GlobalSoilMap for soil organic carbon mapping and as a basis for global modeling.

Dominique Arrouays, Budiman Minasny, Alex B Mcbratney, Mike Grundy, Neil J. Mckenzie, James Thompson, Alessandro Gimona, Suk Young Hong, Scott Smith, Alfred Hartemink, et al.

Food and Agriculture Organization of the United Nations

PROCEEDINGS
OF THE GLOBAL SYMPOSIUM ON SOIL ORGANIC CARBON 2017

GLOBAL SYMPOSIUM ON SOIL ORGANIC CARBON | 21 - 23 MARCH 2017 | FAO - ROME, ITALY

GLOBAL SOIL PARTNERSHIP

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An event co-organized by:

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GSP | Global Soil Partnership

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MEETING ORGANIZATION AND ADMINISTRATIVE SUPPORT

The Proceedings of the Global Symposium on Soil Organic Carbon 2017 (GSOC17) were compiled by FAO based on the extended abstracts submitted to the Scientific Committee previous to the event. The abstracts gathered in this publication represent a summary of the presentation held during the GSOC17, excluding accepted abstracts with a withdrawn presentation. Not included abstracts of key note presentations were not submitted by the presenting authors. To avoid conflicts with on-going peer-review processes, some abstracts were only included in their short form following requests from the respective abstract authors.

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PREFACE

The Global Symposium on Soil Organic Carbon (GSOC17) was jointly organized by the:

- Food and Agriculture Organization of the United Nations (FAO);
- Global Soil Partnership (GSP) and its Intergovernmental Technical Panel on Soils (ITPS);
- Intergovernmental Panel on Climate Change (IPCC);
- Science-Policy Interface (SPI) of the United Nations Convention to Combat Desertification (UNCCD); and
- World Meteorological Organization (WMO).

The symposium was held at FAO headquarters in Rome, Italy, on 21–23 March 2017 and attended by 488 participants (33 percent women, 67 percent men) from 111 countries, including representatives of FAO member states, organizing institutions, the private sector and civil society, as well as scientists and practitioners working on soil organic carbon (SOC) and related fields.

The overall aim of the symposium was to review the role of soils and SOC in the context of climate change, sustainable development and land degradation neutrality (LDN). The three-day symposium was structured around three main themes focusing on the assessment of SOC, the maintenance and increase of SOC stocks, and SOC management in specific types of soil:

Theme 1: measuring, mapping, monitoring and reporting soil organic carbon stocks and stock changes

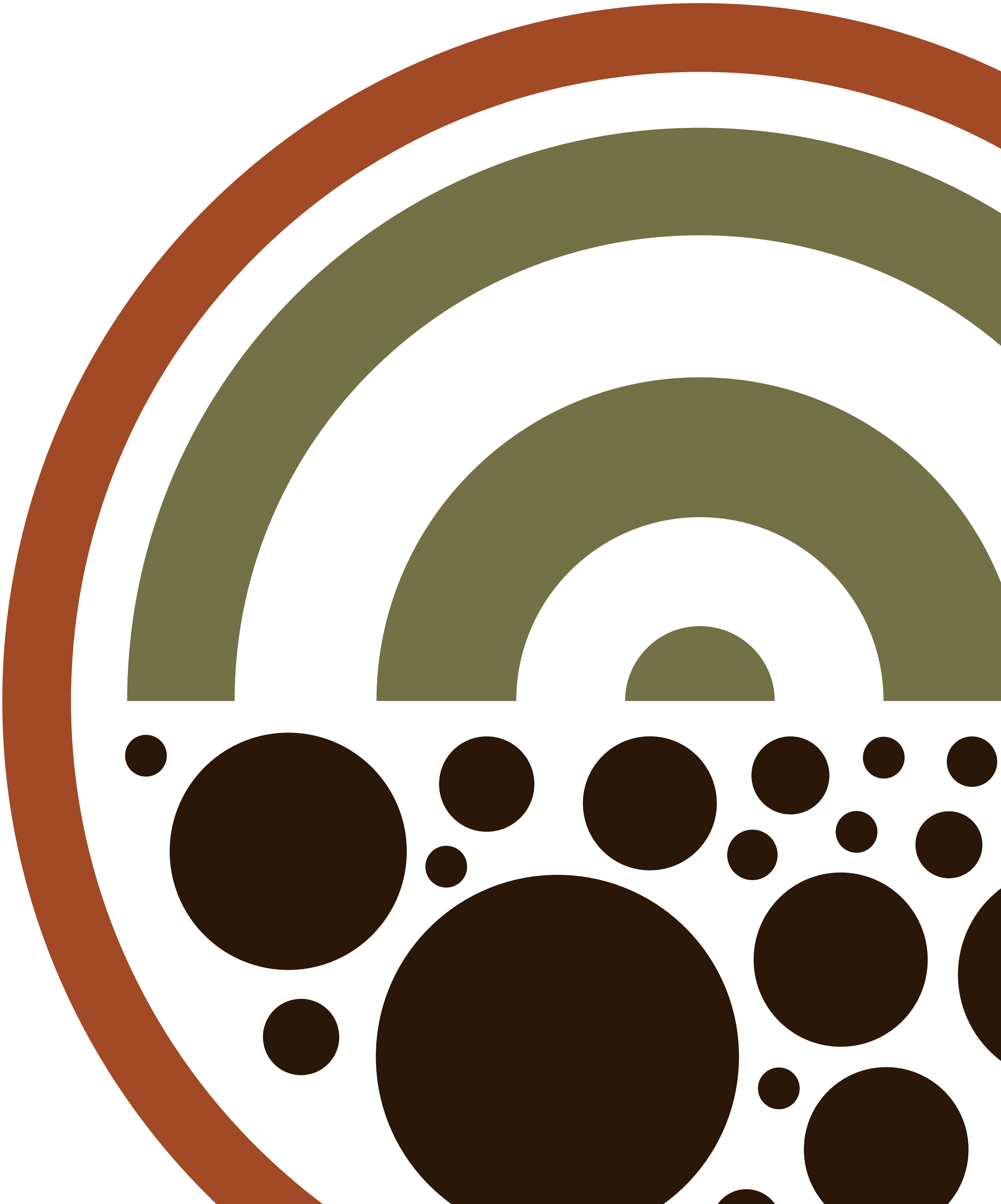
Theme 2: maintaining and/or increasing SOC stocks (fostering SOC sequestration)

Theme 3: managing SOC in:
a) soils with high SOC (peatlands, permafrost and black soils);
b) grasslands and livestock production systems; and
c) dryland soils.

The present abstract compilation starts with abstracts from the Keynote presentations and is subsequently structured according to these three themes, presented in alphabetical order by name of the first author. Theme 1 and 2 include also the presented posters during the GSOC17.

Beyond the presentations of results of studies demonstrating the potential and challenges of managing and monitoring SOC, participants from across the globe engaged actively by discussing and developing the key messages reflected in the Outcome Document of the GSOC17. The present Proceedings are a complement to the Outcome Document.

KEYNOTE PRESENTATIONS



K.1 | QUANTIFYING THE LOSSES OF SOIL CARBON IN RESPONSE TO WARMING AT A GLOBAL SCALE

Thomas W. Crowther[1]

Email: Thomas.crowther11@gmail.com

Affiliation: Netherlands Institute of Ecology, Droevendaalsesteeg 10, 6708 PB Wageningen, The Netherlands

INTRODUCTION

Most of the Earth's terrestrial carbon (C) is stored in the soil and changes in the size of this C stock represent a dominent control on atmospheric C concentrations. Increasing soil C sequestration at a global scale represents one of our best tools in the fight against climate change. But it is still unclear how these C stocks are currently changing so it is difficult to establish meaningful sequestration targets. One of the greatest threats to global C sequestration is rising atmospheric temperatures. If warming drives the loss of even a small proportion of soil C into the atmosphere, it could initiate a positive land C-climate feedback that could cause additional planetary warming(Bradford *et al.*, 2016; Davidson, E.A., Janssens, 2006). This feedback could threaten our capacity to increase C sequestration over the rest of this century. Yet, despite considerable scientific attention in recent decades, there remains no consensus on the direction or magnitude of warming-induced changes in soil C stocks (Arora *et al.*, 2013; Crowther *et al.*, 2015). Warming generally enhances fluxes both into and out of the soil, but the net global differences in these responses remain unclear and direct estimates of soil C stocks are limited to single-site experiments that generally reveal no detectable effects (Lu *et al.*, 2013; Sistla *et al.*, 2013).

In the absence of global estimates of how soil C stocks are responding to warming, Earth System Models (ESMs) must rely heavily on short-term temperature responses of soil respiration (Q_{10}) to infer long-term changes in global C stocks. With empirical observations that capture longer-term C dynamics, we are limited in our ability to evaluate model performance, or constrain the uncertainty in model projections. As such, the land C-climate feedback remains one of the largest sources of uncertainty in current ESMs(Todd-Brown *et al.*, 2014), restricting our understanding of how soil C stocks will change over the rest of the century. This uncertainty limits our capacity to develop emissions targets that are compatible with specific climate change scenarios, or to establish meaningful conservation targets to increase C sequestration in soil(Bradford *et al.*, 2016).

METHODS

In our paper(Crowther et al., 2016) we took advantage of the growing number of climate change experiments around the world to compile the first global database of soil C stock responses to expected warming. Soil samples were collected from replicate plots in 49 climate change experiments conducted across six biomes, ranging from arctic permafrost to dry Mediterranean forests (Extended data Figure 1). We compared soil C stocks across 'warmed' (treatment) and 'ambient' (control) plots to explore the effects of temperature across sites. The measured differences in soil C stocks represent the net result of long-term changes in soil C inputs (plant production) and outputs (respiration) in response to warming. By linking these soil C responses to climatic and soil characteristics we are able to generate a spatial understanding of the temperature-sensitivity of soil C stocks at a global scale. To standardize collection protocols and account for the considerable global variability in soil horizon depths, we focus on C stocks in the top 10 cm of soil. At a global scale, this upper soil horizon contains the greatest proportion of biologically active soil C by depth(Jobbágy and Jackson, 2000).

RESULTS

The effects of warming on soil C stocks were variable, with positive, negative and neutral impacts observed across sites (Figure 1). However, the direction and magnitude of these warming-induced changes were predictable, being contingent upon the size of standing soil C stocks and the extent and duration of warming(Crowther *et al.*, 2016). The interaction between 'control C stocks' and 'degree-years' (the standardised metric to represent the extent (°C) and duration (years) of warming) in explaining warmed soil C stocks was a strong explanatory variable when predicting final warmed C stocks(Crowther *et al.*, 2016). Specifically, the impacts of warming were negligible in areas with small initial C stocks, but losses occured beyond a threshold of 20 – 40 kg C m-3 and were considerable in soils with ≥ 60 kg C m-3 (Figure 1). No other environmental characteristics (mean annual temperature, precipitation, soil texture or pH) significantly ($P > 0.1$) affected the responses of soil C stocks to warming in our statistical models(Crowther *et al.*, 2016).

DISCUSSION

The dominant role of standing C stocks in governing the magnitude of warming-induced soil C losses fits with expectations from previous empirical and theoretical research(Carey *et al.*, 2016; Jones *et al.*, 2013; Serreze and Barry, 2011). The temperature-sensitivity of soil microbes is known to be highest in cold regions(Carey *et al.*, 2016; Crowther and Bradford, 2013), where limited C decomposition has led to the accumulation of large C stocks. The thawing of permafrost soils, is likely to contribute to this phenomenon. However, our analysis also revealed considerable C losses in ligh-latitude non-permafrost regions, suggesting that additional mechanisms may contribute to the large soil C losses in those regions. In these areas, warming drives an imbalance between soil C inputs (photosynthesis) and outputs (respiration). That is, in ecosystems with lowstanding soil C stocks, minor losses that result from accelerated decomposition under warming may be offset by concurrent increases in plant growth and soil C stabilization(Bradford *et al.*, 2016; Day, Ruhland and Xiong, 2008; Macias-Fauria *et al.*, 2012). In contrast, in areas where the soil initially stores a greater amount of carbon, the change in decomposition outpaces that of photosynthesis, causing net C losses into the atmosphere.

By combining our measured soil C responses with global maps of standing C stocks(Hengl *et al.*, 2014) and soil surface temperature change(Meehl *et al.*, 2013), we reveal the global patterns in the vulnerability of soil C stocks (Figure 2). Given that high-latitude regions have the largest standing soil C stocks(Hengl *et al.*, 2014) and the fastest expected rates of warming(Meehl *et al.*, 2013; Serreze and Barry, 2011), our results suggest that the overwhelming majority of warming-induced soil C losses are likely to occur in Arctic and sub-Arctic regions (Figure 3). These high-latitude C losses drastically outweigh any minor changes expected in mid- and lower latitude regions, providing additional support for the idea of Arctic amplification of climate change feedbacks(Serreze and Barry, 2011). These warming-induced soil C losses need to be considered in light of future changes in moisture stress and vegetation growth, which are also likely to increase disproportionately in high-latitude areas(Serreze and Barry, 2011).

We extrapolated the observed relationship over the next 35 years to indicate how global soil C stocks might respond by 2050. If we make the conservative assumption that the full effects of warming are fully realized within a year, our extrapolation suggests that approximately 30 (± 30) Pg C would be lost from the surface soil for 1 degree (ºC) of warming. Given that global average soil surface temperatures are projected to increase by ~2 ºC over the next 35 years under a business-as-usual emissions scenario16, this extrapolation would suggest that warming could drive the net loss of ~55 (± 50) Pg C from the upper soil horizon. If, as expected, this C entered the atmospheric pool, this would increase the atmospheric burden of CO_2 by approximately 25 ppm over this period. The estimated losses represent a warming-induced carbon loss of approximately 1.57 Pg C per year over that period. This value represents approximately 12–17 per cent of the expected anthropogenic emissions over this time.

Incorporating these data into ESMs to constrain our projections of soil C stock changes over the rest of the century. Once we can understand future soil C sequestration we will be able to establish effective conservation targets in the fight against climate change. For example, if global soil C stocks fall by 1.5 Pg C per year over the rest of the century, we know that efforts to increase global soil C sequestration by 1 Pg C per year will be insufficient. This would suggest that increased funding will be necessary to increase the scale and scope of such efforts, particularly in the high-latitude regions of the world. Of course, our estimates only address the impacts of warming - considerable additional research is necessary to understand these results in light of the many other global change drivers that will interactively influence soil C stocks over the rest of the century.

CONCLUSIONS

Our global analysis of experimental data allows us to see past the contradictory results in previous single-site studies in order to detect larger patterns in the sensitivity of soil C to warming. The measured changes in soil C stocks suggest that, at a global scale, warming generally stimulates decomposition more than photosynthesis. These observations can augment modeling efforts to project Earth system dynamics into the future. Ultimately, our analysis provides conclusive empirical support for the long-held concern that rising temperatures stimulate the loss of soil C into the atmosphere, driving a positive land C-climate feedback that will accelerate planetary warming over the 21st century. Minimizing increases in soil temperature using effective land management strategies (i.e. increasing vegetation cover) may be an effective means of limiting these soil C losses. Continued research to understand how the other global change drivers interactively affect global soil C stocks will be necessary if we are to establish meaningful policy or conservation targets in the fight against rizing atmospheric CO_2 concentrations.

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Figure Legends

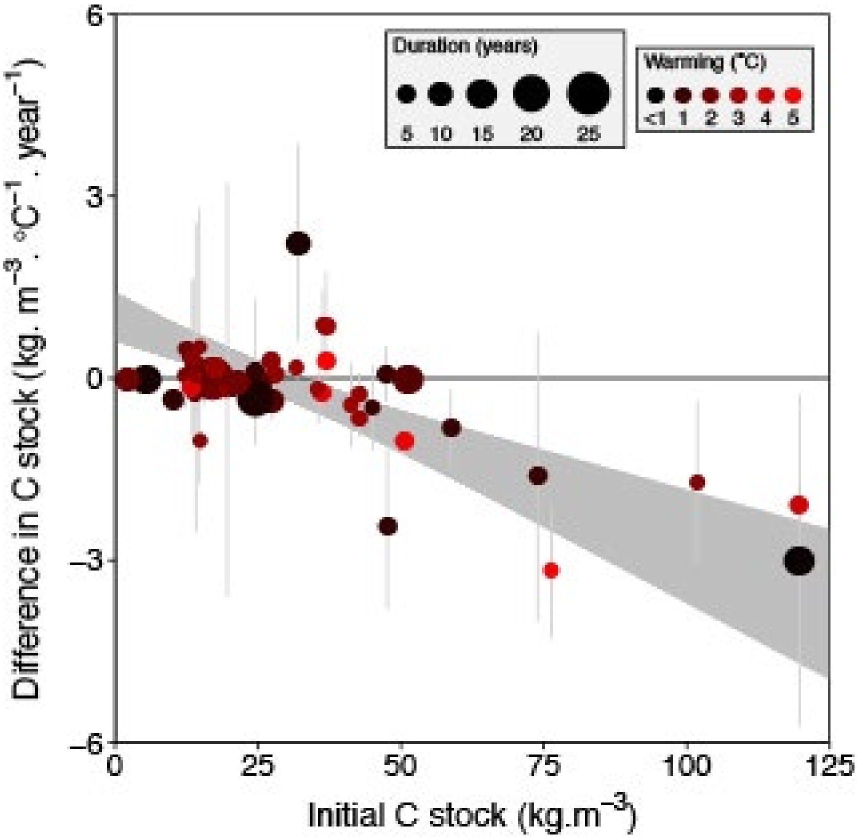

Figure 1: Initial soil C stock determines the effects of warming on soil C stocks.

Each point represents the difference (mean±SE) between soil C stocks in warmed and ambient plots within an individual experiment. The size of the points indicates the length of each study, and the colour highlights the extent of warming. The bootstraped 95% conficence interval is represented by the shaded area represents (Figure modified from Crowther et al. 2016(Crowther *et al.*, 2016). See full paper for details).

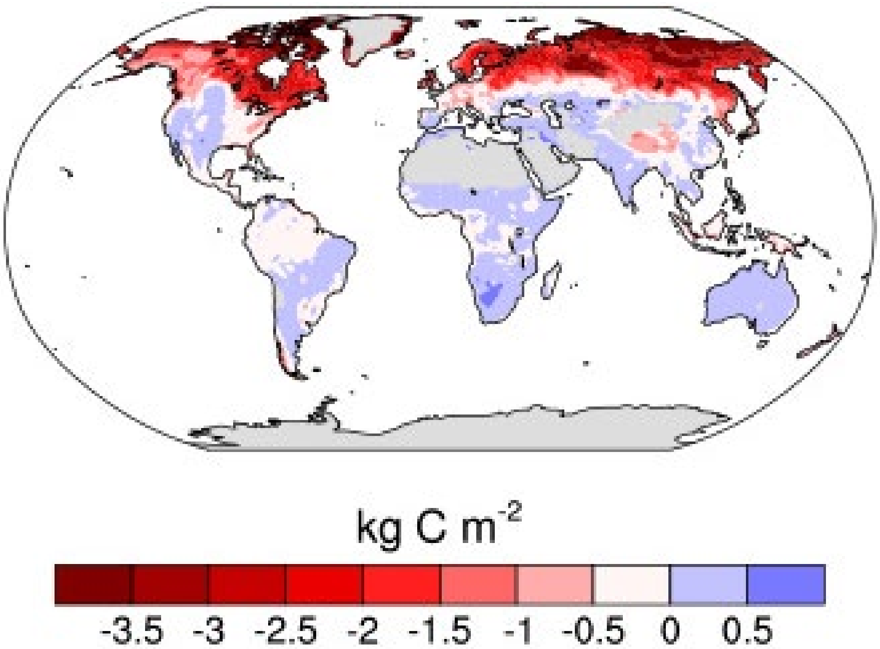

Figure 2: Spatial map of the temperature-sensitivity of soil C stocks.

The map reveals the spatial variation in projected surface soil C stock changes (0-15 cm) expected under a 1°C rise in global average soil surface temperature. (Figure modified from Crowther et al. 2016(Crowther *et al.*, 2016). See full paper for details).

K.2 | SOIL ORGANIC CARBON SEQUESTRATION: IMPORTANCE AND STATE OF SCIENCE

Rattan Lal[1*]

1[C-MASC, The Ohio State University, lal.1@osu.edu, 2021 Coffey Road, Columbus, OH 43210]

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Management of soil carbon (C), increasing and sustaining concentration and stock with a long mean residence time (MRT), is important to addressing pertinent global issues of the 21st century: adapting and mitigating climate change, advancing food and nutritional security, improving quality and renewability of water, increasing biodiversity etc. Soil C stock consists of two components (Fig.1): soil organic C (SOC) and soil inorganic C (SIC). SOC, a component of soil organic matter (SOM); is a heterogeneous pool of C comprising of diverse materials including fresh litter, microbial biomass C (MBC) and products of microbial and other biotic processes such as humic substances; and simple compounds such as sugar and polysaccharides (Jansson *et al*., 2010). The SOC fraction is highly dynamic and strongly impacts soil health and its functionality. Depending on the land use and management, there may be a critical/threshold range of SOC concentration in the root zone below which use efficiency of inputs and agronomic productivity may decline. The critical range may differ among soil types, eco-regions, land use, farming systems and the management. Being a dynamic and a reactive fraction, SOC is a strong determinant of soil health and productivity through its impact on soil structure, bulk density, porosity and pore size distribution, water retention and transmission, heat capacity and soil temperature regime, MBC, and activity and species diversity of soil biota (Lal, 2016). The SOC fraction and its dynamics also impact exchange of greenhouse gases (GHGs) between soil and the atmosphere with the attendant impacts on climate change (IPCC, 2014; Melillo *et al*., 2014). In contrast, the SIC fraction is rather stable, less reactive, has a long MRT, and consists of two related but different components: lithogenic and pedogenic carbonates (Fig.1). Lithogenic carbonates are derived from the weathering of parent rock and pedogenic from dissolution of CO_2 to from carbonic acid and its reaction with cations (Ca2+, Mg2+) in the soil solution to form carbonates. SOC sequestration is defined as the process of transferring CO_2 from the atmosphere into the soil of a land unit plants, plant residues and other organic solids which are stored or retained in the unit as a part of the SOM with a long MRT (Olson *et al*., 2014). Accepting this definition implies that the following processes and activities do not result in a net SOC sequestration and are merely redistribution of C over the landscape: deposition/burial of C by erosion, land application of C-enriched amendments (e.g., biochar, compost, manure, mulch) and the burial of biomass in deep mines or ocean floor when the C-enriched materials are brought in from outside the land unit (Olson *et al*., 2014). In addition to formation of secondary carbonates, leaching of bicarbonates also leads to sequestration of SIC (Monger *et al*., 2014), which is an important process in soils of arid and semi-arid regions.

With a strong interest of scientists, policymakers, and land managers in enhancing and sustaining SOC stock for adaptation/mitigation of climate change and advancing food/nutritional security, the objectives of this articles are to: (1) deliberate those processes, factors and causes which strongly impact SOC concentration, stock, and MRT, (2) describe soil properties and landscape factors which enhance SOC sequestration, and (3) identify land use, management and policy options to sequester SOC for delivery of ecosystem services of interest to human wellbeing and nature conservancy. These objectives will be realized by testing the hypothesis that: (i) creating a positive soil C budget by adopting site-specific land use and management practices can lead to SOC sequestration, (ii) the rate and magnitude of SOC sequestration depend on key soil profile characteristics (e.g., texture, mineralogical composition, soil depth, moisture and temperature regimes, and iii) increasing SOC concentration to the critical/threshold level enhances agronomic productivity and use efficiency of inputs as ancillary to adaptation and mitigation of climate change.

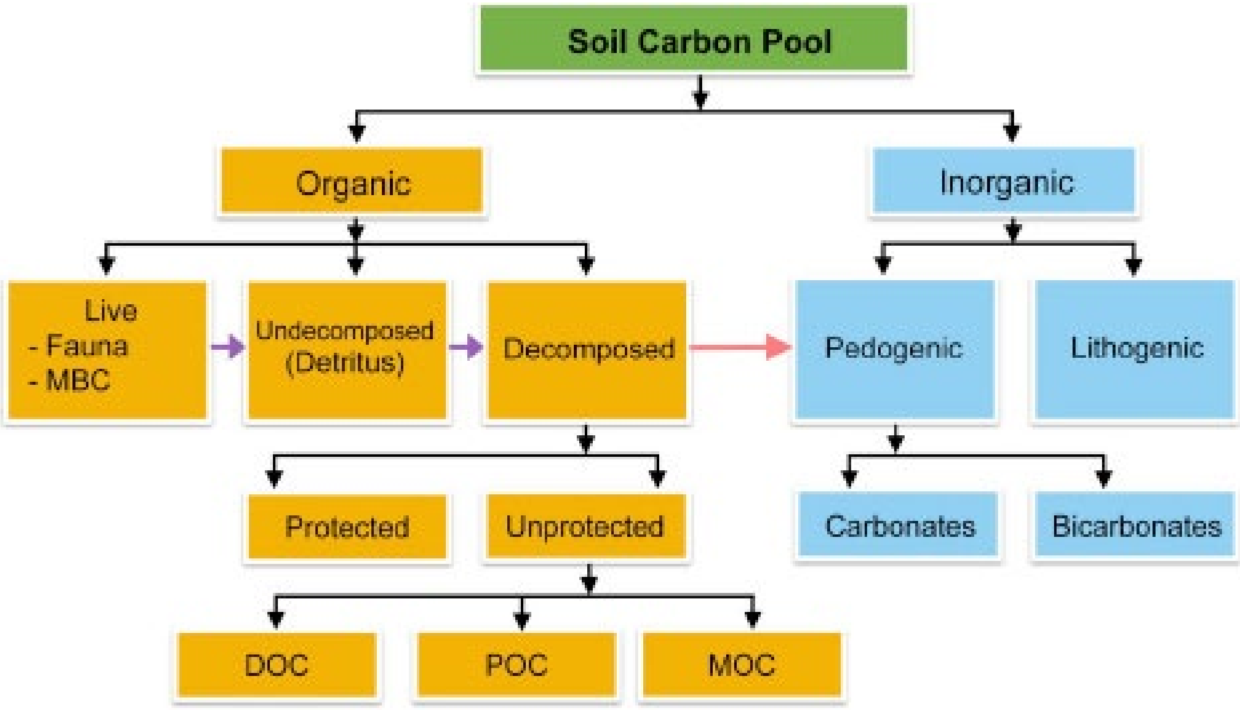

Fig.1: Constituents of soil carbon pool.

METHODOLOGY

A Process, Factors and Causes

The strategy of SOC sequestration is to create a positive soil C budget for specific land use and management systems such that input or biomass C (both above and below ground) by plants growing on the land unit exceeds the losses of SOC through erosion, oxidation/mineralization and leaching. Additionally, the biomass-C added must be protected against microbial attack (decomposition) and processes that lead to physical removal (e.g., erosion and leaching). Thus, SOC sequestration is caused by increase in input of biomass-C through photosynthesis, its conversion into humic substances and protection against biotic and abiotic reactions. Processes, causes and factors affecting SOC sequestration are outlined in Table 1. Processes (mechanisms) of SOC sequestration include: (1) photosynthesis and the net primary productivity (NPP), (2) humification or conversion of biomass-C into SOM through enrichment of N, P, S and other elements (Lal, 2014), (3) aggregation and aggregate stabilization through formation of organo-mineral complexes, and 4) illuviation of dissolved (DOC) and particulate organic C (POC) into sub-soil horizons. Factors of SOC sequestration are soil, climate and landscape parameters which impact the rate and capacity of principal processes. These include soil texture (clay plus silt contents), mineralogical composition, soil moisture and temperature regimes as regulated by climate and landscape position along with slope gradient and aspect, vegetation cover, input of biomass-C and the proportion of belowground biomass, activity and species diversity of soil biota (macro, meso, and micro). Causes of SOC sequestration and its fate are anthropogenic activities including land use, farming/cropping systems, adoption of recommended management practices (RMPs), tillage methods, conservation-effective measures, use of organic and inorganic amendments etc.

Processes (Mechanisms)	Factors (Environment)	Causes (Anthropogenic Activities)
Photosynthesis and NPP, distribution of biomass in above- and below-ground components, structure or organic substances **Humification** of biomass-C by its enrichment with N, P, S and other elements through biogeochemical and biogeophysical transformations **Aggregation** and their stabilization through formation of organo-mineral complexes by absorption on reactive clay surfaces. **Illuviation** and translocation of SOC into sub-soil horizons	**Climate**: Precipitation, evaporation, temperature, growing season duration, the number of frost-free days. **Soil**: Texture, structure, clay minerals, pH, CEC, salinity, elemental balance, biotic activity and diversity, solum depth, water table. **Landscape**: slope length, steepness, aspect, shape, drainage density, internal drainage. **Vegetation**: groundcover, biomass (above- and below-ground) species diversity.	**Land use**: Natural, agricultural, urban, plantations, recreational. **Farming systems**: traditional, commercial, cereals, livestock, agroforestry, rotations, mechanisms, varieties. **Tillage**: Conservation agriculture, traditional residue management **Water management**: Drainage, irrigation, fertigation, DSI, water harvesting. **Nutrient management**: Rate and formulation of fertilizers, BNF, INM, mycorrhizal inoculation, amendments, liming, biochar, compost. **Pest Management**: IPM, pesticide rate and formulation.

Table 1: Processes, factors and causes affecting SOC sequestration

Plant Functional Attributes for SOC Sequestration

The primary process of SOC sequestration is photosynthesis and the NPP. Therefore, SOC depends on the rate of C assimilation by the plant species growing on a specific landscape unit. The NPP is the difference between gross primary productivity (GPP) and the autotrophic (plant) respiration (R_a). The net ecosystems productivity (NEP) is GPP minus R_a and the heterotrophic (microbial) respiration (R_h), and comprises of both the above- and below-ground components. The net biome productivity (NBP) is NEP minus the losses of C by erosion, fire, harvesting, etc. (Jansson *et al*., 2010). Root architecture, depth distribution and size of roots, is also an important aspect of SOC sequestration. In addition, presence of recalcitrant aliphatic compounds (macro molecules), and phytoliths (occluded C) in cereals also affect SOC sequestration.

The Priming Effect

It refers to the enhanced or retarded rate of SOM decomposition due to addition of fresh biomass-C or mineral-N. Large amounts of C, N and other nutrients can be released or immobilized over a short-time by microbial activities. The priming effect is attributed to: (i) interactions between different qualities of biomass, and (ii) interaction between living and dead organic matter. There is a wide range of factors which influence the priming effect: (i) effects of macro-organisms or micro-flora, and (ii) impact of the strategies of nutrient management (e.g., INM). Therefore, availability of plant nutrients, in addition to that of the biomass-C, is essential to humification of cellulosic material. In comparison with crop residues, humus is enriched in N (C:N ratio of 12 vs. 100), P (C:P ratio of 50 vs. 200) and S (C:S ratio of 70 vs. 500). Thus, availability of additional nutrients is essential to SOC sequestration (Lal, 2014).

Soil Attributes Affecting SOC Sequestration

Important soil attributes affecting the rate and sink capacity have been listed in Table 1. The soil C sink capacity also depends on the historical land use, the severity of soil degradation and the magnitude of depletion of SOC since conversion of a natural into managed ecosystem. Severely eroded and depleted soils have a higher SOC sink capacity than slightly or uneroded phases.

Ramifications of Coupled Cycling of Carbon With Other Elements

In nature, everything is connected to everything else (Muir, 1911; Commoner, 1971). Thus, cycling of C is intricately linked to that of H_2O, N, P, S and other elements (Lal, 2010). It is the coupling of biogeochemical and bio-geophysical cycles that leads to delivery of essential ecosystem services (e.g., C sequestration, climate moderation NBP, Water quality, biodiversity). However, mismanagement-induced disruption of these cycles have numerous adverse consequences and trade offs. Notable among the adverse ramifications are: gaseous emissions of N_2O and CH_4, leaching of NO_3, or NH_3, changes in SIC and N, and reduced net sequestration of SOC.

Mechanism of Stabilization of SOC

Diverse mechanisms of protection of SOC, that prolong its MRT, are listed in Fig.2. Important among these are physical, chemical, biochemical and ecological. It is now widely recognized that physical access rather than molecular structure is the important factor affecting MRT. Indeed, SOC concentration is an ecosystem property (Schmidt *et al*., 2011), and the molecular structure alone does not control SOM stability. The environmental and biological controls are predominant determinants (Schmidt *et al*., 2011). Therefore, management (soil, plants, animals, nutrients, water, tillage, residues, cover crops, phyto-engineering) are major factors affecting MRT, rate of sequestration and feedback to climate change (Lal, 2004; 2010).

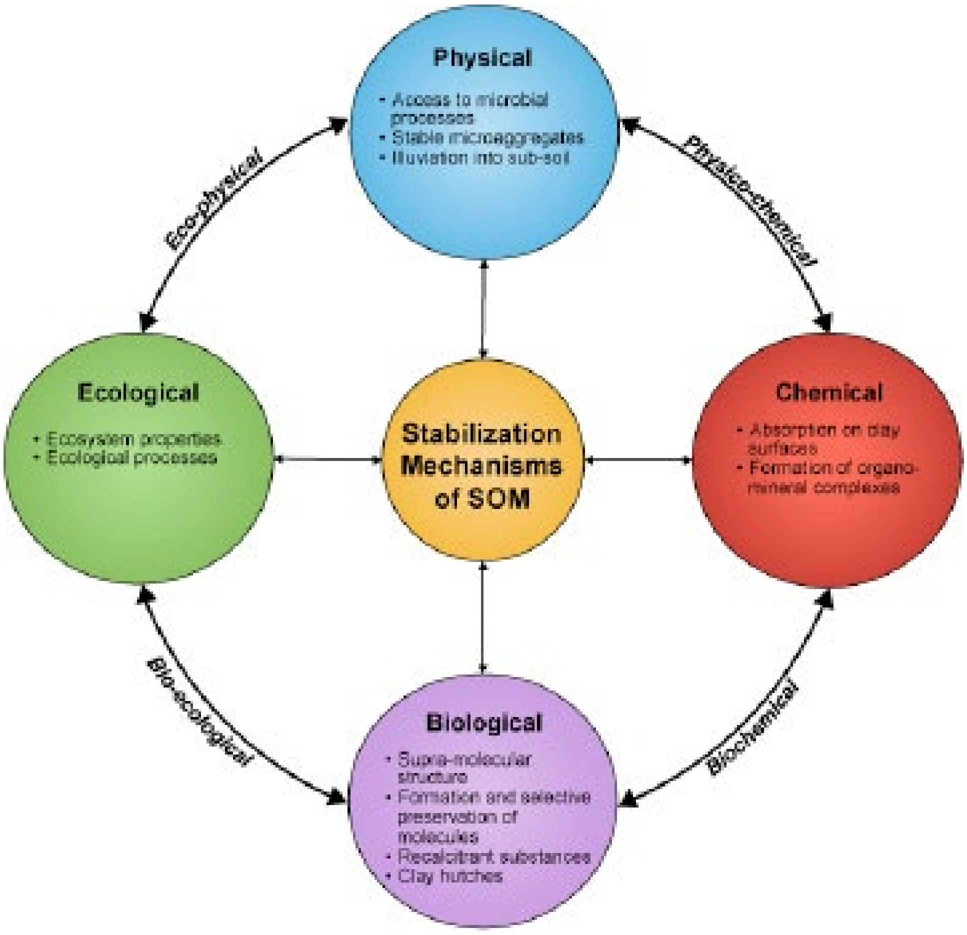

Fig.2: A wide range of mechanisms of stabilization of soil organic matter.

Temperature-Dependence of the Decomposition Process and Feedback to Climate Change

The rate of decomposition of SOM increases with an increase in temperature, especially when substrate availability and enzyme activity do not constrain the reaction rate (Davidson and Janssens, 2006). Further, the rate of increase with the increase in temperature is more in colder than in warmer climates (Kirschbaum, 1995). The decomposition reactions with high activation energy (i.e., slow rate) will experience greater temperature-sensitivity than those with low activation energy (i.e., faster rate). Therefore, the projected global warming may accelerate the rate of decomposition of recalcitrant materials resulting in a large loss of SOC stock and a strong positive feedback. However, the decomposition rate of SOM also depends on the accessibility (Dungait *et al*., 2012), the physiology of the microfauna (von Lützow *et al*., 2009), and the ecosystem properties (Schmidt, 2011).

The projected increase in temperature may affect decomposition of the large SOC stock (1672 PgC) in Cryosols (Tanocai *et al*., 2009). There are possibilities that thawing of permafrost may accentuate mineralization even of older and recalcitrant SOM (Nowinski *et al*., 2010). However, formation of pedogenic carbonates (Strigel *et al*., 2005) and enhanced aggregation in active layer (Schmidt *et al*., 2011) may stabilize the SOM stock.

CONCLUSIONS

- The global SOC stock plays an important role in the global C cycle, and soils can be source or sink of CO_2 and other GHGs depending on land use and management.
- Increase in SOC concentration to above the threshold level has numerous co-benefits such as increase in food and nutritional security through improvements in soil health and the attendant increase in use efficiency of inputs (e.g., fertilizer, water, energy).
- The SOC sink capacity depends on the historic land use, and severity of degradation, profile properties (silt+clay content, mineralization, depth, etc.), and vegetation characteristics.
- The SOC stock is stabilized by a range of protection mechanisms (e.g., physical, chemical, biological, ecological), and it is an ecosystem property.
- Increase in temperature by the projected global warming may increase the rate of decomposition, leading to a positive feedback to climate change. The temperature-sensitivity may be specifically high for the large SOC stock of Cryosols (1672 PgC). However, there are numerous counteracting mechanisms and the temperature-sensitivity is a complex process.
- Sequestration of SOC is a win-win option: it mitigates climate change, improves the environment and advances food and nutritional security. It is a bridge to the future until no-C or low-C fuel sources take effect.

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K.3 | LAND DEGRADATION AND RESTORATION ASSESSMENT OF THE INTERGOVERNMENTAL PLATFORM ON BIODIVERSITY AND ECOSYSTEM SERVICES (IPBES)

Anne Larigauderie*[1]

[1]IPBES, secretariat@ipbes.net

ABSTRACT

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is the intergovernmental body (with 126 government members), which assesses the state of biodiversity and of the ecosystem services it provides to society, in response to requests from decision makers. Acting upon one such request, IPBES has initiated a thematic assessment on Land Degradation and Restoration in 2015 involving about 100 experts from all regions of the world. This expert-led assessment will provide the information and guidance necessary to support stakeholders working at all levels to reduce the negative environmental, social and economic consequences of land degradation and to rehabilitate and restore degraded land to aid the recovery of nature's benefits to people. It will draw on information from scientific, indigenous and local knowledge systems to increase awareness and identify areas of concern. It will help to identify potential solutions to the challenges posed by land degradation, informing decision makers in public, private and civil society sectors.

Keywords: biodiversity, ecosystem services, ecosystem functions, land degradation, land restoration

EXTENDED ABSTRACT
INTRODUCTION TO IPBES

Overall presentation

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is the intergovernmental body (with 126 government members), which assesses the state of biodiversity and of the ecosystem services it provides to society, in response to requests from decision makers. IPBES has a collaborative partnership agreement with four United Nations entities: UN Environment, UNESCO, FAO and UNDP and is administered by UN Environment. Its secretariat is hosted by the German government and located on the UN campus, in Bonn, Germany. One thousand scientists from all over the world currently contribute to the work of IPBES on a voluntary basis. They are nominated by their government or an organisation, and selected by the Multidisciplinary Expert Panel, the scientific body of IPBES appointed by the Plenary. Peer review forms a key component of the work of IPBES to ensure that a range of views is reflected in its work, and that the work is completed to the highest scientific standards.

IPBES Functions

IPBES engages scientists and other knowledge holders around the world to review and assess the most recent scientific and technical information produced worldwide in relation with biodiversity and ecosystem services. The work of IPBES is centered around four complementary core functions:

1. Assessment – Deliver global, regional and thematic assessments of knowledge regarding biodiversity and ecosystem services
2. Knowledge generation catalysis – Identify knowledge gaps, and catalyze efforts to generate new knowledge
3. Policy Support Tools – Identify policy relevant tools/methodologies, facilitate their use, and promote and catalyse their further development
4. Capacity Building - Increase capacity at different levels: for example, strengthen the capacity of the scientific community to contribute to IPBES (e.g. the early career fellows programme) and strengthen the capacity of policymakers to use assessments and other products of IPBES (e.g. science-policy dialogues between experts and Governments)

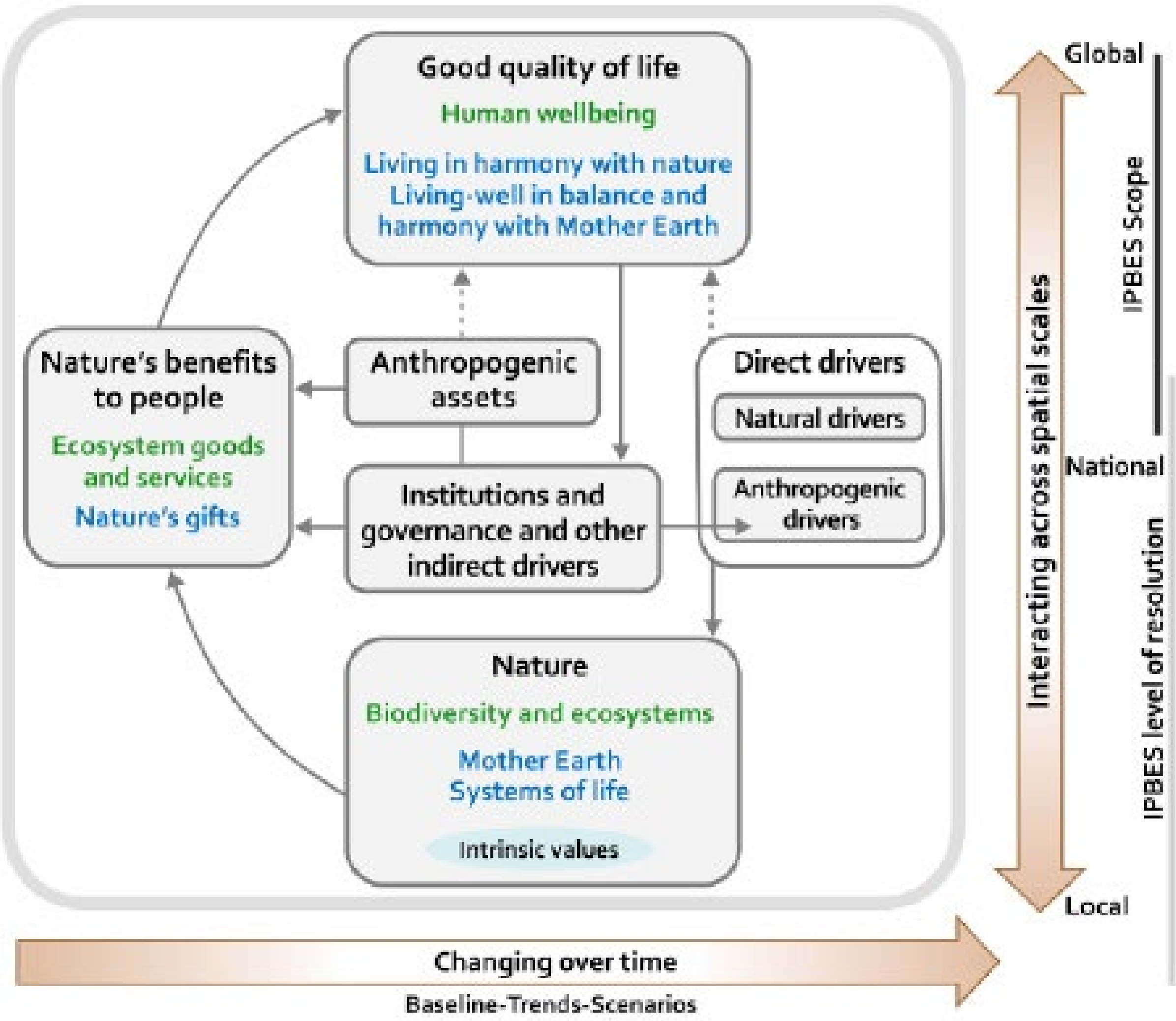

Fig. 1: Conceptual Framework of IPBES work, which acts as a guiding principle for past and ongoing assessments (Díaz et al. (2015) "A Rosetta Stone for Nature's Benefits to People." PLOS Biology 13: 1)

IPBES ASSESSMENTS

The first two assessments of IPBES have been approved at the fourth session of its Plenary in February 2016, namely, the methodological assessment of *Scenarios and Models of Biodiversity and Ecosystem Services* and the thematic assessment of *Pollinators, Pollination and Food Productions*. The latter, especially, has generated significant media coverage and catalyzed action in the political sphere (e.g., formation of a "Coalition of the Willing" by a growing number of governments to protect pollinators and to promote pollination; incorporation of assessment findings into national strategies in a growing number of countries; decision made by COP13 of the Convention on Biological Diversity (decision XIII/15) on the implication of the IPBES assessment on pollinators for the work of the convention).

