZ is proving to be an essential tool in developing freshwater management plans especially in relation to the improvement of fresh and coastal water bodies being adversely affected by sediment.

Conclusions

The use of the SedNetNZ model provided information at a large scale that could not be provided in any other way at a cost and in time period that would be useful for the plan change process. The information gave the stakeholders the confidence to make decisions and to get an idea what effect their actions may have on mitigating erosion and sediment in the TANK catchment. The TANK stakeholder group was largely made up of non-scientists but this example of using SedNetNZ to present scientific data in a simple way shows the importance of modelling but even more so the importance of how that modelling is communicated.

References

AgriBase. 2011. AsureQuality New Zealand Ltd. http://www.asurequality.com/

Dymond, J.R., Herzig, A., Basher, L., Betts, H.D., Marden, M., Phillips, C., Ausseil, A-G., Clark, M. & Roygard, J. 2016. Development of a New Zealand SedNet model for assessment of catchment-wide soil-conservation works. *Geomorphology*, 257: 85–93.

NIWA. 2016. River environment classification. Available at : https://www.niwa.co.nz/freshwater-and-estuaries/management-tools/river-environment-classification-0

Wilkinson, S., Henderson, A., Chen, Y. & Sherman, B. 2004. SedNet user guide: Client Report. Canberra, CSIRO Land and Water. 96 p. Available at: www.toolkit.net.au/sednet.

Reversing soil erosion trends at the river basin scale: A participatory model of intervention for building resilience in developing countries

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Abstract

An action-research project is under way to create and make available a model of intervention for reversing soil erosion trends at the river basin scale. This scale is significant for policymaking and for the practical achievement of multiple UN SDGs. The project is interdisciplinary, involving social and natural sciences; is led by Chilean and UK researchers, and includes partners from Argentina, Brazil and Mexico. Project activities centre on advanced soil analysis techniques combined with a participatory approach to define action for change in Chile's Rapel river basin. The soil analysis elements are not discussed in detail here.

Participatory Innovation Praxis is an action-orientated approach for activating complex social transformations, rooted in complex thinking and associated theories. Activities include pilot-testing with public and private sector, research and civil society participants; validating results at the supra-national scale; and launching the model at the global scale. The project's outcomes will make it possible to establish long-term, transformative processes to build resilience in river basin communities by implementing locally-designed innovations, supporting community-led governance processes and generating 'cultures of innovation'.

Keywords: Soil erosion, soil degradation, policy making, innovation, participation, culture, resilience, radioisotope techniques

Introduction, scope and main objectives

Every year circa 10 000 000 hectares of cropland around the world are lost through soil erosion (Pimentel, 2006). This loss undermines food production, water quality, energy supply and threatens ecosystem stability and services, including climate regulation and biodiversity.

The objective at the heart of this project is to enable practical, effective and transformative action for reversing this trend, from the local to the global scale, by developing and testing a model of intervention at the river basin scale. The project hypothesis is that latent potential exists for soil erosion reversal, derived from two synergistic components. These components are: (1) Upstream; new, sustainable agricultural and forestry paradigms that are mature, available worldwide, and could reverse soil erosion trends if widely applied; and (2) downstream; reversing soil erosion trends could significantly enhance infrastructure life cycles and reduce sedimentation impacts on irrigation, water supply, hydropower, fisheries, aquaculture, and tourism. A basin-wide, systemic innovation effort can realise this potential, with significant benefits to all actors.

This two-year project successfully secured funding from a UK-Chile Newton Fund call focussing on the food-water-energy-environment nexus, to which 120 research groups applied and which just three were funded. The initiative emerged from a partnership between the University of Plymouth (UK); Universidad Austral (Chile) and Foundation for Participatory Innovation (Chile), and includes a capacity building element with researchers from Argentina, Brazil and Mexico. The work focusses on the Rapel Basin in Chile as a case study, and includes assessment of soil erosion rates using advanced radioisotope techniques combined with a basin-wide pilot, testing the participatory model of intervention (Participatory Innovation Praxis (PIP)). The outcomes from the first stages of the PIP approach (discussed below) will be evaluated at a Latin American seminar, with support from FAO, and the project will culminate in a global conference in the UK, which will seek support for the promotion, adoption and application of the model in multiple contexts around the world.

This project's ultimate objective is to build resilience to soil erosion in river basin communities across the world. Community resilience can be supported (or, where necessary, rebuilt) by recognising and sustainably engaging local resources to enable actors to thrive in an environment characterized by change, uncertainty, unpredictability and surprise (Kelly *et al.,* 2015). Members of resilient communities intentionally develop personal and collective capacity in order to create new pathways towards better community futures (Magis, 2010).

Methodological approach

This project draws on resilience theories to apply Participatory Innovation Praxis (an action-oriented approach for addressing 'high-complexity' problems) to address soil erosion in a river basin context (Del Valle, 1999; Del Valle and Benavides, 2016; Kelly *et al.*, 2015). High complexity problems are real-world problems that typically involve many actors across socio-economic, environmental and institutional domains; competing interpretations and conflicts; are multi-disciplinary; and often encompass hard-to-reach actors. These are 'real world' problems with many examples from across civil society, including education, resource management and development. The PI Praxis approach draws on systems thinking, complex thinking and other contemporary theories to derive a suite of principles, concepts, methods and techniques. PI Praxis pays particular attention to local cultural contexts, and has been applied in multiple settings over four decades.

Some key aspects of the PI Praxis are: (a) It does not simplify reality but works with its complexity, which is considered wealth rather than obstacle. (b) It looks for the unique 'potential' that is hidden within high-complexity problems, rather than for multiple 'causes'. (c) It addresses high-complexity problems by activating long-term processes of social transformation, with clear strategies, effective governance and multiple innovations. (d) Such processes lead to a transformation of existing 'cultures of adaptation' into new 'cultures of innovation'. (e) It makes social complexity understandable and manageable by means of simple and powerful language-based tools. (f) Such tools use 'strong participation', i.e., effective co-construction of meanings and actions by the actors themselves; (g) Its methods and tools are efficient, and yield tangible results in very short time-frames; and (h) The process must be led a PIP-trained 'animator'.

The PIP process involves two phases and several steps, as shown in Figure 1, below. The Identity and Strategy Phase takes approximately one year and requires external animation; its output is an action strategy with multiple specific innovations and clear priorities; it also yields intangible outputs, such as trust and motivation. The Co-construction Phase may take many years and works with trained internal animators; its tangible outputs are an innovations management system and a continuous flow of innovations; its outputs will eventually lead to the establishment of a ‘culture of innovation’. The project reported here is a pilot and will complete the Identity and Strategy Phase in the Rapel Basin.

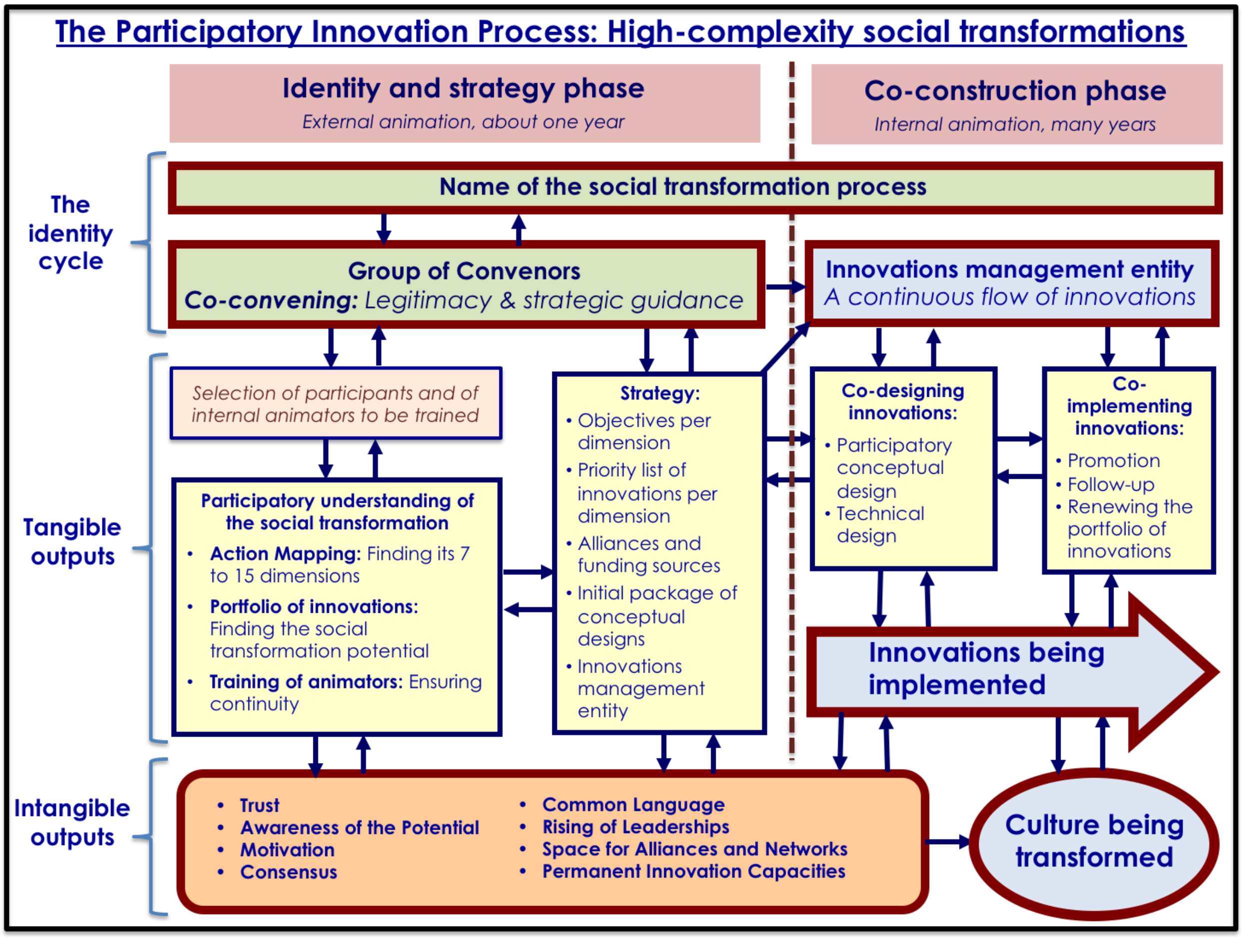

Figure 1: The participatory Innovation Process (Adapted from Del Valle and Benavides, 2016)

Outcomes to date: The Identity and Strategy Phase

The Identity and Strategy phase begins by establishing a Group of Convenors (GoC), formed of key actors, to provide legitimacy and strategic guidance. The GoC subsequently identifies further participants, prioritises innovations and oversees the final strategy. The key tool used in this phase is the Action Map, which makes the transformation possible by creating a shared understanding between actors of the soil erosion problem, and by providing a clear pathway for action. The GoC was established in October 2018, completed the first step in identifying key actor groups, and in December 2018, the Action Map was prepared. The process is elucidated below.

The Group of Convenors

Establishing this Group was a delicate task that involved identifying key actors, consulting knowledgeable informants, visiting prospective members and sending formal invitations. All those who were invited, agreed to participate. The 14-member Group of Convenors includes:

- Five government agencies, including the Ministries of Agriculture and Environment
- Three farmers’ associations (two representing large farms and one cooperative of small farmers)

- Two research institutions (regional university and national agricultural research institute)
- One UN agency (FAO)
- One multinational power company (ENEL, owner of two hydropower stations in the basin)
- Two international research networks dealing with soil erosion and with agro-ecology

The Action Map

The creation of the Action Map (Figure 2, below) was a consensus-building activity with 25 key actors selected by the Group of Convenors. Also included were our project partners (partner capacity building and training) from Argentina, Brazil and Mexico. The Map provides structure to the social transformation through its 'lines of action', which are 'general' (A - G) and 'specific' (A-1, A-2 - G-5 etc.). Each line of action is an actual or potential domain, where specific actors undertake actions with clear objectives. Key to note here is that the general lines of action correspond to the social dimensions of the problem; they 'emerged' from interaction between participants and were not pre-defined or imposed beforehand. The specific lines provide rich and cross-cutting content for envisaged transformations.

Action Map: **System for Reversing Soil Erosion in the Rapel River Basin**

Key: Upper case = Established line of action (with responsible actors, permanent activities and, impact). Lower case = Non-established line of action.

A. Integrated river basin management

- A-1 Permanent strategic governance mechanism for the basin, with public, private, citizen and academic participants
- A-2 Linkage of the erosion reversal process with the debates about regional development
- A-3 Characterisation and dimensioning the basin's ecosystem services with reference to soil
- A-4 Identification and measurement of impacts of soil erosion upon other activities
- A-5 Integrated platform with public access for measuring, monitoring and evaluating soil and water quality
- A-6 Development of policy instruments for territorial management in rural areas
- A-7 Zoning for reforestation and recovery of biodiversity
- A-8 Regional risk map for building and operating infrastructure associated to climate change
- A-9 Development of strategies for resilience and protection against vulnerabilities
- A-10 Mitigation strategy vis-à-vis extreme events or natural disasters
- A-11 Monitoring the impacts of infrastructure built in riverbeds upon the erosion of riverbanks
- A-12 Integrated management of the disposal of mining waste

B. Incentives and promotion of sustainable soil management

- B-1 Creation of public-private-citizen-academic mechanism for promoting the reversion of soil erosion
- B-2 Plan for reforestation and recovery of biodiversity
- B-3 Promotion of the recovery of vegetal covers
- B-4 Mechanisms for incentive, promotion and protection of agroecological production
- B-5 Mechanisms for incentive, promotion and protection of organic production
- B-6 Regional seal for sustainable soil use in agricultural and forestry production
- B-7 Incentive system for management of drinking water supplying micro-watersheds
- B-8 ORIENTATION TO SUSTAINABILITY OF ENTREPRENEURSHIP INCENTIVES FOR THE RURAL YOUNG
- B-9 Generation of minimal standards for business ventures that impact upon soil
- B-10 Incentives to the use of sustainable techniques for crops on slopes
- B-11 Widening the spectrum of practices considered in SIRSD-S
- B-12 Revision of the access requirements of SIRSD-S in order to expand its coverage

C. Cultural transformation towards understanding soil as an ecosystem

- C-1 Restatement of the soil-water link in Chilean culture and norms
- C-2 Promotion and dissemination of the concept of river basin as a unit of action
- C-3 Communicational strategy about the importance of soil
- C-4 Programme to generate ecological management competences for farmers, and for professionals and technicians in agriculture and forestry
- C-5 Awareness raising for citizens, government and business
- C-6 Formal and informal education at all levels
- C-7 Updating of curricula and graduation profiles in related programmes
- C-8 Education plans in rural schools that consider local and regional sustainability
- C-9 Awareness raising for tourists, sports people and others about responsible use of the territory

D. Dissemination of agronomic practices that activate soil's life

- D-1 Systems of transition from monocultures to policultures
- D-2 Agronomic practices that regererate soil's life in highly eroded zones
- D-3 Keeping vegetal covers in zones of slope
- D-4 Use of machinery and equipment that do not damage the soil
- D-5 Use of irrigation techniques that avoid soil losses
- D-6 Building of infiltration ditches, stockades, terraces and other containment works
- D-7 Rescue and revaluation of ancestral and peasant knowledge and practices about ecological use and management of the territory

E. Mechanisms for technological innovation, development and demonstration

- E-1 Development of new parameters for classification of soil use capacity that consider sustainability factors
- E-2 Alternatives to agricultural burning
- E-3 Alternatives to the use of synthetic fertilisers
- E-4 Alternatives to conventional management of plagues and diseases
- E-5 Promotion of landscape redesign (keyline)
- E-6 Integration of animals into soil recovery (holistic management)

F. Promotion of a law of general bases for soil conservation and use in Chile

- F-1 Norm that defines degradation, erosion, fertility, health, functionality, use capacity, soil quality, etc.
- F-2 Definition of norms about parameters and indicators for measuring soil erosion
- F-3 Consideration of citizen participation as binding in Environmental Impact Assessments
- F-4 Limitation of the conversion of forest to agricultural soil for sustainability considerations
- F-5 Mechanisms of compensation to society due to loss of rural soil to urban expansion, its equipment and other uses
- F-6 Specifications for soil protection and use in the norms for rural property subdivision (DL 3516)
- F-7 REGULATION OF THE USE OF AGROCHEMICALS IN RURAL AND URBAN AREAS
- F-8 REGULATION OF THE USE OF HARMFUL CHEMICAL SUBSTANCES IN AGRICULTURL AND FORESTRY MANAGEMENT
- F-9 Restriction of soil degrading practices
- F-10 Regulation of crops in steep slopes
- F-11 Prohibition of agricultural burns
- F-12 Regulation and enforcement of the extraction of ground leaves
- F-13 Regulation and enforcement of river bank ecosystems
- F-14 Regulation and enforcement of excavations in watershed slopes for infrastructure, tourism and other activities

G. Sufficient and effective enforcement of norms for soil conservation and use in Chile

- G-1 Norm enforcement of minimal ecological water flows
- G-2 Norm enforcement of extraction and recharge of underground water
- G-3 Norm enforcement of the exploitation of aggregates in rivers and quarries
- G-4 Norm enforcement in the use of agrochemicals in urban and rural areas
- G-5 Norm enforcement in the use of harmful chemical substances in agricultural and forestry management

Figure 2: Action Map for reversing soil erosion in the Rapel Basin

Discussion and Conclusions

The outcomes to date have provided evidence of the viability and applicability of the project's design, objectives and methods. The elements above will continue to be integrated with the detailed natural science data, once they are available. The following aspects are relevant:

River basin scale

The scale of this model of intervention makes it a practical instrument that brings together specific actors from multiple spatial levels and sectors, including farmers; energy and water companies; government actors; and many others whose day to day actions and complex interactions give rise to soil erosion and/or its impacts. Scale is key to this process; the farm scale does not encompass the full complexity of the challenge and the regional and national scales are too distant to resolve the detail of daily actions, or be truly transformative. Action at national and supra-national scales, however, is essential to provide the necessary momentum alongside financial support, and to ensure that the experiences gained are disseminated effectively through learning and exchange networks (Pimentel, 2006).

Erosion reversal 'potential'

By accepting the invitation to become members of the Group of Convenors, key actors in the Rapel Basin (government, farmers, businesses, researchers, civil society) have shown that there is clear potential and a desire to address the complex issue of soil erosion in this river basin. The project's novel approach will enable the actors in the Rapel basin to: (a) Jointly understand their basin's potential; (b) create a shared vision for a sustainable future based on that potential; and (c) take tangible steps to build that future by implementing multiple social and technological innovations to realise that potential.

A structure for action

The Action Map for reversing soil erosion in the Rapel basin has brought order to the complexity of this socio-ecological challenge. Seven dimensions and 65 specific lines of action have been identified, that are rich in narrative content. To reverse erosion trends, the basin's actors have identified the need to undertake a system-wide process of innovation. The Action Map provides the structure and content to enable them to identify, design and implement innovations through strong participation.

Building resilience to soil erosion across the world

The Rapel Basin community has started on a new trajectory for its future by collectively identifying and beginning to tackle complex soil erosion challenges. Once validated, this model of intervention could be applied in many other contexts to support resilient and sustainable development.

Acknowledgements

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References

Del Valle, A. 1999. Managing complexity through methodical participation: The case of air quality in Santiago de Chile. *Systemic Practice and Action Research*, 12(4): 367-380.

Del Valle, A. & Benavides, D. (eds). 2016. *Transición a la agricultura sustentable: Redes de innovación multi-actor en Chile.* Valparaíso: Ediciones Univeritarias de Valparaíso, 279 pp.

Kelly, C., Ferrara, A., Wilson, G. A., Ripullone, F., Nolè, A., Harmer, N. & Salvati, L. 2015. Community resilience and land degradation in forest and shrubland socio-ecological systems: Evidence from Gorgoglione, Basilicata, Italy. *Land Use Policy*, 46: 11-20.

Magis, K. 2010. Community resilience: an indicator of social sustainability. *Society and Natural. Resour*ces, 23: 401–416.

Pimentel, D. 2006. Soil erosion: A food and environmental threat. *Environment, Development and Sustainability,* 8: 119-137.

15 years of experience with the use of detailed erosion maps in soil erosion policy in Flanders, Belgium

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Abstract

For over 15 years territory covering potential soil erosion risk maps, detailed at the field parcel level, were at the core of erosion policy in Flanders. Intensive use of the maps in policy preparation, implementation and evaluation, resulted in improved maps and a soil erosion risk indicator. Examples of the different uses of the map are given. Obligatory erosion control measures, as part of the Good Agricultural and Ecological Conditions of the Common Agricultural Policy (CAP) of the EU, are linked to the potential erosion risk class of individual fields according to the erosion map. In addition, voluntary erosion control measures are reimbursed on erosion sensitive arable land, as part of the agri-environmental measures of the CAP. The soil erosion risk indicator proved sensitive enough to show the impact of policy and external factors on actual erosion risk. A recent tightening of the obligatory measures under CAP resulted in halving the agricultural area in the over 20 ton.ha^{-1}.year^{-1} actual erosion risk class. Further analysis of the attributes of fields in the different indicator classes highlights potential policy improvements.

Keywords: soil erosion, water erosion, policy, map, indicator

Introduction

Over the last 15 years the erosion policy in Flanders has been oriented towards both local authorities and farmers. Local authorities can tackle the more complex problems involving muddy floods towards infrastructure and residential areas and sediment transport to watercourses. Subsidies to draw up municipal soil erosion action plans and to carry out small scale erosion combating works can be received from the government of Flanders since 2002. To encourage farmers to take source-oriented measures protecting the soil at field level, financial instruments in the form of both reimbursements and conditions for income support in the framework of the Common Agricultural Policy (CAP) of the EU have been in place since 2005. Awareness raising and technical support complete the approach.

In 2000 a very important tool to back both policy decisions and awareness raising became available, i.e. a modelled, territory covering soil erosion map of Flanders at field parcel level (erosion map) based on a 20 m grid. In 2006, an improved map at higher resolution (5 m) was introduced. This map was in use until the third fully revised version became available in 2018. The erosion map provided the basic information layer for the ex-ante evaluation of a policy adjustment in 2015 and for the development of a soil erosion risk indicator.

15 years of experience in using and consequently improving the erosion map, will be reviewed with main emphasis on its use in the framework of the obligations due to the Good Agricultural and Ecological Conditions (GAEC) for income support of the CAP.

Methodology

Erosion map

In 2000, Van Rompaey *et al.* (2000) published the first erosion map of Flanders. It represented a mean soil erosion risk at the level of individual parcels, calculated with the RUSLE-based (Renard *et al.* 1997), spatially distributed model WaTEM, (Van Oost *et al.*, 2000). This model used a digital elevation model (DEM) with a grid cell resolution of 20 m, interpolated from maps with regionally varying accuracy and a 2D procedure to calculate the topographical factor (Desmet and Govers, 1996).

The second version, launched in 2006, used a newly available DEM with a much higher accuracy and a resolution of 5 m. A constant value of 0.37 was used for the crop management factor of fields in agricultural use, resulting in a potential soil erosion risk map. All parcels are classified in 6 risk classes ranging from 'very high' to 'negligible'. This second version is fully documented in Notebaert *et al.* (2006). As parcels change, the map was recalculated yearly, and minor improvements were implemented (see meta-data).

The availability of a more accurate DEM triggered a major revision, first implemented for the 2018 map. Procedures for filtering and pit-filling were finetuned, different information layers were updated, and the code was rewritten in SAGA GIS resulting in the third version of the erosion map (Oorts *et al.*, 2019).

Ex-ante analysis

In 2015 the second version of the erosion map was an important tool in an ex-ante analysis to underpin a policy adjustment to the GAEC-CAP (Swerts and Vandekerckhove, 2015). The impact on soil erosion of 4 different sets of measures, differing in stringency as well as in types of measures and in risk classes involved, was calculated. Worst-case and best-case scenarios were defined for each set to cope with the flexibility given to farmers to choose which measures to take on their fields.

Soil erosion risk indicator

Based on the third version of the erosion map a soil erosion risk indicator was developed (Swerts *et al.* 2019, in preparation). Contrary to the erosion maps, where potential erosion risk is calculated, the indicator considers actual crop information at the parcel level, and information on the obligatory measures in the frame of the GAEC-CAP (Danckaert, 2016; data for internal use only) and on reimbursed voluntary measures. For the indicator a rainfall erosivity factor of 1250 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$ is used, based on data for the period 1988-2017 (Deproost *et al.*, 2018), contrary to the earlier value of 880 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$, calculated for 1898-2004 and used in the erosion map versions 2 and 3.

This indicator was developed from a soil protection point of view. It does not consider sediment transport processes, thus is not fit to evaluate the impact of measures aimed to control muddy floods or to reduce sediment transport to rivers.

Results and discussion

The first erosion map provided a clear picture of the spatial variability of soil erosion risk, concentrated in the southern part of Flanders. The map was extensively used in awareness raising and as a tool to target erosion control measures towards the most erosion prone areas.

From 2006 on the erosion map became a major tool in erosion policy towards farmers. In the context of the Agri-environmental measures of the CAP, farmers could receive reimbursements for establishing grass buffer strips or grassed waterways and for applying reduced tillage. The possibilities depend on the risk class of the parcel. Furthermore, as part of the GAEC-CAP, farmers were obliged to take erosion control measures, such as reduced tillage and soil cover. The obligations were first introduced on the 10 000 ha classified in the erosion map as 'very high'. In 2015, the area was extended with the class 'high' to cover a total of 50 000 ha.

Given the considerable consequences of the risk class of a parcel, an objection procedure was established involving field verifications of the 5 m grid erosion map. After extension of the area concerned in 2015, a peak of 2 600 objections was received, gradually decreasing to 106 in 2018. The field verifications provided a targeted evaluation of the map. Most overestimates were caused by an excessive influence of strong differences in level on the edges of parcels (sunken lanes, road sides…) and by inaccuracies of the DEM (on the edges of woodlands, in residential areas, close to territorial borders…). Underestimates were mainly due to pit fills in the DEM close to major infrastructure lines (railroads, highways…). Field evaluations in 2018 confirmed the significantly better results with version 3 of the model. Figure 1 shows the erosion map as calculated for 2019.

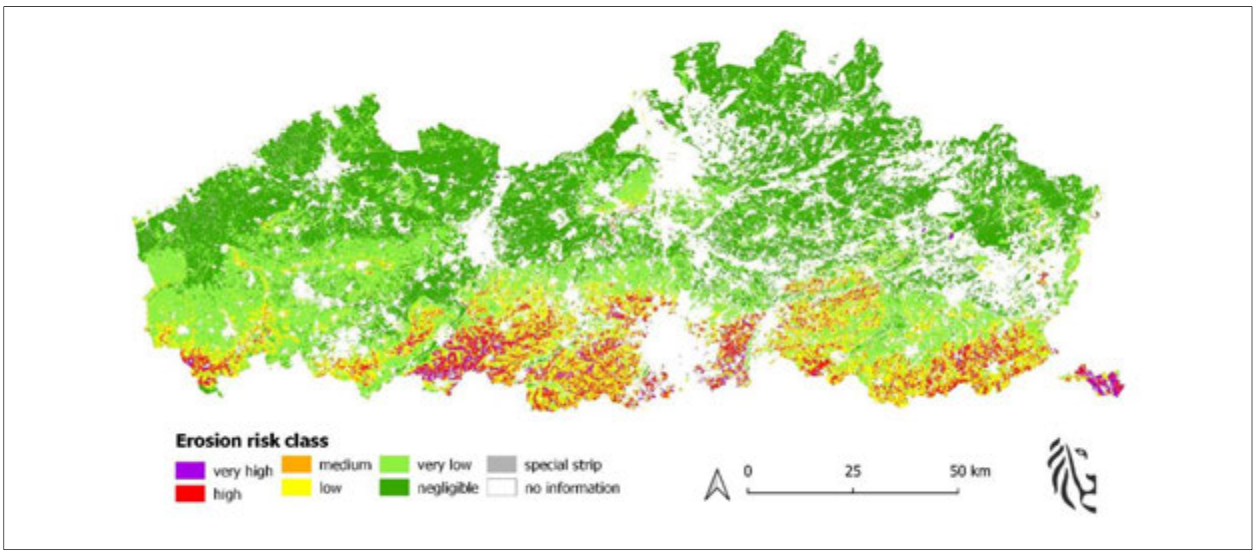

Figure 1: Erosion map of Flanders (2019) at the field parcel level, calculated as the average of the modeled potential soil erosion risk (ton.ha^{-1}.year^{-1}) on a 5 m grid resolution

The quantitative results of the ex-ante analysis, comparing the differences in erosion reduction, proved a valuable complement to the qualitative evaluation of the feasibility for the farmers. The erosion reduction for the 4 different sets of measures ranged from 30 % to 75 % for the erosion map class 'very high' and from 10 % to 78 % for the class 'high' (Swerts *et al.*, 2015).

The soil erosion risk indicator (Figure 2) clearly shows the impact of the strengthened obligations under the GAEC-CAP since 2016. The acreage with a calculated actual soil erosion risk of over 20 ton.ha^{-1}.year^{-1} has halved, mainly due to applying highly efficient measures. E.g. a considerable percentage of the area cultivated with maize and sugar beet applied reduced tillage in combination with a cover crop. The fluctuations in the period 2008-2014 can be explained by differences in crops and cover crops, mainly due to weather and market circumstances, and to changing policies.

Further analysis of the indicator for 2017 reveals that 76 % of the area remaining in the highest risk category concerns fields failing to take measures for in-situ soil protection against erosion. On another 18 % of this area measures with a very low efficiency are taken, confirming the importance of enforcing measures with a high efficiency. Furthermore, 11 % of the area in the highest risk category of the indicator are fields with highly erosion sensitive crops, mainly vegetables; 61 % of the area is cropped with maize, 9% with potatoes and 8% with sugar beet, indicating priority crops for policy.

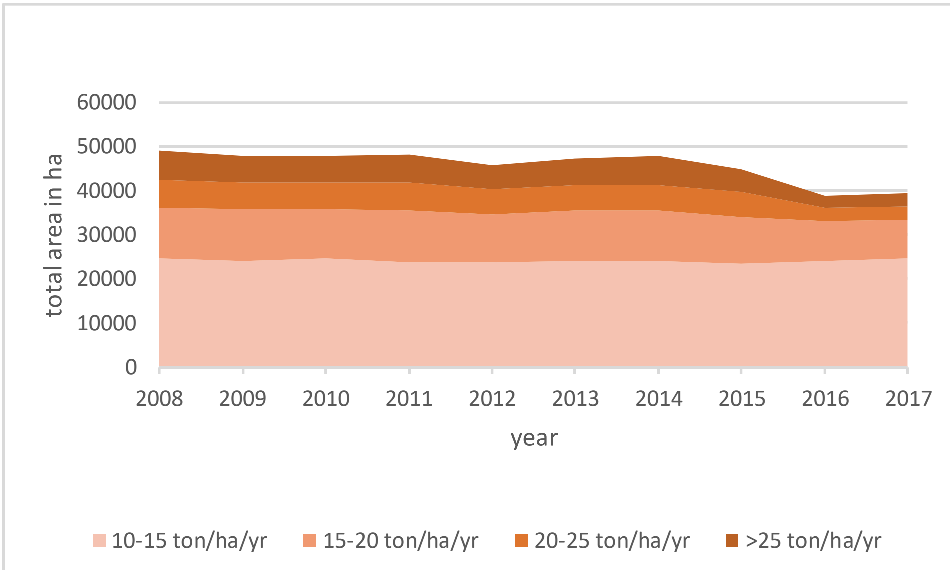

Figure 2: Soil erosion risk indicator for the period 2008-2017, showing a clear reduction of the surface area with the highest erosion risk after the implementation in 2016 of strengthened obligations for the GAEC-CAP

Conclusions and lessons learned

The erosion maps proved very useful as a tool for erosion policy. Using the maps intensively for planning at the local level and for both reimbursements and obligations for farmers, provided very valuable feedback on inaccuracies of the map. The multiple field visits to evaluate contested risk classes resulted in a targeted refinement of the maps. However, even the first, less accurate map was very helpful in focusing policy and in communication.

Because the maps involve obligations at parcel level, it is important to keep the maps as stable as possible. Adjustments must bring about clear improvements. For policy, a constant acreage on which obligations rest proved important. Therefore, equal area within a class was considered more important, than fixed class boundaries.

To underpin a policy adjustment, the erosion map provided a sound basis for the quantitative ex-ante analysis of the erosion reduction potential of different sets of measures. However, some stakeholders would have preferred a more qualitative approach.

The soil erosion risk indicator is sensitive enough to reflect the impact of policy and external factors. The implementation of strengthened obligations for GAEC-CAP halved the area in the over 20 $ton.ha^{-1}year^{-1}$ risk class of the indicator. Analysis of the different risk classes provides useful insights to focus future policy actions.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

References

Deproost, P., Renders, D., Van de Wauw, J., Van Ransbeeck, N. & Verstraeten, G. 2018. Herkalibratie van WaTEM/SEDEM met het DHMV-II als hoogtemodel: eindrapport. Departement Omgeving, Brussel, 47 pp.

Desmet, P.J.J. & Govers, G. 1996. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *Journal of soil and water conservation*, 51(5): 427-433.

Notebaert, B., Govers, G., Verstraeten, G., Van Oost, K., Ruysschaert, G., Poesen, J. & Van Rompaey, A. 2006. Verfijnde erosiekaart Vlaanderen: eindrapport. Onderzoeksgroep Fysische en Regionale Geografie, KU Leuven, 73 pp.

Oorts, K., Buyle, S., Van de Wauw, J, Deproost, P., Swerts, M., Vermang, J., Vandekerckhove, L. & Renders, D. 2019. Eindrapport potentiële bodemerosiekaart per perceel (2018). Departement Omgeving, Brussel, 19 pp.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. & Yoder, D.C. 1997. *Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE).* Agriculture Handbook, 703, USDA, Washington, DC.

Swerts, M. & Vandekerckhove, L. 2015. Haalbaarheid en effectiviteit randvoorwaarden erosie - Eindrapport expertengroep evaluatie beheereisen randvoorwaarden erosie. Departement Leefmilieu, Natuur en Energie, Brussel. 99 pp.

Van Rompaey, A., Govers, G., Waumans, T., Van Oost, K., Poesen, J. & Desmet, J. 2000. Een regionale bodemerosiekaart voor Vlaanderen. @WEL, 3, 6 pp.

Supporting Regionally Integrated Agro-Forestry practices in Mountain Regions to Prevent Erosion, comparing China-EU Cases

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Abstract

Understanding the complex nature and human causes of soil erosion from interdependent regional, inter-regional and international levels, the paper analyses proper policy making, technical solutions, educational means and financial value chains of erosion-related policy-in-actions. Firstly, a detailed case study in Lin'an, China, shall be explained, that pulled directly half million people and indirectly many more out of poverty. The policies, actions and key players on regional and national level, as well as international policy exchanges made best evidence of effective anti-erosion measures, that change hazardous areas through territorial-based **Regionally Integrated Agro-Forestry practices** in Mountain Regions. Secondly, through comparison to policy-in-action cases in European Mediterranean Zone, erosion resilient solutions, present and next challenges for Lin'an will be brainstormed, including: spatial, territorial and infrastructure planning (technical and responsible mechanism between governments and related societal players), educative capacity building (on local agro-forestry heritages and practice models for erosion mitigation and control), organisational controlling improvements (tailored open data and participative methods) and green finance tool development (bankable sustainable soil management schemes and territorial destination promotion).

Thirdly, recommendations will be made to global policy-in-actions, to bring feasible soil-erosion mitigation and control to multi-location practical actions and opportunity dialogues.

Keywords: Agro-Forestry, Erosion Resiliency, Sustainable Soil Management, Nature Capital Compensation, Soil Testing, Green Fertilizer, Bamboo and Edible Forestry, Green Finance

Introduction, scope and main objectives

Soil degradation via erosion is one of the four major global challenges currently facing humanity (Berhe *et al.,* 2018). Human activity and related land use change are the primary cause of accelerated soil erosion (Borrelli *et al.,* 2017). Water and soil erosion are tightly connected to a variety of severe and frequent disasters that have wide impacts in most global regions. Because of dynamic nature and human influences, increasingly extreme weather and climate changes, heavier torrential rains, hydrogeological instability and serious wild fires, mountain regions are prone to erosion threats. According to Panagos *et al.* (2019), to acquire a comprehensive picture of soil erosion threats more processes need to be addressed and made visible to decision-makers.

Mitigating, monitoring and controlling soil erosion, as well as emergency measures to control soil erosion disasters, are global challenges that are getting each day more complex. Looking at the global soil erosion, related land-soil-water threats and other erosions (especially water), most severe erosions happen unfortunately at less developed regions. The very combat is about local-based solutions to bring swift multiple benefits, different players, as well as economic resources together.

Water and soil erosion are also a sensitive work, which detailed information and integral management are often centralized and not always publicly available. To better exchange on similar territorial solutions between different regions, communication to real situations and knowledge-based networks is equally important, to identify best technical approaches, product and value chain development to each situation.

In the European Union (EU), the common agricultural policy (CAP), among other objectives, has to help tackle climate change and the sustainable management of natural resources and to maintain rural areas and landscapes across the EU. Member States of the EU are tackling soil erosion through many different measurements, e.g. CAP cross compliance, adoption of agriculture conservation, environmental stewardship, forest management, water frameworks, maintenance and management of abandoned areas (Lahmar, 2010; Calatrava *et al.*, 2011; Prager *et al.*, 2011; Varotto and Lodatti, 2014; Borrelli *et al.*, 2016).

A more detailed study of Lin'an in Tianmu Mountain region (Chinese Yangtze River Delta) analyses a regional approach of **policy formulation** addressing mitigation and emergency mechanism of soil erosion in mountain regions, especially the process to **put policies into feasible actions**, driven by social-economic-environmental necessity, assessment and results.

The key experiences and challenges will be compared with erosion management cases from European Union's Mediterranean zone in order to share regional policy actions and link with relevant global frameworks, which is one of the special focus of the Global Symposium on Soil Erosion.

Methodology

The methodology is about three interactive levels to put erosion protective policies in actions. Sustainable agro-forestry and circular economy growth in mountain regions are unseparated to feasible approaches in regions and between them:

1. On regional level, through Lin'an case study (1984-present) (Figure 1 and 2), an evolution of Chinese regional and national soil erosion related policy-in-actions practice will be analysed. The special focus on **Spatial Land-Use Policies for Erosion-Resiliency and Circular Economy over Agro-Forestry** will be narrated to reveal regional development threats, opportunities and their valuable, mindful solutions. These include heritage-led, science-based, and innovative planning practices to forest farmers and farming systems, that have been driving of integrated policy making, actions and upscaling.

2. On an inter-regional level, from policy to actions for territory-based agro-forestry and agroecology, China and Europe have both positive and negative trends in their regions and share mutual tackles and experiences. Comparing with Lin'an, Zhejiang, and similar mountain regions in Sichuan, Yun'nan and Guizhou, etc., European Mediterranean Zone has interesting similarity in climate, plantation,

nature-culture values and hazardous challenges. Special geographic situations and management cases will be discussed over the facilitation of in-situ measures on effective soil erosion protection.

3. On international level, as erosion management is highly location dependent, there are considerate gaps between global programs and practical needs in countries and regions. Through present experiences and challenges from Lin'an, with progressive regional and national policies and their actions, global policy action on soil erosion will be analysed for their roles and next potentials.

Figure 1: Case studies of Mountain Regions: A more detailed study of Lin'an – Tianmu Mountain in South China, comparing cases from the Mediterranean Zone in EU.

Figure 2: Chronological key info over regional policy-in-action and Erosion-Resilient Agro-Forestry Model for Mountain Regions, Lin'an, China

Soil erosion mitigation and control is hard work on regional level, very location and situation based. Excellent regional experts and their versatile, multi-facet and practical skills are needed, alongside national and international policy stimulation including investment, trading rules and platforms.

In Lin'an case, three elements – Policy instruments, technical solutions and in-situ education - are equally important to inform direct players (farmers). In Mediterranean cases, change of climate and local life styles brought new erosion hazards to world heritage locations. However, the continuous protection combats thrive into new technical possibilities and successes.

They show that, international institutions and platforms have indispensable role to understand and facilitate regional combats of similar nature and experiences to workable approaches. These are not only in writing but making reports useful to the world of inter-regional practices and integrate them into global realities and efforts.

"Knowledge@Terra" (http://www.natureherit.com/) is building an educational project that integrates climate, land, soil and water into theory and practice. "Knowledge@Terra" focus on farmers and local policymakers. Result of its work is the "Chronological key info over regional policy-in-action and international exchange in the case of Lin'an".

Discussion

What are most important for the communication and implementation?

1. Comparing present experiences and from Lin'an, why are mountain regions face common or similar threats?
2. Are next challenges and opportunities of erosion combat, e.g. climate change, sufficiently understood, and by whom?
3. The cases show that, China and EU have done a great deal over soil erosion control. How should soil erosion combat informed positively to the public and the global media system for awareness raising over erosion threats and emergencies?
4. Soil erosion risk under current climate trends will increase through changing extreme weather. How could changing emergencies, such as heavier rainfall, wild fires etc. be swiftly addressed?
5. Bamboo is a very useful and lesser-known regenerative natural resource (FAO, INBAR, 2018). What do you know over its multiple functions?

Conclusions

Positive results obtained in Lin'an and Mediterranean, when policies and practices are consistently maintained in a long period. Among others, **two key "Policy-in-Actions"** to fight Soil Erosion in mountain regions:

1. From Writing Reports to "Reporting": Communicate and report policy message in local knowledge to different local players.

2. Calling the Most Vulnerable as Opportunities:

For urgent global, national and regional actions, connect regional hazards tightly to inter-regional & international actions, e.g. calls for paying attention to endangered and precious agro-forestry heritage solutions.

Three Systematic Recommendations to support Regionally Integrated Agro-Forestry practices in Mountain Regions to Prevent Erosion:

1. “Searching and finding” -- Integrate and inform technical Solutions connecting Soil Erosion and other threats;
2. Knowledge & Solution Education in multiple forms;
3. Unite investment and financial value chains.

References

Zhu, Z., Cai, M., Wang, S. & Jiang, Y. 1991. Agroforestry Systems in China. Published jointly by Chinese Academy of Forestry, People’s Republic of China and International Development Research Centre, Canada. ISBN-T-5038-0857-8/S.0441.

Berhe, A. A., Barnes, R.T., Six, J. & Marín-Spiotta, E. 2018. Role of soil erosion in biogeochemical cycling of essential elements: Carbon, nitrogen, and phosphorus. *Annual Review of Earth and Planetary Sciences*, 46: 521-548. https://doi.org/10.1146/annurev-earth-082517-010018.

Borrelli, P., Paustian, K., Panagos, P., Jones, A., Schütt, B. & Lugato, E. 2016. Effect of good agricultural and environmental conditions on erosion and soil organic carbon balance: a national case study. *Land Use Policy*, 50: 408-421. http://dx.doi.org/10.1016/j.landusepol.2015.09.033.

Borrelli, P., Robinson, D. A., Fleischer, L. R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Van Oost, K., Montanarella, L. & Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*, 8(1): 2013. http://dx.doi.org/10.1038/s41467-017-02142-7.

Calatrava, J., Barberá, G.G. & Castillo, V.M. 2011. Farming practices and policy measures for agricultural soil conservation in semi-arid Mediterranean areas: The case of the Guadalentín basin in southeast Spain. *Land Degradation & Development*, 22(1): 58-69. https://doi.org/10.1002/ldr.1013.

Cappellazzi, M. & Pinzut, V. undated. Revolve water, Liguria: Preserving the Land. Available at: www.parconazionale5terre.it/pdf/Liguria-5Terre.pdf [accessed 01.03.19].

FAO. 2005. Asia model forests project (International Model Forest Network). Available at: http://www.fao.org/forestry/32687/en/ [accessed 01.03.19]

FAO. 2016. State of the World’s Forests 2016. Forests and agriculture: land-use challenges and opportunities. Rome. http://www.fao.org/3/a-i5588e.pdf [accessed 01.03.19].

FAO & INBAR. 2018, Bamboo for land restoration -- Drawing recommendations and best practices from case studies where bamboo has been used for land restoration: China, Colombia, Ghana, Indi, Nepal, South Africa, Tanzania and Thailand. Policy Synthesis Report. INBAR: Beijing, China, 2018.

International Model Forest Network. 2019. Lin'an Model Forest. Available at: https://imfn.net/regional-networks/linan-model-forest/ [accessed 01.03.19].

Joint Research Center. 2018. Sino-EU Panel on Land and Soil, concept note. Available at: https://esdac.jrc.ec.europa.eu/networkcooperations/sino-eu-panel-land-and-soil [accessed 01.03.19].

Lahmar, R. 2010. Adoption of conservation agriculture in Europe: lessons of the KASSA project. *Land Use Policy*, 27(1): 4-10. https://doi.org/10.1016/j.landusepol.2008.02.001.

Panagos, P., Borrelli, P. & Poesen, J. 2019. Soil loss due to crop harvesting in the European Union: A first estimation of an underrated geomorphic process. *Science of The Total Environment*, 664: 487-498. https://doi.org/10.1016/j.scitotenv.2019.02.009.

Paolillo, S. undated. Prosit - Planning and restoring of Cinque Terre coastal traditional agricultural landscape, European LIFE Project, LIFE00 ENV/IT/000191. Available at: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=1922&docType=pdf [accessed 01.03.19].

Prager, K., Schuler, J., Helming, K., Zander, P., Ratinger, T. & Hagedorn, K. 2011. Soil degradation, farming practices, institutions and policy responses: An analytical framework. *Land Degradation & Development,* 22(1): 32-46. https://doi.org/10.1002/ldr.979.

Varotto, M. & Lodatti, L. 2014. New family farmers for abandoned lands. *Mountain Research and Development*, 34(4): 315-326. https://doi.org/10.1659/MRD-JOURNAL-D-14-00012.1.

Yapo, T. & Mengistu Woldie, T. 2019. Bamboo in Ethiopia: can it help stimulate its economy while at the same time help achieve REDD+ objectives? Available at: https://www.un-redd.org/single-post/2019/02/14/Can-investment-in-bamboo-jointly-help-Ethiopia-achieve-REDD-objectives-while-stimulating-economic-development [accessed 01.03.19].

National Plan participatory construction against Soil Erosion in Brazil

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Abstract

With the increased demand for agricultural and forestry products, the pressure on soil and water resources intensifies, leading the world to food insecurity, malnutrition and several socio-economic problems. The challenge imposed is the reversion of this framework through access opportunity and low cost to application of conservation technologies already available for the various levels of land degradation. This project aims to provide guidelines for the participatory construction of National Plan for Sustainable Soil and Water Use in Brazil, a multi-institutional and participatory public policy. The Plan seeks to contribute to the implementation of programs related to degrade areas recovery for environmental restoration and reintegration into production chains, soil and water use, management and conservation. Therefore, strategic, tactical and operational level will count on all social organization level to involve people on this campaign, coming from family nucleus at the field to ministries decision makers. A competence mapping will be also used of be made among the involved actors and proposed participatory methodologies to include the key actors from the elaboration, implementation and development of the Plan. The effective participation of society is expected, contributing to the dialogue with other current public policies and with the United Nations Sustainable Development Goals.

Keywords: Land degradation, Soil erosion prevention, Sustainable Development Goals, Participatory Policy, Society Empowerment

Introduction, scope and main objectives

About 33 % of the world's soils are degraded. Erosion, salinization, compaction, sedimentation, acidification and contamination are among the main problems. On the other hand, when managed sustainably, soil can play an important role, especially for agricultural powers such as Brazil: produce more in the same area while reducing negative environmental impacts and increasing natural capital and water flows environmental services (FAO and ITPS, 2015).

Figure 1: Examples of land degradation - compaction, unproductive soil and sedimentation.

To contain the advance of erosion with the increase of agricultural exploitation in the country, the National Soil Conservation Plan was created in Brazil, which was replaced by the National Program of Hydrographic Microbots (PNMH). Currently, only some States of the Federation have this active Program and there is no National Plan that addresses the integrated management of soil and water resources. Other advances were conquered, such as the institution of the National Soil Survey and Interpretation Program of Brazil (PronaSolos). However, both decrees (PNMH and PronaSolos), which are an important part of the legal framework in relation to soil issues in Brazil, present gaps in relation to the use, management and integrated conservation of soil and water resources.

There are many methods, instruments and technological solutions that could be adopted for the proper use and management of soil and water in rural areas. However, many obstacles still remain for the expansion of more sustainable agricultural production systems, which encourage an increase in the income of the farmer, the quality of the products and the provision of environmental services.

Figure 2: Sustainable technologies to contribute with soil and water conservation.

Given the breadth and diversity of the Plan's action that should cover the entire national territory, it is necessary to establish a structure and instrumentality of governance that considers the strategic, tactical and operational levels. In this sense, the present proposal intends to contribute to the development of methodology of construction, implantation and participative management of National Plan for Sustainable Soil and Water Use. For this, it intends to consider mainly that the knowledge of the existing competences, as well as of the factors that interfere in the adoption of practices of use, management and conservation of the soil and water resources on a large scale are essential for the success of the Plan.

Methodology

Methodology to realize this project will concentrate in three main points:

- Survey and analysis of data and information: The collection of data and information relevant to the subject of the study will be carried out considering the strategic, tactical and operational levels. Identify and analyze similar, complementary and convergent actions already existing and classified in priority levels in relation to their contribution to the Plan. Through consultation with specialists and decision makers through structured questionnaires to address the participatory construction of the Plan, the attributions and goals existing in those documents are classified and reconciled and / or reformulated to meet the premises of the new Plan under construction.

- Mapping of competences: the identification of the set of skills, knowledge and attitudes available to the professionals of an organization and which enables them to carry out certain activities (Pires *et al.,* 2015). It will be carried out initially by a documentary investigation, which includes the analysis of the process, the content of the mission, the vision of the future, the objectives and other documents related to the organizational strategy (Carbone *et al.*, 2005). Afterwards, data collection will be carried out with key people of the organizations to support the documentary analysis (Faria and Brandão, 2003). Other methods and other research techniques can also be used, such as observation, focus groups and structured questionnaires with evaluation scales, as suggested Guimarães (2001) and Santos (2001).

- Selection of participatory construction methodologies: a broad review will be carried out on existing participatory construction methodologies and proposals for adjustments according to the levels of governance addressed (strategic, tactical and operational) and selected participatory methodologies best suited to each segment, enabling more effective participation of technicians, farmers and society in general in the construction of the Plan. Social transformation implies the co-participation of different social actors involved in the process. For that the process of action research, which seeks to know and intervene in a reality, but jointly between the proponent and the beneficiary of the proposals (Thiolent, 1988; Vasconcelos, 1998; Santos, 2003), and considering the historical, ethical, political and socio-cultural dimensions of knowledge in the different Brazilian regions.

Plan participatory construction will be synchronized with main guidelines, which are focus in prevention, conservation, monitoring and recovery degraded lands with low cost conservation technologies. For society empowerment there´ll be a strong integration among teaching, research, extension and field inspection.