Aside from the two completed assessments, there are currently six ongoing IPBES assessments:

- Four regional assessments on biodiversity and ecosystem services (due to be considered by the IPBES-6 Plenary in March 2018):
  - Africa
  - Americas
  - Asia-Pacific
  - Europe and Central Asia
- One thematic assessment on land degradation and restoration (due at IPBES-6 Plenary in March 2018)
- One global assessment on biodiversity and ecosystem services (due at IPBES-7 Plenary in May 2019)

THE IPBES LAND DEGRADATION AND RESTORATION ASSESSMENT

Overall presentation

The thematic assessment on Land Degradation and Restoration has been undertaken in response to a request from the IPBES Plenary, originating from requests made to IPBES by several multilateral environmental agreements (CDB, UNCCD), several governments and several non-governmental stakeholders. At the second session of the IPBES Plenary, held in Antalya, Turkey (9-14 December 2013), member States approved the initiation of scoping for that assessment. Accordingly, a scoping report was developed by an expert group, containing a chapter outline for the assessment, a timeline and a budget. Following the approval of that scoping document, the Plenary approved the undertaking of the assessment on land degradation and restoration for consideration by the Plenary at its sixth session (March 2018).

Composition of the expert group

A group of 86 experts composed of 2 co-chairs, 18 coordinating lead authors (CLAs) and 66 lead authors (LAs) was selected, from nominations received from governments and other stakeholder, by the Multidisciplinary Expert Panel (MEP). Once selected on merit, further selection was focused on balancing disciplinary, regional and gender diversity.

Outline of the assessment

The assessment will be presented in a summary for policymakers and an eight-chapter report (Table 1). Each chapter will have an executive summary, which will present key findings and policy-relevant conclusions.

Chapter 1	**Benefits to people from avoidance of land degradation and restoration of degraded land.** This chapter will present a brief summary of the benefits to human well-being and quality of life that can be achieved by the halting, reduction and mitigation of degradation processes as well as the restoration of degraded land, highlighting examples of success stories of how land conservation and restoration measures have helped to deliver improvements in livelihoods, reduce poverty and strengthen the long-term sustainability of land use and the extraction of natural resources.
Chapter 2	**Concepts and perceptions of land degradation and restoration.** This chapter will focus on assessing and comparing differing concepts and perceptions of land degradation and restoration, stemming from both science and other knowledge systems, including indigenous and local knowledge.
Chapter 3	**Direct and indirect drivers of land degradation and restoration.** This chapter will assess how land degradation and restoration are the result of multiple drivers, involving both direct anthropogenic and natural factors and interactions between them, as well as underlying indirect drivers. The assessment of direct drivers will include anthropogenic drivers at global, national, regional and local scales, including human-driven climate change, as well as natural drivers and interactions between anthropogenic and natural drivers. Particular attention will be paid to climate change and its interaction with other anthropogenic drivers of land degradation, including interactions between processes of land degradation and extreme weather events.
Chapter 4	**Status and trends of land degradation and restoration and associated changes in biodiversity and ecosystem functions.** The chapter will assess levels of land degradation and restoration with regard to the type, extent and severity of changes in both biodiversity and ecosystem structure and functioning in different biomes and under different land-use and management systems. Changes in biodiversity include changes to both wild biodiversity and agrobiodiversity, including both above-ground and below-ground biodiversity. Changes in ecosystem structure and functioning include aspects such as primary productivity, nutrient cycling and the provision of habitat for species. Particular attention will be given to understanding system resilience (capacity to recover systems structure and functions following a perturbation), including the potential for thresholds and sudden changes in key attributes of biodiversity and critical ecosystem functions.

Chapter 5	**Land degradation and restoration associated with changes in ecosystem services and functions and human well-being and good quality of life**. This chapter will focus on the impact of land degradation and restoration on changes to the delivery of nature's benefits to people and the resultant impact on quality of life. The impact on the diverse dimensions of a good quality of life will include the impact on health, poverty, income-generating opportunities, meaningful livelihoods, the equitable distribution of natural resources and rights and values considered important in different cultures. The chapter will consider the diverse costs of land degradation and benefits of restoration for people, including the overall economic and non-economic costs and benefits, encompassing those that are associated with the area of degraded or restored land itself, as well as costs or benefits borne by people in other areas who are affected by degraded or restored sites.
Chapter 6	**Responses to avoid land degradation and restore degraded land.** This chapter will develop a framework for assessing the effectiveness of existing interventions to prevent, halt, reduce and mitigate the processes of land degradation and to rehabilitate and restore degraded land through the recovery of biodiversity and ecosystem structure and functioning and their benefits to people. The chapter will assess how past and current responses to degradation problems and restoration approaches vary according to context, including the type and severity of land degradation and underlying direct and indirect drivers, as well as the consequences of land degradation and the restoration for nature's benefits to people and quality of life. It will assess the relative success or failure, as well as the potential risks, of different institutional, governance and management response options against a range of social, cultural, economic, technological and political criteria.
Chapter 7	**Scenarios of land degradation and restoration.** This chapter will explore the implications of a range of plausible development scenarios, including the adoption of different response options across multiple scales, and their implications for land degradation and restoration globally, including impacts on human well-being and quality of life and possible trade-offs between social, economic and environmental objectives.
Chapter 8	**Decision support to address land degradation and support restoration of degraded land.** This chapter will consolidate and rationalize information necessary to support evidence-based decision-making and institution-building for policymakers and practitioners responsible for selecting and implementing strategies for addressing land degradation problems and restoring degraded land. The chapter will assess actions necessary to develop institutional competencies in the detection and analysis of land degradation problems and the design, implementation, management and monitoring of response strategies, including data, methods, decision support tools and stakeholder engagement.

Table 1: Outline of the 8 chapters of the Land Degradation and Restoration Assessment

THE PHASES OF THE ASSESSMENT

The expert group works mostly by virtual means with the exception of three in-person author meetings. The main phases of the assessment are outlined below:

Sept 2015	First author meeting
Jun – Jul 2016	First external review by experts of the First Order Draft of the chapters
Aug 2016	Second author meeting
May – Jun 2017	Second external review by governments and experts of the Second Order Draft of the chapters and the First Order Draft of the Summary for Policymakers
July 2017	Third author meeting
Aug – Nov 2017	Revision and finalization of the chapters and Summary for Policymakers
March 2018	6th session of the IPBES Plenary to approve/accept the land degradation and restoration assessment, including its summary for policymakers

UPCOMING OPPORTUNITIES TO CONTRIBUTE TO THE ASSESSMENT

One of the most important phases in drafting assessments is the period in which they are opened for external review by any interested expert, ranging from scientists and decision-makers, to practitioners and the holders of indigenous and local knowledge. From **1 May to 26 June 2017**, the Second Order Draft of the chapters of the assessment and the First Order Draft of its Summary for Policymakers will be open for review by expert and governments.
Further information on how to register for external review can be found here: *http://www.ipbes.net/article/external-review-ipbes-assessments-governments-and-experts*

K.4 | ESTIMATING SOIL ORGANIC CARBON CHANGES: IS IT FEASIBLE?

Eleanor Milne[1*], Mark Easter[1] and Keith Paustian[1]

[1]The Natural Resource Ecology Laboratory, Colorado State University (CSU)

* Email: eleanor.milne@colostate.edu

ABSTRACT

This presentation asked whether estimating SOC changes is feasible by considering work from the Natural Resource Ecology Laboratory, Colorado State University, over the past 15 years. Firstly, what can be done when you have good data and an appropriate model (a model developed for the specific conditions you are working in), was considered - COMET Farm, which uses the Daycent model. The second example looked at what can be done in areas without comprehensive data sets and models developed for their specific conditions (the case in many developing countries). This example considered the GEFSOC system which links Century to a geographical information system. Application of models developed in temperate conditions to non-temperate areas requires model parameterization using long term experiments. The last example therefore considered what is feasible when you have less data and no time/data to parameterise and validate models. This example considered non-dynamic 'calculators' based on the IPCC method (such as the Carbon Benefits Project tools). Finally, review work in Sub-Saharan Africa was used to illustrate the fact that even if we have complete data and fully parameterised models there are still many areas of the world where we have gaps in our understanding of C sequestration potential.
Keywords: Soil organic carbon changes, models, The Carbon Benefits Project

EXTENDED ABSTRACT

INTRODUCTION

This presentation asked whether estimating changes in soil organic carbon (SOC) is feasible by considering work from the Natural Resource Ecology Laboratory, Colorado State University (CSU) over the past 15 years (the length of time the lead author has been associated with the institution). The ability to estimate change in SOC depends on the following:

1. The availability of data for soils, climate, land use and land management (both historical and current) for the scale you are working at.
2. The availability of suitable models or methods for the land use and management systems you are considering.
3. The level of uncertainty you are willing to accept in the estimate you produce. The level that is acceptable, depends on the purpose for which the estimate is being made for example estimates produced for a C market require less uncertainty than estimates made to report to funding bodies.

In turn, all of these factors depend on where in the world you are working. Typically, most models were originally developed for temperate areas and data sets tend to be more comprehensive for temperate areas.

WHAT CAN BE DONE WHEN YOU HAVE GOOD DATA AND AN APPROPRIATE MODEL

The first example considered what can be done when you have comprehensive data and a model which has been developed for the specific conditions you are working in. COMET Farm is a web based system which allows farmers in the US to make assessments of the net GHG effects of activities over time (Paustian, 2012). The tool works at the farm scale and estimates changes in SOC using the Daycent model (Del Grosso et al. 2001). The system uses comprehensive soils and climate data that is available for the US (SSURGO and NARR respectively) and draws on 4 main sources of information for historical land use and management practices in any given region. This allows the system to account for the impacts of land use history on SOC estimates. The user only has to input information on recent and projected land use/management. This example shows that with good data and models, it is possible to build a cutting edge system where farmers can click on a button and get a reasonable estimate of how SOC would change on their farm if they change management practices.

WHAT CAN BE DONE IN AREAS WHERE DATA IS LIMITED?

The second example looked at what can be done in areas without comprehensive data sets and models developed for their specific conditions (the case in many developing countries). One approach is to assemble the necessary data sets and parameterise the models using long term experimental or chronosequence data. This approach was taken in the GEFSOC project (Easter et al, 2007; Milne et al 2007), which linked Century and other models to a geographical information system. The system was developed using 4 case studies in non-temperate areas; the Brazilian Amazon, Jordan, Kenya and the Indo-Gangetic plains in India. The GEFSOC system requires monthly climate data, a soils map which includes soil type (sand/silt/clay fraction + bulk density), land use history going back 100 yrs if applicable or to the time of land use change from native vegetation and native vegetation type. To parameterise the models, long term experiments or chronosequence data are needed which have information on the same parameters. The approach can be time consuming but can ultimately give spatially explicit, relatively accuarte estimates of SOC change over time.

NON-DYNAMIC APPROACHES

The last example therefore considered what is feasible when you don't have LTEs or chronosequence data to parameterise the models, you don't have information on landuse transitions and you don't have the data sets needed to run the models. This may be the case if you are reporting SOC changes as part of a sustainable land management or other type of project where there is no access to teams with expertise in ecosystem modeling and/or model parameterisation. One option is to take a computational approach based on the IPCC method using the land use and management information available. There are several 'calculators' which do this. The Carbon Benefits Project (CBP) tools provide two examples of these types of calculators, the Simple Assessment (SA) and the Detailed Assessment (DA) (www.unep.org/CBP_PIM/). Both the SA and the DA are online tools aimed at landscape scale assessments of NET GHG balance including estimates of SOC stock change. They take no account of land use history so doesn't capture long term dynamic changes. However, they are simple to use and just require the user to input land use and management information. Soils and climate default data layers are provided. The CBP has a spatial element, so the first step is for the user to designate polygons or points on a map. Spatially explicit SOC changes are then produced for different land use and management scenarios determined by the user. In the SA the users chooses land use and management options from pre-populated menu's and uses Tier 1 default stock change and emission factors. In the DA the user can develop their own land use (crop, grass and forest etc.) types and systems and input their own factors. The CBP tools were originally developed for Global Environment Facility (GEF) projects but can be used by any land management projects.

GAPS IN OUR UNDERSTANDING OF C SEQUESTRATION POTENTIAL

Even if we have complete data sets and fully parameterised models there are still many areas of the world where there are gaps in our understanding of C sequestration potential which limits the feasibility of making accurate estimates of SOC change. A recent review of C sequestration potential in grazing lands in Sub-Saharan Africa provided an example of this (Milne et al. 2016). For grasslands in Sub-Saharan Africa there is a lack of understanding of:

- Phosphorus and the role it plays in C sequestration in C4 grasslands
- The effect of ultraviolet radiation on decomposition
- Termites- how they affect the amount and distribution of organic matter and C in soils
- Shifts between shrublands and grasslands and the impact this has on above and below C stocks
- The rate of C sequestration and saturation levels

and this is just for one land use type in one area of the world.

CONCLUSION

Estimating SOC change is more feasible for some areas of the world than others. More work needs to be done on; improving data sets for areas outside of Europe, North America and Australia, parameterising models for non-temperate conditions and improving our understanding of C sequestration potential for those land use systems where knowledge gaps exist.

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K.5 | SOC AS INDICATOR OF PROGRESS TOWARDS ACHIEVING LAND DEGRADATION NEUTRALITY (LDN)

Barron J. Orr[1], Annette L. Cowie[2]

[1],*School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona, USA - barron.orr@gmail.com
[2]NSW Department of Primary Industries, University of New England, Armidale, Australia

ABSTRACT

Land degradation neutrality (LDN) is a new approach to management of land degradation, which is intended to encourage action to avoid or reduce degradation, and also to restore degraded land, in order to achieve the goal of no net loss in healthy, productive land. The aspirational goal of LDN is to maintain or enhance the natural capital of the land and associated land-based ecosystem services. The scientific conceptual framework for LDN provides scientifically-based guidance in planning, implementing and monitoring LDN. Monitoring the achievement of neutrality is based on the evaluation of significant change in three land-based progress indicators (and associated metrics): land cover (land cover change), land productivity (net primary production) and carbon stocks (soil organic carbon stocks). SOC is viewed as relevant indicator of ecosystem function, its adaptive capacity and resilience to perturbations, and thus its capacity to provide ecosystem services flowing from land-based natural capital in the long term.

Keywords: [land degradation neutrality; LDN; monitoring; land-based progress indicators; SOC; UNCCD; natural capital; ecosystem services]

EXTENDED ABSTRACT

INTRODUCTION

Land Degradation Neutrality (LDN) is the new paradigm for managing land degradation, introduced to halt the ongoing loss of healthy land as a result of unsustainable management and land conversion. Defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems", the goal of LDN is to maintain the land resource base so that it can continue to supply ecosystem services such as provision of food and regulation of water and climate, while enhancing the resilience of the communities that depend on the land. The target of LDN is a major plank in the global 2030 Agenda for Sustainable Development: LDN will underpin the achievement of multiple SDGs related to food security, environmental protection and the sustainable use of natural resources.

OVERVIEW OF THE LDN SCIENTIFIC CONCEPTUAL FRAMEWORK

The Scientific Conceptual Framework for LDN (Orr *et al*., 2017) provides a scientific foundation for planning, implementing and monitoring LDN. It was developed by a group of experts led by the Science-Policy Interface (SPI) of the United Nations Convention to Combat Desertification (UNCCD), and has been peer-reviewed by technical experts and policy makers. By defining the LDN concept in operational terms, the framework is designed to create a bridge between the vision and its practical implementation. It articulates the scientific basis for the vision and logic of LDN, and, based on this, presents a strategy for achieving LDN, an approach to monitoring LDN status, and guidance on interpreting the results of. The conceptual framework is summarised in Figure 1.

The objectives of LDN as articulated in the conceptual framework are to:

- Maintain or improve ecosystem services;
- Maintain or improve productivity, in order to enhance food security;
- Increase resilience of the land and populations dependent on the land;
- Seek synergies with other environmental objectives;
- Reinforce responsible governance of land tenure.

The framework is structured around five 'modules': the Vision of LDN, which articulates the aspirational goal of LDN; the Frame of Reference, that explains the LDN baseline against which achievement is measured; the Mechanism for Neutrality, that describes the counterbalancing mechanism; Achieving Neutrality, that presents the theory of change (logic model) describing the pathway for implementing LDN, including preparatory analyses and enabling policies; and Monitoring Neutrality, which presents the indicators for assessing achievement of LDN. The conceptual framework is described in a report that presents the five modules, and focuses on the neutrality aspect of LDN, highlighting the features of LDN that differ from historical approaches to land degradation assessment and management.

The framework presents principles to be followed by all countries that choose to pursue LDN. Principles govern application of the framework and help prevent unintended outcomes during implementation and monitoring of LDN. Principles are provided to govern application of the framework, giving bounded flexibility while preventing unintended outcomes during implementation and monitoring of LDN. Due to inter-dependence between the elements, the fundamental structure and approach of the framework are fixed, to protect its functional integrity, and to ensure consistency and scientific rigour.

The Vision and Baseline

The aspirational goal of LDN is to maintain or enhance the natural capital of the land and associated land-based ecosystem services. Pursuit of LDN therefore requires effort to avoid further net loss of the land-based natural capital relative to a reference state, or baseline. Therefore, unlike past approaches, LDN creates a target for land degradation management, promoting a dual-pronged approach of measures to avoid or reduce degradation of land, combined with measures to reverse past degradation. The intention is that losses are balanced by gains, in order to achieve a position of no net loss of healthy and productive land.

Integrated land use planning and the counterbalancing mechanism

Achieving LDN will require tracking land use changes where degradation is anticipated so that cumulative negative impacts can be estimated, and implementing an optimal mix of interventions designed to avoid, reduce or reverse land degradation, with the intent of achieving neutrality at national scale. Therefore, the conceptual framework introduces a new approach in which land degradation management is coupled with land use planning. Decision-makers are encouraged and guided to consider the cumulative effects on the health and productivity of a nation's land resources caused by the collective impact of their individual decisions that influence management of particular parcels of land. LDN thus promotes integrated land use planning, with a long-term planning horizon including consideration of the likely impacts of climate change. The counterbalancing mechanism requires implementation of interventions that will deliver gains in land-based natural capital equal to or greater than anticipated losses due to degradation elsewhere (Figure 1).

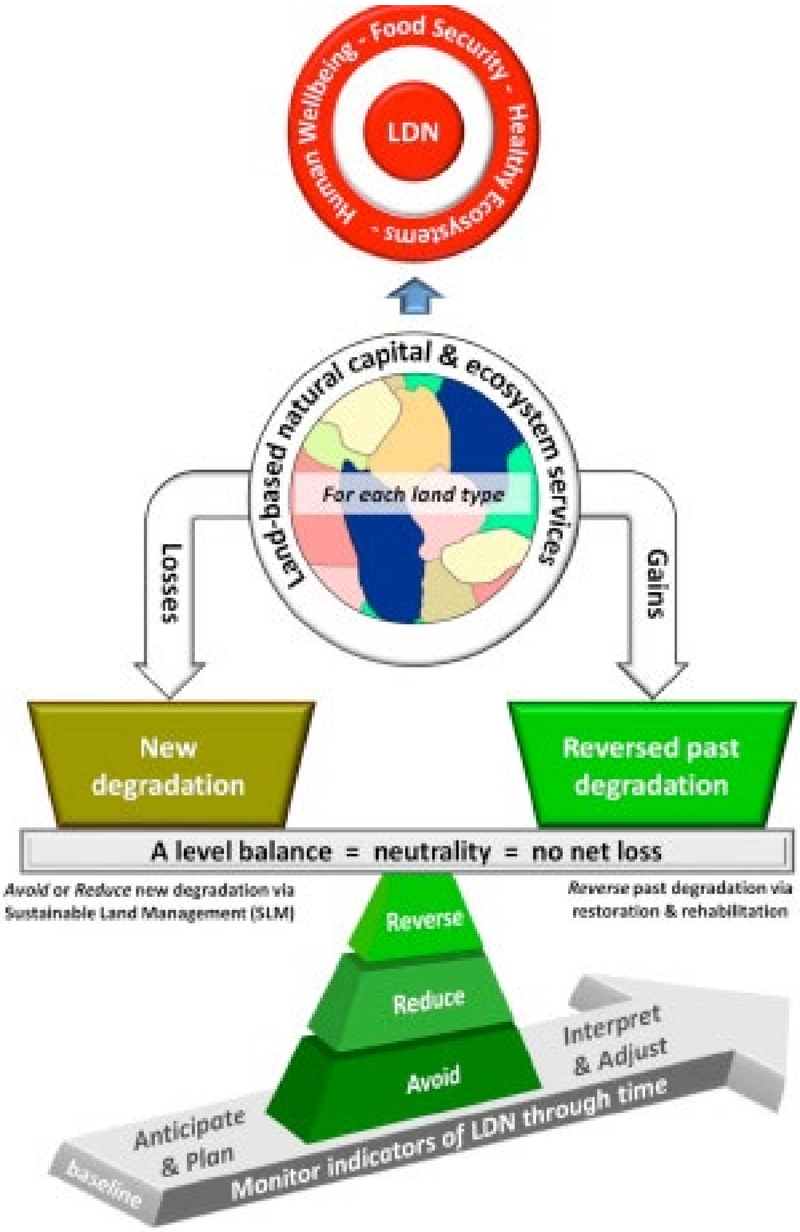

Fig. 1: Schematic of the scientific conceptual framework for land degradation neutrality (Source: Orr et al. 2017)

Achieving neutrality

Actions to achieve LDN include sustainable land management approaches that avoid or reduce degradation, coupled with efforts to reverse degradation through restoration or rehabilitation of degraded land. The response hierarchy of Avoid > Reduce > Reverse land degradation expresses the priorities in planning LDN interventions: most effort should be applied to avoiding land degradation, on the basis that "prevention is better than cure", because restoring degraded land is time-consuming and expensive. The implementation of LDN is managed at the landscape scale. Counterbalancing anticipated losses with measures to achieve equivalent gains is to be undertaken within each land type. Land types are defined by land potential, which is a reflection of inherent properties such as soil type, topography, hydrology, biological and climatic features.

Monitoring LDN

Monitoring achievement of neutrality will quantify the balance between the area of gains (significant positive changes in LDN indicators=improvements) and area of losses (significant negative changes in LDN indicators=degradation), within each land type across the landscape. The LDN indicators specify what to measure, while the metrics state how each of the indicators is assessed. Indicators for LDN were selected to reflect the land-based ecosystem services that LDN seeks to support. The global LDN indicators (and associated metrics) are land cover (land cover change), land productivity (net primary production) and carbon stocks (soil organic carbon stocks). These indicators are applied in a "one out, all out" approach: where any of the indicators shows significant negative change, it is considered a loss, and conversely, if at least one indicator shows a positive trend and none shows a negative trend it is considered a gain. Countries are encouraged to supplement the three global indicators with additional indicators for the ecosystem services not covered by the three global indicators, which may include other SDG indicators and/or national indicators that are relevant to their context, such as measures of land contamination or biodiversity impacts. A participatory review of monitoring results will help ensure their accuracy and local relevance, allowing for refinements to account for false positives, such as invasive shrub encroachment.

The importance of SOC as an indicator of LDN

SOC is an indicator for LDN because of its intrinsic role in ensuring multiple environmental and socio-economic benefits, as well as its integrative potential (relative to the two other global LDN indicators, land cover and land productivity). Changes in SOC stocks reflect the integration of processes affecting plant growth and turnover of terrestrial organic matter pools. Thus, SOC reflects trends in ecosystem function, soil health and climate, as well as land use and management. This helps detect trends in the processes leading to, and the management of, climate change, desertification/land degradation and biodiversity loss.

Change in SOC is strongly influenced by anthropogenic activities, such as land-use change, and management practices that influence the productive potential of the soil. SOC is therefore a responsive measure that reflects progress in sustainable land management (SLM) and restoration/rehabilitation interventions designed to provide multiple benefits. Soil organic carbon is an indicator of overall soil quality associated with soil nutrient cycling, soil aggregate stability and soil structure, with direct implications for water infiltration, vulnerability to erosion and ultimately the productivity of vegetation, and in agricultural contexts, yields. The soil carbon pool plays the role of both a source and a sink of carbon dioxide and thus is critical to the estimation and management of greenhouse gas fluxes. Soil carbon stocks reflect the balance between organic matter inputs (dependent on plant productivity) and losses due to decomposition through action of soil organisms and physical export through leaching and erosion. On seasonal to decadal timescales, change in total carbon stocks of natural and managed systems may be explained largely by relatively fast changes in plant biomass, but on longer time scales, SOC is a more relevant indicator of the functioning of the system, its adaptive capacity and resilience to perturbations (e.g. drought), and thus its capacity to provide ecosystem goods and services in the long term.

SOC plays a pivotal role in the natural and human-influenced biophysical processes that drive and impact the provision of ecosystem services flowing from land-based natural capital, and which ultimately contribute to human well-being. Figure 2 presents these complex interrelationships within a structure that seeks to simplify the complexity while emphasising the multiple linkages and pertinent processes, highlighting the ecosystem services delivered by the land-based natural capital. It demonstrates how human needs are met by these ecosystem services. Figure 2 identifies the relevant features of land-based natural capital that are influenced by degradation processes, which are listed along with their drivers and pressures (natural and anthropogenic). It also shows the relationship between the stocks of land-based natural capital and the flow of valuable ecosystem services that fulfil human needs.

Figure 2 demonstrates that the global LDN indicators provide good coverage and together can assess quantity and quality of land-based natural capital, and most of the associated ecosystem services. In addition, the metrics for these indicators address changes in the system in different yet highly relevant ways. NPP, the metric for land productivity, captures relatively fast changes, while SOC, the metric for carbon stocks, reflects slower changes that suggest trajectory and proximity to thresholds. Land cover provides a first indication of changing vegetation cover, to some extent as proxy of the underlying use, and of land conversion and resulting habitat fragmentation.

While the three global indicators address key aspects of land-based natural capital, additional indicators may be required to fully assess trends in land-based ecosystem services. Therefore, the global indicators should be supplemented by national (or sub-national) level indicators to provide coverage of the ecosystem services associated with the land that are important in each context.

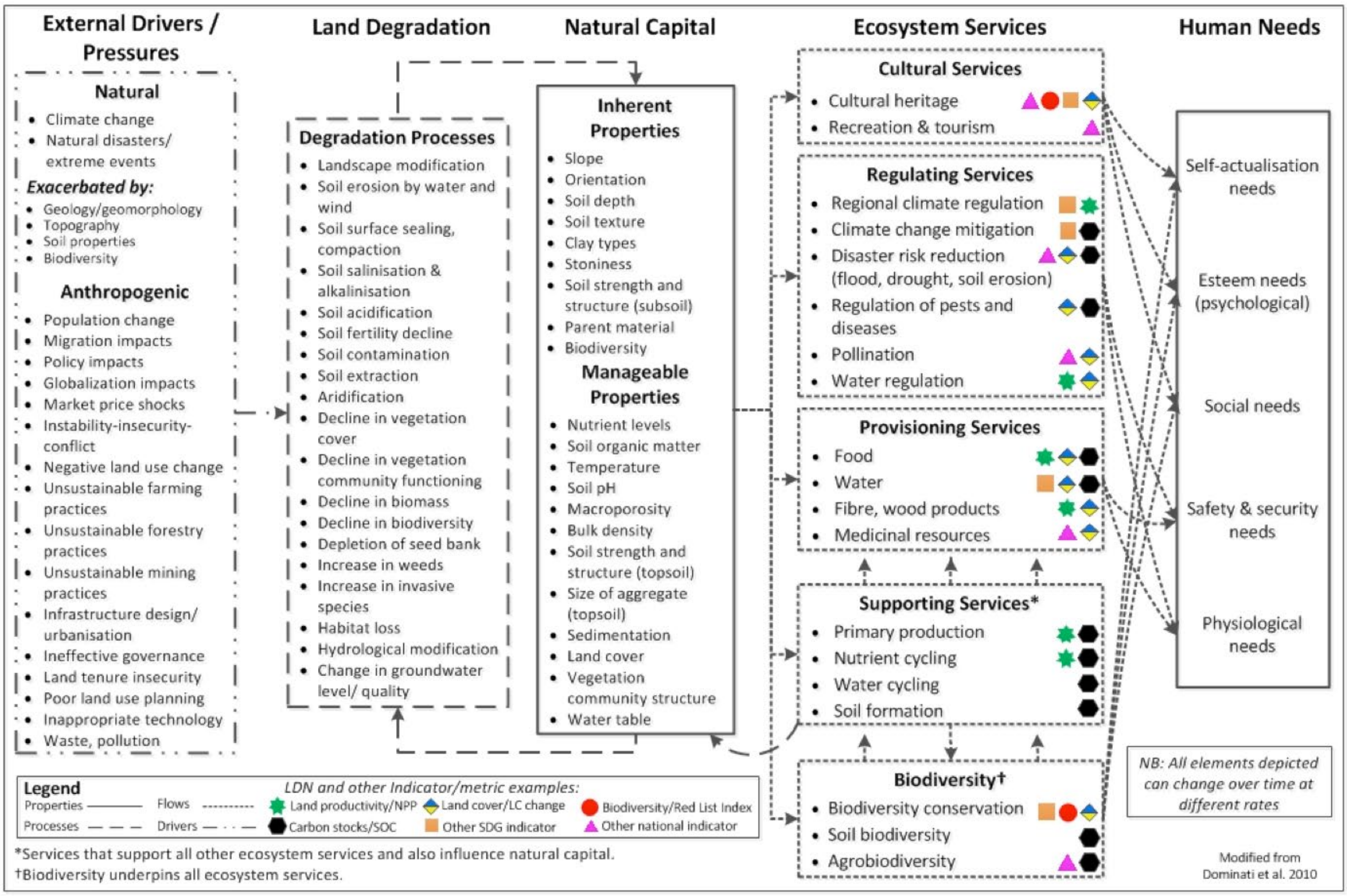

Fig. 2: System description relating the provision of ecosystem services to the land-based natural capital (with indicator/metric examples mapped to specific ecosystem services) (Source: Orr et al. 2017)

CONCLUSIONS

SOC is pivotal to addressing the environmental challenges of our time. Increasing SOC builds a precious reservoir of soil organic matter and reduces greenhouse gas emissions. It also contributes to the fertility of the soil, the foundation for all land-based natural and agricultural ecosystems which provide a major part of the world's food supply, natural resources and biodiversity. Moreover, ecological and societal resilience – the capacity to bounce back after disruptive change – is greater when and where soils are productive. This one-to-many relationship is central to achieving the broader development objectives of the Rio conventions and the Sustainable Development Goals. SOC is therefore one of the three global indicators identified for monitoring LDN, that reflects progress of SLM and restoration/rehabilitation interventions undertaken to reduce or reverse land degradation. When pursuing the goal of no-net loss into the future, these interventions should seek to deliver 'win-win' outcomes whereby gains in natural capital contribute to improved and more sustainable livelihoods. This means pursing solutions designed to maintain or increase SOC in the soil, so that ultimately the vision of a land degradation neutral world can be ensured. It also means that advances in our capacity to monitor changes in SOC are essential.

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THEME 1

MEASURING, MAPPING, MONITORING AND REPORTING SOIL ORGANIC CARBON STOCKS AND STOCK CHANGES

1.1 | GLOBALSOILMAP FOR SOIL ORGANIC CARBON MAPPING AND AS A BASIS FOR GLOBAL MODELING

Dominique Arrouays[1*], Budiman Minasny[2], Alex. B. McBratney[2], Mike Grundy[3], Neil McKenzie[3], James Thompson[4], Alessandro Gimona[5], Suk Young Hong[6], Scott Smith[7], Alfred Hartemink[8], Songchao Chen[1], Manuel P. Martin[1], Vera Leatitia Mulder[9], Anne C. Richer-de-Forges1· Inakwu Odeh[2], José Padarian[2], Glenn Lelyk[7], Laura Poggio[5], Igor Savin[10], Vladimir Stolbovoy[11], Yiyi Sulaeman[12], Dedi Nursyamsi[12], Gan-Lin Zhang[13], Mogens H. Greve[14], Zamir Libohova[4], Philippe Lagacherie[16], Pierre Roudier[17], Johan G.B. Leenaars[18], Gerard B.M. Heuvelink[18], Luca Montanarella[19], Panos Panagos[19], Jon Hempel2°

1 INRA Orléans, InfoSol Unit, Orléans, France.
2 The University of Sydney, New South Wales, Australia.
3 CSIRO, Australia
4 USDA-Natural Resources Conservation Service, USA.
5 The James Hutton Institute, Aberdeen, Scotland (UK).
6 Rural Development Administration (RDA), Republic of Korea.
7 Agriculture and Agri-Food Canada, Canada.
8 University of Wisconsin-Madison, Madison, WI, USA.
9 Wageningen University, Wageningen, The Netherlands
10 People's Friendship University of Russia, Moscow, Russia.
11 V.V. Dokuchaev Soil Science Institute, Moscow, Russia.
12 Indonesian Agency for Agricultural Research and Development, Indonesian Ministry of Agriculture, Bogor, Indonesia.
13 Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China.
14 Department of Agroecology, University of Aarhus, Denmark.
16 INRA, UMR LISAH, Montpellier, France.
17 Landcare Research, New Zealand.
18 ISRIC Soil Information, Wageningen, The Netherlands.
19 European Commission, JRC, Ispra, (VA), Italy
20 Department of Land Resource Management, Darwin, NT, Australia

ABSTRACT

The demand for information on functional soil properties is high and has increased over time. This is especially true for soil organic carbon (SOC) in the framework of food security and climate change. The *GlobalSoilMap* consortium was established in response to such a soaring demand for up-to-date and relevant soil information. The majority of the data needed to produce *GlobalSoilMap* soil property maps will, at least for the first generation, come mainly from archived soil legacy data, which could include polygon soil maps and point pedon data, and from available co-variates such as climatic data, remote sensing information, geological data, and other forms of environmental information.
Several countries have already released products according to the *GlobalSoilMap* specifications and the project is rejuvenating soil survey and mapping in many parts of the world. Functional soil property maps have been produced using digital soil mapping techniques and existing legacy information and made available to the user community for application. In addition, uncertainty has been provided as a 90% prediction interval based on estimated upper and lower class limits. We believe that *GlobalSoilMap* constitutes the best available framework and methodology to address global issues about SOC mapping. Main scientific challenges include time related and uncertainties issues.

INTRODUCTION

The demand for information on functional soil properties is high and has increased over time. This is especially true for soil organic carbon (SOC) due to its major role in climate change mitigation and adaptation and in maintaining and enhancing many soil ecosystem services, among which food production. The GlobalSoilMap consortium was established in response to such a soaring demand (Sanchez, *et al.*; 2009; Arrouays *et al.*, 2014) for up-to-date and relevant soil information. This consortium has undertaken the task of producing soil property maps at a fine resolution (90 m) using digital soil mapping techniques and state-of-the-art and emerging technologies for soil mapping. Many countries have abundant legacy soil data that includes soil maps at a variety of scales, soil point data collected over decades, environmental covariate information and a network of partners that have contributed to building the soil information over many years. In addition, many have some additional soil sites sampled for soil carbon stock and baseline assessment. The majority of the data needed to produce GlobalSoilMap soil property maps will, at least for the first generation, come mainly from archived soil legacy data, which could include polygon soil maps and point pedon data (e.g. Leenaars *et al.*, 2014), and from available co-variates such as climatic data, remote sensing information, geological data, and other forms of environmental information. Procedures and methodologies to produce this information vary depending on the types and amount of available data, but all information meet the GlobalSoilMap standards and specifications. In this communication, we review the specifications and the state of progress of GlobalSoilMap products delivery. We focus on information on SOC and related soil information useful for mapping and modelling SOC and their changes over large areas.

THE GLOBALSOILMAP SPECIFICATIONS

The GlobalSoilMap project aims to produce a digital soil map of the world. A common set of soil properties at specific resolution with a defined spatial entity, specified depth increments and uncertainty calculations will be available consistently across the globe. The ultimate objective of the project is to build a free downloadable database of key soil properties at multiple depths, mostly using existing soil information and environmental covariates. Maps and data are released both on a 3 arc-sec by 3 arc-second grid on point and block supports. In the first tiers of the specifications, the soil properties are delivered as predictions with uncertainty quantified by means of 90% prediction intervals.

The GlobalSoilMap specifications require the estimation of soil property values along with their uncertainty at each of six specified depth increments (0-5, 5-15, 15-30, 30-60, 60-100 and 100-200 cm) for the following soil properties: SOC, clay, silt, sand and coarse fragment contents, pH, ECEC, soil depth and available depth to rooting, bulk density (whole soil and fine earth fraction), and available water capacity. Definitions and methods of analysis of the soil properties are defined in the specifications. As many methods may have been used to measure the soil properties included in the minimum data set they have to be translated to a standard method and the specifications provide guidance on how to do this. The spline function and similar methods are used to transform horizon data into continuous depth functions of soil properties. The estimation of uncertainties is a unique feature but also a major challenge of this project. The uncertainties may determine, for example, whether the soil maps are sufficiently accurate for the intended use or where to conduct new surveys or additional soil sampling to obtain more accurate predictions of soil properties. The GlobalSoilMap specifications do not prescribe the methods of prediction, because of diverse soil legacy data situations in various countries. However, Minasny and McBratney (2010) provide a flow chart that outlines different models that can be applied.

GLOBALSOILMAP STATE OF PROGRESS

Several countries have already delivered products according to the GlobalSoilMap specifications and the project is rejuvenating soil survey and mapping in many parts of the world. Australia and the USA have already released a first complete version of the GlobalSoilMap products (Grundy *et al.* 2015; Viscarra Rossel *et al.* 2015; Odgers *et al.*, 2012). Some of the most advanced countries include France (Mulder *et al.* 2016), Denmark (Adhikari *et al.*, 2014), Scotland (Poggio and Gimona, 2014, 2017a &b), Chile (Padarian *et al.*, 2017), Korea (Hong *et al.*, 2010, 2013), Indonesia (Sulaeman *et al.*, 2013) and Nigeria (Akpa *et al.*, 2014). Many other countries (e.g., Canada, Mexico, Iran, China Mainland, Brazil, Argentina, Tunisia, New Zealand, Russia) have developed some trials for part of their territory and/or part of the GlobalSoilMap properties. In parallel to these bottom-up approaches from countries, several top-down continental or global predictions have been made, following more or less strictly the GlobalSoilMap specifications (Ballabio *et al.*, 2016; Hengl *et al.*, 2015, 2017). In this communication we will present some examples of such products and review their differences according to the data and the model used, their geographical coverage and their uncertainties on SOC predictions.

GLOBALSOILMAP ISSUES AND CHALLENGES FOR SOC

Issues related to time

GlobalSoilMap uses legacy soil data collected over many decades. Data for any point reflect the state of the soil at the time the point was sampled and analyzed. A major challenge for SOC is to reconcile differences in SOC reported for different times and under different land uses to one or more reference dates (e.g. 1990, 2000, 2010) and for each major regional land use type.

Issues related to uncertainty

The evaluation of uncertainty of soil properties prediction is in our view an aspect where most progress is needed. For instance, using *GlobalSoilMap* predictions to run a model of SOC stocks evolution over time requires at least to be able to predict initial SOC stocks and their uncertainties. In this case, these uncertainties come from predictions of various properties (SOC content, coarse element content, bulk density soil depth) and the model itself may require other soil properties (e.g. soil texture, soil available water capacity).

Merging predictions

We think that combining local and global predictions should be the way forward both to enhance the quality of digital soil maps and their use, and to map the entire world. For this purpose both top-down and bottom-up approaches are necessary. In many cases, we feel that bottom-up products better allow to take full advantage of local data and knowledge, and to take into account local soil distribution controlling factors. However, global models have a big advantage in that they avoid spatial gaps and may be a useful tool for harmonizing countries products.

CONCLUSION

The *GlobalSoilMap* raster based digital soil information will be an essential component in geographic information systems to assist a wide range of users in the decision making process for a range of issues from global to local, one of which being climate change mitigation by SOC sequestration. This information can be produced even with limited background information, but the paucity of data has a strong effect on the uncertainty on predictions. Several countries have already produced maps according to the *GlobalSoilMap* specifications and the project is rejuvenating soil survey and mapping in many parts of the world. We believe that *GlobalSoilMap* constitutes the best available framework and methodology to address global issues about SOC mapping. Main scientific challenges include time related and uncertainties prediction issues.

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1.2 | ESTIMATION OF SOIL ORGANIC CARBON STOCK IN ESTONIAN AGRICULTURAL LAND FROM PLOT TO NATIONAL SCALE

Alar Astover[1*], Priit Penu[2], Elsa Putku[2], Enn Lauringson[1], Kerttu Tammik[1], Karin Kauer[1]

[1]Estonian University of Life Sciences, alar.astover@emu.ee, Kreutzwaldi 1, 51014 Tartu, Estonia
[2]Agricultural Research Centre, Teaduse 4/6, 75501 Saku, Estonia

ABSTRACT

We are presenting review study in example of Estonia based on latest and current research projects dealing with SOC stock of agricultural land. General aim is to have best available site-specific knowledge of current SOC stock and relate its changes with land use decisions. Methodological principle is to use jointly legacy soil map and repeated monitoring data for modelling. We have developed framework (including several pedotransfer functions, mixed model approach etc) for SOC stock prediction which could be integrated to existing digitized large-scale soil map (1:10,000). SOC predictions can be used for practical farming purposes at the field scale and estimations can easily be up-scaled up to regional or country level. Our legacy soil map originates from 1960-80s and recent pilot study on agricultural land revealed that for nowadays approximately 30% of previous Histosols have been mineralized due to the intensive drainage and tillage. There is urgent need to update existing soil map before SOC prediction can be extrapolated across all soil types.

1.3 | SOIL ORGANIC CARBON MAPPING AND ESTIMATION OF STOCK IN RICE SOILS OF INDIA

V RAVINDRA BABU

***V Ravindra Babu, B Sailaja and Brajendra**
ICAR- Indian Institute of Rice Research, Rajendranagar, Hyderabad, India

Presenting author - Dr. V Ravindra Babu, Director, ICAR- Indian Institute of Rice Research, Rajendranagar, Hyderabad, India
Email id: rbvemuri1955@gmail.com

ABSTRACT

Rice is the most important crop and lively hood for millions in India. It is widely cultivated in diverse ecologies and agro ecological zones. The differential paddy productivity across different rice growing environments in India is a potential threat for its sustainability. The present study is to develop Carbon maps and estimation of stock in rice soils of India under All India Coordinated Rice Improvement Programme (AICRIP). Soil samples from 0-10 and 10-20 cm depths were collected from >500 locations representing most of the rice growing districts from irrigated, rainfed shallow lowlands, deep water and upland/hilly land use systems. A large variation upto the tune of >70 % was noticed for soil organic carbon percentage and stocks among the four different rice ecologies. In the irrigated rice ecologies and more specially of the Indo-Gangetic Plains the decline in soil organic carbon was to the extent of 69.6% in comparison to the upland/hilly rice ecologies. This was closely followed in rainfed shallow lands where decline in soil organic carbon due to cultivation was to the tune of 67.0%. Decline of soil organic carbon in the surface soils of IGP plains of India is a cause of concern. Estimation of soil organic carbon status and its stock will be of immense benefit to the rice growers and its sustainability.