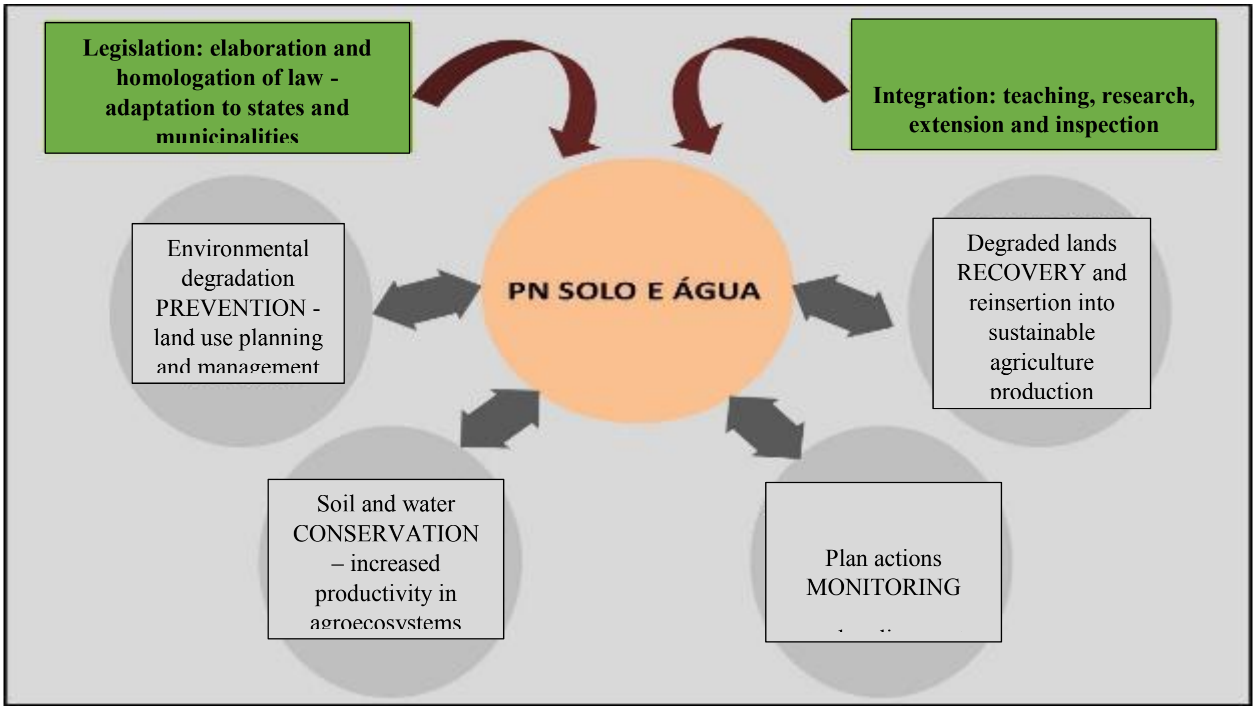

Figure 3: Plan framework.

Results

Preliminary studies indicate that there are other instruments that are intended to be analyzed, such as the National Program of Hydrographic Microbots (PNMH), National Agroecology Plan, National Action Plan to Combat Desertification and Mitigate the Effects of Drought, National Plan of Water Resources, Low Carbon Agriculture Plan, among other pertinent. With the information generated it is intended to contribute to raising awareness in society of the need to expand actions that promote the proper use of soil and water resources and the recovery of degraded lands. To do this, it will seek to propose guidelines and action strategies for the implementation of the Plan in the different Biomes, Hydrographic Basins, States and Municipalities of the Federation.

The result is to create guidelines to guide the management of soil and water in Brazil in terms of its use, management, conservation and recovery in rural areas in a participatory manner. These actions will also promote benefits also in the urban environment, especially in improving the supply of water and agricultural products, in quantity and quality, to the whole society, contributing to the food, water and energy security of the country. In addition, it is intended to contribute to the fulfillment of the goals of most of the Sustainable Development Goals (SDGs) established by the UN.

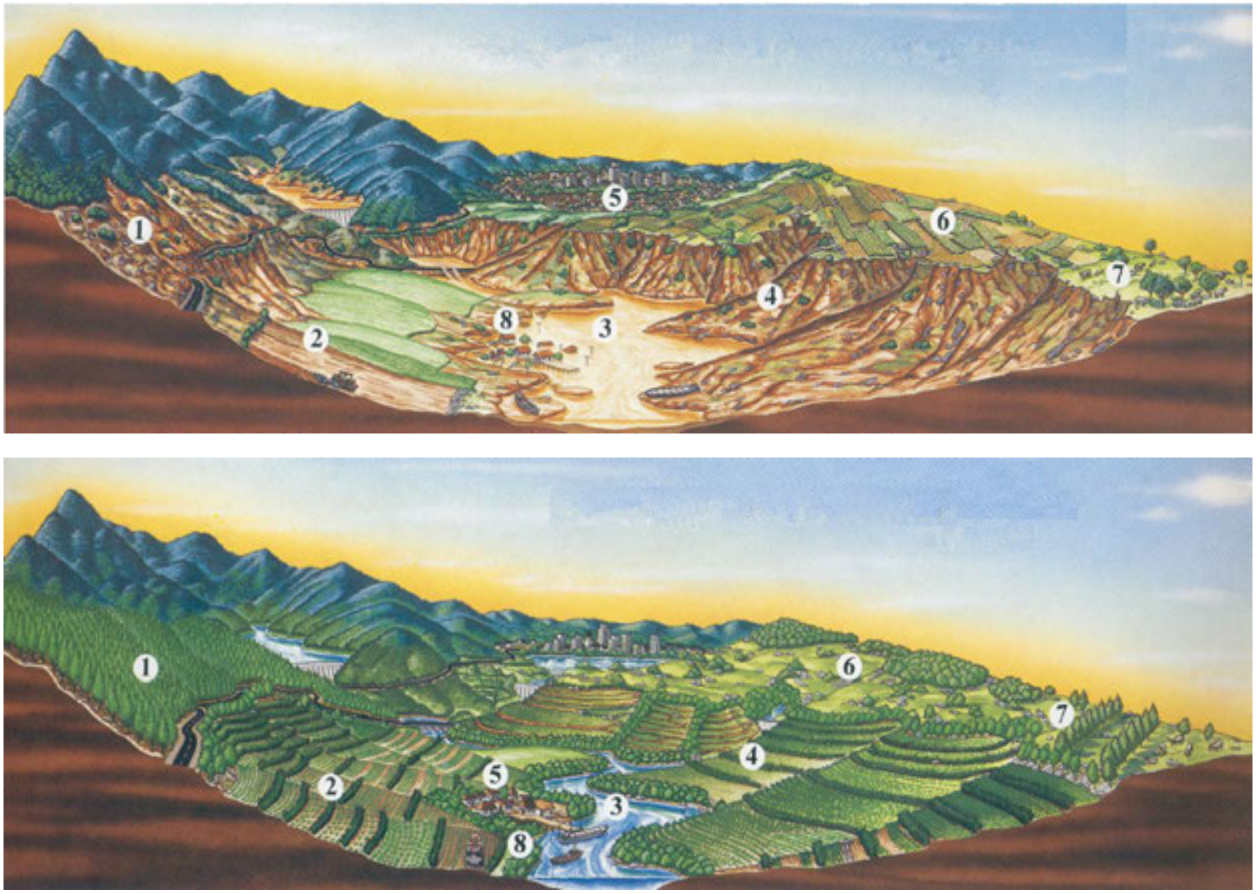

Figure 4: Degraded landscape changing through low cost conservation practices providing water, production and food.

Discussion

To build a Plan of national scope and to contribute effectively to the confrontation of the problems caused by the acceleration of the erosive processes and the consequent degradation of the soil and water resources, a broad mobilization of the society will be necessary. Thus, its structure should be based on levels of strategic, tactical and operational planning. In the strategic, it has been planning several meetings where there will be involved the ministries related and their respective institutes to elaborate the main idea. For the tactical would be mobilized related society committees, strong local cooperatives and associations, and special communication and dissemination institutes to create campaigns according to different biomes. Finally, the operational planning should involve all those related directly to the land use, working with workshops and different publicity sorts (as videos, booklets, posters, cards). Even though it may have a regionalized cut, conferring greater flexibility and adaptation to regional differences according to the six mainly Brazil´s biomes by the continental dimension of Brazil.

For the planned changes to occur, it is necessary for the agents of degradation to become agents of sustainable development. The premise is that the joint and continuous construction is that it is in fact capable of promoting degraded landscapes transformation into productive landscapes of greater environmental quality. In this way, it is suggested that the Plan should be a comprehensive and permanent program, in accordance with the different needs of the country, and should be constructed in a participatory manner so that it gains legitimacy in the different follow-ups of the society and regions of the country.

Conclusions

This project aims to contribute on better life quality for Brazilian citizens, seeking for better agricultural practices to promote more productivity on the field and food security. Besides, to improve ecosystem services provision and management, with a special attention on clean water production, soil quality against desertification and halting biodiversity loss, promoting the restoration of eroded sites. Society empowerment should bring the belonging sense for each stakeholder involved in its biomes context, counting on governmental efforts to promote the Plan in each one.

Prevention, conservation, monitoring and recovery will be part of stakeholders´ empowerment, through integration with other policies and actions. Besides that, low cost technologies and information access will be added to this campaign to aims to make people understand the importance of their actions related to the consequences of land use. , through empowerment decisions and actions to minimize soil erosion.

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References

Bruno-Faria, M.F. & Brandão, H.P. 2003. Gestão de competências: identi-ficação de competências relevantes a profissionais da área de T&D de uma organizaçãopública do Distrito Federal. *Revista de Administração Contemporânea*, 7(3): 35-56.

Carbone, P.P., Brandão, H.P. & Leite, J.B.D. 2005. Gestão porcompetências e gestão do conhecimento. Rio de Janeiro: Fundação Getúlio Vargas.

FAO & ITPS. 2015. Status of the World´s Soil Resources (SWSR) – Technical Summary. Food and Agriculture Organization of the United Nations and Intergovernamental Technical Panel on Soils. Italy, Rome. 77p.

Guimaraes, T.A., Borges-Andrade, J.E., Machado, M. dos S. & Vargas, M.R.M. 2001. Forecasting core competencies in an R&D environment. *R&D Management*, 31(3): 249–255. https://doi.org/10.1111/1467-9310.00213.

Pires, A.K., Prata, C.F., dos Santos, D. M., Brandão, H.P., Moraes, H., de Carvalho, I., Monteiro, J.C., Dias, J.C., E. Filho, J.V., Oliveira, M.M.S., Marques, M.I.C., Amaral, P.A., Araújo, P.B.C., Hashimoto, R., Machado, S.S., Dantas, V.C., Lima, S.P. (Relator). 2005. *Gestão por competências em organizações de governo.* Brasília. Escola Nacional de Administração Pública (ENAP). 100 p.

Santos, A.C. 2001. O uso do método Delphi na criação de um modelo de competências. *Revista de Administração*, São Paulo, 36(2): 25-32.

Santos, T.M.S. 2003. Estratégias de comunicação para o desenvolvimento local e os desafios da sustentabilidade. In: LIMA, J. R. T.(Org). Extensão rural e desenvolvimento sustentável. Recife: Bagaço. p. 9-23.

Thiollent, M.J.M. 1988. Metodologia da pesquisa-ação. 4. ed. São Paulo: Cortez. 108 p. (Coleção Temas básicos).

Vasconcellos, H.S.R. 1998. A pesquisa-ação em projetos de educação ambiental, In: PEDRINI, A.G. (Org). Educação ambiental: reflexões e práticas contemporâneas. Petrópolis: Vozes. 123 p.

Integrating data and assessment evidence across disciplines to co-design soil erosion solutions in degraded pastoral land

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Abstract

We present an integrated, interdisciplinary approach to support co-design of land management policy tailored to the needs of specific communities and places in degraded pastoral land in the East African Rift System. Natural science assessment using hydrological and sedimentary diagnostic tools shows that, over the past two decades, drought and grazing have reduced grass cover leading to reduced infiltration capacity and loss of soil aggregate stability. During severe rainstorms, sheet wash erosion has occurred and overland flow has been concentrated along convergence pathways and livestock tracks leading to incision and gully development. While there is much appetite for soil conservation and mitigation, social science assessment via stakeholder interviews identified significant barriers to adoption of soil conservation measures, despite local awareness the challenges. Barriers were rooted in specific pathways of vulnerability, such as a strong cattle-based cultural identity, weak governance structures, and a lack of resources and motivation for community action to protect shared land. There are however opportunities rooted in willingness to change land management practice and widespread support for participatory decision-making. We used a participatory approach to integrated disciplinary evidence bases and enable practitioners to start co-designing potential solutions.

Keywords: land degradation, grazing, drought, erosion, co-design

Introduction, scope and main objectives

The problem of soil erosion and land degradation has traditionally been investigated through a sectoral or disciplinary lens, rather than holistically. In addition, the formulation of policy solutions for achieving sustainable land management has often been detached from those responsible for implementing them on the ground. We demonstrate a field-based approach designed to address specifically '*interdisciplinary*' and ‘*implementation*’ gaps that hamper soil erosion control (for full details of this work please see Blake *et al.*, 2018a).

Soil erosion has far-reaching implications for the food, water, and energy security nexus (Blake *et al.*, 2018b; Cook, 2017) since on-site loss of soil and nutrients threatens food security (Pimentel, 2006), pollution of waterways by silt and nutrients impacts water security, and siltation threatens freshwater biodiversity, tourism and efficiency and lifespan of hydropower dams (Kondolf *et al.*, 2014).

Soil erosion and resulting land degradation are a consequence of both individual and community land management choices (Stocking and Murnaghan, 2001; Boardman, Poesen and Evans, 2003) compounded by dynamic environmental factors which are evolving with climate change (García-Ruiz *et al.*, 2017). Against this complex context, attention needs therefore to focus on co-production of sustainable land management practice.

Methodology

Our ‘assessment to action’ concept is founded on the assertion that the intractability of soil erosion and land degradation problems can only be addressed though inter-disciplinary collaboration, rather than a narrowly sectoral approach (full details are available in Blake *et al.*, 2018a).

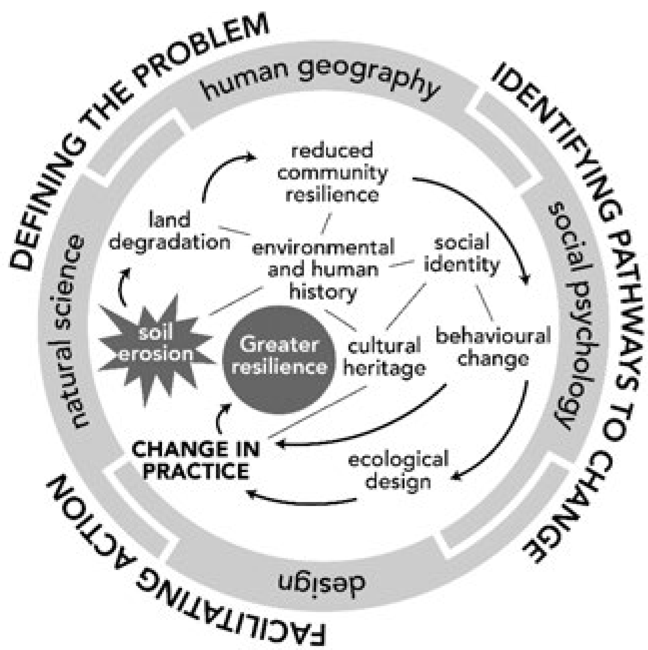

Figure 1: Development of evidence and pathways to action across disicplines to increase socio-ecological resileince to soil erosion (Blake *et al.*, 2018a)

We selected the Lake Manyara basin system in Tanzania to represent a natural ‘socio-ecological laboratory’ typical of East African Rift System (EARS) landscapes that support vulnerable pastoral and agricultural communities in East Africa. The key natural science objective was to develop comparative datasets of soil erosion risk in different geomorphic zones of the study area, from lowland to upland pastoral land, and relate this to aerial photography-based analysis of rill and gully incision.

Direct assessment of soil vulnerability to erosion was made via test on samples to evaluate aggregate stability, total organic matter, by loss on ignition, and particle size, by laser granulometry. Alongside, the soil sampling regime, soil surface permeability measurements were made using a Decagon minidisc infiltrometer. Sediment cores were recovered from exposed lake bed in sub-catchments heavily impacted by erosion and these were subjected to environmental forensic (e.g. nuclear techniques (Dercon *et al.*, 2012)) analysis to evaluate changes in upstream erosion process and sediment source (cf Blake *et al.*, 2018b). Social science approaches evaluated the interlinkage between the environmental problems evaluated above and social drivers. To achieve this a mixed-method inductive approach was used to identify stakeholder perceptions through semi-structured interviews with pastoralists and farmers living in the areas where the soil samples were collected as well as with other stakeholders (e.g., representatives of farmer organisations and local government). The interviews focused on stakeholders' awareness of the soil erosion problem, perceptions of drivers and impacts, understanding of land management and cattle-keeping practices that might be contributing to the problem, and perceived barriers and opportunities for new approaches. A stakeholder workshop was held to (i) exchange knowledge between researchers and the study communities, (2) explore the opportunities for co-design of solutions and (3) lay the foundation for a co-designed framework within which to support future land management change(Sanders and Stappers, 2008). The approach was closely aligned with *Reed et al's* (2017) 'bottom-up' participatory principles (cf (Pretty, 1995)) in that workshop participants included stakeholders from each of the study communities as well as District and Regional Council representatives and NGOs. Within this, innovative art-science tools were deployed including photojournalism and infographic posters and games.

Summary of key findings

The data and assessment evidence bases were evaluated in terms of: (1) the *present* soil erosion processes, dynamics and societal challenges, (2) the *past* dynamics of social change and landscape response and (3) the *future* potential with interdisciplinary integration to underpin behavior change (summarized here from Blake *et al.*, 2018a).

Integrated evidence bases revealed a complex picture of path-dependent interlinked social, economic and environmental drivers of change which amplify and reinforce the social impacts. Sedimentary archival data derived from environmental forensic tools cohered with community anecdotal evidence to reveal an increase in the rate and extent of erosion processes and increased landscape vulnerability through loss of vegetation cover (forest thinning and overgrazing) leading to increased soil surface fragility which, coupled with the onset of intense climate events, has resulted in widespread sheet and gully erosion. Stakeholder views implied that weak economic and institutional resilience through a lack of alternative livelihood opportunities and little enforcement of environmental protection legislation compound this problem. Barriers to sustainable change were surmised to be inherent within cultural identity and lack of community cooperation around shared resources (cf. Heath *et al.*, 2017). Socio-economic processes operating at higher spatial levels (population growth, urban expansion, and land tenure change) have constrained opportunities for change and locked pastoralist communities in the study area into restricted decision-making pathways (Kelly *et al.*, 2015; Ferrara *et al*, 2016) with positive feedback on environmental degradation. Regarding future potential, opportunities for 'bounce back' were identified through openness to new knowledge and awareness of the inevitability of change forced upon communities by rapid environmental deterioration. A 1 year follow up demonstrated that in one severely degraded area, livestock are now permanently excluded from the damaged area until full recovery of vegetation cover is achieved. Elsewhere, a concerted effort is being made to implement rotational landscape recovery enforced by village leaders.There was a unanimous appetite amongst all community participants for land management change to be supported by new local byelaws, co-designed by communities and the Local Authority, exemplifying the benefit of multi-stakeholder participation (de Vente *et al.*, 2016) in a non-hierarchical setting. This suggests theintegrated approach has a strong potential for future impact on land management practices.

Conclusions

Risk of land degradation is accentuated during period of socio-cultural transition e.g. sedentarisation of pastoralist communities. Associated socio-economic processes can overlay and amplify environmental factors such as drought of extreme rainfall events. Environmental protection and sustainable resource management is essential in the early stages of such transitions, especially in the context of soil which is non-renewable in human timeframes. Implementation of interventions must be grounded in data and evidence-based participatory engagement. Holistic, interdisciplinary systems thinking is required to enable co-design of solutions that empower local communities to break themselves out of the vicious circle of soil erosion.

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References

Blake, W.H., Rabinovich, A., Wynants, M., Kelly, C., Nasseri, M., Ngondya, I., Patrick, A., Mtei, K., Munishi, L., Boeckx, P., Navas, A., Smith, H.G., Gilvear, D., Wilson, G., Roberts, N. & Ndakidemi, P. 2018. Soil erosion in East Africa: an interdisciplinary approach to realising pastoral land management change. *Environmental Research Letters*, 13(12): 124014. https://doi.org/10.1088/1748-9326/aaea8b.

Blake, W.H., Boeckx, P., Stock, B.C., Smith, H.G., Bodé, S., Upadhayay, H.R., Gaspar, L., Goddard, R., Lennard, A.T., Lizaga, I., Lobb, D.A., Owens, P.N., Petticrew, E.L., Kuzyk, Z.Z.A., Gari, B.D., Munishi, L., Mtei, K., Nebiyu, A., Mabit, L., Navas, A. & Semmens, B.X. 2018. A deconvolutional Bayesian mixing model approach for river basin sediment source apportionment. *Scientific Reports 2018 8:1*, 8(1): 13073. https://doi.org/10.1038/s41598-018-30905-9.

Boardman, J., Poesen, J. & Evans, R. 2003. Socio-economic factors in soil erosion and conservation. *Environmental Science {&} Policy*, 6(1), pp. 1–6. doi: 10.1016/s1462-9011(02)00120-x.

Cook, H. F. 2017. *The Protection and Conservation of Water Resources*. Chichester, UK: John Wiley & Sons, Ltd. doi: 10.1002/9781119334316.

Dercon, G., Mabit, L., Hancock, G., Nguyen, M.L., Dornhofer, P., Bacchi, O.O.S., Benmansour, M., Bernard, C., Froehlich, W., Golosov, V.N., Haciyakupoglu, S., Hai, P.S., Klik, A., Li, Y., Lobb, D.A., Onda, Y., Popa, N., Rafiq, M., Ritchie, J.C., Schuller, P., Shakhashiro, A., Wallbrink, P., Walling, D.E., Zapata, F. & Zhang, X.

2012. Fallout radionuclide-based techniques for assessing the impact of soil conservation measures on erosion control and soil quality: an overview of the main lessons learnt under an FAO/IAEA Coordinated Research Project. *Journal of Environmental Radioactivity*, 107: 78–85. https://doi.org/10.1016/j.jenvrad.2012.01.008.

Ferrara, A., Kelly, C., Wilson, G.A., Nolè, A., Mancino, G., Bajocco, S. & Salvati, L. 2016. Shaping the role of "fast" and "slow" drivers of change in forest-shrubland socio-ecological systems. *Journal of Environmental Management*, 169: 155–166. https://doi.org/10.1016/j.jenvman.2015.12.027.

García-Ruiz, J.M., Beguería, S., Lana-Renault, N., Nadal-Romero, E. & Cerdà, A. 2017. Ongoing and Emerging Questions in Water Erosion Studies. *Land Degradation & Development*, 28(1): 5–21. https://doi.org/10.1002/ldr.2641.

Heath, S. C., Rabinovich, A. & Barreto, M. 2017. Putting identity into the community: Exploring the social dynamics of urban regeneration', *European Journal of Social Psychology*, 47(7):855–866. doi: 10.1002/ejsp.2296.

Kelly, C., Ferrara, A., Wilson, G.A., Ripullone, F., Nolè, A., Harmer, N. & Salvati, L. 2015. Community resilience and land degradation in forest and shrubland socio-ecological systems: Evidence from Gorgoglione, Basilicata, Italy. *Land Use Policy*, 46: 11–20. https://doi.org/10.1016/J.LANDUSEPOL.2015.01.026.

Kondolf, G.M., Gao, Y., Annandale, G.W., Morris, G.L., Jiang, E., Zhang, J., Cao, Y., Carling, P., Fu, K., Guo, Q., Hotchkiss, R., Peteuil, C., Sumi, T., Wang, H.-W., Wang, Z., Wei, Z., Wu, B., Wu, C. & Yang, C.T. 2014. Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. *Earth's Future*, 2(5): 256–280. https://doi.org/10.1002/2013EF000184.

Pimentel, D. 2006. Soil Erosion: A Food and Environmental Threat. *Environment, Development and Sustainability*. Kluwer Academic Publishers, 8(1):119–137. doi: 10.1007/s10668-005-1262-8.

Pretty, J. N. 1995. Participatory learning for sustainable agriculture. *World Development*. Pergamon, 23(8):1247–1263. doi: 10.1016/0305-750X(95)00046-F.

Reed, M.S., Vella, S., Challies, E., de Vente, J., Frewer, L., Hohenwallner-Ries, D., Huber, T., Neumann, R.K., Oughton, E.A., Sidoli del Ceno, J. & van Delden, H. 2018. A theory of participation: what makes stakeholder and public engagement in environmental management work? *Restoration Ecology*, 26: S7–S17. https://doi.org/10.1111/rec.12541.

Sanders, E.B.-N. & Stappers, P.J. 2008. Co-creation and the new landscapes of design. *CoDesign*, 4(1): 5–18. doi: 10.1080/15710880701875068.

Stocking, M. A. & Murnaghan, N. 2001. *Handbook for the field assessment of land degradation.* London: Earthscan.

de Vente, J., Reed, M.S., Stringer, L.C., Valente, S. & Newig, J. 2016. How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands. *Ecology and Society*, 21(2): art24. https://doi.org/10.5751/ES-08053-210224.

An integrated approach to tackle soil erosion – insights from Burundi

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Abstract

This paper lays out a concept for an integrated, holistic approach to combating soil erosion based on experiences from Burundi. It provides details on two approaches for creating sustainable land administration systems and peer learning systems for improved agricultural practices, which in combination with the Burundian SoilCares system can provide a sustainable, comprehensive approach to tackle the challenge of human induced soil erosion in Burundi and elsewhere. The paper provides insights from the work of one Netherlands-based NGO and its partners in Burundi.

Keywords: Land rights, governance, soil erosion, Burundi

Introduction, scope and main objectives

Environmental degradation and the effects of climate change have a particularly strong impact on poorer countries. In contexts with limited state capacities, comprehensive approaches to tackle this challenge are often missing. The rural poor are often the first to suffer from dwindling resources. Soil erosion is one of a number of serious challenges that Burundian farmers face. The country has a very high population density (reported at 423 p. sq. km in 2017 see: World Bank, 2019) which puts additional pressure on natural resources. Moreover, the land governance system is of limited functionality, and large numbers of returnees have led to a strong increase in land-related conflicts over the past years. Among other challenges, these factors have contributed to a lack of investment in the protection of natural reosurces.

It has long been realized that there are a range of factors that determine if and how much people invest in the conservation and restoring of resources (FAO, n.d.). People are more likely to invest in land to which they have a strong claim and the access to which they consider to be safe. Local institutions play a key role in facilitating conservation and improving the farming and other environmental practices. Both, individual and collective land rights as well as local institutions need to be strengthened in order to support sustainable and effective conservation practices to combat soil erosion. This paper lays out two methodologies that have been applied in the Burundian context and that can lead to 'wise governance of land resources in coupled human-environment systems' which is needed to combat environmental degradation (Briassoulis 2019: 2).

First, an approach that facilitates the establishment of functional local land administration systems, and a second which creates a system of peer-learning and support for increased agricultural production and the application of conservation agriculture for soil protection. Furthermore, it is described how these two approaches can be combined to facilitate an integrated approach, which in combination with the Burundian SoilCares soil analysis system (or similar systems) can provide for a holistic approach to combat soil erosion, improve land governance and land use.

Methodology

This paper draws on insights from five years of work on land tenure security and improved agricultural practices in Burundi. It utilizes impact evaluations for two land tenure projects (Securing Land Tenure Security in Burundi, financed by the government of the Netherlands and USAID) based on the Fit For Purpose Land Administration Approach (Enemark *et al.*, 2016) as well as a (climate smart) agriculture project based on the innovative PIP approach developed by Alterra Wageningen (van Duivenbooden *et al.*, 2015). The outcomes of these projects in terms of improved agricultural practices and investments in land are assessed and gaps in both approaches identified. Based on this comparative assessment an integrated approach is developed which promises to address significant shortcomings that hinder sustainable and broad-scale achievements in fighting soil erosion in Burundi and which has a potential to be adapted in other contexts. This analysis is embedded into a broader assessment of the literature on sustainable land management in developing and in particular post-conflict countries.

Results

The result of the paper is a concept for an integrated approach towards improved land management, including land tenure security (and reduction of land related conflicts), improved agricultural productivity and climate smart practices with a focus on combating soil erosion. It is argued that sustainable results, in particular in (post-conflict) developing countries, will only be achieved through such integrated approaches. Soil protection and more broadly the combating of environmental degradation are not simply technical issues and in many countries around the world sate actors lack the capacities to deliver the necessary services. Complex land systems involve multitudes of actors that place demands on natural resources which can only be addressed through coherent land use planning (Briassouli 2019: 2). The paper demonstrates the following:

1. Participatory approaches are needed to enable sustainable land governance and soil protection.
2. Long-term soil protection (and soil improvements) requires protected land rights, economic- and food security.
3. Despite the challenges that such complex objectives present, workable solutions are possible as the Burundi case indicates.

Strong cooperation with state actors can be highly beneficial and the experience of the Burundian SoilCares approach demonstrates that strong ownership of adopted solutions contributes significantly to sustainability. However, the experience from the land rights component of the work also demonstrates how significant capacity building and a phased-approach with gradually increasing ownership can be necessary in the face of extremely limited capacities of (local) state actors as well as limited trust by local populations in state institutions.

Discussion

The paper contributes to the literature on sustainable land management in (post-conflict) development settings (see: Betge, 2019). Furthermore, it shows a way to create synergies between two relatively new and highly innovative approaches in development cooperation, the PIP approach and the Fit For Purpose approach. It integrates lessons from the implementation of these two approaches and holds lessons for other parties implementing them.

Conclusions

The argument made in the paper is that significant results regarding improved land management and in particular relating to soil erosion can be achieved through an integrated approach such as the one proposed. This requires different actors to adapt their ways of working, including donors to adapt their ways of funding in order to make such projects possible. Short-term financing or consortia of implementers who work alongside each other instead of together will not suffice to make sustainable and scalable results possible. Furthermore, clear regulatory frameworks are needed that enable efficient and effective consortia management including necessary lobbying and advocacy activities towards policy makers.

References

Betge, D. 2019. Land Governance in Post-Conflict Settings: Interrogating Decision-Making International Actors. *Land*, 8(2): 31. https://doi.org/10.3390/land8020031.

Briassoulis, H. 2019. Combating Land Degradation and Desertification: The Land-Use Planning Quandary. *Land,* 8: 27. doi:10.3390/land8020027**.**

Enemark, S. 2016. Keith Clifford Bell, Christiaan Lemmen, Robin McLaren: Fit-For-Purpose Land Administration, Joint FIG/World Bank publication.

FAO. n.d. Human Barriers to Conservation. Available at: http://www.fao.org/3/t0389e/T0389E04.htm (accessed: 21-02-2019).

World Bank. 2019. Available at: https://data.worldbank.org/indicator/en.pop.dnst (accessed: 21-02-2019).

Van Duivenbooden, N., Kessler, A., Moed, I. & Nsabimana, F. The PIP approach – Fostering Sustainable Agriculture Through Integrated Farm Plans. Alterra Wageningen WUR. Available at: http://library.wur.nl/WebQuery/wurpubs/fulltext/378310 (accessed: 06-03-2019).

Soil and water conservation policy evolution and its human-environment contexts in China since 1949

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Abstract

Policy plays a very important role in natural resource management, especially when it lays out a government framework for guiding long-term decisions. This paper focuses on soil and water conservation (SWC) policy evolution in China based on a selection of 26 important and typical formal documents at the national level since the foundation of China in 1949. Main aims and tasks, institutional aspects and strategic option change are analysed to make the policy evolution process in each stage clear. The information of human and environment are analyzed to describe the changes as driving forces and influences of policy improvement and evolution. There were 3 clear stages which coincided with changes in main aims and tasks, main institutional set-up and the strategies based on the overview of the problem, important documents and actual SWC measures. These results from concrete history experiences could be used in other areas with soil and water losses worldwide. All the important details of policy should be assessed carefully and SWC should be underpinned by science.

Keywords: soil and water conservation, policy, Driving force – Pressure – State – Impact - Response (DPSIR) framework, natural resource management, rural development, environment governance, ecosystem function, sustainable development

Introduction, scope and main objectives

Soil erosion has been a major environmental issue in China for a very long time because of the physical geographic condition and the poor economic history of China. China is located in the east of the Asian continent and its geographic characteristics are very diverse. It covers a great range of climatic zones from frigid-temperate, temperate, warm temperate, subtropical and tropical zones that are dominated by the eastern Asian monsoon climate (Zhao *et al.,* 1995). Basins and plains form about 31% of its terrestrial land surface and the remaining areas are mainly mountains, plateaus and hills prone to soil erosion. Therefore, all types of soil erosion, such as water erosion, wind erosion, gravity erosion, freezing erosion, glacier erosion and landslides, occur every year and soil erosion rates change greatly (Jing and Chen, 1990).

According to the National Soil Conservation Scientific Survey in 2006-2008 by the Ministry of Water Resources, there are about 3.57 million km^2 of land suffering from soil erosion, of which about 1.61 million km^2 and 1.96 million km^2 suffer from water and wind erosion respectively, accounting for 37.2 % of China's territory (Xinhua News Agency November 21, 2008). The annual soil erosion was about 4.52 billion tons and the estimated yearly economic loss due to soil erosion from 2000 was at least 200 billion yuan (US$ 29.4 billion). It is a big and ever-present challenge to control the soil erosion and to improve the condition of agricultural land, and to reduce the risks of flooding and sedimentation of reservoirs and riverbeds induced by soil erosion.

Science and policy are both relevant to land management (Freyfogle and Newton, 2002; Stringer and Dougill, 2013). Although policy plays an increasingly important role in environment and resources management, and is considered fundamental to biodiversity conservation and watershed management (Jansen *et al.,* 2006; Miller *et al.,* 2009), the success of policy initiatives is contingent on effective stakeholder engagement (Cocklin *et al.,* 2007). Policies can include land rent change, voluntary or 'soft' policy based mainly on education, legal regulation, and national and local laws and actions (Bennett and Vitale, 2001; Kelly, 2006; Gotmark *et al.,* 2009; Angelsen, 2010). Policy in this article is defined as “a set of decisions which are oriented towards a long-term purpose or to a particular problem. Such decisions by governments are often embodied in legislation and usually apply to a country as a whole rather than to one part of it” (Sandford, 1985, p. 4).

In this paper we analyse the soil and water conservation (SWC) policy changes in China since the foundation of the People’s Republic of China in 1949. This period fits well with document availability at each level and we try to describe the stages of soil and water conservation policy and it relating information including natural and economic background, runoff and sediment load of rivers and practices and approaches and their benefits. The Driving force – Pressure – State – Impact - Response (DPSIR) framework (OECD, 1993; Gabrielsen and Bosch, 2003; Gobin *et al.,* 2004) is used to draw the whole picture of the backgrounds, objectives, options of practices and strategies of policy.

Methodology

Framework of analysis: the Driver, Pressure, State, Impact, Response (DPSIR) framework provides the conceptual framework for better understanding the complex relationship between soil erosion and policy responses (see Figure 1 for a brief overview). Policy is treated as a kind of response, positive mainly, that affect driving forces (R1), pressures (R2) and/or states (R3) for soil and water conservation.

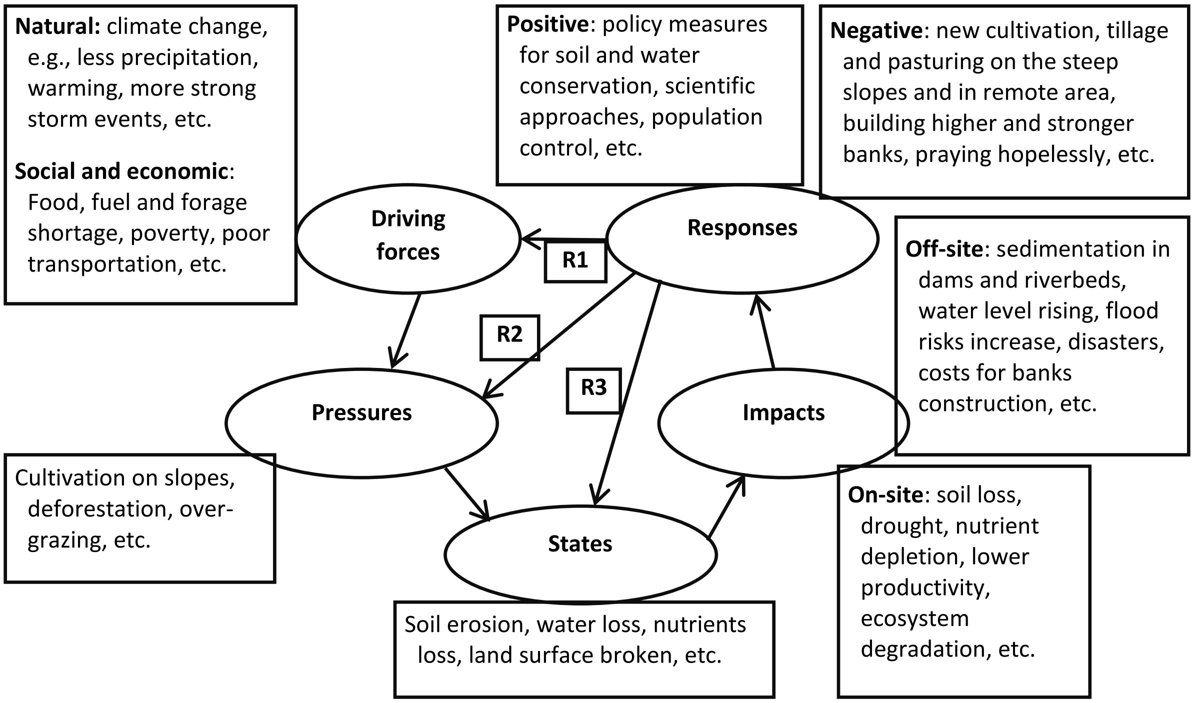

Figure 1: DPSIR Framework for soil and water conservation (Wang *et al.,* 2015)

Documents relating to SWC policy in China: we selected 26 important and typical formal documents from more than 180 policies defined from 1949 to 2017 at the national level to analyze the policy change. The documents were issued by Chinese Academy of Sciences, Central Committee of the Chinese Communist Party, General Office of the Central Committee of the Communist Party of China, Government Administration Council, Ministry of Finance, Ministry of Water Resources, National Development and Reform Commission, National People’s Congress, National Planning Commission, National Water and Land Conservation Work Coordination Group of State Council, the State Council and Yellow River Water Resources Commission, etc. Main aims and tasks, institutional aspects and strategic option change are analyzed to make the policy evolution process in each stage clear.

The information of human and environment: the soil and water conservation progress, land use and land cover change, runoff and sediment load change of several large rivers of China, food production are collected from the relating yearly books to describe the changes as driving forces of policy improvement and evolution.

Results

The SWC policy presents three stages based on the two important events of the publication of the Act of Soil and Water Conservation at the small watershed scale in 1979 and Law of The People's Republic of China on Water and Soil Conservation in 1991. With the change of the driving forces, pressures and states, the main objectives of SWC practices changed consequently from soil erosion control for improvement of agricultural condition and crop yield in the 1st stage, to taking a small watershed as a whole unit to plan and control with integrated control measures in the 2nd stage and to ecological restoration and eco-civilization development in the 3rd stage we are in now.

Main changes observed within SWC policies showed that the main aims and tasks became more and more general and complex from soil conservation on the slopes for food and flood control mainly in the 1st stage, to integrated control of a small watershed as a unit for overall benefits in stage 2, and current objectives of the improvement of ecological environment and eco-civilization development. The responsibility for SWC shifted from local farmers to local and central government step by step, and the financial support changed from private to local government and central government and to ecological compensation relating to public benefits from SWC. The strategic options of SWC technology and approach improved from local scale and single methods to comprehensive and sustainable approaches for development of agriculture, ecosystems, environment, economy and society.

The areas where SWC is implemented in China extends all the time and the results of SWC are obvious when considering the reduction of flooding and sediment load of the rivers, increase of crop yields, vegetation cover and ecosystem services and values including carbon consequence for the mitigation of climate change (Wang *et al.,* 2013; Wang *et al.*, 2015; Wang *et al.,* 2017).

Discussion

The DPSIR framework is a cyclical cause–effect model describing the driving forces, pressures, state, impact and the policy responses induced by impacts which in turn have feedback effects on driving forces, pressures and states. Considering these feedbacks could make the policy-making process more efficient and pertinent. It is necessary to improve such method in other places worldwide to find a locally suitable solution in SWC.

Scientific research and multi-stakeholder analysis are key activities in the understanding of soil erosion problems, local economic condition and capacity, objectives of different stages, best SWC practices and how to improve the benefit with the same SWC inputs.

Conclusions

The SWC policy could act on the factors of driving forces, pressures and states directly based on DPSIR and it was carried out with institutional, financial and technology support from government and the motivation of local people. There were 3 clear stages which coincided with changes in main aims and tasks, main institutional set-up and the strategies based on the overview of the problem, important documents and actual SWC measures. These results from concrete history experiences could be used in other areas with soil and water losses worldwide.

All the important details of policy, from for whom and for what to depending on whom, from technology to approach, from benefits on-site to off-site, from scale of the slope and patch to watershed and basin, should be assessed carefully. Natural resource management, technology and economic sciences play a more and more important role in SWC.

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References

Angelsen A. 2010. Policies for reduced deforestation and their impact on agricultural production. P*roceedings of the National Academy of Sciences of the United States of America,* 107(46): 19639-19644.

Bennett, D.A. & Vitale, A.J. 2001. Evaluating Nonpoint Pollution Policy Using a Tightly Coupled Spatial Decision Support System. *Environmental Management*, 27(6): 825-836.

Cocklin, C. *et al.* 2007. Public policy, private landholders: Perspectives on policy mechanisms for sustainable land management. *Journal of Environmental Management*, 85(4): 986-998.

Freyfogle, E.T. & Newton, J.L. 2002. Putting Science in its Place. *Conservation Biology*, 16(4): 863-873.

Gabrielsen, P. & Bosch, P. 2003. *Environmental Indicators: Typology and Use in Reporting*, EEA internal working paper, European Environment Agency. Available at: https://www.eea.europa.eu/publications/TEC25 [accessed 31.03.19]

Gobin, A. *et al.* 2004. Indicators for pan-European assessment and monitoring of soil erosion by water. *Environmental Science and Policy*, 7(1): 25-38.

Jansen, L.J.M. *et al.* 2006. Analysis of the spatio-temporal and semantic aspects of land-cover/use change dynamics 1991-2001 in Albania at national and district levels. *Environmental Monitoring and Assessment,* 116(1-3): 107-136.

Jing, K. & Chen, Y. 1990. Relations between soil erosion and geographic environments. *Geographic Research*, 9(2): 29-38.

Kelly, A. 2006. Securing urban amenity: does it coincide with biodiversity conservation at the local government level? *Australian Journal of Environmental Management*, 4: 243-253.

Miller, J.R. *et al.* 2009. Biodiversity conservation in local planning. *Conservation biology: the journal of the Society for Conservation Biology*, 23(1): 53-63.

OECD. 1993. OECD core set of indicators for environmental performance reviews. *OECD Environment Monographs No. 83*. Available at: www.oecd.org/environment/indicators-modelling-outlooks/31558547.pdf [accessed 31.03.19].

Stringer, L.C. & Dougill, A.J. 2013. Channelling science into policy: enabling best practices from research on land degradation and sustainable land management in dryland Africa. *J Environ Manage*, 114:328-335.

Wang, F. *et al.* 2013. Runoff and Sediment load of the Yan River, China: changes over the last 60 yr. *Hydrol. Earth Syst. Sci.*, 17: 2515-2527, DOI: 10.5194/hess-17-2515-2013.

Wang, F. *et al.* 2015. Co-evolution of soil and water conservation policy and human–environment linkages in the Yellow River Basin since 1949. *Science of The Total Environment*, 508:166–177, DOI: 10.1016/j.scitotenv.2014.11.055.

Wang, J.T. ***et al.*** 2017. Significant trade-off for the impact of Grain-for-Green Programme on ecosystem services in North-western Yunnan, China. *Science of The Total Environment*, 574: 57-64, DOI: 10.1016/j.scitotenv2016.09.026.

Zhao, J. ***et al.*** 1995. *China Physical Geography*. Beijing: China Higher Education Publishing House, pp342.

The evolution of soil conservation policies targeting land abandonment and soil erosion in Spain: A review

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Abstract

Spain is dealing with extensive land degradation caused by land use and land cover change (LULCC), e.g. by land abandonment, and local geoecological conditions. The radical LULCC by land abandonment resulted in two opposite trends; towards greening-up and towards land degradation. To mitigate negative effects on the environment, appropriate management and conservation strategies are necessary. We analyzed the top-down policy framework of soil conservation in Spain, with a focus on the Region of Murcia. We found that multiple international policies, e.g. the United Nations Convention to Combat Desertification and the European Common Agricultural Policy (CAP), contribute to soil and water conservation at the national level, where the national administration selects most appropriate measures. These are incorporated in national policies, such as the National Rural Development Programme (RDP). In case of the CAP, agro-environmental subsidies are an instrument to promote soil protection at a national level. Regionally adjusted sub-measures are then integrated in Regional RDPs. The application of subsidies, related to soil protection, is found to be controversial, as its effect on soil erosion and land degradation control is unsure. To improve decision-making, concepts as the ecosystem service approach and nature-based solutions are suggested to be included in future policies.

Keywords: Land degradation, policy-making, subsidies, CAP, Murcia, land use change

Introduction, scope and main objectives

Land degradation is a major environmental problem affecting natural and cultivated socio-ecosystems worldwide, with negative consequences for the well-being of least 3.2 billion people (IPBES, 2018). Land degradation is defined as the process leading to persistent reduction of land's productivity (MEA, 2005a, 2005b) expressed by a declining provision of the land's ecosystem services (Sanz *et al.*, 2017). Soil erosion is one of the main processes leading to land degradation and is accelerated under anthropogenic influence. In the last 50 years natural erosion rates in Spain are being accelerated by many socioeconomic drivers, with LULCC identified as most important (García-Ruiz, 2010). Land use intensification and extensification are the main contributors to abrupt LULCC and are driven by local and global socioeconomic conditions. Within the Mediterranean, Spain has a long LULCC history, characterized by land abandonment, and together with local geoecological conditions these changes have often resulted in relatively high soil erosion rates (García-Ruiz *et al.*, 2013).

Abandonment of agricultural fields has had enormous environmental consequences in Spain, due to its effects on soil hydrology, runoff, sediment sources, soil erosion, fluvial channel adjustments and forest fire risks. As climate change is likely to intensify the process of land abandonment, proper environmental management is essential to prevent further land degradation by LULCC. Environmental management consists of a combination of formal governance through local, regional, national and international policy frameworks, but also often includes local bottom-up initiatives.

This research was based on a literature study. We reviewed the characteristics, views and effectiveness of top-down implemented policies to tackle land degradation driven by farmland abandonment in Spain. Soil conservation policies in Spain were analyzed, with special emphasis on environmental and socioeconomic drivers of land abandonment as driver of land degradation and soil erosion. The research moved through different spatial scales of policy implementation, where the most detailed level focuses on the Region of Murcia and the highest level refers to the UNCCD. Since bottom-up restoration initiatives can be just as important as formal policy levels, we also reviewed the changing social perception of soil conservation.

Results

A changing perception on soil conservation

A review of the historical evolution of public perception and decision-making at different administrative levels related to soil conservation shows a shift from production-oriented exploitation of natural resources towards public awareness of both the importance and fragility of agriculture, indicated by nature conservation and holistically integrated management of coupled socio-ecosystems (De Graaff *et al.*, 2013). Over the past century, declined productivity of degraded lands, international market development and policy incentives have resulted in large scale abandonment of rainfed agriculture, accompanied by reforestation projects and the expansion of irrigated agriculture in rural Spain (Cazcarro *et al.*, 2015). In some cases, these land use changes have resulted in greening up and land restoration, while further land degradation can also be observed. Soil degradation has been politically approached with a complex network of policies from the international to the regional level. Over the past decades, there is a growing insight in the need for better rural planning, paying attention to land restoration, protection of ecosystem services and development of innovative economic models that are necessary for sustainable environmental and socioeconomic development.

Policies to mitigate land degradation

Effective mitigation and prevention of land degradation, desertification and deterioration of water resources resulting from climate change and human impacts, including land abandonment, requires careful coordination between different international conventions, and national and regional administrative levels. Multiple policies are active on the international level, i.e. the UNCCD, the European Water Framework Directive (WFD) and the European CAP. The UNCCD is the main international body aiming to fight land degradation, desertification and drought. To achieve its objectives, the 2015 sustainable development goals (SDG) are relevant, and especially SDG 15: Life on Land. It was established after a call of the international community for a global goal, specifically focusing on land degradation and desertification. UNCCD's main objectives are captured by SDG target 15.3, mainly though the introduction of the Land Degradation Neutrality concept. To focus on the quality of water bodies and stimulate sustainable use of water resources, the European WFD was established in 2000 by the European Commission. The directive plays an important role in achieving SDG 6: Clean Water and Sanitation. The last international policy that is relevant is the European Common Agricultural Policy. After Spain joined the European Union in 1986, the CAP has enormous impact on agricultural production, and thus also on LULCC (Van Zanten *et al.*, 2014). The last CAP reform in 2013 considers climate change and sustainable management of natural resources as relatively new challenges. Just as UNCCD, the CAP's main objectives are captured within an SDG, the second goal: zero hunger.

Measures from these international policies move downwards to the national policy level, where they are incorporated in the National Action Plan to Combat Desertification, the National RDP, the Spanish National Forest Programme and the National Water Plan. Again, local conditions are considered before deciding which of the national measures are appropriate to include in regional policies. For the Region of Murcia, selected measures are eventually incorporated in the RDP Programme for the Region of Murcia, the Forest Strategy for the Region of Murcia and the Segura River Basin Management Plan. Figure 1 provides an overview of the top-down implementation of policies.

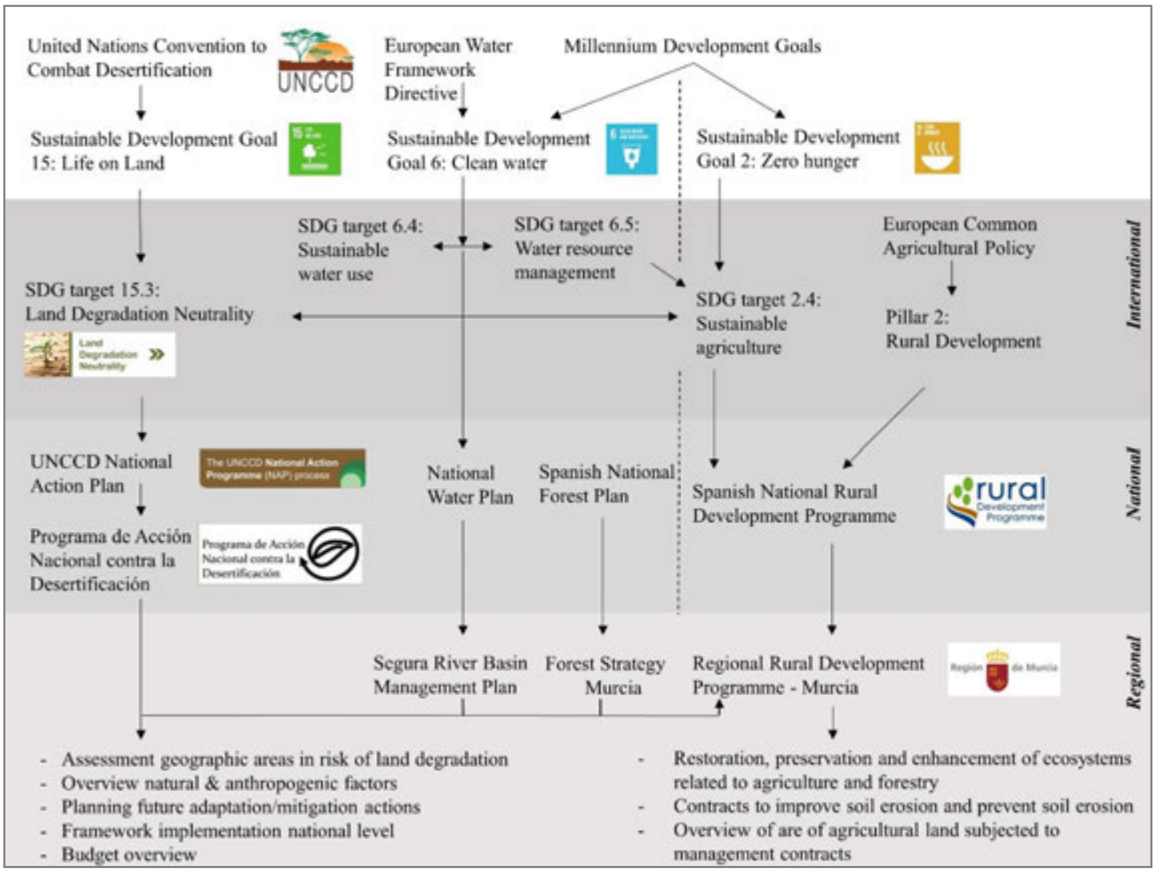

Figure 1: Policy analysis, visualizing the top-down implementation of policies through different administrative levels. Division made between policies focusing on soil and water conservation, and on the development of agriculture and rural areas.