Keywords: SOC, Irrigated , Rainfed shallow lowlands, GIS maps

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Rice is life in India and is grown in almost all the agro ecological regions. Worldwide, India stands first in rice area with 44.8 million hectares and second in production with 105 million tonnes after China. Within the country, rice is a major crop which accounts for 45.4% of area and 46.9% of total food grain production, thus playing a pivotal role in the food and livelihood security of the people. The diversity in the rice growing environments *viz*., water logged to rainfed uplands, jhums to deep water, high humid to arid temperatures and flood prone to drylands, wherein, irrigated ecology accounting for the largest area (24.5 m ha) and highest production (70.5 m t) and productivity (2.87 t/ha) closely followed by rainfed shallow lowlands. Rainfed upland, which accounts for nearly one fourth of the rainfed lowland area, records one seventh of production. Region wise, distribution pattern of rice growing districts based on productivity range reveal that of 563 districts, 115 districts (20.4%) contribute to 36.9 mt production with an average yield of 3.15 t/ha. Over 345 (61.3%) districts with yield levels less than that of the national average. Soils are varied extraordinarily in the country that there is hardly any type or texture of soils on which rice cannot be grown viz. acid peaty soils of Kerala (pH 3), highly alkaline soils (pH 8.5 & above) of Punjab, Haryana and Uttar Pradesh. The differential paddy productivity across different rice growing environment however, is often pointed and reasoned towards highly skewed and declining soil organic carbon status. The intensity and extent of nutrient stress concomitant with the loss of soil organic carbon in intensively cultivated areas makes it absolutely necessary, that the deficiencies and status of soil organic carbon of different soils are to be identified. This warrants a knowledge based alleviation and management of soils and inputs keeping in view the resource availability, cropping system, cropping intensity and nutrient flows in the system to economize input costs and improve factor productivity. Soil carbon has received great attention during the development of the greenhouse gas (GHG) reporting programme of the IPCC since the mid-nineties. This was done to address the contribution of intensive land management and the vast amount of degraded land to GHG emissions, since these have caused tremendous historic losses of SOC, resulting in high potentials for future carbon storage. Recently, an increasing number of authors have stressed the crucial role of healthy soils, with soil carbon being the most important indicator, for food security and resilience against climate change. Hence, above and below ground carbon (SOC) became sub-indicators for SDG target 15.3 (degraded land). The renewed recognition of the central role of soil organic carbon as a basis for food security and their provision of key ecosystem services, including climate change adaptation and mitigation, has triggered numerous mapping projects across the globe.

At the same time, knowledge about SOC baselines and changes, and the location of vulnerable hot spots for SOC losses and gains under climate change and changed land management for all the rice ecologies of India is still fairly limited. Accurate baselines are still missing for all the rice ecologies of India, and estimates about the role of soils in the carbon cycle are still only based on rough estimates with large uncertainties. The present study, is an ongoing program of All India Coordinated Rice Improvement Programme (AICRIP) to develop soil quality maps of rice soils. **Carbon mapping and estimation of stock in rice soils of India** is being carried out to ascertain the role of carbon content in the soil, their depth wise stocks in all the major rice ecologies of India. This has an ultimate objective that better soil carbon management practices have potential to correct the existing differential paddy production pattern visible across different rice ecologies of India.

METHODOLOGY

From the year 2014 onwards, triplicate soil samples from 0-10 and 10-20 cm depths were collected from all the rice ecologies covering entire geographical distribution of India where, rice is cultivated using a core sampler. Mean of soil samples collected constituted one replication (for statistical analyses). Similarly, soil samples from 0-10 and 10-20 cm depths were collected from >500 locations representing most of the rice growing districts from irrigated, rainfed shallow lowlands, deep water and upland/hilly land use systems. Thus, there were four land use systems/treatments considered for statistical analyses of all obtained data and three replications. The entire volumes of soils from each land use systems were meticulously mixed and representative samples were used for the analysis. Soil samples were then air-dried for a week, sieved through a 2 mm sieve, mixed and stored in sealed plastic jars for further analysis. Representative sub- samples were taken to determine various physico-chemical properties using normal protocols (Page *et al.*, 1982).

GIS BASED SOIL ORGANIC CARBON MAPPING AND STOCKS ESTIMATION FOR RICE SOILS OF INDIA

A district wise database was created for mapping of Soil carbon status and soil carbon stock. The database was joined to the digital map of India at district level (Survey of India- Everest India Geodetic coordinate system) and district wise maps were generated for Soil carbon and soil carbon stock using polygon symbology of ArcMap software (version 9.2). Secondary data on total rice area and rice area under irrigation were collected for the year 2009-10 (http://lus.dacnet.nic.in/). Rice area under the ecosystems like rainfed upland, low land and deep water were derived. Dot density map was generated to present district level irrigated, rainfed upland, lowland and deep water rice areas in India. The regular spacing of the dots in the map produces a visual display of denser pattern of dots representing the density of rice area under different ecosystems.
Soil carbon and soil carbon stock maps were overlaid with rice area under different ecosystems map to study the soil carbon and SC stock under different ecosystems of rice crop(Fig 1). We analysed soil properties using ANOVA for a randomized block design (with four treatments and three replications). Tukey's honestly significant difference test was used as a *post hoc* mean separation test ($P < 0.05$) using SAS 9.1 (SAS Institute, Cary, North Carolina, USA). Statistical analysis were carried out at all depths within a land use and the differences were considered significant when $P < 0.05$.

RESULTS

This is a first attempt to characterize the rice ecologies for its soil organic carbon and their stocks. A large variation up to the tune of >70 % was noticed for soil organic carbon percentage and stocks among the four different rice ecologies. This ongoing study indicated that decline in surface soil organic carbon in the rice ecologies of India reduced two times faster than that of the soil carbon storage in the upland/hilly rice ecologies. In the irrigated rice ecologies and more specially of the Indo-Gangetic Plains the decline in soil organic carbon was to the extent of 69.6% in comparison to the upland/hilly rice ecologies. This was closely followed in rainfed shallow lands where decline in soil organic carbon due to cultivation was to the tune of 67.0%. Invariably, cultivation leads to decline in soil organic carbon in the range of 19-70% from the initial value. It is particularly to be noticed that the agricultural soils of northwest India exclusive of the Himalayas have lost about one half to two thirds of their original organic carbon content. In the different ecology wise studies, the mean surface soils carbon content of irrigated areas was 0.39 % and it ranged from 0.13% to 0.78%.
Mean bulk density in the plots under irrigated rice ecologies (1.06 Mg m^{-3}) was significantly higher than the upland/hilly rice ecologies (0.92 Mg m^{-3}). Rainfed shallow lowlands had the highest mean average bulk density (1.23 Mg m^{-3}). Irrespective of the land use systems, soil bulk density augmented with soil depth. Soil bulk density values for different

depths among the rice ecologies systems were non-significant. However, down the profile bulk density values increased due to more compaction in the soil strata.

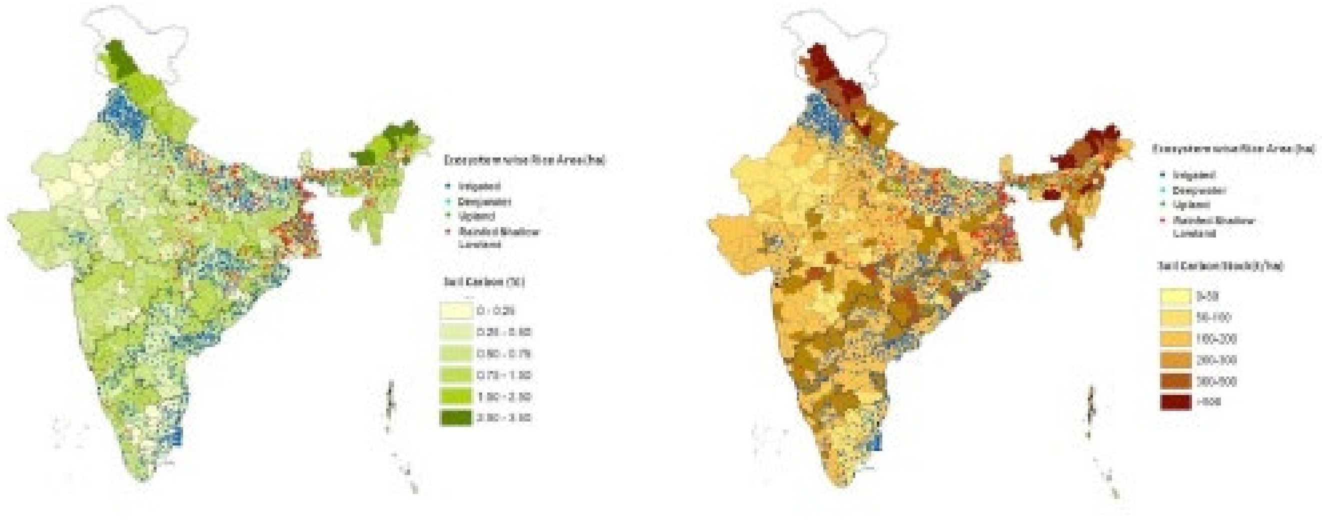

Fig. 1: First map showing Soil Carbon status in 0-20cm depth and the second map depicts the soil organic carbon stock in the same depth in all the rice ecologies of India

DISCUSSION

Districts falling under irrigated rice ecologies and districts under shallow lowlands had almost similar decline in mean SOC values and had higher SOC contents in the sub-surface soil layer than the surface layer (0-20 cm). Mean SOC stock was highest in the districts under upland/hilly rice ecologies.

This is especially true because there are large carbon storage potentials due to unsustainable management, land-use change and land degradation; increasing SOC levels also improve the resilience of soils to climate change effects (e.g. drought; increased SOC improves various soil functions including water holding capacity and nutrient availability). Efforts to increase SOC by increasing organic matter levels in soils require baseline data (location of degraded sites, hot spots for restoration) in order to plan action on the ground, and monitoring in order to verify that the intended effects are achieved. Soil carbon sequestration through the restoration of soil organic matter can further reverse land degradation and restore soil "health" through improved soil water storage and nutrient cycling, land use practices that sequester carbon will also contribute to stabilizing or enhancing food production and optimizing the use of synthetic fertilizer inputs, thereby reducing emissions of nitrous oxides from agricultural land.

CONCLUSIONS

This is a first attempt to characterize the rice ecologies for its soil organic carbon and their stocks. The SOC status often found to decrease sharply with soil depth in each of the selected rice ecologies. Large variation up to the tune of >70 % was noticed for soil organic carbon percentage and stocks among the four different rice ecologies. Mean bulk density in the plots under irrigated rice ecologies (1.06 Mg m^{-3}) was significantly higher than the upland/hilly rice ecologies (0.92 Mg m^{-3}). Rain fed shallow lowlands had the highest mean average bulk density (1.23 Mg m^{-3}). This had an influence on estimation of soil organic carbon stocks in 0- 20cm depths. Decline of soil organic carbon in the surface soils of IGP plains of India is a cause of concern. Rehabilitation measures are the need of the hour for vast areas of slash and burn cultivation in the hilly region of North eastern regions of India.

1.4 | MEASURING AND MONITORING THE IMPACT OF AGRICULTURAL MANAGEMENT ON SOIL CARBON STOCKS FROM POINT TO CONTINENTAL SCALE IN AUSTRALIA

JA Baldock[1*] and M Grundy[2]

[1]CSIRO Agriculture and Food, PMB 2, Glen Osmond, SA 5064, Australia (jeff.baldock@csiro.au)
[2]CSIRO Agriculture and Food, Building 80, University of Queensland, St Lucia, QLD, 4067, Australia (mike.grundy@csiro.au)

ABSTRACT

Soil organic carbon (SOC) content and stock contribute positively to soil productivity, resilience and stainability and provide a potential mechanism for mitigating greenhouse gas emissions. Australia has completed projects examining how to measure SOC stocks and monitor temporal changes. A method exists to allow landowners to receive financial rewards for accumulating additional carbon in their soils. The main features of the method are presented. A significant soil sampling project was completed to quantify the impact of management practice on SOC stocks across Australia's intensive agricultural zone. Significant variations in SOC stocks within management practices limited the ability to make conclusive statements about practice impacts. The SOC stock data generated, when combined with other data, has enabled maps of SOC stocks and certainty to be created which now underpin the soil component of Australia's National Inventory Report. A framework integrating measurement, monitoring and prediction of the magnitude and certainty of the outcomes of management practices on SOC stock that can evolve and improve over time will be presented.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Interest in quantifying and monitoring the content and stock of soil organic carbon (SOC) arises from the contributions it makes to soil productivity, resilience and sustainability and because increases in SOC stocks can mitigate emissions of greenhouse gases. Land use and land use change may induce sequestration or emission of carbon depending on the balance between carbon additions (C_A) derived from plant growth or organic amendments and carbon losses associated with decomposition induced mineralisation (C_M) or material transfers associated with erosion (C_E) or leaching (C_L) (Equation [1]).

$$\Delta SOC = C_A - C_M - C_E - C_L \quad [1]$$

Initiating agricultural production typically, but not always, results in net losses of SOC amounting to 20-70% of the original SOC stocks. However, the introduction of SOC friendly management practices (e.g. reduced tillage, residue retention and increased productivity) can result in sequestration or reductions in the magnitude of SOC loss (avoided emissions).

The objectives of this paper are to report results from recent Australian research programs that have: 1) developed approaches for quantifying and monitoring SOC stocks, 2) assessed the potential impact of management practises on SOC stocks, and 3) used point based SOC stock data to produce national SOC surfaces that underpin the SOC component of Australia's National Inventory Report (NIR). The paper will conclude by presenting a measurement/modelling/prediction framework that can evolve over time.

QUANTIFYING SOC STOCKS AND TEMPORAL CHANGE

Various methods exist for quantifying and monitoring SOC stocks (Figure 1). Direct measurement methods provide the most accurate assessment at a defined location, and indeed, provide the SOC stock data required to calibrate other methods. In progressing from direct measurement, through proximal sensing to remote sensing and computer simulation, the accuracy of estimates of SOC stock at a particular location and time declines. However, the ability to take many more measurements and obtain more complete spatial coverage increases. Developing a range of methods for quantifying SOC stocks over space and time and selection of the most appropriate method for a particular SOC project will be important.

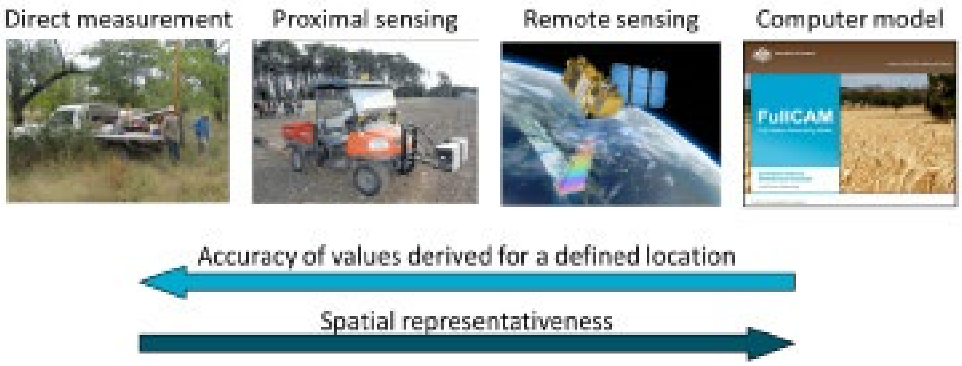

Figure 1. Potential methods for quantifying and monitoring soil carbon stocks.

In the Australian government's Emission Reduction Fund (ERF), the first SOC method developed (Sequestering carbon in soils in grazing systems) used a direct measurement approach. It was designed to be broadly applicable and assumed no prior information on SOC stock variation within a carbon estimation area (CEA). Under this method, baseline SOC stocks are measured, new management activities are implemented and future SOC stocks are monitored over time.

The method uses a stratified simple random sampling design (Figure 2) in which a CEA is divided into equal area strata (n=9 for Figure 2). Soil samples randomly located within the strata are combined to form composite samples (n=3 for Figure 2). Each composite sample comprises one soil sample from each stratum. The CEA is repeatedly sampled through time (t_0, t_1, …,t_n). To be consistent with the Australian NIR and IPCC recommendations, the collection of soil to a minimum depth of 30 cm was adopted; however, proponents may nominate to collect additional soil to depths >30cm.

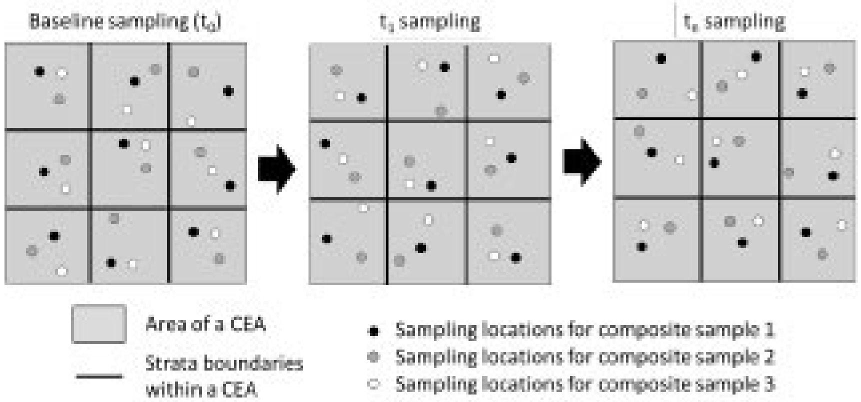

Figure 2. Sampling design defined for the "Sequestering carbon in soils in grazing systems" methodology.

The mass of soil collected (Equation) and SOC stock (Equation) are calculated. An equivalent soil mass corresponding to the 10th decile of all soil masses obtained during the baseline sampling is defined. All SOC stock values (baseline and subsequent values) are adjusted to provide the mass of SOC associated with the equivalent soil mass (Equation). The equivalent mass approach accounts for variations that may occur in soil bulk density due to altered management practices and to reduce the impact of error that may occur during sample collection.

$$\text{Soil mass (Mg/ha)} = \text{Dry bulk density (Mg/m}^3\text{)} \times \text{Soil layer thickness (cm)} \times 100$$

[2]

$$\underset{(\text{Mg C/ha})}{\text{Soil organic carbon stock}} = \left[\underset{(\text{mg C/g})}{\text{Soil organic carbon content}} \times \left(1 + \underset{(\text{g/g})}{\text{Water content}} \right) \right] \times \underset{(\text{Mg/m}^3)}{\text{Dry bulk density}} \times \underset{(\text{cm})}{\text{Soil layer thickness}} \times \left(1 - \text{Proportional mass of gravel} \right) \times 0.10$$

[3]

$$\underset{(\text{Mg C/ha})}{\text{Equivalent soil mass organic carbon stock}} = \underset{(\text{Mg C/ha})}{\text{Soil organic carbon stock in the entrie soil layer}} \times \frac{\text{Equivalent soil mass for the layer sampled (Mg/ha)}}{\text{Soil mass for the layer sampled (Mg/ha)}}$$

[4]

After the baseline and t_1 sampling, a one tailed t-test assuming unequal variance across time is used to define the SOC stock change associated with a 60% probability of exceedance. Since it is difficult to be confident that the temporal change in SOC is discounted to 50% of the calculated change.

Once three or more temporal measurements of equivalent mass SOC stocks are completed, a regression approach is used (Figure 3). In this approach, the magnitude and standard error of the slope of the regression line obtained for equivalent mass SOC stock expressed as a function of the duration of the project is calculated. These values are used to define the slope (annual change in equivalent mass SOC stock) associated with a 60% probability of exceedance, which is then multiplied by the duration of the project and the CEA area, to define the amount of SOC sequestered.

From the onset of its development, it was identified that this sampling design may not provide the most efficient approach, and additional components are being incorporated to allow stratification based on prior information and other improvements.

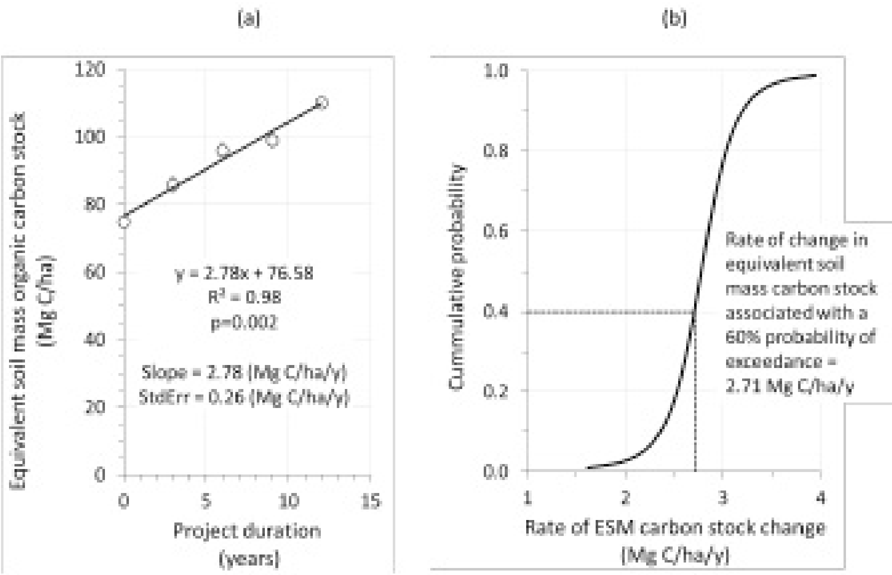

Figure 3. (a) Temporal measurements of equivalent mass SOC stocks within a CEA and the required regression statistics. (b) The probability of exceeding a particular rate of change of equivalent mass SOC stock defined from the slope and standard error of the regression equation.

POTENTIAL IMPACTS OF AGRICULTURAL MANAGEMENT ON SOC STOCK

As part of a Soil Carbon Research Program over 4,500 agricultural soils (Figure 4a) were sampled and analysed to calculate 0-30 cm SOC stocks using measured values for all parameters in Equation . Second and subsequent sampling is now needed to begin quantifying SOC stock change and sequestration rates.

Although a wide range of soil organic carbon stocks were obtained (Figure 4b), a shift towards higher SOC stocks with increasing average annual rainfall was evident. In Figure 4c, the two distributions of SOC stocks obtained under rotational and set stocking grazing regimes could not be differentiated given the significant variation in SOC stocks within each management practice.

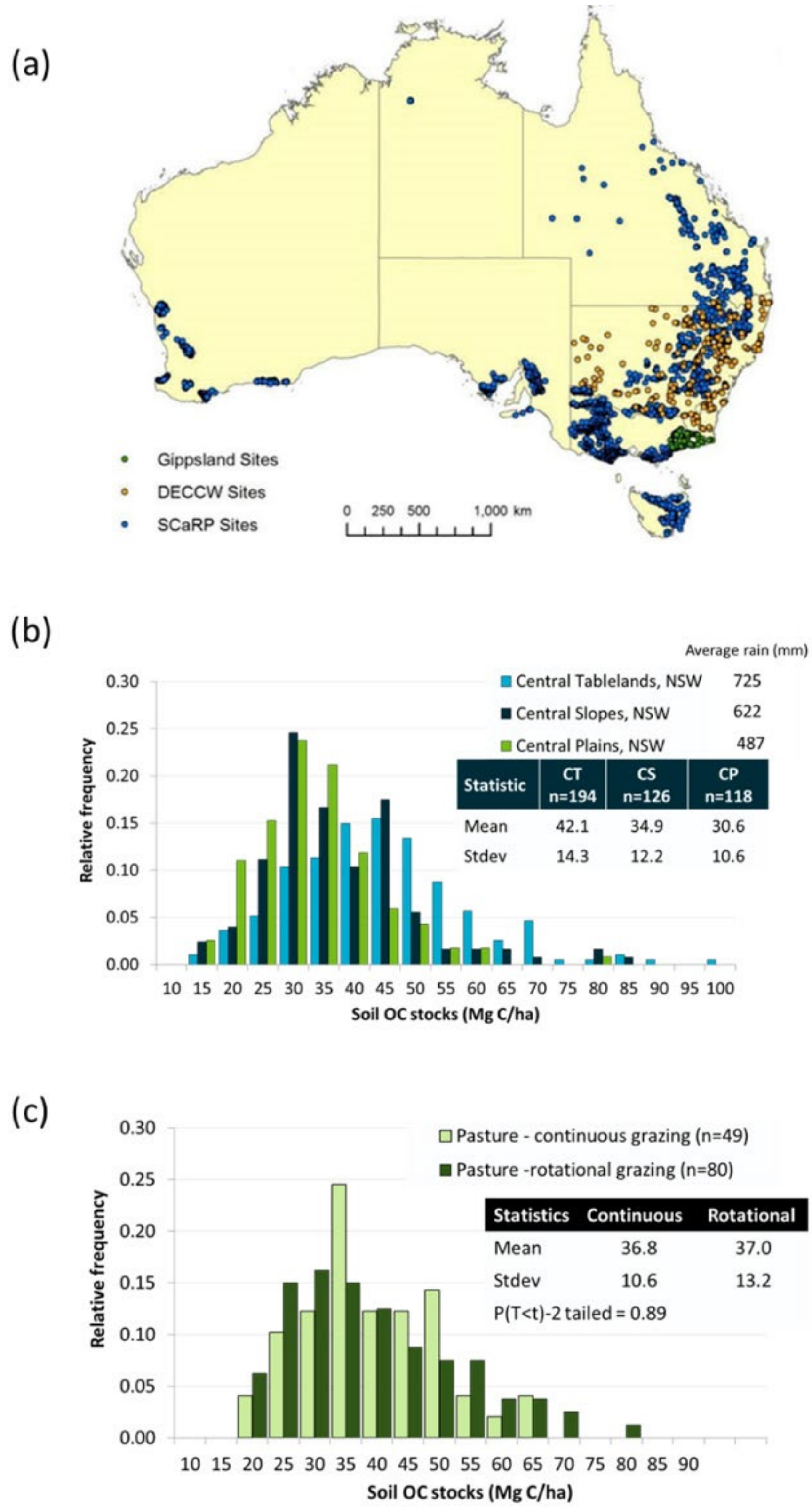

Figure 4. (a) Location of soil profiles sampled in SCaRP. (b) Frequency distributions of 0-30cm soil carbon stocks within each of three regions across a rainfall gradient in NSW. (c) Frequency distributions of 0-30 cm soil carbon stocks under two different grazing regimes within a single region of NSW (Baldock et al. 2013).

Variations in soil type, climate and topographic properties within the region contributed to the range of SOC stocks; however, differences in the way individual landowners implement practices in response to personal preferences or business requirements also contributed. Within particular management practices, the dynamics of carbon inputs and losses led to large variations in SOC stock that made general conclusions difficult. There is potential to use other aggregations that better reflect carbon dynamics, e.g. the net primary productivity achieved in response to environment and management options employed.

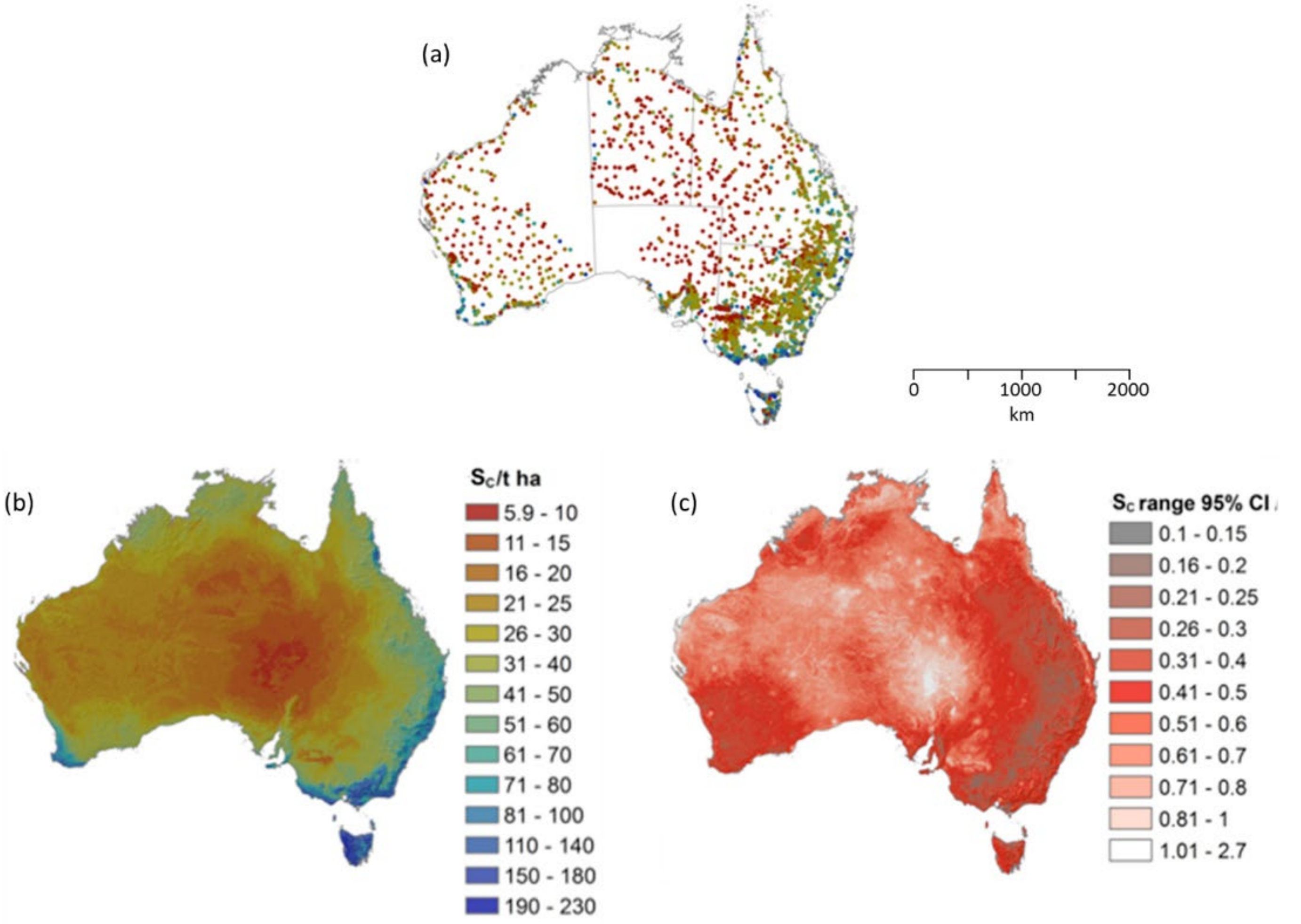

Figure 5. (a) Locations of the soil profile data. (b) Predicted spatial distribution of Australian 0-30cm SOC stocks in 2010. (c) Standardised uncertainty estimates expressed as the size of the 95% confidence interval divided by the mean predicted value (Viscarra Rossel et al. 2014).

LINKING SOC STOCK MEASUREMENTS AND COMPOSITION TO SIMULATION MODELS

The soil component of Australia's NIR uses a computer model to simulate dynamics of a series of measureable fractions of SOC referred to as particulate, humus and resistant organic carbon (POC, HOC and ROC, respectively). The decomposition rate constants of the fractions were defined through a calibration process using field trial data (Figure 6). The analytical process of quantifying the allocation of SOC to its component fractions is time consuming and expensive. To facilitate extension and possible use of the SOC fractions within the agricultural industry, a capability of predicting contents of SOC and its component fractions by mid-infrared spectroscopic analysis was developed (Figure 7). Reasonable estimates of the contents of each SOC fraction can be obtained from one mid-infrared analysis.

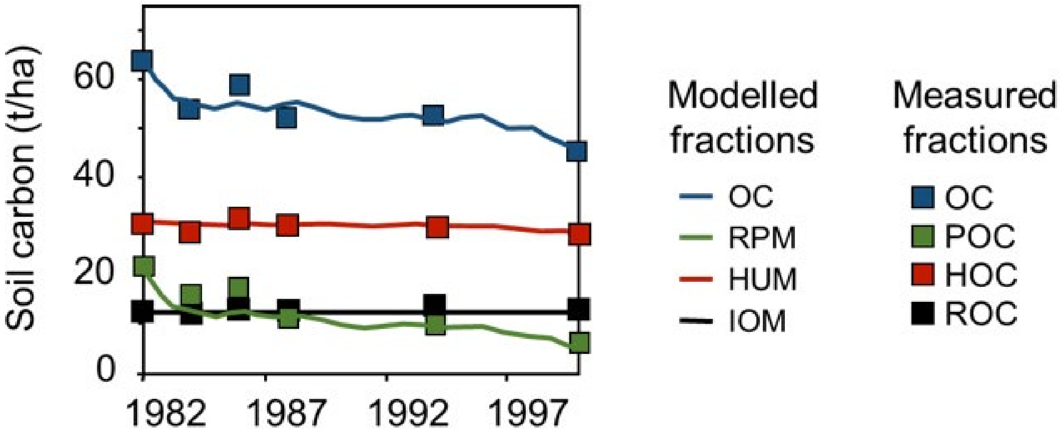

Figure 6. Relationship between measured and predicted stocks of soil carbon fractions (Skjemstad et al. 2004).

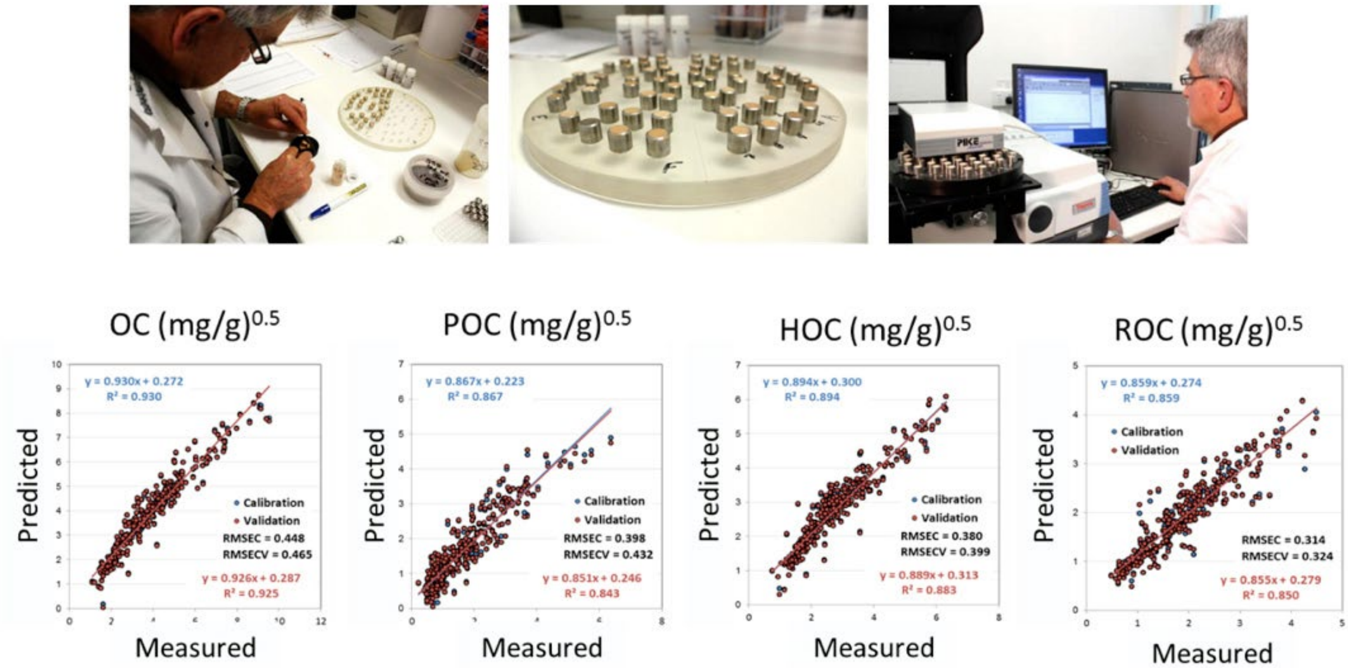

Figure 7. The process of scanning soil samples by MIR and the MIR/PLSR prediction algorithms developed for SOC, POC, HOC and ROC contents (Baldock et al. 2013).

ASSEMBLING A MORE COMPLETE MEASUREMENT/MODELLING/PREDICTION SYSTEM FOR SOC STOCKS THAT CAN EVOLVE OVER TIME

Once the linkages between point measurements of SOC stock and composition, data layers, and models are established, development of a capability to continuously improve predicted SOC stock outcomes can occur (Figure 8). Component (a) contains data defining current SOC state used to initialise and validate subsequent modelling. Component (b) defines the temporal carbon inputs from plants and is required to estimate likely outcomes of management practices on SOC stocks. Plant input data can come from direct measurement, simple or complex models or sensing. Component (c) is the SOC model predicting the likely outcome of applied management practices. Component (d) represents the model output designed to provide useful information that could take the form of:

1. a national map of predicted SOC stocks and the associated uncertainty at some point in time,
2. a cumulative probability distribution of the SOC stock outcome associated with applying a particular management practice at a particular location.
3. a series of trajectories of potential SOC stock changes associated with the application of different management practices.

Component (e) provides a mechanism for using the available data to test and revise the magnitude of the model parameters in a Bayesian Hierarchical Modelling approach. Component (f) provides a mechanism to include algorithms to shift plant production in response to increased soil carbon values and thus provide a feedback that is absent from many modelling systems.

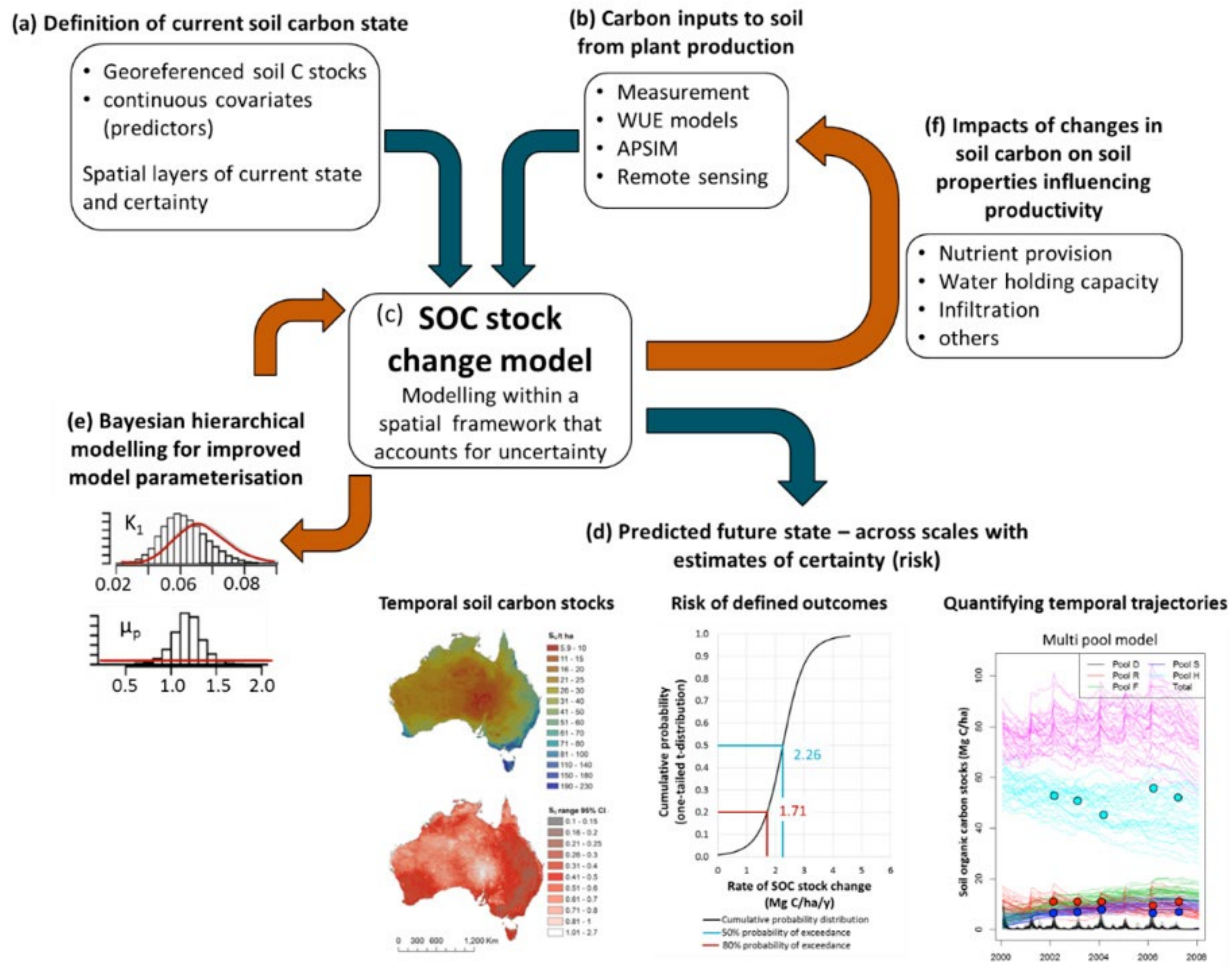

Figure 8. Conceptualisation of a complete data/modelling/prediction system for SOC stocks.

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1.5 | GLOBAL SOIL ORGANIC CARBON MAP

Rainer Baritz

Global Soil Partnership, Food and Agriculture Organization of the United Nations, Rome, Italy

ABSTRACT

Towards achieving the SDGs and given the need to make soil organic carbon (SOC) baselines available as part of SDG indicator 15.3.1 addressing land degradation, there was an urge from the UNCCD-SPI for ITPS to prepare a Global Soil Organic Carbon (GSOC) map as part of the Global Soil Information. This map which is intended to be completed by 5 December 2017 will come with great value to agencies including UNCCD, UNFCCC/IPCC, UN-FAOSTAT, GSP, UNCBD/IPBES that require SOC data in meeting their targets such as the SDGs (specifically 2.4, 15.2, and 15.3) and Land Degradation Neutrality, among others. In an attempt to supplement the current fragmented spatial SOC information, the GSOC map strives to encompass a comprehensive map on GSOC stocks all the while accounting for soil depth curves and spatial uncertainties using GlobalSoilMap.net specifications and ISRIC SoilGrids 1km/250m. This will be done using a bottom-up approach through the compilation of national maps for which respective country representative agencies will be given a set of resources to aid in this initiative, including GSOC mapping guidelines, a GSOC cookbook, capacity building through trainings on Digital Soil Mapping, and quality assurance and review. As such, the GSOC mapping process is foreseen to enable and empower countries to build their own National Soil Information Systems.

Key words: carbon stocks, soil organic carbon mapping

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1.6 | CARBON DYNAMICS IN SOILS OF WETLANDS IN NORTHEASTERN ALGERIA

By BENSLAMA mohammed[1] and BENSLAMA-ZANACHE Habiba[1]

Laboratoire de Recherche en Sols et Développement Durable, Université Badji Mokhtar Annaba Algérie. e-mail : bensamrane@yahoo.fr

SUMMARY

The monitoring of the carbon dynamics in the soils of the northern Algerian wet complex has shown that the organic matter levels increase from the upstream to the downstream of the depressions and decrease from the surface to the depth of the soils except for the soils Peat where the accumulation of organic products is often less important at the surface because of the oscillation of the level of the water table.

The fractionation of organic matter in the different soils revealed a predominance of the light fraction relative to the humified fraction. The presence of water in large quantities saturates the soil, inhibits biological activity and promotes the physicochemical transformation of organic matter (physicochemical humification). The products of humification are dominated by relatively weakly polymerized compounds with relatively low molecular weights. These are soluble fulvic acids in low acid solutions. Humic acids are relatively small and do not exceed about 30% of the humified fraction. This fraction has a relatively homogeneous distribution in all the profiles. The stable fraction of the organic matter represented by the humine is very low in all the soils studied, which means that the processes of maturation of the organic matter remain unfinished and that the organic products remain in the young state.

Key words: Carbon, fulvic acid, humic acid, humine, wet complex, Northeast Algeria

1.7 | PREDICTION FOR THE CHANGES OF SOIL ORGANIC CARBON UNDER CLIMATIC CHANGE SCENARIO BY USING DENITRIFICATION DECOMPOSITION (DNDC) MODEL

Chang Hoon Lee[1*], Byong Gu Ko[1], Seong Jin Park[1], Myeong Sook Kim[1], Sun Gang Yun[1], Seok Cheol Kim[1], Suk Young Hong[1]

[1]National Institution of Agricultural Sciences, Rural Development Administration (RDA), Republic of Korea.
* Presenting author

ABSTRACT

Soil organic carbon has been issued on food security and global warming over several decades. The change of soil organic carbon is necessary to soil monitoring in soil management. Nevertheless, long-term experiment could be alternative tools for estimating the changes of soil organic carbon in agricultural management practices. DNDC model as carbon modelling for predicting the changes of soil organic carbon was used and corrected main parameters of DNDC model with observation data of long-term field for 30 years. Then, the modified DNDC model was used to predict the changes of soil organic carbon and additional input of organic sources into soil under elevated air temperature scenario. In long-term experiment, Organic input as compost and NPK+compost continuously increased soil organic carbon in surface soil, but NPK and No fertilizer were resulted in the decrease of soil organic carbon. The modified DNDC model by observation data with time was applicable to predict the changes of soil organic carbon in agricultural soils. The modified DNDC model predicted the effect of organic source input on the changes of soil organic carbon and emission of greenhouse gases under short-term fields of paddy and upland, when organic sources such as cow and pig compost, and rice straw were applied with 12.0, 2.6, and 6.0 Mg ha^{-1} for rice and corn cultivation, respectively. According to the modified DNDC model, additional organic input under elevated air-temperature were ranged from 8.3 to16.7% for paddy soil and 3.3 to 5.9% for the cultivated corn soils, respectively, compared to that of present. These results indicate to be necessary of management for soil organic carbon in agricultural soils under climatic changes. Therefore, we should need effort to find best soil management for conservation of conserve soil organic carbon considered on food sustainability and mitigation of global warming in agricultural soils in future.