Improvements to future policies

Translational science and integration into policies stimulates the development of soil conservation and is crucial to bridge the gap between science and policy-making. Bottom-up participatory approaches have shown to increase awareness and co-responsibility by involved stakeholders regarding soil conservation (De Vente *et al.*, 2016). Furthermore, concepts as ecosystem services and nature-based solutions are starting to be introduced in soil conservation policies but would deserve a deeper integration in environmental policy plans (Cohen-Shacham *et al.*, 2016; MEA, 2005a, 2005b).

Conclusions

Soil degradation has been politically approached with a complex network of policies from the international to the regional level. Over the past decades, there is a growing insight in the need for better rural planning, paying attention to land restoration, protection of ecosystem services and development of innovative economic models that are necessary for sustainable environmental and socioeconomic development. Current instruments such as subsidies, designed to reduce soil erosion and restore degraded soil, are still controversial as it is not clear if their application along decades has resulted in net benefits. To improve future policies aiming for land degradation neutrality and sustainable socio-ecosystems, quantification of ecosystem services, identification of nature-based solutions and sustainable business models need to be further developed. To achieve large-scale implementation of these solutions, traditional top-down policy-making must be integrated with bottom-up identification of most urgent problems and feasible solutions.

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References

Cazcarro, I., Duarte, R., Martín-Retortillo, M., Pinilla, V., Serrano, A. 2015. Water scarcity and agricultural growth in Spain: from curse to blessing. *Natural Resources and Economic Growth: Learning from History. Routledge, London*, 339-361.

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. 2016. Nature-based solutions to address global societal challenges. *IUCN, Gland, Switzerland*, 97.

De Graaff, J., Aklilu, A., Ouessar, M., Asins-Velis, S., & Kessler, A. 2013. The development of soil and water conservation policies and practices in five selected countries from 1960 to 2010. *Land Use Policy*, 32: 165–174.

De Vente, J., Reed, M. S., Stringer, L. C., Valente, S., & Newig, J. 2016. How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands. *Ecology and Society*, 21(2).

García-Ruiz, J. M. 2010. The effects of land uses on soil erosion in Spain: a review. *Catena, 81*(1): 1–11.

García-Ruiz, J. M., Nadal-Romero, E., Lana-Renault, N., & Beguería, S. 2013. Erosion in Mediterranean landscapes: changes and future challenges. *Geomorphology, 198*: 20–36.

IPBES. 2018. Summary for policymakers of the assessment report on land degradation and restoration of the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. Available at : https://www.ipbes.net/system/tdf/spm_3bi_ldr_digital.pdf?file=1&type=node&id=28335.

MEA – Millennium Ecosystem Assessment. 2005a. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC. Available at: https://www.millenniumassessment.org/documents/document.356.aspx.pdf.

MEA – Millennium Ecosystem Assessment. 2005b. Ecosystems and Human Well-being: Desertification Synthesis. World Resources Institute, Washington, DC. Available at: https://www.millenniumassessment.org/documents/document.355.aspx.pdf.

Sanz, M.J., de Vente, J., Chotte, J.L., Bernoux, M., Kust, G., Ruiz, I., Almagro, M., Alloza, J.A., Vallejo, R., Castillo, V., Hebel, A. & Akhtar-Schuster, M. 2017. Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

Vanmaercke, M., Poesen, J., Verstraeten, G., de Vente, J., & Ocakoglu, F. 2011. Sediment yield in Europe: spatial patterns and scale dependency. Geomorphology, 130(3-4): 142–161.

Van Zanten, B. T., Verburg, P. H., Espinosa, M., Gomez-y Paloma, S., Galimberti, G., Kantelhardt, J., Kapfer, M., Lefebvre, M., Manrique, R., Piorr, A., Meri, R, Schaller, L., Targetti, S., Zasada, I. & Viaggi, D. 2014. European agricultural landscapes, common agricultural policy and ecosystem services: a review. *Agronomy for sustainable development, 34*(2): 309–325.

The New Zealand Soil Erosion Control Experience 1919 to 2019: Lessons for Policy and Practice

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Abstract

Policy initiatives to address soil erosion caused by agriculture in New Zealand have evolved over the last 100 years. Using documentary analysis this study describes the trajectory of policy documenting the different policy objectives and instruments used focused on three legislative periods 1919-1940; 1941 to 1990; and 1991 to 2019. It highlights the tensions with other policy initiatives focused on enhancing agricultural production whilst ignoring environmental costs and the synergies associated with policy initiatives focused on improved environmental outcomes. It discusses the interaction with the evolving agricultural economy associated with changes in technology and prices. Policy has been substantially shaped by scientific research identifying causes and potential solutions and associated extension activity. Policy implementation has occurred at a regional level framed by national policies and resources. Policies have had to cope with significant storms and adverse events. Changing political pressures have been the primary driver of change with the limited use of economic analysis. The major instruments of policy was initially education, technical facilitation and subsidies with a gradual movement to a regime dominated by regulation.

Keywords: soil erosion, New Zealand, policy, technology, prices, research, subsidies, regulation

Introduction, scope and main objectives

This study documents the evolution of soil erosion control policies in New Zealand over a period of 100 years. During this century pastoral agriculture grew rapidly and has remained the dominant land use. The study identifies the challenges of each period and the policy responses in terms of both general approach and specific policy instruments. It evaluates policy evolution from a 21st century economics perspective which pays particular attention to policy goals, policy instruments and policy evaluation.

Methodology

The study reviews official reports and documents that present government policy, and the reporting of Government activities. The study does not include evaluation from the perspective of land owners or other analysts/researchers independent of Government. The analysis focuses on three time periods. The initial period from 1919 to 1940 was a period of policy exploration as soil erosion manifest itself as a major problem following the establishment of agriculture by European settlers (McCaskill, 1973). The study documents the initiatives taken and evaluates their success. The second period from 1941 to 1990 was a period where soil conservation activity was guided by the Soil Conservation and Rivers Control Act (1941) (Waikato Catchment Board, 1989). This was a period of significant state-led activity in collaboration with communities via catchment Boards. The study documents the evolution of both institutions and instruments in response to increased scientific knowledge and the evolving agricultural economy. During the third period from 1991 through to 2019 activity was guided by the Resource Management Act (1991). In this period the policy environment has been characterized by more holistic environmental expectations, greater responsibility by landowners and minimal use of subsidies (Clough & Hicks, 1993). The paper documents the type of regulations and analyses public expenditure in this period. The paper concludes with a summary of challenges and successes that characterised each period and their implications for future policy.

Results

The study identifies the importance of scientific measurement and local observation in accurate characterisation of erosion problems and potential solutions. Erosion problems are exacerbated by ignorance and inappropriate risk taking and impose high costs on land users and off-sitestakeholders. Despite the wide range of potential policy instruments education, technical facilitation, subsidies and regulations have been the dominant instruments of choice (Braden, 1990). Erosion control policy was compromised at times by policies focused on increasing agricultural output. Erosion control policy has been enhanced by synergies associated with the pursuit of clear water ways and reduced greenhouse gas emissions. Policy institutions have evolved though time. There has been ongoing tension between land owners and government institutions but at its best this engagement has produced better policy. Policy has been impacted by shocks associated with major storms and the growth of pest populations. Major outcomes have been better practice on farmed areas and the retirement of other areas of land to conservation status.

Discussion

Appropriate soil erosion control policies requires both consistency of purpose and evolution in response to the changing biophysical, economic, and social environment. The NZ experience suggests that earlier intervention increases the possibility of success but that remedial action can be successful where scientific knowledge, economic resources and political commitment focus on the challenge. Political commitment by itself is insufficient. Careful instrument design leads to greater land user commitment and more efficient outcomes. Soil conservation programmes can be undermined by other policies that are inconsistent with soil conservation policies.

Conclusions

Successful soil conservation activity in New Zealand has required long term investment and consistent policy settings. Scientific research has been essential throughout the century – initially to accurately characterize problems and potential solutions and subsequently to better integrate soil conservation activity with production practices and other environmental goals. Soil conservation policy has required local engagement which was initially undertaken by Catchment Boards and since 1991 by Regional Councils. Subsidies were initially a helpful instrument to facilitate land user engagement but subsequently have become undesirable through time as efficient management requires land users to accept the costs of environmental protection in order to maintain the value of their own assets and not impose costs on other parties. A major challenge for Government is to sustain the necessary scientific infrastructure and to sustain robust links between the science community and other stakeholders in agribusiness, the environment and public policy.

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The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

References

Braden, J. 1990. *Policies for Soil Conservation in New Zealand: Options for Government.* Centre for Resource Management, Christchurch.

Clough, P., & Hicks, D. 1993. *Soil Conservation and the Resource Management Act*. Ministry of Agriculture and Fisheries, Wellington.

McCaskill, L. W. 1973. *Hold This Land*. Wellington: A.H. and A.W. Reed.

Waikato Catchment Board. 1989. *Waikato Valley Authority, Waikato Catchment Board Final Report 1979-1989: The Last Decade*. Hamilton.

Education for soil science conservation research with children from the Alto del Naranjo village in the municipality of Manizales Caldas, Colombia

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Abstract

In order to raise awareness of soil knowledge, conservation and sustainability among children between the ages of 6 and 13 from rural schools in Manizales, a research, extension and education project was developed in the Alto del Naranjo village, at an altitude of 1 700 m in soils derived from volcanic ashes dedicated to coffee production. The works were developed by students of the Soil Deepening and the research seedbed in soil fertility and crop nutrition of the Agronomy Program of the University of Caldas coordinated and advised by the director of the seedbed and deepening and an official of the ICA. The methodology used was based on the program "La Main à la Pate" ("with hands in the mass") (1996), developed on the initiative of the Nobel Prize in Physics (1992) Georges Charpak, and Pierre Lena, Yves Quéré of the French Academy of Sciences to renew the teaching of science and technology at the primary school level, favouring a teaching based on the methodology of scientific research. Using simple tests of worm survival, pesticide application, covering, soil respiration and plant nutrition, children were involved in these subjects. The experience of learning about soil science enabled them to achieve meaningful learning by making soil science available to them.

Key words: "La Main à la Pate" children, soil science, research, sustainability

Introduction

Soil degradation, especially water erosion with its mass removal variant, is present in the rural area of the municipality of Manizales, standing out as the problem that most threatens the stability, productivity and sustainability of the territory. Despite the fact that there are all the technologies to prevent and correct erosion, the message does not seem to have penetrated deeply into the farmers of the area and the use of the soil continues to negatively impact its quality and conservation with consequences of economic, social and environmental impact since the problem of erosion in Colombia is not technical, it is cultural and social (Salazar, 2011). A cultural change must begin with a change in education, beginning with childhood, since it is the children who, as owners, workers or professionals of the Agro, will inhabit, produce and conserve the soil of these mountains.

If there is one thing scientists and children have in common, it is their curiosity, their desire to know and to know more; to play with the world and shake it so that all its secrets fall away. Because that is what science is all about: beyond sophisticated apparatuses and inscrutable equations, it is a question of looking with other eyes, of returning to the age of endless questions, the game of chemistry, the meccano and puzzles. It's about embarking on an innovative educational adventure that is being applied all over the world.

"Science gives children the superb gift of refining their imagination, encouraging their curiosity, stimulating their manual talents, initiating them in discovery, bringing them closer to intellectual rigour, strengthening their mastery of language and opening them up to the universal" (Charpack, 2006).

The objective of this work was to contribute to the future sustainability of the hillside soils of the rural area of the municipality of Manizales through the education of the new generations of inhabitants of this area.

Methodology

The experiments, the transfer of results and the educational process were carried out in the village five of the rural area of the municipality of Manizales in the village: Alto del Naranjo. The trail is settled in soils derived from volcanic ash, with steep slopes and susceptible to erosive processes, most of which are dedicated to the production of coffee in small plots.

The work developed with the children was:

Experiment 1: Effect of the use of glyphosate on the survival of the Californian red earthworm (Eisenia foetida) in the village Alto del Naranjo of the Municipality of Manizales- Colombia

Treatment	No earthworms in box	Repetitions
Rabbit manure +red earthworm	10	4
Rabbit manure + worms + glyphosate	10	4

Experiment 2: Use of Respiratory Activity as an Indicator of Soil Quality in Conventional and Organic Coffee Crops (Coffea spp.), in the Village Alto del Naranjo of the Municipality of Manizales.

The respiratory activity of a soil cultivated in organic coffee was compared with a soil cultivated in conventional coffee.

60 grams of fresh soil were taken in a wide-mouth container, into which a smaller container containing 3 ml of NaOH 1 Normal was introduced, the large container was hermetically sealed and placed in the oven for 24 hours at 28° Celsius. Subsequently in the presence of 2 drops of phenolphthalein and 1 milliliter of 50% barium chloride ($BaCl_2$), NaOH was titrated with 1 M HCl measuring the amount of HCl that was required, then proceeds to obtain the amount of gas produced by respiration using the following formula:

$R= (B-V) NE$

Where R is microbial respiratory activity of CO_2 in mg, B is the volume of acid needed to titrate the NaOH of the control sample in ml, V is the amount of acid needed to titrate the Nao of the sample in ml, N is the normality of the acid and E is the equivalent weight of CO_2. Breathing data are expressed as mg CO_2/g (Anderson, 1982).

Experiment 3: Effect of the use of Hedges on the Losses of a Soil derived from volcanic Ashes in the Vereda Alto del Naranjo of the Municipality of Manizales

Two 2.5 L soda bottles were filled with soil of apparent density 0.98 g/cc. Each bottle was previously opened a hole of 12cm x 20 cm. In one bottle only soil was placed and in another soil with vegetal cover. Later the bottles were fixed on a table and placed forming an angle of 45 0 to simulate the slope and with a watering can (capacity 8 L) began to apply water to observe soil loss.

Results

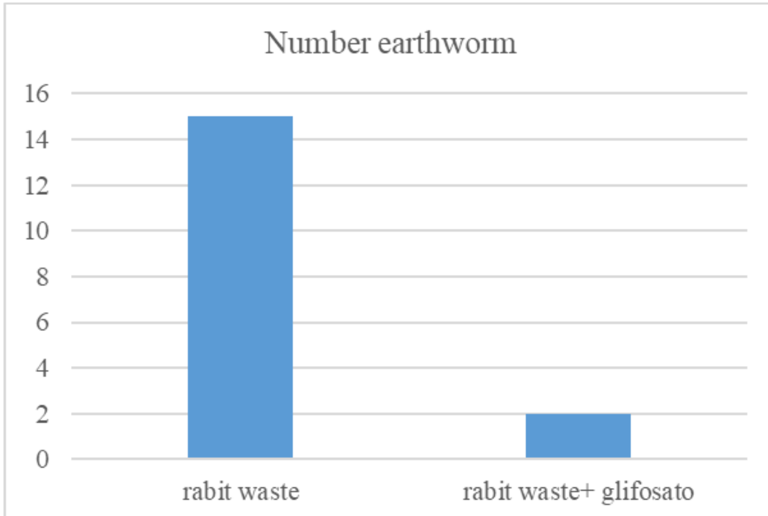

Figure 1: Effect of glyphosate application on the survival of Californian red earthworm Eisenia foetida

The death of the worms is due to the acute toxicity produced by this herbicide on the worms. Earthworms exposed to glyphosate showed, a lower growth rate, a reduction in cocoon hatching and behavior (Monsanto, 2012).

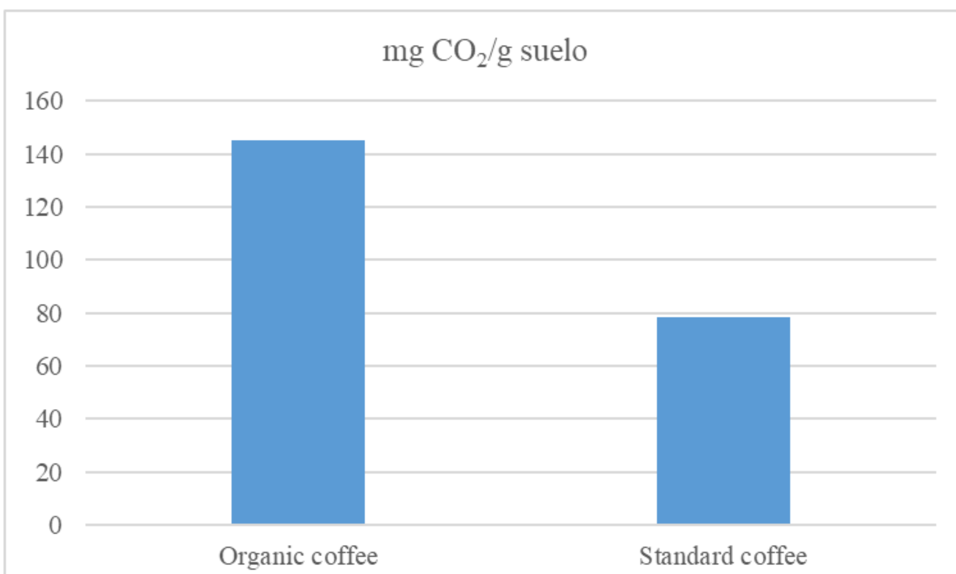

Figure 2: Effect of soil management on soil respiratory activity.

According to Cambell *et al.* (1992). The use of this indicator has made it possible to estimate global microbial activity and how it is influenced by climate, physical and chemical properties, or agricultural management practices, such as tillage and crop rotations.

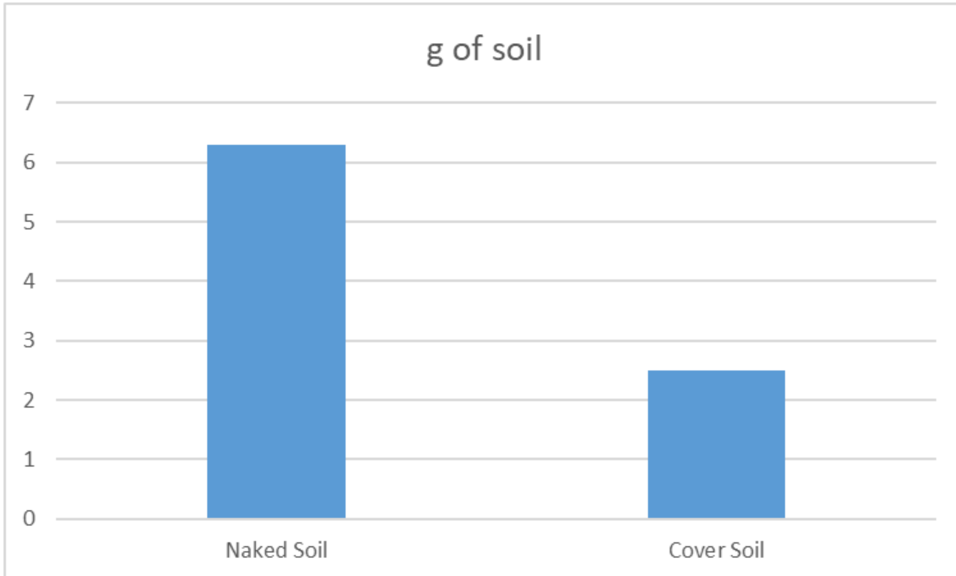

Figure 3: Comparison of Soil Losses in Bare Soil and Covered Soil

These results are explained by the concept "Plant coverages largely prevent soil loss due to surface erosion" (Salazar, 2011).

Discussion

Samplings were carried out in 23 localities of the province, where were determined the level of disturbance of soil use, soil properties and population density, richness and species diversity for each sites. and conclude earthworms are significantly affected by the use of the herbicide glyphosate.

The release of CO_2 can be considered as one of the parameters sensitive to changes that occur in the transformation of organic matter and can be affected by the application of pesticides (Guerrero, 2012)

Practices that increase infiltration, such as cover crops and tile drainage, reduce runoff and therefore limit the transport of detached particles. Practices that reduce runoff, such as terraces and buffer strips, promote the deposition of suspended sediments before they leave the field. The reduction and deceleration of runoff also limits the cleaning effects of concentrated surface flow Gruver (2013)

Conclusions

The children of the High Orange School acquired significant learning in chemical physics, biology and soil conservation.

The children finished:

- Poisons that kill weeds kill worms

- The soil lives because it breathes and if we take care of it, it breathes more.

- The ground coverings with their roots are like little hands that intertwine so that the ground does not go away.

Acknowledgements

The authors of this work thank the children of the Alto del Naranjo school in the municipality of Manizales for stimulating us with their curiosity and tenderness, their teacher Maria Lucy Castro Henao, Mrs. Cecilia Rivas, leader of the village, and the students of the soil deepening area of the Agronomic Engineering program at the University of Caldas.

References

Anderson, J.P.E. 1982. Soil respiration. In: A.L. Page, R.H. Miller, and D.R. Keeney (Eds*). Methods of soil analysis, Part 2, Chemical and Microbiological Properties*, p. 831–871. ASA and SSSA, Madison, WI.

Charpak, G., Léna, P. & Quéré, Y. 2006. Los niños y la Ciencia. La aventura de la mano en la masa. Ciencia que ladra. Serie Mayor. Editorial Siglo XXI. 1ª Edición. Argentina. 239 p.

De Andréa M. 2010. O Uso de Minhocas Como Bioindicadores de Contaminação de Solos. *Acta Zoológica Mexicana*, 2: 95-107.

Gruver, J. B. 2013. Predicción, prevención y remediación de la degradación del suelo por erosión del agua. *Conocimiento de la educación de la naturaleza,* 4(12): 2.

Guerrero, O.P., Quintero, L.R, Espinosa H.V, Benedicto. V.G & Sánchez, C.M. 2012. Respiration of CO_2 as an Indicator of Microbial Activity in Organic Fertilizers of Lupinus. Terra Latinoamericana, 30:4: 355-362.

Masin, C. E. 2017.Efectos de largo plazo del uso del suelo sobre la comunidad de lombrices de tierra (Annelida, Oligochaeta) en la provincia de Santa Fe. Tesis Doctorado en Ciencias Biológicas. Universidad Nacional del Litoral Santa Fé Argentina. Available at: http://bibliotecavirtual.unl.edu.ar/tesis/handle/11185/937.

Monsanto Argentina. 2012. Roundup®, Hoja de Datos de Seguridad de Materiales.

The Uruguayan Official Soil Conservation Policy and its Results

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Abstract

Soil erosion is the main environmental and productivity problem in Uruguay. USLE/RUSLE model was validated in long-term runoff plots experiments and a software was developed for users. In 2009 soil conservation law was updated and applied in 2013, after 3 years of extension and training for farmers and agronomists. Cropland farmers must have a soil use and management plan (SUMP) developed by a certified agronomist covering the planned rotation period. The SUMP should demonstrate that the estimated annual erosion rate is below the official T value of the soil used. All the needed information to run the model is available on-line and should be verified or modified by the responsible officially certified agronomist in the field. SUMPs are presented on-line and constitute official ores that can be prosecuted by the authority (Ministry of Agriculture). Those in violation can be fined according to the regulation. At the end of 2017 over 95 % (1 513 679 ha) of the Uruguayan cropland implemented the SUMPs. SUMPs results are coincident with the best management practices proposed in the Voluntary Guidelines of Sustainable Soil Management (GSP-FAO), and are in line with the achievement of the UN Sustainable Development Goals.

Introduction

Uruguayan cropped area reached a maximum of 1.6 Mha.yr^{-1} by mid 1950s, being continuous cropping of wheat using moldboard plow, the main soil management system. This resulted in important soil degradation due to erosion and soil organic carbon loss, affecting 30 % of the territory by mid 60s. The first soil conservation law was passed in 1968 and was modified in 1980 and 2009. During 1970-1980 the cropping area was reduced to around 0.5 Mha.yr^{-1}, and was mainly made in rotation with pastures, significantly reducing erosion in the country. This was reinforced during the 90s thru general adoption of no-till (NT) substituting conventional tillage. From the onset of the XXI century, a new crop area growth took place, arriving to 1.6 Mha.yr^{-1} by 2010, being soybean the leading crop. Despite using NT, the new cropping intensification was made abandoning the rotation with pastures, going back to continuous cropping. These changes resulted again in soil erosion problems that despite of being of less magnitude than the ones in the 50s, raised concern in farmers, technicians, scientists, and government. The soil conservation law was updated in 2009 and effectively applied from 2013.

Scope and Objective

Recently, a chapter was published in an IUSS book (Pérez-Bidegain *et al.*, 2018), presenting the technical and political aspects of the Uruguayan soil conservation legislation. The present paper deals with the political details and results of the policy, contributing to the discussion of Theme 2 of the Global Symposium on Soil Erosion.

Methodology

The Uruguayan law is based on the principle that soil conservation is of general interest, what, according with the country Constitution, is over any particular interest. Therefore, the regulation can limit what the private land owners and land tenants can do with the soils in their properties. The law determines that the Ministry of Agriculture is the authority that dictates the Technical Normative on soil conservation, and prosecutes its fulfillment. The Technical Normative has to be applied by the land tenants, no matter the kind of contract or form of land tenancy that gives their right of land use. This Technical Normative is established by executive resolutions of the authority. The last law modification in 2009, added that when the land tenant is not the land owner, the last is jointly liable with the tenant in case of regulatory violation. This provision was to make the landowners be the first stewards of soil conservation, and was triggered by the fact that the majority of the country cropping is made by persons not owning the land that they use. The violations can be fined from U$S 300 to U$S 300000, according with their gravity.

There are several general technical norms defining "bad" soil use and management practices, like the generation of oriented roughness in the direction of the main slopes, performing tillage operations or herbicides applications in the areas of surface runoff concentration conducting to gully erosion, etc. However, the main technical norm from 2009 is that each unit of soil management (lot or parcel) should have filed a Soil Use and Management Plan (SUMP), for the duration of the complete rotation that is going to be done in the immediate future. The SUMP information contains: 1) precise geographic location, 2) description of the rotation to be made, including all the details of soil management, 3) projected yields of the different crops, and eventually, pastures in the rotation, 4) dominant soil in the polygon, identifying to which Soil Map unit belongs, and 5) topographic characteristics defining L and S in USLE/RUSLE. This model was validated in the country in long-term experiments (Pérez-Bidegain *et al.*, 2018). Using the above mentioned information, an estimate of annual average soil erosion has to be done with USLE/RUSLE, using EROSION 6.0.20 (García Préchac *et al.*, 2016), and has to be presented to the authority demonstrating that it is not over the tolerance officially established for the used soil.

An officially certified Agronomist, contracted by the land tenant, prepares the technical work. To be certified, the Agronomist has to pass a specific exam taken by the Faculty of Agronomy of the public University of Uruguay, working in agreement with the Ministry of Agriculture. The professional work of the certified Agronomists is under the scrutiny of an ethical and technical board.

Once the SUMPs are presented, the Soils Division of the Ministry of Agriculture studies and prosecute them, using satellite images and other forms of remote sensing to verify their real implementation, visiting the field when irregularities are suspected, and contacting the responsible Agronomists and Farmers. If technical irregularities are found in a SUMP, the authority suspends the responsible Agronomist certification. If irregularities are detected in the execution, the land tenants (and eventually the land owners) can be fined, as it was said above.

Some key points to be highlighted are the following. It is a general law indicating the executive authority and the ones subject to prosecution. The authority can change the Technical Normative of soil conservation when needed via executive resolution. All the procedure is based on punishment of the normative violations and does not use monetary incentives.

Before the obligation to present the SUMPs in 2013, there were three years of extension work and training for Farmers and Agronomists. It consisted of short courses, workshops and field works on selected cases, including from the study of antecedent information to the visit to the field and the exercise of elaborating the SUMPs. This was a critical stage in the process, conducting to the results that are presented below.

Results

At the end of the 2015-16 agricultural year, over 95 % (1 513 679 ha) of the Uruguayan cropland presented and implemented the SUMPs, which is considered a success relative to mitigating soil erosion and collateral environmental impacts of runoff (Figure 1).

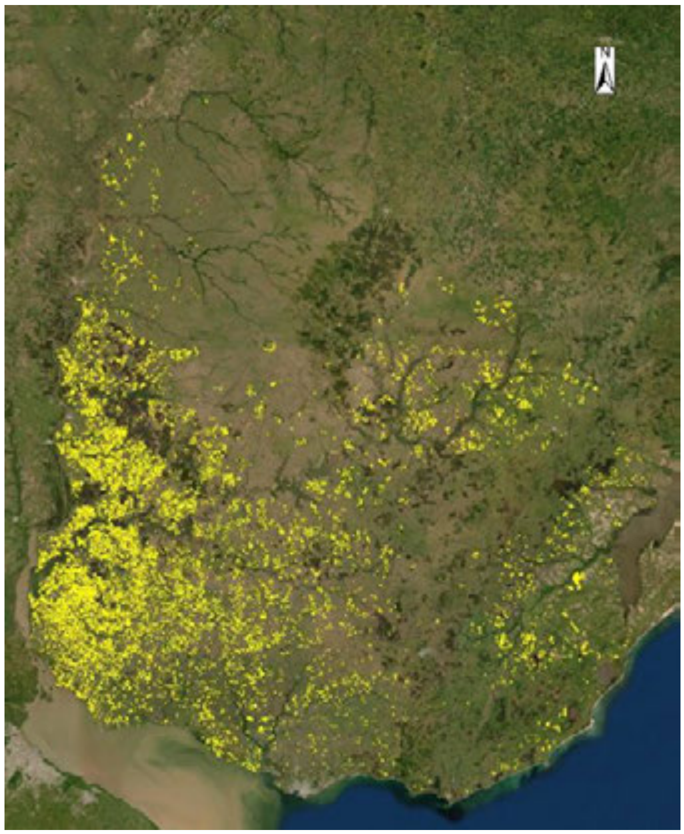


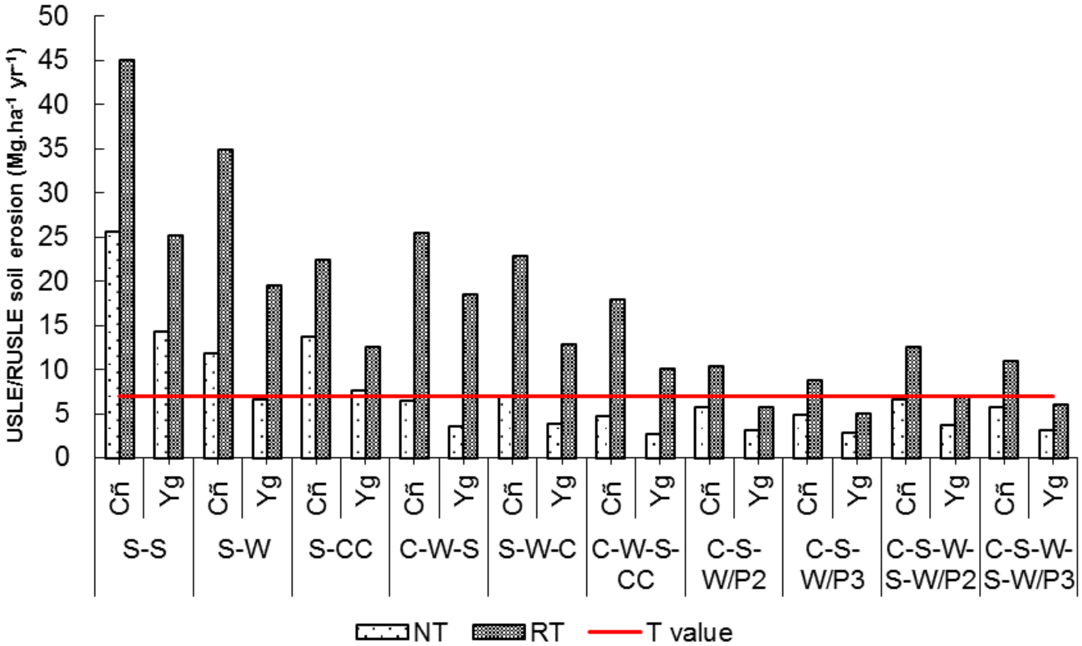
Figure 1: Soil use and management plans distribution in Uruguay in 2016 (Pérez-Bidegain *et al.* 2018).

At the end of 2017, 16 121 SUMPs were filed, and 1 645 (10 %) of them were visited in the field. In 660 (4 %) cases there were found normative violations.

Discussion

Having been implemented two years before the publication of the Sustainable Development Goals of the UN and the Voluntary Guidelines for Sustainable Soil Management (FAO, 2017), the Uruguayan soil conservation regulation result in the application of the "best management practices", that are behind the concept of achieving neutral land degradation and sustainable soil management.

Figure 2 presents the USLE/RUSLE estimates for two contrasting Mollisols of good agriculture potential in Uruguay using the EROSION 6.0.20. Both soils have contrasting erosion and degradation potential. Assuming reference conditions (bare and continuously tilled soil in the direction of the main slope: Factors C and P equal to 1.0), the product of R.K.L.S in a slope length of 100 m is 262 $Mg.ha^{-1}.yr^{-1}$ for the Cañada Nieto soil and 100 $Mg.ha^{-1}.yr^{-1}$ for the Young soil. The erosion estimates show that if continuous cropping of soybean is performed, only in the Young soil it is just reached the tolerance in a double annual cropping with wheat and using no-till; all the other cases, in both soils, generate erosion over the tolerance. If in the summers of the different years continuous cropping alternate soybeans with corn or sorghum for grain, with no-till it is estimated tolerable erosion rate in all the cases in both soils, but not using reduced tillage. In the cases of the different rotations of crops and pastures, soil loss estimates are tolerable in both soils using no-till, and in the Young also using reduced till.



Cñ=Cañada Nieto soil; Yg=Young soil; NT=no till; RT=reduced tillage; S=soybean; W=wheat; C=corn; CC=winter cover crop; P2= two years pasture; P3= three years pasture

Figure 2: Soil erosion rate estimated for two contrasting Mollisols under different cropping systems using EROSION 6.0 software (Pérez-Bidegain *et al.*, 2018).

The presented exercise, as the ones that the certified agronomists make with the farmers in defining their SUMPs, show that the following principles are accomplished, in coincidence with the 3 first technical recommendations arising from Status of the Soils World´s Resources (FAO and ITPS, 2015). First, results are better if tillage is eliminated. Second, estimates are lower if the cropping sequences rotate grass crops, leaving more residues of longer decomposition time with broadleaf crops, like soybean. Third, the inclusion of perennial pastures in the rotations, with their permanent soil cover and soil enrichment with fresh residues of their roots, result in the lowest estimates of erosion. The last was demonstrated in the experimental results of the runoff plots, with soil losses of the crop-pasture rotations with no-till being not significantly different than the ones under natural pastures (García-Préchac *et al.*, 2004), and in long-term experiments where soil organic carbon content was measured yearly (García-Préchac *et al.*, 2017). Finally, the most important issue is that the required SUMPs are elaborated before acting in the field, meaning that the policy has preventive intention. As it was discussed, it conducts the agricultural activity towards the best soil use and management practices, based on the available scientific knowledge. Therefore, it is expected that the main soil properties status is going to be preserved in the future. It is a way different from monitoring after productive actions were executed. The monitoring should be to verify that the evolution of soil properties is not showing degradation but staying the same or improving.

References

FAO & ITPS. 2015. Status of the soils world´s resources (SWSR)-Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

FAO. 2017. Voluntary Guidelines for Sustainable Soil Management. United Nations Food and Agriculture Organization. Roma, Italy.

García-Préchac, F., Ernst, O., Siri-Prieto, G. & Terra, J.A. 2004. Integrating no-till into crop pasture rotations in Uruguay. *Soil & Tillage Res.,* 77: 1–13.

García-Préchac, F., O. Ernst, G. Siri-Prieto, L. Salvo, A. Quincke & Terra, J.A. 2017. Long-term effect of different agricultural soil use and management systems on the organic carbon content of Uruguay prairie soils. Proceedings of the Global Symposium on Soil Organic Carbon 2017, FAO, Rome: 449-452.

García-Préchac, F., Clérici, C., Hill, M. & Hill, E. 2016. EROSION v. 6.0.20, (Computer program to use USLE/RUSLE in the southern La Plata river basin), available in www\fagro.edu.uy: Dpto. de Suelos y Aguas, Manejo y Conservación.

Pérez-Bidegain, M., Hill, M., Clérici, C., Terra, J.A., Sawchik, J. & García-Préchac, F. 2018. Regulatory utilization of USLE/RUSLE erosion rate estimates in Uruguay: a policy coincident with the UN Sustainable Development Goals. In R. Lal *et al.* (Eds.), *Soil and Sustainable Development Goals*, Catena-Schweizerbart, Stuttgart, p. 82-91.

The impact of plans, policies, practices and technologies based on the principles of conservation agriculture for controlling soil erosion in Brazil

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Abstract

Assessments of land coverage in Brazil indicate that almost 28 % of the territory of 8.5 million-km^2 is occupied with the production of food, fibers, bio-fuels and raw material for agroindustry and different usages. The estimated annual soil loss is of 1.18 billion tons, being 697 million tons from cropped areas and 270.8 million tons from pasture. This paper reports Brazilian efforts to control erosion of the already vulnerable tropical soils. It starts with the setup of a national governmental program for Soil Survey and Usage Interpretation (PRONASOLOS), and the impact of adoption of practices and technologies based on zero tillage conservation agriculture (ZT/CA) and integrated crop-livestock-forest (iCLF) management systems on soil erosion mitigation. ZT/CA and iLPF are present in an area of 32.88 million ha and 11.5 million, respectively, which proofs the success of these policies. The economic impact, estimated considering the complete mitigation, and the removal of highly fertile surface soil by soil erosion if it is not adopted, is estimated in 1.84 billion US dollars. This is a result of determination of farmers, extensionists, technical consultants, agricultural researchers, and professors, to promoting the control of soil erosion in an extensive agricultural area of Brazil.

Keywords: tropical soil, soil survey and usage interpretation, zero tillage conservation agriculture, integrated crop-livestock-forest, economic impact

Introduction

In the context of agriculture, land degradation leads to decreasing of agricultural production, through the reduction of soil quality with a negative impact on soil physical, chemical and biological attributes. In the tropical world the main agent of soil degradation is water erosion, which is a natural process in the formation of landscapes, but it is intensified by the anthropic actions and inadequate land usage. In Brazil, the absence of information on the spatial distribution and type of soil resources, at compatible scales with the agriculture demand, has led to expansion of crops and pasture in areas with low productive capacity or where careful soil management is required. A detailed spatial soil distribution and better knowledge is important to achieve a sustainable land use and reducing soil erosion.

The first step to control soil erosion in the tropical soils is a better planning of land usage according to its agricultural suitability (Ramalho Filho and Beek, 1995). Estimates based on soil maps of Brazilian States indicate that over 5.5 million km^2 or 65 % of the territory are apt for annual and perennial crops (Manzatto *et al.*, 2002).

This paper reports the efforts to control soil erosion in the highly vulnerable Brazilian soils, which starts with the setup of a national governmental program for Soil Survey and Usage Interpretation (PRONASOLOS). In the next three decades, this program will work to overcome the lack of proper information on soil and water resources and to provide means to evaluate them in order to mitigate land degradation processes caused by water erosion, desertification, contamination, surface and subsurface compaction, surface impermeabilization, risk of natural disasters and the emission of greenhouse gases.

Methodology

The estimation of the economic impacts of the adoption of conservation agriculture principles towards soil erosion control considered concepts proposed by Hernani *et al.* (2002a; 2002b), based on costs of liming and nutrient replenishment using fertilizers (organic and mineral).

Results and Discussion

Assessments of land usage in Brazil indicate that around 68 million ha of the 8.5 million km^2 territory are covered with annual and perennial crops, including planted forests, and 167.50 million ha of pastures (forage, natural and planted), in different stages of degradation. The total impact of soil loss is estimated as of 5.2 billion dollars per year in the agricultural areas.

The 1970's models of agriculture in Brazil were not efficient to control soil erosion, mainly due to the intensive usage of mechanization, and major changes were necessary. It was recognized that, for an effective soil erosion mitigation, it was necessary the integration of cultivation practices with biological technologies. The no-till concept refers to direct placement of seeds into the previous crop residues, which is not enough to control water erosion in any climate, and especially in the tropics. Soil erosion mitigation is only achieved when no-tillage, crop rotation (pluri-annual rotation of annual crops with no repetition of crops in subsequent years), permanent soil cover and traffic control are associated. These are the technological pillars of the ZT/CA management system (Landers *et al.*, 2001b; Landers *et al.*, 2013).

According to FAO (2019) the basic principles of Conservation Agriculture (CA) are: minimum tillage and soil disturbance; permanent soil cover with crop residues (straw) and live plants; and, crop rotation, intercropping and root diversity.

The application of these principles may reverse the historically accelerating soil erosion, and degradation of soil organic matter and structure, also increasing soil biodiversity (Landers *et al.*, 2013). The basic principles of ZT/CA are universal, while technical solutions depend on local conditions of soil, climate, relief, and socio economical (Landers, 1999). It is also recognized the impacts of ZT/CA in reducing the emission of greenhouse gases (GHGs) and improving agriculture sustainability. On Brazil, soil carbon sequestration can be approximately 350 kgC $ha^{-1}year^{-1}$ to a depth of 20 cm in the tropical savannahs, and up to about 480 kgC $ha^{-1}year^{-1}$ in sub-tropical regions (Freitas *et al.*, 2007). The emissions of GHG are reduced by decreasing usage of fossil fuels for crop production, chemical fertilizers and lessening N_2O emissions, as well as decreasing soil erosion.

The adoption of ZT/CA as major management system in Brazil is based on principles of sustainability. It integrates high productivity, low consumption of fossil fuels, increase of carbon sequestration, and mitigation of water and wind erosion. The success of these efforts is illustrated by the fact that ZT/CA systems are used in over 50 % of the area with annual crops in Brazil. Data from IBGE's agricultural census (2017) refers to an area of 32.88 million hectares of Brazilian territory (Fuentes Llanillo, 2018).

An evolution of the ZT/CA, the integrated crop-livestock-forest (iCLF) combines annual crops, livestock and forest, which affects positively soil physical and chemical attributes, increasing C, N, water retention, and reducing erosion soil losses. Adoption of iCLF management systems improves environmental, social and economic services and is a promising alternative to recover degraded areas (Lima *et al.*, 2018).

The main consequence of iCLF adoption is the efficient usage of nutrients, agrochemicals and energy, increasing soil biodiversity, and improving soil structure and fertility. It allows recovering degraded pastures and agricultural intensification, thus reducing GHG emissions (Pacheco *et al.*, 2009) while mitigating soil erosion in all Brazilian biomes. Estimations from ICLFI Development Network, by Kieffmann Group (2016) show that iCLF was adopted in 11.47 million ha.

The economic impact of ZT/CA and iCLF adoption was estimated considering reduction in fertilizer that would be lost by water erosion without these systems (Hernani *et al.* 2002b. An economy of 1.4 billion US$ is etimated when ZT/CA is adopted in an area of 32.9 million ha, and with both ZT/CA and iCLF the value is of 1.84 billion US$.

Table 1: Annual cost reduction by mitigation of soil loss with ZT/CA and iCLF management systems.

	Unit Cost	**Annual Cost Reduction**	
	US$/ton	***million ton***	***million US$****
Dolomitic limestone	29.74	3.641	108.31
Triple superphosphate	500.24	0.236	117.82
Potassium chlorate	513.76	0.745	382.95
Urea Fertilizer	446.16	1.181	526.85
Ammonium sulfate	346.11	0.259	89.53
Organic fertilizer	37.86	16.351	618.97
Total			**1,844.44**

** US Dollar - Commercial (average value from Jan 2018 to Jan 2019): R$ 3.698.*

The economic impact of ZT/CA management system on off-farm costs, considering an area of **32.8 million ha,** were estimated in 3.67 billion USD (Table 2).

Table 2: Estimation of economic impact of the adoption of ZT/CA on off-farm costs.

Impacts	Economic Impact (USD)*
A. On-farm benefits (direct to farmers)	**943.7**
Incremental net benefits by adoption of ZT/CA compared to conventional systems due to land value appreciation	882.2
Economy in irrigation water pumping energy	61.5
B. Off-farm reductions in public spending	**164.6**
Maintenance of rural roads	128.3
Municipal water treatment	1.3
Incremental reservoir life	24.4
Reduced dredging costs in ports and rivers	10.6
C. Off-farm environmental cost to society	**487.9**
Increase in water offer due to aquifer recharge	303.2
Carbon credits for diesel economy	1.6
Irrigation water economy	17.5
Carbon credits from decrease in CO_2 emission due to lower fuel consumption, soil and biomass C sequestration	165.7
D. Benefits for mitigating de-forestation with iCLF adoption	***2077.6***
Total Benefits - annual basis	***3673.7***

*re-calculated by Freitas and Landers (2014), based on Landers *et al.* (2001).

Adoption of ZT/CA represents a radical change in agronomical practices, eliminating soil tillage, promoting agrobiodiversity (crop rotations), and keeping soil surface covered with crop residues (Machado; Freitas, 2004; Landers *et al.*, 2001b.

Conclusion

ZT/CA integrates reduction of soil revolving for different use and crop rotation, permanent soil cover, integrated pest, disease and weed management, development of productive and adapted species, varieties and cultivars, rational fertilization systems. This results from determination of farmers, extensionists, technical consultants, agricultural researchers, and professors, making Brazilian agriculture the most sustainable in the world.

The adoption of ZT/CA and iCLF systems leads to **economy of inputs** (fertilizers, seeds and chemicals), fuel and manpower, as well as public resources.

The soil conservation initiative in Brazil is marked by historical farmers and technicians' pioneers, which dedicated years to experimentation with innovative ideas, advancing the soil science towards a sustainable agriculture.

References

De Freitas, P.L. & Landers, J.N. 2014. The transformation of agriculture in Brazil through development and adoption of Zero Tillage Conservation Agriculture. *ISWC Res*., 2(1): 35-46.

De Freitas P.L., Martin-Neto, L. & Manzatto, C.V. 2007. Solos: além de tudo, sequestro de carbono. In: Revista Agroanalysis, Fundação Getúlio Vargas, *Caderno Especial: Serviços ambientais no negócio agrícola*, 27: 04, E15-E16.

FAO. 2019. Conservation Agriculture Principles. In: FAO CA Website. Available at www.fao.org/conservation-agriculture/overview/principles-of-ca/en/ [accessed 10.03.2019]

Fuentes Llanillo, R. 2018. Relation of CA to healthy farms and healthy landscapes. Invited paper presented in 21st World Congress of Soil Science, Rio de Janeiro, Brazil, 2018. Interdivisional Symposia 3.2 - Sustainable soil management. Available in https://www.21wcss.org. [accessed 10/03/2019]

Hernani, L.C., De Freitas, P.L., Pruski, F.F., De Maria, I.C., Castro Filho, C. & Landers, J.N. 2002a. A erosão e seu impacto. In: Manzatto CV, Freitas Junior E, Peres JRR. (eds.). *Uso agrícola dos solos brasileiros.* Rio de Janeiro, Brasil: Embrapa Solos, 174 p. Cap. 5. pp. 47-60

Hernani, L.C., de Freitas, P.L., Denardin, J.E., Kochhann, R.A., De Maria, I.C. & Landers, J.N. 2002b. Uma resposta conservacionista: o impacto do sistema plantio direto. In: Manzatto CV, Freitas Junior E, Peres JRR (eds.). Uso agrícola dos solos brasileiros. Rio de Janeiro, Brasil: Embrapa Solos. 174 p. Cap. 14. pp. 151-161.

Landers, J.N. 1999. How and why the Brazilian zero tillage explosion occurred. Buenos Aires: ISCO. (Proceedings...).

Landers, J.N., Barros, G.S., Rocha, M.T., Manfrinato, W.A. & Weiss, J. 2001a. Environmental impacts of zero tillage in Brazil – a first approximation. In: Congress on Conservation Agriculture. Madrid: FAO-ECAF, V. I, Chapter 34, pp. 317-26.

Landers, J.N., De Freitas, P.L., Guimarães, V. & Trecenti, R. 2001b, The social dimensions of sustainable farming with zero tillage. In: International Conference on Land Degradation and Meeting of the IUSS Subcomission C - Soil and Water Conservation, Rio de Janeiro, Brazil. Paper S6-03. 12 p.

Landers, J.N., Rass, G., De Freitas, P.L., Basch, G., González-Sanchez, E.J., Tabaglio, V., Kassan, A., Derpsch, R. & Friedrich, T. 2013. Effects of zero tillage (no-till) conservation agriculture on soil physical and biological properties and their contributions to sustainability. Proceeding of EGU Meeting 2013, Vienna, Geoph. Res. Ab., Vol. 15, EGU2013-11756-1.

Lima, M.A., Paciullo, D.S.C., Morenz, M.J.F., Gomide, C.A.M., Rodrigues, R.A.R. & Chizzotti, F.H.M. 2018. Grass forage Sci. 1–11.

Machado, P.L.O. de A. & De Freitas, P.L. 2004. No Till farming in Brazil and its impact on food security and environmental quality. In: Lal R, Hobbs P, Uphoff N, Hansen D. *Sustainable Agriculture and the Rice-Wheat System.* ed. : Marcel Dekker, Inc., Chapter 18. pp. 291-310.

Manzatto, C.V., Ramalho Filho, A., Costa, T.C. e C. da, Santos, M. de L.M., Coelho, M.R., Da Silva, EF. , De Oliveira, R.P. 2002. Potencial de uso e uso atual das terras. In: Manzatto CV, Freitas Junior E, Peres JRR. (eds.). *Uso agrícola dos solos brasileiros*. Rio de Janeiro, Brasil: Embrapa Solos, 174 p. Cap.2. pp. 13-21.

Pacheco, L.P., Pires, F.R., Monteiro, F.P., Procópio, S.O., Assis, R.L., Cargnelutti Filho, A., Carmo, M.L. & Petter, F.A. 2009. Soybean crop oversowing used as a technique to suppress weed emergence. *Planta Daninha*, 27(3) Viçosa.

Ramalho Filho, A. & Beek, K.J. 1995. Sistema de avaliação da aptidão agrícola das terras. 3. ed. rev. Rio de Janeiro: EMBRAPA-CNPS. 65p.

Socio-Economic and Policy Issues Associated with Increasing Erosion and Sedimentation in the River Basins and Coastal Zones of Kerala

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Abstract

Changing climate together with anthropogenic pressure on the environment leads to soil erosion and sedimentation in rivers and reservoirs, creating food and water crises leading to several socio-economic issues in the State of Kerala in India. Encroachment and deforestation in the Western Ghats Mountains where the rivers originate, sand quarrying from riverbeds and basins, riverbank agriculture and unscientific construction of dams cause erosion and release large amount of sediment into the rivers. Forty one rivers flow fast to the Arabian Sea through steep slopes, eroding river banks and carrying tremendous sediment loads during monsoons. Convective clouds with large raindrops and intense and highly seasonal rainfall denude the hills where forests have already been cleared. Landslides, seasonal floods and droughts hit downstream frequently. Sedimentation made seven once perennial rivers seasonal, affecting the life of thousands of poor fishermen and marginal farmers. The State that receives more than 300 cm annual rainfall starves for water in non-rainy months. Abnormal flood during the 2018 monsoon largely eroded banks of all major rivers and the resulting sedimentation leads the state to a severe water crisis. Around 63% of the coastal zone of Kerala also faces erosion. Implementation of environmental policies often fails because of socio-economic and political reasons.

Keywords: climate change, erosion, sedimentation, human impact, Kerala, water crisis, solo-economic

Introduction, scope and main objectives

The thickly populated narrow State of Kerala (Figure 1) that lies in the Arabian Sea coast of India receives more than 300 cm annual rainfall from monsoons and pre-monsoon thunderstorms. Eastern side of the State is bordered by the Western Ghats Mountain where 41 rivers originate and 41 of them flow west to the Arabian Sea. Because of the steep slope, the rivers flow fast westwards to the Sea causing large scale erosion and sedimentation in all rivers and reservoirs en-route. Of the 580 Km long coastline, 63 % is threatened by erosion (Roy Mathew, 2011). Objective of the study is to assess the impact of climate change and human interference on the environment resulting in erosion and sedimentation in rivers, reservoirs and coastal zones and associated environmental, social and economic issues. This may help developing an appropriate policy and adaptation strategy to control erosion to overcome the food and water crises.