Key words: Soil organic carbon, Prediction, Long-term, Organic sources

1.8 | ASSESSMENT, MONITORING AND MANAGING SOIL ORGANIC CARBON (SOC) FOR CLIMATE CHANGE MITIGATION AND ADAPTATION: AN INDIAN PERSPECTIVE

SK Chaudhari[1] and *PP Biswas[2]

[1]adgswm@gmail.com, Indian Council of Agricultural Research, New Delhi-12, India
[2]parthabiswas.1957@gmail.com, Indian Council of Agricultural Research, New Delhi-12, India

ABSTRACT

Soils are the largest terrestrial reservoir of organic carbon, yet great uncertainty remains in estimates of soil organic carbon (SOC) at global, continental, regional and local scales. SOC is an unique indicator which exerts major influence on a number of soil physical, chemical and biological attributes. Soil monitoring involves the systematic measurement of soil properties to record their spatial and temporal changes. The assessment of SOC stock at a given site or for a given region will require analyses of OC concentration, bulk density, content of coarse fragments (>2 mm) and soil depth. Spatial representation of the SOC is considered very essential for regional planning and management. Geospatial modelling approach would help in monitoring SOC stocks as a function of change in climate, land use and can be linked to global models to understand the organic carbon dynamics besides helping in developing necessary management interventions to reduce CO_2 emissions from soils.

The management practices that increase soil C sequestration and mitigate C loss include improved water and nutrient management, adoption of diversified crop rotation, adoption of resource conserving technologies, crop residue recycling, soil and water conservation, application of organic materials (compost, green manure, biochar) and adoption of agroforestry systems.

Keywords: Soil organic carbon, Assessment and monitoring, Soil carbon sequestration, GHGs emission, Management of SOC, Policy initiatives

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Globally, the soil carbon pool is estimated at 2,500 Gt up to a 2-m depth; out of this, the soil organic carbon pool comprises 1,550 Gt (Batjes, 1996). Soils are critically important in determining global carbon cycle dynamics because they serve as the link between the atmosphere and vegetation. Though soil C pool constitutes only 3.5 % of the global C cycle, it comprises the most actively cycling C in terrestrial ecosystems.

Soils in tropical regions like India are low in SOC as they fall under the influence of arid, semiarid and sub-humid climates and this is a major factor contributing to their poor productivity (Katyal *et al.*, 2001). Indeed, an increase of SOC stock by 1 Mg C ha^{-1}in the root zone can raise the crop yield by 15-33 kg ha^{-1} for wheat (Benbi and Chand, 2007), 160 for kg ha^{-1} for rice, 170 kg ha^{-1} for pearl millet, 13 kg $ha^{-1}$for groundnut and 145 kg ha^{-1} for soybean, (Srinivasarao *et al.* 2013). Therefore, greater SOC content can result in higher foodgrain production in the country.

Soil organic carbon (SOC*)* provides energy to soil biota which act as the primary driving agents of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emission, modifying soil physical structure and water regimes, enhancing the amount and efficiency of nutrient acquisition by the vegetation and enhancing plant health (Benbi, 2015). Assessing spatial distribution of SOC, thereby, is important for improving soil quality and SOC sequestration.

METHODOLOGY

Soil carbon assessment methods can be broadly classified into direct and indirect methods, depending on whether carbon content in soil samples is directly measured or inferred through a proxy variable. The most established type of direct soil carbon assessment entails collecting soil samples in the field and analyzing them in the laboratory using combustion techniques. Field sampling is technically challenging, but most of its challenges can be addressed through an appropriate design that accounts for soil spatial variation. Direct methods are more precise and accurate but also more time and labor intensive as well as very expensive.

The *in situ* soil carbon analytical methods include mid-infrared (IR) spectroscopy, near-IR spectroscopy, Visible and near-infrared (VIS/NIR) spectroscopy, laser-induced breakdown spectroscopy (LIBS), and inelastic neutron scattering (INS). While LIBS and INS technologies are still in their infancy, IR spectroscopy has proven valuable in developing soil spectral libraries and for rapid characterization of soil properties for soil quality monitoring and other agricultural applications in developed and developing countries.

Remote sensing and GIS play vital roles in the preparation of spatial illustration. The prediction of topsoil SOC content from remotely acquired spectral data is generally based on an empirical approach. Reference soil analyses of samples collected in the field are related to the spectral information through a multivariate calibration model used to predict the SOC values at locations.

RESULTS

The first report on SOC stock in India made by Gupta and Rao (1994) was 24.3 Pg (1 Pg = 10^{15} g) using a database of 48 soil series for soil depths ranging between 44 and 186 cm. However, this estimate was based on a hypothesis of enhancement of OC level judging by success stories of afforestation programmes on certain unproductive soils.

Based on the geographical distribution of soils throughout the country, SOC stock in different physiographic regions of India was estimated to be 21 Gt (1 Gt = 1 billion tons) up to 0.3 m depth and 63.2 Gt up to 1.5 m depth using 1800 soil samples (Bhattacharyya *et al.*, 2010).

An estimation of status and spatial variability of SOC for surface soils across six states of NER (viz. Assam, Manipur, Meghalaya, Nagaland, Sikkim and Tripura covering a geographical area of 15.61 m ha) in Geographical Information System (GIS) environment revealed that the soils were very high in SOC content – 98.54% area had >1% and 14.4% area had > 2.5% SOC content (Choudhury *et. al*., 2013). While 76.5% area had SOC density of 20– 40 Mg/ha, 8% area had very high SOC density of 40–60 Mg/ha. A total of 339.8 Tg (1 Tg = 10^{12} g) SOC stocks was estimated on an area of 10.10 m ha surface soils representing all major land-use systems, with a major share (>50%) coming from forest soils. Tiwari et. al. (2015) through pedometric mapping of soil organic carbon loss using soil erosion maps worked out a threshold limit of 150 kg ha^{-1} $year^{-1}$ SOC loss above which the areas are to be considered as susceptible demanding immediate conservation measures.

In India, first spatially explicit 250m map of soil organic carbon stock was generated through Random forest(RF) based digital soil mapping technique using a large number of remote sensing derived data layers and data mining approach (Sreenivas *et al.,* 2016). For modelling with RF algorithm, about 898 soil profile observations were used, while the rest of 300 were used for validation. The soil organic carbon pool size of India has been estimated at 22.72 ± 0.93 Pg, which is comparable to previous studies.

Sarathjith *et al.* (2016) reported a R^2 value of 0.81 for SOC with VisNIR DRS which has been proven valuable in developing soil spectral libraries enabling rapid characterization of SOC and other soil properties for soil quality monitoring and other agricultural applications in developed and developing countries.

DISCUSSION

There are considerable opportunities to build up soil organic carbon through C sequestration for enhancing the soil quality. C sequestration potential of different nutrient management practices across various agro-climatic zones of India is estimated to range between 2.1 and 4.8 Mg C ha^{-1} with a total potential of 300 to 620 Mt (Pathak *et al.,* 2011). In India, balanced application of fertilizers can enhance SOC concentration by 6 to 100% and C sequestration by 20-600 kg ha^{-1} yr^{-1}, while integrated nutrient management practices is estimated at 100-1200 kg C ha^{-1} yr^{-1} with an enhance SOC concentration of 17-132 % under various soil, crop and climatic conditions (Benbi, 2013). Carbon-sequestration potential of rainfed production systems under different nutrient management practices ranges between 0.04-o 0.45 Mg ha^{-1} yr^{-1} (Srinivasarao *et al.*, 2014). C sequestration potential of agro-forestry systems very widely (1.3-173.0 Mg C.ha^{-1}) depending on tree species, climatic conditions and age of plantation (Nair *et al.*, 2009). Total potential of SOC sequestration through restoration of degraded and desertified soils in India has been put at 10-14 Tg C yr^{-1}(Pathak *et al.*, 2015) Raising Jatropha on degraded lands can increase C content in surface soil by 19 % resulting in about 2500 kg C ha^{-1} sequestered over a 4 year period (Wani *et al.*, 2012). Besides C sequestration and rehabilitation of degraded lands, Jatropha has the biodiesel C replacement potential of 230 kg ha^{-1} yr^{-1}.

Zero tillage (ZT) agriculture can enhance soil-C sequestration by reducing the degree of soil disturbance and C turnover. In wheat based cropping systems in India, conversion from CT to ZT resulted in net C sequestration rates ranges from 219-359 kg C ha^{-1} yr^{-1} (Grace *et al.*, 2012).

In India, agriculture contributes nearly 18% of total GHGs emission in the country. Crop residues burning is a potential source of Green House Gases (GHGs) causing global warming. In India, an estimated 141 Tg crop residues are surplus most of which are burnt *in situ*. The crop residues on an average contain 45% C and assuming a humification rate 10% the incorporation of surplus crop residues can result in C sequestration of 6.3 Tg C annually (NAAS, 2012).

Adoption of improved water management such as alternate wetting and drying, direct-seeding of rice (DSR) and System of Rice Intensification (SRI) in place of submerge rice reduce or totally eliminate methane emission. The DSR and SRI have potential to reduce the global warming potential (GWP) by about 25-50% compare to the conventional puddled transplanted rice (Pathak *et al.*, 2015).

CONCLUSIONS

SOC is sensitive to impact of human activities, viz. deforestation, biomass burning, land use changes and environmental pollution. Sustainable land management delivers carbon benefits in three important ways namely carbon conservation, carbon sequestration and reduction of GHGs emissions. The triple imperatives provide resilience to agricultural ecosystems in terms of increasing climate change adaptation and mitigation with higher crop productivity.

In order to improve SOC and enhance soil C sequestration, the Government of India has taken several initiatives namely National Mission of Sustainable Agriculture for promotion of integrated nutrient management and production of organic fertilizers, Nutrient Based Subsidy scheme to ensure balanced fertilization, promotion of organic farming, National Biogas and Manure Management Programme, promotion of City/urban compost, Watershed Development programme for soil & water conservation and National Food Security Mission for promotion of conservation agriculture. Recently National Mission on Soil Health Cards has been launched to provide every farmers soil test based fertilizer recommendations. This will ensure assessment, mapping, monitoring of SOC at village level under actual field conditions.

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1.9 | INTEGRATED MONITORING OF CARBON STORAGE AND LOSS THROUGH EMERGING ISOTOPE TECHNOLOGY

Chen, J.[1,*], Dercon, G.[1], Heiling, M.[1], Slaets, J.[1], Resch, C.[1], Weltin, G.[1], Mayr, L.[1], Gruber, R.[1], Zaman, M.[1], Adu-Gyamfi, J.[1], Heng, L.[1]

[1] Soil and Water Management & Crop Nutrition Subprogramme, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Vienna, Austria

ABSTRACT

The ability to trace carbon (C) in soil and the atmosphere is essential for optimizing soil management practices to foster soil organic carbon (SOC) sequestration for climate change adaptation and mitigation. Emerging isotope technology plays a major role in better understanding land and soil management impacts on SOC, including its stabilization and destabilization mechanisms. This paper highlights progress made at the Soil and Water Management & Crop Nutrition Laboratory (SWMCNL) of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture in the development of carbon-13 stable isotope technology for integrated monitoring of C storage in the soil and loss through CO_2, and how this technology can be used for *in situ* assessment of climate-smart soil management practices. An example is given of the use of stable isotope technology in monitoring SOC dynamics under mulch-based cropping systems.

Keywords: stable isotope technology, mulch, climate-smart soil management

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Agricultural soils have the most potential to store a large pool of C and, depending on the farming techniques applied, can either effectively store C belowground, or further release C, in the form of CO_2, into the atmosphere. Farming practices, such as mulch application, are frequently proposed to increase C content belowground and improve soil quality and can be used in efforts to reduce greenhouse gas levels, such as in the “4 per 1000” Initiative.

Soil organic C studies through conventional methods are often labor-intensive and time-consuming. As only total organic C stocks can be assessed, scientists cannot distinguish new from old C, or extract information to better understand the specific role of each crop or components in SOC storage or loss within a cropping system. Stable isotope technology, however, can help overcome most of these constraints.

For instance, depending on the source of the SOC present, the carbon-13 (^{13}C) stable isotope signature of SOC will range from about -10‰ until –30‰. The difference in ^{13}C signature of different organic carbon residues will allow tracing the source of C stored in the soil or lost through CO_2 or can assist in calculating proportions of new and old C and so estimate SOC stability. In addition, ^{13}C stable isotope studies can be based on the use of ^{13}C labelled or enriched plant materials. This allows more specifically targeting of certain processes within C storage or loss.

The scope of this paper is linked to the following themes of the Global Symposium on Soil Organic Carbon:

1. Measuring, mapping, monitoring and reporting SOC;

2. Maintaining and/or increasing SOC stocks (fostering SOC sequestration) for climate change mitigation and adaptation.

The objective is to demonstrate the latest development of isotope technology for monitoring C storage and loss and how this technology is envisaged to be used for *in situ* assessment of climate-smart soil management practices. Examples of recent highlights of research and development activities at the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture will be shown, with focus on the use of stable isotope technology in monitoring soil organic C dynamics under mulch-based cropping systems.

METHODOLOGY

1. Laser Isotope Spectroscopy for tracing CO_2 in cropping systems

Isotope analysis with laser spectroscopy is an emerging technology that is growing in scientific demand. Because this technology allows for real-time, *in situ* measurements of ^{13}C of CO_2, it is increasingly being used to monitor fluxes of CO_2. However, despite its potential to provide robust data to researchers, methods of calibration and data correction are still being developed and refined. Furthermore, standard reference gases are currently not available and researchers must make their own gases to ensure proper calibration and data correction. To improve quality of data and allow for comparison of data between studies, it is essential that standard CO_2 gases are accessible to researchers.

2. Quantitative isotopic tracing using homogeneously ^{13}C labelled plant material

Carbon-13 labelled plant material is increasingly being used to trace the fate of plant-derived C into the atmosphere, soil, water and organisms in many studies, including those investigating the potential of soils to store CO_2 belowground. However, accurate quantitative tracing of plant-derived C in such studies is only possible if plant material is labelled both homogeneously and in sufficient quantities. The SWMCNL has developed a method that achieves these two requirements for ^{13}C labelling by monitoring $^{13}CO_2$ labelling of plants in a 15m^3 walk-in growth chamber with laser spectroscopy. This approach allows production of homogeneously labelled material at the intra-plant, inter-plant and metabolic level, which can be used for quantitative tracing.

3. Evaluating the effectiveness of mulch application to store carbon belowground

To test the effectiveness of mulch application to store carbon belowground in the short term and improve soil nutrient quality, we maintained agricultural soils with low and high organic carbon content in FAO/IAEA greenhouse mesocosms with controlled moisture for 4 years. Over the 4 years, maize and soybean were grown yearly in rotation and mulch was removed or applied to soils once plant material was harvested. After 4 years, we measured effects of mulch application on soluble soil and microbial carbon and nitrogen in the mesocosms and compared effects of mulch application versus no mulch on soils with low and high organic matter. We predicted that mulch would increase soil C and nitrogen (N) content and mulch application would have a greater effect on soils with low organic matter than soils with high organic matter.

RESULTS AND DISCUSSION

1. Laser Isotope Spectroscopy for tracing CO_2 in cropping systems

Within the SWMCNL, methods are being developed to make CO_2 gas standards on a universal gas mixing line that can both evacuate gas bottles and fill them with desired gas mixtures (Fig. 1). These gases are being isotopically labelled at natural isotope abundance levels as well as depleted and enriched isotope abundance levels so that they can be used in both natural abundance and tracer isotope studies. Furthermore, these gas mixtures will be produced at ambient and elevated concentration levels similar to those measured in natural environments and experiments. In addition to filling gas bottles to create larger volumes of standard gases, our universal gas mixing line can be used to produce mixed gases in small volume multi-layer foil gas sampling bags.

With use of standard CO_2 gases in laser isotope analysis studies we can improve confidence and accuracy in reported data and larger comparisons across studies. Once our methods for making gas standards for laser isotope analyzers are finalized, we plan to develop standard operating procedures for FAO and IAEA Member States to replicate our gas standards.

Fig. 1: Gas mixing line (left) linked to a vacuum pump, pressure gauge, CO_2 and synthetic air gas tanks for mixing of gases into desired containers, such as this 1L gas cylinder, to make standard reference gases for laser isotope analyzers; 13C - CO_2 laser isotope analyzer (right) for measuring emissions of CO_2 from soils.

2. Quantitative isotopic tracing using homogeneously carbon-13 labelled plant material

Our initial labelling trials focused on maize due to its global importance as a crop and due to its potential to produce relatively large amounts of biomass, yielding one kilogram of dry plant material per run. With successful ^{13}C labelling of corn plants achieved, we are now further attempting to label other agricultural plants, such as soybeans, that can open more research avenues to better understand carbon dynamics. Additionally, we are attempting to create homogeneously labelled ^{13}C and ^{15}N plant material by supplying both labelled $^{13}CO_2$ and ^{15}N -labelled hydroponic nutrient solution during plant production. Dual labelling of plants is advantageous when studying agricultural greenhouse gas emissions, as it allows researchers to simultaneously account for plant-derived CO_2 as well as another greenhouse gas, N_2O.

In addition to homogenous ^{13}C and ^{15}N labelling of plant material, we also plan to produce heterogeneously labelled plant material. By performing incubation and field decomposition experiments using both types of labelled plant material, researchers will investigate the forms of plant material that more significantly contribute to greenhouse gas emissions and, conversely, store them belowground. Furthermore, a comparison between the two types of plant material should allow us to elucidate the error propagation that can occur from using heterogeneously labelled material and its effects on accuracy of estimating sequestration rates, emission rates as well as residence times.

In summary, the method developed at the SWMCNL for producing large amounts of homogeneous ^{13}C labelled plant material opens up new research pathways and assessment methods in the field of soil carbon dynamics and agricultural greenhouse gas emissions. Further development of homogenous ^{15}N labelled plant material will also help with research in the field of soil nitrogen dynamics and agricultural greenhouse gas emissions, as will the production of additional ^{13}C and ^{15}N labelled agricultural plants. This plant material will allow IAEA and FAO Member States to accurately quantify carbon storage and reduction of atmospheric greenhouse gas levels of various agricultural systems as well as assess the efficacy of different agricultural practices under local conditions, both via *in situ* and incubation experiments.

3. Evaluating the effectiveness of mulch application to store carbon belowground

To test the effectiveness of mulch application to store carbon belowground in the short term and improve soil nutrient quality, we maintained agricultural soils with low and high organic carbon content in greenhouse mesocosms with controlled moisture for 4 years. In soils with low organic C content and larger predicted potential to increase soil C, mulch application did not increase soluble soil or microbial C or N compared to the treatments without mulch application. However, mulch application significantly increased the $\delta^{13}C$ of both microbial and soluble soil C in these soils by 1 ‰ each, indicating a shift in belowground processes, such as increased decomposition coupled with increased C inputs. In soils with more organic content and lower potential to increase soil C, mulch application decreased microbial C by 0.01 mg C g soil-1 and increased soluble soil nitrogen by 0.01 mg N g soil^{-1}. Soluble soil C also decreased by 0.04 mg C g soil-1 and microbial N increased with mulch application by 0.006 mg N g soil-1, but only in 5-15 cm soil. Mulch application only decreased $\delta^{13}C$ of soluble soil carbon by 1.5 ‰, likely indicating a decrease in decomposition. Contrary to our initial predictions, mulch did not increase soil C content and only increased N content in soils that already had relatively higher organic matter content. These results suggest that mulch application (with only soil surface disturbance) may not play a significant role in increasing soil C content and overall soil quality, at least in a short 4-year term.

CONCLUSIONS

The development of isotope technologies is essential to improve the resilience of farming communities to climate change by optimizing soil management practices. These efforts are supported by a new generation of robust and affordable isotope techniques that can be used *in situ* at the plot (on-farm) and provide data in real-time.

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1.10 | SOIL ORGANIC MATTER DERIVED CO_2; COMPARISON OF PARTITION METHODS FROM AN ACRIC UMBRISOL IN A SUBTROPICAL FOREST

Louis-Pierre Comeau[*1], Derrick Y. F. Lai[1], Jane Jinglan Cui[1]

[*]comeau_louis@hotmail.com
[1]Department of Geography and Resource Management, Chinese University of Hong Kong, Shatin, Hong Kong.

ABSTRACT

Without accurate data on soil heterotrophic respiration (Rh), assessments of soil carbon (C) sequestration rate (or C balance) are challenging to produce. Accordingly, it is essential to determine the contribution of the different sources of the total soil CO_2 flux (Rs), but to date no single, fully satisfactory partitioning procedure exists. We partitioned soil carbon dioxide (CO_2) flux into Rs and Rh component in a subtropical secondary forest in Hong Kong. We combined automated chamber measurements of Rs with five different partitioning methods: (1) regression between root mass and root derived CO_2; (2) root exclusion bags with intact soil blocks; (3) root exclusion bags with hand-sorted roots; (4) lab incubations with minimally disturbed soil microcosm cores; and (5) $\delta^{13}C$ natural abundance (experiment in progress). Excised roots and litter decomposition rates were also assessed with decomposition bags to further segregate microbial respiration of dead plant material from soil organic matter (SOM) derived CO_2. Preliminary results showed large variance of Rh fluxes and Rh/Rs ratio between the different methods analyzed. The lowest Rh/Rs ratio was produced by the lab incubations (22.5% Rh) and the largest by the intact root exclusion bags (61.3% Rh). Both root exclusion bags techniques produced very similar Rh flux and these fluxes were slightly larger than the one produced by the root regression method but notably larger than the lab incubation with soil cores.

Keywords: soil organic matter derived CO_2 fluxes; partitioning methods for heterotrophic respiration assessment.

INTRODUCTION

Last year during the COP21 (United Nations Climate Change Conference), a goal of increasing the global soil organic carbon (SOC) stocks by 0.4 percent per year, to mitigate global anthropogenic greenhouse gas emissions, was set (Budiman *et al.,* 2017). This ambitious aim was made with the notion that the SOC in the top soil layer is sensitive and responsive to management changes and this might offers opportunities to slowdown the current increase rate in atmospheric CO_2 concentration (Kuzyakov, 2006).

It is known that carbon (C) enters into ecosystems via photosynthesis then a fraction of this C is directly respired by the roots and above ground plant parts (autotrophic respiration) to produce energy (i.e. adenosine-5'-triphosphate) and the other fraction is synthesized into organic molecules. Some of these C-containing compounds are harvested and the remainder is added to the soil as plant residues (Janzen *et al.,* 1998). Subsequently, a portion of these fresh organic compounds is respired by organisms (heterotrophic respiration) and another portion is converted into SOC by the processes of soil organic matter (SOM) genesis (Janzen, 2006; Lal, 2005). In sum, when the amount of new organic residues added to the soil is greater than the C lost by SOC decomposition, SOC content increases (Ellert and Bettany, 1995). However, SOM structure and genesis are not yet fully understood and there are still many uncertainties about the rates of SOC accumulation and decomposition in many ecosystems (Schmidt *et al.* 2011). These uncertainties are due in large part to the fact that total CO_2 flux (Rs) from soil do not provide the necessary information to assess whether the soil is a net source or net sink for atmospheric CO_2 (Kuzyakov, 2005). Specifically, the autotrophic (Ra) part of the Rs does not cause net C losses to the atmosphere because this C is simply cycling around inside the ecosystem. Conversely, microbial respiration (i.e. heterotrophic; Rh) represent net C losses. For the reason that, the boundary between Ra and Rh is nor sharp (i.e. the rhizo-microbial respiration is linked to both) realistic Rh assessments are difficult to produce (Braig and Tupek, 2010). In turn, it is then problematic to assess soil C sequestration (or C balance) rate without accurate Rh data. As a result, many years (up to decades) are currently needed to assess SOC stock changes in order to evaluate which management practices are beneficial for SOC sequestration (Harmon *et al.*, 2011; Wood *et al.*, 2012).

The goal of our study was to compare five different partitioning methods to separate CO_2 flux into its Rs and Rh component in a subtropical secondary forest in Hong Kong. In addition, excised roots decomposition and litter-fall/decomposition rate were determined to further segregate microbial respiration of dead plant material from SOM derived CO_2.

METHODOLOGY

This study was made in a subtropical secondary forest of Hong Kong (Tai Po Kau Nature Reserve; 22° 27´N, 114° 11´E, 250 m.a.s.l.). The mean annual temperature was 23.3°C and annual precipitation 2400 mm with a hot-humid season (April–September) and a cool-dry season (October–March) (Hong Kong Observatory). The soil was classified as Acric Umbrisol (Nechic).

The regression between root mass and root derived CO_2 was made following Farmer (2013) with 22 sampling spots. The experiment was made in October 2016. Each spot was a square of 20 x 20 cm randomly distributed in a one ha area. In each spot, Rs was determined per triplicate using a portable IRGA EGM-4 (Environmental Gas Monitor, PP Systems, UK) attached to a soil respiration chamber (SRC-1, PP Systems, UK). Concurrently with CO_2 flux measurements, air and soil (10 cm depth) temperatures and soil moisture were measured at each sampling spot. Immediately after the Rs measurement, the 20x20 cm square were excavated 25 cm depth. All the visible roots (diameter larger than 0.1 cm) from the excavated soil were collected. In the lab, the roots were washed and then oven dried at 60°C until a steady dry weight was attained, which was then recorded. Linear random effects modelling was performed using the R statistical package (R Development Core Team 2008).

To measure Rh in root exclusion bags with hand-sorted/removed roots Fenn *et al.* (2010) method was followed with seven root exclusion pits (20 × 20 cm, depth: 25 cm) using mesh bags. Briefly for each root exclusion hole, soil was excavated in 10 cm layers and visible roots were removed from each layer. Then a micromesh bag was placed inside each hole. Subsequently, soil was repacked in respective 10 cm layers (5cm for the 20-25 cm depth) and each repacked. For the Rh with root exclusion bags with intact soils blocks, seven soil block (20 × 20 cm, depth: 25 cm) were removed from the soil. Then they were put into the above mentioned micromesh bags and inserted back into their original pit. Each intact root exclusion block was paired (i.e. 150 cm distance) with a hand-sorted root exclusion bags.

For the lab incubations, undisturbed soil cores of volume 98 cm^3 (inner diameter 5 cm, height 5 cm) were collected using a stainless steel core soil sampler from the upper part of the soil profile (0–5 cm). Four groups of four soil cores were collected then pooled per group and brought to the lab. Subsequently all visible roots were removed but with special care to not destroy the small aggregates. The soil was then repacked to original bulk density in minimally disturbed soil microcosm cores of 45 cm^3 (inner diameter 3.5 cm, height 5 cm). The soil cores were separated in four groups of different volumetric moisture content (i.e. 15, 25, 35 and 45 %; equivalent to % of maximum water holding capacity of 30, 48, 66 and 84). These moisture levels corresponded to the natural annual fluctuation in the field (i.e. from dry to moist season). After moisturizing the samples, each individual soil core was placed into a hermetically sealed 2.9 dm^3 plastic container. The experiment lasted four weeks and had four different incubation temperature levels (one per week; 14°C, 20°C, 26°C and 32°C) corresponding to the minimum, intermediate maximum soil temperature values in the field based on preliminary studies (Cui, 2017). At the beginning of each week, the soil cores were pre-incubated in their incubation box to their corresponding weekly temperature (i.e week #1 14°C … week #4 32°C) for 3 days and then opened and vented for one minute. From all the boxes gas samples were collected (20 ml) with an air-tight syringe (t= 0, 24, 72 hour) after box closure. The CO_2 concentrations were analyzed within 48 hours with a gas chromatograph (GC system7890A, Agilent Technologies). The GC system was equipped with a flame ionization detector and an electron capture detector to quantify and CO_2. Between each measurement session, the boxes opened to vent and the moisture of the soil cores was readjusted if needed.

The $\delta^{13}C$ of Rs/Rh respiration will be determined following Lin *et al.* (1999) and Millard *et al.* (2010). The isotopic partitioning experiment will assess values of the $\delta^{13}C$ of the Rs, Ra and Rh. The sampling will take place in February 2017. Briefly, in ten closed chambers (10 cm diameter, 10 cm high) will be randomly positioned in the study area at least 24 hours prior to sampling. The $\delta^{13}C$ of the Rs will exclude any atmospheric CO_2. Then the root will be incubated in CO_2 free air in a Tedlar bag. For the $\delta^{13}C$ Rh respiration, root free, soil samples will be collected from up to 25 cm below the chambers, placed in CO_2 free air in Tedlar bags. The $\delta^{13}C$ ratios, all expressed relative to VPDB, will be calculated with respect to CO_2 reference gases injected with every sample and traceable to International Atomic Energy Agency reference material NBS 19 TS-Limestone.

Litterfall was collected each month from 7 traps randomly distributed in the one ha study area. Root and litter decomposition rate were assessed with mesh bags following Steward and Davies (1989).

RESULTS

Regression of the CO_2 fluxes against root density of the 22 quadrants yielded a statistically significant slope correlation of 0.08 g CO_2 m^{-2} s^{-1} (P=0.03), and set the intercept at 25 g CO_2 m^{-2} s^{-1} (P=0.02) which was assumed to be the basal flux in absence of root representing the Rh (Fig. 1 and Table 1).

Regarding the other methods to assess Rh, our preliminary results are showing large variance of fluxes and Rh/Rs ratio between the different techniques analyzed. Specifically, our preliminary data have revealed that both root exclusion bags techniques produced very similar Rh flux values and these fluxes were slightly larger than the one produced by the root regression method but notably larger than the lab incubation with soil cores (Table 2).

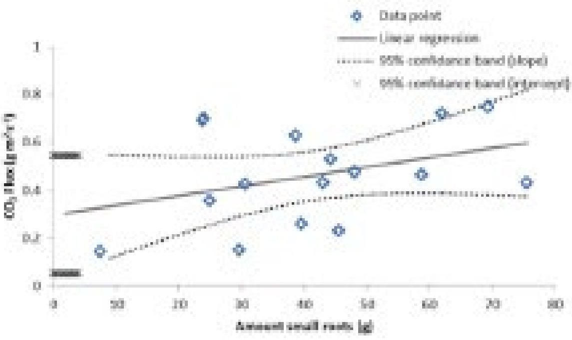

Fig. 1. Linear regression between root quantity and CO_2 flux

Table 1. Linear regression report between root quantitya and CO_2 fluxb

Parameter	Value (mg cm3)	SEc	t value	P value
Interceptb	0.25	0.10	2.50	0.02
Slopeb	0.08	0.04	2.31	0.03

Overall r^2 of the linear regression: 0.21.

[a] root quantity in unit of milligram, small (radius between 0.1-0.5 cm) dried roots (60°C) per cm^3 of soil.

[b] CO_2 flux in unit of gram per m^2 per second.

[c] SE, standard error.

Table 2. Preliminary results of the comparison of heterotrophic respiration assessment methods

Method	Rh fluxa (g CO_2 m3 h-1)	SEb	Rh to total soil CO_2 flux (%)
Soil cores incubation	0.11	0.01	22.5
Root regression	0.25	0.10	51.1
Hand-sorted root exclusion bags	0.29	0.04	59.2
Intact root exclusion bags	0.30	0.06	61.3
$\delta^{13}C$-CO_2			

[a] Rh, heterotrophic respiration.

[b] SE, standard error.

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1.11 | ENHANCEMENT ON ESTIMATES OF ORGANIC CARBON IN MEXICAN SOILS

Cuevas-Corona, R.[1]; Saynes-Santillán, V.[1,5]; Etchevers-Barra, J.[1,5]; Leyva-Reyes, J.[3]; García-Carreón, S.[3]; Vargas-Rojas, R.[7]; Báez-Pérez, A.[1,4]; Cueto-Wong, J.[1,4]; Cruz-Gaistardo, C.[1,2]; González-Acuña, I[1,4]; Guerrero-Peña, A.[1,5]; Hidalgo-Moreno, C.[1,5]; Padilla-Cuevas, J.[1,5]; Jarquín-Sánchez, A.[1,6]; López-Anaya, M.[1,6]; Martínez-Vargas, M.[1,2]

[1]Red Nacional de Laboratorios para el Análisis, Uso, Conservación y Manejo del Suelo. REDLABS. rosochkaa@gmail.com
[2]Instituto Nacional de Estadística y Geografía, INEGI.
[3]Comisión Nacional Forestal, CONAFOR.
[4]Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias. INIFAP.
[5]Colegio de Postgraduados, COLPOS.
[6]Colegio de la Frontera Sur, ECOSUR.
[7]Organización de las Naciones Unidas para la Agricultura y la Alimentación. FAO.

INTRODUCTION

The study of soil organic carbon (SOC) is a challenge in that it has a heterogeneous horizontal and vertical distribution, it may be present in thousands of organic compounds, and may remain in them for thousands of years (Field and Raupach, 2004; Gaudinski *et al.*, 2000; Gougoulias, Clark and Shaw, 2014; Janzen *et al.*, 1992; Lal, 2002; Schlesinger, 1977; Schlesinger and Bernhardt, 2013; Schmidt *et al.*, 2011; Six *et al.*, 2002; Sohi *et al.*, 2001; Stewart *et al.*, 2008). The magnitude of the SOC storage is spatially and temporally variable and determined by different abiotic and biotic factors (Weissert, Salmond and Schwendenmann, 2016). Our ability to detect vulnerable hotspots for SOC losses and gains and its uncertainty is still limited, and accurate baselines are still missing for many countries. Every nation needs to quantify its carbon reserves and implement management practices (designed and implemented for specific site conditions) focused on the preservation and increase of SOC in a global warming setting (GSP-ITPS, 2016).

In this context, and in compliance with the General Law on Sustainable Forest Development, the National Forestry Commission (CONAFOR) through the "Reinforcing REDD+ Readiness in Mexico and Enabling South-South Cooperation" designed and implemented a National Measurement and Monitoring, Reporting and Verification (MRV) System to estimate forest greenhouse gas (GHG) emissions.

Part of the MRV system has been designed to quantify and reduce the uncertainty associated to these estimates. Soil CO_2 emissions originate from the decomposition of soil organic matter, which is roughly 58% carbon (C) (Pribyl, 2010). The estimate of these emissions represents one of the main challenges of the MRV system due to the complexity and high uncertainty associated to the quantification of C in the soil matrix. The main sources of this uncertainty are associated to: field sampling, preparation and storage of samples, analytical methods used in the laboratory and variability in the space-time scales of the soil (Field and Raupach, 2004; Gardi *et al.*, 2014; Houghton and A., 2003; LeMay and Kurz, 2017; Liski *et al.*, 2005; Morfín Rios *et al.*, 2015).

Within the framework of the MRV system and focusing on the improvement of the SOC quantification for samples from the National Forestry and Soil Inventory (INFyS), in 2014 the CONAFOR proposed the formation of a National Network of Laboratories for Analysis, Use, Conservation and Soil Management (REDLABS). This network emerged from a Strategy for Strengthening National Laboratories[1] focused on soil carbon quantification aimed at homologating the methodologies and analytical quality control protocols (Cuevas-Corona, 2016).

1
INEGI: Laboratorio de Análisis de Materiales. COLPOS: Laboratorio de Fertilidad de Suelos Química Ambiental y Laboratorio Agroindustrial, Suelos, Plantas y Agua. INIFAP: Laboratorio Nacional de Fertilidad de Suelos y Nutrición Vegetal (Campus Celaya y Santiago Ixcuintla) y Laboratorio de Suelos del Campo Experimental La Laguna. ECOSUR: Laboratorio de Biogeoquímica y Laboratorio de Suelos y Plantas.

OBJECTIVES

- To work in the reduction of the uncertainty associated to SOC stocks of Mexican ecosystems.
- To become an advisory body with a leadership position in the analysis and measurement of soils aimed at contributing to the establishment of national information systems.

METHOD HARMONIZATION

One of the main goals of the REDLABS are the increase of reliability and the reduction of uncertainty of laboratory analytical practices related to physicochemical properties relevant to soil quality. In order to accomplish said goals, the REDLABS is working on:

- *International Quality and Comparison Program for Plant and Soil Analysis (IQCP):* Reducing the uncertainty associated to analytical measurements through a continuous engagement in the 2017 cycle of the IQCP.
- *Accreditation strategy:* Developing a strategy including actions aimed at achieving REDLABS analytical accreditation through the ISO/IEC 17025 Standard[2] in order to demonstrate technical competence and generation of reliable results.
- *Standardized consensual manual:* Developing a standardized consensual manual to provide access to analytical methodologies associated to carbon and other physicochemical soil properties. The scope of this manual contemplates ability-oriented courses and is addressed to the Central American and Caribbean countries in the subjects of SOC and standardization analytical processes.

Methodology and Results

IQCP

- In order to ensure analytical quality and technical proficiency, accuracy assessments were conducted under conditions of repeatability, reproducibility and authenticity of SOC data generated and processed by the REDLABS.
- Staff qualification and technical competence had a significant positive impact on analytical quality. Results obtained by the REDLABS were repeatable and reproducible since non-significant statistical differences were observed in the SOC concentration measurements conducted in the soil samples selected.

Accreditation strategy

- This strategy includes operational goals for the short, medium and long-term. Operational ongoing short-term goals include the preparation and use of internal and certified reference materials (soil and plant standardized tissues), the REDLABS participation in the IQCP, generation of standard protocols under ISO Standards revised and updated by the REDLABS experts.
- The analysis of certified reference material compared to reference value obtained by the REDLABS did not show significant statistical differences. These findings reinforced the veracity of our analytical capability.

Standardized consensual manual

- This manual was structured by: 1) Updating and standardizing existing protocols for several physicochemical soil properties; 2) Format review; 3) Sharing protocols among the REDLABS experts for feedback purposes; 4) The integration of remarks from the REDLABS members; 5) Compilation of the Manual.
- We rely at this stage on an initial draft of the Manual that contains 14 analytical harmonized protocols including application fields, operation principles, common materials and reagents, as well as approved and standardized methods and controls. The manual includes protocols for carbon content and the quantification of other physicochemical soil properties.

2 General requirements for the competence of testing and calibration laboratories

In 2016, the Global Soil Partnership and the International Technical Panel on Soils (ITPS) presented the global guidelines for integration of a Global Soil Organic Carbon (GSOC) Map. The GSOC map consists of national SOC maps that incorporate inputs from countries that have developed their own national SOC maps. The development of the GSOC map will help the different countries to generate their soil carbon baselines in support of the Sustainable Development Goals (SDG) and the assessments related to the effects of climate change.

At the second workshop of the International Network of Soil Information Institutions (INSII), cartographic specifications and detailed methodologies were discussed, as well as examples of national SOC maps. One such example was the National SOC and Litter Map generated by the REDLABS.

Methodology

The Soil Organic Carbon Map calculation (2017) is the result of a series of concatenated processes that include sampling design and analysis, field and laboratory standardized protocols, quality control and spatial data propagation techniques, as well as an iterative process to assess and reduce uncertainties.

Carbon stocks (SOC stock) are calculated based on the carbon concentration (SOCconc) product, the actual depth of sampling (for map effects is used from 0-30 cm) and the bulk density in the stoniness-free fine fraction of soil (ton ha^{-1}).

Results

A total of 36,015 SOCconc several analyses were performed and concentration values varied from 0.1 to 89.3%. The results of soil analyses obtained by the REDLABS in 2015 showed the following average percentages of SOC: litter (41.1%), fermentation layer (26.2%) and mineral soil (5.7%) for the first 30 cm of soil depth and 3.3% for the 30-60 cm layer.

The total SOC stock in Mexico is 7.12 Pg (Uj = 53.6%) based on detailed physiography and vegetation polygon type maps as a baseline for regionalization purposes. The average national SOC stock was 36.4 Mg ha^{-1} (Figure 1a) and the total national organic carbon stock of the litter layer was 0.35 Pg (Figure 1b).

Figure 1a: National Map of Organic Soil Carbon (2017)

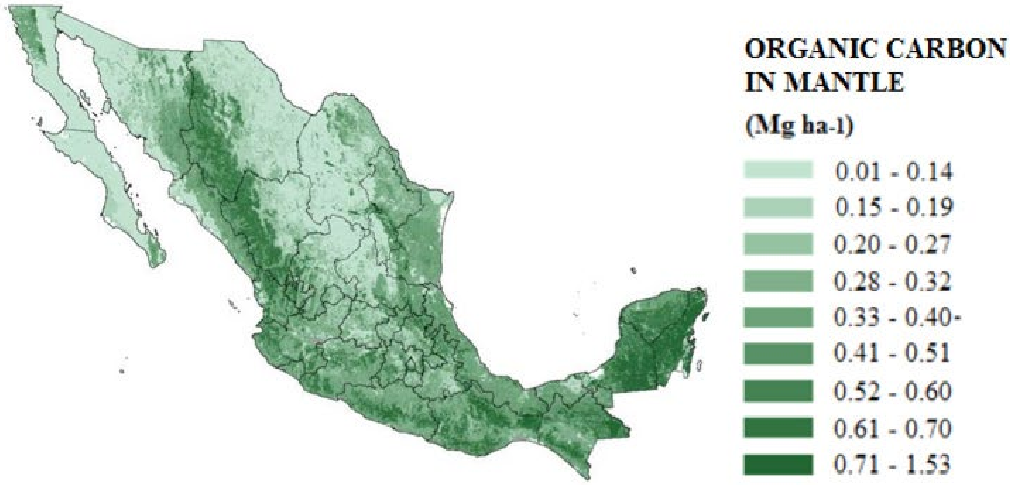

Figure 2b: National Map of Organic Carbon of the Litter (2017).

NATIONAL RESEARCH NETWORKS

The REDLABS were recognized in 2016 as a Research Network within the framework of the Institutional Strategy of National Networks of Research, Development of Forestry Technology Transfer of CONAFOR. Whose activities are the establishment of monitoring sites in the field, aimed at the assessment of soil quality indicators as well as technology transfer processes associated to the forestry sector.

In addition, we have been recognized as Thematic Research Networks of the National Council for Science and Technology (CONACyT) of México, engaged in the enhancement of SOC stocks measurements at national level through the association of academy, the government and society.

Results

- Consolidation of high quality training, and capacity building strategies associated to analytical procedures.
- Creating the foundations of our analytical accreditation.
- Updating of SOC and other analytical methodologies of physicochemical properties.
- Development of national-scale relevance scientific information through academic, educational activities and dissemination of soil science.
- Establishment of an international collaboration basis, and location of funding sources.

INTERNATIONALIZATION OF THE REDLABS

As part of the REDLABS significant efforts, the collaboration with the Global Soil Partnership (GSP) is highlighted. These collaboration agreements include the contributions of REDLABS to the pillars of action.

Results

Pillar 2: Encourage investment, technical cooperation, policy, education, awareness and extension in soil

One of the main objectives of the REDLABS is to contribute to scientific development through academic activities, disclosure and dissemination of soil science.

Video of soil science: The multifunctional nature of soil provides a wide range of ecosystem services to society. Despite this, there are in Mexico few dissemination actions to emphasize the relevance of this natural capital. For this reason, the REDLABS made a playful and visually attractive video to raise the society's awareness

of the urgency of using this invaluable resource sustainably. To watch the video click on the following link: *Https://www.youtube.com/watch?v=bRLcVYQsQJU*
Scientific forums: During 2016, the REDLABS participated in the Mexican and Latin American Congress of Soil Science.
Scientific papers: These papers will report on the measurements of quality of total carbon in soil through inter-comparison programs, and the generation of the National Map of Organic Carbon in the Soils and Litter of Mexico.

Pillar 4: Enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines
Contribution by the REDLABS to Global Soil Organic Carbon (GSOC) Map by means of data generated for Mexico (See section: Soil Organic Carbon Map).
Participation of Mexico through the REDLABS at the second workshop of International Network of Soil Information Institutions carried out by GSP (See the section: Soil Organic Carbon Map).

Pillar 5: Harmonization of methods, measurements and indicator for the sustainable management and protection of soil resources
During 2017 the REDLABS will, jointly with the GSP-FAO, teach capacity building courses for laboratories of Central America and the Caribbean in the subject of SOC, including analytical standardization processes (See the section: Method harmonization).
Contribution of the REDLABS to the development of manuals and on-line courses related to soil science that the GSP-FAO would publish and disseminate among all member countries.

DISCUSSION

One of the main conclusions of the report "Status of the World's Soil Resources" refers to the most significant threats to the function of soil at a global scale; unfortunately the loss of SOC is one of them. In Mexico, 61% of the soils are shallow, poorly developed and poorly fertile, and these conditions make them unsuitable for agriculture, vulnerable to degradation and potential GHG emitters such as CO_2.

For these reasons, it is essential to generate basic (*i.e.,* measurements of SOC stocks) and specific information (*i.e.,* measurements of carbon associated to recalcitrant, very slow, passive and inert fractions, and measurements of carbon associated to fast-active, and labile fractions) in order to contribute to the understanding of the mechanisms by which the SOC is sequestered and released into a global warming setting.

In this context, it is important to highlight the fact that the work of the REDLABS in collaboration with the CONAFOR will allow the generation of basic and specific information of SOC in order to:

- Contribute to the efforts aimed at increasing SOC (the increase of SOC levels in soil require baseline data in order to plan actions and monitoring on the site in order to verify that the expected effects have been obtained).
- The generation of the SOC map of México (Result of a series of concatenated processes that include sampling design and analysis, field and laboratory standardized protocols, quality control and spatial data propagation techniques, as well as an iterative process to assess and reduce uncertainties).

CONCLUSION

Taking into account that one of the main inputs for the national MRV system is the data collected in the CONAFOR´s INFyS, it is expected that the work developed by the REDLABS will contribute to reducing the uncertainty associated to the determinations of SOC content. In addition, these data will contribute to develop better national emission factors. The effort of methodologies/protocols homologation and implementation of quality control processes in all analysis is the best reference to be able to aspire to that purpose.

The data generated by the REDLABS are national interest issues aimed at enhancing the planning, sustainable management and conservation of soils in México. These outcomes also contribute to the generation of national and international reports (i.e., FRA, UNFCCC) and the generation of national SOC maps that serve as input to the creation of the Global SOC map.

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1.12 | LOW-TEMPERATURE ASHING (LTA) APPROACH FOR ASSESSING THE PHYSICALLY PROTECTED ORGANIC MATTER IN SOIL AGGREGATES

Luigi P. D'Acqui[1*], Roberto Pini[2], Giacomo Certini[3]

[1]Istituto per lo Studio degli Ecosistemi, CNR, via Madonna del Piano, 50019 Sesto Fiorentino, Italy
[2]Istituto per lo Studio degli Ecosistemi, CNR, via Moruzzi 1, 56124 Pisa, Italy
[3]Dipartimento di Scienze delle Produzioni Agroalimentari e dell'Ambiente, Università di Firenze, Piazzale delle Cascine 28, 50144 Firenze, Italy

ABSTRACT

Physical stabilization of soil organic matter (SOM) was assessed by a Low-temperature ashing (LTA) approach in cultivated or afforested minesoils with different species for 30 years. Aggregates of 0.5 to 1.0 mm were subjected to LTA by oxygen plasma, a technique able to progressively remove SOM with minimal or no damage to mineral constituents and soil fabric. All investigated minesoils had behaved as C sinks, although to a different extent depending on land use, the cultivated soil storing around half C than the afforested ones. The C in the aggregates after 48h of LTA treatment ranged from 49 to 65% of total C, depending on land use, and it was able to resist to longer treatments. This C was confidently assumed as the one contained in the inner side of these aggregates, and the best protected from decay.
The study showed the effectiveness of LTA to distinguish soil C pools benefiting from different physical protections within aggregates and confirmed that this technique could give an important support for assessing the potential of soils to sequester C and\or of the responses of individual ecosystems to changes in land use and management. In addition, this approach could be useful for the establishment of the baseline of organic C level in different soils. In fact, it could give the actual amount of stabilized C in the soil.

Keywords: Low-temperature ashing (LTA); carbon sequestration; physical protection; soil structure; minesoils

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The assessment of stabilised OM in soil aggregates is of paramount importance for implementing strategies to increase C sequestration in soil and consequently mitigate climate change.
Soil organic carbon dynamics are driven not only by the intrinsic properties of the organic matter itself but also by the environmental and biological influences, which may reduce the rate of decomposition, thereby allowing the organic matter to persist for long time (Schmidt *et al.*, 2011). The physical protection of C in soil aggregates is a sound parameter to describe the processes that affect directly or indirectly the sequestration of C in soil. The main objective of this work is revealing the possibility to measure the actual C stabilized in soil aggregates. For this purpose a reclaimed minesoil, cultivated or afforested with different species since 30 years was investigated. In particular, the studied land uses were: 1) a managed (thinned and mowed) English oak (*Quercus robur* L.) plantation; 2) a similarly managed 1:1 mixed plantation of Italian alder (*Alnus cordata* Loisel.) and English oak; 3) an unmanaged portion of the mixed plantation; 4) a cropland tilled and manured every year (D'Acqui *et al.*, 2017).

METHODOLOGY

The proposed approach to disentangle the role of physical protection of aggregates to SOM is based on Low-Temperature Ashing (LTA) by oxygen plasma, which enables a controlled removal of SOM from the surface of soil samples inwards without damaging the inorganic constituents or the aggregate fabric. On this basis, it is possible to obtain a dynamic of C removal from soil aggregates. The LTA treatment was performed by the self-assembled equipment described in D'Acqui *et al.* (1999). Aggregates of 0.5 to 1.0 mm were allocated in the LTA reactor and evacuated to 45 Pa under an oxygen 20 mL min^{-1} flow rate. Oxygen plasma was produced applying a radiofrequency of 13.56 MHz by a power input of 100 W and a reflected power of 5 W. In these conditions the surface temperature was maintained below 80 °C. Carbon was measured by dry combustion with a Carlo Erba NA 1500 CHNS Analyzer (Milan, Italy) on three aliquots (~1 g) per sample exposed to different treatment times, i.e. 5h, 24h, and 48h by LTA. No further C removal was noticed beyond 48h, which was therefore selected as longest LTA exposition time and the residual C assumed as "physically protected C. Such physical protection was however proved by the fact that, after grinding the 48h LTA treated aggregates and successively subjected again to LTA, they lost almost completely their C content.

RESULTS

The C removal from the aggregates is related to the nature and organization of soil particles that, in turn, determine the size, shape and network of pores and the exposition of organic matter at the plasma-substrate interface. The diffusion of plasma into microaggregates is low, similarly to gases in soil, hence its oxidative power mimics natural oxidative processes. There is a relatively rapid reduction of C in the first 5 hours of treatment (Figure 1), then the slope decreases much up to reach a "plateau" phase at around 20 h, when evidently no further C is removed.

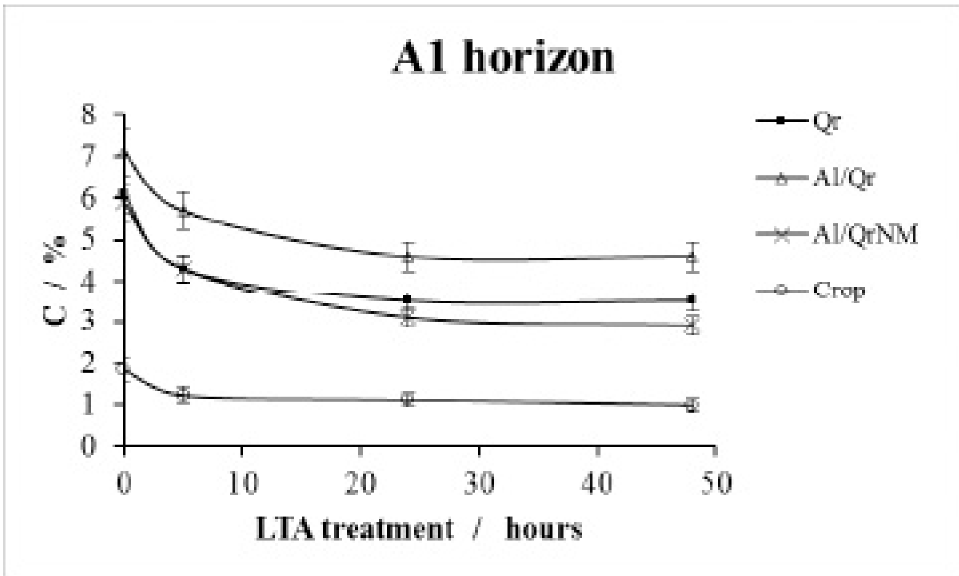

Fig. 1: C removal by LTA from 0.5-1.0 mm aggregates in the A1 horizon of afforested or 0-5 cm layer in cropped soil (D'Acqui et al., 2017). Qr=managed English oak (Quercus robur L.) plantation, Al/Qr=managed mixed plantation of English oak and Italian alder (Alnus cordata Loisel.), Al/QrNM=unmanaged mixed plantation of English oak and Italian alder, Crop= cropland.

Table 1: Residual C in 0.5-1.0 mm aggregates after different times of LTA treatment. Total C is the one measured in untreated aggregates, i.e. 0 h LTA treatment. The residual C after 48h of LTA treatment was assumed as "protected C". Number in brackets are standard deviations of n=3. (D'Acqui et al., 2017)
Qr=managed English oak (Quercus robur L.) plantation, Al/Qr=managed mixed plantation of English oak and Italian alder (Alnus cordata Loisel.), Al/QrNM=unmanaged mixed plantation of English oak and Italian alder, Crop=cropland..

Residual C				
A1 horizon				
	Qr	Al/Qr	Al/QrNM	Crop
LTA treatment			C (%)	
0 h	6.1 (±0.3)	7.1 (±0.3)	5.9 (±0.3)	1.8 (±0.2)
5 h	4.3 (±0.2)	5.7 (±0.3)	4.3 (±0.2)	1.2 (±0.1)
24 h	3.5 (±0.2)	4.6 (±0.2)	3.1 (±0.1)	1.1 (±0.1)
48 h	3.5 (±0.2)	4.6 (±0.2)	2.9 (±0.1)	1.0 (±0.1)

DISCUSSION

Figure 1 and Table 1 both show that almost half of initial C content (0h LTA treatment) of all soils was physically protected. Protection within the aggregates entails the inaccessibility of soil microbes to organic compounds and a limitation in O_2 availability with the consequent reduction of bio-chemical activities (Six *et al.*, 2004; von Lützow *et al.*, 2006; Stockmann *et al.*, 2013). As a consequence, the physically protected SOM undergoes lower rate of decomposition and longer turnover time than the rest of SOM (Shrestha and Lal, 2006; Stockmann *et al.*, 2013). The significant C loss in the first 5 hours of LTA treatment (around 30%) both in the forest and the cropland is most probably due to the oxidation of matter located in easily accessible niches of aggregates and not closely associated with minerals (Stockmann *et al.*, 2013). Such a SOC fraction could be assumed as the one most prone to bio-chemical decomposition processes, hence with shorter turnover time. On the other hand, the SOC fraction oxidised by further LTA treatment, i.e. the one removed between 5h and 48h of treatment, which amounts to around the 22% of initial C in afforested soils and 6% in the cultivated soil, respectively, can be considered as partially protected, because unreachable or intimately bound to mineral particles. Such organic fraction can be assumed to have intermediate turnover time.

CONCLUSIONS

The approach used in this study provided insights into the amount of "physically protected C" in minesoils and confirmed that the LTA technique could give an important help for the assessment of the potential of soils in sequestering C and\or of the responses of individual ecosystems to changes in land use and management. In addition, this approach could be useful for the establishment of the baseline of organic C level in different soils. In fact, it could give the actual amount of stabilized C in the soil.

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1.13 | THE EFFECT OF THE CONTINUUM REMOVAL IN MEASURING SOIL ORGANIC CARBON WITH NEAR INFRARED SPECTROSCOPY (NIRS) IN THE SENEGAL SAHELIAN SOILS.

M. Loum[1], M. Diack[2], M. A. SOW[3], P.N. Diagne[3]

macoumbaloum@yahoo.fr , mateugue.diack@ugb.edu.sn, mamadaboso@yahoo.fr , papanekhou@yahoo.fr

[1] Institut National de Pédologie (SENEGAL) ,[2] Université Gaston Berger de Saint-Louis

Corresponding author: pedologie.inp@maer.gouv.sn

The need to have detailed information on soils with alternative methods, at lower cost, is a real challenge in the developing countries where the availability of analytical equipment of soils remains widely insufficient. Organic matter is recognized as good indicators of the quality of the soil in the sahelian agrosystem in Senegal. In this fact, calibration of models to measure the agro-pedological variables becomes an issue of sustainable development knowing that agricultural production plays a major role in food security and climate change The objective of this study was to evaluate the effect of the continuum removal (CR) in the validation of the accurate prediction model of the soil properties with Vis-NIR spectroscopy data. We used the remote sensing software ENVI 4.7 to compute the CR function where the value of the continuum for each sample and for each spectral wavelength was obtained by dividing the reflectance values of the full spectrum (FS) with those of the continuum curve (CC). The partial least square regression (PLSR) model was applied in the spectral data from the soil of the Senegal sahelian region. It was calibrated with both data from the full spectrum (FS) and those obtained after the application of the continuum removal. Our findings show a positive effect of the application of CR in the measure of soil organic carbon. In calibration, the R2 increased up to 10% with the continuum removal in the model of 12 components (CP). In terms of validation, it's the 15-component model which is the most accurate with the same range in calibration between the FS and the CR. The lowest RMSE ranged from 0.04 with the FS to 0.03 with the application of the CR in calibration and validation. These results show the interest of this study as soil organic carbon is recognized as a key indicator of fertility of the soil in sahelian-african regions. For future studies, it's important to apply the model of neural networks to better evaluate the effect of the CR in predicting soil properties from the spectral data and other methods of preprocessing like the multiplicative scatter correction (msc).

Key words : "NIRS", "soil proprieties", "continuum removal", "PLSR model"

1.14 | TOWARDS A TIER 3 APPROACH TO ESTIMATE SOC STOCKS AT SUB-REGIONAL SCALE IN SOUTHERN ITALY

Roberta Farina*, Claudia Di Bene, Rosa Francaviglia, Rosario Napoli, Alessandro Marchetti

Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria – Centro di ricerca per lo studio delle relazioni tra pianta e suolo (CREA-RPS), via della Navicella 2-4, 00184 Rome - Italy
*Corresponding author: roberta.farina@crea.gov.it, phone +39 067005413, fax +39 067005711

ABSTRACT

A combined modeling - GIS platform was developed to estimate the long term soil organic carbon (SOC) stocks and CO_2 emissions with the IPCC Tier 3 approach, in relation to local soil properties and climate, land use (LU), and land use change (LUC). Arable rainfed (ACR) and irrigated crops (ACI), vines (VIN), olives (OLI), and grasslands (GL) were considered as LUs; the transition from arable to permanent crops (A2P) and from permanent to arable (P2A) as LUCs. Model simulations showed that OLI and VIN were able to store a considerable amount of C. Conversely, arable crops led to a reduction which was higher when the rotation included an irrigated summer crop. The transition A2P showed higher SOC stock increases compared to P2A. The CO_2-C released to the atmosphere was higher in ACI, P2A, and VIN, lower in OLI and GL. Main mitigation and adaptation strategies to prevent SOC decline in the study area are: conservation tillage, improvement of crop rotations with legume crops, retention of crop residues into the field, rational use of irrigation for the summer crop, use of cover crops during the winter season to replace fallow periods, and supply of organic fertilizers (compost or manure).

Keywords: CO_2 emissions, Land use; Land use change; Mediterranean systems, GIS, EBK spatialization; RothC10N model; Soil organic carbon.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

In Mediterranean cropping systems, agricultural practices were progressively intensified, with intense mechanization, high external inputs and monocropping with major environmental impacts and agro-ecosystem services reduction. To date, semi-arid areas of Southern Italy are dominated by arable rainfed cropping systems (winter cereals-based rotations, ACR), irrigated crops (winter cereals in rotation with irrigated tomato, ACI), forage-based systems (GL), woody crops (such as vines, VIN, and olives, OLI) (Di Bene *et al.*, 2016). In agricultural soils intensive management practices, like deep ploughing, land use changes from both pasture to rotation or pasture to crop, crop residue removal, and erosion, causes SOC depletion. Thus, prediction of soil organic carbon (SOC) stocks has become a key issue over recent years, because of the potential contribution to climate change of soil carbon dioxide (CO_2) emissions. Soils, if well managed, represent a possible sink of C and a viable option to reduce the CO_2 concentration in atmosphere. Soil C stocks at regional or national level are influenced by many factors, such as climate, soil properties, land use (LU) and land use change (LUC) and agricultural management that act and interact with complex relationship and exhibit a strong spatial variability. Studies of SOC dynamics based on field experiments and local surveys are costly and time consuming. Alternatively, many process-oriented models are available for predicting SOC dynamics on a temporal and spatial basis (Farina *et al.*, 2016). The Intergovernmental Panel on Climate Change (IPCC) in the Guidelines for National GHG (greenhouse gas emissions) inventories and reporting (IPCC, 2006), set up the methodologies for estimating soil C stock, considering three different levels of complexity or Tiers (1, 2, and 3). Tier 1 and 2 use the same methodological approach but with default or country-specific emission factors respectively. Tier 3 employs higher-order methods and resolutions, that include models and inventory measurement systems, repeated over-time, possibly disaggregated at the sub-national level (IPCC, 2006).
The study aimed to propose a methodology to predict the effect of LU and LUC in Southern Italy (province of Foggia) on the temporal and spatial variability of soil C and CO_2 emissions between 1994 and 2013, using a process-based modelling approach and a GIS-based spatialization procedure. The main purposes was: i) evaluating temporal and spatial SOC stock variations affected by LU, LUC from permanent to arable crops (P2A) and vice versa (A2P), crop management, using RothC10N model (Farina *et al.*, 2013), a RothC (Coleman *et al.*, 1997) version modified to simulate SOC dynamics in Mediterranean

regions; and ii) understanding the factors influencing SOC sequestration and CO_2 emissions to propose alternative effective management practices to be implemented in the agro-environmental policies.

The novelty of this study is represented by the interpolation at spatial scale of the RothC10N model predictions applied to annual crop rotations, using the Empirical Bayesian Kriging (EBK) procedure, that, to our knowledge, has not been used before for regional SOC stock assessments.

METHODOLOGY

To estimate the SOC stock and CO_2 emissions at regional level, a tool was developed to link the SOC dynamics simulation model with a soil, land use and climate spatially explicit database used with a GIS. The main steps were:

- Set-up of a harmonized spatially explicit database, obtained by assembling in a GIS environment soil, climate, and 20-yrs crop succession data.
- Run the RothC10N model to simulate 20-yrs SOC dynamics in batch mode that routinely takes inputs from the unique spatially explicit database and writes SOC and CO_2 outputs to the same database.
- Use of EBK to interpolate the RothC10N SOC stocks predicted variation and CO_2 emissions to estimate the potential to sequester C of the different land uses and soil types.

RESULTS

EBK spatial interpolation of the SOC stock after 20-yrs (from RothC10N modeled crop successions) are presented in Fig. 1 and Table 1. The final EBK SOC stock was 19.0 Tg, 42.6 Mg C ha^{-1} (SD 5.9),. The SOC stock variation in 20 yrs was 0.3 Tg C. In detail, the arable crops stored 86.7% of the total SOC, of which 11.8 Tg in ACR and 5.6 by ACI. VIN and OLI stored 2.2 Tg C. Grassland and LUC stored 0.3 Tg C. The validation of modeled SOC with an independent set of data, showed a standardized error of -0.3 Mg C ha^{-1} and a standardized RMSE of 1.01 Mg C ha^{-1}.

CO_2 cumulated emissions in 20 years, were 16.95Tg CO_2-C and followed the ranking: ACR>ACI> VIN> OLI> GL > A2P> P2A> (Table 1).

Table 1. Empirical Bayesian Kriging (EBK) final spatialization of SOC stock and CO_2 emissions (2013) in the agricultural land use categories, in Foggia Province (Apulia Region, Italy).

	EBK spatialization						
Land use	Surface* (ha)	Mean SOC stock (Mg ha^{-1})	SD	Mean CO_2-C emissions (Mg ha^{-1})	SD	Amount of SOC (Tg)	Cumulated CO_2-C emissions (Tg)
Arable crops							
Rainfed rotations	261000	45.38	6.41	38.91	3.40	11.85	10.16
Irrigated rotations	105245	43.86	4.95	41.62	2.42	4.62	4.38
Woody crops							
Vines	31408	39.33	5.70	40.11	3.16	1.24	1.26
Olives	23365	42.27	7.51	38.25	3.14	0.99	0.89
Grasslands							
Pastures	6342	44.95	5.76	38.45	3.14	0.29	0.24
Land use change							
A2P	200	42.55	5.70	39.64	2.82	0.01	0.01
P2A	105	39.50	5.50	40.81	2.80	0.004	0.004
Total	427665	42.55	5.93	39.69	2.98	18.98	16.95

*Source: CORINE land cover 2012 map

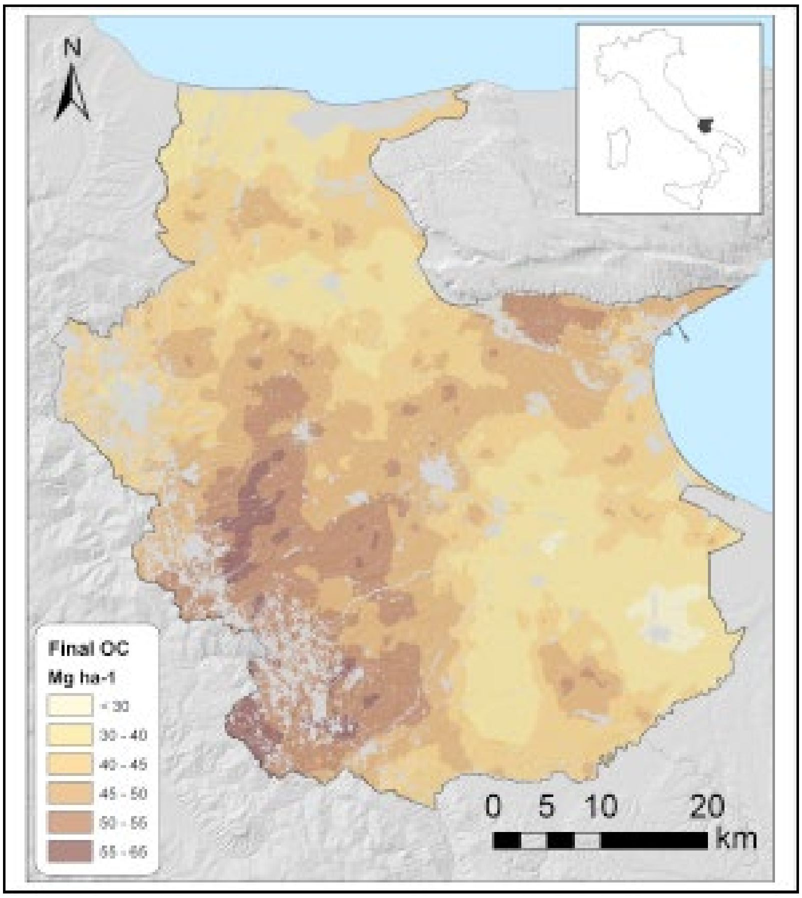

Fig. 1: Final regional SOC stock (Mg C ha^{-1}) obtained spatializing the RothC10N output by the EBK procedure in Foggia Province in 2013.

DISCUSSION

Many authors agree on the importance of land use on soil C stocks level. The use of a detailed annual land-use history information allowed accurate simulations of SOC dynamics at regional scale. This approach provided information not only regarding the best land use in terms of C sequestration and CO_2 emissions and to predict the loss of C due to land use change, but also to evaluate which crop rotations, within the arable crops, could favor the C sequestration and reduce the soil CO_2 emissions. The different soil types showed a different value of C stock and a range of capacity in accumulating C in the period considered. The data obtained by overlaying the final EBK-SOC and CO_2-C maps with Corine Land Cover (CLC), allowed to predict the soil C stock and emissions for each land use category . All these information represent a valuable tool for the Kyoto Protocol accounting of soil C activities in cropland and grassland and as indicator for the effectiveness of the CAP (Common Agricultural Policies of European Union) measures to drive regional agricultural policies.

The long-term soil C assessment by modeling evidenced the following aspects: the soils C level in rainfed arable crops in the Foggia province, with the current practices, are almost at a steady state. The adoption of affordable practices like no-tillage (NT) or minimum tillage (MT), and the improvement of crop rotations with legume crops could increase the C sequestration. More complex is the management of rotations including summer crops, that are normally irrigated, and in this study showed important losses. As alternative management options MT and NT and reduction of irrigation volumes are feasible options.

Despite the inherent limitations, due to the algorithms used to simulate the C dynamics, RothC10N have proved to produce robust estimations. Uncertainties can be linked to data input quality, but the model validation with an independent set of data demonstrated that estimations were accurate and that the model was able to reproduce in average the dynamics of C in the study area.

CONCLUSIONS

This study is one of the first attempts to predict SOC stocks and changes at a regional scale in Italy, by using a Tier 3 approach, linking a biophysical model with an EBK spatial interpolation in a GIS environment. The methodology can be applied to other regional estimations, provided that the relevant data are available. The other peculiarity of our study is that the point data database included actual cropping sequences, and hence reproduced with a high degree of accuracy the farm management. The RothC10N model showed to predict accurately the C dynamics during the twenty years simulations, as confirmed by the comparison with a set of independent data used for validation. The spatial predictions allowed to identify the land use potential to sequester SOC, and to diversify this potential on the basis of the soil type and crops sequence. Such information represent an useful tool for policy makers to assess the past agricultural policies effects on SOC trends and to provide effective agro-environmental measures for implementing soil C sequestration in the carbon-credit market. The accuracy of the predictions could be improved through a more detailed dataset regarding farms management and yields obtained by local survey or remote sensing. Finally RothC10N model could be improved to take into account the effect of conservation tillage, that is a suggested practice to reduce SOC losses and CO_2 emissions in the Mediterranean systems. The proposed methodology can be applied if similar types of data can be retrieved either in all Italy or in other countries.

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1.15 | A HIGH-RESOLUTION SPATIALLY-EXPLICIT METHODOLOGY TO ASSESS GLOBAL SOIL ORGANIC CARBON RESTORATION POTENTIAL

Luuk Fleskens[1,2*], Michel Bakkenes[3], Coen Ritsema[1] Ben ten Brink[3], Klaas Oostindie[1], Gudrun Schwilch[4]

[1]Soil Physics and Land Management Group, Wageningen University (WUR), Wageningen, The Netherlands
[2]Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, UK
[3]PBL-Netherlands Environmental Assessment Agency, The Hague, The Netherlands
[4]Centre for Development and Environment CDE, University of Bern, Switzerland

ABSTRACT

Soil carbon sequestration is high on the policy agenda but understanding of its climate change mitigation potential is limited. The bulk of available research on Soil Organic Carbon (SOC) restoration concentrates on local scales. We made a first high resolution spatially-explicit estimation of the global and regional SOC restoration potential over time transposing this research to a higher scale. We group available soil restoration technologies into 16 restoration categories. Of each category, we determine i) the potential for soil organic carbon (SOC) restoration based on a SOC restoration curve and ii) annual soil loss prevention over the period 2010-2050 derived from WOCAT expert opinion and a literature review. We then determined local suitability of a restoration category considering biome, climate, land use and topography. We used maps of SOC content (30 arc sec) derived from S-World in the natural, current, and continuing production loss scenario to 2050 in natural, agricultural and forestry areas as initial conditions and restoration ceilings. A full-scale SOC Restoration scenario is developed by selecting the most effective restoration technology considering both SOC restoration and soil loss prevention. The Restoration scenario results in a SOC restoration potential of about 15 Gt and prevention of 7 Gt SOC.

Keywords: Soil carbon sequestration; land degradation; sustainable land management; technology applicability limitations; integrated assessment.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Land degradation poses significant multi-faceted problems to mankind in terms of food and water security, economic development, and wellbeing, and is moreover closely intertwined with other grand challenges: loss of biodiversity and climate change. It is from such a broad perspective on challenges ahead that this study was conceptualised to explore potential options to restore soil organic carbon as one component of land degradation.

Recently, the role of soils and improved soil management in addressing global challenges has gained significant political momentum. The Sustainable Development Goals (SDGs) explicitly mention the urgent need to tackle land degradation, through target 15.3: to "strive towards Land Degradation Neutrality" by 2030. Also, at the UNFCCC COP21 the role of soils in climate change mitigation discussions was significantly upped, including the launch of a new policy initiative (4 per mille) to exploit soil carbon sequestration in agricultural land as a major potential sink. Bonn Challenge pledges from Africa and Latin America to restore 125 million ha of degraded/deforested land point to large scale interventions to improve soil status.

In response to these developments, there is an urgent need for spatial data to guide initiatives on restoration and prevention of land degradation: what practices are available, possible and feasible in each location, and how do they perform? Much research exists on restoration opportunities, but the bulk of it concentrates on local scales. A new approach is therefore much needed that, based on the state of knowledge, enables a global outlook on opportunities and challenges of SOC restoration. Such an approach necessarily combines results from field studies and experimentation with projections.

This paper addresses the following three aims: i) construction of average SOC restoration curves and soil loss reduction rates for different categories of SOC restoration practices, including both SLM practices and reforestation practices; ii) mapping the geographical applicability of each restoration category by application of decision rules per pixel on global map-based local conditions (e.g. biome, climate, land use and topography); and iii) determining a global and spatially-explicit soil carbon sequestration potential up to 2050. It does so by gathering evidence on the velocity of SOC restoration and prevention of SOC losses from SOC restoration practices, grouping restoration practices into categories, considering the applicability limitations of different restoration categories, selecting the most effective restoration categories in each pixel, and finally assessing the aggregated potential for global SOC restoration over all pixels with a restoration potential.

METHODOLOGY

We model the global SOC restoration potential in the top 30-cm of soil as a full-scale SOC Restoration scenario by aggregating the effects of the most effective restoration category in each location. The approach is built on the premise that SLM and reforestation practices can affect SOC in two ways:

1. Restoring SOC by improving vegetation cover, productivity, and enhancing soil health, either through amendment of chemical soil fertility (manuring, composting) or altering the physical or biological properties of soils (mostly indirectly).
2. Preventing SOC loss by controlling soil loss by reducing the susceptibility of soils to the impact of rain and wind, e.g. by re-vegetation, soil cover, wind and runoff barriers, and terracing, or by reducing oxidation by decreasing soil disturbance, e.g. through minimum tillage.

Most SLM practices contribute to both effects simultaneously. The extent to which they do so depends on time. However, the shape of the restoration and prevention trend lines is governed by a number of factors:

- Time after investment; A literature survey on results from multi-year and long-term field experiments of restoration options was conducted to construct a SOC restoration curve. This curve provided the basis for SLM category-specific curves.
- SOC restoration potential; S-World input data (Stoorvogel *et al.*, 2017; Stoorvogel *et al.*, under review) provided the potential SOC in soils under natural conditions and optimal agricultural conditions. The S-World methodology generates maps of SOC content under equilibrium conditions, but does not give an indication on the time required to achieve natural or optimal agricultural restoration ceilings. It is important to understand what time is required for restoration to set realistic goals. In this paper this question of restoration speed is addressed. The SOC restoration potential is defined as the difference between current and potential SOC.
- Current levels of soil loss and SOC loss; Schut *et al.* (2015) provide a methodology to establish ongoing trends of NDVI loss over the period 1982-2010. Ten Brink *et al.* (under review) extrapolated these trends towards 2050, corrected for climate change over the period 1982-2010 as a proxy for soil-based production loss (Trend scenario). NDVI losses were translated into SOC losses and diminution of topsoil depth over time due to soil erosion processes using the S-World modelling approach (Stoorvogel *et al.*, 2017). The simulation for 2050 was used in relation to current (2010) topsoil depth to determine annual soil loss over the 40-year interval considering current land use conditions. Top soil loss is considered linearly in this study.

The restoration category allocation mechanism and the determination of the speed and effectiveness of SOC restoration and SOC-loss prevention of the different restoration categories is the focal methodology described in this paper. A second methodological advancement is the use of the restoration category allocation mechanism in conjunction with S-World and the Trend scenario to quantify a first spatially-explicit estimation of global SOC restoration potential. The S-World and Trend scenario datasets provide the current best high-resolution spatially distributed current and potential SOC values on which to apply the allocation mechanism.

RESULTS

When the most effective restoration categories are allocated and theoretically implemented over the period 2010-2050, three outcomes are possible per pixel:

1. There is no restoration potential given the current land use.
2. The potential is not reached, restoration will continue
3. The potential level of restoration is reached; further increase of SOC stops.

Figure 1 shows the selected restoration category per pixel. As costs play no role, categories such as multi-faceted intensification dominate densely populated areas. Agroforestry and grazing management are other categories that are frequently selected.

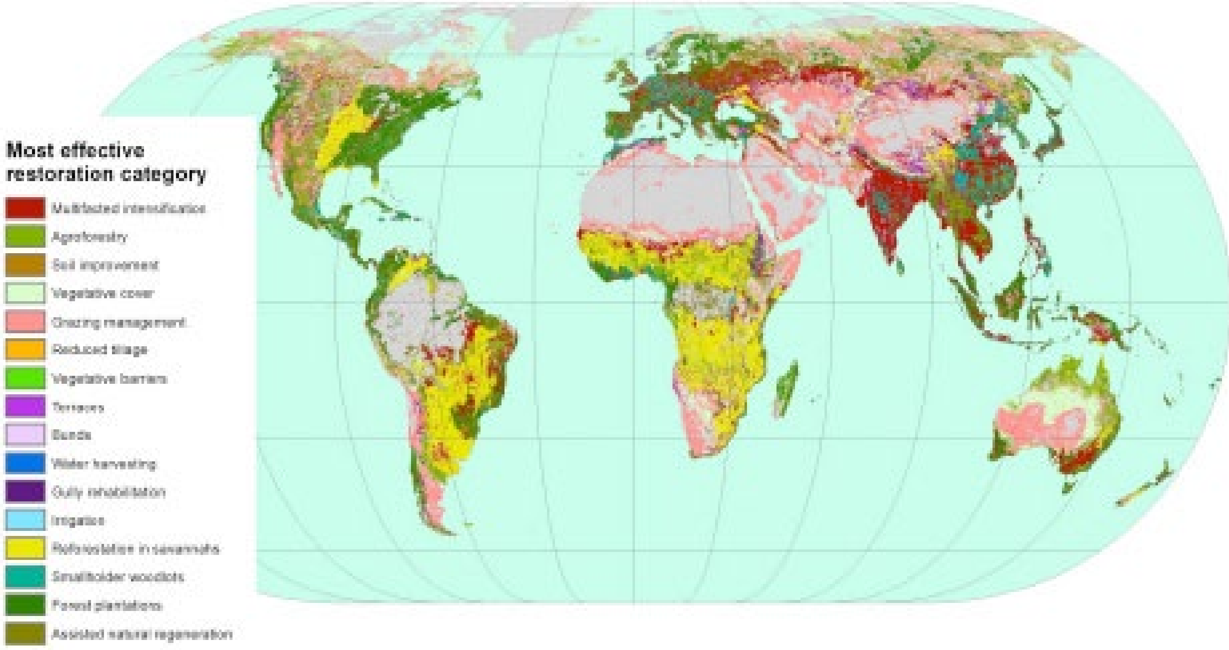

Fig. 1: Most effective restoration technology per location/pixel.

The total global SOC restoration potential of our assessment is 15 Gt. In our assessment, potential SOC restoration was governed by restoration speed and restoration ceilings. Preventable SOC losses by soil loss until 2050 amount to 7 Gt. The total SOC restoration potential is this determined at 22 Gt, spatially distributed as in Figure 2.

Fig. 2: Soil organic carbon restoration potential until 2050.

DISCUSSION

Smith *et al.* (2008) produced a global estimate of the potential of the agricultural sector to mitigate greenhouse gas emissions, including an assessment of global SOC restoration (maximum of 1.44 Gt $year^{-1}$). However, they did not consider applicability limitations of individual practices and assumed similar potentials across climatic zones, whereas current soil status was not considered. Sommer and Bossio (2014) estimated the carbon benefits of a highly ambitious but realistically-phased global C sequestration effort in agricultural and grazing land. Their phasing strategy paid due attention to a gradual decline of sequestration potential as soils approach the local equilibrium SOC content. In their approach, a peak SOC accumulation of 1.37 Gt year^{-1} is reached after ~20 years with a total C sequestration potential of 30-64 Gt over a 87-year period. Admunsen *et al.* (2015) build on the work of Smith *et al.* and project a total global effect of restoration of 16.4 Gt to be realized (and exhausted) by 2050. Paustian *et al.* (2016), also elaborating on Smith *et al.* (2008), estimate the total potential contribution of a wider set of soil management practices to be 2.18 Gt C year^{-1}.

There is generally a lack of data on the state of degradation of global soils, but even more so a study that points out the potential for different restoration practices. While other studies have already presented estimates of the global SOC restoration potential (Smith *et al.*, 2008; Sommer and Bossio, 2014), to our knowledge none has jointly considered the restoration of historical and prevention of ongoing losses, its spatial distribution, and related effective restoration categories. Most degraded areas can be restored, but the extent to which is often limited if the same land use is to continue. Hence productivity impacts of SOC restoration should be considered strategically.

The '4‰ Initiative' launched by the French Government, aiming stocking 4‰ SOC every year into cropland and grassland soils (Smith, 2008; IPCC, 2014) to counter balance 3.5 Gt C of the annual fossil fuels seems out of reach when considering our results.

CONCLUSIONS

In this paper, we presented a first, high resolution (30 arc second) and spatial-explicit assessment of the global SOC restoration potential. Considering 16 restoration categories covering both SLM and reforestation practices, we defined a theoretical full-scale Restoration scenario assuming instant implementation of the most effective restoration category in each pixel. The potential SOC restoration potential, considering both restoration of historical and prevention of ongoing SOC losses, amounts to 22 Gt. Comparing our results to findings by others, the potential contribution of SOC restoration to climate change mitigation is low, mainly governed by SOC ceilings associated to current land use.

1.16 | ESTIMATION OF REFERENCE SOIL ORGANIC CARBON FOR MINERAL SOILS OF COLOMBIA

Neira Fredy[1], Turriago Juan, Berrio Viviana

[1]email: fredyhnm@gmail.com.

ABSTRACT

Sponsored by FAO – The National Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), soil organic carbon reference content (SOC) was estimated for Colombian mineral soils using the IPCC methodology, which involves homologation of national soil and climate maps to the classification systems proposed by the Intergovernmental Panel on Climate Change "IPCC". Initially, Colombian soil map was homologated from USDA taxonomy to IPCC soil types. Consecutively, climatic zones from Caldas-Lang were also homologated to climate types proposed by the IPCC. Based on the integration of soil type maps and climatic zones (IPCC), resulting units were assigned the IPCC proposed content factors of SOC for every type of soil according to its climate unit. As soil units are composed of more than two soils, each unit was weighted with the percentage of soil type. Results indicate that for Colombian mineral soils, ranges vary from 6 and 135 tons of Carbon per hectare. The lowest values correspond to the driest and warmest areas and the highest values to humid and colder zones. The IPCC method classification systems are considered an approximation for Colombia. Some adjustments were required for both homologation systems (soil and climate), due to the fact that the IPCC system is global and for a national scale in equatorial conditions there are specific characteristics not considered by IPCC.

Keywords: Soil Organic Carbon, Colombia, IPCC methodology

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The main objective is to estimate lost carbon in tonnes per hectare per year for a depth of 30 cm, taking into account soil types and living areas defined by the IPCC, using factors proposed by the IPCC reference content of Carbon in soils and based on factors of use, management and proposed inputs.

METHODOLOGY

The methodology consisted in integrating soil and climate type information for Colombia with the categories of use defined by the IPCC and then taking the reference Organic Carbon values for soils established by the IPCC by climatic zone. Climate zones for Colombia were obtained based on the scheme proposed by the IPCC (Vol. 4 IPCC, 2006). The climate zones determined by the "Forest and Carbon Monitoring System" (SMByC) project were homologated to IPCC climate zones.

Based on the integration of soil type and climatic zone maps (IPCC), each of the soil unit was weighted, taking into account Soil Organic Carbon (SOC) reference factors. IPCC defines seven soil types such as: Organic soils, Sandy soils, Wetland soils, Volcanic soils, Spodic soils, Low Activity Clays soils and High Activity Clays (HAC).

The determination of the SOC of reference for the mineral soils of Colombia was made taking into account the values defined by the IPCC, in Vol. 4, table 2.3 (IPCC, 2006). From this table, reference values were taken for sandy soils, volcanic soils, spodic soils, low activity clay and high activity clay soils. For wetland soils, Table 5.2 of the wetland supplement document (IPCC, 2014) was used.

Table 1. SOC reference values for mineral soils (IPCC, 2006 and 2014)

Climate zones *(IPCC)	IPCC Soil type					
	Sandy soils	Wet land soils	Volcanic soils	Spodic soils	Low Activity Clay soils "LAC"	High Activity Clay soils "HAC"
Nival	10	116	20	117	NA	68
Cold temperate dry	34	87	20	NA	33	50
Cold temperate humid	71	128	130	115	85	95
Tropical dry	31	22	50	NA	35	38
Tropical humid	39	68	70	NA	47	65
Tropical Mountainous	34	82	80	NA	63	88
Tropical moist	66	49	130	NA	60	44
Warm temperate dry	19	74	70	NA	24	38
Warm temperate humid	34	135	80	NA	63	88

* Climate zones adjusted with national data.

Due to the general detail scale of the soil map, each soil unit has more than one type of soil, so the reference SOC value is weighted according to the unit content. The objective of the weighting is to give approximate values to each soil unit and avoid either over or under-estimation of carbon content in soils.

The SOC value for each unit (SOCu) was estimated as follows:

$$SOCu = (SOC_{s1} *\% \, s1 + ... + SOC_{sn} *\% \, sn) / 100$$

Where "*s1*" corresponds to soil 1 and "*sn*" to the possibilities of different soil types in the unit.

The weighting was done taking into account only mineral soils. For mixed units, where a portion of the unit corresponds to one or more mineral soils and another part to organic soils, only the mineral soils and the total percentage of them were taken into account.

RESULTS

Although the seven IPCC soil types are present in Colombia, the low-activity clay soils predominate in 66.7% of the country soils, distributed mainly in the Amazonas, Orinoquia, Pacific, northern and southern parts of the Caribbean region and other dispersed areas in the Andean region. However, not all of these soils have similar characteristics. Soils with totally different taxonomic differences are grouped into this type: *Entisols*, *Inceptisols*, *Aridisols*, *Ultisols* and *Oxisols*. The genetic conditions of each of those soils vary. Climatically, they cover the conditions from the soils in the climates to the floors of the very humid zones. Due to relief conditions, they predominate in relatively flat areas but also occur in areas with steep slopes (especially *Entisols*).
Wetland soils occupy the second place, with 12.4% of the country area. These soils include those with high moisture content or *aquic* soil moisture regimes associated with poor drainage. It includes partially covered soils, or enclosures in relatively flat areas from warm climates in lowlands to very cold climates, in high mountain or paramos ecosystems (Andean moors).

The volcanic soils refer to *Andisols* originated from volcanic ash. It includes the soils of taxonomic order *Andisol* according to the American taxonomy and other soils of intergrades to *Andisol* that presents / displays at least 30 cm of the surface with *andic* properties It is estimated that 7.3% of the country as soils *Andisols*. Sandy soils include *Entisols* with high sand content, mainly the suborder: "*psaments*" as well as sand beaches or sandy deposits.

High Activity Clay soils (HAC) mainly correspond to the *Mollisol* and *Vertisol* taxonomic orders, but also include some intergrades to "*mollic*" and "*vertic*" *Inceptisols* and *Alfisols*, with high contents of bases (cations). This is because it is not possible for the country to determine the type of soil clays, due to lack of data, in this case mineral clay analysis. It is estimated that 3.8% of the country's soils are soils of "high activity clays". Estimated organic soils in Colombia are about 0.5% of the country area. Those correspond mainly to the order *Histosols* and some intergrades that present organic materials in the upper 30 cm of their surface layer. Figure 1 shows distribution of IPCC soil types for Colombia. Most soil units are composed by two or more different type soils.