Methodology

This paper analyses the factors affecting erosion and sedimentation in the rivers and coastal zones of Kerala and associated environmental and socio-economic issues under a changing climate and environment. Meteorological and hydrological data from the India Meteorological Department and Central Water Commission have been statistically analysed. Change in seasonality has been studied using the method suggested by Walsh & Lawler (1981). Data of daily sediment and water yield data of 10 selected west flowing rivers have been analysed using daily discharge-sediment concentration data for 20 years (1997 to 2017). The daily suspended sediment concentration (mg/l) and corresponding discharge (cusecs) data were collected. Information on socio-economic issues has been collected from the reports of Medias, NGOs and Department of Agriculture and details of landuse change have been collected from the Soil Survey & Conservation Directorate.

Figure 1: Kerala

Results

Total rainfall in the State doesn't show much inter-annual variability. However, the seasonality and intensity of rainfall show an increasing trend. Rainfall in now confined to four or five months. Intensity of rainfall has increased from around 2 cm/rainy day to around 3 cm/rainy day in three decades. In addition to monsoons, thunderstorms and tropical storms that form in Bay and Arabian Sea hundreds of kilometres away give very heavy rainfall. The State witnessed the worst flood in history during 2018 monsoon. Increasing frequency and intensity and change in the track of tropical storms result in increased wave action in the coast.

Analysis shows significant erosion in the major river basins. Northern rivers of Kerala have comparatively large sediment yield, followed by southern rivers. (Table 1). Erosion rate has significant correlation with rainfall intensity and seasonality. Most of the coastal districts experience very high erosion rates associated with wave action.

Table 1: Erosion and sedimentation in the major river basins of Kerala

River Basin	Average Yearly Sediment Load (Tones)	Erosion rate, t/km2 /year	Increase in sediment load (1997-2017) %
Valapatanam	253151	240	3
Chaliyar	438615	238	3.2
Bharathapuzha	417077	78	6
Periyar	388612	101	5
Muvattupuzha	182741	153	5.6
Meenachil	43006	94	5.3
Pamba	186208	108	5.7
Achankovil	91437	126	4.2
Kallada	131315	118	4.8
Vamanapuram	84026	164	4.1

Discussion

Characteristics of the land, type of vegetation, amount and intensity of rainfall and flow control by dams influence erosion. All rivers show an increasing trend in sediment load transport. Geographical variation in rainfall is reflected in sediment yield. Depending on particle size and flow velocity determined by slope, sediment is deposited in various parts of the river. Trends warn of an increasing stress on reliable water soon.

Encroachment and deforestation in the mountains started decades before with the introduction of plantation agriculture. Wetlands and paddy fields have been widely encroached for settlements, industries and tourism. Unsustainable quarrying of sand in the mountain, riverbeds and watersheds and agriculture in the riverbank have become common, enhancing erosion during every monsoons. Unscientific construction of dams affect land stability and release large amount of sediment into the rivers. Steep slopes of the Western Ghats Mountain where all rivers originate permits fast flow of water to the Sea, eroding the already degraded mountain soil. This is deposited in the rivers and reservoirs. Erosion increases with increasing seasonality and intensity of rainfall. Convective clouds with large raindrops denude the hills where forests have already been cleared (Nair, 2009). Landslides are becoming common. Seven of the once perennial rivers have become seasonal in last five decades, affecting the life of thousands of poor fishermen and marginal farmers (Nair, 2007). Sedimentation has reduced the capacity of the major reservoir Idukki by 30 %. Erosion and sedimentation were the factors that increased the severity of the disastrous flood during monsoon 2018. Inefficient dam management worsened the condition. Erosion in river basins was abnormally high and caused widespread damage to nearby buildings. Tremendous loads of sediment deposited in rivers and wetlands significantly reduced water availability. Water table has receded abnormally and in early 2019 itself, this heavy rainfall region is heading towards a major water crisis. Groundwater in level in the state has already depleted by more than a metre in two decades.

Erosion and sedimentation leads to several socio-economic issues related to food and water such as falling availability of reliable water that leads to pricing of water, hiking price of food products, suicide of farmers facing loss in agriculture, internal migration and conflicts over allocation of water and food. In the thickly populated coastal zones, internal migration has become a serious issue. Shortage of reliable water is more severe in these areas. Hundreds of people lose their houses and agriculture every year. Unscientific construction of sea walls produces adverse effect (Mongabay, 2017). Sediments carried by the rivers to the Cochin estuary is a threat to the existence of the major port that may affect the State's revenue significantly.

Dredging for inland navigation will have severe consequences in near future. Measures for food and water security, widening and deepening of canals for inland navigation, new settlements and promotion of hill tourism may encourage more encroachment into the forests and river basins. Possible changes in rainfall intensity and runoff associated with global anomalies will have added effect on erosion.

Conclusions

Human impact on the land and water resources and the natural climate change lead to widespread erosion and sedimentation in Kerala, affecting river runoff and water availability. This is a threat to the securities in food, water and energy. Impact of increasing population and industrial and economic development associated with globalisation is a new challenge. Erosion and sedimentation have indirect impact on the society. They create disputes over resources allocation and widen economic impact. Peculiar social, political and economic conditions and high level of corruption in the government sector in the State make implementation of rules and regulations to control human interference on the environment difficult. State government has initiated several soil conservation measures such as arable land treatment, earthen bunds, coir geo textiles, check dams, stone pitched and graded contour bunds, vegetative hedges, trenches, strip terraces, moisture conservation pits, agrostological measures, agroforestry, drainage line treatments, stream bank stabilization, farm ponds & water harvesting structures, percolation ponds, spring water development/aquifer protection and well recharge, but, the progress is very slow.

Kerala should urgently take measures for erosion control such as planting strong rooted native plants and mangroves along river banks and coasts, promotion of environmental hill tourism and afforestation programmes. The State also needs an efficient dam and river management, an appropriate policy for land, water and environment and an effective mechanism for the implementation of rules and regulations. Political morality and effective control of shadow economy becomes necessary. There should be better coordination among various government agencies involved and an increased public participation in development programmes. Proper awareness on environmental issues, on the rights and duties of a citizen and on the utilization of available legal mechanism could improve the condition. Since finance is a major hurdle in realising development projects and adaptation measures, private sector participation may be sought, but with strict control by the Government. More powers may be handed over to the local self governments for the control of activities leading to erosion and for the protection and management of riverine and coastal environments. In the peculiar social setup in the state, only a strong political will without vested interests and partiality can improve the situation.

References

Mongabay. 2017. Coastal erosion is chipping away at homes in Kerala, displacing hundreds. Available at: https://scroll.in/article/884068/coastal-erosion-is-chipping-away-at-homes-in-kerala-displacing-hundreds [accessed 08.03.19].

Nair, G.K. 2007. Major rivers in Kerala losing course, *Business line*, pp2-3.

Nair, K.S. 2009. Rainfall characteristics of the Western Ghats region, *Project report submitted to CEREM,* P9.

Roy, M. 2011. 63 percent of Kerala coast faces erosion. *The Hindu.* Available at: https://www.thehindu.com/news/national/kerala/63-per-cent-of-kerala-coast-faces-erosion/article2104112.ece [accessed 03.03.19].

Walsh R.P.D. & Lawyer D.M. 1981. Rainfall Seasonality: Description, Spatial Patterns and Change Through Time. *Weather,* 36(1): 201-208.

Policy framework on soil erosion and land degradation from the post conflict perspective of Bosnia and Herzegovina

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Abstract

B&H is a post-conflict society and developing country facing serious challenges in sustainable land management, including poor socio-economic development and widespread perception of land as a less important resource. During the Land Degradation Neutrality Target Setting Process in B&H, land degradation status as well as drivers of land degradation were assessed in order establish the current state of land resources and plan for achieving the LDN target by 2030, in line with the LDN Global Agenda. Identifying and understanding land degradation drivers is critical for sustainable land use planning as well as the prevention of further soil degradation. Identifying the current state and pressures on land is a prerequisite for creating the necessary policy framework to achieve LDN from the local to the national level. However, the existence of a land-related policy framework may not be enough in a developing country where the supporting environment for implementation may be weak, and where the perception of decision makers varies. Some local government, for example, perceive some land degradation drivers e.g. floods, drought, landslides, as very important because these drivers affect them directly. In contrast a driver like soil erosion, this is less directly visible, and might be perceived as a “scientific” problem. This paper is aimed to present a policy framework related to land degradation, and particularly soil erosion, to efficiently address main challenges from the post conflict perspective of Bosnia and Herzegovina.

Keywords: land degradation drivers, soil erosion, legislation, implementation

Introduction, scope and main objectives

Land degradation (LD) and associated soil erosion is an important challenge in Bosnia and Herzegovina (BiH) due to unsustainable land management ongoing for the last 25 years. BiH is a sovereign state with parliamentary state regulation and a decentralized political and administrative structure. Land and land resources are under exclusive jurisdiction of two entities (the Republic of Srpska Entity and Federation of Bosnia and Herzegovina Entity); therefore, land is regulated by the Entity-level rather than State-level legislation. The only land-related strategic document at the state level is the Action Program (AP) to Combat Land Degradation and Mitigate the Effects of Drought in Bosnia and Herzegovina (UNEP, 2017), while the main strategic documents are adopted and implemented on entity level. Since 2016, the Land Degradation

Neutrality (LDN) Target Setting Process has been started in B&H (separately by entities), whereby main LD drivers are identified together with assessment of land resources, and wherein targets and associate measures are planned separately by each entity (Kapović Solomun, 2018; Čustović and Ljuša, 2018). Moreover, land monitoring systems have not been developed, so there are no exact data, complicating any estimation related to conditions of land resources in BiH, including soil erosion. Furthermore, the implementation of the existing policy framework is challenging under such a complex political and administrative structure. Policy and legal frameworks often mainstream sustainable land management (SLM) practices, but significant barriers exist for their effective implementation (Kapović Solomun *et al.*, 2018).

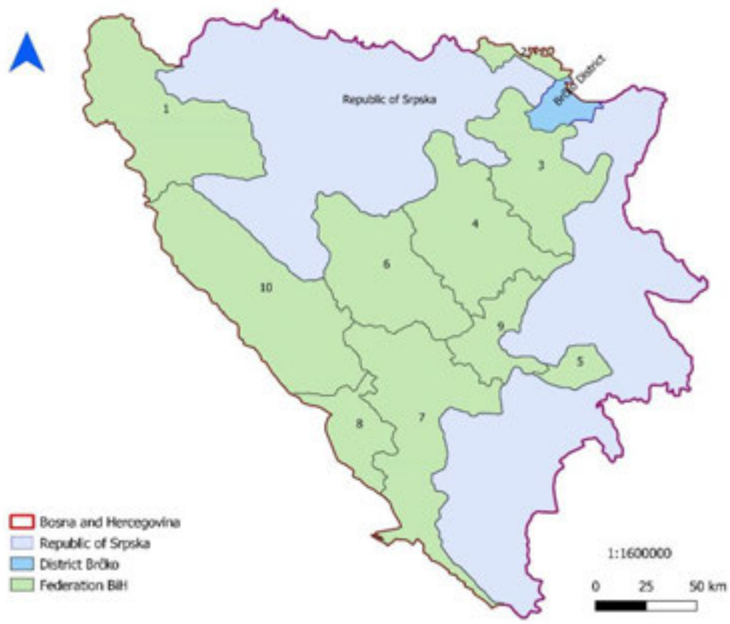

Figure 1: Administrative structure of BiH.

This paper is aimed to present a policy framework related to land degradation, particularly soil erosion, to efficiently address main challenges from the post conflict perspective of Bosnia and Herzegovina.

Methodology

Methodology is based on comprehensive review of existing national, entity and local policy frameworks in line with international commitments of Bosnia and Herzegovina in addressing land degradation (including soil erosion).

Results

BiH ratified the United Nations Convention to Combat Desertification (UNCCD) in 2002, recognizing the importance of land degradation and committing to Convention implementation, together with some EU Directives based on global policy documents. However, in reality addressing land degradation is very complex in BiH. This includes the decentralization and jurisdiction over lands that are reliant on Entity levels, together with complex political communication among institutions that together present great challenges for SLM. The existence of a defined policy framework sometimes is not sufficient to address environmental problem on the ground, including land degradation (Marković and Brujić, 2017). Furthermore, knowledge and awareness of decision makers about land is variable and often insufficient, and general public perception about land is not favorable. LDN processes in BiH revealed several land degradation drivers including: population migration and land abandonment, weak implementation of policy frameworks to protect the land; soil erosion, floods and drought; illegal felling that is conducive to erosion and landslides; industrialization and expansion of the area under exploitation of minerals as well as the landfills of mining waste; inadequate agricultural systems. Unfortunately, significant amounts data (e.g. Map on Soil Erosion of BiH) were destroyed during the Bosnian War (Witmer and O'Loughlin, 2009). Today BiH lacks reliable data and is behind on soil/land related research from the last century. The latest research on soil erosion in BiH dates from 1985, when a Map of Soil Erosion of BiH was developed by Lazarević (1985). Unfortunately that map has not been updated and moreover, data disappeared during the conflict period in Bosnia (Tošić, 2007). Since 2004 part of soil of the erosion map was reconstructed, but only for the Republic of Srpska territory (Tošić and Hrkalović, 2009; Tošić *et al.*, 2012).

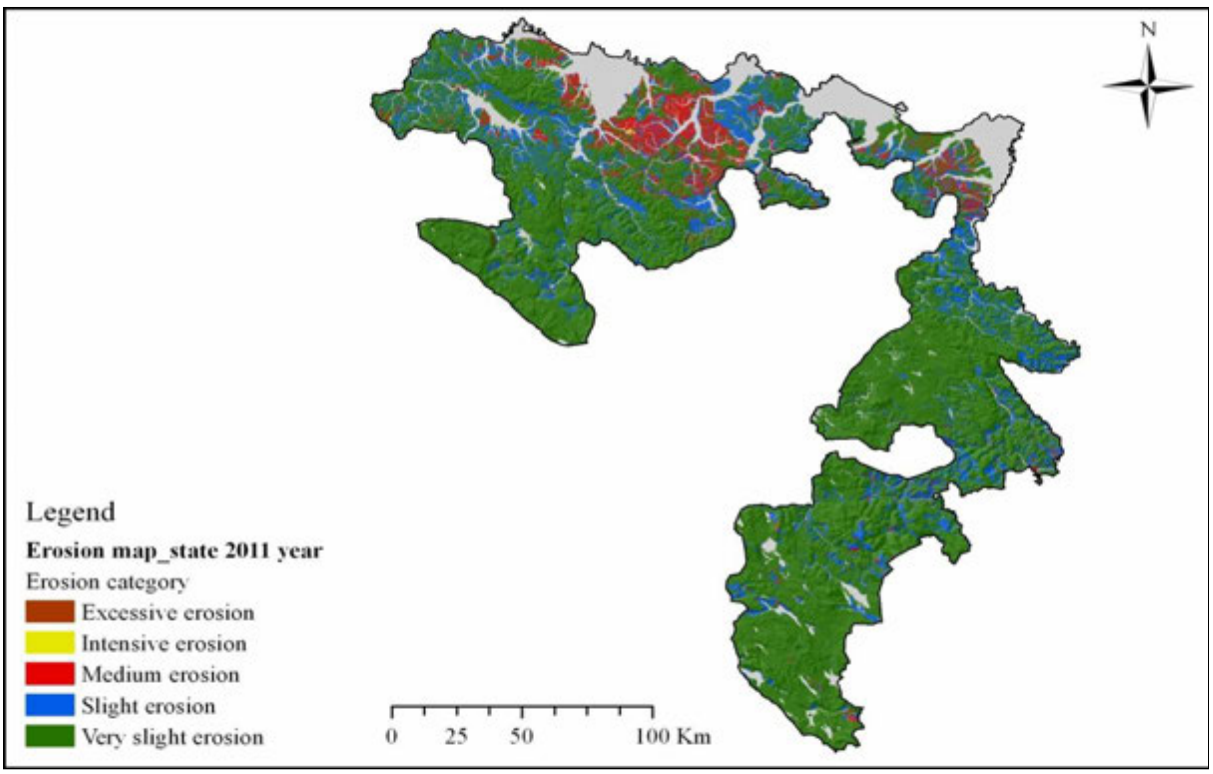

Figure 2: Erosion Map state in 2011 in the Republic of Srpska (Tošić *et al.*, 2013)

Existing legislative framework on the Entity and local levels does not recognize soil erosion explicitly and there is no law on soil erosion. Main laws on the Entity level that indirectly address soil erosion are: Law on Water (Official Gazette of Republic of Srpska no. 7/06, 20/07, 86/07, 71/09), Law on Agriculture of the RS (Official Gazette of Republic of Srpska no. 7/06, 20/07, 86/07, 71/09), Law on Agricultural Land of the FBiH (Official Gazette of FBiH, no. 52/09), Law on Agricultural Land of the RS (Official Gazette of FBiH, no. 93/06, 86/07, 14/10, 5/12), and Law on Forestry of the Republic of Srpska (Official Gazette of Republic of Srpska no. 75/08, 60/13), Law on Spatial planning and Construction of the Republic of Srpska (Official Gazette of

Republic of Srpska no. 55/10), Law on Spatial Planning and Land Use of FBiH (Official Gazette FBiH, no. 2/06) and Law on Environmental Protection of the Republic of Srpska (Official Gazette of Republic of Srpska no. 71/12) etc. In regards to the local policy framework and land use planning, legislation prescribes obligations for local governments to create local strategies on Land use planning. In the Republic of Srpska Entity, the majority of local communities did not create and adopt this strategy, due to the weak economic situation. However, after the LDN process where the Government took strong leadership, numerous local communities started with development of this important strategic document.

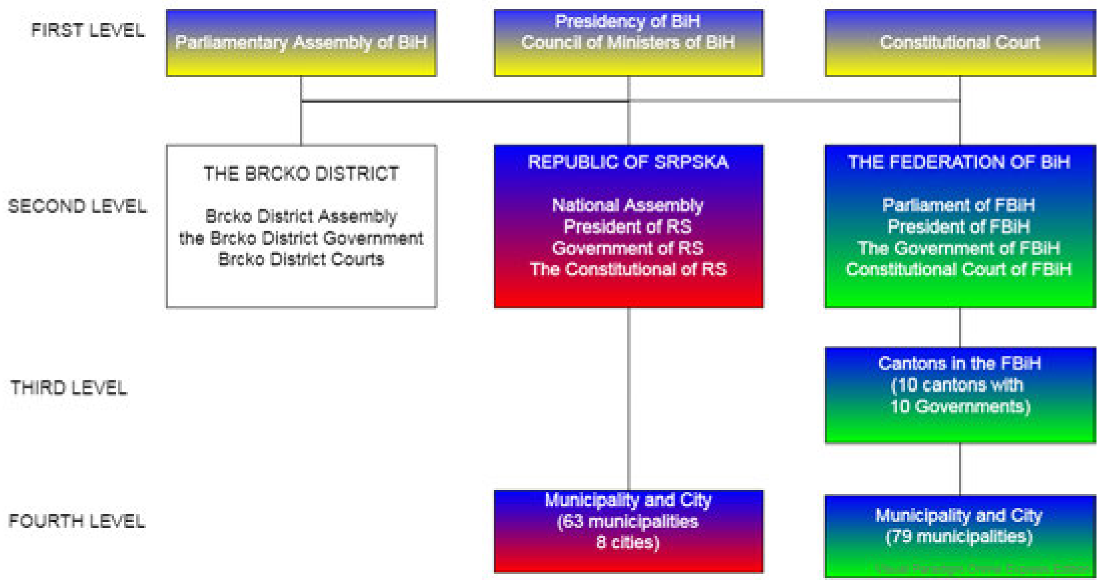

Figure 3: Governance structure of Bosnia and Herzegovina

The Ministry of Agriculture, Forestry and Water Management of the RS (MAFWMRS) and the Ministry of Agriculture, Forestry and Water Management of the FBiH are the main institutions on the Entity level responsible for land and soil erosion. There are also other Ministries with jurisdiction related to land. Protection from soil erosion is important segment of water legislative framework, for example. MAFWMRS monitors and implement activities related to the development of documentation to determine erosion areas, erosion types, intensity etc. in accordance with Law on water, including prohibitions in the erosive areas. In FBiH, the implementation of strategic documents and legal acts is aggravated by the fact that the Federation of BiH has ten cantons that each have their own competences for land management, environmental and spatial planning. The cooperation of relevant ministries is not at a satisfactory level, as the strategies of various sectors are not harmonized. This creates additional pressure on land as well as conflicts (Čustović and Ljuša, 2018). The strategic framework follows existing policies, but national allocations for implementation of prescribed action plan are very limited, and many activities rely on international resources.

Discussion

Considering the complex political and administrative structure of BiH, where land-related competences are at the entity level, the appropriate implementation of the existing legal and strategic framework and their synchronization and mutual co-ordination is of great importance to combat land degradation. As a post-conflict society with a weak socio-economic situation, BiH is often faced with the misunderstanding of the importance of land conservation, not only by decision makers but also by the population itself. Also, Civil

War contributed to the destruction of valuable data, which implies the need for further research to update what has been done in the past Century. Land related issues most often rely on the academic community and non-governmental organizations, particularly in regards to understanding the consequences of soil erosion and soil degradation. Existing strategic and legislative frameworks have many disadvantages, but even as such (if implemented appropriately) land degradation issues would be addressed more effectively. However, the implementation of the legal framework is not effective, and the system of control often fails. The lack of data on land erosion as well as land monitoring makes it difficult to assess real land condition and to define priorities. Also, the existing land use planning system differs between entities and cantons in FBiH. Thus, the complexity of the legislative and strategic framework also creates complexity in approaches and implementations. In an environment with rising corruption, this presents a significant challenge to reduce, restore and reverse land degradation, starting from the local to the entity level and state level. This research has shown that political and administrative organizations have a significant influence on the implementation of land-related legal and strategic frameworks. In addition, the socio-economic impact of land perception is of great importance.

Conclusions

- The existence of a policy framework is important, but not sufficient if implementation is weak;
- Complex political and administrative structures complicate implementation of SLM, including soil erosion;
- Land degradation starts on the local level, so local decision makers play an important role in soil protection, particularly from a land use planning perspective;
- Stronger cooperation between science and policy is needed to improve land data exchange and the usage of scientific knowledge to address land degradation, such as soil erosion, through the introduction of new SLM;
- Development of a new, updated Soil Erosion Map of BiH is key to identify current soil erosion intensity and serve as a strategic document for development of Cadastre of torrents and torrent watersheds;
- Raising awareness and knowledge is generally important, especially at the local level. Existing agriculture advisory services under Governments should include more extensive education about soil erosion.

References

Kapović Solomun, M., Barger, N., Keesstra, S., Cerda, A. & Marković, M. 2018. Assessing land condition as a first step to achieving Land Degradation Neutrality: A case study of the Republic of Srpska. *Environmental Science and Policy*, 90: 19-27.

Kapović Solomun, M. 2018. Program dostizanja neutralnosti degradacije zemljišta u Republici Srpskoj, Banja Luka (Final report on Land Degradation Neutrality Target Setting Program in the Republic of Srpska, Banja Luka). Available at: http://www.vladars.net/srSP-Cyrl/Vlada/Ministarstva/mps/Documents/LDN%20TSP%20Report%20za %20Republiku%20Srpsku_470474363.pdf.

Lazarević. 1985. Soil Erosion Map of the Bosnia and Herzegovina, Sarajevo.

Law on Agriculture of the Republic of Srpska (Official Gazette of Republic of Srpska no. 7/06, 20/07, 86/07, 71/09).

Law on Agricultural land of the FBiH (Official Gazette of FBiH, no. 52/09).

Law on Agricultural Land of the Republic of Srpska (Official Gazette of FBiH, no. 93/06, 86/07, 14/10, 5/12).

Law on Environmental Protection of the Republic of Srpska (Official Gazette of Republic of Srpska no. 71/12) etc.

Law on Forestry of the Republic of Srpska (Official Gazette of Republic of Srpska no. 75/08, 60/13).

Law on Spatial planning and Construction of the Republic of Srpska (Official Gazette of Republic of Srpska no. 55/10),

Law on Spatial Planning and Land Use of FBiH (Official Gazette FBiH, no. 2/06)

Law on Water (Official Gazette of Republic of Srpska no. 7/06, 20/07, 86/07, 71/09),

Marković, M. & Brujić, J. 2017. Overview of the natural resource management in Bosnia and Herzegovina. In: Dragovic, N., Ristic, R., Pülzl, H., Wolfslehner, B. (Eds.), *Natural Resource Management in Southeast Europe: Forest, Soil and Water.* Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Skopje, pp. 87–130 ISBN: 978-608-4536-07, Chapter 2.

Tošić, R. 2007. Problem erozije i upravljanje nanosom u Republici Srpskoj, Zbornik radova sa naučnog skupa “Srbija i Republika Srpska u regionalnim i globalnim procesima”, Beograd - Banja Luka.

Tošić, R., Dragićević, S. & Lovrić, N. 2012. Assessment of soil erosion and sediment yield changes using erosion potential method - Case study: Republic of Srpska – BiH. Carpathian Journal of Earth and Environmental Sciences, 7 (4), 147-154

Tošić, R. & Hrkalović, D. 2009. Inovacija karte erozije Republike Srpske, Voda i mi, Časopis agencije za vodno područje rijeke Save Sarajevo, Vo. 65, pp.54-66. Sarajevo.

Tošić, R., Kapović, M., Dragićević, S. & Lovrić, N. 2013. Assessment of soil erosion potential using RUSLE and GIS: A case study of Bosnia and Herzegovina. *Fresenius Environmental Bulletin*, 22 (11a), 3415-3423.

Šarić, T. & Sijahović, E. 2015. Održivo korištenje zemljišta na nagibima kao način smanjenja poplava i šteta od njih u poljoprivredi. Simpozijum “Upravljanje rizicima od poplava i ublažavanje njihovih štetnih posljedica”, Sarajevo.

United Nations Environmental Programme (UNEP). 2017. Action Program for Combat Land Degradation and Mitigate the Effects of Drought in Bosnia and Herzegovina. UNEP, Sarajevo, Bosnia and Herzegovina. http://www.unep.ba/tl_files/unep_ba/PDFs/BHAP_eng_FINAL.pdf.

Čustović, H. & Ljuša, M. 2018. Finalni izvještaj o programu dostizanja neutralnosti degradacije zemljišta u Federaciji Bosne i Hercegovine, Sarajevo (Final report on Land Degradation Neutrality Target Setting Program in the Federation of Bosnia and Herzegovina, Sarajevo).

A Generic Policy and Implementation Model to Address Soil Erosion

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Abstract

A policy and implementation framework is proposed to counter the threat soil erosion poses to nutrition and global food security. Its synthesis involves identification of the generic causes of soil erosion and means of addressing them and mapping them onto policy domains concerned. Survey and research are incorporated into the model to ensure its relevance and flexibility, and enable its revision. Inter- and intrapolicy harmony among the constituent policies and their Recursive implementation are essential for its success.

Keywords: Distributed policy, Recursive design and implementation, Intra and inter-policy Harmony, Relevance, Appropriateness, Prevention, Soil Restoration

Introduction, scope and main objectives

The consequences of human activities have exacerbated the erosive effect of daily temperature fluctuations, wind and rain on top soil leading to a quantitative and qualitative loss of world's arable land. This has serious direct implications for global nutrition and food security. Its impact on climate reduces the ecosystems services available to agriculture and ecological recovery, creating a dangerous circular chain reaction which progressively diminishes soil fertility and worsens the climate. This paper suggests a policy and implementation framework to address the problem.

Methodology

First, the significant causes and distribution of soil erosion at global, regional or local level are identified. This is followed by a compilation of the most appropriate means of their prevention and the greatest possible restoration.

Next step undertakes a holistic mapping of those causes and appropriate means of addressing soil erosion onto all the areas of policy concerned. How these means are applied within a policy domain is embodied in the implementation of that element of the policy involved.

Flexibility and relevance of the framework are sustained by timely surveys to estimate the changes in qualitative and quantitative dimensions of the problem and its resolution. Its enhancement involves periodic revisions as required by those estimates, and/or the use of better means that may be uncovered by technical research.

Its successful use depends on the completeness and appropriateness of the structure of the framework and how competently it is implemented. The two former are ensured by a holistic analysis of the problem and a synthesis of the proposed solution recursively relative to the politico-geographic areas involved, and some policy suggestions on ensuring the requisite competence have been incorporated.

As for terminology, every effort has been made to use standard terms, where a new one has been introduced, it is given in 'bold' type, and its meaning as used here, made amply clear in the text.

Development of the Policy and Implementation Framewor

Soil erosion results from activities undertaken in diverse areas coming under different policy domains, for instance, agriculture, log trade and transport may lead to deforestation. Therefore, a policy to address it and its implementation will have to be incorporated into all the policies involved. But, restoration of the eroded land is often beyond the competence of most of those who design and implement the policies concerned with erosive activities.

The question of sovereignty limits the domain in which a policy may be implemented. Using the terms global, regional and local in their technical sense, this difficulty may be overcome by resorting to recursive policy design and implementation as follows. When world-wide

Applicability is desired; a global policy will have to cover every known cause of soil erosion, means of their prevention and eroded soil restoration.

But limits on the sovereignty of international organizations and distribution of the causes of erosion makes it pragmatic to confine the design and implementation of a global policy on soil erosion to providing guidance and technical and other help generally beyond a regional group or a country. It may also include strategic persuasion and inducements to authorities to encourage them to adapt better policies and modes of implementation to address the problem.

Apart from the EU, legal and resource-related considerations may limit the range of the coordinated regional efforts to address the problem. Thus in addition to the foregoing, a regional policy framework would have to be tailored to address only the shareable aspects of the problem. Here, a regional policy is technically global within it while national and sub-national authorities would be responsible for its regional and local elements respectively. Uneven qualitative and quantitative distribution of the causes of erosion within a nation would make it necessary to regionalize and localize the design and implementation of the national policy which would be global for the country.

The success of the present framework depends on three of its structural attributes and how skilfully it is implemented. Those are a framework compatible with the sovereignty of the politico-geographic zone to which it applies, the harmony among and within each policy domain and a mechanism employed to identify the relevant causes of the problem and the appropriateness of the means used to address it.

A policy consists of several elements, some of which may embody components of another one. Labour and finance policies are often ubiquitous in this respect. Mutual support among such elements represents intra-policy harmony. Similar support among various policies towards their own objectives indicates inter-policy harmony.

Appropriateness of a means involves its effectiveness and its practicability relative to the human and other resources needed to put it into timely use at a given place. Thus, the most effective or modern means may not always be the most appropriate.

Now it is easy to develop a suitable policy and its implementation strategy relative to a given politico-geographic area, and the causes of soil erosion involved. Even though some knowledge of such causes is already available, it would be sound practice to undertake a comprehensive survey to gather as much data as possible to enhance the ongoing policy design. In addition to the research institutions, much useful information may be obtained from concerned farmers, environmental groups, citizens, etc.

This would be followed by a similar survey to ascertain the known effective means of preventing erosion and restoring the eroded areas by enabling them to acquire some degree of green cover. Traditional knowledge based on experience would be useful here, for some past methods of agriculture promoted soil erosion and it is likely that some remedies have been developed to counter it.

It is difficult to envisage the usefulness of any research on prevention here, for it only needs a sound legal framework which is enforced with impartial vigour. Therefore, this provision should be incorporated into policies governing those areas wherein actions promoting soil erosion are undertaken.

Restoration of the eroded soils is an area where much research remains to be carried out. Improved design of contoured ditches or walls, ways to preserve rain water in situ, identification of those endemic species suitable as green cover or wind breaks, how to achieve maximum restorative vegetation with minimal irrigation and fertilizer use, etc., are among the most important research areas here.

No mention of research has been made in connection with the initial survey because it would be redundant. Some modern surveying methods may prove too expensive to some countries where the problem is acute. There, it would repay to use the scarce resources on immediate preventive and remedial action and would thus be more appropriate.

Next, the causes of soil erosion are mapped onto the appropriate policy areas. A given generic cause for instance, deforestation may come under the policies governing industrialization, agriculture, local government, trade, environment, etc. It is crucial that this mapping out is as complete as possible for reasons that will become clear later on.

Once all the relevant policies are linked to a generic cause of soil erosion, one can begin to assign means of prevention and restoration appropriate to each policy domain.

For instance, the scarcity of arable land may compel subsistence farmers to clear the forest from a hill-side while illegal logging there would have the same result indicating ineffective law enforcement. Inept agricultural and/or legal policies would likewise promote extensive monoculture on open plains. Inappropriate policy on development/trade may advocate introduction of some cash-crop by capital-intensive monoculture resulting in a catastrophe like the Aral Sea disaster.

One may now envisage a set of the relevant policy domains from which pointers would indicate the one or more generic cause of soil erosion brought about by the activities carried out under its ægis.

Effective means of its prevention and restoring eroded soil are listed under each of their causes.

Then, it would be easy to match to a policy domain the appropriate elements it should it embody to prevent soil erosion and to undo the harm as far as possible. A cause of erosion may be mapped onto more than one policy domain. Thus, the completed policy on addressing soil erosion represents a cluster of policy elements distributed among several relevant domains.

The completed model may be envisioned as constitutive of a set of relevant policy domains, each embodying the elements required to address soil erosion insofar as the jurisdiction and the competence of its implementers would permit. Surveys and research noted above, and dissemination of information acquired by them is best undertaken by one or more suitable agencies to serve the others. While prevention remains matter of enforcing pertinent laws, industrial and agricultural research on methods that do not lead to significant erosion are logically subsumed by the legal requirements to undertake them. Hence, only their effective enforcement and not research is preventive of soil erosion.

The limited extent of the available know-how makes it difficult to identify any single institution as the most suited to the development and application of sound means of restoring the eroded soils. Agriculture appears to be a good choice, but in most countries where the problem is acute, resources at the disposal of the authorities concerned, is scarcely adequate for food production. A world-wide and/or regional approach seems to be the most tenable option here.

The last component of the model is how each relevant domain is to implement its complement of the policy. Preventive strategies available here are legal requirements to halt the use of practices resulting in erosion and requiring the use of more benign methods and research thereto. Regional and local implementation of this strategy may require the design of suitable regional and local policies and appropriate ways of putting them into practice. It will be noted that as one proceeds down from the global level, policy and strategy involved become increasingly specific until it manifests itself as field work.

Discussion

This model unifies various fragmented research, surveys, and legal instruments etc., related to the present problem into a policy channel towards its practical resolution. It identifies the justifiable location each of those efforts may occupy in a holistic scheme with respect to their value in enabling one to address soil erosion.

While emphasizing the necessity of having a suitable distributed policy to channel the problem-specific work towards a unified objective, its generic character enables the policy makers at a given level of sovereignty to deploy various types of available expertise in appropriate niches for their optimal utilization in achieving a larger objective. It gives them a dynamic tool of great flexibility open to evolutionary improvement.

Conclusions

The suggested model seems to fulfil the urgent need for a template to mould the ongoing multifarious efforts to address soil erosion into a holistic and pragmatic means of achieving that objective. It allows the elements of this endeavour such as research, surveys, preventive and restorative actions to be tailored to actual needs, thus enabling the optimal use of resources.

Although it is restricted to addressing soil erosion, reader would perceive that the complexities of modern life would make this approach seems to be necessary in most other problem areas, for unless effectively coordinated and directed by an appropriate unifying policy framework towards a greater objective, isolated efforts of high repute on problem resolution would be of limited value.

Western Balkan Countries vs. Mediterranean Region Policy on Soil Erosion

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Abstract

The western Balkan Countries and the Mediterranean region is particularly prone to erosion. This is because it is subject to long dry periods followed by heavy bursts of erosive rainfall, falling on steep slopes with fragile soils, resulting in considerable amounts of erosion. This contrasts with NW Europe where soil erosion is slight because rain falling on mainly gentle slopes is evenly distributed throughout the year. With a very slow rate of soil formation, any soil loss of more than 1 t/ha/yr can be considered as irreversible within a time span of 50-100 years. Losses of 20 to 40 t/ha in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t/ha in extreme events. Though protection provisions indirectly contribute to the protection of soils in the Community acquis in areas such as agriculture, water, and environment, there is no specific EU legislation on soil protection, and only a few Member States have specific legislation on it

Keywords: soil erosion, WBC, Mediterranean, legislation, policy

Introduction, scope and main objectives

This study aims at specifying the possible obstacles, differences, and gaps between the goals set by the Directive and the legislature and administration in the countries that formed the blocking minority, resulting in the refusal of the Directive. The current study focuses on the legislative and administrative aspects present in the five countries and does not aim to make a comprehensive assessment for all EU Member States, nor an assessment of any political or economic motivation that may be present when regulating the protection of soil resources. Though protection provisions indirectly contribute to the protection of soils in the Community acquis in areas such as agriculture, water, and environment, there is no specific EU legislation on soil protection [6], and only a few Member States have specific legislation on it [1].

Methodology

The materials used in the research part of the study include the Soil Framework Directive, and English citations of legal documents of the Western Balkan Countries, Mediterranean countries (other than Albania), and EU countries, blocking five Member States at national, regional and local levels. The sources were the official governmental websites, the official website containing EU laws (EUR-Lex), and national legal experts' contributions (e.g., websites, articles, and comments). The different types of legal acts [2], such as: Regulations—binding legislative acts, which must be applied; directives—legislative acts that sets out goals; decisions—binding on those to whom they are addressed and are directly applicable; recommendations; communications; and opinions were assessed according to the level of legal obligation they represent.

Results

Erosion, organic matter decline, salinization, compaction, and landslides were addressed within the legal framework. Within five years from transposition date, Member States should have identified the risk areas in their national territory, where there was evidence or suspicion that one or more soil degradation processes had occurred or would have been likely to do so in the near future. Member States may have based the identification of risk areas on empirical evidence or on modelling. The risk areas were to have been reviewed every ten years. Under each risk area, Western Balkan Countries and EU Member States were to draw up a program of measures including risk reduction targets, the appropriate measures for reaching those targets, a timetable for implementation, and an estimate of the funding allocation. Member States were encouraged to use their own existing monitoring schemes and improve them if necessary. Different programs have been built on measures already implemented at national and EU level (such as cross-compliance and rural development under the Common Agricultural Policy (CAP), codes of good agricultural practice and action programs under the Nitrates Directive, future measures under the river basin management plans of the Water Framework Directive, national forest programs and sustainable forestry practices, and forest fire prevention activities). These approaches to combat threats to soil should have been combined as well, benefiting in particular those Member States, which had already been addressing soil loss

Discussion

At present, neither the preservation of soil functions nor the management of soil threats are comprehensively regulated by the EU legislator, and soil protection seems to be merely the by-product of different provisions which are mainly preventive, qualitative, and non-strictly binding [5]. The Directive would not necessarily have exceeded these in mandatory authority but could have provided a legal background for the enhancement of these issues and served as legal reference beyond national governments [6]. The Member States of the EU did not reach a political agreement about an overarching legislative control system over soil protection. Western Balkan Countries, The UK, Germany, France, Austria, and The Netherlands have argued that the new Directive would not respect the principle of subsidiarity and would interfere with domestic soil policy. Their objection was specifically about Member States' rights in the EU. The British and German governments claimed that unlike air and water, soil is not a cross-border issue and therefore the EU had no right to regulate it [7]. They were concerned about the extra costs of soil protection in other, possibly more problematic Member States and additional policy obligations, as well as a possible restriction on housing developments, and criticised the proposal on the grounds that it would lead to disproportionate cost with a negligible environmental benefit. As public concern over sovereignty and bureaucracy within the EU increased, these governments saw the proposed EU legislation as unnecessary meddling in an area best dealt with at the local level. Farmers lobbied intensely against the legislation too. It was also argued that soil is already protected under such EU legislation as the CAP [8]

Conclusions

Results of our gap analysis suggest that—although legislation related to soil protection may be fragmented in some states—overall gaps in the contents of soil protection legislations are rather narrow among the Mediterranean, WBC and EU member states. Thus, given that an agreement on the control of soil sealing can be reached, technical solutions are available to support the construction of a common political will to introduce a common soil protection legislation in the EU, and WBC as well as Mediterranean countries.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

References

Musaraj A. & Janku K. 2017. Legal framework of western Balkan countries on preventing soil erosion. *Environmental Management*, 48: 490–499.

Abu Hammad, A. & Borresen, T. 2006. Socioeconomic factors affecting farmers' perceptions of land degradation and stonewall terraces in Central Palestine. *Environmental Management*, 37: 380–394.

Alberti, M. 2005. The effects of urban patterns on ecosystem function. *International Regional Science Review*, 28: 168–192.

Arhonditsis, G., Giourga, C., Loumou, A. & Koulouri, M. 2002. Quantitative assessment of agricultural runoff and soil erosion using mathematical modeling: applications in the Mediterranean Region. *Environmental Management*, 30: 434–453.

Barrow, C.J. 1990. *LAND DEGRADATION - Development and Breakdown of Terrestrial Environments*. Cambridge University Press: Cambridge.

Hillel, D. & Rosenzweig, C. 2005. The role of biodiversity in agronomy. Advances in Agronomy 88: 1–34. Hussein MH. 1998. Water erosion assessment and control in Northern Iraq. *Soil and Tillage Research*, 45: 161–173.

Issac, J., Hirimat, N., Qumsiya, V. & Uweiwi, M. 1997. Encyclopedia of the Palestinian Environment (First Volume)- Environmental Features. ARIJ: Bethlehem.

Johnson, D.L. & Lewis, A.L. 1995. Land degradation, Creation and Destruction. Blackwell: Oxford.

Lubwama, F.B. 1999. Socio-economic and gender issues affecting the adoption of conservation tillage practices. In Conservation Tillage with Animal Traction, Kaumbutho P, Simalenga T, (eds). Animal Traction Network for Eastern and Southern Africa (ATNESA): Harare; 155–162.

Promoting the Adoption of Soil Conservation Practices in Manitoba

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Abstract

Zero tillage has been practiced in Manitoba since the 1970s, with the widest adoption occurring in the late 1990s. However, the percent of cropland under zero tillage has plateaued around 25%, mostly due to a wide range of soil types and moisture regimes in the province. Regions with heavy clay soils have had almost no adoption of zero tillage due to the excess moisture inhibiting crop residue break down and proper drying/warming of the seedbed. Manitoba Agriculture offers incentive programming to farmers not only to adopt zero tillage, but also other conservation techniques such as the use of cover crops and perennial forages to protect the soil from erosion. Using a combination of conservation practices to help deal with extreme wet and dry periods may increase the adoption of zero tillage or conservation tillage practices, even in the regions that have typically been conventionally tilled.

Keywords: Zero Tillage, Manitoba, Soil Conservation, Incentive Program

Introduction

Zero tillage has had a long history on the Canadian prairies, having been first tried in the 1970s as a soil erosion and moisture conservation tool. Much of the prairies experienced periods of extreme drought in the 1970s and 1980s, which led to increased interest in direct seeding into last year's crop stubble. Standing stubble allows for snow capture during the winter months, improving soil moisture levels in the spring, as well as reducing evaporative losses. Additionally, the elimination of tillage not only decreases the risk of tillage erosion in hilly landscapes, it also improves soil structure making the soil less susceptible to wind and water erosion.

Historical Change in Tillage Practices

The adoption of zero tillage in Manitoba has been mostly restricted to the Western side of the province. The soils in this region have historically been drier with more rolling topography at risk of tillage erosion. While the early adoption of zero tillage began in the 1970s and 1980s, wider adoption did not begin until the later 1990s (Table 1), primarily due to the continued dry weather conditions in Western Manitoba, as well as increased equipment availability and the lower cost of glyphosate.

Table 1: Reported Land Use and Tillage Practices in Manitoba (1991-2016). Source: Statistics Canada

	1991	1996	2001	2006	2011	2016
Total Farmland Acres	19 088 868	19 106 531	18 784 407	19 073 005	18 023 472	17 637 639
Total Cropped Acres	11 764 813	11 611 844	11 650 599	11 616 450	10 746 290	11 530 095
Total Seeded Acres	10 425 498	9 781 611	9 693 855	9 613 927	9 223 901	10 300 825
Summerfallow (as % of cropland)	6.2 %	6.9 %	5.4 %	2.7 %	2.2 %	0.9 %
Conventional Tillage (as % of seeded acres)	66.3 %	63.4 %	54.5 %	43.4 %	38.3 %	41.3 %
Conservation Tillage (as % of seeded acres)	28.7 %	27.5 %	32.6 %	35.3 %	37.7%	38.7 %
Zero Tillage (as % of seeded acres)	5.0 %	9.1 %	12.9 %	21.3 %	24.0 %	20.0 %

Since the late 2000s, Western Manitoba has experienced abnormally high rates of precipitation, combined with major flood events in 2011 and 2014. As a result, there has been a slight reduction in zero tillage acres as farmers have struggled with extremely wet soils. Some regions saw fields go unseeded for two or more years; therefore, tillage became a tool to attempt to dry out the soil, incorporate crop residue into the soil to break down, and to fill in ruts caused by wheel traffic.

Towards the eastern side of the province, the soils are high in clay content and naturally are poorly to imperfectly drained, having been developed at the bottom of glacial Lake Agassiz (commonly referred to as the Red River Valley). Here soil moisture is often in excess, due to spring flooding of the Red River and the slow internal drainage of the soil. Farmers in the Red River Valley are generally resistant to the concept of zero tillage, as heavy untilled clay soil is slower to dry out and warm up for spring seeding. There has also been an expansion of long season, heat-loving crops like soybeans and corn in the rotation, which require earlier soil warming in the spring. However, 2017 and 2018 were abnormally dry years across Manitoba resulting in wind erosion events, especially in spring on fields that were conventionally tilled or had low residue cover. These erosion events have had farmers in the Red River Valley consider decreasing tillage, with some even leaving fields untilled in fall of 2018.

Promoting Soil Conservation Practices in Manitoba

While the adoption of zero tillage has been farmer-driven, based mostly on a need to conserve soil moisture and reduce input costs, there have been government-supported programs to promote adoption over the years. Manitoba Agriculture has been active in providing extension services and support to farmers as they consider changes in their tillage practice. Financial incentives, in the form of Beneficial Management Practice (BMP) programs, have also been offered by both the federal and provincial governments, beginning around 2004. These programs have provided financial assistance for adopting reduced tillage practices; however, uptake of these practices has remained relatively low. Even with funding available, a maximum of 25 % of Manitoba's acres have been under zero tillage. This is not surprising as there are large regions of the province with heavier clay soils where zero tillage may not be the more feasible option. Due to the regional differences in weather, soil moisture, and soil types across the province, it is difficult to approach soil conservation in Manitoba with just one BMP alone. In order to adopt zero tillage, or even conservation tillage, in the Red River Valley, one must consider how to deal with excess moisture and the poor internal drainage of clay soils. For this reason, Manitoba Agriculture not only promotes zero tillage, but also promotes the use of cover crops and perennial cover to protect soil from erosion and improve water uptake during wet periods.

The most recent program, AgAction Manitoba, provides incentive funds for practices to enhance soil conservation. Farmers are expected to first complete an Environmental Farm Plan, a self-assessment of environmental risk on the farm. Once completed, their Plan is reviewed and they are issued a Statement of Completion. With this Statement, farmers can apply to BMP categories that address the risks they have identified on their farm (Table 2). All applications are rated based on their overall environmental benefit, then ranked according to their score. Farming practices deemed to be creating the greatest risk to the environment receive higher priority. Funding is provided to projects that meet a certain base-level score, or, in the case where there is a high volume of applications, funds are provided to the highest scoring projects first, continuing down the ranking until funds have been fully allocated. Applications are currently being reviewed for the 2019 cropping season, the first year that the full suite of soil conservation BMPs are being offered.

Table 2: AgAction Manitoba – Beneficial Management Practices for Soil Conservation; Source: Manitoba Agriculture

Beneficial Management Practice	**Cost Share (government:applicant)**	**Funding Cap**
Resource Management Planning	50:50	$ 15 000
Establishment of a Cover Crop	25:75	$ 10 000
Increased Frequency of Perennials in Annual Crop Rotations	25:75	$ 10 000
Perennial Cover for Sensitive Land	50:50	$ 10 000
Improved Pasture and Forage Quality	25:75	$ 10 000
Intercropping	50:50	$ 10 000

By promoting a wide range of soil conservation practices, Manitoba Agriculture hopes to provide more tools for farmers to cope with soil moisture extremes. The use of cover crops may not only provide soil cover during the fall to protect from erosion, but it may also help de-water the soil during wet fall months and possibly allow farmers to transition to zero tillage practices. Where soils are at high risk of erosion, providing funds to seed that area down to permanent perennial cover may halt any future erosion from taking place. To date, cover crop adoption has been very limited without financial incentives since the economic benefits are not well established for the short growing season (i.e. there is little time for a cover crop to establish between harvest of the main crop and snowfall).

Summary

In Manitoba, much of the adoption of zero tillage has been due to a need to conserve soil moisture, protect the soil from erosion, and reduce input costs. However, the rate of adoption of zero tillage seems to have stalled due to a range of regional differences, including different moisture regimes and soil types. While recent environmental changes, such as the abnormally dry conditions in the Red River Valley, may convince farmers to revisit zero tillage, this may not be a permanent change once weather patterns return to normal. Combining other soil conservation practices such as the use of cover crops and perennial forages may allow farmers to decrease tillage over time, if not eliminating it altogether.

References

Manitoba Agriculture. Ag Action Manitoba Program for Farmers Guidebook. Available at: https://www.gov.mb.ca/agriculture/canadian-agricultural-partnership/pubs/guidebook/ag-action-mb-program-guide-for-farmers.pdf [accessed 16.03.2019]

Statistics Canada. 2016 Census of Agriculture, Farm and Farm Operator Data, catalogue no. 95-640-XWE. Available at: https://www.statcan.gc.ca/eng/ca2016 [accessed 16.03.2019]

Collective action in the face of the water crisis and desertification in the Atacama Desert.

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Abstract

In Chile, in the indigenous area in the Atacama desert, the flows of the main rivers and groundwater have decreased more than 50 %. The summer rains fall in just a couple of days, causing alluvions, floods, loss of crops and soil. In addition to mining activity and tourism, high pressure on natural resources, especially water. All this causes deforestation, the effect of biodiversity, decrease of agricultural land and livestock, advance of dunes and high desertification.

A project product of a doctoral thesis initiative, that among its results, the crisis, the agroproductive system, a platform of common action, unite between the different actors. It is about forestation and replenishment with native species for multiple purposes: to promote native biodiversity, sustainable tourism, value chains, sustainable livelihoods, dune containment, resilience to desertification and climate change, combining ancestral knowledge and new technologies. This first stage shows a process in which it is possible to build territorial governance for a common purpose, the sustainability of the territory.

Keywords: Desertification, water, forestation, agro-ecological system, collective action, biotrade

Introduction

Within the National Action Plan on Climate Change 2017-2022 among the countries part of the UNFCCC, Chile established the National Strategy on Climate Change and Vegetational Resources 2017-2025 and the Programmatic Agenda for Arid and Semi-Arid Zones 2018-2021, where they were established as strategic axes forestry institutions, productivity and growth, equity and social inclusion, and protection and restoration of forest heritage, the fight against desertification and degraded soils. Among the agreed objectives are to increase forestation and management of high standard and quality of native plantations, and enhance their sustainable productive functions.

The Atacama la Grande Indigenous Development Area (ADI) is part of this macrozone, and in its capacity as ADI under Law No. 19.253 approved in October 1995, the State must focus its actions for the improvement of livelihoods and quality of life of the people of indigenous origin who live in this territory of 23 439 km² and close to 10 000 inhabitants. This policy considers a development from the perspective of self-development and / or self-management, with the rational use of its own natural, human, economic and cultural resources and thus provide itself with sustainable processes conductive to development with identity, as defined by its own communities involved. In this regard, communities through the Council of Atacameño Peoples, which brings together 18 indigenous communities, has among its priorities water management for the preservation and sustainability of ecosystems and agriculture on which their identity is based. The communities have been able to build strategies, using the Indigenous Law, achieving important advances such as collectively obtaining water rights, improving and adapting irrigation infrastructure in the face of the water crisis (Sepúlveda, 2015) and have managed to reach consensus efforts and resources around a project of forestation of native species for their multipurpose, contain desertification, give added value to agricultural products, through the associativity for production of local products under the alternatives of biotrade.