Table 2. Distribution of IPCC soil types for Colombia

IPCC Soil type	Area (Km2)	% of the Country
Organic soils	5795.11	0.51
Sandy soils	72762.36	6.39
Wetland soils	141319.37	12.41
Volcanic soils	83249.48	7.31
Spodic soils	81.59	0.01
Low Activity Clays (LAC)	760138.24	66.73
High Activity Clays (HAC)	43234.11	3.80
No soil – others	13796.05	1.21
Water	18818.68	1.65
Evaluated area	1139194.99	100.00

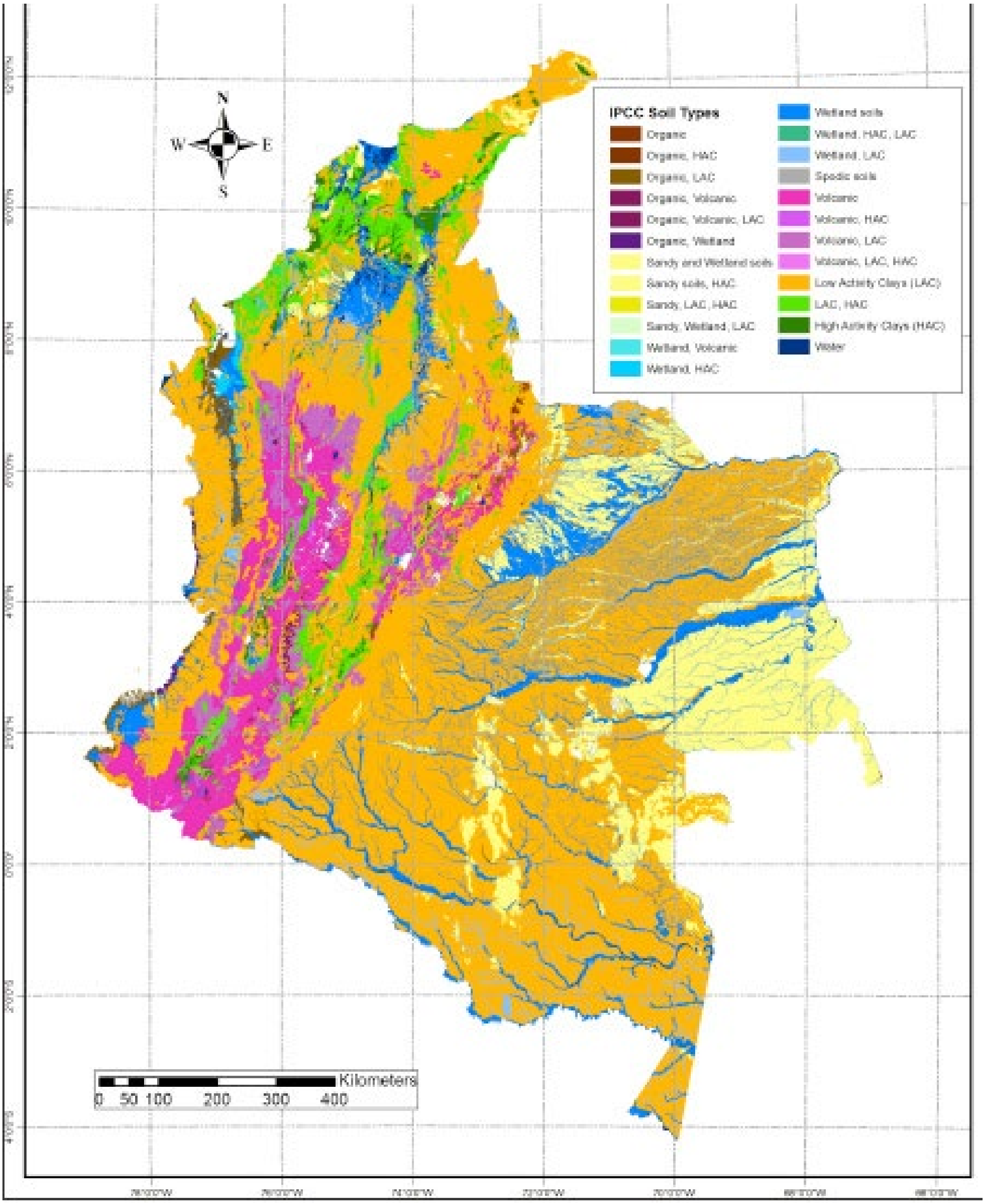

Fig. 1: IPCC Soil Types of Colombia

According to the IPCC classification system of climate zones, adjusted for Colombia, 62% of the country corresponds to "Tropical moist". The estimated area is higher when adjusting classification considering higher limits of precipitation values for very humid areas than when using IPCC classification without adjusting. This results in a difference between a large part of the Pacific region with the most extreme precipitation values (from more than 7500 mm up to 1400 mm per year), with other regions such as the Orinoquia and Amazonia where precipitation values are less than 4000 mm per year.

It is estimated 6.5% of the national area as "Tropical wet", which corresponds mainly to the Pacific region with some inclusions in the south of the Caribbean and to the east of the Andes.

Most of the Caribbean lowlands, along with the Cauca and Magdalena valleys and a small area in the Arauca department are considered "Tropical dry", covering about 10.5% of the country. 1

The climate zones considered as "Tropical montane" is estimated to be about 10% of the country, located mainly in the lowlands of the Andean region.

The climate zone "nival" is used to replace the "Dry Polar" class purposed by IPCC. This, in order to avoid names that do not correspond to a latitudinal or geographical position. The "nival" climate zone estimated for Colombia is about 0.02% of the country, located in the top of the Andes.

Table 3. IPCC climate zones adjusted for Colombia

IPCC climate zone	Area (ha)	%
Nival	25456.0	0.02
Cold temperate humid (Frio templado húmedo)	4254134.0	3.73
Warm temperate humid (Cálido templado húmedo)	7252057.5	6.36
Warm temperate dry (Cálido templado seco)	561067.0	0.49
Tropical montane (Tropical montano)	11374199.7	9.98
Tropical dry (Tropical seco)	11950956.0	10.49
Tropical humid (Tropical húmedo)	71128239.5	62.43
Tropical moist (Tropical muy húmedo)	7391420.0	6.49
Total evaluated	113937529.7	100.00

Once the SOC values for each soil unit were obtained, the area estimate was obtained, obtaining a total of 5.95 Gigatonnes of Carbon for the evaluated area of Colombia (1,139,960.4 Km^2). This value indicates an estimated Carbon content in soils under natural conditions of original coverage, not under agriculture or anthropic use.

As product, a map of units each with a SOC value was obtained. The ranges obtained vary between 6 and 135 (tonnes of Carbon per hectare). Areas in dark indicate the highest values of carbon content.

For Colombia, taking into account the reference values for the mineral soils classified by the IPCC system and according to the IPCC climate types, the areas with the highest carbon content are located in the Andean region in the medium to high thermal floors and in the Valleys of the Cauca Rivers and high plateaus. The Caribbean region is the area where most of the soils have less carbon content, especially in Guajira. The Orinoquia, Amazonia and Pacific regions present relatively low carbon contents in mineral soils.

In general, most of the soils of Colombia have medium to low carbon contents, which would indicate that even small carbon losses could have very high impacts on the reduction of soil quality, since organic carbon is associated to the organic matter and is in turn with the properties and characteristics that determine the fertility of the soils.

Table 4. Estimated reference SOC per Natural Region

Mayor Natural Region	Tonnes of C (30 cm)
Amazonas	2182790682.0
Andes	1928400275.4
Caribbean	628269836.6

Orinoquia	851854167.6
Pacific	363641238.9

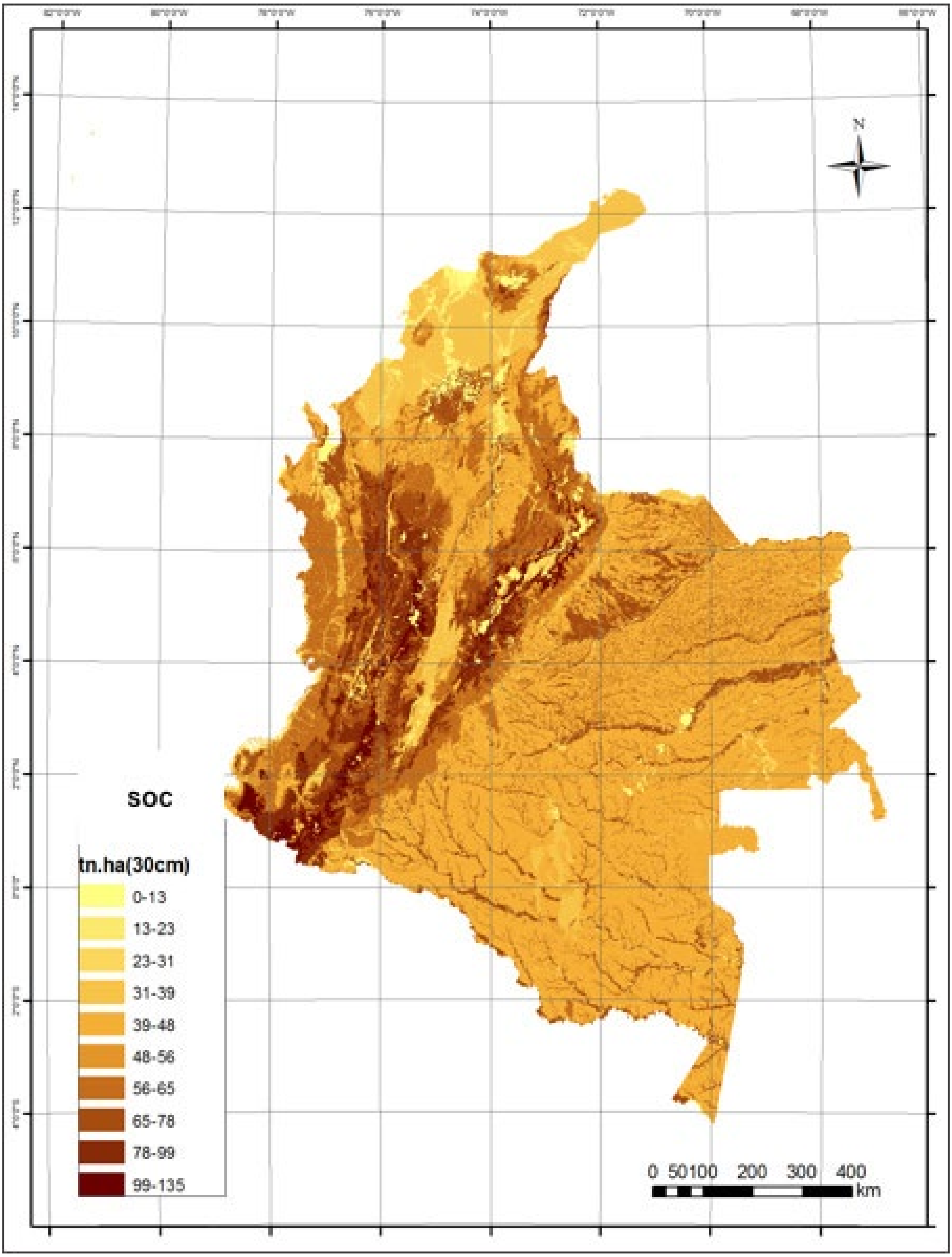

Fig. 2: Reference Organic Carbon (SOC) for Colombian mineral soils in tons of C per hectare

DISCUSSION AND CONCLUSIONS

The Colombian soil map used corresponds to a general scale, so the classification of the map units takes into account the percentages of each type of soil. This allows more accurate estimations and avoids either over or under estimating calculations such as soil content, loss and carbon emissions.

Based on the classification of IPCC soils for Colombia, organic soils in Colombia are about 0.5% while the remaining 99.5% correspond to mineral soils.

It is necessary to take into account that the Colombian soil map corresponds to a compilation of studies of soils of more than fifty years, reason why many of the soils, especially those used in agriculture have undergone processes of degradation and perhaps at present time correspond to other categories. Also, some soils such as organic or wetlands have undergone changes in the last decades, because of burning and drainage activities.

The climate zones established by the IPCC are very general, so a proposed adjustment was made based on the ranges established by the Monitoring System of Forest and Carbon “SMByC”. However, it is necessary to take into account that the climate zones do not present natural boundaries, due to the interpolation methods used, reason why it is suggested to consider adjustments to the interpolation methods, especially because a great part of Colombia does not have enough meteorological stations.

A revision of IPCC methodology must be considered, especially defining new soil types and new climate zones for equatorial and tropical lands, as well as definition of emissions factors related to those new zones.

In terms of soil types IPCC defines seven classes from which LAC are representing mostly *Oxisols* and *Ultisols*, while HAC represents *Mollisols* and *Vertisols*. As LAC indicates low fertility soils and HAC, high fertility soils, it is proposed to create a intermediate class for other soils that are not extreme either or low or high, this, to avoid under or over estimation of soil carbon content.

Climate IPCC zones must be also adjusted for tropical and equatorial zones because of great differences of humidity subclasses. IPCC does not consider for these zones mean temperatures under cero degrees where glaciers and surrounding ecosystems indicates differences in soil carbon. Montane zones should be differentiate by humid content, due that this zone varies from very dry to very humid or moist. And moist climates should be also differentiate in other classes especially because precipitation ranges vary up to 14000 mm per year in some regions.

Finally, adjustments can be very useful for countries that are located in equatorial latitudes, in Latin America, Asia and Africa, where most countries do not have enough data and the IPCC methodology can be used to obtain a more precise map of SOC.

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1.17 | APPLICATION OF THE FAO EX-ACT TOOL FOR CARBON BALANCE ACCOUNTING IN THE AGROECOSYSTEMS OF TAJIKISTAN

*Olga Golubeva[1], German Kust[2], Murod Ergashev[3],Olga Andreeva[4]

[1]Environmental Land management proj., CEP, Tajikistan; Moscow University PhD student. golubeva190@gmail.com
[2]World Bank, Consultant; Moscow Lomonosov State University, Professor. gkust@yandex.com
[3]Environmental Land management project, Committee for Environmental Protection, Tajikistan. soil_m@rambler.ru
[4]Moscow Lomonosov State University, Associate Professor. andreevala@yandex.ru

ABSTRACT

The FAO Ex-ACT tool was applied for the calculation of the carbon balance in the agro-ecosystems of Tajikistan. This method allows to make decisions on the use of low-carbon (low-emission) technologies in the agricultural sector. There were studied about 800 micro-projects implemented by local communities in the three macro-regions: Moist and semi-dry highlands; Moist foothills, and Dry downlands. It is shown that the Ex-Act can successfully define the groups of sustainable land management mini-projects by using the "carbon balance" criterion. According to this criterion the activities implemented by local communities in the highlands, are 10 times more effective than those in the lowlands. The highest specific efficiency for the formation of carbon stocks in soils and of the long-term sequestration in the above-ground biomass (per unit area) is typical for pasture management projects, horticulture, and deforestation control. Infrastructure projects (roads, greenhouses, etc.), on the contrary, contribute to increased CO_2 emissions and necessarily require appropriate compensatory measures.

Keywords: Ex-ACT, carbon balance, agricultural ecosystems, sustainable land management

INTRODUCTION, SCOPE AND MAIN OBJECTIVES.

There is no uniform opinion among scientists how to consider the role of agricultural sector in the carbon balance. Apparently, the most likely opinion should be considered that the various agricultural branches and technologies can contribute to both the emissions of greenhouse gases (GHG) and to reduce them. The last is linking with the absorption of carbon by formation of the soil humus (long term storage), and with the accumulation of the slowly mineralized biomass of wood and/or industrial crops.

For decision-makings on the use of low-carbon (low emission) technology in the agricultural sector it is important to know their effectiveness and the overall carbon balance, taking into account the above-ground and below-ground carbon pools in the complex of interrelated activities of the agricultural cycle. There is no single mechanism designed at the moment taking into account the absolute values of GHG emissions and carbon accumulation in agriculture, but there are mathematical models to assess the main trends in the carbon balance change within different land use and land management methods and approaches. The Ex-ACT modelling tool developed by FAO to assess the carbon balance is among these models, and is based on the 'estimated quantities' in agricultural and forestry projects (Bernoux *et al.*, 2010; Ex-ante Carbon-balance Tool - Ex-ACT). The method was used in our study to assess the "low-emission" efficiency of small-scale testing projects on sustainable land management. These projects are implementing in Tajikistan with the support of the World Bank, GEF and the Pilot Program for Climate Resilience within the project "Environmental land management and improving people livelihoods in rural areas". In the future, it is assumed that the carbon balance criterion will be used to recommend the most efficient technologies for dissemination. The tool can also be useful for the selection of project activities that provide the greatest benefits in economic terms and climate change mitigation, and evaluation results can be used during the financial and economic assessment of the projects (Cerri *et al.,* 2010).
Thus, the purpose of our study was solved with the help of two interrelated tasks: (a) using the criterion of "carbon-

reduction" to conduct a comparative assessment of agricultural technologies and complex of economic activities potentially considered to be sustainable in different natural and socio-economic conditions of a particular country; (b) to evaluate the possibility of using the Ex-ACT method to assess the perspectives of the carbon balance control at the level of communities and small farmers.

It is also important to note that the Ex-ACT method demonstrated good results in more than 20 project sites in Africa, Asia-Pacific and Latin America, but in Central Asia this tool was used at such a large scale for the first time.

METHODOLOGY

In total the Ex-ACT method was used for processing the information about 800 local projects implementing in the rural area Tajikistan in 2015-2016. We studied not only technologically different projects (cereal plants production, water management and irrigation, cattle breeding, pasture management, horticulture, road and canal rehabilitation, soil protection and eroson control, creenhouses, biofuel and alternative energy sources, etc.), but also compared the carbon balance of the similar activities implementing in different biophysical and economic conditions. In this respect, Tajikistan is very attractive country, because different natural zones are presented here: from high mountains with predominantly pastoral use, to the foothills with a rapidly developing horticulture and rainfed agriculture on slopes, upto the lowlands with well developed but devastated irrigation systems, where the current active search for effective cost-effective crop rotation (to replace the pre-existing monoculture of cotton using a water and soil conservation techniques) are taking place. The complexity as a combination of multicultural planting in the farms with cattle breeding is the main feature and at the same time a basis of the small private farms in Tajikistan. In combination with different climatic conditions a variety of impacts contributing to the carbon footprint provides a good platform for testing the functionality and applicability of the Ex-ACT method.

The Ex-ACT tool is a system for accounting carbon stocks and their changes in per unit area or yield, measured in equivalent tonnes of CO_2/ha per year. The carbon balance is calculated as the difference between the two scenarios of the development: "with" and "without" project activities. The Ex-ACT is based on the Microsoft Excel platform and consists of a number of modules, which describe the main directions of the agricultural and forestry sectors in terms of the carbon balance components, and works on the principle of "black box": after data entry in the relevant cells the output is the value of the carbon balance taking into account the capitalization time (we used the 20-years period). The main advantage of this approach is that it is accessible by trained users, who do not necessarily have a deep knowledge of the mechanisms of the carbon balance in the upper and below ground ecosystems (such as farmers, governmental field officers, NGOs, and others.). Therefore, the profile-based questionnaire was developed to collect primary data, where local farmers inserted the necessary information. Thereafter, it was checked for consistency and entered into a database for the purpose of further calculations. The coefficients used in some of the Ex-ACT modules were also checked (to be modified if need) on the basis of field and laboratory studies of the carbon balance in randomly selected sites.

RESULTS

The application of the Ex-ACT tool for small areas (less than 1 hectare) it was discovered that the sensitivity of the method is low, because the values of the carbon balance do not exceed tenths or even hundredths tonnes of CO_2. In these cases the combination of similar projects in one can help, or alternatively more details in the description of the project are required, which is often beyond the scope of a standard questionnaire.

With these modifications the results obtained characterize the project activities as positive in terms of reducing carbon emissions. The most effective is the horticulture development (more than 34% of the total project activities, leading to carbon sequestration), the second is the perennial planting (about 24%), and the third is the rehabilitation of irrigation systems and canals, especially in arid regions (about 19 %).

More detailed results are given in the tables. Effective interventions are characterized by a negative carbon balance (absorption and long-term carbon sequestration), inefficient are characterized by positive balances (emission into the atmosphere).

Macro-Region	Number of subprojects	Gross carbon balance	Average carbon balance per project	% of the total carbon balance	Carbon balance per year
Moist and semi-dry highlands (Tavildara and Jirgatol districts)	186	-42083	-226	63	-2077
Moist foothills (Baljuvon and Khovaling districts)	218	-12987	-60	19	-641
Dry lowlands (Farkhor and Kulob districts)	380	-11702	-31	18	-578
Total	784	-66771	-85	100	-3296

Table 1: Carbon balance in the project's macroregions

Type of activity	Macroregion	Sequestration: t CO_2-eq per hectare		
		Maximum	Mean	Minimum
Deforestation control	Midlands	-458	-255	-54
	Lowlands	-363	-312	-210
Horticulture	Highlands	-355	-176	-16
	Midlands	-183	-151	-64
	Lowlands	-153	-135	-92
Perennial meadows and pasture management	Highlands	-233	-63	-20
	Midlands	-44	-42	-32
	Lowlands	-26	-22	-16
New technologies for crop production	Highlands	-54	-39	-7
	Midlands	-54	-48	-44
	Lowlands	-30	-15	-4
Rehabilatation of irrigation canals	Highlands	-20	-19	-15
	Lowlands	-57	-24	-16
Water management	Highlands	-20	-19	-16
	Midlands	-21	-19	-17

Table 2: Specific carbon balance for some key activities

DISCUSSION

The data obtained show that although the investments in the micro-projects are of the close scale, but in different macro-regions and invested in the development or application of different technologies they have different results in the carbon deposition: almost 60% of the effective carbon sequestration accounts for sustainable land management activities implemented in the highlands, primarily due to the micro-projects in horticulture and pasture management. Specific efficiency of the micro-projects evaluated by the carbon absorption criterion is almost 10 times higher in the highlands than in the valleys with irrigated agriculture. This is largely due to the fact that the local communities in the highlands invest the bulk of funds for the projects directly contributing to improving the state of natural resources (soil, forests, alpine meadows, pastures), and in the valleys farmers mostly invest in infrastructure projects (roads, greenhouses, water facilities and channels).

The specific values of carbon emissions (equivalent tonnes CO_2/ha per year.) are of particular interest. The data clearly shows that the most effective measures for carbon storage are: deforestation control, horticulture, and pasture management. The stabling activities and infrastructure development and rehabilitation as well as greenhousing promote the largest carbon emissions.

CONCLUSIONS

The results suggest that the mathematical models underlying the method of Ex-ACT are able to adequately describe the carbon fluxes within different land-use types, and can used for the planning of environmentally effective activities in different biophysical conditions.

The method helped to determine these most effective activities in the region (by the criterion of the annual carbon emission): deforestation control, horticulture, and pasture management. The stabling activities and infrastructure development and rehabilitation as well as greenhousing promote the largest carbon emissions. Among the local communities, who have been granted an independent right to choose the direction of the project activities, the most effective in the development and application of low-emission and low-carbon technologies are those who live and operate in high-altitude regions. Their efficiency is 10 times higher compared with those communities living in low-lying valleys.

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1.18 | DIGITAL SOIL ORGANIC CARBON MAPPING ACROSS MEXICO AND THE CONTERMINOUS UNITED STATES

[1, 3] Mario Guevara, [2] Carlos O. Cruz-Gaistardo, [3] Carlos Arroyo, [4] Nathaniel Brunsell, [2] Carlos O. Cruz, [5] Grant Domke, [3] Julian Equihua, [6] Jorge Etchevers, [7] Daniel Hayes, [8] Tom Hengl, [2] Alejandro Ibelles, [5] Kris Johnson, [9] Ben de Jong, [10] Zamir Libohova, [11] Lucas Nave, [2] Jose L. Ornelas, [6] Fernando Paz, [3] Rainer Ressl, [12] Anita Schwartz, [2] Arturo Victoria, [10] Skye Wills and [1] Rodrigo Vargas

Correspondance to: mguevara@udel.edu

[1] Department of Plant and Soil Sciences, University of Delaware, Newark DE United States
[2] Instituto Nacional de Estadística y Geografía, Aguascalientes México
[3] Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México
[4] Department of Geography and Atmospheric Science, The University of Kansas, Lawrence, KS
[5] United States Forest Service, Pensilvannia and Minneapolis, United States.
[6] Colegio de Postgraduados, Texcoco, México
[7] School of Forest Resources University of Maine, Maine United States
[8] International Soil Resource Information Center, Wageningen, The Netherlands
[9] El Colegio de la Frontera Sur, Villahermosa, México
[10] National Soil Resource Conservation Service, Lincoln, Nebraska, United States
[11] The International Soil Carbon Network-University of Michigan Biological Station, Michigan
[12] Information Technologies, University of Delaware, Newark DE United States

Abstract: Soil organic carbon (SOC) is key to combat climate change. The objective was to develop a reproducible, interpretable and predictable model of SOC variability for the first 30cm depth across Mexico and conterminous United States. Linear models, machine learning algorithms and Bayesian statistics for upscaling SOC observations from the field to the continental scale were compared. All analyses were based on 38150 spatial coordinates representing soil organic carbon concentration in gr/cm^2 for the first 30 cm of mineral soil surface. Soil forming environment-related covariates were derived from remote sensing, digital terrain analysis and climate surfaces. The enhanced vegetation index, air temperature and the topographic wetness index were found to be the most informative predictors for SOC. The SOC estimates varied from 1.66 to 5.75 Pg for Mexican territory and from 21.53 to 29.87 Pg for conterminous United States. Therefore, we highlight important levels of remaining uncertainty and significant differences of SOC estimates associated with the number of covariates, the pixel size and the statistical performance of the modeling approaches.

Keywords: Soil organic carbon, Mexico, United States, digital soil mapping

Introduction

SOC has major implications in food and water security and therefore, accurate estimates are required to facilitate the formulation of reliable climate change adaptation guidelines and the establishment of global SOC monitoring networks (Stockmann *et al.*, 2015). However, uncertainty of current SOC available information is expected to be significant (Hengl *et al.*, 2017). The highest source of discrepancy across carbon cycle-related estimates concerns with soil carbon (Murray-Tortarolo *et al.*, 2016). Consensus is lacking on the size of global SOC stocks, their spatial distribution, and the carbon emissions from soils due to changes in land use and land cover (Scharlemann *et al.*, 2014). The variation of several estimates of SOC could relate to measurements based on differing spatial data-sets, which consist of various sample sizes, but may also reflect data collected at different times (Stockmann *et al.*, 2013).

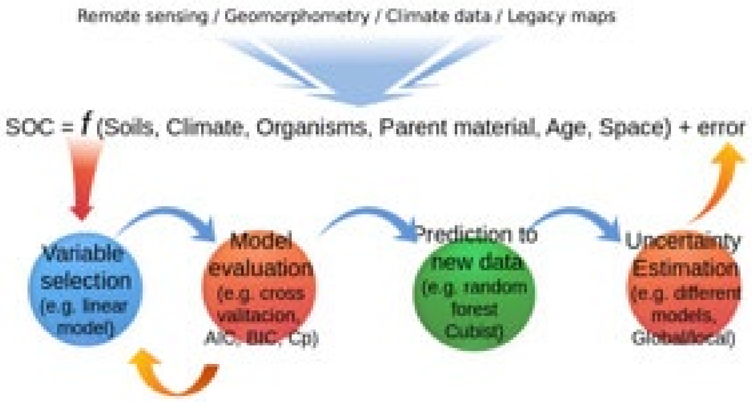

Fig 1. Digital soil mapping framework. SOC can be described as a functions (f) of the information available of the soil forming environment (McBratney et al., 2003). We use high performance computing to couple environmental information with SOC field information through lineal and machine learning statistics.

This study focuses in the spatial variability of SOC across Mexico and the conterminous United States. Country specific and regional efforts to map SOC are required to better inform global models and increase the accuracy of current SOC estimates. Here, we use digital soil mapping to predict SOC and its associated uncertainty aiming to provide a base line estimate useful for accounting and monitoring soil carbon. The objective of this study was to develop a reproducible, interpretable and predictable model of SOC variability for the first 30cm depth across Mexico and United States, aiming to support Global Soil Partnership implementation decisions across both countries.

METHODOLOGY

Digital Soil Mapping (DSM) is the creation and the population of a geographically referenced soil database, generated at a given resolution by using field and laboratory observation methods coupled with environmental data through quantitative relationships (see http://digitalsoilmapping.org/). We use digital soil mapping to predict SOC across Mexico and the conterminous United States.

We assume that different models will capture different portions of SOC variability (Fig. 1). We combine linear models with data driven statistics (kernel weighted nearest neighbors and random forests) for variable selection, prediction to new data and uncertainty estimation. We coupled remote sensing, geomorphometry and climate surfaces to generate a multiscale and multisource set of prediction factors. These prediction factors were provided by the ISRIC-SoilGrids250m initiative (www.soilgrids.org). SOC covariates were re-sampled using standard GIS procedures (bicubic splines) to a 5x5km regular grids. All analyses were based on 38150 spatial coordinates representing soil organic carbon concentration in gr/cm^2 for the first 30 cm of mineral soil surface calculated by the International Soil Carbon Network (http://iscn.fluxdata.org/) and The National Institute of Statistics and Geography (http://www.inegi.org.mx/).

We cross-validate our models to provide information criteria about model performance (e.g. R^2). We calculate uncertainties using the generic quantile regression forests framework (Meinshausen, 2006). This method was used to estimate the full conditional distribution of SOC as a function of its predictors (a statistical distribution of predicted values) for each pixel and then 95% intervals were calculated. We predict SOC variability at 5x5km and 250m of spatial resolution across both countries.

RESULTS

Highest correlations of SOC and the covariate space were found in the positive side with the enhanced vegetation index (r=0.44) and accumulated precipitation (r=0.39). In the negative side, most correlated variables with SOC were temperature (r=-0.24), and the topographic wetness index (r=-0.14). The highest correlation found among predictors was between the enhanced vegetation index and accumulated precipitation (r=0.87). This means that SOC tends to increase with vegetation, decrease with temperature and increase in areas where water tends to accumulate.

The best (linearly) correlated variables with SOC (temperature, vegetation index and the topographic wetness index) were selected to build a model that is easy interpretable, but conservative in terms of explained variance (10-fold cross validation R^2 0.29). The use of flexible (non-parametric) machine learning models increased the R^2 (0.39 for kernel weighted nearest neighbors and 0.49 for random forests). Figure 2 shows a SOC predictive map using random forests and the three selected prediction factors that we use to illustrate a potential scenario of SOC variability at the continental scale.

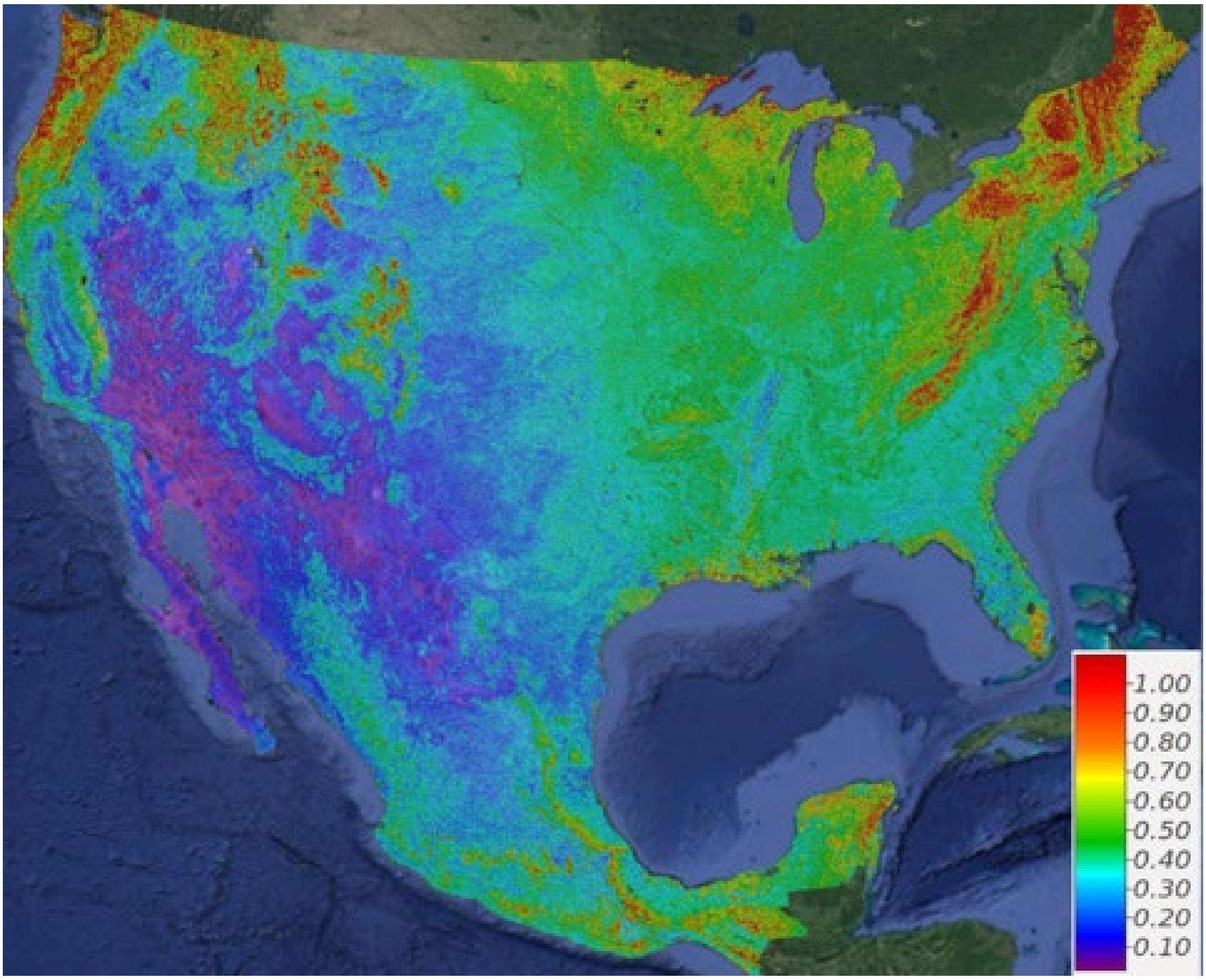

Fig 2. Digital SOC map (gr cm-2). This map is a visualization example of a SOC prediction derived using a random forest technique that was parameterized by the means of 10-fold cross validation using high performance computing.

Important differences in the statistical performance and the SOC stocks were observed by replacing the 5x5 selected set of predictors with the original 250m of spatial resolution SoilGrids covariants. Random forests (the model with higher accuracy to predict SOC in this study) was used to estimate a SOC stock of 1.74 Pg for Mexico and 21.53 Pg for Conterminous United States. The same model (using the same training data) predicted using the original SoilGrids250m predictors generated a SOC of 5.75 for Mexico to 29.33. With prediction factors at 250m of spatial resolution random forests was able to explain over >60% of SOC variability.

Despite the relatively high values of explained variance modeling SOC with random forests at 250m, the full conditional distribution reveal high uncertainty of SOC estimates. Figure 3A shows a visualization example of the spatial detail that is achieved by mapping SOC at 250m of spatial resolution across the surrounding of the San Francisco Bay, in western United States. Figure 3B shows the uncertainty (the range of confidence intervals at 95%) estimated for the same area. Note the relatively high uncertainty dominating SOC predicted values.

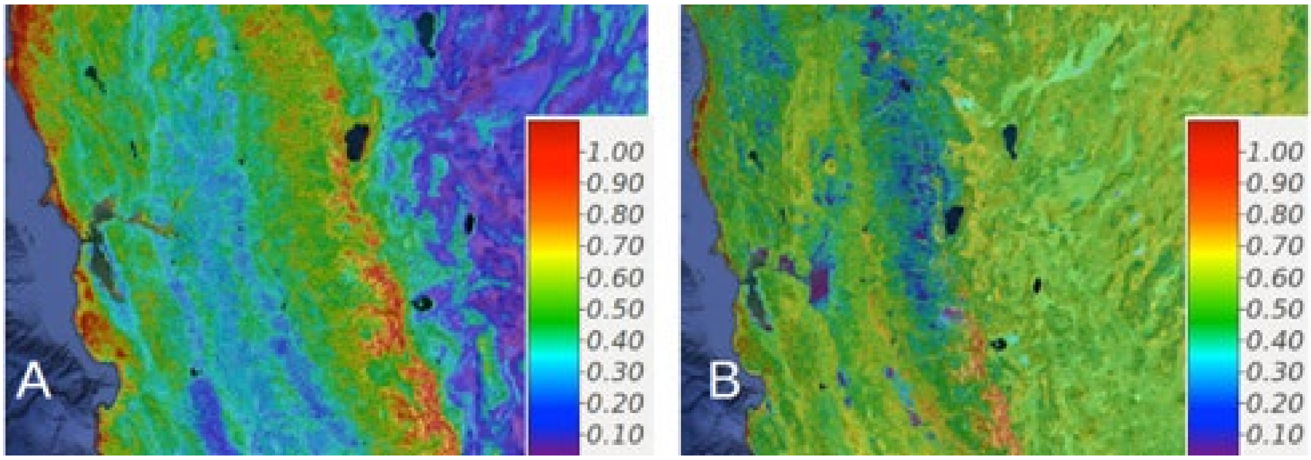

Fig 3. Model prediction and model uncertainty. Spatial detail achieved by mapping SOC at 250m. Prediction (A) and its associated uncertainty (B) derived using quantile regression forest. Note the relatively high uncertainty of the methods generating higher R2.

DISCUSSION

We provide a reproducible digital SOC mapping estimate across conterminous United States and Mexico to support Global Soil Partnership implementation decisions. We argue that digital SOC mapping efforts should consider to build both, interpretable and predictable models. In contrast to global efforts (e.g. Hengl *et al.* 2017). We found that only three variables are needed to generate a model that is easily interpretable. This random forest model also yields relatively high SOC explained variance. However, our results also indicate that there are important levels of remaining uncertainty (in some places up to two times the predicted value) in spatial SOC variability models (Figure 3B).

The spatial resolution used to predict SOC in digital soil mapping efforts represent a major source of uncertainty. Finding the right pixel size (Hengl, 2006) for SOC mapping is an important consideration to better understand the sources of uncertainty. Coarse scale predictions (e.g. 5x5km) generated lower SOC stocks and lower accuracy than fine scale predictions (e.g. 250m). SOC stocks derived at 250m of spatial resolution are closer to nationwide expert based SOC mapping efforts (Bliss *et al.*, 2014, Cruz-Gaistardo *et al.*, 2017) than predictions at 5x5km of spatial resolution. Generated information (e.g. models, maps) can be used to better inform global SOC geo-spatial information (Köchy *et al.*, 2015, Hengl *et al.* 2017). It cal also be used to improve the accuracy of national efforts to digitally map SOC in Mexico (Cruz-Cárdenas *et al.*, 2014) and the conterminous United States (Padarian *et al.*, 2015).

We argue that there are important levels of remaining uncertainty in SOC available information. Therefore this information should be used with extremely caution in policy decisions. Uncertainty in SOC information can outweigth our capacity to detect changes in the climate system and in the future of crops (Folberth *et al.*, 2016). Principles such as data sharing and reproducible research are important drivers to reduce uncertainty towards an reliable SOC map of North America in a reasonable time frame.

CONCLUSIONS

- Land modeling efforts to predict climate change rely on SOC estimates but no uncertainty assessment is available.
- We provide a spatially explicit measure of uncertainty of SOC variability models across Mexico and United States.
- We could explain over 60% of SOC variability at the spatial resolution of 250m.
- We found that topography, temperature, vegetation cover and its greenness are the most informative drivers for SOC at the continental scale.
- We report high uncertainties and significant differences of SOC estimates associated with the number of covariates, the pixel size and the statistical performance of the modeling approaches.

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1.19 | STATUS OF SOIL ORGANIC CARBON STOCKS IN THE SMALL ISLAND DEVELOPMENT STATES (SIDS)

Siosiua Halavatau[1]
[1][siosiuah@spc.int; Pacific Community (SPC) Land Resources Division, Suva, Fiji Islands]

ABSTRACT

The paper collated works on soil organic carbon in SIDS and establish SOC status in the islands. In volcanic islands the SOC is rapidly lost in the first few years from the top soil but is redistributed to the subsoil with SOC dominated by C4 sources. Though there is overall no loss but these changes indicate that careful management of topsoils is essential for maintaining soil fertility and hence crop productivity on these highly weathered soils.

The atolls is much more vulnerable and rely heavily on SOC for nutrient supply, CEC and regulating other properties like water holding capacity. Atolls will rely on compost and organic sources of nutrients which most time are low in critical nutrients like K, Fe, Cu and Mn.

Keywords: Volcanic soils, Atoll soils, Soil Organic Carbon, Mulching, Compost

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

SIDS are small, isolated islands or coastal areas of larger islands that are vulnerable to climate change and sea level rise, along with natural disasters like cyclones and droughts. They generally have inherently poor soils, and have suffered biodiversity loss. They are dependent on fossil fuel, have poor quality water and waste disposal issues. SIDS capacity to adapt to climate change and non-climate change stressors are low. They generally have weak technical, financial, and institutional capacity. They also do not have much capacity in terms of data essential for planning and decision making. Despite this, SIDS dwellers are committed to achieving food and nutrition security and to adopt climate smart agriculture.

The aim of this paper is to establish the status of soil organic carbon (SOC) in SIDS and ways found to help maintain or increase SOC in soils of the islands.

METHODOLOGY

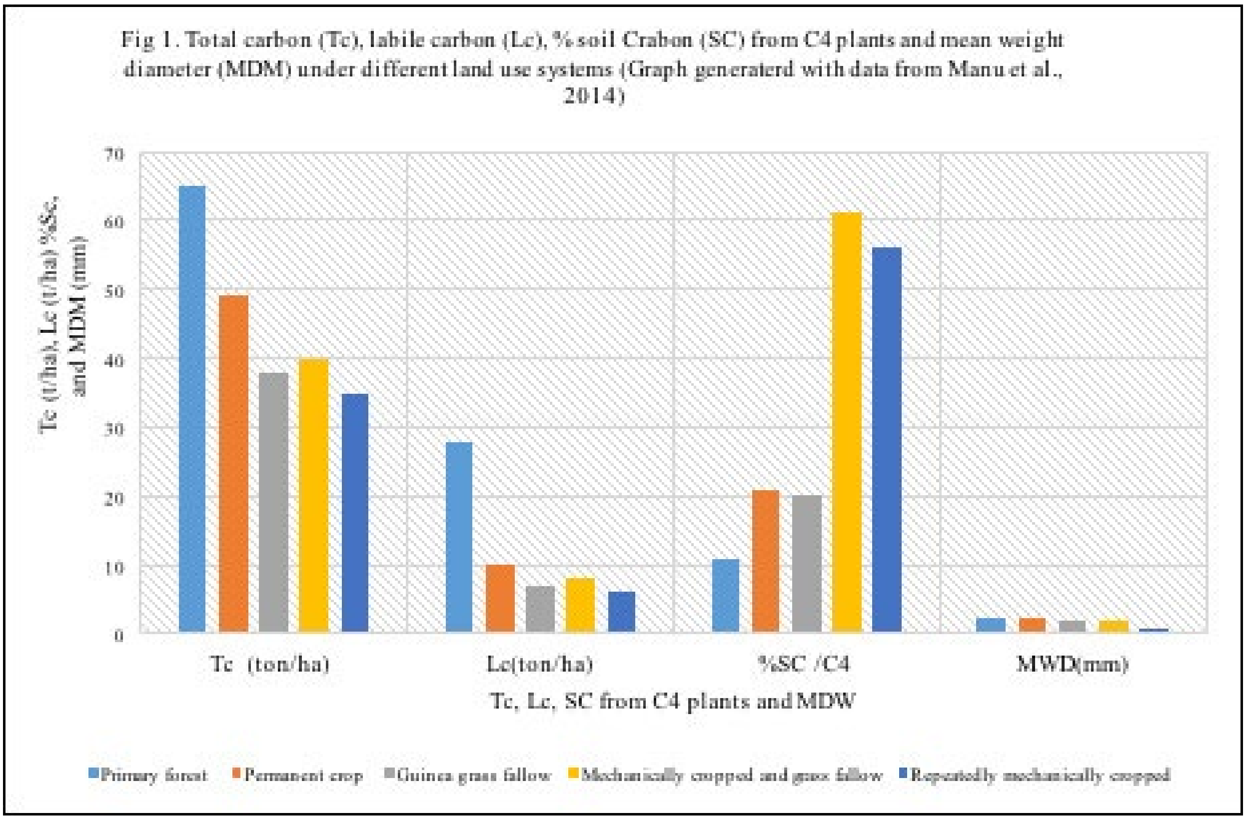
This paper collated works on soil organic carbon that had been done in SIDS regions of CARICOM, AIMS, and the Pacific Region with the aim of establishing the status of SOC in SIDS and answering the key question: how can SIDS keep producing food and yet maintain SOC and if SOC is improved to an adequate level will the secondary cascade of problems associated with decreasing organic carbon be alleviated as well?