The present work emphasizes circular economy and agroecology approach and aims to show how in the face of the problems of soil degradation especially product of the water crisis, it is possible to build collective actions to address these problems on platforms governance of territorial sustainability.

Methodology

This work is based on the doctoral thesis "Water and Access to Livelihoods in an Indigenous Agroecological System: Adaptation to External Influences" (2015). Other relevant secondary sources are official statistics of flows and groundwater studies and the Municipal Development Plan. The work is based on the participatory action research method, applying ethnographic analysis based on interviews and participant observation given that the researcher is part of the indigenous community of San Pedro de Atacama and is a member of the Association of Irrigators and Farmers and coordinator of the project.

The technology for plantation is The Cocoon, this system is designed to support a seedling through its first critical year. The system requires only 25 liters of water in the plantation, is 100% biodegradable and ensures high survival (75-95%).

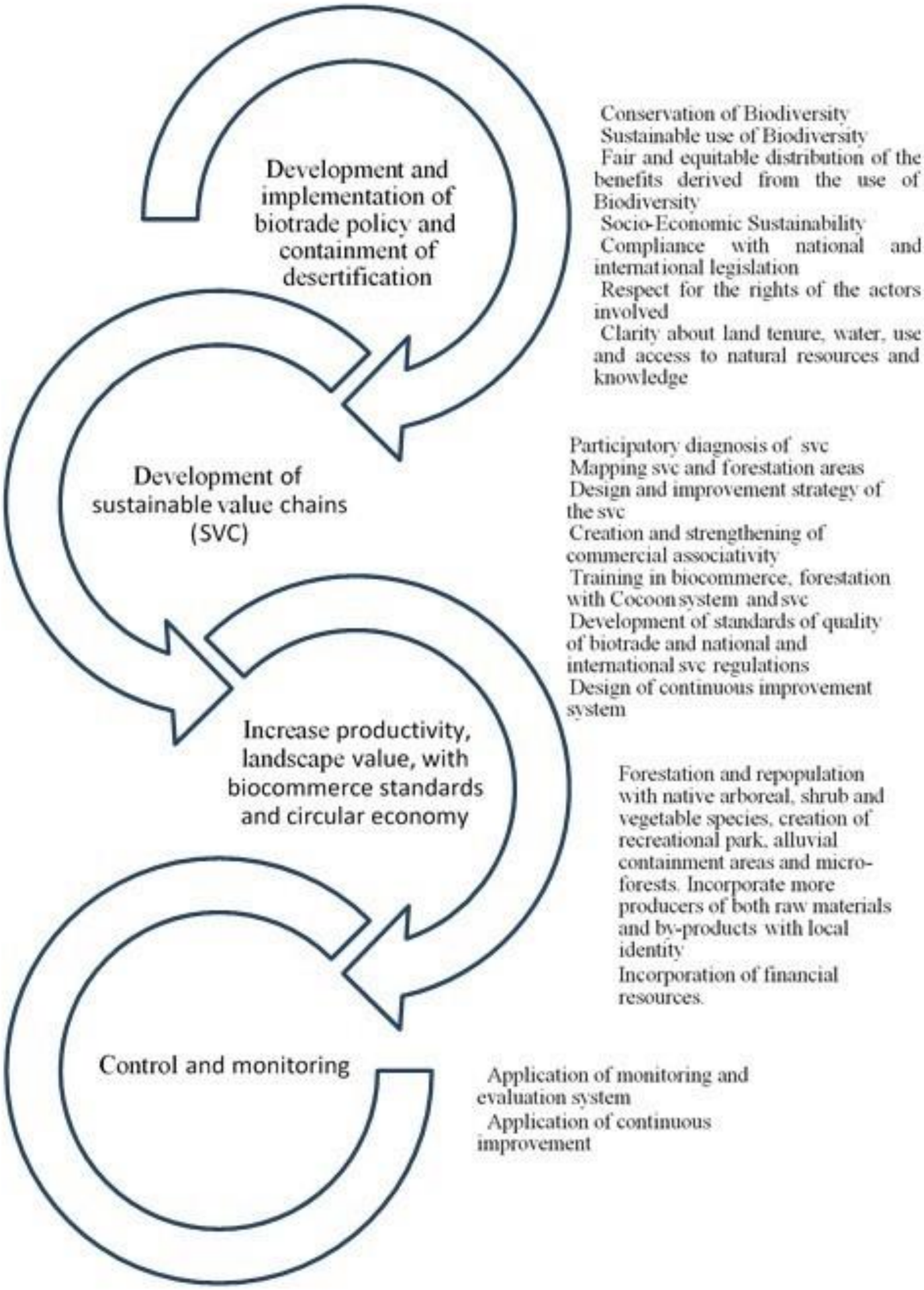

Figure 1: Stages and contents of the project

Results

Figure 2: Flows of the rivers San Pedro and Vilama (Sepúlveda, 2015).

The management process involves:

- Communities
- Association of Irrigators
- Municipality, Ministeries of Agriculture and of the Environment, National Forestry Corporation (CONAF), Agricultural Development Institute (INDAP), Regional Government (GORE).

It was determined to establish pilot test areas in two sectors, with 1 Ha in total, agreed by the Council of Peoples and the technical support of agriculture and agricultural equipment of the municipality.

Funding was provided by indigenous communities, the municipality, GORE and is applying for GEF funds through the Ministry of Environment. The design of monitoring has been agreed with the stakeholders and has a team that is responsible for keeping the community and the stakeholders involved and informed.

It was agreed to plant 200 Ha in four years, in the town of San Pedro and another 50 Ha for green areas in each of the 7 localities that make up the Area of Indigenous Development with the Cocoon System. In the first year, 30 Ha was planted, resulting in an 80% survival rate.

The forestation of dunes and alluvial areas in combination with civil works and recreation areas, has managed to give a complementary approach in a system to improve the quality of life, the quality of the landscape and the diversity of environmental, economic and social services.

The process of associativity has allowed producers of chañar (Geoffroea decorticans) and algarrobo (Prosopis alba) wines and flour to join the biotrade line, with an emphasis on ecological economics.

The project includes practical training for farmers and agriculture students, providing a space for knowledge exchange between traditional know how and new technologies.

Discussion

With the last events of overflow of the principal rivers and floods given the events of summer rains presented in a short period of time, the communities and the local government have had to react to contingencies, leaving as evidence those problems that have been getting worse each year.

The drag of soil, loss of crops and flooding of populated areas, makes evident among others, the deforestation of sectors in which since the 1960s, with 1400 Ha of crops and forest area that made up the agricultural matrix, has now been reduced to 800 approximately, proportional to the decrease of irrigation water. So there has been no vegetation cover that allowed to contain the alluvial effect in which agriculture and the territory shows a clear process of desertification and degradation of soils. With the decrease in the flow of surface water, it is evident that the concentration of salts is increasing. From the State, resources have been injected into the irrigation infrastructure, thanks to the canals and accumulators farmers can optimize the use of scarce water, otherwise the crisis would be even more acute. In addition, the communities are investing in their own monitoring systems of water flow and quality. However, it has also become clear that the state policies, although they have allowed advances in the recognition of indigenous communities, lack coordination of efforts and a platform is needed that allows common actions to be combined around the governance and sustainable development of the territory.

The communities have prioritized agriculture in their plans, however there has been a dissociation between agriculture and tourism, without having seized the opportunity that exists there. Thus, producers have turned to tourism as a means to obtain economic resources, maintaining agriculture as an activity of self-consumption and mainly as a way of holding on to their identity, but without giving added value. Thus the agricultural teacher Pamela Yere of the local technical agricultural school explains that "many parents do not want their children to study agriculture because they do not see a future there."

The discussion generated in the project management process, has made the communities revalue their agroecological systems from a perspective of sustainable development, through biocommerce constituting a sustainable way of life, taking advantage of the market opportunity presented by the tourism sector. The Council of Indigenous Peoples is currently committed to injecting financial resources into agricultural activities, funds originating from entrance fees to wilderness areas and agreements with lithium mining companies that contribute resources within the framework of social responsibility. Although the origin of these latter resources are a cause of internal discussion, the Council has managed to combine efforts in water protection and to agree on a management platform in which one of the concrete actions is this particular forestation and biocommerce project, in which the state, the municipality and various actors come together. This step is substantial in that it will contribute in halting the process of desertification and deal with vulnerability to climate change and shows that despite the differences between actors, there are common objectives, such as the problem of desertification, in which they can and should join forces.

Conclusions

There is a desertification process caused by evidential decrease of superficial and subterranean water resources.

The research process and the management of this project, the evidence and the improvement of the irrigation infrastructure, requires a comprehensive forestation and reforestation plan, as well as to give added value to native products and thus to preserve the atacameño agroecological system for the present and the future.

In an association of diverse actors and resources it is possible to form a joint governance and action platform and strengthen sustainable development of the territory based on water and natural resources management. The Cocoon System has proved to provide good results in facing water crises and the desertification process.

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References

Dirección General de Aguas (DGA) & Ministerio de Obras Públicas (MOP). undated. Información Oficial Hidrometeorológica y de Calidad de Aguas en Línea Available at: http://snia.dga.cl/BNAConsultas/reportes.

Holmgren, M., Stapp, P., Dickman, Ch., Gracia, C., Graham, S., Gutiérrez, J., Hice, C. Faksic, J., Kelt, D., Letnic, M., Lima, M., López, B., Meserve, P., Milstead, B., Polis, G., Previtali, M.A., Richter, M., Sabaté, S. & Squeo, F. 2006. Extreme climatic events shape arid and semiarid ecosystems. *Front Ecol Environ*, 4(2): 87–95. Available at: https://doi.org/10.1890/1540-9295(2006)004[0087:ECESAA]2.0.CO;2.

Land Life Company Technology. Undated. A new way to fix the planet. Available at: https://landlifecompany.com/technology/.

Municipalidad de San Pedro de Atacama. Actualización Plan de Desarrollo Comunal 2006-2010 Comuna San Pedro de Atacama, SGAIBERSIS Consultores.

Pourrut, P. & Nuñez, L. 1995. El Agro y la identidad atacameña: Entre la crisis y la esperanza. En : *Agua, ocupación del espacio y economía campesina en la región atacameña, aspectos dinámicos*. Universidad Católica del Norte, Antofagasta, Pp. 107-110.

Sepúlveda, I. 2015. Thesis *Water and Access to Livelihoods in an Indigenous Agroecological System: Adaptation to External Influences*, University of Cordoba Spain, 201pp. Available at: https://helvia.uco.es/xmlui/handle/10396/13364.

Universidad Arturo Prat, Comisión Nacional de Riego & l. Municipalidad de San Pedro de Atacama. 2000. *Agricultura en el Desierto de Atacama* II Región de Chile, Proyecto Agrícola "San Pedro de Atacama".Pp 1 – 47.

Unidad de Cambio Climático y Servicios Ambientales (UCCSA), Gerencia de Desarrollo y Fomento Forestal (GEDEFF) & Corporación Nacional Forestal (CONAF). *Reporte de Neutralidad en la Degradación de las Tierras ante la Convención de las Naciones Unidas de Lucha Contra la Desertificación*. Estrategia Nacional de Cambio Climático y Recursos Vegetacionales 217-2025 de Chile.

Theme 3: the economics of soil erosion prevention, management and remediation

Sustainability and production: analysis of a successful soil conservation strategy in the province of Entre Ríos, Argentina

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Abstract

Agriculture productivity is significantly affected by soil erosion. Entre Ríos province addresses the impact of water erosion in most of its territory, driving to economic losses and requiring investments for soil conservation. The most appropriate soil conservation structural practice for the Entre Ríos landscape is soil systematization by evacuation terraces. Although this is a very known and available technology, it is not sufficiently widespread to ensure the sustainability of regional agricultural production. The objective of this work lies in the productive and economical comparison of two scenarios (with and without systematization), based on information registered in a rural firm of that province, for soybeans, wheat and corn crops. A crop yield variations analysis was carried out during 8 campaigns in which simultaneous conditions with and without soil conservation were presented, using a multiple linear regression model. The technology of control of water erosion through evacuation terraces ensures the sustainability of agricultural yields and its investment is shown to be economically efficient in the province of Entre Ríos

Keywords: soil conservation, yield impact, economic valuation, drainage terraces, Entre Rios, Argentina

Introduction, scope and main objectives

Soil degradation is one of the main concerns in the economic and political analysis of agricultural sustainability. The erosion of soil generates losses in production, demands time and high costs to conserve or recover its productive capacity, and can be irreversible.

In Argentina, approximately thirty-five percent of the surface area of productive soils is affected by water erosion (WE), close to 64 million hectares (Casas and Albarracin, 2015). The province of Entre Ríos is one of the most impacted by water erosion with more than 2.3 million hectares under erosion and 75 % of its surface susceptible to erosion (Panigatti, 2016).

This susceptibility of provincial soils to erosion is generated in i) its undulating topography with very long slopes (1-4 %) where water runoff is not interrupted, ii) low infiltration due to the high content of expandable clays in soils (Gvozdenovich, 2018), and iii) the concentration of precipitation (1 200 mm/year) by 80 % in the spring-summer period. This scenario is aggravated in the context of climate change, when an increase of 20 % of the R factor of the USLE in the last fifteen years is identified (Crettaz *et al* 2016).

An average loss of soil is estimated at a rate of 15 to 20 tn/ha/year (Panigatti, op cit), which increases to 48 tn/ha/year in vertisol soils of the new areas impacted by the expansion of agriculture, especially of soybean crops, in the province (Gvozdenovich, op.cit).

The decrease in yield is one of the key indicators of the loss of soil quality due to erosion. Soybean yield losses of 470 kg/ha (Gvozdenovich and Paparotti, 2011) and 413 kg/ha (Maggi *et al.,* 2016) were identified in agricultural soils.

Based on the loss generated by erosion, the Province of Entre Ríos implemented since 1989 a strategy of conservation of agricultural land based on regulatory instruments (Law 8318 for Soil Conservation) and economic (exemptions and tax reductions) for agricultural firms that adopt conservationists practices

A conservation technique adopted within the framework of the mentioned law has been the systematization of the soil in the form of evacuation terraces, one of the structural practices with the greatest positive impact for erosion control (Oszust *et al.,* 2014).

But, despite being a widely known and available technology in the territory, it is not sufficiently widespread, reaching only 6-7 % of the provincial agricultural area (Paparotti *et al.,* 2013). This deficit lies in the financial costs involved and the lack of producer perception or confidence on the sustainable increase in productivity over time and little knowledge of the level of return on investment in the agricultural enterprise.

The water erosion impact has been extensively studied and evaluated in its physical and biological variables, but an economic valuation on agricultural costs and benefits of the firm has not been developed in equal depth. It is not expected in the producer a behavior tending to the conservation of the resource as long as the erosion symptoms are not translated in economic damages (Longo and Tomasini, 2018).

An evaluation of the Conservation and Use of Soil and Water Provincial Program proposed for Entre Ríos (1994), estimated that the implementation of terraced systems, producers could obtain a return on invested capital (TIR) of up to 34% (Tomasini, 2003).

The objective of the present work is to analyze the variation of yields, benefits and profitability of the production from empirical information generated by an agricultural firm of the province of Entre Ríos involved in an integral strategy of soil conservation.

Methodology

This research applies the Scenario Analysis Methodology -TSA- (Alpizar and Bovarnick, 2013; Longo and Tomasini, 2018) to evaluate the different ecosystem services provided by soil conservation, such as biodiversity protection, management of water in soil and water water, and the provision of food.

The theoretical core of the TSA is the configuration and comparison of two scenarios, which are called BAU (Business as Usual) understood as "usual unsustainable practices" and SEM (Sustainable Ecosystem Management) as a sustainability scenario

In this case, the compared scenarios are an agricultural business model with soil conservation (SEM) and a conventional one (BAU), through the technical and economic appraisal of productivity changes. Incremental costs of new practices, benefits of productive soil conservation impacts, and profitability levels with and without conservation, were assessed.

The firm Estancia Centella, located in the Department of Concepción del Uruguay, Province of Entre Ríos, from year 2004 until 2012 began a systematization process of 20 000 hectares with broad-based terraces technology and generates more than 1 300 annual yield performance data for different crops in both simultaneous management scenarios.

The study empirically quantifies the impact of soil conservation on yield and on the economy of the firm, comparing the yields of non-systematized fields (SS) with systematized fields (CS). During the period of analysis the applied crop technology has been identical for both cases, as well as climate and edaphic conditions, given the simultaneity of the observations.

An exploratory analysis was made of the variations in time of the yields of soybeans, soybean (second seeding), wheat and corn crops. The model used to evaluate the effect of the systematization was multiple linear regression, where time (years) and rainfall were the explanatory or independent variables, and returns the response variable.

The dominant assumption is that if soil conservation does not take place, erosion impacts on the crop yield levels over time. An opposite effect can be expected with the application of conservation techniques. This model obtains the estimators of the regression coefficients associated with the years ($\beta 2$), which are interpreted as trends or changes over time in crop yield means.

Rain were included in the model in order to extract its effect on the yield variability and thus being able to estimate independently the time trend. A mixed model was adjusted to eliminate the temporal correlation between the fields, including them as a random effect and modeling the correlation structure according to the case (Zuur *et al* 2009). To avoid multicollinearity in the multiple regression, it was corroborated that rains did not correlate linearly with the campaigns. Models for systematized fields and non-systematized fields were adjusted separately. The program used was InfoStat version 2011 (Di Rienzo *et al* 2011).

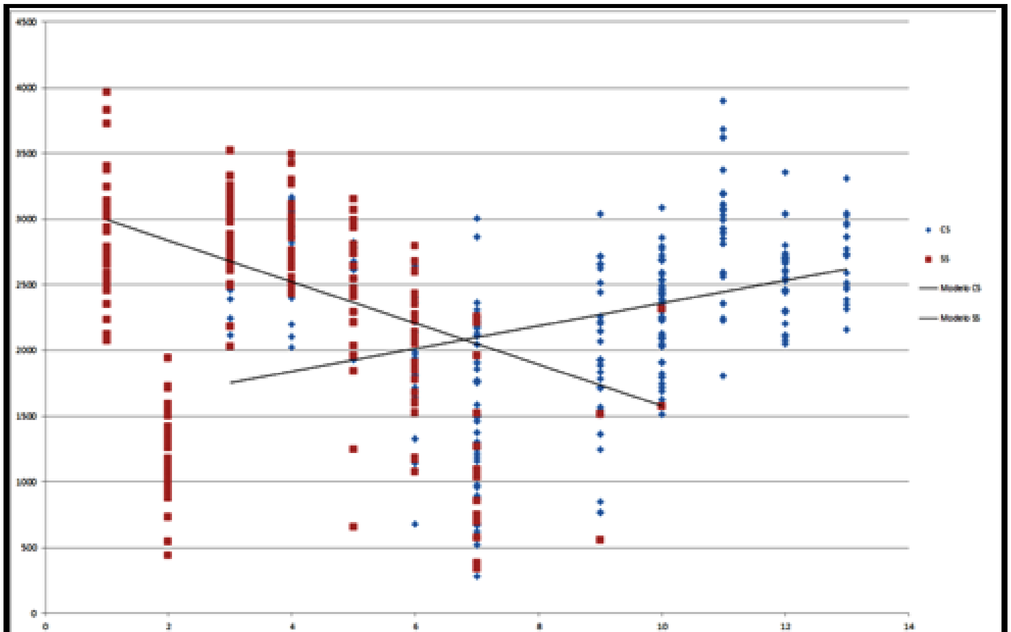
An economic analysis of the impact of changes in agricultural yields in the firm, was addressed through a production model designed on 1000 hectares, considering the yields and agricultural income of the case under study for the 2004/2012 period (soybean, wheat-soybean second seeding and corn rotations), under the two conditions: without conservation (BAU) and with conservation (SEM).

The firm also provided data on investment costs (US$ 71.20/ha) corresponding to the planning and construction of wide-based terraces and drainage channels, removal of fences and layout of new roads, and annual maintenance of the systematization (10 US $/ha), as well as the incentives obtained by reduction of rural real estate tax from Provincial Law 8318 (US $ 7.43/ha systematized for 10 years). The structural interventions on soils were carried out during four years and maintenance during the whole live of project. An eight-year project planning horizon is considered, in which only yields between treatments of the same year are compared.

Results

The analysis revealed significant differences in the trend of yields over time, in favor of the "CS" treatment, showing an advance towards the sustainability of production.

This situation has been particularly important in soybean, the most relevant crop for sown area and for its impact on water erosion. In the SS treatment, the yields decreased at an average rate of 157 kg/year, while in the CS treatment this tendency was reversed, reaching an average increase of 86 kg/year (Figure 1). For the case of the other crops, the systematization did not yield such significant results.



Treatment	$\hat{\beta}_0$ (kg)	$\hat{\beta}_1$ (kg/mm)	$\hat{\beta}_2$ (kg/year)	
◆ With Soil Terraces	1431,66	0,45	86,29	a
■ Without Soil Terraces	2075,51	7,62	-157,10	b

Figure 1: Observed yield data (Kg/ha) as a function of time (years) for soybean crop. The adjusted straight lines correspond to the models estimated for average rainfall values in each year, $\hat{\beta}_0$, $\hat{\beta}_1$ and $\hat{\beta}_2$ indicate ordered to the origin and estimated regression coefficients for the effect of the rains and the years respectively. Different letters in the same crop indicate significant differences at 5%.

The cost-benefit analysis of the economic model designed is based on the cash flow of eight years of production (Figure 2), with a first year of initial investment. The following indicators stand out:

• Total investment in systematization: US$ 71 200

• Net Present Value (NPV) of the project (8%): US$ 70 006

• Internal Rate of Return (IRR) of the project (eight years): 18 %

Year	2003 (0)	2004 (1)	2005 (2)	2006 (3)	2007 (4)	2008 (5)	2009 (6)	2010 (7)	2011 (8)
Income SEM	0	312.205	449.384	626.796	608.783	417.523	604.610	480.429	680.452
Income BAU	0	359.496	455.142	643.382	622.469	320.919	481.371	392.132	611.919
Net Income	0	-47.291	-5.758	-16.586	-13.686	96.604	123.239	88.297	68.533
Investment	-18.693	-18.693	-18.693	-18.693	0	0	0	0	0
Maintenance	0	-2.500	-5.000	-7.500	-10.000	-10.000	-10.000	-10.000	-10.000
Subsidy	0	0	1.857	3.714	5.571	7.428	7.428	7.428	7.428
Annual balance	-18693	-68.484	-27.594	-39.065	-18.115	94.032	120.667	85.725	65.961

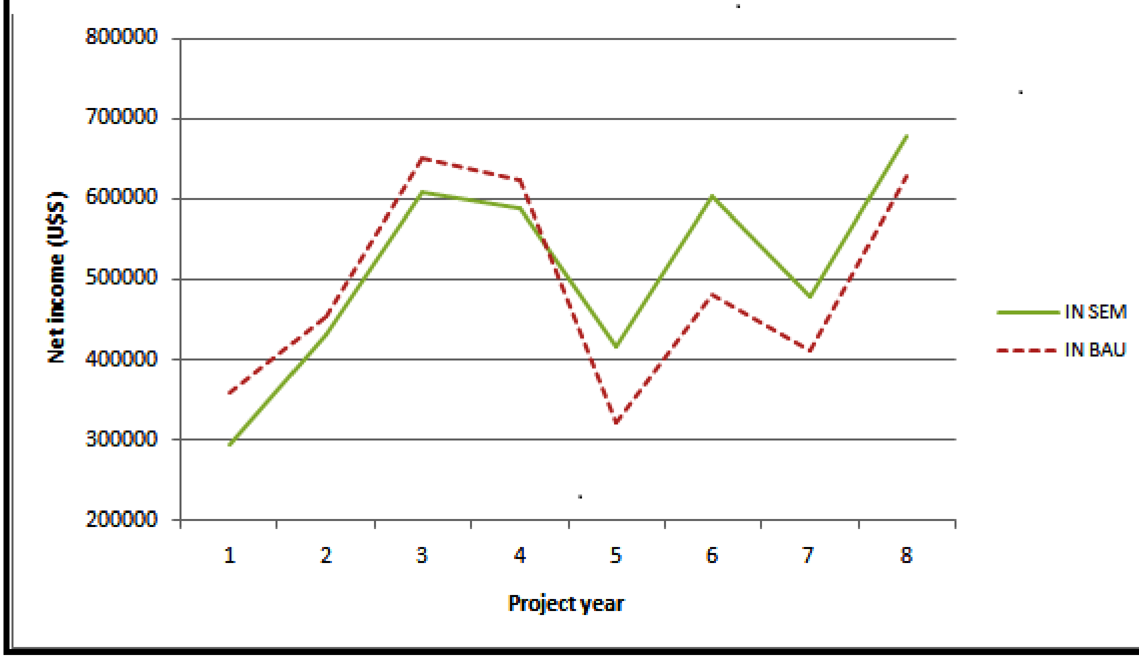


Figure 2: Flow of costs, revenues and benefits for two scenarios: BAU (without systematization) and SEM (with systematization). Data in constant dollars of 2004

Discussion

The incorporation of broad-based terraces technology confirms the reversal of the degradation process and the increase of specific agricultural yields.

Without intervention, the drop in the yield registered in soybeans (-157 kg/ha/year) and in corn (-244 kg/ha/year) show a negative trend for the firm's economy, without considering possible irreversible damage by gullies.

The intervention with terraces projects sustained increases in soybeans of 86 kg/ha/year, and reduces the loss of productivity of corn at a noticeably lower rate (-95 kg/ha/year).

The economic evaluation of a SEM management scenario compared to BAU (Figure 2), shows that the profitability levels of the investment in land systematization are significantly positive (IRR 18%) based on the sustainability of production and the increase in crop yields. The contribution of the tax reduction applied on the basis of the Provincial Law of Soil Conservation is very significant for the model, explaining a 3% of the rate of return.

The profitability of the model increases significantly with the mere extension in two years of the planning horizon (IRR of 24 %)

Conclusions

The technical and economic analysis incorporated into the TSA methodology (Target Scenario Analysis) made it possible to identify through physical indicators (yields/change in productivity) and economic indicators (IRR/VAN/others) the effort that a producer must assume in order to undertake the business of the sustainable agriculture.

The SEM scenario is highly competitive, contributing to the environmental and economic sustainability of agricultural production and the conservation of ecosystem services associated with the appropriate land use (biodiversity, regulation of water flow, carbon sequestration, climate stabilization, recreation, others) in the provincial territory.

The government support policy helps to create a positive environment for decision making, promoting a public-private financing model leveraged by the guarantee of tax relief.

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References

Alpizar, F. & Bovarnick, A. 2013. Targeted Scenario Analysis: A new approach to capturing and presentingecosystem service values for decision making. UNDP. New York.

Casas, R. & Albarracín, G. 2015. El deterioro del suelo y del ambiente en Argentina. Fundación para la Educación, la Ciencia y la Cultura. Buenos Aires.

Crettaz, E., Gvozdenovich, J. & Saluzzio, M. 2016. Cálculo del Factor R de la USLE a través del Índice Modificado de Fournier. Facultad de Ciencias Agropecuarias (UNER), Oro Verde, Entre Ríos.

Di Rienzo, J.A., Casanoves, F., Balzarini, M.G., Gonzalez, L. & Tablada, M. 2011. Grupo InfoStat. Facultad de Ciencias Agrarias, Universidad Nacional de Córdoba, Argentina.

Gvozdenovich, J. & Paparotti, O. 2011. Variación del Rendimiento del Cultivo de Soja Debido a la Erosión Hídrica en Entre Ríos. Campañas 2009/2010 - 2010/11. INTA EEA Paraná, Entre Ríos.

Gvozdenovich, J. 2018. Estimación de la Erosión Hídrica y Escurrimiento con el uso del Modelo Físico WEPP. Universidad Nacional de Entre Ríos, Oro Verde, Entre Ríos.

Longo, L. & Tomasini, D. 2018. El Análisis de Escenarios Meta (Targeted Scenario Analysis - TSA) como estrategia para la promoción de la conservación de servicios ecosistémicos en: C. Vicién (ed) *Modelización económica en el sector agropecuario.* Libro digital. Facultad de Agronomia. UBA. Buenos Aires.

Maggi, A., Behrends, K.F., Introcaso, R. & Thompson, D. 2016. Caracterización física y química de un Argiudol vértico de la Pampa Ondulada con erosión hídrica en el surco y entresurco. *Ciencia del suelo*, 34(1): 113-126.

Oszust, J., Wilson, M., Gabioud, E. & Sasal, M. 2014. Importancia y función de la sistematización de tierras para la conservación del suelo y la biodiversidad en: Zaccagnini, ME (ed.), *Manual de Buenas Prácticas para la conservación de Suelo, la Biodiversidad y sus servicios ecosistémicos*. PNUD, Bs. As. Argentina.

Panigatti, J.L. 2016. Aspectos de la erosión de los suelos en Argentina II. Ed. Asociación Argentina de la Ciencia del Suelo. Buenos Aires.

Paparotti, O., Pioto, A.C. & Gvozdenovich, J.J. 2013. Acciones de Conservación de Suelos del INTA Paraná en el Territorio. En Actas de las Jornadas Argentinas de Conservación de Suelos 2013. Buenos Aires. Julio de 2013.

Tomasini, D. 2003. Valoración económica del ambiente. En Lidia Giuffré (coord.) *Impacto Ambiental en Agrosistemas*. Editorial Facultad Agronomía UBA. Buenos Aires.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A. & Smith, G.M. 2009. Mixed Effects Models and Extensions in Ecology with R. Statistics for Biology and Health, Springer Science+Busines.

Farmers’ preferences for controlling soil erosion in Sicily

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Abstract

We used discrete-choice experiments (DCE) to estimate farmers’ preferences among alternative agri-environmental schemes (AES) designed to enhance sustainable agricultural practices in arable lands of Sicily (Italy). Using appropriate econometric models, we investigated farmers’ preference heterogeneity and identified factors affecting the farmers’ Willingness to Accept (WTA) for the adoption of farm level soil conservation practices. Results demonstrated a general positive and highly heterogeneous attitude in farmers toward the adoption of environmentally friendly practices, and suggested the need of modulate AES according to preferences’ heterogeneity respect to sustainable agricultural practices.

Keywords: soil conservation, water erosion, furrows sinks, turfing, heterogeneity, discrete choice models

Introduction, scope and main objectives

The approach generally adopted by policymakers to design agri-environmental schemes (AES) presents some weaknesses that may limit either the effectiveness or the efficiency of such sustainability tool. Compensations are often established on the basis of income forgone and/or additional costs associated with the adoption of more sustainable practices. The premium for the risk associated with the adoption of a conservation plan is generally not considered (Cooper and Signorello, 2008). The common method of establishing economic compensation and the “fixed” nature of this compensation exclude the possibility of further compensation for farmers who are willing to practice high-level environmental management (Whittington and Pagiola, 2012). Moreover, heterogeneity of preferences is often not considered in AES design, despite numerous studies demonstrating the presence of large variation in AES preferences among farmers and spatial context (Ruto and Garrod, 2009; Espinosa-Goded *et al.*, 2010; Christensen *et al.*, 2011; Broch and Vedel, 2012).

Previous research on the determinants of farmers’ participation in AES is principally based on actual participation behaviour (Defrancesco *et al.*, 2008; Hynes and Garvey, 2009), rather than on contingent behaviour. Information on how farmers percept such schemes and how react when their characteristics are modified in hypothetical scenarios could provide important inputs to better design AES and increase the farmers’ participation rate. Contingent behaviour experiments could inform policymakers about heterogeneity in relation to AES content.

To address these research requirements, we implement a stated-preference study that simulates the steps that should precede the definition of agri-environmental contracts. The objective of this study is twofold. First, we analyse farmers’ preferences for alternative AES schemes, highlighting which sustainable goals are perceived as more important, and evidencing farmers’ willingness to adopt proposed schemes. Second, we explore farmers' preference heterogeneity, focusing on the analysis of what factors are the main determinant of farmers' Willingness to Accept (WTA) for the adoption of practices aimed at control soil risk of erosion.

Methodology

In this study, we designed a DCE where farmers have the possibility to choose among hypothetical AES, that are more binding than the current local regulatory framework. The simulated scenarios were modulated on five attributes. Four attributes were concerned with agricultural sustainability goals. The fifth attribute was the additional cash compensation that farmers could receive for their participation in a more coercive AES (see Table 1). The full factorial design lead to 288 alternative scenarios (alternatives). Given that this number was too large if compared with operating constraints, we implemented an orthogonal main-effect-only design, which reduced the number alternative profiles to sixteen. Each of these alternatives represents option A in the choice set. Option B is identified by the fold-over technique (Hensher *et al.*, 2015). The status quo was identified as the minimum level for each attribute. Famers were asked to select between the option A, option B and the status quo, in an iterative manner, four times.

Table 1: Attributes and levels of the experimental design

Attributes (Sustainable objectives)	Levels
<u>Protection of soil from water erosion</u>	- Turfing sloping surfaces* (*Turfing*); - Construction of temporary furrows sinks at a distance (*Furrows sinks*): - 20 m; - 40 m; - **80 m**.
<u>Maintenance of soil organic matter</u>	(*Soil_fertility*) - Grazing stubble, straw and crop residues; - Creation of firebreaks** and burying of crop residues*;* - **Burning of crop residues**.
<u>Maintenance of landscape features</u>	(*Landscape*) - excellent; - very good; - good; - **sufficient**.
<u>Agro-biodiversity conservation</u>	Percentage of crop area with endangered varieties (*Agro-biodiversity*)*:* - 75%; - 50%; - 25%; - **0%**.
<u>Additional compensation</u>	(*WTA*):

Attributes (Sustainable objectives)	Levels
	- 1,000 €/ha; - 800 €/ha; - 600 €/ha; - 400 €/ha; - **0 €/ha**.

* Sloping surfaces with an average slope more than 15%;

** Firebreaks with amplitude not less than ten meters.

In **bold** status quo levels, and in parentheses the *acronyms* of each variables.

The interviews covered a random sample of 125 cereal farmers who grow crops in the Sicilian slopes inland areas, with average gradients of farmland over 15 %. To analyze DCE data, we used econometric models based on random utility maximization framework (McFadden, 2001), that are the Multinomial logit (MNL) model (McFadden, 1974), which implies homogeneity among individual preferences; and the Mixed logit (MXL) (Train, 2003) which relaxed the homogeneity assumption. Moreover, using a Seemingly Unrelated REgression (SURE) model (Greene, 2005) we identified factors that influence the farmers' willingness to adopt soil conservation practices. This model was specified by using two equations and assuming a contemporaneous cross-equation error correlation. Dependent variables for the two equations are respectively the marginal WTA for turfing sloping surfaces and for the construction of temporary furrows sinks.

Results

Table 2 reports estimates of MNL and MXL models. In the MNL model, variables representing practices aimed at controlling the risk of soil erosion (*Turfing* and *Furrows_sinks*) were highly significant ($p<0.001$). Turfing sloping surfaces is preferred to the realization of furrows-sinks, because this practice assures a higher level of protection against water erosion. Coherently, in the hypothesis of furrows sinks, the realization of more closed sinks is preferred. The coefficient of *Soil_fertility* shown a lower significance level ($p<0.05$) and was positive, meaning that the practice of grazing stubble and firebreaks was preferred to the creation of firebreaks and burying of crop residues, and that the creation of firebreaks and burying of crop residues was preferred to the burning of crop residues. The improvement in the degree of maintenance of the countryside features (*Landscape*) presented a higher level of significance ($p<0.01$) and was negative due to the effort (which is also economic) that is not accompanied by additional revenues. The increase of the surface dedicated to crop local endangered varieties (*Agro-biodiversity*) negatively affected the farmer's utility ($p<0.05$), because it implies a lesser yield when compared with commercial crop varieties. The coefficient of WTA was highly significant ($p<0.001$) and its sign was positive, meaning that the farmer's utility increases with higher compensation. The constant term (β_0), which represents the Alternative Specific Constant (ASC) for the status quo alternative, was negative and highly significant ($p<0.001$). This result was coherent with that obtained by similar studies, confirming the farmers' preference for the non-status quo alternative.

As it concerns MXL model, results confirmed our hypothesis of heterogeneous farmers' preferences for agri-environmental practices. The better statistical performance was shown by the specification where attributes' coefficients—except the coefficient of WTA—were randomly and normally distributed. The z value of standard deviation refused the hypothesis that the parameter for *Landscape* variable was randomly distributed.

Results of the SURE model shown that marginal WTA for turfing sloping surfaces is negatively and significantly affected by farmer's family size (coefficient: -0.1971; p>0.10), and significantly increases if farmer was previously granted by Common Agricultural Policy measures (coefficient: 0.547; p>0.10). The marginal WTA for the construction of temporary furrows sinks, instead, depend only on the farmer's experience (coefficient: 0.0002; p>0.001).

Table 2: Estimated MNL and MXL models

	MNL		**MXL**[a]			
			Mean		**Standard deviation**	
Turfing	1.7979 (0.3485)	****	3.0557 (0.9806)	****	2.8491 (1.6340)	*
Furrows_sinks	0.0541 (0.0121)	****	0.0802 (0.0266)	***	0.0559 (0.0173)	****
Soil_fertility	0.3005 (0.1390)	**	0.4691 (0.2498)	*	1.4513 (0.3950)	****
Landscape	-0.1436 (0.0556)	***	-0.2208 (-0.2208)	*	0.0843 (0.2446)	
Agro-biodiversity	-0.6229 (0.2442)	**	-1.3069 (0.5672)	**	3.6914 (0.9583)	****
WTA	0.0025 (0.0004)	****	0.0039 (0.0007)	****		
Constant	-3.6336 (0.8492)	****	-8.5365 (1.8721)	****		
Log pseudo-likelihood	-392.78		-352.89			
AIC	799.56		729.77			
BIC	836.75		793.53			

no. of individuals: 125; no. of observations: 1.500. Standard error in parenthesis. * p<0.10, ** p<0.05, *** p<0.01, **** p<0.001.

[a] For random parameters, we assumed they are normally distributed; simulation was conducted through 1,000 random draws.

Discussion

General findings indicated that farmers were aware on the rules of eco-conditionality locally in force, and positively welcomed the opportunity to exercise more restrictive eco-friendly agricultural practices. Farmers stated positive preference towards the maintenance of soil fertility and the control of the risk of soil erosion. In particular, turfing sloping surfaces was preferred to furrows-sinks. Among furrows sinks, farmers declared to prefer more closed sinks. Estimates revealed also that farmers' preferences were heterogeneous respect to practices to protect soil from water erosion. The marginal WTA for turfing sloping surfaces depend on the farmer's family size: it decreases if family size increases, meaning that in the presence of larger households, farmers are less oriented to produce externalities in terms of soil conservation. Moreover, farmers are more willingness to accept compensation if they have in the past benefited from CAP support meaning that this experience satisfied them. The marginal WTA for the construction of temporary furrows sinks, instead, increases with the farmer's experience. More experienced farmers are willing to make more closer temporary furrow sinks, but to do this they require higher compensation.

Conclusions

Understanding in advance farmer's preferences for environmental friendly practices is useful to design effective AES and promote sustainable agriculture in sensitive areas. We believe that policy makers could benefit from the empirical evidence provided by our study. Especially in Mediterranean areas where the risk of desertification, and loss of agrobiodiversity is shifting to higher level as a consequence of climate change. AES remain the main tools to mitigate damages and promote sustainable agriculture. Our study reveal that AES currently in force do not fully capture the availability of farmers to more commit themselves to protect land and environmental resources, and heterogeneity and local spatial pattern in preferences.

References

Broch S.W. & Vedel S.E. 2012. Using choice experiments to investigate the policy relevance of heterogeneity in farmer agri-environmental contract preferences, *Environmental and Resource Economics*, 51(4): 561-581.

Christensen, T., Pedersen, A.B., Nielsen, H.O., Mørkbak, M.R., Hasler, B. & Denver, S. 2011. Determinants of farmers' willingness to participate in subsidy schemes for pesticide-free buffer zones-a choice experiment study. *Ecological Economics,* 70(8): 1558-1564.

Cooper, J. & Signorello, G. 2008. Farmer premiums for the voluntary adoption of conservation plans. *Journal of Environmental Planning and Management*, 51(1): 1-14.

Defrancesco, E., Gatto, P., Runge, F. & Trestini, S. 2008. Factors affecting farmers' participation in agri-environmental measures: a northern Italian perspective. *Journal of agricultural economics*, 59(1): 114-131.

Espinosa-Goded, M., Barreiro-Hurlé, J. & Ruto E. 2010. What do farmers want from agri-environmental scheme design? a choice experiment approach. *Journal of Agricultural Economics,* 61(2): 259-273.

Greene, W. H. 2005. *Econometric Analysis*. Fifth edition. Pearson Education.

Hensher, D.A., Rose, J.M. & Greene, W.H. 2015. *Applied choice analysis. A Primer*, second edition, Cambridge University Press, Cambridge.

Hynes, S. & Garvey, E. 2009. Modelling farmers' participation in an agri-environmental scheme using panel data: an application to the rural environment protection scheme in Ireland. *Journal of Agricultural Economics*, 60(3): 546-562.

McFadden, D. 1974. The measurement of urban travel demand. *Journal of public economics*, 3(4): 303-328.

Ruto, E. & Garrod, G. 2009. Investigating farmers' preferences for the design of agri-environment schemes: a choice experiment approach. *Journal of Environmental Planning and Management*, 52(5): 631-647.

Train, K. 2003. *Discrete choice methods with simulation*, Cambridge University Press.

Whittington, D. & Pagiola, S. 2012. Using contingent valuation in the design of payments for environmental services mechanisms: a review and assessment, *The World Bank Research Observer*, lks004.

Economic evaluation of water erosion and Sustainable Land Management

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Abstract

The study of water erosion processes requires analysis and measurements at various scales and integration of various methodologies. Hydrological measurement, to be correlated effectively with soil processes for example, needs to be made at the micro-scale of experimental catchments; while the environmental and social change analysis should be understood at the level of a larger territory. The multi-scalar approach has the advantage of allowing to conduct assessments that complement, in order to permit economic evaluation and to identify both development and soil conservation opportunities.

Keywords: water erosion, hydrology, watershed, soil, assessment, development, conservation

Introduction, scope and main objectives

The agro-pastoral activity through its evolution, in the Atlantic plateaus of Morocco, led to unsuitable forms of resources use, which carried damage in the balance of water and the stability of the soil. It was thus necessary to propose a revision of these practices. The strategy of farmers is based on two main traditional activities, annual crops for food production and livestock for immediate income. For most farmers, these two activities remain vital, because they complement each other. But, both suffer from over-harvesting and over-grazing, leading to land degradation and severe soil erosion. To mitigate water erosion effect, Sustainable land management must take into account the phenomena at several levels, and various scales, in order to succeed the integration that allows the synthesis and interrelationships between parameters, concerning both the loss due to erosion and the cost of SLM.

Figure 1: The Bouregreg watershed (Atlantic Morocco)

Methodology

In this paper, we integrate data at three degrees of scale, the great watershed of the Bouregreg (SMBA dam), the watershed of the Korifla tributary, and the micro-catchment of Hannanet.

At the scale of the big watershed, the follow up of Solid transport and of the reservoir bathymetry and the data about the needs of water permitted to build a balance of water and siltation dynamics.

At the level of the Korifla tributary watershed the work consisted in mapping land use and its evolution from 1969 and 2016, using remote sensing.

At the scale of the Hannanet catchment, the monitoring concerned several parameters, the herbaceous cover, its biomass, the floristic biodiversity, fodder production, the soil surface in term of moisture, resistance to penetration, cohesion, rate of pebbles and of the encrusted parts. In addition, we made observations on the gullies profile and their extension.

Results

Erosion upstream the SMBA dam affects the potential use of water downstream because of siltation. The measurements show an increase of specific Degradation (185 t/km²/year in the 1970s; 270 after 2000), which means an exaggeration of the erosion mechanisms in parallel with a negative evolution of the occupation and land management practices (Laouina *et al*., 2004).

The needs of drinking water supply to the coastal cities of Rabat and Casablanca are growing, while annual silting which varies from 2.5 to 3.2 Mm^3/year represents a threat to the future of this service.

While the average annual discharge is 530 Mm^3, the demand for drinking water that was only 300 Mm^3 in 2000, will amount to 590 Mm^3 in 2030. But silting has already deprived the storing ability about 112 Mm^3 during 45 years (Mahe *et al.*, 2013).

To compensate for the effort needed from the local stakeholders, the concept of payment for ecosystem services would facilitate the adoption of SLM. Ecosystem accounting needs to be based on verified information on services offered and benefits obtained by the local farmers (Bordt and Saner, 2019).

The most contributory areas to the production of siltation were identified by comparison of the suspended load in the hydrological stations and the reservoir bathymetry measurements. The main part of siltation comes from the micro-watersheds dominating the dam, and namely those of the low part of the Korifla.

Within this watershed of 14 000 ha, 3 500 ha are considered as stable (forest, matorral); 40 % of the watershed are annual crops affected by sheet wash with a temporary effect, but long-term reduction of the soil capacity and fertility; 16 % of the watershed have superficial water erosion, carrying fine particles and fertilizers, by the impact of splasch (crust waterproofing) and the energy of runoff ; on 18 % of the remaining area, processes are much more virulent (rills, active gullies and bad lands).

This configuration of 2016 represents the result of a significant and fast worsening over the past 50 years. The active erosion on one third of the area today, affected only 10 % in 1969 and about 20 % at the end of the twentieth century. The rills tend to become processes of desertification and at the same time of massive export of material. Some gullies grew strongly in size at a speed that reached a third of their volume in only 2 years and tend to extend on fragile sites within stables areas.

There is a certain parallelism between the current extension of the soil degradation by erosion (35 % of the basin) and areas with a high K-factor (high vulnerability) which represent about 31 % of the surface.

In these spaces, the rate of erosion reached values greater than 13 t/ha, while in areas of low erosion, the rate is less than 5 t/ha. The plant cover has dramatically changed since 1984, as a result of the anthropogenic impact, but perhaps also because of climate change. This rapid progression of the erosive phenomenon has a real impact on the vegetation recovery rate and the productive potential of the land.

In terms of ablation, the plowing land (5 600 ha) would lose annually 28 000 tons of superficial soil; the degraded pastures (2 214 ha) about 18 000 t. The rills extending over 1 800 ha exported approximately 24 000 t of material, leading to desertification of fields. Gullies (750 ha) have exported nearly 10 000 t of material, but at the expense of both the soil and the substrate. In terms of space able to support a biomass and to provide an annual income, erosion has affected from 1969 to 2016, 3 364 ha of land which were previously stable or very weakly affected by erosion.

In the Hannanet catchment, hydro-meteorological monitoring over 3 years was followed by the analysis of the hydrologic response of the rain events. Autumn floods and incisions are the result of rains of short duration and high intensity, over freshly tilled soils, where surface crusting accelerates runoff. Winter floods are due to rains that sometimes last several days. Vegetation, already developed at this time, does not prevent the heavy rain to generate important flows, but with less solid transport.

Within the European project DESIRE, our team approach has been to experiment the integration of new practices to mitigate the most aggressive dynamics, raise agricultural production, increase the farmers income. Two actions have been performed.

Direct seeding, in a perspective of minimal disturbance of the soil, has been attempted on a small field, in agreement with the land owner, on a stony soil thinned by sheet wash. At 5 cm depth and during normal events of less than 20 mm, direct seeding keeps moisture significantly better than in the plowed plot. Productivity under direct seeding is slightly higher than under plowing, as a result of the improvement of moisture and a better structuring of the soil.

In the long term it can be expected a productive horizon with expanded aggregation, rich in nutrients, organic and microbial activity, water properties and hydro-dynamics improved compared to the plowed fields. But in the short term, the cost-benefit of direct seeding ratio remains negative. Besides, the technique does not seem to be adapted to marginal and stony land with steep slopes, since these conditions prevent the proper functioning of the seeder and burial of seeds in the furrow.

Rehabilitating the land incised by deep parallel gullies, rapidly evolving, was selected to demonstrate the possibility to mitigate the effect of the incisions and rehabilitate the function of grazing (Poesen *et al.*, 2003). Fodder shrubs were arranged in spaced strips of 6 m parallel to the contour lines, with a density of 760 plants/ha. The plantation was fenced to keep it out of grazing and irrigated every 20 days during the summer 2009. The monitoring was conducted on 3 plots of the same slope: the planted plot of 5000 m², a gullied parcel unimproved and a gullied plot in fallow, previously cultivated.

The cost of the management (salaries for the establishment, acquisition of fodder shrubs, irrigation, fence) is high. Profits, from 18 months after development, are: more fodder availability, improved plant cover, more moisture in the soil, and a beginning of healing of gullies, with reduction of ablation and effects of silting downstream. After two and a half years resting, there was the start of a rehabilitation of gullies by progressive filling and relative stabilization of their edges. While, outside the fence, gullies remain bright with steep edges due to the undermining of their banks. On the economic side, the operation is expensive compared to the expected environmental improvements. Some owners said in interviews that they are not willing to invest that much money for a non evident benefit.

Discussion

SLM behavior, approaches and techniques have a very low rate of chance for success, without a deep change in term of land ownership, law constraints, agrarian structures.

Conclusions

The choice for planting gullied plots with fodder plants and the no tillage of cultivated land demonstrated, after 2 years of monitoring, its effective potential for land rehabilitation, fodder supply of the cattle and for evolution towards a new semi-intensive breeding. But, how to encourage the farmers to invest in this effort?

The farmers are more concerned by their immediate income than by sustainability and the long term effects; it is then necessary to alleviate their level of conscience and at the same time make the remediation techniques profitable and have a real effect on their income. The selected actions must be simple and easy to reproduce, in order to facilitate their gradual adoption by other farmers.

Incentives to land users are recommended to exclude grazing in order to prevent soil erosion and stabilize gully formation. At the same time, bold political decisions are needed to reverse the trend and challenge of natural resource degradation. It is also urgent to identify new legal contexts that can enable effective implementation of reforms and improvements.

References

Bordt, M. & Saner, M. 2019. Which ecosystems provide which services? A meta-analysis of nine selected ecosystem services assessments. *One Ecosystem*, 4: e31420. https://doi.org/10.3897/oneeco.4.e31420.

Laouina, A., Coelho, C., Ritsema, C., Chaker, M.., Nafaa, R., Fenjiro, I., Antari, M., Ferreira, A. & Van Dijck, S. 2004. Dynamique de l'eau et Gestion des terres dans le contexte du changement global, analyse agro-hydrologique dans le bassin du Bouregreg (Maroc). *Sécheresse*, 15(1): 66-77.

Mahe, G., Aksoy, H., Brou, Y.T, Meddi, M. & Roose, E. 2013 Relationships between man, environment and sediment transport: a spatial approach. *Revue des Sciences de l'Eau*, 26(3): 235-244.

Poesen, J., Nachtergaele, J., Verstraeten, G. & Valentin. 2003. Gully erosion and environmental change: importance and research needs. *Catena,* 50: 91– 133.

Challenges and opportunities to scale up the application of sustainability guidelines and voluntary standards

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Abstract

Despite an increasing evidence of the multi-faceted benefits of sustainable natural resource management, soil and land degradation continues to expand. Promoting sustainable soil management and restoration at a scale that is commensurate with the global developmental-environmental challenge is a complex endeavour that requires consistent policies, integrated models, and multi-stakeholder approaches. While conceptual frameworks, pioneering solutions, collaborative instruments and demonstrative projects exist, the principal challenge today is to scale them out and up. This research focusses on five 'enabling environment' conditions and the associated factors that can underpin this scaling effort. The analysis of real-world examples of solutions implemented across this spectrum reveals that action is hampered mainly by the lack of independent, integrated assessment systems and de-risking instruments that can provide assurance of performance and impact to policy-makers, investors and stakeholders.

Keywords: sustainable soil management, SDG financing, sustainable investment, impact rating, assurance, scaling, enabling environment, integrated assessment

Introduction, scope and main objectives

Over the past few years, the international community adopted a number of important policy frameworks that lay the foundations for an inclusive economy that acknowledges the value of ecosystem services, protects natural resources and promotes a sustainable future, such as the UN 2030 Agenda for Sustainable Development (UN, 2015).

Without finance, all these objectives and commitments will remain on paper. While the public sector can cover part of the finance gap, the largest investment is expected to come from the private sector. Yet, the global financial system is not channelling sufficient investment towards sustainable development (UNCTAD, 2014).