RESULTS

SOC Status

The SOC status of SIDS are influenced by land use practices such as mechanization that can cause oxidation of organic C, use of plant residues which are burnt in many cases, agricultural intensification resulting in shortened fallow periods and loss of biodiversity resulting in SOC reduction, overstock of animals that in conjunction with other practices mentioned earlier like mechanization can result in increasing soil erosion.
In higher islands of SIDS with mostly volcanic soils, the effects of cropping on soil biological quality are in general the same in that cropping leads to a decline in topsoil organic matter and microbial biomass contents. Studies from the 3 SIDS regions (Manu *et al.*, 2014; Morrison and Gawander, 2016; Ng Cheong, Kwong and Du Preez, 2008; Sierra *et al.*, 2015; Umrit *et*

al., 2014) observed that topsoil changes could generally be related to changes in organic matter and associated ion exchange properties. The major changes occurred in the first few years after clearing, but some changes continued for many years. Subsoil samples (below 30cm) showed an increase in organic carbon after cultivation (many studied cane cultivation), probably due to soil mixing during land preparation, organic matter movement during cropping and decay of crop roots. Some studies also found a change in the carbon source from natural vegetation to C4 plant remains over time (Manu *et al.*, 2014). Studies also show that there was decline in water stable aggregates with increasing intensity of cultivation. Overall, these changes indicate that careful management of topsoils is essential for maintaining soil fertility and hence sugarcane or crop productivity on these highly weathered soils.

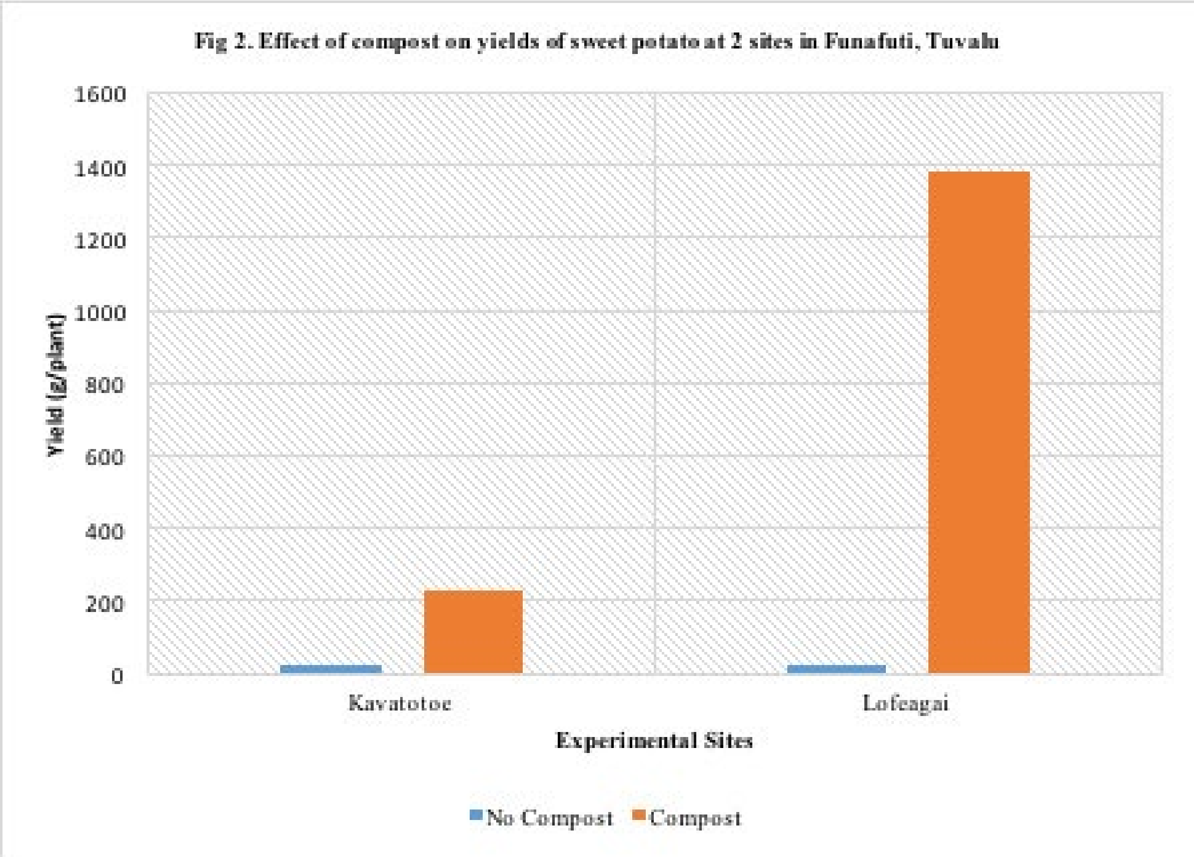


The most vulnerable SIDS are the atolls with inherently low soil fertility and productivity relying heavily on SOC. Donato *et al,* 2012 in the first field estimate of island-wide carbon storage in ecosystems of Oceania, on two island groups of Micronesia (Yap and Palau), sampled all above- and belowground C pools, including soil and vegetation, in 24 sites distributed evenly among the three major vegetation structural types: mangroves, upland forests, and open savannas (generally on degraded lands formerly forested). Total C stocks were estimated to be 3.9 and 15.2 Tg C on Yap and Palau, respectively. Mangroves contained by far the largest per-hectare C pools (830 -1218 Mg C ha^{1}), with deep organic-rich soils alone storing more C (631 - 754 Mg C ha^{1}) than all pools combined in upland systems. This is in line with other studies that found soil to be the principal C pool in these ecosystems. Deenik and Yost (2006) however in their study in Marshall Islands showed that surface SOC was a good predictor for total N and Ca2+, but showed a less robust relationship with K, Mn, Fe, P, and Mg. Organic C was a poor predictor of soil B, Cu, and Zn.

Farm Smart Technologies

Studies in SIDS have shown that SOC can be maintained or increased. A study conducted in Tonga by Manu, Whitbread and Blair (2017) investigating the effect of a once-off application of mulch on yield and quality of watermelon, maize and capsicum grown in rotation over a 1-yr period. The treatments applied were a nonmulched control, transparent plastic and 200-mm-thick applications of locally available coconut sawdust, guinea grass and mature coconut fronds. The soil total carbon in the sawdust treatment was 13% higher than that in control treatment. The soil labile carbon LC in the grass mulch and sawdust treatments were significantly higher than in other treatments. In combination with decreased temperature and more moisture conserved increased the yields of the crops relative to the nonmulched control. Use of grass and *Mucuna pruriens* fallows in in Tonga, Samoa and Fiji has shown increase in total organic C and labile Carbon and with other benefits like improved physical properties and chemical properties increased yields of crops (Anand, 2016; Halavatau and Asher, 2003; Lal, 2013).

And on atolls in Kiribati and Tuvalu a summary of soil analyses from improved and unimproved soils showed an increase in OC in the improved soil. Results of use of compost on atolls in Tuvalu on two sites showed significant effects on yields of sweet potato (Fig 2).



Source: Unpublished report of Inaugural Atoll Soil Health Workshop, April 2017

DISCUSSION

The results show the vulnerability of soils of SIDS to management with topsoil properties changing within 3 years but results also show the potential to manage SOC on these soils. It will be an easier task on higher volcanic islands with studies showing that organic matter loss can be reduced by adding organic residues as mulch, compost or use of leguminous cover crops. The biggest challenge will be maintaining SOC on atolls which because of vulnerability of water table to nutrient pollution means relying on compost and organic sources of nutrients which most time are low in critical nutrients like K, Fe, Cu and Mn.

CONCLUSIONS

The results of studies in SIDS indicate that long-term intensive cultivation leads to marked changes in the topsoil properties. The changes may be attributed to decreases in topsoil organic matter and its effects in other soil properties like bulk density. In volcanic soils overall the OC status of the profiles remained relatively unchanged with topsoil losses being balanced by accumulations lower in the profile mostly by C4 plant remains.

The atoll soils relying largely on soil organic carbon for nutrient supply and organic carbon is not a good predictor of micronutrient supply.

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1.20 | NATIONAL LAND DEGRADATION NEUTRALITY TARGETS FOSTER SOC SEQUESTRATION IN TURKEY

Hamza Keskin[1*], Ahmet Şenyaz[1], Günay Erpul[2]

[1][Republic of Turkey Ministry of Forestry and Water Affairs, General Directorate of Combating Desertification and Erosion, Ankara, Turkey, *hkeskin@ormansu.gov.tr]
[2][GSP/ITPS Member, Ankara University Faculty of Agriculture Department of Soil Science Ankara, Turkey]

ABSTRACT

Turkey assumes a leading position solving one of the global challenges of our time Land Degredation Neutrality as a laudable target of a Sustainable Development Goals under UN 2030. Turkey has set voluntary LDN targets to be implemented by 2030, and launched Ankara İnitiative to support countries worldwide need assistance to formulate their LDN targets. Soil organic carbon stocks as well as land productivity and land cover changes have been identified as main indicators to monitor achievements in LDN targets. This brief explains voluntary national LDN targets and existing SOC stocks status of Turkey based on existing literature. Also, it attempts to quantify potential benefits of land management practices through LDN targets on SOC stocks.

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Keywords: Land degradation neutrality (LDN), soil carbon sequestration, sustainable land management, digital soil mapping

INTRODUCTION

Land Degradation Neutrality (LDN) is included in Sustainable Development Goal (SDG) 15.3 and considered as a vital tool for enhancing the implementation of the United Nations Convention to Combat Desertification (UNCCD). During the UNCCD COP 12 in Ankara, Turkey, LDN is defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security such that it remains stable or increases within specified temporal and spatial scales and ecosystems". The UNCCD COP 12 also invites Parties to formulate voluntary LDN targets for the next 15 years, in accordance with their specific national circumstances and development priorities.

Turkey participates in second phase of LDN Pilot Project and LDN Target Setting Programme of the UNCCD and completed its first national report on LDN Target Setting. While conducting LDN Target Setting Programme at country level, Turkey also supports some countries that need assistance in formulating national LDN targets through Ankara Initiative, covering the years 2016-2019. Turkey has set LDN targets to be implemented by 2030, taking into account of current national conditions. In this context, establishing a monitoring system in order to monitor progress or achievements in LDN targets through three biophysical indicators (land cover, land productivity and carbon stocks), mainly by soil organic carbon (SOC) is still a question to be answered. This brief presents Turkey's national LDN targets process and explains main efforts in initiating activities for measuring SOC at country level to establish a monitor system for LDN targets.

PRELIMINARY ASSESSMENT

Development of up-to-date SOC stocks baseline to monitor LDN in Turkey

Preliminary assessment of SOC stocks in Turkey is based on the map produced by General Directorate of Agricultural Research and Policies (TAGEM) with the cooperation of FAO-SEC under FAO/TURKEY Partnership Programme. The generated map predicts an average value of 34.5 t C ha^{-1} from the soil depth of 30 cm overall Turkey. According to this study; agricultural land, forest land and pastureland could store about 29.8 t C ha^{-1}, 45.1 t C ha^{-1} and 37.1 t C ha^{-1}, respectively. Another study of SOC stocks mapping using the World Reference Base (WRB) soil classes at the country scale in Turkey estimates SOC stocks as 27 t C ha^{-1} based upon the depth of 20 cm (Aydın et. al., 2014). However, existing soil map needs improvement by taking advantage of digital soil mapping discipline. For example, sampling design and size should be carefully evaluated due to their direct influence on the accuracy of geospatial soil prediction models (McBratney, Mendonça Santos and Minasny, 2003). Therefore, a nationally scaled, accurate and reliable SOC stocks map is urgently needed to use as an indicator of identifying land degradation and monitoring progress towards combatting desertification and achieving national LDN targets.

Recently, "Turkey Soil Organic Carbon Modelling and Mapping Project" has been initiated to generate best possible estimates of SOC stocks based on Global Soil Map (GSP) specification. Within this scope, under the supervision of General Directorate of Combating Desertification and Erosion (ÇEM) multi-stakeholder interested parties – General Directorate of Agricultural Research and Policies (TAGEM), General Directorate of Agricultural Reform (TRGM), Directorate General of Forestry (DGF), Turkish State Hydraulic Services (DSI), and Scientific and Technological Research Council of Turkey (TUBİTAK) – have formulated the project to be completed within the next two years. The project will be utilizing state-of-the-art sampling design such as cLHS (Minasny and McBratney, 2006) to quantify and understand state factors affecting SOC. Beyond that a modeling approach such as machine learning kriging (Hengl *et al.*, 2015).may be employed to account for stochastic and deterministic variation. Eventually, utilizing external validation, the uncertainty will be defined for further analysis.

EXPECTED CONTRIBUTION OF NATIONAL LDN TARGETS ON SOC BUDGETS OF TURKEY

In order to take an active part in LDN activities, Turkey participated in the 2014-2015 "Towards Achieving Land Degradation Neutrality: Turning the Concept into Practice" project. As one of the outcomes of this project, Turkey prepared the national LDN report in which voluntary LDN targets have been identified to get implemented by 2030. Voluntary national LDN targets mainly consist of the activities such as afforestation, soil conservation afforestation, forestland rehabilitation, decreasing area per fire, reduction in the number of human-induced forest fires, mining site rehabilitation, pasture rehabilitation, increasing irrigation areas, land consolidation works and rehabilitation of degraded land areas. Table 1 indicates national LDN targets and their expected impacts on SOC stocks in next 15 years. Reference carbon values given practices has been gathered from national literature (Tolunay and Çömez, 2008). Expected contribution of defined LDN targets are expected to increase SOC stocks per year as follows: afforestation, soil conservation afforestation 5.8 Tg C year^{-1}, rehabilitation of forest lands about 1.53 Tg C year^{-1}, pasture rehabilitation 0.36 Tg C year^{-1}, increasing the irrigated area 1.99 Tg C year^{-1}, and rehabilitation of degraded land area 1.46 Tg C year^{-1}. Therefore, implementation of LDN targets in a national scale would increase the carbon stocks around 168.73 Tg C year^{-1} by 2030. If existing SOC stocks map is considered as a baseline, approximately 0.5% SOC will be increased up to depth of 30cm by 2030. Even though some think accomplishing high C sequestration rate(up to 0.5% per year) is technically impossible, some think it is achievable with best recommendable practices (Minasny *et al.*, 2017)

Table 1: Voluntary LDN targets of Turkey targets (Turkey Land Degradation Neutrality National Report 2016-2030)

Negative Trend	km²		Corrective Measures		LDN Targets		Expected increase in C stocks
	Collect Earth (2001-2015)	(EC-JRC) (2000 – 2010)		Unit	Area	Year	Tg
Declination of Forest Areas	+11,542 (Increase according to Management Plan Data – 2000-2015) (1)	388	Increasing the ratio of country's forest areas	%	5(2)	2030	87.43
			Afforestation	km²	6,000		
			Soil Conservation afforestation	km²	9,000		
Declining Productivity in Forest land	460	2,1125	Decrease in Forest Crimes	Number	1,416(3)	2017	22.99
			Increase in Ratio of Mechanical, Biological, and Biotechnical Forest Pest Control	%	2.7(4)		
			Rehabilitation of forest lands	km²	15,000	2030	
			Reducing the amount of area affected per fire	km²	0.005(5)		
			Reducing the number of human-caused fires	%	3(6)		
			Rehabilitation of mine sites	km²	58	2019	
Declining productivity in pastures	3,710	2,582	Pasture rehabilitation	km²	7,500	2030	5.46
Declining productivity in agricultural land	1,250	5,045	Increasing the irrigated area	km²	22,000	2030	29.87
			Land consolidation activities	km²	140,000	2023	21.98
			Identifying plains of great agricultural potential and registering them as agricultural lands	km²	55,000	2023	
			Amount of rehabilitated land	km²	20,000	2030	
TOTAL	+6,122	10,140			274,558	--	168.73

(1) Net amount of decrease in forestlands in Turkey between 2000-2015; the difference between forest assets of 2015 and 2000 reveals that there is indeed an increase in forestlands, rather than a decrease (Table 1).
(2) As of 2015, forestlands cover 28.5% of Turkey's total area. Target for 2030 consist of reaching 30% in area, by increasing another 5% within the time period.
(3) Forest crimes will be decreased down to 11,000 by 2017, from 12,416 in 2011.
(4) While mechanical, biological, and biotechnical forest pest control ratio was 87.3% in 2011, targeted ratio is 90 % for 2017.
(5) Targets for 2030 include decreasing area affected per fire to 2.2 ha from 2.7 ha.
(6) Turkey aims to decrease human-induced fires to 85% from 88% by 2030.

OUTLOOK

Turkey takes an active role in the implementation of the UNCCD COP decisions and its programs, by aligning its national action plan on combating desertification. Also, Turkey has participated in LDN pilot project organized by the UNCCD secretariat and prepared a national report on LDN which indicates Turkey's LDN targets to be implemented by 2030.

Despite the importance of SOC to achieve land degradation neutral world, existing information about SOC baselines and changes under different land uses and management practices is still fairly limited and largely uncertain in Turkey. Thus, ÇEM has coordinated data collection, analysis, modelling, assessment and reporting network through multi-stakeholder in a harmonized fashion. Geo-spatial soil landscape prediction models to produce reliable and accurate SOC stocks baseline are under development. A long-term, cost-effective, spatially representative soil carbon monitoring network will be established to monitor and asses processes of land degradation and land management efficiency. Given the importance of LDN practices on mitigating climate change and sequestrating C from the atmosphere, potential C benefits of these intervention may be further quantified for uncertainty- guided policy making.

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1.21 | DEVELOPING GROUND PENETRATING RADAR (GPR) FOR ENHANCED ROOT AND SOIL ORGANIC CARBON IMAGING: OPTIMIZING ROOT DERIVED CARBON SEQUESTRATION, CROP ADAPTATION AND AGRO-ECOSYSTEM SERVICES

Dirk B. Hays[1], Russell Jessup[2], Nithya Rajan[2], Haly Neely[2], Frank Hons[2], Ben Wu[3], Ronald Lacey[4], Michael Bishop[5], Alexander Novo[6], Enrico Boi[6], Dean Goodman[7]

[1]dbhays@tamu.edu Molecular and Environmental Plant Sciences, Texas A&M University,
[2]Soil and Crop Sciences, Texas A&M University
[3]Ecosystems Sciences, Texas A&M University, College Station
[4]Biological and Agricultural Engineering, Texas A&M University, College Station, Texas
[5]Geography, Texas A&M University, College Station, Texas
[6] IDS Georadar North America, Denver Colorado
[7]Archaeometry Geophysical Laboratory, Woodland Hills, California

Selection of the ideal high biomass forages and crop cultivars for our should consider not only the value of the harvested above ground feedstock, but also the local and global environmental services it provides in terms of terrestrial carbon (C) phyto-sequestration and improved soil organic matter enrichment. Selection of ideal crops cultivars is mature. What is lacking, however, is high throughput phenotyping (HTP) and integrated real-time data analysis technologies for selecting ideal genotypes within these crops that also confer recalcitrant high biomass or perennial root systems not only for C phyto-sequestration, but also for adaptation to conservation agro-ecosystems, increasing soil organic matter and soil water holding capacity. In no-till systems, significant studies have shown that increasing soil organic carbon is derived primarily from root and not above ground biomass. As such, efforts to increase plant soil phyto-sequestration will require a focus on developing optimal root systems within cultivated crops. We propose to achieve a significant advancement in the use of ground penetrating radar (GPR) as one approach to phenotype root biomass and 3D architecture, and to quantify soil carbon sequestration. In this context, GPR can be used for genotypic selection in breeding nurseries and unadapted germplasm with favorable root architectures, and for assessing management and nutrient practices that promote root growth some of which are genotype specific or genetically regulated responses. GPR has been used for over a decade to successfully map coarse woody roots. Only few have evaluated its efficacy for imaging finer fibrous or tap roots systems found in grasses, or legumes. Our focused efforts focus on: i) Empirically defining the optimal ground penetrating radar (GPR)-antenna array for 3D root and soil organic carbon imaging and quantification for use in crop systems; ii) Developing novel 3- and 4-dimensional data analysis methodologies for using GPR for non-invasive crop root and soil C phyto-sequestration 3-D imaging and quantification within a spatially variable soil matrix; iii) breeding ideal perennial forages and row crops with high biomass carbon root systems with increased recalcitrance for increased soil organic carbon retention; iv) integration of new cropping systems with high biomass root crops that foster maximal root carbon sequestration.

1.22 | COUPLING HIGH SPATIAL RESOLUTION DATA, GIS APPROACHES AND MODELLING FOR RELIABLE ESTIMATES OF SOC STOCKS AND THEIR HISTORICAL CHANGES IN AGRICULTURAL LANDS

M.I. Khalil*, B. Osborne

UCD School of Biology & Environmental Science and UCD Earth Institute, University College Dublin, Belfield, Dublin 4, Ireland.
E-mail: ibrahim.khalil@ucd.ie

ABSTRACT

The reduction of greenhouse gases and the quantification of the offsetting potential of SOC are a global necessity. Data generated previously (Khalil *et al.*, 2013) through overlaying land uses (LUs) and soil databases/maps using ArcGIS were reprocessed to develop non-linear depth-distribution models and pedotransfer functions, with R^2 ranging from 0.53-1.00, for estimation of SOC concentration and bulk density. An historical land use database (2000-2014) was also used to categorize grassland (G), rough grazing (R), tillage (T) and their rotations (GT), together with the corresponding SOC concentrations, and densities/stocks on mineral, organo-mineral and organic soils. The SOC densities for 2006 were significantly higher in organic and organo-mineral than in mineral soils and for the R, G, GT and T land use categories (0-30 cm depth) were 242, 215, 162 and 80 t ha^{-1}, respectively. The national total stock was 316, 838 and 1679 Tg for the 0-10, 0-30 and 0-100 cm soil depths, where G shared 81%, R 13%, and T and GT rotations 3% each. Historical changes in SOC density/stocks were estimated from the 2006 data using bi-exponential models that indicated that grasslands were a sink and arable a source of carbon. An overall balance for agricultural SOC stock was 1.38, 3.65 and 5.53 Tg C yr^{-1} in the 0-10, 0-30 and 0-100 cm layers, respectively. The findings imply that the approaches used could reliably estimate SOC for LULUC and GHG offsetting accounting and reporting, and contribute to the goal of an increase in SOC of 4 per mille per year.

Keywords: *Depth distribution models, Pedotransfer functions, GIS approaches, SOC densities and stocks, Soil types, Agricultural land uses, Land use changes.*

INTRODUCTION

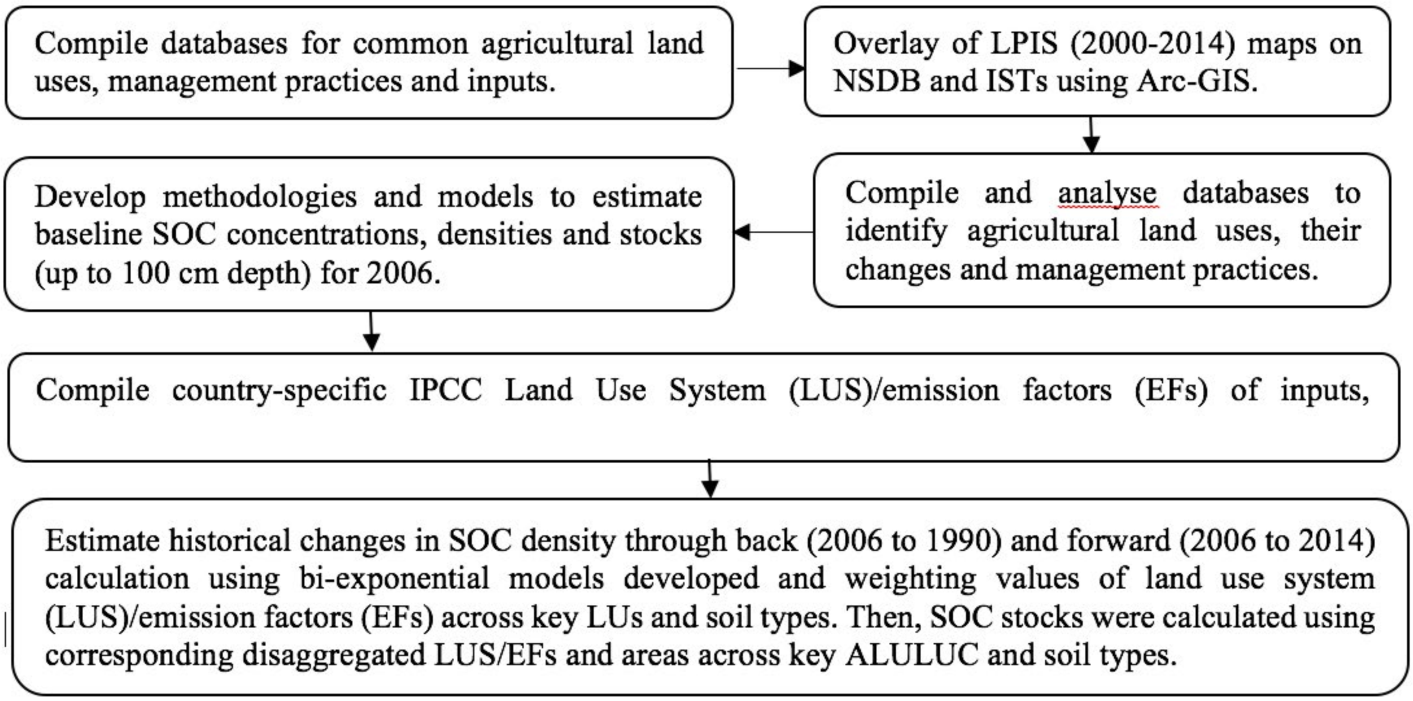
Recent international negotiations underscore the importance of significantly reducing anthropogenic greenhouse gas (GHG) emissions to keep global temperature below 2°C relative to pre-industrial times. The Paris Agreement emphasises the need for enhanced mitigation measures, a reduction in GHG assessment uncertainties, better quantified sinks, and the tailored use of different offsetting mechanisms (UN, 2015). However, technological and economical limitations, and large uncertainties in achieving these goals exist. In addition to improved agricultural management practices, the SOC pool has the potential to act as a major source or sink of GHGs due to its large size and active interaction with the atmosphere. Due to the lack of detailed, spatially explicit activity data, the Annex-I countries use the IPCC Good Practice Guidance Tier 1 methodology (IPCC, 2014) for inventory reporting. For quantification of baseline SOC stocks, robust country-specific activity data (Tier 2 approach) are essential to account for the diversity of practices that influence soil carbon within a country or region, and to identify potential land uses and soil types for achieving the 4 per mille SOC initiative (Minasny *et al.*, 2017).

Pedotransfer functions (PTFs), depth distributions, and regression modelling have been used to obtain a more complete and detailed spatial distribution of SOC content, with or without GIS techniques (e.g., Meersmans *et al.*, 2009; Khalil *et al.*, 2013). To reconcile existing discrepancies, a more detailed spatial assessment of baseline SOC stocks covering disaggregated agricultural land uses, soil types and management scenarios at land parcel level, leading to the option of upscaling to national/regional level, is required. This will contribute to national assessment methodologies, provide an improved understanding of the consequences of historical changes in SOC stocks across land uses, and identify potential GHG mitigation and offsetting approaches. This will also build capacity in the understanding and application of model interfaces. The end target is to provide a tool for the quantitative assessment of the consequences of different scenarios on carbon stocks and GHG emissions from agricultural systems in particular.

METHODOLOGY

Based on United Nations Framework Convention on Climate Change (UNFCCC) reporting requirements, methodologies and models for estimates of SOC stock changes in agricultural land use and land use change (ALULUC) were developed. SOC concentration and bulk density across major land covers and general soil groups (GSGs) were estimated through the development of depth-distribution models and PTFs (Khalil *et al.*, 2013). The model-derived data was reprocessed to refine the depth distribution models and PTFs covering various soil types as per Indicative Soil Types (ISTs; EPA, 2006), representing major soil characterises (e.g., acidity, mineral/organic, and drainage classes) and the corresponding key ALUs and their rotations. For this, the IST database was overlaid on the National Soil Database (NSDB, measured in 2006 containing SOC data at 10 cm depth), and Land Parcel Identification System (LPIS), consisting of historical changes in land use from 2000 to 2014, for 2006. The derived LUs were grassland (G), rough grazing (R) and tillage (T), and their rotations (GR merged to G, GT, RT merged to GT). Soils were categorized as mineral (M = SOC<10%), organo-mineral (OM = SOC 10-20% and >20% at <30cm depth: degraded and non-degraded) or organic (SOC >20% and 10-20% at >30cm depth: degraded and non-degraded).

The database resulted in 490 of 1310 sampling/grid points included in the NSDB. They were synthesized and compiled for the assessment of SOC concentration and densities (SOC concentration*soil mass, derived from bulk density for the respective depth) up to 100 cm depth using the depth distribution models and PTFs. We considered 2006 as the base year for the analysis, as soils were sampled around this year for the determination of SOC concentration as part of the NSDB. SOC stocks were computed by multiplying its densities with the distribution of the total agricultural farmed area reported by the Central Statistics Office (www.cso.ie) to the proportion of land uses on three soil categories derived from 490 sampling points. Synthesis/collation of the fractional contribution of key soil variables, inputs and management, as well as estimation of SOC stocks and their historical changes in agricultural soils was carried out. The following steps were taken:



The coefficient of determination (R^2) and coefficient of variations (CV) were used to compare the extent of any relationships and the degree of uncertainty for variables. The indices used were mean square errors (MSE), and the root mean square error (RMSE). Statistical analyses were performed in Microsoft Excel (v.2013,) and JMP v.13.1 (SAS Inc., USA). For overlaying maps and geo-processing of data, ArcGIS version 10 (ESRI, Ireland) was used.

RESULTS

Depth distribution models and PTFs

The non-linear (exponential for mineral and organo-mineral; natural logarithmic for organic soils) depth distribution models redeveloped using data of Khalil *et al.* (2013) with soil depth ratio functions fitted well for all soil types (mineral, organo-mineral and organic) and the corresponding IST categories (e.g., acidity and drainage classes) and agricultural land uses (G, R and T) with the R^2 and CV ranging from 0.54-1.00 and 09-63%, respectively (data not shown). The k values (scale constant, cm^{-1}) differed between mineral and organo-mineral soils (-0.025 to -0.042) within or between land uses. For organic soils the values differed widely, with non-degraded soils ranging from -0.066 to -0.164, and degraded ones from 0.269 to 1.352.

The soil type-specific and land use-specific empirical equations (Exponential 3P) were redeveloped using the data of Khalil *et al.* (2013) to estimate bulk density (ρd) from PTF (SOC) (data not shown). The k values, which varied between the soil types and land uses, ranged from -0.031 to -0.260, and the R^2 varied from 0.67 to 0.99. Statistical evaluation of the models for the predictions of ρd from SOC was also performed. Irrespective of soil types and land uses, the MSE was ≤0.028 and RMSE was ≤0.166.

Key land use categories
The preliminary compilation of the LPIS (2000-2014) and other databases resulted in 13 agricultural land use classes and theirrotations. Rough grazing (R) in rotation with G and T was limited and that GR rotation merged to G whereas RT rotation to GT, leading to 9 key agricultural land use classes on mineral, organo-mineral and organic soils (data not shown). Analyses indicate that G occupied the major share (79%) of Irish land uses and was dominant on mineral (55%), followed by organo-mineral soils (14%). Grassland-tillage (GT) rotation on mineral (9%) and organo-mineral (2%) soils, and R, mainly on organo-mineral and organic soils (7%), was significantly less. Tillage (T) on mineral soils only represented 10% of the total agricultural land uses.

SOC density
Irrespective of land use and soil layers/profiles, there were significant variations in SOC densities among the three soil categories, showing the highest from organic soils followed by organo-mineral and mineral soils (Fig. 1a). For 0-10, 0-30 and 0-100 cm layers, the corresponding SOC densities for 2006 were the highest (75-101, 225-307 and 425-1080 t C ha^{-1}) for R, G and GT on organic and organo-mineral soils, and the lowest from T (30, 80 and 142 t C ha^{-1}). Considering the 0-10 cm layer, the average SOC density was higher from R (86 t C ha^{-1}) and G (72 t C ha^{-1}) than for the other land uses (30-58 t C ha^{-1}), with the lowest from tillage lands. Similar trends were observed for the 0-30 cm layer, and the corresponding values wee 215-242 t C ha^{-1} versus 80-162 t C ha^{-1}. For the 0-100 cm layer, the weighted average of SOC density was significantly higher from R (614 t C ha^{-1}) and G (562 t C ha^{-1}) than from GT (194 t C ha^{-1}) and T (142 t C ha^{-1}).

Following the calculation of SOC density for 2006, its historical changes across agricultural land uses and soil types were estimated through back (2006 to 1990) and forward (2006 to 2014) calculations, using the bi-exponential model that was developed (Fig. 1b). The SOC density at 1990 was considered as the first equilibrium value and the bi-exponential models provided two separate gain or loss processes of SOC i.e. fast during initial and slow at the later periods. Considering the 0-30 cm soil layer, the historical changes in SOC density resulted in a sink (+) for G and R and source (-) of carbon for T and GT across soil types. The corresponding density differences in 25 years were estimated to be 13.8 to 21.2, 4.6 to 6.1, -22.8, and -4.6 to -10.5 t C ha^{-1}, and the overall balance resulted in a sequestration of 1.28 t C ha^{-1} yr^{-1}.

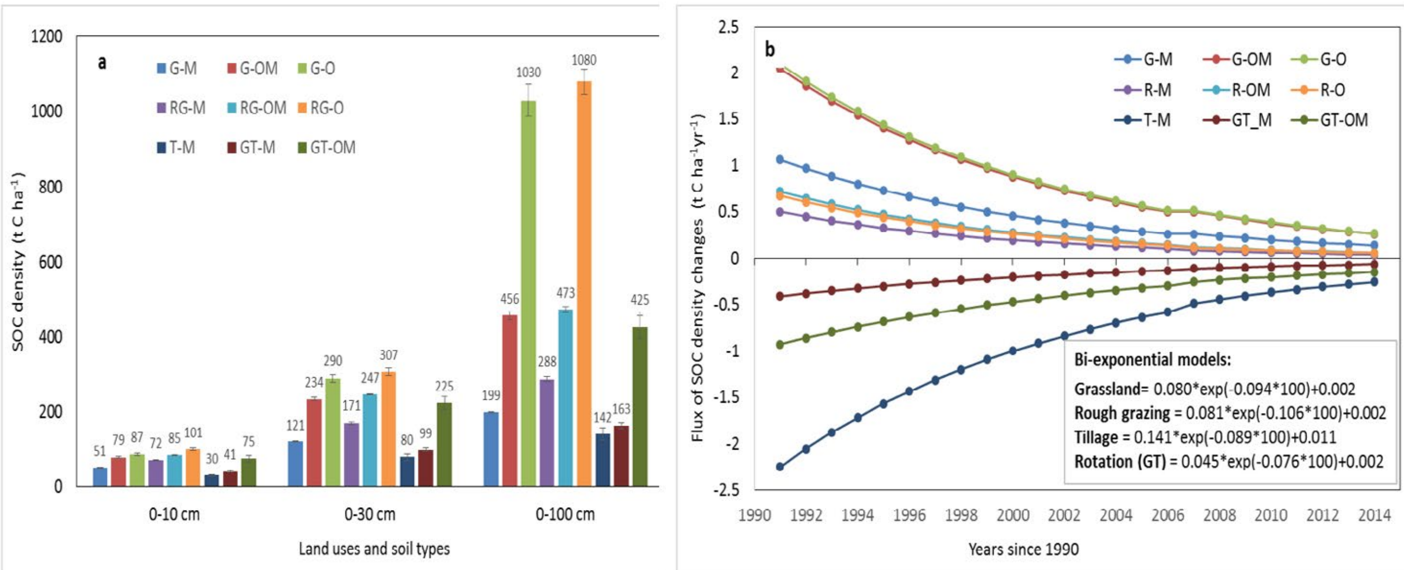


Fig. 1: Estimates of soil organic carbon (SOC) density (tonne per hectare) for 2006 (a) and the rates of their historical changes since 1990 for the mineral (M), organo-mineral (OM) and organic (O) soils for three soil layers under major agricultural land uses (G= Grassland, R= Rough grazing and T= Tillage and their rotations i.e. GT).

SOC stocks
As the dominant land use, G had a higher SOC stock of 253, 675 and 1368 Tg for 2006 at 0-10, 0-30 and 0-100 cm soil depths, respectively, than the other land uses (Fig. 2a). This was followed correspondingly by R (42, 108 and 217 Tg) and the GT (12, 29 and 50) rotation, with the lowest from the tillage (9, 25 and 44 Tg). The percent national total for G was found to be 81%, R 13%, and T and GT 3% each of the total SOC stock (316, 838 and 1679 Tg for 0-10, 0-30 and 0-100 cm layers).

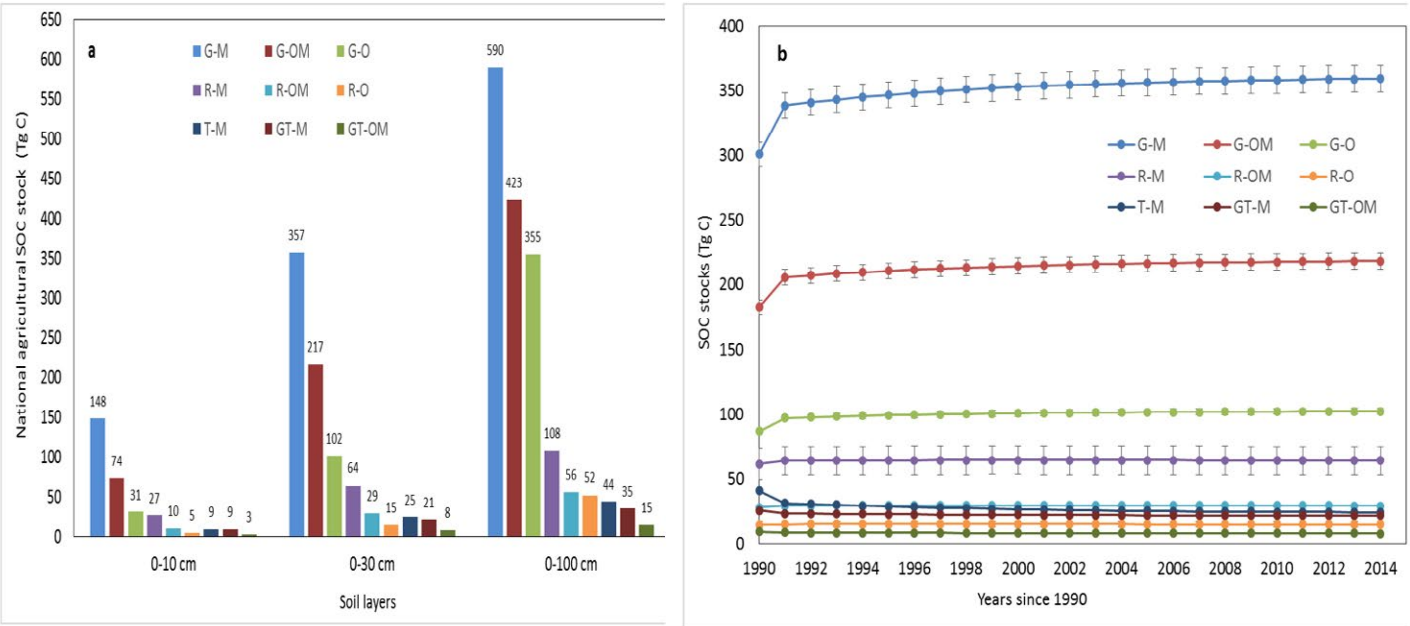


Fig. 2: Areas (hectare, ha) and soil organic carbon (SOC) stocks (Tg, Terragram) for key agricultural land uses and their rotations (G= Grassland, R= Rough grazing and T= Tillage and their rotations i.e. GR, GT and RT).

The historical changes in SOC stocks for the 0-30 cm soil layer showed an initial sharp increase for G and R and a decrease for T and GT, and thereafter the changes were small in both land uses and soil types (Fig. 2b). The difference in 25 years for G, R and T+GT was 109.7, 4.5 and -22.8 Tg C, and the overall balance was 3.65 Tg C annually for the 0-30 cm soil layer.

DISCUSSION

Previous work developed both depth-distribution models and PTFs across key land cover categories considering general soil groups (Khalil *et al.*, 2013). Given the strong relationships between land use classes, management practices and soil types, which impact on soil carbon, ISTs denoting acidity, drainage and other soil characteristics are well-thought-out for the development of methods/models and the estimation of SOC content. Both LPIS and NSDB are unable to provide detailed disaggregated land use classes in Ireland but grassland (G), rough grazing (R), tillage (T) and their rotations, grassland/rough grazing-tillage (G-T), can be derived from the historical LPIS (2000-2014) data. This approach was found to be promising in providing further details of the impact of land use change and other variables with reduced uncertainty, leading to more reliable estimates of SOC densities/stocks across agricultural land uses and soil types.

Despite some variations within the key soil types across land uses, the redeveloped models provide a good estimate of the SOC concentration and thereby its density for different soil depths. The current estimates of SOC density considered disaggregated lands uses and soil types including widely applicable categories such as mineral, organo-mineral and organic soils. This study also observed significant variations in SOC densities among the ISTs although they were comparable to the previous study (Khalil *et al.*, 2013). Importantly, the approach can distinguish between the three soil categories and the overlapping of organic versus mineral soil types that was observed earlier (Khalil *et al.*, 2013) have been removed. However, SOC densities were remarkably high in the GT rotation on organo-mineral soils in line with the previous study and that the errors, if any, associated with this needs to be corrected through field investigation. Overall, the SOC densities for 2006 and their historical changes estimated using bi-exponential models developed across land uses and soil types provide reasonable estimates. However, it is anticipated that the IPCC country-specific LUS/EFs for mineral soils overestimated SOC content for organo-mineral soils, and that proportional distribution (LUS/EFs) of LUs, management and other factors for the estimation of SOC and their stock changes should be either disaggregated across soil types based on SOC content or weighted average at a required level (national/regional), and/or accounted by weight.

The estimated national SOC stocks for the three soil layers are somewhat lower (838 and 1679 Tg for the 0-30 and 0-100 cm reference layers, respectively), taking into account the variations found within the three soil categories, than the previous estimate of 888 and 1832 Tg for the same reference layers, respectively (Khalil *et al.* 2013) and slightly higher than estimated by Eaton *et al.* (2008). In this study, the approaches considered the factors that influence variations in SOC content. Thus, the estimates of SOC stocks are consistent with historical changes when LPIS data is coupled with LUS/EFs and related information on agricultural inputs, soil types and management practices, as weather conditions are considered to have an insignificant impact on SOC sequestration under Irish conditions. However, the IPCC country-specific LUS/EFs for SOC stock estimation probably overestimated the SOC stocks for organo-mineral soils in particular, as stated above and that needs to be take into account in future research.

CONCLUSIONS

The reprocessed depth-distribution models and PTFs as well as newly developed bi-exponential models will be useful for the estimation of SOC concentration and thereby annual density/stocks at national and regional levels. The higher spatial resolution databases (LPIS, ISTs and NSDB) and coupled empirical modelling and GIS approaches have the potential to provide robust estimates of SOC density/stocks in disaggregated agricultural land uses and soil types (Tier 2 development). The estimated baseline SOC stocks can be used for ALULUC accounting and offsetting, as stratified input data, for incorporation in ecosystem models and for their verification, as well as for quantification and refinement of land use and soil-specific carbon sequestration capability that is required to achieve 4 per mille per year. The data can be used for mapping and for developing a widely applicable tool to estimate historical changes in SOC stocks and with the potential for GHG estimations through further improvement. However, apportioning of land use and management-specific gain or loss of SOC (LUS/EFs, even when country-specific) as proposed by the IPCC and also the 4 per mille per year concept may be a concern for precise estimations of SOC stocks and their temporal or spatial variability, particularly for soils having a high organic carbon content.