This is partly due to the lack of instruments to mitigate risks and uncertainty, and lack of appropriate investment vehicles. One particularly underutilized instrument is a form of public-private partnerships called blended finance. A number of blended finance vehicles specifically anchored to a SDG target have recently been launched, but they are struggling to reach their capitalization targets (Quatrini, 2018).

Beyond finance, another major bottleneck is assurance that processes, products and services comply with best-in-class standards. This requires robust and widely accepted conceptual frameworks, guidelines, metrics, indicators and models. Comprehensive assessments and independent verification of performance and impacts are essential to overcome the credibility deficit that obstructs large-scale adoption of sustainability principles, voluntary standards and guidelines, such as the Voluntary Guidelines for Sustainable Soil Management (FAO, 2017).

Sustainable soil management and restoration is a complex endeavour that requires an integrated and scalable approach. Most certification programs to-date focus on a single resource or commodity, or address only a narrow definition of sustainability. However, new initiatives that assess environmental protection, ecological restoration, ecosystem services, and sustainable production outcomes and impacts in an integrated manner are gradually emerging (ISEAL, 2018).

This paper provides an overview of some of the issues and innovations that are relevant to, illustrating key opportunities and challenges ahead.

Methodology

A mixed-method approach was used to examine the challenges and opportunities related to the mobilization of finance for the implementation of the SDGs (UN, 2015). This includes inter-alia:

- Quantitative analysis of financial flows for sustainable land management between 2008-2013;
- Survey and analysis of private investors' motivations using Theory of Planned Behavior (TPB);
- Participatory mapping of investment priorities via semi-structured interviews of local stakeholders;
- Corporate surveys and literature review for key land-use sectors, such as agriculture and mining;
- Consultations and workshops with industry experts and national/international stakeholders;
- Cascade framework to assess the effectiveness of policy interventions on agricultural landscapes and ecosystem services (Van Zanten *et al.* 2014).

The research focused on five 'enabling environment' conditions for sustainable development and the associated drivers or 'preconditions', as illustrated in the Theory of Change presented in Figure 1.

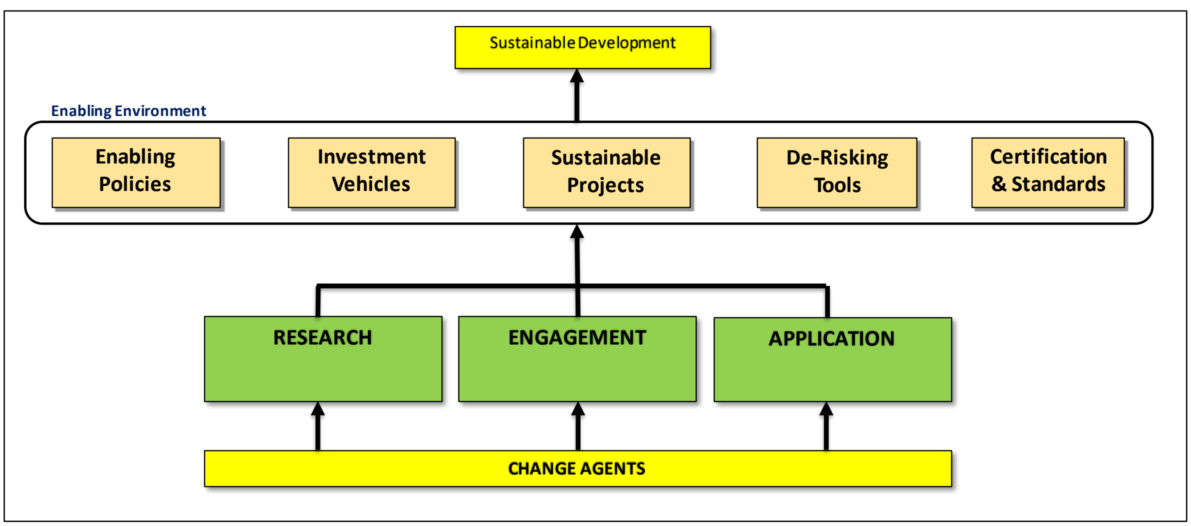

Figure 1: The underlying theory of change. Boxes on the lower part of the chart illustrate inputs and preconditions (text labels) in order for the next intermediate outcomes (orange and blue boxes) in the pathway (solid arrows) to be achieved. Positive impact (green box) is the ultimate outcome, or the goal. Dotted arrows indicate feedback or backward mapping mechanisms (Quatrini, 2018).

Results

The main results of the research are summarized in Table 1.

Table 1: Main results (Quatrini, 2018)

#	Result
1	Most sustainable land management projects (85%) have synergistic value (multiple benefits)
2	Public investment in land restoration is less than $10 billion/year, leaving an estimated gap of $2 billion/year
3	Private investors expect market to increase and attach high importance to non-financial aspects
4	Dedicated public funding is needed to mitigate risks, but is not sufficient to attract private capital at scale
5	Institutional investors face other barriers to entry, including conservative investment strategies
6	Innovative assurance mechanisms are needed to lower risk-adjusted returns and enable the development of a track record
7	Lack of deals with credible claims about overall performance and impact across all sustainability dimensions

Discussion

Despite an increasing body of literature and evidence of the multi-faceted benefits of sustainable natural resource management, soil and land degradation still continues on a large scale. According to many observers, "an important reason is that money spent on nature conservation, landscape restoration and sustainable land management is still seen as a cost and not as an investment with a high return in benefits: ecological, social and economic" (Ecosystem Services Partnership, ESP)[2].

To address this issue, the ESP is currently working on the development of guidelines to assess, quantify and verify – using robust models and certification standards – a series of returns on investment (ROI), comprising both financial and non-financial (e.g. environmental, socio-economic) returns (De Groot *et al.* 2018).

Another reason for 'inaction', particularly by farmers, landowners and investors, is perceived low risk-adjusted returns of converting to sustainable soil/land management techniques involving prevention, mitigation, conservation, remediation. This mainly depends on two factors: (i) uncertainty about yields, particularly under extreme weather events and slow onset events (e.g. climate change) and (ii) lack of harmonized measures and indicators of non-financial returns (e.g. net environmental/social impacts).

The former (i.e. point i) can for example be addressed with financial risk transfer instruments, such as (subsidized) insurance, such as weather index-based insurances. See for example, IFAD-WFP's Weather Risk Management Facility, which aims at reducing vulnerability to weather and other production risks, in order to encourage and protect investments in smallholder agricultural production and contribute to food security[3].

As regards the latter (i.e. point ii), the lack of harmonization is illustrated by the recent debate on ecosystem services/benefits definitions (see e.g. Diaz *et al.* 2018, Masood 2018).

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[2] https://www.es-partnership.org/esp-guidelines/
[3] https://www.wfp.org/climate-change/initiatives/weather-risk-management-facility

It should be noted that most quantification, valuation and certification models, as well as voluntary/industry standards, tend to focus on a single resource or commodity, are site-specific, or address only a narrow definition of sustainability. This leads to a large variety of numbers, values, and claims in both the scientific and grey literature, depending on the metrics, models and approach used, the scale or scope of the study, etc. (Adhikari and Nadella, 2011).

These cost-benefit analyses can be highly subjective and uncertain. The credibility deficit due to lack of accuracy and quality, in turn, can be further aggravated by failing verification and auditing practices (ISEAL, 2018).

Against this backdrop, it is essential to identify and use robust and reliable metrics, indicators and models that can capture the full range of performance and impact effects generated by the project or activity at farm, landscape or broader scale.

To this end, a comprehensive, integrated assessment approach has been developed by a coalition of partners that includes international conservation NGOs, among others, such as WWF and the Society for Ecological Restoration (SER). This approach was presented at the Global Landscapes Forum (GLF) in December 2018[4]. It harvests data and indicators from multiple authoritative sources, generates composite indices covering all sustainability dimensions, and produces performance and impact ratings that are dynamically updated using artificial intelligence (AI) calibration. The resulting scores can guide the governance of ecosystems, their conservation, resilience to climate change, restoration and sustainable use, while optimizing values across all four dimensions of ecosystem services, as well as biodiversity (AEDIS, 2018).

Conclusions

The demand for rigorous and integrated assessment approaches is tremendously growing. This demand mainly originates from a broad community of practitioners other than researchers, among which public and private sector investors, multilateral and intergovernmental authorities, regulators, landowners and land users, which require best-in-class, customized and harmonized monitoring and management practices, guidelines and standards to systematically incorporate all sustainability dimensions in their decision-making processes.

Channeling state-of-the-art knowledge into policy and decision-making practice further requires the harmonization of definitions, the standardization of classification processes and the streamlining of methodological and epistemological properties of relevant accounting, quantification, valuation and mapping approaches.

This presentation provides an overview of recent efforts to overcome the current analytical and methodological gaps, and harness machine learning technology to facilitate the combined analysis of multiple indicators of socio-ecological performance and impact in an integrated manner. These innovations have the potential to catalyze evidence-based action at scale to reduce land degradation and related issues such as soil erosion while increasing food security, a balance of ecosystem services (FAO, 2015) and promote the restoration of eroded sites.

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[4] https://events.globallandscapesforum.org/launchpad/Bonn-2018/day-1/landscape-finance-lab-wwf-a-philosophy-of-landscapes-standardized-approaches-to-help-scale-up-landscape-restoration/

The views expressed in this information product are those of the author and do not necessarily reflect the views or policies of FAO.

References

Adhikari, B. & Nadella, K. 2011. Ecological economics of soil erosion: a review of the current state of knowledge. *Annals of the New York Academy of Sciences*, 1219(1), 134-152.

AEDIS. 2018. Integrated Ecosystem Assessment & Rating System (IERS). Unpublished manuscript.

de Groot, R., Moolenaar, S. & Van Weelden, M. 2018. Guidelines for Integrated Ecosystem Services Assessment (under review). Available at: https://www.es-partnership.org/esp-guidelines/ [accessed 10.03.2019].

Diaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K.M.A., Baste, I.A., Brauman, K.A., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P.W., van Oudenhoven, A.P.E., van der Plaat, F., Schröter, M., Lavorel, S., Aumeeruddy-Thomas, Y., Bukvareva, E., Davies, K., Demissew, S., Erpul, G., Failler, P., Guerra, C.A., Hewitt, C.L., Keune, H., Lindley, S. & Shirayama, Y. 2018. Assessing nature's contributions to people. *Science*, 359(6373): 270–272. https://doi.org/10.1126/science.aap8826.

FAO. 2015. Revised World Soil Charter. Food and Agriculture Organization of the United Nations. Rome, Italy. Available at: http://www.fao.org/3/a-i4965e.pdf [accessed 10.03.2019].

FAO. 2017. Voluntary Guidelines for Sustainable Soil Management. Food and Agriculture Organization of the United Nations. Rome, Italy. Available at: http://www.fao.org/3/a-bl813e.pdf [accessed 10.03.2019].

ISEAL. 2018. Framework to Support Credible Landscape and Jurisdictional Sourcing Claims. Unpublished manuscript.

Masood, E. 2018. The battle for the soul of biodiversity. *Nature*, 560, 423-425.

Quatrini, S. 2018. Mobilizing blended finance for sustainable development: experience and lessons from the investment fund for land degradation neutrality (LDN). Doctoral Dissertation. ETH Zurich Research Collection.

UN. 2015. Transforming our world: the 2030 Agenda for Sustainable Development. Resolution adopted by the United Nations General Assembly on 25 September 2015 (A/RES/70/1). United Nations.

UNCTAD. 2014. World Investment Report: Investing in the SDGs - An Action Plan. United Nations.

Van Zanten, B.T., Verburg, P.H., Espinosa, M., Gomez-y-Paloma, S., Galimberti, G., Kantelhardt, J., ... & Raggi, M. 2014. European agricultural landscapes, common agricultural policy and ecosystem services: a review. *Agronomy for sustainable development*, 34(2), 309-325.

The economics of soil erosion and benefits of sustainable land management in Asia and Africa

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Abstract

The economic costs of soil erosion and associated nutrient loss and benefits of sustainable land management are examined in 44 Asian and 42 African countries using an integrated biophysical and econometric modelling approach that is then used to develop cost-benefit analyses. The overwhelming evidence is that the introduction of SLM practices to prevent soil erosion and other degradative processes has a net positive effect. Benefit-cost ratios range from an average of 7 for African countries and 4.5 for Asian countries. The implication of the results for poverty reduction, employment and the achievement of the Sustainable Development Goals will be discussed.

Keywords: Economics, Land Degradation, Cost-benefit analyses, Africa, Asia

Introduction, scope and main objectives

Over the last 50 years land degradation/desertification has affected around 33 % of the global land surface and erosion has removed around one third of the arable land from production. This includes about 45 % of African land but biggest impacts in terms of numbers of affected people have occurred in Asia. The economic costs are generally known to be about 3-5 % of GDP but there is widespread variation between and within countries. The Economics of Land Degradation Initiative (ELD) was established in 2012 partly in order to raise the profile of the costs of soil erosion and other forms of land degradation but also to estimate the economic benefits of sustainable land management. The initiative was predicated on the fact that after decades of work on the biophysical aspects of soil erosion, there was little evidence expressed in terms of metrics useful to policy maker, i.e., money. Only values from economic losses of provisioning services such as crops and timber are generally available to policy makers to compare choices for investments in natural resources and the environment versus other major issues like climate change, loss of biodiversity and pro-poor economic growth. The ELD initiative takes a total economic value approach to derive a cost-benefit analyses of sustainable land management (SLM) practices (ELD, 2015). This approach examines the value to society of all use and non-use values of land. Many countries however still lack sufficient basic information on costs of soil erosion and benefits of SLM practices l*et al*one the economics of other ecosystem services. This paper subsequently presents the results of studies done at the country and continental scales for soil erosion for

Africa and Asia as a first step to encouraging more studies on the valuation of ecosystem services and their contribution to pre-poor economic growth.

Methodology

The studies involved empirical analyses of arable and permanent croplands of over 487 million ha in Asia and over 105 million ha of arable land in Africa. Biophysical modeling of soil nutrient balance in agricultural ecosystems was integrated with econometric modeling to estimate the net benefits of investing in sustainable land management and the costs of the loss of major nutrients via erosion. The results are then used to provide estimations of the costs of inaction, the costs of implementing sustainable land management and the derived benefits in order to complete a cost-benefit analyses. Details are reported in UNEP, 2015; Tilahun *et al.*, 2018) and the conceptual framework used is shown in Figure 1 below.

Conceptual Framework

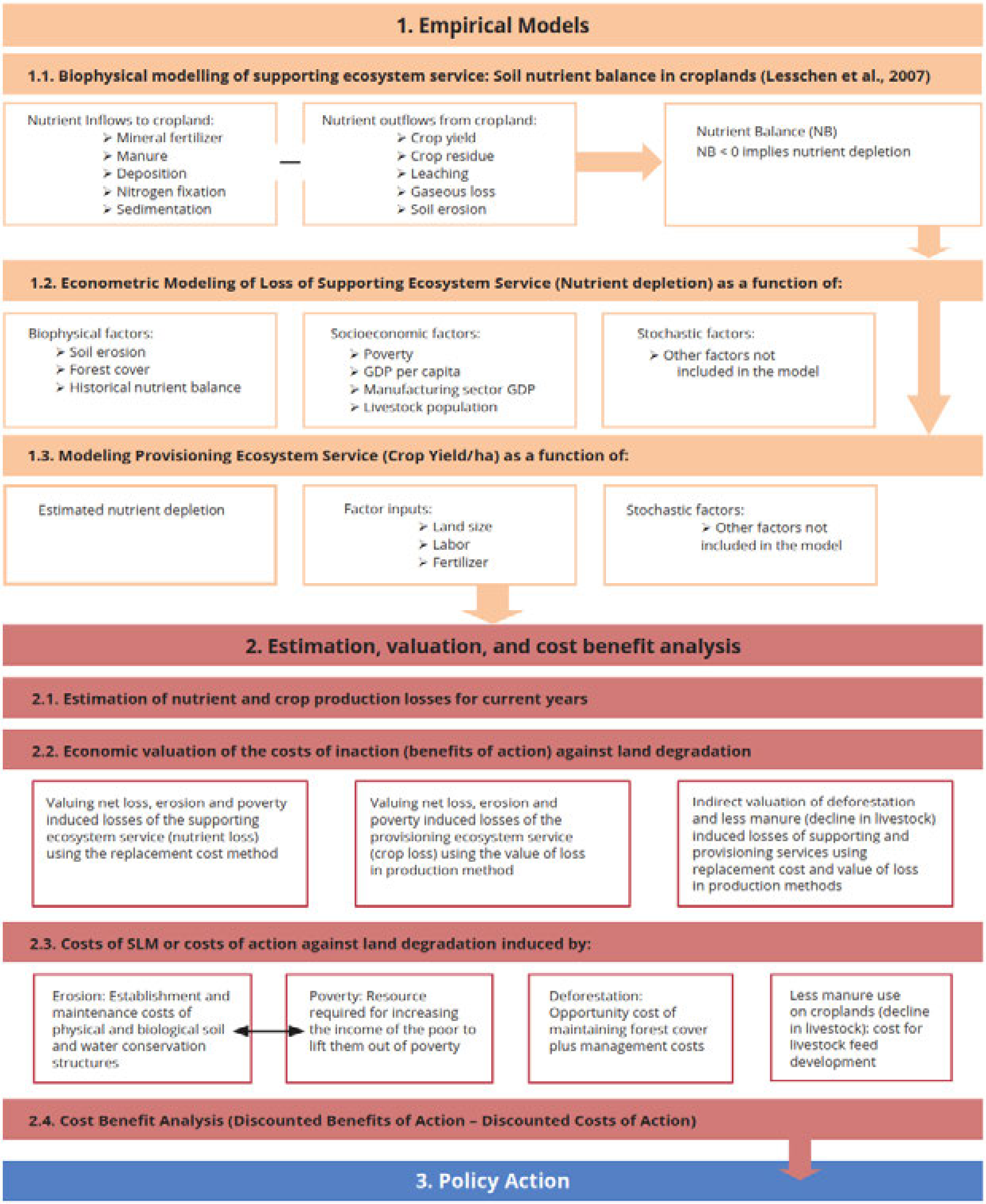

Figure 1: The conceptual framework used for the empirical studies for Africa and Asia.

Results

For Asia (44 countries, 127 crop types) the average rate of soil loss was estimated at 11.9 tonnes/hectare/yr during the period 2002-2013. Aggregating this results in an estimated loss of crop production of about 1.31 billion tonnes amounting to USD 732.7 billion/yr, enough to feed over 4 billion people. Soil nutrient loss (N,P and K) resulted in a depletion of soil reserves of about 108 kg/ha/yr. If Asian countries invested in SLM technologies to replace lost soil and nutrients productivity could be increased by 5 to 8 tonnes/ha/yr. The costs of investing in SLM practices were estimated to be about USD 2 494/ha; broken down to 19 % for establishment, 58 % for maintenance, 20 % for planning and implementation and 3 % for monitoring and evaluation. The total benefits are equal to USD 8 663/ha giving a net benefit of USD 6 182/ha or a benefit:cost ratio of 3.5. Further details of the breakdown of cost-benefits are available on a country basis (Tilahun *et al.*, 2018).

Similarly for 42 countries in Africa around 5.2 million tons of N, P and K would be lost per year or 50 kg/ha/yr. This means a loss of some 278 million tons of cereal equivalents per year or a staggering USD 4.6 trillion over the next 15 years or around 127 billion per year. The costs of action against nutrient loss was estimated to be USD 25.2 billion/yr. However the benefits from action to prevent nutrient loss are estimated to be 71.8 billion/yr, generating a net benefit of around 62.4 billion/yr. This translates into a benefit-cost ratio of 6.6 for practices to combat soil erosion. For Africa the estimated benefits to food security and poverty reduction from investing in preventing soil erosion represent about 58 % of the full cost or income required in the next 15 years in order to lift all of the poor to an income level equal to the poverty line. This is a significant number that policy makers should be made aware of.

There are large variations amongst countries in terms of the % gains to be expected based on their areas under cultivation. For example 10 countries (China, India, Iran, Turkey, Japan, Indonesia, Thailand, Kazakhstan, Pakistan and Malaysia) comprise 85 % of the total agricultural land in Asia meaning the benefits will be skewed accordingly. This will have implications for policy makers in terms of achieving food security, either via internal production and investments or the need to be able to generate alternative income to import food from others.

Discussion and Conclusions

The results from both continents show the positive economic benefit of introducing practices to combat soil erosion and associated nutrient losses. This is particularly important in Africa where application of fertilizer is generally far below the global average and hence there is scope for much greater efficient use of inputs. Our results agree with others in terms of the net positive economic benefits of investing in SLM practices. Countries can now use the results as a basis for discussion and interactive processes on questions of land use and land use change at the local level and at the national level as an input into their responses to the Sustainable Development Goals and Natural Capital accounting exercises More studies are now needed to examine how these numbers can translate into poverty reduction strategies with an emphasis on rural employment opportunities along food and other provisioning services value chains. In particular, researchers and countries will need to assess if the adoption of SLM practices that prevent soil erosion and other degradative processes can stimulate greater investments in agriculture and related sectors. The focus of these efforts should be on decentralized, low costs, labor-intensive options that are not only profitable but that also encourage entrepreneurial activities, especially for women who dominate the labor market for food production.

For complementary studies on additional practices beyond soil erosion and nutrient loss the reader is encouraged to visit the ELD website (www.eld-initiative.org). For example other ELD studies are available on SLM practices in Sudan, Kenya, Namibia, Botswana, Mali and Ethiopia with on going additional studies in Senegal, Ghana, Niger, Rwanda and Somalia.

Acknowledgements

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References

ELD. 2015. The value of land: Properous lands and positive rewards through sustainable land management. ELD Initiative, Bonn, Germany. Available at: www.eld-initiaitve.org.

Tilahun, M., Singh, A., Apindi, E., Shaure, M., Libera, J & Lund, G. 2018. The economics of land degradation neutrality in Asia: Empirical analyses and policy implications for the Sustainable Development Goals. Available at: http://www.eld-initiative.org/fileadmin/pdf/Asia_Report_EN.pdf.

UNEP. 2015. The economics of land degradation in Africa. ELD Initiative, Bonn, Germany. Available at: www.eld-initiative.org.

Economic Analysis of Soil Erosion Control in New Zealand: Robust Identification of Benefits, Costs and Investment Priorities at the National Level

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Abstract

Economic analysis of soil erosion control is essential to optimize investment in activity that will achieve biophysical, economic and social goals. This study reports preliminary estimates of the benefits from erosion control benefits for the period 2021 to 2040. Outcomes, benefits and costs are sensitive to estimates of the prevailing state of degradation; land use; the risk profile of land; anticipated product prices; erosion control costs; and the valuation of offsite benefits associated with erosion control. The analysis is ground in production economics and the extra productivity associated with improved soil management complemented by the non-market benefits. It considers eight classes of land used for sheep and beef farming and two classes of land used for dairy farming and land used in horticulture. Estimates will be refined on the basis of further analysis but the preliminary results provide information of value for public policy and private land users.

Keywords: soil erosion, New Zealand, economics, investment, costs, benefits, risk

Introduction, scope and main objectives

This study estimates the value of soil erosion control in New Zealand for the period 2021-2040. Estimating the value of soil erosion control is essential to provide robust evidence of the value of value such work relative to investment in alternative environmental initiatives. It is helpful in providing better estimates of agricultural productivity which adequately consider environmental capital and environmental services. This work is a useful contribution to global consideration of investment in protecting soil resources. The simulation analysis is built on the tradition of non-market valuation (Hufschmidt *et al.*, 1983) and more recent economic analyses of soil erosion in New Zealand (Fernandez and Daigneault, 2017; Jones *et al.*, 2008).

Methodology

The study estimates a production function for 14 categories of agricultural land use with extensive use of production data from industry organizations. For each land category erosion estimates are made based on policy and management practices. Key coefficients derive from NZ soil maps and conversations with industry professionals. Each level of erosion is associated with a level of agricultural production, an on-farm damage function, and a level of environmental externalities. Soil erosion impacts production through damage to soils and damage to structures such as fences and farm tracks. Costs of soil conservation activity are estimated based on current best practice. The result is best and worst case estimates of the value of soil conservation activity. These are available for the 14 land categories and for the nation. The results are indicative given that more than one hundred thousand land users with variable aspiration and abilities are making choices on individual properties each with unique bio-physical characteristics. Further, not only is there aggregation of production and onsite benefits there is aggregation of non-market benefits across diverse sites which carries significant risk (Newbold *et al.*, 2018).

Results

The results show benefits vary significant across land use and location. Soil conservation activity on hill country sheep and beef farms enhances pastures productivity and reduces sediments flows, on farm damage and off farm impacts. Major differences exist within the eight sheep and beef farm categories analysed. Soil erosion on dairy farms and horticulture operations is modest where best practices are in place. The largest per hectare benefits accrue in farming activity where substantial reductions in erosion can occur with modest investment in soil conservation activity. The ratio of on-farm benefits to off-farm benefit also varies considerably between land categories. These estimates are important for identifying areas that require greater regulatory attention and potentially may be suitable for subsidized soil conservation activity.

Discussion

The results signal the importance of accurate measures of erosion control benefits to appropriately justify and target public investment. Projected benefits are sensitive to production assumptions (land use choice and management practices) and the expected policy environment. Soil conservation objectives interact with other environmental objectives pertaining to improving water quality and reducing greenhouse gas emissions. Improved estimates can be achieved by increasing the number of land categories utilised. Further, a major question to be considered is to what extent the economic analysis should focus on refining the estimates of the benefits from controlling erosion vis-à-vis measuring the total environmental and economic impact of agriculture on soil and the environment more generally.

Conclusions

Soil is a capital asset that generates benefits over long time horizons. The results show that benefits from soil erosion control vary greatly with location, land use and the wider policy settings. However, measures of benefit can be made that can inform domestic policy and be a useful contribution to global estimates of the value of controlling soil erosion. The resulting estimates are informative for high level choices but further detailed analysis is required by utilising the estimates in specific locations.

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References

Fernandez, M.A. & Daigneault, A. 2017. Erosion mitigation in the Waikato District, New Zealand: economic implications for agriculture. *Agricultural Economics*, 48(3): 341–361.

Hufschmidt, M., James, D., Meister, A., Bower, B.T. & Dixon, J.A. 1983. *Environment, Natural Systems and Development: An Economic Valuation Guide*. John Hopki edition. Baltimore.

Jones, H., Clough, P., Hock, B. & Phillips, C. 2008. Economic costs of hill country erosion and benefits of mitigation in New Zealand: review and recommendation of approach. Rotorua.

Newbold, S., Simpson, R.D., Massey, D.M., Heberling, M.T., Wheeler, W. & Corona, J. 2018. Benefit Transfer Challenges: Perspectives from U.S. Practitioner. *Environmental and Resource Economics*, 69(3): 467–481.

A synergy between the biophysical and the economic: the global market impacts of soil erosion

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Abstract

Employing a linkage between a biophysical and an economic model, this study estimates the economic impact of soil erosion by water on the world economy. The global biophysical model estimates soil erosion rates, which are converted into land productivity losses and subsequently inserted into a global market simulation model. The headline result is that soil erosion by water is estimated to incur a global annual cost of eight billion US dollars to global GDP. The concomitant impact on food security is to reduce global agri-food production by 33.7 million tonnes with accompanying rises in agri-food world prices of 0.4 % to 3.5 %, depending on the food product category. Under pressure to use more marginal land, abstracted water volumes are driven upwards by an estimated 48 billion cubic meters. Finally, there is tentative evidence that soil erosion is accelerating the competitive shifts in comparative advantage on world agri-food markets.

Keywords: soil erosion, land productivity loss, computable general equilibrium, model integration, global economy, agriculture

Introduction, scope and main objectives

Employing a linkage between a biophysical and an economic model, this study estimates the economic impact of soil erosion by water on the world economy.

In a changing world of eight billion people with the critical threats of climate change, water scarcity and depletion of soil fertility, the agricultural economy should adapt taking into account environmental and ecological aspects (Altieri and Nicholls, 2017). A key element for ensuring a sustainable system of food production is linked to effective soil management, which implies a reduction of soil erosion rates (Poesen, 2018). Among various land degradation processes, soil erosion is recognized as a major environmental problem causing loss of topsoil and nutrients, reduced soil fertility (Zhao *et al.*, 2013) and, as a consequence, reduces crop yields (Telles *et al.*, 2011). Furthermore, soil erosion may increase the losses of CO2, exacerbating the climate change (Lugato *et al.*, 2018).

A recent estimation of land degradation costs shows that the global economic impact is highly uncertain, from 40 to 490 billion US$, and varies from country to country (Nkonya *et al.*, 2016). More than two decades ago, Pimentel *et al.* (1995) estimated the on-site costs of water erosion in the United States of America to be about 16 billion US$ per year based on expert knowledge. Similarly, the agricultural productivity loss due to soil erosion in the European Union is estimated to be around 300 million € (Panagos *et al.*, 2018) using a combination of the recent soil loss assessment and the well-known Global Trade Analysis Project (GTAP) computational general equilibrium (CGE) simulation model. A recent application on the African continent estimates the annual loss of crop yield to be about 280 million tonnes (Wolka *et al.*, 2018), compared with only six million tonnes estimated in the European Union.

With one notable exception (Panagos *et al.*, 2018), a typical feature of these studies is that they carry out a 'first-order' cost evaluation exercise focusing in agricultural production losses (e.g., Erkossa *et al.*, 2015). More specifically, the economic value of land productivity loss is calculated by the direct loss in production of the affected crops (tonnes) multiplied by their respective average market prices ($/tonnes). This analysis does not, however, capture the resulting 'second-round' effects of economic structural change that arise owing to shifts in primary resources, particularly the land factor.

Methodology

This study estimates the impact of soil erosion by water on the world economy, employing a linkage between a biophysical and an economic model. To the best of our knowledge, there is no study that fully captures the aforementioned structural impacts from land productivity losses due to soil erosion at the global scale. To close this gap in the literature, an approach akin to Panagos *et al.* (2018) is followed. Soil erosion rates are first estimated by the Global RUSLE biophysical model (Borrelli *et al.*, 2017), converted into land productivity losses and then fed into the Modular Applied GeNeral Equilibrium Tool (MAGNET) (Woltjer and Kuiper, 2014). Whilst the core of MAGNET is the GTAP model, it is superior to GTAP because it contains a greatly improved treatment of agricultural factor markets. The counterfactual thus captures the resulting marginal market impacts in agricultural (and non-agricultural) activities, which arise in each region due to soil erosion.

Results

As a headline Figure, the results show that soil erosion is unambiguously detrimental to global food production, resulting in a non-trivial decline in agricultural and food production of 33.7 million tonnes. Due to the lower amount of agri-food products available in the international markets and the consequent price increase, the total value of these goods has increased by 24.9 billion US$. Globally, land demand increases by approximately 223 000 km^2, equivalent to a 0.5 % increase in global land use in agriculture. The largest contributions arise from cereals (27 %), driven by the positive change in production, horticulture (19 %) and oil seeds (19 %) activities. Globally, soil erosion has also brought about a 1.6 % increase of the water withdrawn for agricultural purposes (which is equal to more than 48 billion cubic meters). In absolute terms, China, Indonesia and South-East Asia represent approximately 14 %, 12 % and 23 % of the global increase, due to the irrigation intensive system of rice production. In proportional terms, Brazil, the 'USA and Canada' region and South America witness water abstraction increases of up to 5 %. Detailed results can be found in Sartori *et al.*, 2019.

Discussion

Compared with previous ‘first-order’ estimates of soil erosion costs, these findings draw markedly different conclusions. For example, in contrast to 'first order' estimates from Wolka *et al.* (2018), who measure a soil erosion driven production loss of 280 million tonnes in Africa, our study reveals a surprisingly diverse picture. Crop production in the African continent increases marginally by 0.35 million tonnes (due to the positive production changes in South Africa and North African countries), since marginal land productivity losses for this continent as a whole are estimated to be lower than in other regions (e.g., China, Brazil, Indonesia). Nonetheless, within the Sub-Saharan African region, the prospects for a number of African countries are more concerning. For example, some West African (Cameroon, Cote d'Ivoire, Ghana and Nigeria) and East African countries (Ethiopia, Kenya, Madagascar and Rwanda) suffer losses in horticultural and cereals production, which are typically high value added cash crops for these countries. Drilling down into the results, one also observes that even with an erosion shock corresponding to a single year, there are noticeable global shifts in agricultural production in China, India and Brazil. These changes are particularly prevalent in the production of rice (and oilseeds on a lesser degree), which decreases by almost 0.5% globally. Indeed, our study reveals that falling land productivity, particularly for rice production, is a major driver of increased water abstraction in Asia. From a trade perspective, the heterogeneous rates of erosion across the planet give rise to accelerating current trends where net agri-food exporters such as USA, Canada, Europe and Oceanian countries continue to improve their net trade balances at the cost of net food importers such as China and South East Asian countries.

Conclusions

In the context of the broader debate, this study provides a direct input into recent strategies such as the Economics of Land Degradation initiative (ELD, 2015; Nkonya *et al.*, 2016) and the Global Land Outlook (GLO) currently proposed by United Nations Convention to Combat Desertification (UNCCD).

The economic effects of soil erosion call for the prioritization of soil governance and conservation strategy in all countries and international policy agenda. In this regard, the European Commission launched the Seventh Environment Action Programme, which requires that by 2020 land is managed sustainably and soil is adequately protected (Paleari, 2017). Focusing on agricultural land, the EU's Common Agricultural Policy (CAP) links support directly to the need to maintain agricultural land in good condition, whilst the post- 2020 CAP includes as one of its main objectives, efficient soil management linked to actions to reduce soil erosion and increase soil organic carbon (Panagos and Katsoyiannis, 2019). In the USA, the Farm Bill extends soil conservation compliance requirements in order to qualify for the crop insurance subsidy (Islam *et al.*, 2014). At global scale, the FAO and its Global Soil Partnership launched in June 2018 a new programme to reduce soil degradation for greater food and nutrition security in Africa.

Measures aimed at reinforcing ecosystem services, ad hoc regulation of human interventions and active farmers' participation contribute to minimize soil erosion. To this aim, protection and restoration of diverse plant communities on slopes are essential, as trees and diversified vegetation increase soil resistance to rain erosivity (Berendse *et al.*, 2015). Other measures such as reduced tillage, buffer strips, agroforestry, plant residues and cover crops enhance soil fertility and control water runoff (Triplett and Dick, 2008).

The views expressed in this information product are those of the authors and do not necessarily reflect the views or policies of FAO.

References

Altieri, M.A. & Nicholls, C.I. 2017. The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change*, 140(1): 33-45.

Berendse, F., van Ruijven, J., Jongejans, E. & Keesstra, S. 2015. Loss of plants pecies diversity reduces soil erosion resistance. *Ecosystems*, 18: 881-888. DOI:10.1007/s10021-015-9869-6.

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B. & Ferro, V. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature communications,* 8.

ELD Initiative. 2015. Report for policy and decision makers: Reaping economic and environmental benefits from sustainable land management. Available from www.eld-initiative.org at the web address: http://www.eld-initiative.org/fileadmin/pdf/ELD-pm-report_05_web_300dpi.pdf.

Erkossa, T., Wudneh, A., Desalegn, B. & Taye, G. 2015. Linking soil erosion to on-site financial cost: lessons from watersheds in the Blue Nile basin. *Solid Earth*, 6(2): 765-774.

Islam, R. & Reeder, R. 2014. No-till and conservation agriculture in the United States: an example from the David Brandt farm, Carroll, Ohio. *International Soil and Water Conservation Research*, 2(1): 97-107.

Lugato, E., Smith, P., Borrelli, P., Panagos, P., Ballabio, C., Orgiazzi, A., Fernandez-Ugalde, O., Montanarella, L. & Jones, A. 2018. Soil erosion is unlikely to drive a future carbon sink in Europe. *Science Advances*, 4 (11), art. no. eaau3523.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L. & Saffouri, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science,* 267: 1117–1123. DOI: 10.1126/science.267.5201.1117.

Nkonya, E., Anderson, W., Kato, E., Koo, J., Mirzabaev, A., von Braun, J. & Meyer, S. 2016. Global Cost of Land Degradation. in: Nkonya, E., Mirzabaev, A., von Braun, J. (Eds.), *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development.* Springer International Publishing, Cham, pp. 117–165.

Paleari, S. 2017. Is the European Union protecting soil? A critical analysis of Community environmental policy and law. *Land use policy*, 64: 163-173.

Panagos, P. & Katsoyiannis, A. 2019. Soil erosion modelling: The new challenges as the result of policy developments in Europe. *Environmental Research*, 172: 470-474.

Panagos, P., Standardi, G., Borrelli, P., Lugato, E., Montanarella, L. & Bosello, F. 2018. Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models. *Land Degradation & Development,* 29: 471–484.

Poesen, J. 2018. Soil erosion in the Anthropocene: Research needs. *Earth Surface Processes and Landforms,* 43: 64–84.

Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Montanarella, L. & Panagos, P. 2019. A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion. *Land Use Policy*, 86: 299-312.

Telles, T.S., Guimarães, M.D.F. & Dechen, S.C.F. 2011. The costs of soil erosion. *Revista Brasileira de Ciência do Solo*, 35(2): 287-298.

Triplett, G.B. & Dick Jr, W.A. 2008. No-tillage crop production: a revolution in agriculture! *Agronomy Journal*, 100: S153–S165. DOI:10.2134/agronj2007.0005c.

Wolka, K., Mulder, J. & Biazin, B. 2018. Effects of soil and water conservation techniques on crop yield, runoff and soil loss in Sub-Saharan Africa: A review. *Agricultural Water Management,* 207: 67–79.

Woltjer, G.B. & Kuiper, M.H. 2014. The MAGNET Model: Module description. Wageningen, LEI Wageningen UR (University & Research centre), LEI Report 14-057.

Zhao, G., Mu, X., Wen, Z., Wang, F. & Gao, P. 2013. Soil erosion, conservation, and eco-environment changes in the Loess Plateau of China. *Land Degradation & Development,* 24: 499–510.

Mapping soil loss by water erosion in Argentina and analysis of its economic impact

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Abstract

Water erosion is the main problem of land degradation in Argentina which has substantial implications for nutrient and carbon cycling, land productivity and in turn socio-economic conditions. In this study, we used an USLE-based modelling approach for: 1) mapping the rate of soil loss due to water erosion for Argentina, and 2) analyze the economic loss caused by the effect of water erosion on the decrease in yield of the main crops of the country (soybean, wheat and corn) in the last 20 years. According to our study, the water erosion rate for Argentina is 6.2 $Mg.ha^{-1}.yr^{-1}$ or approximately 0.5 mm of soil per year. Considering only the croplands area, the water erosion rate decreased from 9.23 to 4.14 $Mg.ha^{-1}.yr^{-1}$, between 1998 and 2017, due to the advance in the adoption of the non-till system. For this period, the cumulative economic loss estimated by decreasing soybean, wheat and corn yields was 10.06 billions dollars. The proposed approach, allows for the first time for Argentina, to have a quantitatively and spatially explicit cartography of soil loss due to water erosion, which shows the areas with the greatest erosion problems in the country.

Keywords: USLE, Argentina, crops yield, economic valuation, croplands

Introduction, scope and main objectives

Water erosion is the main problem of land degradation in Argentina (Casas, 2015), compromising the sustainability of all productive systems, given that one of its immediate consequences is the reduction of agricultural productivity, due to the loss of nutrients, to the physical deterioration of the soil and, in extreme cases, the total loss of the soil. Therefore, the estimation of soil losses due to this phenomenon and its economic impact is a very important information for planning and decision-making at different levels. To date, the only study that presents a cualitative map of the state of water erosion in Argentina was made in 1988 (PROSA, 1988). According to this study, the area affected by water erosion in the country was 25 million hectares. In the last decades, in Argentina there has been a process of expansion of agriculture, whose area increased by nearly 50% in the last 20 years (26.5 million hectares to 39.5 million hectares). This process occurred at the expense of lands occupied by native forest or rangelands (Viglizzo and Jobbágy, 2010). Due to these changes, is necessary to update the cartography of the state of soil water erosion on a national scale and estimate its economic impact.

The most widely used models to estimate soil water erosion rates include the Universal Soil Loss Equation (USLE), developed in the United States by Wischmeier and Smith in 1965 and modified in 1978. This equation was derived from data analysis obtained from more than 10 000 runoff plots and allows to estimate quantitatively the erosion for certain conditions of precipitation, soil, relief, vegetation and management practices.

Objectives: 1) Obtain a map with the rate of soil loss due to water erosion for Argentina. 2) Analyze the economic loss caused by the effect of water erosion on the decrease in yield of the main crops of the country (soybean, wheat and corn) in the last 20 years.

Methodology

The USLE model uses five factors: rain erosivity (R), soil erodability (K), slope length and gradient (LS), vegetation cover and crops management (C), and conservation practices (P), to estimate the rate of soil loss (A):

$A = R \cdot K \cdot LS \cdot C \cdot P$

Given that, in order to apply the original USLE methodology on a national scale, the necessary data are often missing, we performing different approaches to estimate the factors of the equation.

The "R" factor of rain erosivity, whose precise calculation requires rainfall intensity data, was estimated from the mean annual precipitation. For the "K" factor, of soil susceptibility to erosion, the map of the Soil Atlas of Argentina (INTA, 1990) was used as a base and “K” estimated for each cartographic unit from soil organic matter and texture data. The "LS" topographic factor establishes the influence of relief on water erosion, resulting from the combination of the gradient (S) with the length of the slope (L). To estimate this factor we used a digital elevation model generated by SRTM (Shuttle Radar Topography Mission) from NASA and we analyze them with the Topographic Indexes of Terrain Analysis module of the SAGA-GIS software following the method of Moore *et al.* (1991). For the estimation of the factor "C", cover and management of crops and residues, three main types of soil cover were considered, which were extracted from the "Map of land cover of Argentina-2007" (Volante *et al.*, 2009): natural and cultivated forests, crops and natural grasslands and shrublands, assigning to each type a “C” value, in the latter case a variable value was assigned according to your % of soil cover, estimated from NDVI data. The "P" factor refers to conservation tillage practices in croplands, such as terraced crops. Given that there is no map, at a national scale, that shows the areas where this type of management practices exist, this factor of the equation was not considered. The factors were integrated using Geographic Information Systems, to generate current and potential soil water erosion maps.

To analyze the economic impact of erosion on the decrease in the yield of wheat, soybeans and corn, the rates of soil loss for the last 20 years in the croplands area were calculated. It was considered that the potential erosion has remained constant in this period and that the factor “C” of the USLE has been varying with the adoption of non-till system (50% of the area in 1998 to 90 % in 2017).

An average C factor was considered for the main agricultural rotations of the country according to data of Marelli *et al.* (2012): 0.398 for conventional tillage system and 0.102 for non-till system. A variable value of “C” for each year was obtained as the weighted average of “C” of each tillage system by its % of adoption in each year.

The soil loss rate ($Mg.ha^{-1}.yr^{-1}$) estimated for each year was converted to soil layer (considering an average soil bulk density of 1.20 Mg/m^3) and accumulated year to year for the entire period analyzed (1998 to 2017). From the layer of soil lost in each year we estimate the decrease in crop yield according to previous studies: soybeans reduced their yield by 95 kg.ha^{-1} for each centimeter of soil lost, corn by 273 kg.ha^{-1}.cm^{-1} and wheat by 71 kg.ha^{-1}.cm^{-1} (Irurtia and Mon, 2000). Yield losses were multiplied by the harvested area of each crop in each year. In this way, the estimated production loss for each year and each crop was obtained. An economic valuation was carried out, at current prices, multiplying the loss of production by the prices of the grains: soybean: 335 $USD.Mg^{-1}, wheat: 185 $USD.Mg^{-1} and corn: 160 $USD.Mg^{-1}.

Results

Figure 1 shows the map of current water erosion in Argentina. The average rate of current water erosion was calculated at 6.2 Mg.ha^{-1}.yr^{-1}, which is equivalent to a loss of approximately 0.5 mm of soil per year and for the total area of the country represents a loss of 1 725 million Mg or 1 490 million m^3 of soil per year. Approximately 60 % of the country's area presents low erosion rates (less than 2 Mg.ha^{-1}.yr^{-1}), most of these areas correspond to wet/sub-humid areas with high vegetation cover. Approximately 12% of the country's area presents erosion rates higher than 10 Mg.ha^{-1}.yr^{-1}, which are concentrated in arid/semi-arid areas with steep slopes and low vegetation cover. Potential erosion estimates the maximum rate of soil loss that would occur if the entire vegetation cover is removed. The average rate of potential water erosion was calculated at 166 Mg.ha^{-1}.yr^{-1}, which would be equivalent to a loss of approximately 1.2 centimeters of soil per year. According to the classification of FAO (1980), almost 40 % of country's area has a slight potential erosion rate (less than 10 Mg.ha^{-1}.yr^{-1}). While about 10 % of the area has very high potential erosion rates (greater than 200 Mg.ha^{-1}.yr^{-1}).

In the 20 years of the analyzed period the erosion rate, in the croplands area of the country, decreased from 9.23 to 4.14 Mg.ha^{-1}.yr^{-1} due to the advance in the adoption of the non-till system. For this period, the cumulative economic loss estimated by decreasing soybean, wheat and corn yields, due to water erosion of the soils, was 10.06 billion dollars (Table 1). If the current year is considered (2018/19), to this value must be added 0.985 billion dollars, which represent 0.16 % of the country's GDP (626 billions dollars, source: IMF).

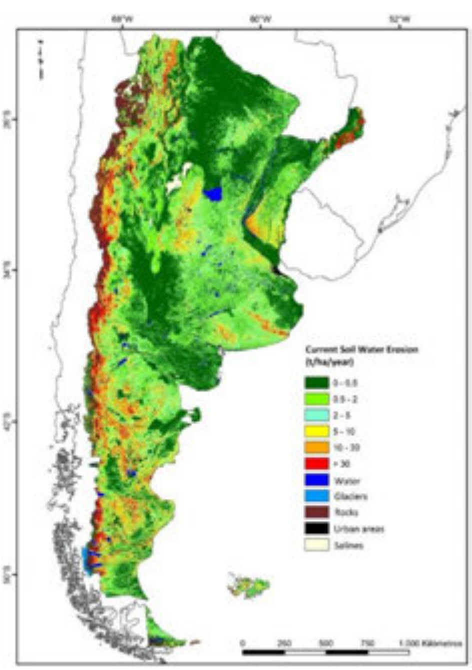

Figure 1: Current soil water erosion in Argentina.

Table 1. Soil erosion rate, cumulative layer soil loss, yield and total production loss for soybean (S), Wheat (W) and corn (C) and economic loss in croplands area of Argentina.

Year	Soil erosion rate ($Mg.ha^{-1}.yr^{-1}$)	Cumula-tive layer soil loss (cm)	Yield loss ($Kg.ha^{-1}$)			Total production loss (thousands of Mg)			Economic loss ($ USD millions)		
			S	W	C	**S**	W	C	**S**	W	C
1998/99	9.23	0.077	7.3	5.5	21.0	59.6	29.5	52.4	20.0	5.5	8.4
1999/00	8.93	0.151	14.4	10.7	41.3	123.9	66.0	126.7	41.5	12.2	20.3
2000/01	8.63	0.223	21.2	15.9	61.0	224.5	101.1	170.4	75.2	18.7	27.3
2001/02	8.33	0.293	27.8	20.8	79.9	316.0	141.7	192.0	105.9	26.2	30.7
2002/03	8.03	0.360	34.2	25.5	98.2	422.7	154.3	224.3	141.6	28.5	35.9
2003/04	7.73	0.424	40.3	30.1	115.8	574.1	172.5	263.0	192.3	31.9	42.1
2004/05	7.43	0.486	46.2	34.5	132.7	645.5	208.5	366.7	216.2	38.6	58.7
2005/06	7.13	0.546	51.8	38.7	148.9	780.7	192.0	358.9	261.5	35.5	57.4
2006/07	6.83	0.602	57.2	42.8	164.5	910.9	236.3	458.8	305.1	43.7	73.4
2007/08	6.53	0.657	62.4	46.6	179.3	1017.9	268.3	603.1	341.0	49.6	96.5
2008/09	6.23	0.709	67.3	50.3	193.5	1124.4	213.3	452.8	376.7	39.5	72.5
2009/10	5.93	0.758	72.0	53.8	207.0	1340.0	175.3	590.3	448.9	32.4	94.4
2010/11	5.64	0.805	76.5	57.2	219.8	1428.7	257.4	812.3	478.6	47.6	130.0
2011/12	5.34	0.850	80.7	60.3	232.0	1413.8	269.9	849.7	473.6	49.9	136.0
2012/13	5.04	0.892	84.7	63.3	243.4	1641.8	189.8	1173.8	550.0	35.1	187.8
2013/14	4.74	0.931	88.5	66.1	254.2	1699.6	228.2	1217.6	569.4	42.2	194.8
2014/15	4.44	0.968	92.0	68.7	264.3	1774.1	340.3	1211.5	594.3	62.9	193.8
2015/16	4.14	1.003	95.3	71.2	273.7	1850.6	278.8	1451.5	619.9	51.6	232.2
2016/17	4.14	1.037	98.5	73.6	283.2	1703.2	407.6	1839.5	570.6	75.4	294.3
2017/18	4.14	1.072	101.8	76.1	292.6	1655.3	440.1	2074.2	554.5	81.4	331.9
Total									**6936.9**	**808.6**	**2318.4**

Discussion

In this study, we provide quantitative, thorough estimates of soil erosion for Argentina by means of a high-resolution, spatially distributed, USLE-based modelling approach. According to our study, the water erosion rate for Argentina is 6.2 $Mg.ha^{-1}.yr^{-1}$, which is higher than 2.8 and 3.53 $Mg.ha^{-1}.yr^{-1}$ estimated by Borrelli *et al.* (2013) for Global and South-America, respectively.

The loss of soil due to water erosion exceeds the tolerance values in 26 % of the country's area (results not shown). The tolerance of soil loss is the maximum erosion rate that allows maintaining a high level of productivity. A tolerable erosion rate could be one in which the annual loss of soil equals the rate of soil formation (Cisneros *et al.*, 2012). In our study, variable tolerance values were considered, between 0.5 $Mg.ha^{-1}.yr^{-1}$ in arid climates and shallow soils and 10.0 $Mg.ha^{-1}.yr^{-1}$ in humid climates and deep soils.

In the croplands area of the country the erosion rate decreased from 9.23 (1998) to 4.14 $Mg.ha^{-1}.yr^{-1}$ (2017), due to the advance in the adoption of the non-till system. These values are lower than the 12.7 $Mg.ha^{-1}.yr^{-1}$ estimated for the croplands areas globally (Borrelli *et al.*, 2013). Our results are in agreement with that indicated by Borrelli *et al.* (2013) that show that Argentina is the country in the world that most reduced the soil loss in croplands areas between 2001 and 2012 (-33%). Despite these advances, in the 20-year period, Argentina lost production, due to soil erosion, equivalent to 20.7, 4.4 and 14.5 million Mg for soybean, wheat and corn, respectively. These losses were valued at approximately 10 billion dollars.

Conclusions

The proposed approach allows for the first time for Argentina, to have a quantitatively and spatially explicit estimation of soil loss due to water erosion. This information is important for decision-making at the governmental level and is the basis to make projections of the effects of different scenarios of (1) climate change, (2) processes of land use change and (3) adoption of conservation tillage practices. Although the country has shown progress in reducing erosion in its cropland areas, the economic loss due to lower yields of the main crops is relevant to the country's economy.

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References

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B., Ferro, V., Bagarello, V., Oost, K. Van, Montanarella, L. & Panagos, P. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature Communications*. https://doi.org/10.1038/s41467-017-02142-7.

Casas, R. 2015. La erosión del suelo en la Argentina. In: R. Casas and G. Albarracín (eds), *Degradación de Tierras en la República Argentina*. FECIC. Tomo II pp. 433-452.

Cisneros, J., Cholaky, C., Gutiérrez, A.C., González, J., Reynero, M., Diez, A. & Bergesio, L. 2012. *Erosión hídrica: principios y técnicas de manejo*. UniRío. Córdoba, Argentina.

FAO. 1980. *Metodología provisional para la evaluación de la degradación de los suelos*. Organización de las Naciones Unidas para la Agricultura y Alimentación. Roma.

INTA. 1990. *Atlas de suelos de la República Argentina*. Escala 1:500.000 y 1:1.000.000. Proyecto PNUD ARG 85/019. Secretaría de Agricultura, Ganadería y Pesca. Centro de Investigaciones de Recursos Naturales, Castelar.

Irurtia, C.B., Cruzate, G. & Gaspari, F.J. 2007. *Aplicación de la USLE en la provincia de Buenos Aires para establecer tasas de erosión hídrica*. Guia de Divulgación Técnica, Instituto de Suelos – INTA.

Marelli, J.H. 2012. *Estimación del potencial erosivo en la provincia de Córdoba a través de la Ecuación Universal de Pérdida de Suelos (USLE).* Publicación INTA Marcos Juarez.

Moore, I.D., Grayson, R.B. & Ladson, A.R. 1991. Digital terrain modelling: a review of hydrogical, geomorphological, and biological applications. *Hydrological Processes*, 5: 3-30.

PROSA. 1988. *El Deterioro del Ambiente en la Argentina*. FECIC. Editorial Orientación Grafica Editora. ISBN: 9789509149274.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. & Yoder, D.C. 1997. *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)*. Washington, DC: US Government Printing Office.

Viglizzo, E. & Jobbagy, E.G. 2010. *Expansión de la frontera agropecuaria en Argentina y su impacto ecológico-ambiental*. Buenos Aires. Ediciones INTA.

Volante, J. 2009. *Cobertura del Suelo de la República Argentina. Año 2006-2007 (LCCS-FAO)*. Programa Nacional de Ecorregiones, INTA.

Wischmeier, W.H. & Smith, D.D. 1978*. Predicting Rainfall Erosion Losses – Aguide to Conservation Planning.* Agriculture Handbook No. 537, USDA-Agricultural Research Service, Washington, DC.

Wischmeier, W.H. & Smith, D.D. 1965. *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains*. Agriculture Handbook No. 282, USDA-Agricultural Research Service, Washington, DC.

Economics of soil erosion in Ukraine

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Abstract

The objective of this paper is to present the results of a study of the economic assessment of impact of soil erosion on the production of crop products in Ukraine. We used such methods: econometric modeling, abstract-and-logical, monographic, expertise, calculated-and-analytical, graphical. To address our objectives, linear and quadratic econometric models (production functions) was developed using a unique dataset from 168 observations (on the example of Ukrainian regions for 2010–2016). The obtained results favor the hypothesis of a negative relationship between gross crop output and the level of land erosion. The findings confirm that the increase in the area of eroded arable land by 1 % leads to a decrease in the gross output of crop production by 0.20 % per 100 hectares of agricultural land in aggregate, and in the third group of subjects (the share of eroded arable land in their total area is more than 50 %) – by 0.61 %, respectively.

Keywords: economics, soil erosion, Ukraine, impact of soil erosion on the production of crop products

Introduction, scope and main objectives

The economics of soil erosion has received relatively little attention until recent years. Although a number of studies have undertaken to quantify the costs of soil erosion, studies that address the economics of soil erosion are still scarce (Adhikari and Nadella, 2011). Soil erosion negatively affects crop yields. However, the issue of how significant is this impact remains debatable. For example, Bakker *et al*. (2007) show that future reductions in productivity through soil erosion in Europe as a whole are relatively small and do not pose a substantial threat to crop production within the coming century. However, within Europe there is considerable variability, and for the southern countries the threat of erosion-induced productivity declines is stronger (Bakker *et al*., 2007). At the same time, according to Panagos *et al*. (2015), soil erosion by water is one of the major threats to soils in the European Union, with a negative impact on ecosystem services, crop production and carbon stocks. The mean soil loss rate in European Union is estimated to 2.46 t/ha annually, resulting in a total soil loss of 970 Mt annually. 12.7 % of European arable lands have soil loss >5 t/ha annually requiring protection (Panagos *et al*., 2015).

Although some studies have addressed the issue of reduced crop productivity due to soil erosion, few have focused on the economic loss in terms of agriculture (Panagos *et al*., 2018). In one such studies carried out an economic assessment of soil erosion in the European Union. According to Panagos *et al*. (2018) the 12 mln hectares of agricultural areas in the EU that suffer from severe erosion are estimated to lose around 0.43% of their crop productivity annually. The annual cost of this loss in agricultural productivity is estimated at around 1.25 bln Euro. The highest economic losses are typical for Italy, whereas the agricultural sector in most Northern and Central European countries is only marginally affected by soil erosion losses (Panagos *et al*., 2018). As for Ukraine that such assessments made by the specified methodology, as far as we know, are absent.

Expert assessment of economic losses (data as of 2016) from spreading soil degradation (including soil erosion) in Ukraine on the area of approximately 10 mln ha has showed that the total economic loss (loss of income (revenue) from sales) due to harvest shortfall is 33.6 bln UAH, the total amount of lost profits due to shortage of harvest (in actual profitability in 2016) is 6.7 bln UAH, or 7.5 % of profits from agricultural crops sales in 2016 (Kucher, 2017).

However, up to present the problem of economic assessment of impact of soil erosion on the production of crop products in Ukraine is not being sufficiently covered, thus determining the topicality of this research issue. The main objective of this paper is to present the results of a study of the economic assessment of impact of soil erosion on the production of crop products in Ukraine.

Methodology

The methodological basis of the research is the fundamental provisions of modern economic theory, ecological economics and economics of land degradation. To achieve the goal, we used such methods: econometric modeling, abstract-and-logical, monographic, expertise, calculated-and-analytical, graphical. To address our objectives, linear and quadratic econometric models (production functions) was developed using a unique dataset from 168 observations (on the example of Ukrainian regions for 2010–2016). This study was conducted in order to test the hypothesis that the increase in the area of eroded arable land has a negative effect on the gross output of crop production.

Results

As a result of the correlation analysis, there was a statistically significant weak feedback (r = -0.227) between the share of eroded arable land in its total area and gross crop production in agricultural enterprises of Ukrainian regions per 100 hectares of agricultural land. However, the volume of gross crop production per unit of land area had a high direct correlation (r = 0.773) with the intensity of production. At the same time, agricultural enterprises did not always invest more in those regions where more eroded arable land is concentrated, since a moderate backward correlation link was identified between them (r = -0.350).

The parameters of the constructed linear two-factor econometric model (Fig. 1) indicate that an increase in the share of eroded arable land in its total area by 1 percentage point (pp) caused a decrease in volume of gross output of crop production by 69.6 USD/100 hectares of agricultural land, while with the increase in production costs by 1 thousand USD/100 hectares of agricultural land, the volume of these products increased by 600.8 USD/100 hectares of agricultural land. The quadratic model indicates a nonlinear (polynomial) dependence of the volume of gross output of crop production from the intensity of its production, which is the result of the economic law of diminishing returns, while the higher the level of erosion of arable land, the more it is necessary to invest money to obtain the same amount of products.

The next step of our study was to assess the impact of land erosion on the analyzed economic indicators by grouping the regions of Ukraine by the share of eroded arable land in its total area, resulting in the formation of three groups of objects:

(i) regions with a relatively small amount of eroded arable land (up to 30.0 %, 70 observations), which are characterized by the following average values of indicators: the share of eroded arable land – 17.8 %; wheat yield – 38.2 centners/hectare; production costs in crop industry per 100 hectares of arable land – 59.7 thousand USD; gross output of crop production per 100 hectares of arable land – 49.9 thousand USD;

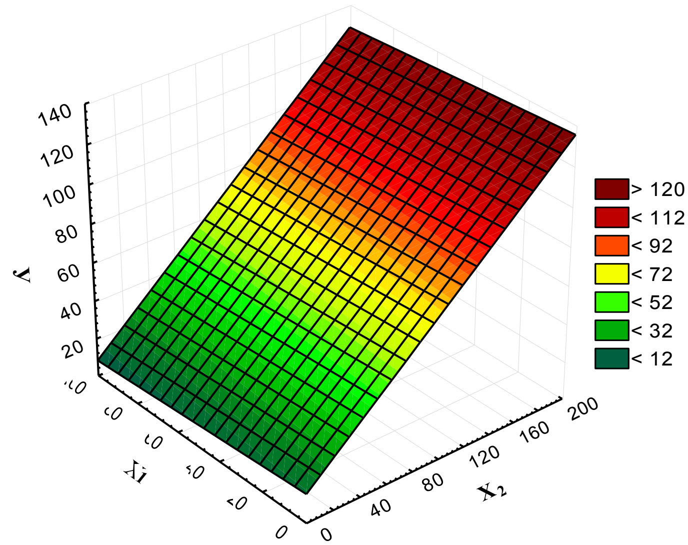
(ii) regions with an average amount of eroded arable land (30.1–50.0 %, 56 observations), they are characterized by the following average values of indicators: the share of eroded arable land – 38.4 %; wheat yield – 37.3 centners/hectare; production costs in crop industry per 100 hectares of arable land – 55.5 thousand USD; gross output of crop production per 100 hectares of arable land – 45.8 thousand USD;

(iii) regions with a relatively large amount of eroded arable land (more than 50.0 %, 42 observations), they are characterized by the following average values of indicators: the share of eroded arable land – 62.2 %; wheat yield – 31.0 centners/hectare; production costs in crop industry per 100 hectares of arable land – 39.3 thousand USD; gross output of crop production per 100 hectares of arable land – 34.4 thousand USD.

Thus, with an increase in the share of eroded arable land, wheat yields and gross output of crop production per 100 hectares of arable land decreased; compared to the first group in the third group they were on average 18.8 and 34.2 % less, respectively.

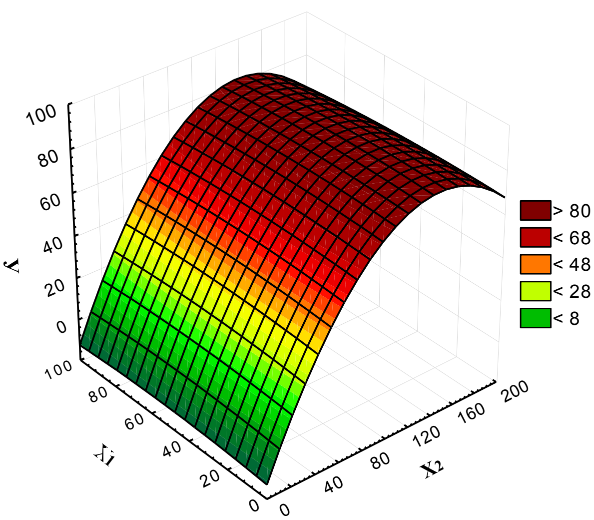
Based on the constructed linear single-factor econometric model, it was established that an increase in the share of eroded arable land in its total area by 1 pp caused a decrease in volume of gross output of crop production by an average of 250.8 USD/100 hectares of agricultural land. However, as a result of one-factor regression analysis in the context of the above three groups, it was found that only in the third group the land degradation factor had a statistically significant negative impact on the resultant indicator, that is, with an increase in the share of eroded arable land by 1 pp in areas where it exceeds 50 % of arable land, the volume of gross output of crop production decreased by an average of 337.4 USD/100 hectares of agricultural land. The coefficient of elasticity for the single-factor model showed that the increase in eroded arable land by 1 % leads to a decrease in gross crop production by 0.20% per 100 hectares of agricultural land in aggregate, and in the third group of subjects – by 0.61 %, respectively. Consequently, the volume of gross crop production in agricultural enterprises of these areas could be large in the absence of soil erosion.

$$У = 15{,}2125+0{,}6008x_2-0{,}0696x_1$$



a)

$$У = -13{,}1393+1{,}3616x_2+0{,}0798x_1-0{,}0048x_2^2-0{,}0002x_1x_2-0{,}0007x_1^2$$



b)

Figure 1: Linear (a) and quadratic (b) models of the dependence of gross crop production per 100 hectares of agricultural land (*Y*, thousand USD) from the share of eroded arable land in its total area (X_1, %) and production costs in crop industry per 100 hectares of agricultural land (X_2, thousand USD) using the example of agricultural enterprises of Ukrainian regions, 2010–2016. Source: built by the author on the basis of his own research according to the form number 50-s.g. and data of the State Service of Ukraine for Geodesy, Cartography & Cadastre.

Discussion

The results of a study of the economic assessment of impact of soil erosion on the production of crop products in Ukraine can be used for the development, substantiation and implementation of soil protection measures for the sustainable use of land in the agricultural sector. Practical application of the research results will contribute to informed decision-making at different levels of management.

Conclusions

For the first time the economic assessment of impact of soil erosion on the production of crop products in Ukraine was conducted. The obtained results favor the hypothesis of a negative relationship between gross crop output and the level of land erosion. The findings confirm that the increase in the area of eroded arable land by 1 % leads to a decrease in the gross output of crop production by 0.20 % per 100 hectares of agricultural land in aggregate, and in the third group of subjects (the share of eroded arable land in their total area is more than 50 %) – by 0.61 %, respectively.

References

Adhikari, B. and Nadella, K. 2011. Ecological economics of soil erosion: a review of the current state of knowledge. *Annals of the New York Academy of Sciences*, 1219(1): 134–152. https://doi.org/10.1111/j.1749-6632.2010.05910.x.

Bakker, M.M., Govers, G., Jones, R.A. & Rounsevell, M.D.A. 2007. The Effect of Soil Erosion on Europe's Crop Yields. *Ecosystems*, 10(7): 1209–1219. https://doi.org/10.1007/s10021-007-9090-3.

Fileccia, T., Guadagni, M., Hovhera, V. & Bernoux, M. 2014. *Ukraine: Soil fertility to strengthen climate resilience. Preliminary assessment of the potential benefits of conservation agriculture*. Rome: Food and Agriculture Organization of the United Nations. 96 p.

Kucher, A.V. 2017. Economics of agricultural land degradation and soil protection: a case study of Ukraine. In: A. Walaszczyk, I. Jałmużna, B. Galińska (eds), *Management and safety in food chain*. Lodz: Lodz University of Technology, pp. 27–38.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & Alewell, C. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, 54: 438–447. https://doi.org/10.1016/j.envsci.2015.08.012.

Panagos, P., Standardi, G., Borrelli, P., Lugato, E., Montanarella, L. & Bosello, F. 2018. Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models. *Land Degradation & Development*, 29(3): 471–484. https://doi.org/10.1002/ldr.2879.

Assessment of the Cost of Soil Erosion to Crop Production in Canada

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Abstract

Canada is one of the world's major crop producers, seeding 37.5 million ha in 2016. Soil erosion is a serious threat to Canada's soil and crop productivity and sustainability. To understand and control this threat, a study of the cost of soil erosion, in term of its impacts on crop production, was undertaken. The cost of soil erosion increased from about $1 billion (B) per year in 1971 to about $3B per year in 2011. Eroded soils have not restored appreciably through current soil conservation practices, and cropping practices and market conditions have greatly increased the cost of soil erosion. These outcomes were not expected especially after 30 years of soil conservation initiatives. This knowledge is critical for decision makers responsible for soil conservation programs.

Keywords: Soil erosion, Land degradation, Crop value, Agriculture in Canada

Introduction

Canada is one of the top five agriculture exporters worldwide, and is recognized as a major world producer of cereals (Bradshaw *et al.*, 2004). The development and sustainability of this production is threatened by soil erosion. Soil erosion is caused by wind, water and tillage, the result of a variety of farming practices that disturb and move the soil and leave the soil unprotected by a vegetative cover (Lobb *et al.*, 2007). Soil erosion is responsible for the loss of soil organic matter, which adversely affects the physical and chemical properties of topsoil, decreasing the soil's infiltration and plant available water holding capacity, reducing soil fertility, and, ultimately, degrading the soil's ability to produce crops.

In the early 1980s, Rennie (1985) assessed the costs of soil degradation in Canada, and found soil erosion to cost about $0.53B per year (equivalent to $1.1B in 2016), the most costly form of soil degradation. These values were alarming at the time. This alarm was a major impetus for the development and enhancement of soil conservation technologies and practices, and for increased awareness and adoption of soil conservation technologies and practices throughout the agriculture industry and across Canada. No-till climbed to about 60% of the cropped area across the country and summerfallow dropped from about 14% to 3%. No assessment of the costs of soil degradation has been carried out in Canada since. With respect to public awareness, to government support through policies, programs and research, and to industry action, there has been a steady decline in interest in soil conservation. There is a pervasive belief amongst all of these stakeholders that "we know all there is to know about soil erosion and soil conservation"; and, that "the job is done and we need to move on".

After almost 40 years, there is a need to improve upon and update cost estimates to assess status and progress. Science and technology have greatly advanced. There is a more complete and accurate understanding of soil erosion processes. There are better models for assessment and prediction. There are more comprehensive and accurate databases to serve as better model inputs for assessment and prediction. Recent advances in computer technology, programming and data science have made it possible to assemble and analyze massive data sets. In response to this need, a study was initiated consisting of five components: (i) a detailed spatial and temporal assessment of soil erosion using models; (ii) a model of the response of soil organic carbon in topsoil to the loss of soil and to the inputs of crop biomass; (iii) a model of the response of crop yield to soil organic carbon content in topsoil; (iv) agricultural market analysis to understand the temporal dynamics of seeded/harvested areas, yield, crop production, market values of each Canadian province in the past 55 years; and (v) data science to build the analytical platform that handle the data management, spatial statistics, and data mining.

Methodology

Soil erosion was assessed using the Soil Erosion Risk Indicator (SoilERI) model as part of Agriculture and Agri-Food Canada's agri-environmental indicators (AEI) program (Lobb *et al.*, 2016). AEI models apply the spatial framework of the Soil Landscapes of Canada (SLC) polygon data. The SLC data are part of the Canadian National Soil Database (NSDB) and portray generalized soil and landscape information for each polygon at a scale of 1:1 million. The polygon size varies, ranging from 10,000 ha to 1 million ha. Each SLC polygon is characterized by one or more representative landforms, and each landform is characterized by a generalized hillslope with four hillslope segments (upper, mid, lower slopes and depression). Each hillslope segment is characterized by a slope gradient and a slope length. Cropping and tillage practices data were obtained from the Census of Agriculture for 1981, 1986, 1991, 1996, 2001, 2006, 2011, and 2016. Modeling processes were carried out using R programming language, and each particular modelling task has a specific script. The data modeling process has three major phases: data preparation, indicator calculation, and aggregation. All results were generated in dBase File format (dbf) for further data visualization and mapping using ArcGIS 10.2.2 software. (see Figure 1)

The seeded/harvested areas (ha), yield (tonnes ha^{-1}), production (tonnes), and market value (\$ $tonnes^{-1}$) were collected for each crop commodity at provincial and national scales for the period between 1961 and 2016. Four major groups of crop commodities were obtained. The data acquisition procedure was based on multi-sourcing the crop metrics for further validations and assessments. The missing numbers were interpolated based on the general trend of a 10-year time interval.

The crop yields are expressed relative to potential crop yield on non-eroded sites, which is assumed to be a function of the organic carbon content of the remaining eroded soil. Several studies, such as Battiston *et al.* (1987), have found a strong relationship between crop yield and soil organic matter. Crop yield is a function of topsoil depth, depth to carbonates and soil organic carbon (SOC) content. These factors affect soil moisture content and soil fertility. Assessing the costs of soil erosion to crop production in Canada has been carried out in several steps, these steps depend on intensive bigdata analysis via a supercomputer platform at University of Manitoba which has the analytical capability to conduct data modeling for more than 5 Terabyte of data using R programming language and ArcGIS 10.x.

Results and Discussion

The cropland area subject to moderate to very high annual rates of soil erosion decreased from 37% to 10% between 1971 and 2011 – 10 % is still a considerable amount of area (see Table 1). This reduction in soil erosion is in response to the adoption of conservation tillage practices and a decline in the use of summerfallow.

Cumulative soil losses have pushed yield losses into a state of steep decline (as soil organic carbon content decreases, a loss in soil organic carbon results in a disproportionately larger loss in crop yield) – increasing from a 17% yield loss in 1971 to a 60 % yield loss in 2011.

Although the area experiencing moderate to very high annual rates of soil erosion has decreased substantially, the cumulative loss of productive topsoil, as indicated by soil organic carbon content, has decreased crop yields by 17 % on 37 % of the area (a product of 6.2) to 60 % on 10 % of the area (a product of 5.7). This indicates little net improvement in soil productivity in response to the adoption of less intensive tillage practices.

The cost of soil erosion, simply in terms of lost crop yield, increased from $1B per year in 1971 (7% of the total value of crop production) to $3B per year in 2011 (10 % of the total value of crop production), a dramatic increase in the absolute cost of soil erosion and a slight increase in the relative cost. The value for 1971 is almost the same as Rennie's (1985) estimate for the 1970s. The value for 2011 is much higher than expected; in fact, the widespread belief is that the cost of soil erosion has declined since the 1970s. This analysis does not consider other on-site costs of soil erosion or off-site costs, which are assumed to be in the same order of magnitude as the cost of lost crop yield.

The cumulative value of yield losses in the 40 to 60 years leading up to 1971 is estimated to be $20-30B. The cumulative value of yield losses between 1971 and 2011 is estimated to be an additional $40-60B. Areas where soil erosion is now controlled through soil conservation practices still suffer from historical losses of soil. In assessing cost, it is necessary to consider cumulative historical soil losses. This is rarely, if ever done in soil conservation planning. The annual lost crop value is expected to have continued since 2011 at similar levels, with the cumulative value continuing to grow.

Changes in crop production are largely responsible for the unexpected increased cost of soil erosion between 1971 and 2011. Higher yielding and higher value crops are being grown on land that has not improved in soil productivity, as noted above. Remarkably, cereal crops have not changed in terms of seeded area, and the yields have tripled in response to better production techniques (varieties, nutrient and pest management, seeding and harvesting practices), in spite of soil losses. The ever-increasing yields would explain an apparent lack of concern expressed by crop producers regarding soil loss and its impacts on crop productivity and profitability, but it should be acknowledged that crop yields on restored (non-eroded) soils would be more than three times higher than in 1971. There has been an expansion of higher value crops such as soybeans, which increased from less than 0.1M ha of seeded area in 1971 to in excess of 0.8M ha in 2011. To understand the impacts of production changes, consider the following: a 10 % loss in yield due to soil loss for a given crop would be triple in its absolute dollar value if either the yield of that crop triples through better production techniques or if that crop is substituted for a crop that has triple the market value. It should be noted that a 10% loss in gross revenue from a crop (its market value) represents a much larger percentage of a crop's net revenue (profit), possibly all of it. This knowledge should motivate crop producers to greatly reduce soil losses and to restore a soil's productivity by rapidly rebuilding its organic carbon content. Rapid rebuilding of soil organic matter requires innovative soil management, such as the use of the practice of soil-landscape restoration, where organic-rich soil that has accumulated at the base of slopes eroded by tillage erosion is applied to the top of slopes where organic-rich soil has been lost.

Conclusion

The adoption of conservation tillage and the decline in the use of summerfallow have dramatically reduced the annual rates of soil erosion on much of the cropland across Canada. However, the cost of soil erosion, simply in terms of lost crop yield, has increased from $1B per year in 1971 to $3B per year in 2011. Although the area experiencing moderate to very high annual rates of soil erosion has decreased substantially, the cumulative historical loss of productive topsoil continues to depress crop yields, and do so more severely; there is little net improvement in soil productivity in response to the adoption of conservation tillage. More aggressive measures to increase soil organic matter levels and restore soil productivity are needed, such as the use of the practice of soil-landscape restoration.

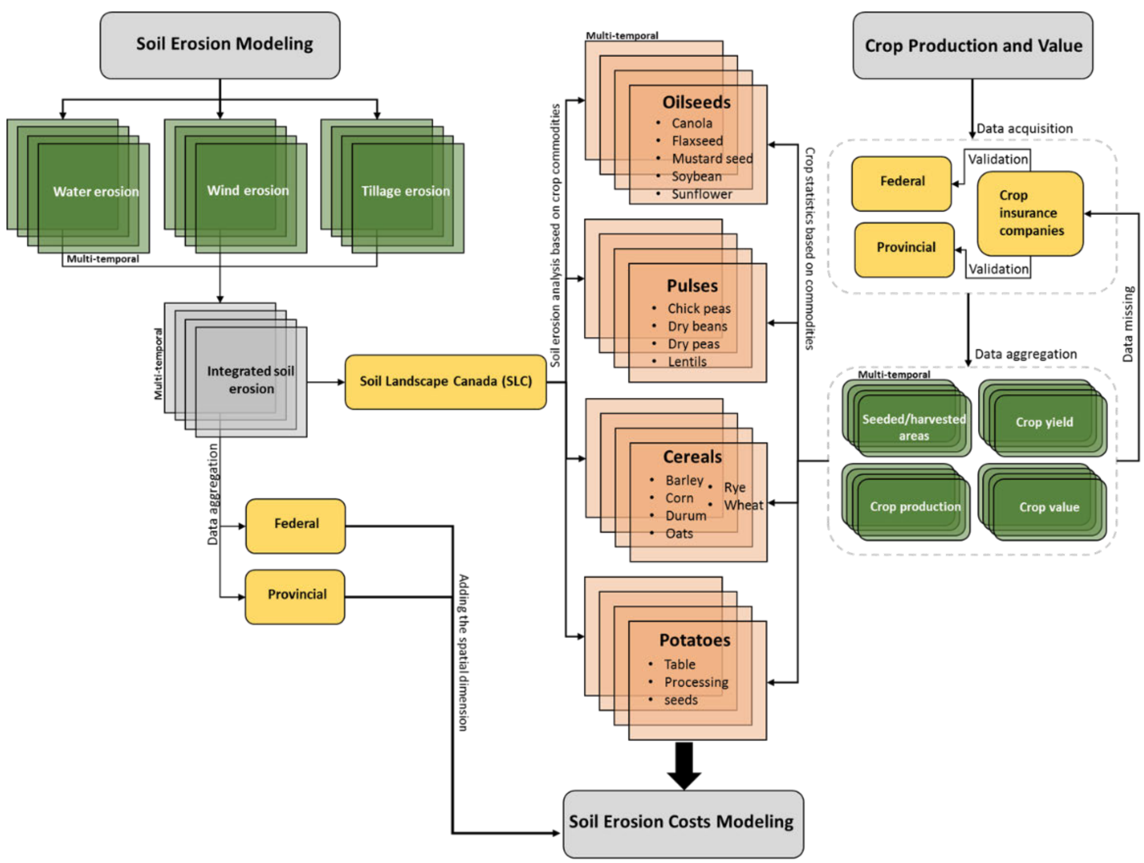

Figure 1: Illustration of the soil erosion costs analysis for crop commodities in Canada for the period between 1961 and 2016.

Table 1: The cost of soil erosion based on relative crop yield and crop yield loss

	Units	1971 Low-Eroding Cropland (N-L)	1971 High-Eroding Cropland (M-VH)	1971 Total	2011 Low-Eroding Cropland (N-L)	2011 High-Eroding Cropland (M-VH)	2011 Total
Cropland Area	ha	25,149,351	14,663,025	39,812,376	35,211,104	3,676,329	38,887,434
	%	63.2	36.8	100	90.5	9.5	100
Soil Loss Rate	t ha^{-1} yr^{-1}	5.9	24.0		3.5	22.7	
Relative Crop Yield	%	99.5	83		95	40	
Crop Yield Loss	%	0.5	17		5	60	
Degraded Value	$2016			13,570,289,116			27,326,006,316
Non-Degraded Value	$2016			14,525,640,873			30,429,706,921
Lost Value	$2016			**$0.96 B yr^{-1}**			**$3.1B yr^{-1}**

* All dollar values are expressed in 2016 Canadian dollars, corrected for inflation.

** Lost value of crop production resulting from soil loss is calculated as the estimated value of production on non-eroded soil minus the reported market value affected by soil loss.

*** Low-eroding cropland is that under Negligible, Very Low and Low erosion risk classes. High-eroding cropland is that under Moderate, High and Very High erosion risk classes.

References

Battiston, L.A., Miller, M.H. & Shelton, I.J. 1987. Soil erosion and corn yield in Ontario. I. Field evaluation. *Canadian Journal of Soil Science,* 67:731–745. DOI:0.4141/cjss87-072.

Bradshaw, B., Dolan, H., & Smit, B. 2004. Farm-level adaptation to climatic variability and change: Crop diversification in the Canadian prairies. *Climatic Change,* 67:119–141. DOI:10.1007/s10584-004-0710-z.

Lobb, D.A., McConkey, B.G. & Li, S. 2016. Soil Erosion. *In:* Clearwater, RL, T Martin, T Hoppe (eds) Environmental sustainability of Canadian agriculture: Agri-environmental indicator report series – Report #4. Agriculture and Agri-Food Canada. Ottawa, Canada. pp. 77-89.

Lobb, D.A., Huffman, E. & Reicosky, D.C. 2007. Importance of information on tillage practices in the modelling of environmental processes and in the use of environmental indicators. *Journal of Environmental Management,* 82:377–387. DOI:10.1016/j.jenvman.2006.04.019.

Rennie, D.A. 1985. Soil degradation, A western perspective. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie,* 33: 19–29. DOI:10.1111/j.1744-7976.1985.tb03229.x.

Assessing land consumption impact on ecosystem services provision: an insight on biophysical and economic dimension of loss of erosion control in Italy

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Abstract

In Europe the area affected by the phenomenon in the EU-27 is 1.3 million Km^2, 20 % of which is affected by soil loss with an average of 2.46 t/ha/year. Among the 28 member states, Italy presents the highest soil loss rate with values of 8.77 t/ha/year against in EU countries. Since 2016, ISPRA produces the evaluation of the biophysical and economic loss of the main ecosystem services resulting from the increase in land consumption. Erosion control is one of the services most affected by land consumption effects. The study provides a national assessment of loss of erosion control in terms of ecosystem service flow, in biophysical and economic dimension using InVEST model and the high-resolution map for Italy of land cover relating to 2012 and land consumption related to 2012 and 2017, produced by ISPRA on the basis of data from the Copernicus-Land Monitoring Services programme and other sources.

Results indicate a quite high level of economic loss, with an average value of 61 M€//year due to land consumption growth produced in Italy between 2012 and 2017, evaluated in 25 000 ha. Economic valuation demonstrates the importance of this ecosystem service and can be helpful supporting land use decision-making.

Keywords: land consumption, soil erosion, ecosystem services, economic loss

Introduction, scope and main objectives

Soil erosion is a natural phenomenon which, through the removal of the topsoil which is richer in organic carbon, contributes to the changing of the earth's surface. The magnitude of this process depends on many factors, including geological, pedological, morphological vegetational and climatic characteristics. A territory in good condition offers protection from soil erosion because it preserves the functionality of the soil. Erosion protection is therefore classified in the CICEC System V. 5.1 (Haines-Young and Potschin, 2018), as one of the main ecosystem services offered by nature to human being, classified among the services of Regulation & Maintenance (abiotic) as Mediation of flows, Mass flows.

According to estimates at European level carried out by the Joint Research Centre of the European Commission, the area affected by the phenomenon in the EU-27 is 1.3 million Km^2, 20 % of which is affected by soil loss with value more than 10 tonnes/ha/year (Panagos *et al.*, 2015).

Among the 28 member states, Italy presents the highest soil loss rate with values of 8.77 t/ha/year against an average of 2.46 t/ha/year in EU countries, due to the combination of steep slopes and the high values in the rainfall erosivity, resulting from intense precipitation after long periods of drought. The natural protection from erosion, depending on the protective capacity of vegetation, and is strongly linked to land-use/land cover changes. The different forms of soil degradation (e.g. sealing, compaction, intensive farming) entail a reduction in water infiltration capacity, a modification of the natural drainage pattern and the alteration of plant coverings a consequent increase in surface water outflows even at high solid load.

Since 2016, ISPRA produces the evaluation of the biophysical and economic loss of the main ecosystem services resulting from the increase in land consumption. The estimate is produced with the aim of providing a knowledge base and economic indicators useful to support the public policies of soil protection and containment of land consumption. The economic quantification of lost services is provided to highlight the largely hidden value of what is lost. It must be not be intended as a way to build a market for non-renewable resources through trade and compensation.

The aim of the study is the evaluation of the change in the ecosystem service "erosion control" resulting from the increase of soil consumption between 2012 and 2017 (ISPRA, 2018).

Methodology

The magnitude of erosion depends on many factors, including different land use/land cover conditions.

The variation of the retention capacity through the comparison between the steady state of land use/cover and soil properties and a different scenario, can be considered as an indicator of the ecosystem service change in biophysical terms, to be further examined for economic value.

Sediment retention or soil loss, in this study, is calculated for each scenario through the "*Sediment Delivery Ratio*" (SDR) model of the InVEST - *Integrated Valuation of Ecosystem Services and tradeoffs* suite of models (Sharp *et al.* 2016), which represents the avoided soil loss, expressed in Tons/pixel, by the current land use compared to bare soil, weighted by the SDR factor as follows:

$$\text{Sediment Retention Index}_\mathrm{i} = \mathrm{R_i} \cdot \mathrm{K_i} \cdot \mathrm{LS_i} \cdot (1 - \mathrm{C_i} \cdot \mathrm{P_i}) * \mathrm{SDR_i}$$

where

- Ri is rainfall erosivity (units: MJ ・ mm (ha ・ hr) -1),
- Ki is soil erodibility (units: ton ・ ha ・ hr(MJ ・ ha ・ mm) -1),
- LSi is a slope length-gradient factor (non-dimensional)
- Ci is a crop-management factor (non-dimensional)
- and Pi is a support practice factor.

The variation of ecosystem service is therefore calculated as the difference between SDR values between two different land use/cover scenario. Input to the model are the digital elevation model and the land use/land cover maps produced by ISPRA, while the values of the other parameters were derived from the Joint Research Centre (Panagos *et al.* 2015). The high-resolution land cover map for Italy (10 metres), relating to 2012, and the land consumption map related to 2012 and 2017 (ISPRA, 2018) are produced by ISPRA on the basis of data from the Copernicus-Land Monitoring Services programme and other sources, and used as reference for changing scenarios.

The economic value used in the study refers to an extensive literature review (Annex to ISPRA, 2018) that shows a large variability of the economic values connected to erosion control.

Main studies concerning this ecosystem service report an economic value for the erosion control between 22 and 235 €/ha/year referred to 2003 (Van der Meulen *et al.*, 2018), that related to the JRC-EC data of the average erosion of 2.46 t/ha/year (Panagos *et al.* 2015 B), allows to estimate an interval for the economic value per tonne of soil between 8.94 and 95.53 €/t (2003). It must be pointed out that these studies refer to replacement or market costs, not including the social component of the cost, thus leading to an underestimation of the problem.

The above-mentioned economic value, is applied to the output of the INVEST model expressed in t/ha, resulting in the economic value of change in ecosystem service in €/ha.

Results

In the period (2012-2017) considered for the study, land consumption increased in Italy of 25,000 ha (ISPRA, 2018). This deal to a decrease of the annual service flow of erosion control between a minimum value of € 10,521,848/year and maximum of € 112 385 949/year, with an average value of € 61 453 898/year.

In comparison to other regulating ecosystem services considered in the study, reported in the table below, the control of erosion shows the higher value following only water flow regulation, which is largely over the others.

Table 1: Variation in the flow of regulating and maintenance ecosystem services due to the soil consumption between 2012 and 2017 in Italy. Source: ISPRA processing

Regulation & Maintenance Ecosystem Services	Minimum value of service loss [€/year]	Maximum value of service loss [€/year]
Carbon sequestration	102 056	538 898
Pollination	4 109 804	5 487 373
Regulation of local climate/temperature	2 251 732	9 006 928
Removal of particulate and ozone	950 980	2 938 569
Control of erosion rate	**10 521 848**	**112 385 949**
Water flow regulation	1 535 630 715	1 789 521 660
Water purification	226 033	60 297 780
Total	**1 553 793 168**	**1 980 177 157**

The Figure 1 shows the geographical distribution of erosion control loss and land consumption between 2012-2017. Both values are represented for each municipality, respectively the maximum economic loss in €/year (average of maximum values in the municipal area) and the density of increase of land consumption in m^2/ha.

As it is expected, the major losses are concentrated in the areas most subject to erosion that correspond to the higher slope, where even a small increasing in land consumption results in relevant economic impact due to loss of erosion control. In Italian small municipalities of piedmont and hilly areas, where erosion control is more needed, land consumption has increased with a higher density than in large urbanized areas, demonstrating the urgency of a proper consideration of land consumption effects.

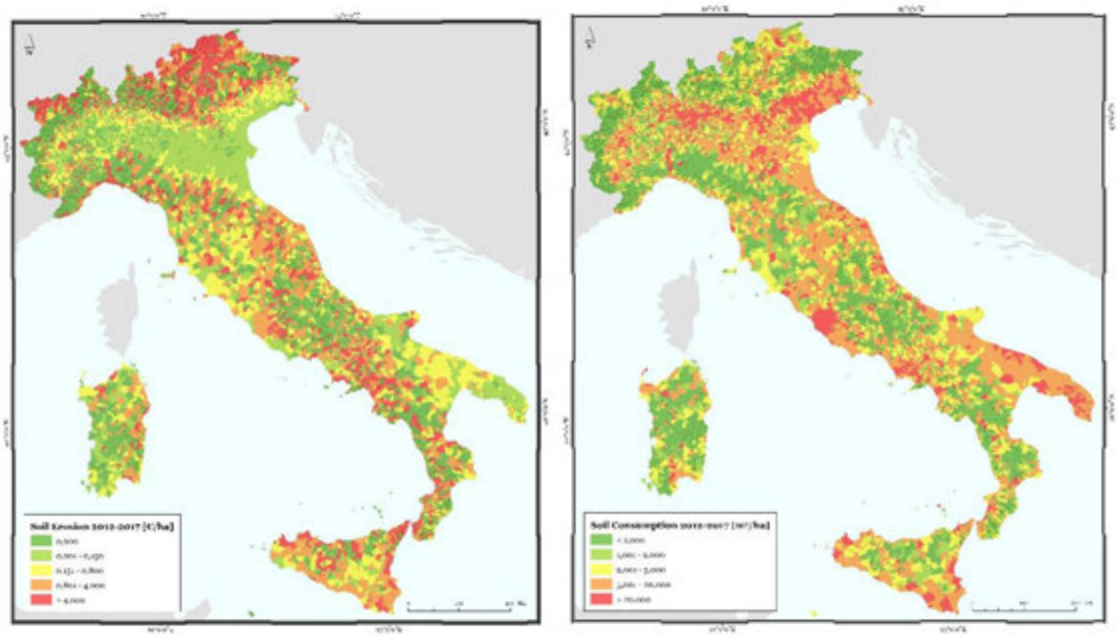

Figure 1: Loss of erosion control produced by land consumption between 2012 and 2017 - maximum value per Municipality €*y^{-1}

Discussion

The study is a first attempt to assess the economic value of ecosystem services loss produced by land consumption at a national level. The main limitations of this approach applied to erosion control are related to the variability in economic values published in the literature and to specific limitations of biophysical model considered. The USLE equation (Renard *et al.,* 1997) is widely used but is limited in scope, only representing rill/inter-rill erosion processes. Other sources of sediment are not considered, including gully erosion, streambank erosion, and mass erosion. In addition, as an empirical equation developed in the United States, the USLE has shown limited performance in other areas even when focusing on sheet and rill erosion. Based on local knowledge, users may modify the soil loss equation implemented in the model by altering the R, K, C, P inputs to reflect findings from local studies (Sougnez *et al.,* 2011).

The sediment retention index computed by InVEST model underestimates retention, since it does not account for the retention from upstream sediment flowing through the given pixel. In some situations, index values may be counter-intuitive: for example, urban pixels may have a higher index than forest pixels if they are highly connected to the stream. In other terms, the SDR (second factor) can be high for these pixels, compensating for a lower service of avoided soil loss (the first factor): this suggests that the urban environment is already providing a service of reduced soil loss compared to an area of bare soil (Sharp *et al.,* 2016). Therefore, the output should not be interpreted quantitatively but as an index able to describe a complex phenomenon.

Conclusions

The ecosystem service flow analysis of the control of erosion indicates that the level of economic loss related to the artificialisation in Italy is quite high (ISPRA, 2018), providing useful indications to the administrations to manage the phenomenon.

Economic valuation demonstrates the importance of ecosystem services for human well-being and can be helpful supporting land use decision-making. Only a small share of the relevant environmental effects is usually accounted for in decision-making processes. Many ecosystem services are public goods not valuable in market terms and the use itself can be a source of externalities, without market valuation.

The "hidden costs" (European Commission, 2012) of land consumption, therefore, could be far greater than the values reported.

References

European Commission. 2012. Guidelines on good practice for limiting, mitigating and compensating for soil waterproofing. Brussels, 15.5.2012, SWD (2012) 101.

Haines-Young, R. & Potschin, M.B. 2018. Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. Available from www.cices.eu

ISPRA. 2018. Soil consumption, territorial dynamics and ecosystem services - 2018 edition. Report 288/2018. Available from www.isprambiente.gov.it.

Panagos, P., Borrelli, P., Meusburger, C., Alewell, C., Lugato, E. & Montanarella, L. 2015. Estimating the soil erosion cover-management factor at European scale. *Land Use policy journal*, 48(C): 38-50.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato E, Meusburger, K., Montanarella, L., Alewell, C. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, 54: 438-447. DOI: 10.1016/j.envsci.2015.08.01.

Renard, K.G., Foster, G.R., Weesies, G.A., *et al.* (Coordinators). 1997. Predicting Soil Erosion by Water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agricultural **USDA.** Undated. Handbook No. 703, 404 pp. Available at http://www.ars.usda.gov/SP2UserFiles/Place/64080530/RUSLE/AH_703.pdf.

Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., Kennedy, C., Verutes, G., Kim, C.K., Guannel, G., Papenfus, M., Toft, J., Marsik, M., Bernhardt, J., Griffin, R., Glowinski, K., Chaumont, N., Perelman, A., Lacayo, M., Mandle, L., Hamel, P., Vogl, A.L., Rogers, L., Bierbower, W., Denu, D. & Douglass, J. 2016. InVEST 3.3.0 User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Sougnez, N.B., van Wesemael, V. & Vanacker. 2011. Low erosion rates measured for steep, sparsely vegetated catchments in southeast Spain. *CATENA*, 84(1–2): 1-1.

Van der Meulen, S. & Maring, L. 2018. Mapping and Assessment of Ecosystems and their Services Soil ecosystems SOILS4EU/DGENV.

20 years of lessons learned with the application of economic-environmental incentives in national programs of erosion control in degraded soils, Chile

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Abstract

The results and lessons learned are presented based on the application of economic-environmental incentives in national programs of erosion control in degraded soils within the framework of the law of Chilean forestry development between the years 1996-2015.

The analysis for the indicated period shows that an incentive has been given for reforestation methods associated with soil preparation practices and, based on erosion control techniques for the recovery of degraded soils, an area of around half a million hectares.

The application of a public-private incentive system aimed at the restoration of ecosystems through soil preparation techniques and the erosion control techniques for the recovery of degraded soils associated with the vegetational component, has made it possible to comply with the spirit of the law by focusing on the management of conservation projects of soils and waters in the social (small and medium owners), in the environmental (eroded and degraded soils) and economically by reincorporating soils to silvoagricultural activity.

Keywords: erosion, conservation and recovery of degraded soils, incentives, lessons learned, Chile

Introduction

Among the environmental problems of Chile it is recognized that erosion, or "soil cancer", constitutes from the environmental point of view and probably in socioeconomic terms, the most relevant in the forestry and agricultural sector. At the national level, according to the official 2010 data, the total area of eroded soils reaches 36.8 million hectares (49.1 % of the national territory).

Therefore, from the economic, environmental and social point of view, the application of soil and water conservation techniques allows the delivery of multiple goods and services, because -among other aspects- it manages to incorporate land without viable economic use, delivery to the owner an incentive for afforestation and soil recovery and generates an additional effect of absorbing rural labor, in addition to improving externalities at the level of ecosystem services of soils.

The purpose of the Chilean Forestry Development Law (1996-2015) was to regulate forestry activity on soils that are preferentially forested and degraded, and encourage afforestation, especially by small forest owners and those needed to prevent degradation. protection and recovery of soils of the national territory.

Methodology

The 27 000 soil conservation projects for the period 1998-2015 are collected, accounted for evaluated and analyzed, by way of recovery modalities of eroded, degraded and desertified soils.

In the experimental planning and development phase, 25 erosion control techniques are considered, executed under the framework of the "Conaf / JICA basins project" between the years 1994-1999, which allows evaluating the effectiveness and efficiency of the different techniques of soil and water conservation (hydrological, edaphic, meteorological and vegetational studies) and 21 regional demonstration centers are established at the national level with soil recovery techniques modules at the micro-watershed level, credit lines are established, technical documents and manuals are prepared of erosion control.

A training, dissemination and extension phase of these erosion control techniques is carried out (13), so that they can be implemented by professionals and technicians from the forestry and agricultural sector, state agencies, private sector companies, small and medium-sized owners. . Ad-doc techniques were transferred to services of the Ministry of Agriculture, Ministry of Public Works and Ministry of the Environment. As well as individual companies and consultants from the private sector. Up to 50000 people are trained nationwide in Conaf's demonstration technology centers at the regional level, which benefits 27,000 small and medium-sized owners.

Results

The analysis for the period 1996-2015 indicates that a surface of the order of 258 310 ha and 240 035 ha, respectively, has been rewarded for the concept of afforestation with soil preparation and erosion control techniques for the recovery of degraded soils. What represents a relevant achievement in terms of incorporating eroded and degraded soils, to viable and sustainable use, reaching an additional area of the order of half a million hectares.

The valuable experience obtained recommends the joint implementation of soil preparation techniques oriented to the "plant" and techniques of soil and water conservation oriented to the "basin" system, associated with afforestation or revegetation techniques in priority areas.

In the same way, the proportion of biological and / or mechanical techniques must be decided casuistically, considering the state of degradation (category of erosion and / or level of fragility index) of the hydrographic basin as a unit of planning and management of natural resources, a proportion of 25% work and 75% vegetation, seems to be reasonable under average conditions.

Practically, 100% of the forested surfaces are made by soil preparation techniques) and soil recovery erosion control techniques (mainly by means of infiltration ditches, channels, wooden scheks dam, manual microterrades, among others.)

The implementation phase has involved a continuous and substantive improvement of the technical standards based on the hydrological design, the simplification of the regulatory, administrative procedures and improvement of the annual cost tables. What implied to improve systems of internal and external articulation, generating an organizational change of institutional estates towards a "pro-soil" culture.

At present, no comprehensive restoration activity is conceived without the application of soil preparation practices and soil and water conservation techniques, depending on the severe edaphic and hydric limitations of the soils available for reforestation in Chile.

Practically, 100% of the area subsidized by forest development law is forested using techniques of preparation of soils (subsoiling, subsoiling with ridge, manual boxes, mechanized boxes) and erosion control techniques of soil recovery, (mainly by infiltration ditches, channels deviation, wooden dykes, manual microterrazes, among others).

The results of hydrological investigations and soil conservation carried out in parallel by landfills, gauging stations in conjunction with plots "type USLE (4 mx 22m) to assess erosion using the RUSLE model at the level of hydrographic basins indicate the following results:

I. Soil losses are evaluated that with soil conservation / erosion control practices decrease from ranges of 15 to 30 Ton / ha / year to 50 to 100 Kg / ha / year. That is, an efficiency in erosion control is obtained 300 times when using techniques.

II. That through the application of soil and water conservation techniques, the productivity of the forest site is significantly and substantially increased in dasometric variables such as height, basal area, volumes and site index, which is explained based on the greater hydrological and edafhological efficiency of associated systems

III. The hydrological efficiency is increased by 50 % and the turbidity of the water is reduced from 8 to 10 times depending on the regulatory function of the vegetation and the soil conservation technique applied together

Discussion

From the point of view of the edaphic soil services, the application of erosion control techniques for the recovery of degraded soils allows the delivery of multiple edaphic services such as erosion control, the reduction of sedimentation, the increase and accumulation of water in the soil, the increase of water recharge and less water turbidity, among other aspects. Environmental economic incentives are transformed into a form of "payment for environmental services" That is, economic incentives as such are facilitated by a transition to payment for environmental services.

The implementation of an integrated system of incentives to recover eroded and degraded soils has been achieved, in such a way as to contribute to economic growth, social equity and environmental sustainability, within the framework of the trilogy of sustainable development. Currently, the results are transferred to ecosystem restoration projects in degraded soils

Conclusions - lessons learned

From the application of the law of Chilean forestry development between 1996-2015, to encourage afforestation, especially by small forest owners and of that necessary for the prevention of degradation, protection and recovery of soils of the national territory, it is possible Get the following lessons:

1- Have public policies of long-term horizons

State public policies, with long-term horizons, with an inescapable state role in coordination with the private sector, within the framework of sustainable development. The experience of recovery of degraded soils and developed afforestation is relevant in Latin America, based on public-private incentive mechanisms.

2- Previously carry out a planning phase as an integrated system

3- Develop an Implementation phase as a process of continuous improvement of technical standards and costs.

4- Promote a phase of technology transfer and dissemination at the sectoral and multisectoral level

5- Combining biotechniques and hydrotechnics at the level of hydrographic micro-basins

6- Apply from incentives to payment for environmental services

7- Solve limiting hydro-edaphic technical aspects with soil and water conservation practices

8- Conceive an associativity of public policies and hydro-edaphic research

9- Develop an integrated incentive system

10- Promote a cultural change towards soil and water

In order to promote a "soil and water culture", technical and informative manuals must be prepared, disseminate topics of interest, extend technological innovations, promote participation at all levels through awareness campaigns of the population, users and actors at the basin level, in such a way to combine wills and commitments, where man is the central beneficiary. In the end, it is about promoting an adaptive cultural change to climate change.

The application of a public-private incentive system aimed at the restoration of ecosystems through soil preparation and erosion control techniques for the recovery of degraded soils associated with the vegetational component, has made it possible to comply with the spirit of the law by focusing on the management of conservation projects of soils and waters in the social (small and medium owners) and in the environmental (eroded and degraded soils) and economically by reincorporating soils to silvoagricultural activity.

Finally as a corollary: If the soil is conserved, the water is conserved. ... the vegetation is preserved and also the man¡¡¡.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

References

Francke, S. & Carnieletto, C. 2017. Guide to soil fragility index for forest soils / forest protocol in forest plantations. 45p.

Francke, S., Vargas, R. & Rodrigo. 2017. Erosion Control Handbook (fourth edition) CONAF - Japan International Cooperation Agency JICA. 73p.

The Economics of Soil Erosion Control and Restoration of Eroded Land

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Introduction

Soil is an essential input to farming while soil erosion is the process by which soil primary particles and aggregates are removed and lost from their point of origin by wind or water. This is especially true throughout East Africa, where agricultural production is crucial to development, the livelihoods of the majority of the population depend on the primary sector, and non-labour inputs for the poorest farms are negligible. And yet agricultural land use in East Africa countries often results in the degradation of natural soil fertility and reduced productivity. Soil degradation under farming also inflicts external or off-site costs, through the processes of erosion, sedimentation and leaching. The impacts of land degradation and the depletion of soil resources have profound economic implications for low income countries. Environmental damage results in loss of current income and increased risk, and particularly affects the poor. Degradation of land resources also threatens prospects for economic growth and future human welfare. In the developing countries, empirical research on the economic costs of land degradation is confined largely to analysis at the level of individual farms or watersheds. On-site impacts are most frequently studied, typically by analysis of the effect of soil loss on crop production. Limited data suggest that the impact of soil erosion on crops may be more dramatic in the tropics than under temperate conditions, due to the relative fragility of tropical soils, or more extreme climatic conditions (Kenya Agriculture Climates). The off-site impacts of land degradation are often much harder to evaluate, because the off-site benefits provided by land resources are not traded at all. The available evidence indicates that the costs of land degradation, and thus the benefits of conservation, may be substantial in developing countries, despite relatively low average returns to agriculture. However, these calculations are often more illustrative than definitive, due to the paucity of empirical data and various methodological problems.

Objectives

The main objective of this paper is to provide an overview of an economic analysis of soil erosion, concentrating particularly on explaining the farm-level economics of soil erosion and discussing with examples the appropriate methodology for measuring on and off-site costs. It was also to assess the causes, extent and types of land degradation with a view to developing and improving the knowledge base to make sound, accurate and timely decision and planning for sustainable land management. Programs to control erosion in Laikipia - Kenya began early in 1970s and have been very successful.

The 3 main principles to control erosion are to:

- use land according to its capability
- protect the soil surface with some form of cover
- Control runoff before it develops into an erosive force.

Land capability

Soil erosion can be avoided by using land within its capability.

The land's position, (soil type) and slope determine how vulnerable it will be to erosion. It may not be suitable for agriculture, or suitable only for an activity which limits erosion.

There are a number of resources to help determine how land should be used to avoid erosion:

- For cropping lands—land management field manuals map and describe the land types in many counties and provide advice on land use and management for each soil type.
- For grazing lands—maps of soils and land types are available for most areas. These give glaziers an indication of what soils their property may have and are a useful planning tool.

Surface cover and runoff

Surface cover is a major factor to control erosion because it reduces the impact of raindrops falling on bare soils and wind removing soil particles. It also reduces the speed of water flowing over the land.

Erosion risk is significantly reduced when there is more than 30 % soil cover. Total cover is achievable for many grazing and cropping systems.

Methodology

Using trees to control erosion

Trees are often considered to be the universal answer to control soil erosion. Tree roots help prevent landslides on steep slopes and stream bank erosion but they don't stop erosion on moderately sloping hill slopes.

In forests, the soil surface is usually protected by a layer of mulch from decaying vegetation as well as a variety of surface growing plants. If the soil is bare under the tree canopy from over grazing, vehicles or pedestrians, soil erosion will still occur.

Tillage

Conservation cropping practices that maintain cover on soil and may also include minimum and zero tillage practices. Nowadays during the fallow period, farmers use tillage implements that kill weeds without burying herbicides to minimize the frequency of tillage.

Figure 1: Contour banks and strip cropping

Terracing for Protection of Soil Erosion and Control of Organic Food Production

Runoff concentration is managed by structural measures such as contour banks in upland areas, or strip cropping on floodplains. These systems involve a total change in the way a farm is managed.

Runoff systems must be carefully planned. Flow between properties and across roads and railway lines must be coordinated and suit those affected by the changes.

When runoff water can impact neighbouring properties or infrastructure, land owners are encouraged to discuss with their neighbours and seek professional advice.

On flood plains, strip cropping is used to spread flood flows rather than allowing it to concentrate.

Green cane harvesting

Another measure that maintains soil cover is green cane harvesting or 'trash blanketing'. When a cane crop is harvested, the leaves and tops of the cane are left on the ground as a 'trash blanket'. This protects the soil from erosion by raindrop impact. This practice has been widely adopted in many Kenya cane growing counties.

Surface cover

Surface cover is the key to erosion control in grazing lands. It prevents erosion by maintaining the soil so it can absorb rainfall.

A well-managed pasture with good cover will ensure that runoff spreads rather than concentrates. Bore drains, tracks, roads, cattle pads and fences concentrate runoff, so careful planning is required to ensure that property improvements are located where they will not contribute to erosion.

The critical level of cover for pastures in tussock grasslands is about 40% cover and 1000 kilograms per hectare of dry grass. Ideally, this level of cover will exist at the beginning of the summer storm season.

The ideal stocking rate is flexible, and stock numbers should match available feed. Regular monitoring of pastures is necessary to achieve this. Long-term weather forecasting, using predictive tools such as the **Kenya Mateorological**, has improved the options available for predicting droughts.

Opportunistic spelling

Opportunistic spelling should also be part of a grazing strategy. A total spell in a good year may be required to allow desirable grasses to recover from past grazing. Grazing pressure can also be managed by locating watering points away from areas vulnerable to erosion.

Fire

Fire is useful for controlling woody weeds but it needs to be managed carefully. Regular burning of pastures will further reduce ground cover and promote runoff and erosion.

Managing erosion in urban areas

Kenya's rapidly increasing population and continued economic development require numerous construction projects and activities that expose soils to erosion.

The following approaches will help reduce erosion on development sites:

- Disturb minimal area when excavating
- Where possible, divert upslope storm water around the work site and other disturbed areas
- install sediment barriers (e.g. sediment fences or turf buffer strips) downslope of the building site to filter coarse sediments
- Restrict vehicle access to one entry point where possible. Graveling the access point will allow all weather access and minimize erosion.
- Connect a temporary or permanent down pipe to a storm water system before laying the roof
- Place all stockpiles on the construction site and behind a sediment barrier
- Landscape all bare areas as soon as possible after construction is completed.

Good surface cover between contour banks and in waterways will ensure their stability and dramatically reduce the amount of soil deposited in waterways.

On flood plains, strip cropping is used to spread flood flows rather than allowing it to concentrate.

Green cane harvesting

Another measure that maintains soil cover is green cane harvesting or 'trash blanketing'. When a cane crop is harvested, the leaves and tops of the cane are left on the ground as a 'trash blanket'. This protects the soil from erosion by raindrop impact. This practice has been widely adopted in many Kenya's cane growing Counties.

Figure 2: Green cane harvesting, Western Kenya

Discussion

Managing erosion in urban areas

Kenya's rapidly increasing population and continued economic development require numerous construction projects and activities that expose soils to erosion.

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- disturb minimal area when excavating
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- Restrict vehicle access to one entry point where possible. Graveling the access point will allow all weather access and minimize erosion.

- connect a temporary or permanent down pipe to a storm water system before laying the roof
- place all stockpiles on the construction site and behind a sediment barrier
- landscape all bare areas as soon as possible after construction is completed.

In addition to agricultural policy, other economic policies can also have profound effects on land use. Virtually any policy which distorts the market prices of agricultural inputs and outputs can alter incentives for soil conservation. The impact of specific policies on farmer decision-making and land degradation is often ambiguous, however, making generalization difficult. Impacts on households will vary to the extent that policies affect certain groups more than others.

Conclusion and recommandation

Small holder farmers posses a vast amount of indigenous knowledge of their local environment and even aware of land degradation indicators which they observed during their daily land use cores and have local ways of recognizing and predestining these, and land degradation was preserved by use of practices such as application of organic manure, planting of trees, crop rotation, use of gabious and stone lines. finally soil conservation requires access to inputs: labour, capital (including land, equipment and materials, or the funds to obtain them) and information (technology). Poorer farmers - particularly female-headed households - often lack access to one own, and may also suffer limited access to preventing them from adopting conservation measures. Even when they know of appropriate technologies, farmers may lack access to sufficient labour to undertake soil conservation measures on their own, and may also suffer limited access to capital with which to hire additional manpower or purchase any tools required. For example, in many areas the best time to install or maintain soil conservation structures is at the beginning of the growing season, when soils are softened by rain and vegetation cover is light. But this is also the moment of peak labour demand for field preparation and planting. The true opportunity cost of soil conservation is thus often higher than at first appears, when considered in relation to other demands on farmers' resources.

Agriculture land use planning and management should be conformed by smallholders farmers knowledge of land scape structures and local micro-environments hence informed decision making.

Aknowledgment

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References

Angima, S.D., Scott D.E. & Weesides, G.A. 2003. Soil Protection using RUSLE for Central Kenya Conditions. *Agriculture Ecosystems and Environment,* 97

FAO. 2011. Sustainable Land Management in Practice Guideline

Ministry of Agriculture. 2003. Kenya Highlands Conditions, Evidence based from Laikipia and Nyeri Counties.

Mwakubo, S.M. & Maritim, H.K. 2004. Does soil Conservation Pay.

Ovuka, M. & Ekbom, A. 1999. Soil Properties and Productivity in Kenya Central Higlands. selected Papers for 10th International Conservation Meeting held May 24-29 1999 at Purdue Unversity USA

Thomas, D.B, editor. 1992. Soil and Water Consrevation Manual for Kenya.

Side event: “Soil erosion assessment: Making a difference with isotopic techniques”, organized by the Joint FAO/IAEA Programme of Nuclear techniques in Food and Agriculture

Stable and radiogenic isotope approaches to assess on-site and off-site soil erosion processes

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Abstract

Isotope applications are today widely used in soil erosion assessment, reaching from quantitative approaches with radiogenic isotopes (e.g. ^{137}Cs, $^{210}Pb_{ex}$, $^{239+240}Pu$, ^{7}Be, ^{10}Be) as well as qualitative evaluations ($\delta^{13}C$, $\delta^{15}N$) and sediment source attribution with compound specific stable isotope analysis (CSIA) of organic compounds like fatty acids but also n-alkanes.

While fallout radionuclide approaches have been set up already for more than five decades, they aim at determining mainly on-site effects of soil erosion and have to tackle the challenge of converting isotopic signals into soil erosion rates as well as finding suitable reference sites (Figure 1).

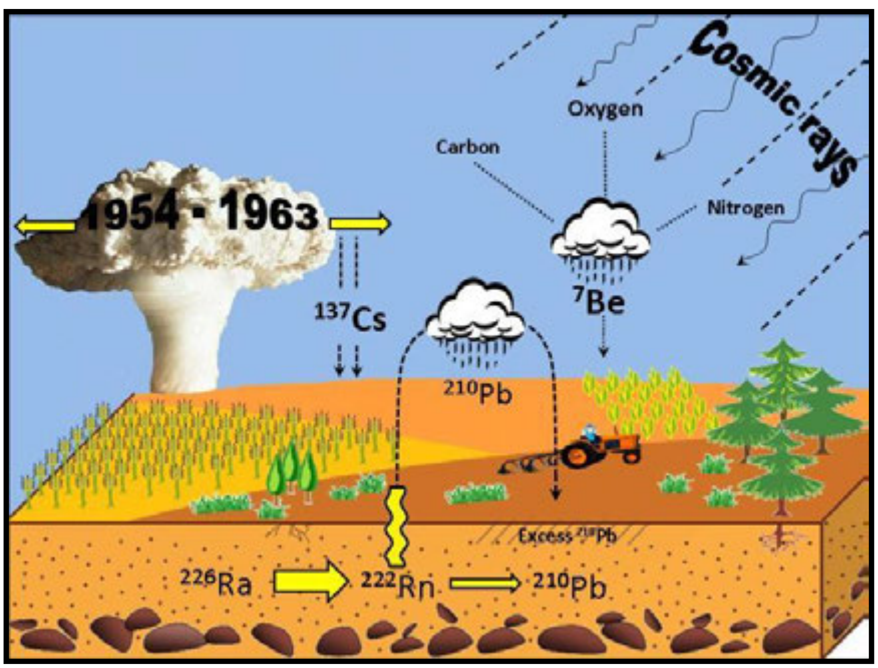

Figure 1: Radiogenic isotopes being used for assessing on-site soil erosion rates. Adapted from Zupanc & Mabit, 2010 – Dela, 33, 21–36.

The challenging task to identify suitable reference sites can be addressed using stable isotope signals of depth profiles comparing undisturbed versus disturbed sites. As such, successful applications of bulk stable isotopes to assess soil erosion mostly target on on-site effects but have been less successful for off-site sediment source attribution, with the exception of significant change in land use history from C4 to C3 plants. On the contrary, the more recently introduced CSIA assess off-site effects and seems to be a very promising tool for quantification of sediment source attribution (Figure 2).

This presentation will give an overview of the scientific concepts using either of the techniques or a combination of the techniques from radiogenic to stable isotopes and CSIA including qualitative as well as quantitative approaches.

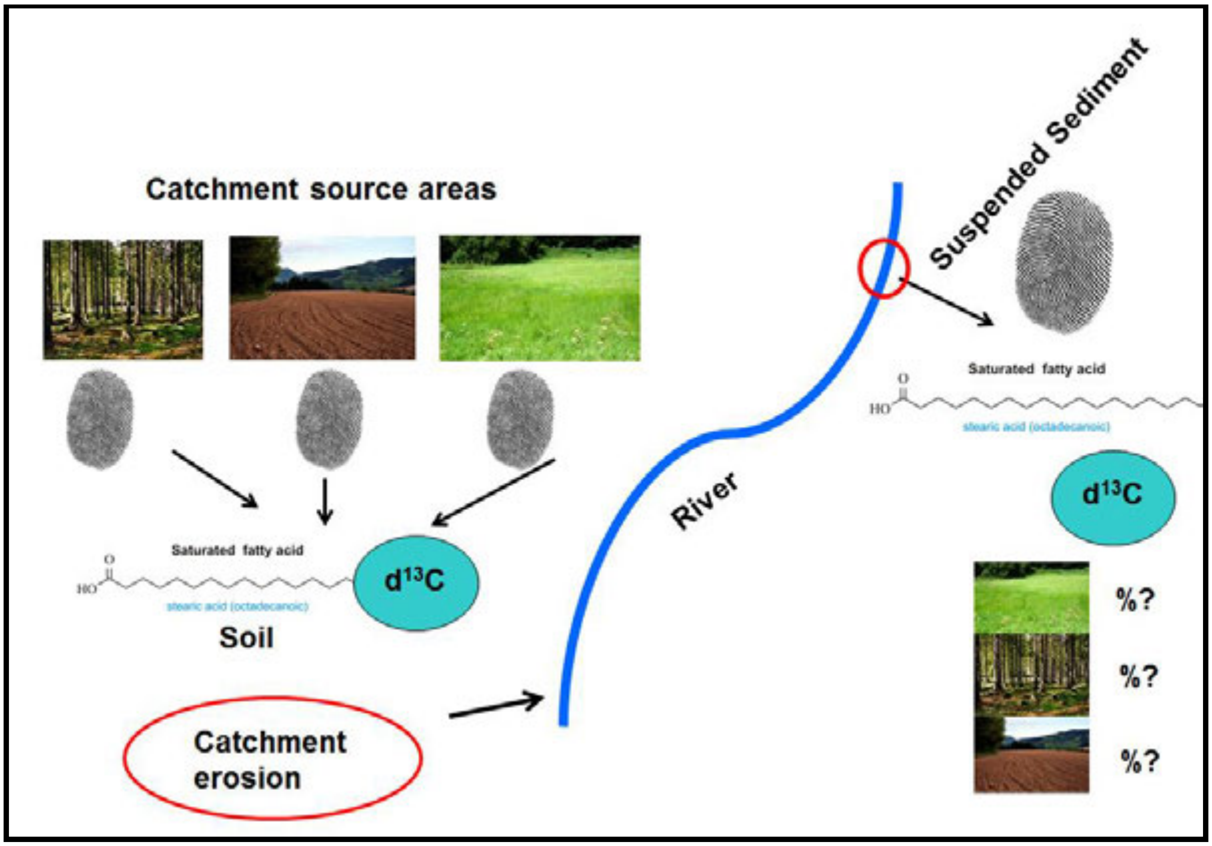

Figure 2: Concept of assessing off-site soil erosion effects in quantifying sediment source attribution of different land use types with compound specific stable isotope analysis

Keywords: caesium, lead, plutonium, beryllium, compound specific stable isotopes (CSSI), soil degradation

Use of fallout radionuclides to assess change in soil erosion and sedimentation rates in Northern Morocco

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Abstract

The aim of this work is to use fallout radionuclides for assessing change in soil redistribution rates, in relation to climate change, and the effectiveness of soil conservation practices tested in Northern Morocco. The study areas are located in El Hachef, Nakhla and Raouz watersheds. The net soil erosion rates obtained ranged between 12.6 and 52.8 t ha^{-1} yr^{-1}. Using the ^{137}Cs re-sampling approach, soil erosion magnitudes were compared between two periods 1954-2002 and 2002-2017 for four fields and by using ^{7}Be, the erosion rates were compared between no-till and conventional tillage practices in 2015 and 2016 for four other fields. Soil erosion have slightly decreased during 2002-2017 as compared to 1954-2002 due to the positive effects of recent agricultural practices and have significantly decreased by up to 40% for fields under no-tillage as compared to conventional tillage. However, for one field where there is no change in agricultural practices, soil loss has increased by 20 %. The use of $^{210}Pb_{ex}$ in a water reservoir of this area shows an increase of around 21 % of the sedimentation rate between the two studied periods, a result which is in agreement with the changes in measured soil erosion rates.

Keywords: soil erosion, sedimentation, ^{137}Cs, ^{210}Pb, ^{7}Be, soil conservation, no-tillage

Introduction

Land degradation by soil erosion has considerable on-site and off-site impacts and it is a major concern for protection of land resources in Morocco, especially in the northern part of the country. Erosion is affecting a total area of 15 million hectares. More than 100 million tons of soil losses and a reduction of 75 million m^3 of dam's storing capacity are registered annually (Dahan *et al.,* 2012). Erosion is encouraged by inappropriate agricultural practices and the impact of climate change causing severe drought periods and extreme rain events.

Reliable datasets on the magnitude, spatial distribution, short-term temporary dynamics and long-term development trends of erosion and sedimentation as well as on effectiveness of soil conservation practices are needed for sustainable land management. Most of the studies carried out in Morocco to establish soil erosion rates used conventional techniques such as experimental runoff plots or empirical erosion models. However, the use of fallout radionuclides (FRNs) such as cesium-137 (^{137}Cs), excess lead-210 ($^{210}Pb_{ex}$) and beryllium-7 (^{7}Be) is an excellent alternative to conventional erosion and sedimentation assessment methods (Mabit *et al.,* 2008). The objective of this work is to use FRNs (i) to assess change in soil erosion and sedimentation rates in relation to climate change and (ii) to evaluate the efficiency of recent soil conservation practices implemented in Northern Morocco.

Methodology

The studied areas are located in Tangier-Tétouan Region (Northern Morocco) in three watersheds: El Hachef, Nakhla and Raouz. This region is characterized by a sub-humid Mediterranean climate with annual precipitation ranging between 600 and 800 mm. It is built mainly by flysch marl–limestone and clay, mudstones, sandstones and dolomite. The soil scape is composed mainly by vertisol, lithosol and luvisol. The main crops of this region are cereals (wheat, barley, maize), legumes (lentil, chickpea) and fruit plantations (olive, almond, fig).

In the present work, eight agricultural fields (HA-1, HA-2, HA-3, HA-4, HA-5, HA-6, NA-1, RA-1), under different agro-environmental conditions as well as one water reservoir (WRH1) were investigated. The slope gradients of these fields range between 6% and 30%. The dominant texture of the soil is clay and silt. The study fields were used in the past (until 2002) for wheat or barley in rotation with lentil using conventional tillage. In the last fifteen years (2002-2017) the land management changed. Some fields were under more frequent fallows with natural vegetation and olive threes while on other fields the no-till land management, implemented since 2010, was tested and compared to the conventional tillage in 2015 and 2016. The ^{137}Cs re-sampling approach was performed in 2002 and 2017 at four agricultural fields (HA-1, HA-2, NA-1 and RA-1) to assess potential change in soil erosion rates during the last 15 years.

^{7}Be was used in 2015 and 2016 to compare short-term soil erosion rates fields under no-tillage (HA-3, HA-5) and conventional tillage (HA-4, HA-6). $^{210}Pb_{ex}$supported by ^{137}Cs was used for establishing the temporal variation of the sedimentation rates in water reservoir in El Hachef watershed (WRH-1).

Guidelines for using FRN methods are reported in several comprehensive handbooks (^{137}Cs: Fulajtar *et al.* 2017; ^{210}Pb: Benmansour *et al.* 2014; ^{7}Be: Mabit and Blake, 2019). These isotopes reach the soil via atmospheric fallout. Once deposited, they bound to soil colloids in the top soil layer. Further they can be moved only by physical processes such as soil erosion. The principle of these methods is to compare the inventories expressed in Bq m^{-2} of selected FRN tracer at studied site to so called reference site which was not affected by soil redistribution processes. The erosion and deposition rates are calculated by so called conversion models (Walling, 2014). The $^{210}Pb_{ex}$ is determined by subtracting ^{226}Ra from total ^{210}Pb.

The soil sampling strategy was based on a transect approach (1-4 transects) and both bulk and sectioned soil cores were collected for ^{137}Cs and ^{7}Be applications. At each field, one sectioned core and from 10 to 20 bulk cores were collected. The distance between the sampling points along the transect was from 5 to 30 m. The reference sites were located near to the study areas and 10 bulk cores and one sectioned core were collected to depth of 20-30 cm for each reference site. In addition, 2 sediment cores were collected to depth of 40 cm in the water reservoir.

After a physical preparation of the samples, ^{137}Cs, ^{7}Be,^{210}Pb and ^{226}Ra were measured by gamma spectrometry and estimates of soil erosion or deposition rates were calculated by conversion models (Walling *et al.* 2014), while the sedimentation rates were determined by using Constant Rate Supply Model (CRS) (Appleby and Oldfield, 1978).

Results

Using the ^{137}Cs re-sampling approach, soil erosion rates associated with two periods (1954-2002 and 1954-2017) were estimated for the four cultivated sites named HA-1, HA-2 (El Hachef area), NA-1 (Nakhla area) and RA-1 (Raouz area) (Figure1A). The values of net soil losses ranged between 12.6 and 52.8 t ha^{-1} yr^{-1} and are likely dependent on many parameters including land use, slope and soil proprieties. The comparison between the two periods of assessment showed a little change in soil loss (Figure1A). Indeed, the mean soil erosion rates have slightly decreased between the two periods by 16 and 20 % for HA-2 and NA-1 fields respectively and remained practically the same for the field HA-1, while for the field RA-1, the mean soil erosion rate has increased in 2017 by 20 %. The use of ^{7}Be in 2015 and 2016 indicated that the soil erosion rates (t ha^{-1}) corresponding to short rainfall events (January-March 2015, 2016) have been significantly reduced by up to 40 % and 35 % for fields under no-till (HA-4 and HA-6) as compared to fields under conventional tillage (HA-3, HA-5) (Fig 1B). The application of $^{210}Pb_{ex}$ and Constant Rate Supply Model (CRS) showed an increase of the sedimentation rate with time from 0.20g cm^{-2} yr^{-1}in 1950 to 0.80 g cm^{-2} yr^{-1} in 2017 (Figure 2).

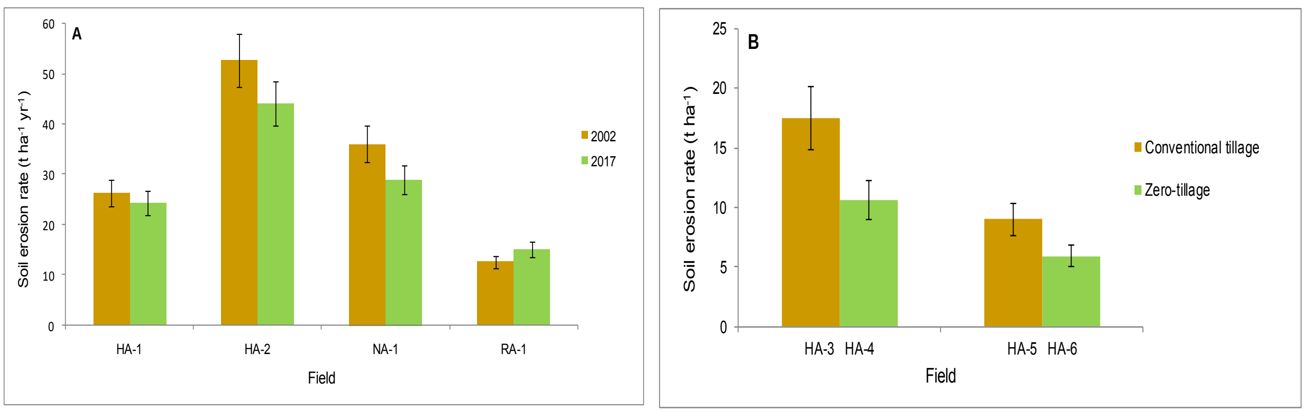

Figure 1: Long-term soil erosion rates using ^{137}Cs re-sampling approach (A) and short-term soil erosion rates using ^{7}Be (B) at the investigated fields HA-1, HA-2, NA-1, RA-1, HA-3, HA-4, HA-5, HA-6

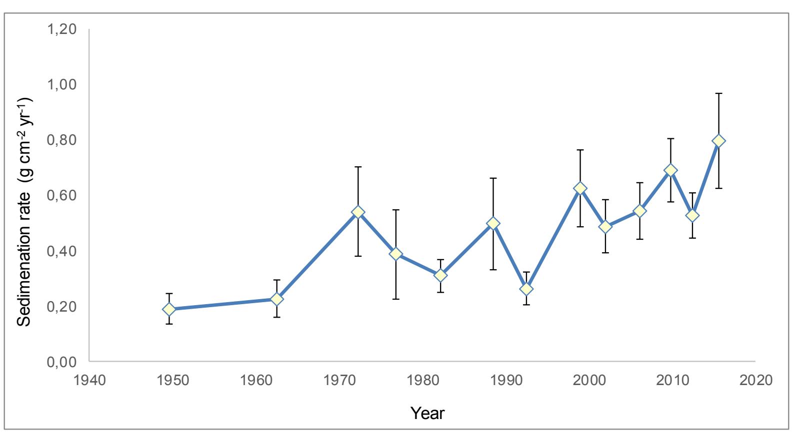

Figure 2: Temporal variation of the sedimentation rate in water reservoir (WRH1)

Discussion

The slight decrease of the net soil erosion rates associated with the fields of El Hachef and Nakhla areas (HA-1, HA-2 NA-1) between the periods of 1954-2002 and 1954-2017 can be explained by the positive effects of the recent agricultural practices used on these fields since 2002. Indeed, in addition to the traditional practices previously adopted, based on the cultivation of cereals in rotation with legumes, more periodic fallows with natural vegetation or fruit plantations were used at these sites. At the field of Raouz area (RA-1), where land use and management was not changed the increase of about 20 % of the net soil erosion rate could be due to climate change impact on soil erosion in this area. Using $^{210}Pb_{ex}$, the change on the mean sedimentation rate in water reservoir (WRH-1) between the periods of 1950-2002 and 2002-2017 is around 21 %. This is consistent with the value found for change in soil erosion rate associated with the field RA-1. The significant reduction of soil erosion rates observed in the north of Morocco by up to 35-40 % for fields under no-till practice compared to conventional tillage confirms the benefit of such practice for combating soil erosion in Morocco. Similar findings were obtained using the same technique in the west of Morocco (Benmansour *et al.,* 2011).

Conclusions

This work highlights the potential of using FRNs to assess the changes in soil erosion and sedimentation rates and the effectiveness of soil conservation strategies. Soil erosion rates have slightly decreased in period 2002-2017 as compared to earlier period of 1954-2002 due to the positive effects of the change of agricultural practices and they significantly decreased by up to 40 % when the no-till technique was applied as soil conservation practice instead of the conventional tillage. The study shows also an increase of the net soil erosion rate by 20 % between the two investigated periods at the field where agricultural practices were not changed. The same result was obtained by the sediment chronology study in water reservoir located in the study area. This increase indicates the negative impact of climate change. These isotopic techniques will be applied in other Moroccan regions for better understanding of the impacts of climate change and land management on soil erosion to provide useful and reliable information for decision makers.

Acknowledgements

The authors gratefully acknowledge the financial support from the International Atomic Energy Agency (IAEA) through the projects RAF5075 and the CRP D1.50.17.

References

Appleby, P.G. & Oldfield, F. 1978. The calculation of ^{210}Pb dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediment. *Catena,* 5: 1-8.

Benmansour, M., Nouira, A., Bouksirat, H., Duchemin, M., Oumri, M.E.L., Moussadek, R., Benkdad, A. & Ibn Majah, M. 2011. Estimates of long and short-term rates of soil erosion using ^{137}Cs, $^{210}Pb_{ex}$ and ^{7}Be

measurements: Case study of one agricultural field in semi-arid west Morocco. *In*: *Impact of Soil Conservation Measures on Erosion Control and Soil Quality*. IAEA TECDOC 1665*,* IAEA, Vienna, 159-174.

Benmansour, M., Mabit, L., Owens, P.N., Tarján, S. & Walling, D.E. 2014. The use of excess ^{210}Pb ($^{210}Pb_{ex}$) as a soil and sediment tracer. *In*: Guidelines for using fallout radionuclides to assess erosion and effectiveness of soil conservation strategies. IAEA-TECDOC-1741. IAEA, Vienna, 79-104.

Dahan, R., Boughlala, M., Mrabet, R., Laamari, A., Balaghi, R. & Lajouad, L. 2012. A review of available knowledge on land degradation in Morocco. Oasis Country Report 2, ICARDA, 48 pp.

Fulajtar, E., Mabit, L., Renschler, C.S. & Lee Zhi Yi, A. 2017. Use of ^{137}Cs for soil erosion assessment, FAO, Rome, 76 pp.

Mabit, L. & Blake, W.H. (Eds.). 2019. Assessing Recent Soil Erosion Rates through the Use of Beryllium-7 (Be-7), Springer Open, 69 pp.

Mabit, L., Benmansour, M. & Walling, D.E. 2008. Comparatives advantages and limitations of ^{137}Cs, ^{210}Pb and ^{7}Be methodologies for assessing erosion and sedimentation. *Journal of Environmental Radioactivity,* 99(12): 1799-1809.

Walling, D.E., Zhang, Y. & He, Q. 2014. Conversion models and related software. *In*: *Guidelines for using fallout radionuclides to assess erosion and effectiveness of soil conservation strategies.* IAEA-TECDOC-1741. IAEA, Vienna, 125-148.

Madagascar highland traditional terracing agriculture improves soil preservation, as evidenced by fallout radionuclide techniques

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Abstract

One of traditional agricultural techniques of Malagasy farmers is terracing to reduce soil erosion. This land conservation approach is widely spread in Madagascar highland, but their soil conserving efficiency is not fully established. To address this issue, a study was conducted in traditional agricultural area of Madagascar highland for evaluating the effectiveness of terraced agriculture in reducing soil erosion. Fallout radionuclides (FRN), i.e. ^{137}Cs and ^{210}Pb were used to estimate soil erosion rates at fields situated at natural slopes and at terraces. At the slope fields, the ^{137}Cs derived annual net soil loss varies from 7.4 $t.ha^{-1}.a^{-1}$ to 9.1 $t.ha^{-1}.a^{-1}$. The $^{210}Pb_{ex}$ derived annual net soil loss varies from 5.9 $t.ha^{-1}.a^{-1}$ to 6.9 $t.ha^{-1}.a^{-1}$. At the terraced fields, the ^{137}Cs derived annual net soil loss varies from 3.4 $t.ha^{-1}.a^{-1}$ to 4.4 $t.ha^{-1}.a^{-1}$. The $^{210}Pb_{ex}$ derived annual net soil loss varies from 3.8 $t.ha^{-1}.a^{-1}$ to 5.1 $t.ha^{-1}.a^{-1}$.

These results demonstrate that terrace agriculture, as compared to slope agriculture, reduces the area impacted by erosion by 4 to 16 %, the soil erosion rate by 52 to 54 % and the sediment delivery ratio by 25 to 31 %.

Keywords: Soil erosion, soil protection, ^{137}Cs, ^{210}Pb, terrace agriculture

Introduction

Soil erosion is a major problem in many parts of the world, leading to concern about the sustainability of agricultural systems to feed future generations (Morgan, 1995). In the Madagascar highland, water induced erosion is considered as a source of agricultural soils degradation along the hillslopes (Ralison and Minten, 2003). Indigenous agricultural practices had addressed the issue by developing terraced agriculture.

As terrace construction is tedious if done by the man and animal power and may take several years before the new terraces are stabilized (Chantal Blanc-Pamard *et al.*, 2005), the farmers lately try to avoid their construction. Moreover, the elementary mechanization such as using animal drawn ploughs is easier on large fields occupying continuous slopes not dissected to small terraces. Inspired by the western schools of agriculture and believed to be more convenient for modern technical inputs (mechanisation, chemical fertilization, row crops, etc), this approach became more popular among the farmers than the traditional terracing.

For the sake of mechanization and rationality, western inspired conventional and modern schools of agriculture is pushing towards the abandonment of the old wisdom related to agricultural practices. This leads farmers to abandon the ancient technique in favour of slope agriculture. The question is raised about the credit that could be granted to the profane knowledge (Henin, 1958). Answering this question is a challenge that needs to be addressed by research. The traditional agricultural terraces in Madagascar highland are not horizontal, they are inclined, but they reduce significantly the original slope steepness. They reduce soil erosion, but they do not prevent it entirely. Erosion rates at terraced fields were never quantified and the soil conservation efficiency of terracing was not yet quantified under Malagasy agroenvironmental condition.

The Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture promote climate smart agriculture practices and assists countries in quantifying soil erosion rates and assessing the effectiveness of their soil conservation practices using nuclear techniques. In order to help Madagascar's farmers with conservation practices, scientists at the Institut National des Sciences et Techniques Nucléaires (INSTN-Madagascar) worked with the Joint FAO/IAEA Division to address the problem and identify the country's most erosion-prone areas. This cooperation already brought valuable results (Rabesiranana *et al.,* 2016). Build on previous experiences in using fallout radionuclides methods, the main objective of this investigation is to compare soil erosion rates in terraced and non-terraced agricultural fields of Madagascar highland and to evaluate the efficiency of terraced agriculture in preserving soil resource against erosion.

Methodology

The study was conducted in traditional agricultural area of Madagascar highland. The study area is located in the eastern central highland of Madagascar, 140 km from the Indian Ocean, near Sambaina, Manjakandriana, 40 km East of Antananarivo (18°54'38" S; 47°46'42" E) at an altitude of 1 400 m a.s.l.

To investigate this specific agroenvironment, FRN, i.e. caesium-137 (^{137}Cs) and excess lead-210 ($^{210}Pb_{ex}$) were used as soil redistribution tracers.

Caesium-137 first reached the soil as fallout following atmospheric nuclear testing in the 1950s and 1960s. When ^{137}Cs gets in contact with soil, it binds to soil colloids in the uppermost soil layer and become chemically non-exchangeable. Then this radioisotope is mostly redistributed by mechanical processes such as soil erosion. Because earlier it did not occur in soil, it can be used as a soil marker to ascertain and compare soil movements in the landscape (Mabit *et al.* 2008). Lead-210 on the other hand is a naturally occurring fallout radioisotope that can also be used as a soil tracer.

Investigations undertaken in different environments worldwide have demonstrated that the use of ^{137}Cs and $^{210}Pb_{ex}$, either independently or in combination, affords a valuable means of assessing rates of soil loss and/or sediment deposition (see Fulajtar *et al.,* 2017; Mabit *et al.,* 2014). The use of FRN possesses many advantages over the conventional monitoring techniques (e.g. Porto and Walling, 2012). Main advantages include: 1) deriving retrospective estimates of erosion and deposition rates based on a single site visit (or short sampling campaign); 2) providing long term mean soil erosion rates; and 3) identifying spatial distribution of soil erosion through grid or multiple transect sampling approaches. Multiple sampling points collected along the landscape can be used to establish spatial patterns of soil redistribution and to support the validation of erosion models (He and Walling, 2003).

In our study, two types of cultivated fields were investigated: slope plots and terraced plots. For each studied field, bulk soil core samples were collected along transect. Additionally, full incremental soil profiles were taken for FRN depth distribution analysis.

Determination of ^{137}Cs and $^{210}Pb_{ex}$ activities were undertaken simultaneously using high resolution, low background, low energy, hyper-pure n-type germanium coaxial gamma-ray detector (detector with 15% relative efficiency). The samples were counted for more than 24 hours, providing a precision of approximately 10-20% at the 95% level of confidence for the measurements. The ^{137}Cs, ^{214}Bi and ^{210}Pb activities were measured at 662 keV, 609 keV and 46.5 keV respectively. The ^{226}Ra concentration was measured through its progeny ^{214}Bi. The unsupported ^{210}Pb ($^{210}Pb_{ex}$) concentration was calculated by subtracting the ^{226}Ra-supported ^{210}Pb concentration from the total ^{210}Pb concentration.

The mass balance model 2 (Walling *et al.,* 2014) was used for converting and estimating mid- and long-term rates of water-induced soil erosion (50 and 100 years for ^{137}Cs and $^{210}Pb_{ex}$ respectively).

Results

At the slope fields, the ^{137}Cs derived annual net soil loss varies from 7.4 $t.ha^{-1}.a^{-1}$ to 9.1 $t.ha^{-1}.a^{-1}$. The $^{210}Pb_{ex}$ derived annual net soil loss varies from 5.9 $t.ha^{-1}.a^{-1}$ to 6.9 $t.ha^{-1}.a^{-1}$. At the terraced fields, the ^{137}Cs derived annual net soil loss varies from 3.4 $t.ha^{-1}.a^{-1}$ to 4.4 $t.ha^{-1}.a^{-1}$. The $^{210}Pb_{ex}$ derived annual net soil loss varies from 3.8 $t.ha^{-1}.a^{-1}$ to 5.1 $t.ha^{-1}.a^{-1}$.

Terrace agriculture, when compared to slope agriculture, reduces the eroding area by 4 to 16%, the soil erosion rate by 52 to 54% and the sediment delivery ratio by 25 to 31%.

Discussion

As reported by other studies, the estimated soil loss magnitude impacting Malagasy agricultural uplands is significant, confirming that soil degradation of natural and/or anthropogenic origin is indeed a global concern experienced by most countries in the world. Transition from forest to agricultural land-uses generally leads to soil degradation. This is proved by the difference between $^{210}Pb_{ex}$ and ^{137}Cs results.

If farmers would apply similar agricultural practices as their ancestors – and create terraces – they could reduce run-off and, in turn, soil erosion in the country by up to 50 percent, when compared to non-terraced agricultural fields, and thereby retain at least 3 tons of soil per hectare every year.

Conclusions

This study corroborates the experience of traditional farmers. Terracing is a useful soil conservation measure. However, its effectiveness in reducing soil erosion should be reinforced by modern approaches of soil conservation land management (no-tillage, etc.). In addition to identifying key areas with high erosion and sediment transfer and assessing the soil conservation efficiency of terracing, FRN methods also enable better targeting of soil conservation measures at non-terraced slope fields. This increases farmers' ability to control and mitigate soil losses caused by erosion and to mitigate its environmental impact.

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The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

References

Blanc-Pamard, C. & Rakoto Ramiarantsoa, H. 2005. Pratiques paysannes et gestion de l'érosion, exemples malgaches. Une ingénierie écologique indigène. *In: Erosion et gestion conservatoire de l'eau et de la fertilité des sols.* Actes des journées scientifiques du réseau érosion et GCES de l'AUF, Antananarivo (Madagascar), 25-27 octobre 2005, pp. 265-273.

Fulajtar, E., Mabit, L., Renschler, C.S. & Lee Zhi Yi, A. 2017. Use of ^{137}Cs for soil erosion assessment, FAO, Rome, 76 pp.

Hénin, S. 1958. Réflexions sur la valeur de la connaissance empirique. C.R. Acad. Agric. Fr., séance du 17 décembre, pp. 881-883.

Mabit, L., Benmansour, M., Abril, J.M., Walling, D.E., Meusburger, K., Iurian, A.R., Bernard, C., Tarján, S., Owens, P.N., Blake, W.H. & Alewell, C. 2014. Fallout ^{210}Pb as a soil and sediment tracer in catchment sediment budget investigations: A review. *Earth-Science Reviews*, 138: 335-351.

Mabit, L., Benmansour, M. & Walling, D.E. 2008. Comparative advantages and limitations of the fallout radionuclides ^{137}Cs, $^{210}Pb_{ex}$ and ^{7}Be for assessing soil erosion and sedimentation. *Journal of Environmental Radioactivity*, 99: 1799-1807.

Minten, B. & Ralison, E. 2003. Environnement, agriculture et pauvreté. *In: Agricultures, pauvreté rurale et politiques économiques à Madagascar*. Randrianarison L. (Ed.). Antananarivo.

Morgan, P.C. 1995. Soil Erosion and Conservation. Longman Scientific and Technical, London England.

Porto, P. & Walling, D.E. 2012.Validating the use of ^{137}Cs and $^{210}Pb_{ex}$ measurements to estimate rates of soil loss from cultivated land in southern Italy. *Journal of Environmental Radioactivity*, 106: 47-57.

Rabesiranana, N., Rasolonirina, M., Solonjara, A.F., Ravoson, H.N., Raoelina, A. & Mabit, L. 2016. Assessment of soil redistribution rates by ^{137}Cs and $^{210}Pb_{ex}$ in a typical Malagasy agricultural field. *Journal of Environmental Radioactivity*, 152: 112-118.

Walling, D.E., Zhang, Y. & He, Q. 2014. Conversion models and related software, In: *Guidelines for using fallout radionuclides to assess erosion and effectiveness of soil conservation strategies*. IAEA-TECDOC-1741. IAEA, Vienna, 125-148.

Use of ^{137}Cs in evaluating conservation agriculture practices on soil erosion control in semi-arid areas of Zimbabwe

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Abstract

In Zimbabwe, soil erosion research has been mostly based on direct measurements using sediment collectors. In this study, the caesium-137 (^{137}Cs) technique has been used to evaluate the effectiveness of three soil agricultural practices in soil erosion control at the Makoholi Research Station located in southern Zimbabwe. The agricultural practices since 1988 include (i) direct seeding (DS) with mulch, (ii) conservation farming basins with mulch (CFB), and (iii) conventional tillage (CT). The ^{137}Cs reference inventory was established at 214 ± 16 Bq/m^2. The mean ^{137}Cs inventories for DS, CFB and CT were 195, 190 and 179 Bq/m^2 respectively. The gross erosion rates along the sampled transects were 7.5, 7.3 and 8.9 t/ha/yr for DS, CFB and the CT while the net erosion rates were 3.8, 4.6 and 6.2 t/ha/yr respectively. The sediment delivery ratios were 50 %, 63 % and 70 % in the respective order. For the same study plots, average rates of soil loss obtained from direct measurements for the period 1988-2014 were generally higher with a similar trend (7.3, 7.9 and 15.2 t/ha/yr). These results highlight the effectiveness of DS, CFB versus CT to reduce soil erosion.

Keywords: soil erosion, soil redistribution, fallout radionuclides, caesium-137, conservation agriculture

Introduction, scope and main objectives

The application of fallout radionuclides (FRNs) such as caesium-137 (^{137}Cs), unsupported lead-210 ($^{210}Pb_{ex}$) and beryllium-7 (^{7}Be) as soil tracers is currently one of the most promising and effective approaches to assess soil erosion and deposition rates (IAEA, 2014; Mabit *et al.,* 2008). These techniques can be used to assess the effectiveness of soil conservation practices or the vulnerability of soils owing to farmer management practices. FRNs can be used to determine extent of soil redistribution in different farming systems. Walling and Quine (1992) reported the potential of ^{137}Cs techniques in assessing soil redistribution on Zimbabwean landscapes. This artificial fallout radionuclide, with a half-life of about 30 years, is the most commonly employed anthropogenic isotope to study soil redistribution (Mabit *et al.,* 2013). The technique is best used to study medium term (50 years) soil redistribution and provides information about the magnitude of soil and sediment redistribution.

The objectives of the presented study were (i) to test the use of ^{137}Cs technique for estimating soil erosion magnitudes under Zimbabwean agro-environmental conditions, and (ii) to assess the effectiveness of conservation agriculture practices in controlling soil erosion using the ^{137}Cs technique.

Methodology

The study was carried out at Makoholi Research Station located in Masvingo Province, 250 km south of Harare. The area is semi-arid, receiving annual rainfall of 450-700 mm. The soils are coarse loamy sands, Gleyic lixisols. The site has a slope of 5 %. Field erosion plots (Figure 1) that are10 m wide and 30 m long were established in 1988 to quantify runoff and soil loss from multi-slot divisor system from two soil conservation practices (direct seeding [DS], and conservation farming basins [CFB]) which were compared to the control practice (conventional tillage [CT]). Conservation farming basins were made by hoes with a radius of 15 cm and depth of 15 cm. Direct seeders were used to sow seed in the soil with very minimum disturbance.

The guidance on ^{137}Cs method is provided by Mabit *et al.* (2014) and Fulajtar *et al.* (2017). The major characteristics of ^{137}Cs is that it gets to soil from atmospheric fallout and once deposited, it is rapidly and strongly bound to soil colloids in the uppermost soil layer. Further it can be moved only by physical processes removing soil particles such as soil erosion. The principle erosion assessment is based on comparing the ^{137}Cs inventories (Bq/m^2) at studied site to so called 'reference site' which was not affected by soil redistribution processes. The erosion and deposition rates are calculated by so called 'conversion models' (Walling *et al.,* 2014).

The soil sampling for ^{137}Cs determination was done in 2013 and 2014. The study design involved two reference sites and 6 slope transects. The reference sites were selected in: 1) fenced area of weather station situated on flat surface overgrown by grass, which is known to be undisturbed by activities other than installing the weather station equipment (Ref.1) and 2) bush land on flat topographic position (Ref. 2). Both reference sites were situated in close neighbourhood (within 500 m distance) of studied site. The transects were distributed over three experimental erosion plots (30 x 10 m). At each plot, two transects situated 8 m apart were selected and the sampling points within the transect were at a distance of 3 m from each other. Geographical coordinates for each sampling point were recorded by GPS.

Depth-incremental sampling was done in 2013 to investigate the distribution of ^{137}Cs within the soil profile. This information was needed to assess whether the reference site is undisturbed and to estimate the depth of ^{137}Cs influx after fallout to set the depth of bulk core sampling. The depth incremental samples were taken at the reference sites and at the study plot with DS. A motorised soil corer was used to sample to a depth of 40 cm from each of the reference sites and the DS study plot. Twin cores were taken for each of the three sampled sites (Ref. 1, Ref. 2 and DS). Each core was sectioned by 2 cm depth increments to a depth of 20 cm, and by 4 cm increments further down to 40 cm. Samples from one of twin cores was used to determine soil properties (e.g. bulk density, particle size analysis, soil organic carbon, nitrogen, exchangeable bases and cation exchange capacity) while the other twin core was used to measure ^{137}Cs activities.

The majority of sampling points were sampled in 2014 using bulk core approach following the effective ^{137}Cs contamination depth of 20 cm established by depth incremental sampling. Six bulk samples were taken at each reference site and 10 in each transect (60 in all transects) so the total number of bulk samples was 72.

All the samples were air-dried, grinded, homogenized and sieved (2 mm). Activities of ^{137}Cs were measured using gamma spectroscopy at the INSTN in Madagascar.

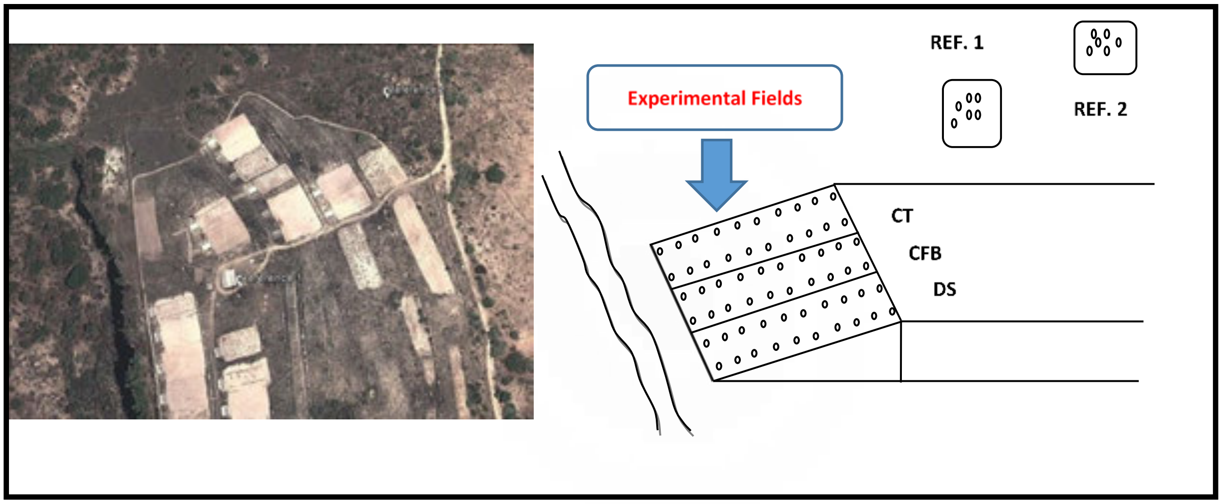

Figure 1: Study site showing field plots (on the left) and scheme of sampling (on the right)

Results

Reference site 2 (180 ± 16 Bq/m^2 of ^{137}Cs), showed exponential decrease of ^{137}Cs activity with depth while Reference 1 (187 ± 18 Bq/m^2 of ^{137}Cs) highlights some disturbance on the surface, maybe during installation of the weather station. The cultivated plot showed mixing up of ^{137}Cs in the profile. Higher ^{137}Cs inventories were obtained for reference sites while lower inventories were obtained for the cultivated plots at eroding sites while the reverse was true for deposition portions in the plots. Highest soil erosion rates were obtained for the conventional tillage practice while direct seeding and the use of conservation basins, both with mulch, reduced rates of soil loss by 74% and 42% respectively (Tab. 1.). Higher soil erosion rates were obtained from direct measurements conducted in the period 1988-2014.

Table 1: Soil erosion rates from ^{137}Cs inventories and direct measurements

Farming Practice	**Mean values using Mass Balance Model 2**			**Direct erosion measurements**
	Gross Erosion rate (t/ha/year)	Net Erosion Rate (t/ha/year)	Sediment Delivery Ratio (%)	Soil erosion rate (t/ha/year)
Direct Seeding + Mulch (DSM)	7.2	3.8	50	7.3
Conservation Farming Basins + Mulch	6.8	4.6	63	7.9
Conventional tillage	8.9	6.2	70	15.2

Discussion

The ^{137}Cs technique proved to be applicable and useful in assessing field-scale variations in soil loss and redistribution arising from different land management practices in semi-arid areas of Zimbabwe despite of the much lower ^{137}Cs inventories encountered in the southern hemisphere as compared to the northern hemisphere. The extent of soil redistribution processes depends on the degree of soil disturbance through tillage and magnitude of soil surface cover by crop residues. Soil loss rates obtained from direct measurements using sediment collectors were higher than those from the ^{137}Cs probably because some years experienced significant floods resulting in escalated erosion rates.

Conclusions

Conservation farming practices reduce rates of soil loss and are important for conserving the fertile top soil and hence sustaining land productivity. However, to convince the farmers and agricultural decision makers about the importance of soil conservation, quantitative data on erosion rates and deterioration of soil fertility, and about the efficiency of conservation measures are needed. This information can be gained partially when using the ^{137}Cs method as demonstrated by this study. Further step could be the use of ^{7}Be for seasonal soil erosion rates assessment under different agricultural practices. Tests of ^{210}Pb in estimating soil erosion rates needs to be explored more especially in Zimbabwe where geological formations are largely granitic, releasing more ^{210}Pb. As ^{137}Cs activities are low and are expected to be much lower over time due to the radioactive decay of ^{137}Cs, another promising method could be the use of plutonium isotopes ($Pu^{239+240}$).

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References

Fulajtar, E., Mabit, L., Renschler, C.S. & Lee Zhi Yi, A. 2017. Use of ^{137}Cs for soil erosion assessment, FAO, Rome, 76 pp.

IAEA. 2014. Guidelines for using fallout radionuclides to assess erosion and effectiveness of soil conservation strategies. IAEA-TECDOC-1741. International Atomic Energy Agency, Vienna, 213 pp.

Mabit, L., Benmansour, M. & Walling, D.E. 2008. Comparative advantages and limitations of the fallout radionuclides ^{137}Cs, excess ^{210}Pb and ^{7}Be for assessing soil erosion and sedimentation. *Journal of Environmental Radioactivity,* 99(12): 1799-1807.

Mabit, L., Chhem-Kieth, S., Dornhofer, P., Toloza, A., Benmansour, M., Bernard, C., Fulajtar, E. & Walling, D.E. 2014. ^{137}Cs: A widely used and validated medium-term soil tracer. In: *Guidelines for using fallout radionuclides to assess erosion and effectiveness of soil conservation strategies*. IAEA-TECDOC-1741. International Atomic Energy Agency, Vienna, 27-78.

Mabit, L., Meusburger, K., Fulajtar, E. & Alewell, C. 2013. The usefulness of ^{137}Cs as a tracer for soil erosion assessment: a critical reply to Parsons and Foster. *Earth-Science Reviews*, 127: 300-307.

Walling, D.E., Zhang, Y. & He, Q. 2014. Conversion models and related software. In: *Guidelines for using fallout radionuclides to assess erosion and effectiveness of soil conservation strategies*. IAEA-TECDOC-1741. International Atomic Energy Agency, Vienna, 125-148.

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