ACKNOWLEDGEMENTS

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1.23 | SOIL CARBON MODELS FOR CARBON STOCK ESTIMATION – WHERE DO WE FAIL?

Aleksi Lehtonen*[1], Boris Tupek, Shoji Hashimoto[2],

[1]Natrual Resources Institute Finland (LUKE), aleksi.lehtonen@luke.fi
[2]Forestry and Forest Products Research Institute (FFPRI)

ABSTRACT

Soil organic carbon (SOC) stock change estimates are needed in order to understand CO_2 exchange between atmosphere and biosphere. Repeated nationwide SOC inventories are rare and expensive. In the absence of soil inventories, models are used to estimate SOC changes. These models are applied widely with GHG inventories under UNFCCC and with earth system models (ESM), e.g. for IPCC assessment reports.
Soil carbon models simplify complex processes and often lack history of soils in a given region. Therefore, it is not surprising that these models fail as sub-modules of ESMs (Guenet *et al.* 2013, Todd-Brown *et al.* 2013). The major reason for poor performance of SOC models results from the uncertainty with steady state SOC stock for model initialization.
Here we compare different soil carbon models (Yasso07, ROMULv, Century and Q) against Finnish and Swedish SOC inventories and we identified conditions under which these models fail. We also analyzed SOC outputs of ESMs and compared those to global SOC databases.
We found that models were failing on nitrogen rich sites, we also found underestimation of SOC stocks on water limited sites and on those with excess water.
Our findings provide directions for modelling community in order to further improve models and their ability to quantify SOC stocks.

Keywords: Yasso07, Century, ROMUL, modeling,

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Several countries apply SOC models for estimating soil carbon stock changes for their forests. Models are often used due to fact that it is the only option due to high price of soil inventories. The use of models has been expanded after Kyoto protocol adoption 1997. Countries have to be able to provide SOC estimates at national level and report those annually for the UNFCCC. In addition to the reporting actual estimates countries report uncertainty estimates for those emissions and therefore there has been lot of research focusing on the uncertainty of SOC models.
At the same earth system modelling (ESM) community develops models and predicts future CO_2 feedbacks between biosphere and atmosphere. According to the results by Guenet *et al.* (2013) ORCHIDEE model is not able to predict SOC observations, they found that model estimates and measurements did not have any correlation. Similarly, Todd-Brown *et al.* (2013) reports that most ESMs are not able to produce measured soil carbon stocks at a grid level. ‘
(i) Here we used Yasso07, Century and Q models to estimate SOC levels for Sweden. We compared models estimates and measured data and evaluated conditions where these models fail (Tupek *et al.* 2016). (ii) We also tested Yasso07 and ROMULv models against Finnish SOC data (Lehtonen *et al.* 2016). (iii) In addition to that we compared ESM SOC estimates against with global SOC databases and we identified those conditions where these global vegetation models fail with soil carbon (Hashimoto *et al.* 2016).
The overall objective of our works has been identify conditions under which typical soil carbon models fail.

METHODOLOGY

This paper is based on three separate studies, where (i) Tupek *et al.* (2016) and (ii) Lehtonen *et al.* (2016) test different SOC models against nationwide SOC inventories in Sweden and in Finland. Study (iii) Hashimoto *et al.* (2016) uses boosted regression tree (BRT) methodology in order to evaluate drivers that affect SOC estimates on both, different ESMs and with global soil carbon databases.
Studies (i) and (ii)

Both studies (i) and (ii) use forest inventory data, biomass models and litter turnover rates to estimate annual carbon flow from vegetation to the soil system. This annual flow is then used as a litter input and with that models have been driven to steady state. Thereafter steady state SOC stocks have been compared against measured soil carbon data. In study (i) this comparison was done in eight classes that were formed by using regression tree technique, while in study (ii) this comparison was done according to the south-north gradient of Finland.

Study (iii)

In study (iii) data mining method BRT was applied. With this method we analyzed ESM inputs and their impact to estimated SOC stocks. Similarly we analyzed with BRT method various candidate drivers for SOC stocks. Comparison of drivers for ESMs SOC stocks and those for observational SOC stocks revealed factors that did not agree between these two independent data sets.

RESULTS

In study (i) we found that Yasso07, Century and Q models were able to estimate SOC stocks on 2/3 of cases. Models were successful on typical nutrient poor and medium fertility sites on Sweden. On the other hand these models failed on nitrogen rich forest soils and also on those that had high nitrogen deposition. Century model outcompeted Yasso07 and Q models on sites with high clay content.

In study (ii) we found that generally models failed on Southern Finland to estimate right SOC levels. This was due to fact that these models did not have decay limitation due lack of moisture. ROMULv model was able to map increased SOC stocks in south when applied with measured soil water holding capacity. We also found out here understorey vegetation has a major role providing litter input especially in Northern Finland. The role of understorey vegetation has been often neglected.

Study (iii) identified that ESM drives were different than those with global soil data. Our analyse indicated that providing use of carbon:nitrogen ratios of soils and soil texture information with SOC models would improve their performance.

DISCUSSION AND CONCLUSIONS

As national SOC inventories are expensive and those should be repeated in order to have soil carbon stock change estimates, the use of SOC models will likely increase.

Our studies reveal that these models are able to estimate SOC stocks under mean conditions, but at the same time we see that these models fail on conditions that have water limitation or excess water or exceptionally high nutrient levels.

In order to have more reliable GHG inventory results and more reliable future CO_2 feedback estimates these SOC models should be improved in a way that those take into account variable soil fertility conditions and also soil texture that affects directly to soil water availability.

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1.24 | THE 4 FOR 1000 INITIATIVE - INCREASING SOIL ORGANIC CARBON TO MITIGATE CLIMATE CHANGE

Andre Leu[1*]

[1]IFOAM Organics International, andreleu.al@gmail.com

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

On December 1, 2015, the French Government launched the *"4 per 1000 Initiative: soils for food-security and climate"*, that will use a range of agricultural systems to sequester CO_2 and store in in the ground as soil organic carbon (SOC). Thirty-one countries signed onto this initiative along with key international organizations such as United Nations Food and Agriculture Organization, the Global Environment Facility, the International Fund for Agriculture Development, the World Bank and the Asian Development Bank. Twenty-six research institutes and universities have signed on along with over one hundred NGOs and private sector organizations. This initiative is intended to complement the necessary efforts needed to comprehensively reduce global greenhouse gas emissions.

The *4 per 1000 Initiative* is part of the framework of the Lima-Paris Action Agenda (LPAA). The title comes from research that determined: "A "4‰" annual growth rate of the soil carbon stock would make it possible to stop the present increase in atmospheric CO_2." (http://4p1000.org)

"This growth rate is not a normative target for every country but is intended to show that even a small increase in the soil carbon stock (agricultural soils, notably grasslands and pastures, and forest soils) is crucial to improve soils fertility and agricultural production and to contribute to achieving the long-term objective of limiting the temperature increase to +1,5/2°C, threshold beyond which the IPCC indicates that the effects of climate change are significant." (http://4p1000.org)

Atmospheric CO_2 level are increasing at 2 ppm per year. The level of CO_2 reached a new record of 400 parts per million (ppm) in May 2016. This is the highest level of CO_2 in the atmosphere for 800,000 years. (NOAS, 2017)

In order for the *4 per 1000 Initiative* to achieve its objective to stop the present increase in atmospheric CO_2, agricultural systems would have to sequester 2 ppm of CO_2 per year. Using the accepted formula that 1 ppm CO_2 = 7.76 Gt CO_2 means that 15.52 Gt of CO_2 per year needs to be sequestered from the atmosphere and stored in the soil as SOC.

Stopping the increase in GHGs and then reducing them must be the first priority and this should be non-negotiable. Just moving to renewable energy and energy efficiency will not be enough to stop the planet from warming over the next hundred years and going into damaging climate change. 400 ppm is past the level needed to meet the Paris objective of limiting the temperature increase to +1.5/2°C. The levels need to be below 350 ppm. The excess CO_2 must be sequestered from the atmosphere to stop damaging climate change.

Soils are the greatest carbon sink after the oceans. There is a wide variability in the estimates of the amount of carbon stored in the soils globally (Scharlemann *et al.*, 2014). According to Lal (2008), there are over 2,700 gigatons (Gt) of carbon stored in soils. The soil holds more carbon than the atmosphere (848 Gt) and biomass (575 Gt) combined. There is already an excess of carbon in the oceans that is starting cause a range of problems. We cannot put any more CO_2 in the atmosphere or the oceans. Soils are the logical sink for carbon.

The scope of this paper is to use examples of agricultural systems that have published studies documenting their increases in SOC and to extrapolate the data to see how much CO_2 could be sequestered per year, globally to meet the aspirational goals of the *4 per 1000 Initiative* to stop the present increase in atmospheric CO_2. It is not the intention of this paper to use these types of generic exercises of globally extrapolating data as scientific proof of what can be achieved by scaling-up these systems. These types of very simple analyses are useful for providing a conceptual idea of the considerable potential of agriculture to sequester CO_2 on a landscape scale.

METHODOLOGY AND RESULTS

Most agricultural systems lose soil carbon with estimates that agricultural soils have lost 50 to 70% of their original SOC pool, and the depletion is exacerbated by further soil degradation and desertification. Agricultural systems that recycle organic matter and use crop rotations can increase the levels of SOC. (Lal, 2014) This is achieved through techniques such as longer rotations, catch-crops, cover crops, green manures, legumes, compost, organic mulches, perennials, agro forestry, agroecological biodiversity and livestock on pasture using sustainable grazing systems. These systems are starting to come under the heading of regenerative agriculture because they regenerate SOC.

The Rodale Institute in Pennsylvania, USA, has been conducting long-running comparisons of organic and conventional cropping systems for over 30 years. The Farming Systems Trial manured organic plots showed that CO_2 was sequestered into the soil at the rate of 3,596.6 kg of CO_2 per hectare per year and when extrapolated globally across agricultural lands, would sequester 17.5 Gt of CO_2 per year. (La Salle and Hepperly, 2008)

Total Agricultural Land: 4,883,697,000 ha *Source:* (FAO, 2010)
Organic @ 3,596.6 kg CO_2/ha/yr x 4,883,697,000 = 17.5 Gt of CO_2 /yr.

A meta-analysis by Aguilera *et al.* 2013 of 24 comparison trials in Mediterranean climates between organic systems and non-organic systems found that the organic systems sequestered 3559.9 kilograms of CO_2 per hectare per year. When the data is extrapolated globally across agricultural lands, these systems would sequester 17.4 Gt of CO_2 per year.

The Louis Bolk Institute made a study to calculate soil carbon sequestration at Sekem, the oldest organic farm in Egypt. Their results show that on average Sekem's management practices sequestered 3,303 kgs of CO_2 per hectare per year for 30 years. Based on these figures, the widespread adoption of these practices globally has the potential to sequester 16 Gt of CO_2 into soils per year. (Koopmans *et al,* 2011)

The Rodale Compost Utilization Trial showed that CO_2 was sequestered into the soil at the rate of 8,220.8 kg of CO_2 per hectare per year and if extrapolated globally would sequester 40 Gt of CO_2/yr. (La Salle and Hepperly, 2008)

68.7% of the world's agricultural lands (3,356,940,000 ha) are used for grazing (FAO, 2010). There is an emerging body of published evidence showing that pastures can build up SOC faster than many other agricultural systems and this is stored deeper in the soil. (Fliessbach *et al,* 1999,Tong *et al,* 2015)

Research by Machmuller *et al.* (2015): "In a region of extensive soil degradation in the southeastern United States, we evaluated soil C accumulation for 3 years across a 7-year chronosequence of three farms converted to management-intensive grazing. Here we show that these farms accumulated C at 8.0 Mg ha−1 yr−1, increasing cation exchange and water holding capacity by 95% and 34%, respectively."

To explain the significance of these figures: 8.0 Mg ha−1 yr−1 = 8,000 kgs of carbon being stored in the soil per hectare per year. Soil Organic Carbon x 3.67 = CO_2, means that these grazing systems have sequestered 29,360 kgs (29.36 metric tons) of CO_2/ ha/yr.

If these regenerative grazing practices were implemented on the world's grazing lands they would sequester 98.5 gt CO_2/yr. (Grasslands: 3,356,940,000 ha (FAO, 2010) x 29.36 = 98.5 gt CO_2/yr)

At the time of writing there are a range other regenerative agricultural systems that are getting high levels of carbon sequestration. These systems are currently in the process of being published in peer reviewed scientific journals.

DISCUSSION

The above examples show that there are agricultural systems that could sequester enough CO_2 and store it as SOC to meet the aspirational goals of the *4 per 1000 Initiative*.The key issues here are:

1. Urgent research should be commenced to understand how and why these systems sequester significant levels of CO_2 and then look at how to apply the findings for scaling-up on a global level in order to achieve a significant level of GHG mitigation.
2. The signatories the *4 per 1000 Initiative*, including governments and international organizations, should start programs training farmers in the regenerative agriculture systems that increase SOC.
3. Further research can improve the rates of sequestration.

The immediate goal must be to stabilize the CO_2 in the atmosphere at 400 ppm to prevent any further increases in the extreme weather events caused by climate change. Ideally, this should be done by capping the current emissions and adopting a combination of renewable energy and energy efficiency. However under the Paris agreement this will not happen until 2030 at the earliest. The widespread introduction of regenerative farming systems can make a considerable contribution to stabilizing atmospheric CO_2.

CONCLUSION

The *4 per 1000 Initiative* has enormous potential to assist in sequestering CO_2 and mitigating climate change. The fact that many countries, international organizations, research institutions, universities, NGOs and private sector organizations are signatories means that there is a significant level of support for the implementation of this initiative. The potential of the regenerative agriculture systems are enormous, considering that these data are based on current practices.

These examples are 'shovel ready' solutions – while research is needed to improve the rates of sequestration, the examples given are based existing practices. There no need to invest in expensive, potentially dangerous and unproven technologies such as carbon capture and storage or geo-engineering. All that is needed is to scale up the existing good regenerative agriculture practices. Their rates of sequestration can be further improved through research.

Regenerative agriculture can change agriculture from being a major contributor to climate change to becoming a major solution. The widespread adoption of these systems should be made the highest priority by governments, international organizations, industry and climate change organizations.

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1.25 | TURKEY'S NATIONAL GEOSPATIAL SOIL ORGANIC CARBON INFORMATION SYSTEM

Bulent SONMEZ[1] ,Aynur OZBAHCE[2], Mehmet KECECI[2], Suat AKGUL[2], Ece AKSOY[3], Sevinc MADENOGLU[1](*), Armagan KARABULUT ALOE[2], Vecihe INCIRKUS[2], Ceren GORGISEN[2], Tulay TUNCAY[2], Ines BEERNAERTS[4], Ronald VARGAS[5]

[1] General Directorate of Agricultural Research and Policies, Ankara-Turkey [2]Soil Fertilizer and Water Resources Central Research Institute, Ankara-Turkey [3]European Topic Center, Malaga University, Malaga-Spain
[4]FAO Sub Regional Office for Central Asia, Ankara-Turkey
[5] FAO Headquarters, Rome –Italy
*Presenting author

ABSTRACT

Soil organic carbon, the major component of soil organic matter, an important indicator for the soil fertility, is not only extremely important in soil processes but also highly related to the climate change, soil/land degradation and soil ecosystem services. Spatially explicit soil organic carbon information system was a great need for Turkeys' soils. This study aimed at developing a territorial national geographical database for soil organic carbon of top soils (0-30 cm) in Turkey. In the first stage of project, 7742 top soil samples provided from different research projects for the period of 2008-2009 that represent the national territory and different land uses were analyzed to determine carbon content of soils. In the second stage, digital soil mapping methodology that applies geostatistical processes of geoferenced soil data has been used to produce maps of soil organic carbon. We expect that Geospatial Soil Organic Carbon Information System can serve as an important spatially explicit base and may guide for the climate change adaptation strategies, achieving of land degradation neutrality, agricultural carbon footprint, rural development and conservation of biodiversity.

Key words: soil organic carbon, regression kriging, digital soil mapping, geodatabase, Turkey

INTRODUCTION

Soil organic carbon is an important parameter that should be known for the studies on climate change, soil fertility and soil water storage capacity. Soils are one of the main reservoirs of carbon together with oceans, lithosphere, atmosphere and terrestrial biomass (Batjes and Sombroek, 1997). Soils have substantial dynamics of carbon sequestration that accumulate approximately %75 of carbon in the terrestrial ecosystems. Carbon stocks in soils depends on many variables interlinked with many other soil properties, particularly soil organic matter and characteristics of biomes and the responses to different land uses and management systems (Batjes, 1998).

The distribution of soil organic carbon (SOC) is under the impact of some subsidiary variables and these variables can be used to better explain the underlying causes of SOC distribution. Some or all of the variables or a single variable could be significant for changing the SOC content of the soils depending on the characteristics of the region. It is widely reported in the literature that the most significant factor affecting the distribution of SOC for the surface layer (down to 30 cm) of the soil was climate, being broadly precipitation and temperature (Jenny, 1980; Bui *et al.*, 2009; Minasny *et al.*, 2013; Viscarra-Rossel *et al.*, 2014; Hobley *et al.*, 2015). It can be concluded from the literature that there is less consistency regarding the relative influence attributed to factors like land use/management, parent material (including lithology and clay content), and topography (including slope and aspect). The relative influence of some factors varies with scale such as land use and topography, which appear to increase in importance at more localized scales (Minasny *et al.*, 2013). There is a global need for spatially quantitative soil information for agricultural and environmental researches and policy making. Digital soil mapping, where soil maps are produced digitally based on different variables such soil properties, climate, organisms, parent materials, age, elevation and spatial position, is one of the solution to this demand (McBratney *et al.*, 2003). Spatially explicit soil organic carbon information system was a great need for Turkeys' soils. Therefore, the main objective of this study was establishing a Turkey's Topsoil Soil Organic Carbon (SOC) Geospatial Database using representative soil samples, available spatial input data sets and reliable scientific methodology.

METHODOLOGY

Soil sampling and analyses

Soil Sampling strategy was established by interpreting spatially explicit a number of characteristics together such as soil properties, land use, land use capability classes, poorly drained alluvial soils with high water table, geothermal sites etc. using different base maps such as CORINE land use, geological maps, digital elevation models, 1/25 000 scale digital soil maps. 7742 top soil samples (0-30 cm) provided from different research projects for the period of 2008-2009 that represent the national territory and different land uses were analysed to determine carbon content of soils. Soil carbon analyse was performed using TOC device. Figure 1 shows spatial distribution of soil samples.

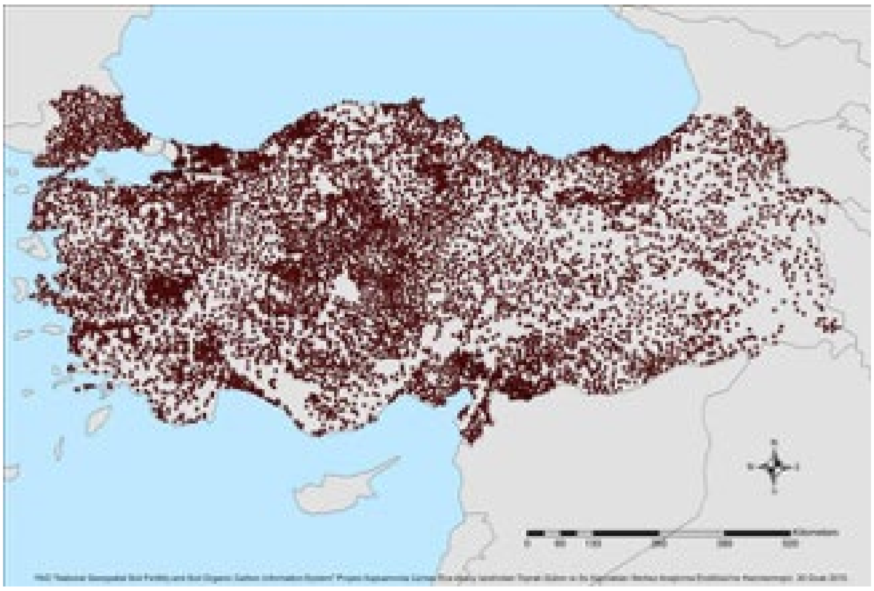

Figure 1: Spatial distribution of soil samples

Auxiliary dataset

In this study, climate (temperature, precipitation, compound topographic index, evaporation), topography (slope, aspect, elevation, etc.), soil texture, parent material, geology, vegetation(minimum, maximum and average data of NDVI) and land use types were used as environmental covariates for predicting soil organic carbon content. Both continuous (slope, aspect, temperature, precipitation) and categorical (elevation, geology, land-cover map, soil map) factors at different scales were used as subsidiary variables to map the distribution of SOC throughout the country.

Data Preparation and Processing

All input data were prepared before executing geostatistical analysis; all input data were prepared using transformations for compliant projection and coordinate system and were resampled to the same resolution (50 m) for ensuring compatible data structure. All covariates were normalized before executing the model. Most of the continuous covariates (slope, temperature, precipitation, etc.) were normalized by using Z-score normalization technique.

Digital Soil Mapping

Digital soil mapping (DSM) Digital soil mapping is an approach to find out relations between known soil data and environmental parameters to produce soil maps. Regression kriging (RK) method as one of the widely used geostatistical techniques has been used for producing of soil property maps (Odeh *et al.*, 1995; McBratney *et al.* 2000). RK is a hybrid method that combines either a simple or a multiple- linear regression model with ordinary, or simple, kriging of the regression residuals.Multiple linear Regression-Kriging geostatistical technique was applied to estimate regression coefficients, calculate residuals and determine significant predictors for soil assessing and producing a continuous covers for soil organic carbon modelling in Turkey scale. After deriving significant predictors, regression model can be determined to predict target variable (soil organic carbon) with the help of those estimated regression coefficients. Residuals are interpolated by ordinary kriging technique. For final output, regression model of the significant predictors and interpolated residuals were summed up.

RESULTS

The geostatistical analysis using regression kriging method has been performed to determine spatial variability of soil organic carbon content in Turkey. Table 1 illustrates the regression coefficient, standard error of regression, and Root Mean Square Error (RMSE) of regression kriging method. Table 2 demonstrates the regression equation and subsidiary parameters used to calculate soil organic carbon. Statistically significant predictors of the models that were best explained by these covariates were determined in the Table 2 for soil organic carbon.

Table 1. Regression results, Standard error of regression, Root Mean Square Error (RMSE) of residuals and Mean of soil properties in National scale (Aksoy, 2014).

Soil Properties	R^2	Standard Error	RMSE	Mean of soil property
Soil Organic Carbon (%)	0.324	0.439	0.422	0,89

Table 2. Regression equations for calculations of soil organic carbon (Aksoy, 2014)

Soil Organic Carbon =
(1.075 +(0.022 *"nkirec")- (0.136*"nkum") - (0.092* "nkil")+ (0.162 *"neto")+ (0.173 *"nkuraklik")+(0.119 *"nndviave")+ (0.941*"nmintemp")+ (0.594* "nmaxtemp")- (1.778*"navtemp")- (0.108* "navprec") + (0.011* "ncti")+ (0.026* "nslope") - (0.101*"cor5") - (0.083* "cor3") - (0.145 *"cor2") - (0.061*"geo5") - (0.084* "geo4") - (0.052* "geo2") - (0.062* "geo1") - (0.218 *"Lpe"))

Semivariograms of the residuals and Q-Q Plots for soil organic carbon are shown in Figure 2.

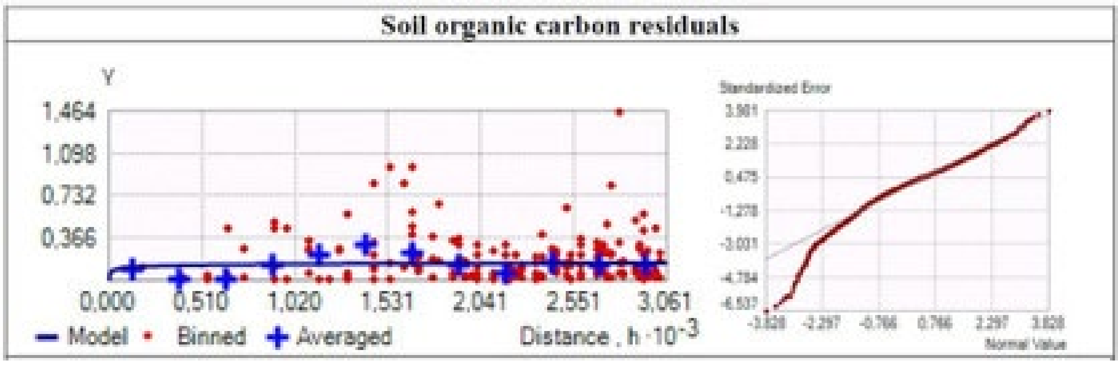

Figure 2: Semivariogram of the residuals and Q-Q Plot for soil organic carbon (Aksoy, 2014).

Significant covariates were selected by "Akaike information criterion (AIC)" in R. The AIC, which is a measure of the relative quality of a statistical model for a given set of data, is used to select a best model for our study. The chosen model is the one that minimizes the Kullback-Leibler distance between the model and the truth. AIC deals with the trade-offs between the goodness of fit of the model and the complexity of the model (Aksoy, 2014). For validation of the model, "repeated random sub-sampling validation" model was used by taking averages of the values comes from 25% validation datasets. The validation result was calculated using R by taking the averages of the results comes from 25% validation datasets. Predicted data were evaluated with repeated random sub-sampling validation datasets and average R^2 and RMSE were found for soil organic carbon.

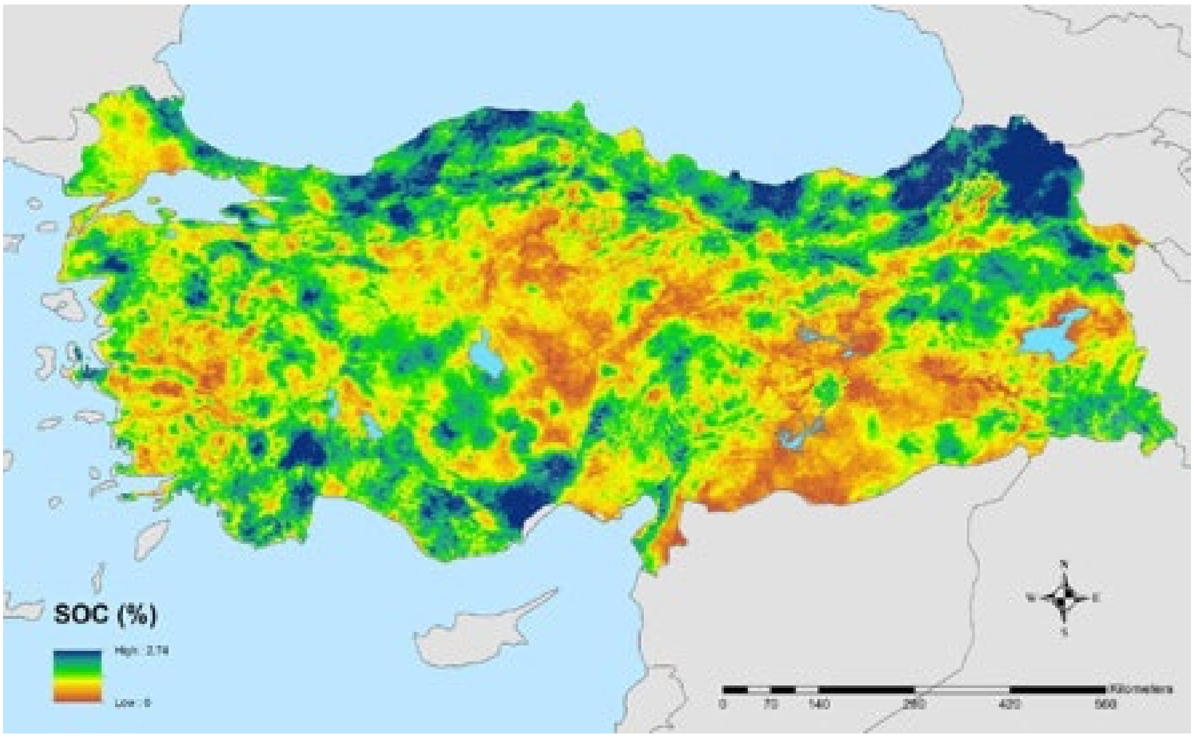

Figure 3: Turkey's soil organic carbon map (Aksoy, 2014).

The Central Anatolia, South-eastern part of Turkey and Central part of Aegean have the lowest soil organic carbon content. Considering that these regions are the main agricultural lands in Turkey we may conclude that the agricultural practices should be tackled in order to avoid carbon emission from those areas. Those areas located in the Black sea region and other forest areas has the higher soil organic carbon content (Figure 3).

DISCUSSION

The geospatial Soil Organic Carbon (SOC) content of Turkey's soils which is necessary for both agricultural and environmental studies will fill up the gaps in the current national soil database of Turkey. Soil organic carbon content in Turkey scale were successfully modelled and mapped using digital soil mapping techniques with technical assistance provided by FAO. The soil carbon maps obtained by this study have the intention to meet one of the important needs of the relevant Institutions, Universities and disciplines in Turkey. These maps can be used as efficient sub-information for the related researches and studies.

CONCLUSION

Soil organic carbon (%) and soil carbon stock were modelled and mapped by digital soil mapping techniques for Turkey. This study is performed with a limited number of soil sample dataset. Despite the fact that the number of the soil samples was not sufficient to represent all land use types, except for agricultural areas, this study is a first attempt at national scale to be updated and improved with incoming works. Therefore, a second complementary project has been performed focusing on improving the geo- database of this project including soil fertility parameters and soil toxic elements (in total 53 soil characteristics) with additional soil samples. The first version of the soil organic carbon map is being updated under this second complementary project.

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1.26 | MONITORING, REPORTING, AND VERIFICATION OF SOIL CARBON SEQUESTRATION ON THE CROPLAND AND GRASSLAND OF CANADA

Brian G. McConkey[1*], Denis Angers[2], Darrel Cerkonwiak[3], Émilie Maillard[2], and Jianling Fan[1]

[1]Agriculture and Agri-Food Canada, Swift Current, SK, Canada, *brian.mcconkey@agr.gc.ca and jianling.fan@agr.gc.ca
[2]Agriculture and Agri-Food Canada, Québec, QC, Canada, denis.angers@agr.gc.ca and emilie.maillard@agr.gc.ca
[3]Agriculture and Agri-Food Canada, Saskatoon, SK, Canada, darrel.cerkowniak@agr.gc.ca

ABSTRACT

From 1990 to 2014, Canada has achieved soil organic carbon (SOC sequestration of 267 Mt of CO_2e in its cropland. This sequestration has reversed much of past land degradation and was largely the result of reducing the frequency of bare fallow and reduced tillage intensity. There are still opportunities to increase sequestration by converting more land from intensive to reduced tillage and by increasing C input to the soil through increased productivity, having more crops with relatively greater C input, and extending period of vegetation growth, such as from cover crops after annual crop harvest. Estimating SOC change on extensive grasslands is more difficult because of the difficulty of monitoring grazing practices and relatively poor understanding of rates SOC change in response to drivers. Meta-analyses across the available scientific literature have not resolved these challenges so more research is needed to develop a workable monitoring, reporting and verification (MRV) system for grasslands. The existing and potential Canadian MRV systems from of SOC change on agricultural land should be widely applicable to countries like Canada where the area of agricultural land is relatively large compared to the size of national economy and so where it is extremely difficult to economically justify monitoring by direct measurement of SOC change.

Keywords: SOC, model, cropland, grassland, measurement, sequestration, fallow, tillage

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Canadian farmers, supported by the Federal and Provincial governments, have had a long standing goal to sustainably achieve high soil quality. Soil organic carbon (SOC) content is an important measure of soil quality as it is related to fertility, structure, and resilience. In the past several decades the value of increasing SOC, or soil carbon sequestration, as a means to remove atmospheric CO_2 has become more important. Canada developed an indicator of SOC status on croplands in late 1990s based on modelling with the Century model (McRae, Smith and Gregorich, 2000). Under the United Nations Framework Convention on Climate Change (UNFCCC) puts an obligation on to report carbon stock changes. For its National Inventory Report of Greenhouse Gas Emissions under the UNFCCC, Canada developed a more rigorous estimation system also based on the Century model. This presentation provides an overview of the current reporting of SOC sequestration in Canada and challenges and opportunities for improving monitoring, reporting, and verification (MRV) of croplands and grasslands.

METHODOLOGY

Carbon changes for croplands are based on applying carbon change factors derived from the Century model to areas causing SOC change: land-use changes, changes in area of bare fallow, changes between annual and perennial crops, change in tillage practices, and changes in woody biomass crops such as fruit trees (Environment and Climate Change Canada, 2016). These areas are monitored over time through survey and census. The C change factors have been validated against observed values from a pre-existing network of long-term field experiments in Canada. Meta-analyses of results of studies in the literature have been used to investigate opportunities for improved MRV of SOC of grasslands (Maillard, McConkey and Angers, 2017; Wang *et al.*, 2016).

RESULTS

Canada has 52Mha of agricultural land, 45.4 Mha of cropland spread across the entire country and 6.6 Mha of permanent grassland (rangeland) in the semiarid western regions. Fig. 1 shows the general change in SOC across Canada in 2014. The Prairie region in western Canada accounts for 81% of cropland and its soils are predominantly sequestering SOC so it has a 2014 sequestration rate of 18.8 Mt CO_2e yr^{-1}. The sink in the prairies is primarily from reduction in fallow and reduction in tillage intensity. In contrast, the rest of Canada has many areas that are estimated to be losing SOC so it was net C source at a rate of 3.5 Mt CO_2e yr^{-1}.

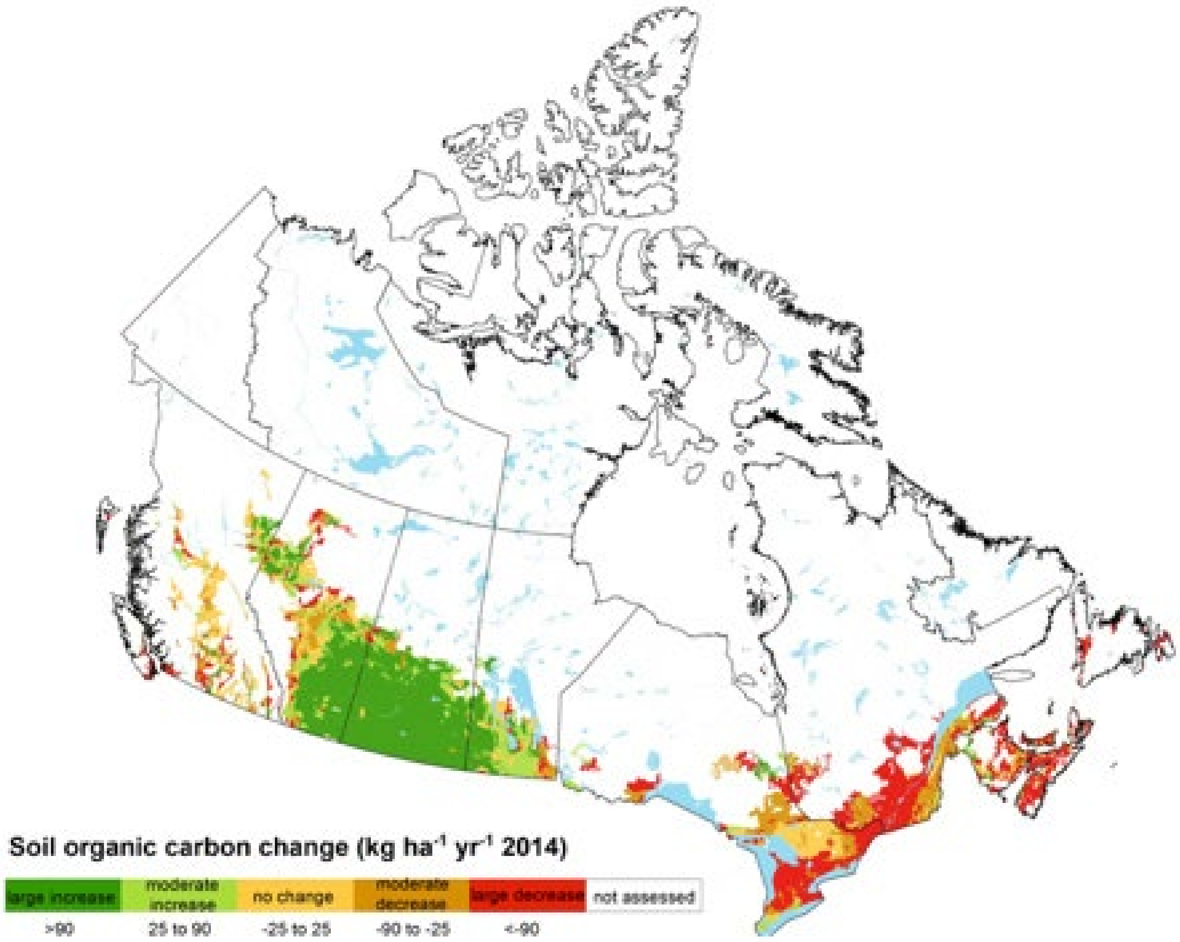

Fig. 1: Estimated soil organic carbon change on the agricultural land of Canada in 2014.

Canadian permanent grassland is overwhelming used to produce beef cattle. Meta-analysis has shown that compared to a continually ungrazed state, grazing grasslands increases SOC by 19 (Wang, VandenBygaart and McConkey, 2014) to 72 kg ha^{-1} yr^{-1} (Wang *et al.*, 2016). However, there is insufficient data to develop an obvious relationship between C sequestration and particular soil state-grazing management systems. Further meta-analysis revealed that validating the expected small changes in SOC change for grassland is difficult due to the high spatial variability that reduces the power for detecting SOC change (Fig. 2). The variability increases with area of grassland and depth of measurement.

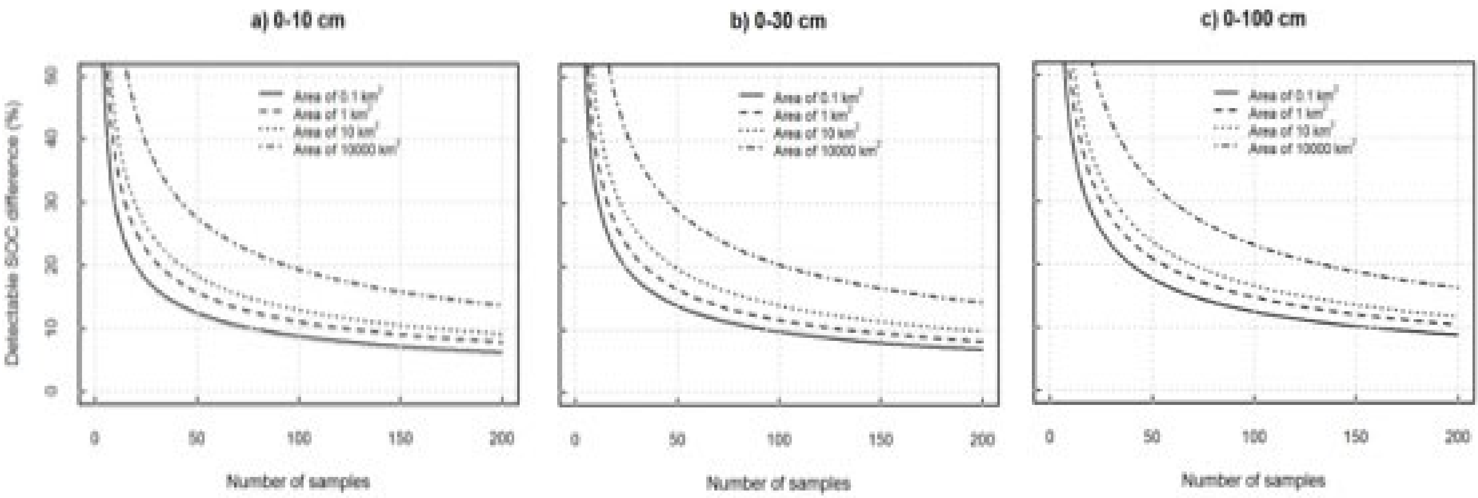

Fig 2: Detectable SOC difference for grasslands as a function of sample size, grassland area, and depth of measurement (adapted from Maillard, McConkey and Angers, 2017).

DISCUSSION

The large sink in the Prairies is attributed to the fact that those soils were degraded due to frequent bare fallow and intensive tillage during most of the 20th Century. Currently no-till is practiced on 62.3% of cropland in annual crops and, due to climatic and soil conditions, there is limited potential for further increases of no-till. The area of bare fallow has decreased from 8.0 Mha in 1990 to 1.2 Mha in 2014. Hence the major sink on croplands is expected to slowly decrease over time as soils move towards new equilibrium. There are still opportunities to change from intensive tillage to reduced tillage systems. The areas of declining SOC are attributed primarily to areas where there has been widespread switch from perennial pasture and forage to annual crops. This reflects a change for mixed livestock-crop farming to more crop-only farming. The adoption of practices to reduce or halt the SOC decline, such as reduced tillage and use of cover crops after harvest, is warranted. Research is underway to address the deficiency that the current methodology does not account for changes in C input to cropland. Crop yields are increasing by about 1.8% per year. An important factor for increasing C input has been the rapid increase in canola (*Brassica* spp), whose area has grown from 2.5 Mha in 1990 to 8.4 Mha in 2014. Compared to traditional crops, canola provides about 50% more C input per ha due to its large root system and low proportion of grain in above-ground growth. Given the large area of agricultural land relative to the Canadian economy, there is no appetite to invest in national systems to directly monitor SOC change on Canada's cropland using measurement. The C change factors derived from modelling are a convenient and transparent estimate of C change and have been used to calculate carbon footprints of specific agricultural products and in trading systems for emission offsets of C sequestered in cropland. Canada plans to continue to rely on MRV systems based on monitoring cropland management practices and using process modelling to estimate the SOC change. Canada's investments in MRV of cropland SOC status has enabled more informed decision making regarding soil management practices and policy.

Estimating SOC from Canadian grasslands remains a challenge. Observed SOC sequestration from grazing has been attributed to recovery from a more degraded soil condition that existed in first half of 20th Century. Heavy grazing reduces the plant community condition and diversity but, because it results in shift to grass species that put more C below ground, there is no clear relationship with SOC change. Moderate to light grazing intensity is normal practice because that provides resiliency in grazing resources to manage regular droughts. There may be C sequestration opportunity from increasing grazing intensity from light to moderate. Grazing practices have been shifting towards more frequent movement of herds between pastures. This intersperses short periods with heavy grazing intensity with longer periods without grazing on each pasture. This combination has been shown to increase productivity and resilience as well as enable grazing pressure to be better matched to the characteristics of each pasture. Due to individual differences in grazing preferences, labour availability, livestock watering availability, and pasture characteristics, the range of grazing management practices is increasing. As a result, monitoring grazing systems is becoming increasingly difficult and SOC change needs to be considered for more individual pastures within a single grazing system. Based on the global meta-analysis, developing C change factors based on observation alone is unlikely given the low power of detecting SOC change (Fig. 2). Most Canadian grassland soils contain more than 30 Mg ha^{-1} in upper 30 cm so detectable SOC changes will only be evident after many decades assuming rates of C sequestration from good grassland management are not greater than 100 kg ha^{-1} yr^{-1}. There are continuing increases in capability of remote sensing from satellites with more frequent passes, more types and capabilities of sensors, and greater spatial resolution. More research is needed to the feasibility of monitoring grasslands with remote sensing and linking the monitored condition to SOC change. To validate the SOC change, one potentially effective approach is to develop an accompanying network of carefully designed experiments to understand and quantify SOC change on grassland and the relationship with monitored condition from remote sensing. Given the challenge to measure small changes in SOC on grasslands, there needs to be careful science to develop powerful sampling strategies for SOC change within any experiment network.

CONCLUSIONS

The Canadian experience shows the feasibility of a system for estimating SOC change on cropland based on 1) monitoring land management practices through survey and census, 2) modelling C change factors for areas of change of practices, and 3) validating modelled C factors with results from a national network of long-term experiments. The basic information to include changes in C input (type of crop, crop yield, and amount of livestock manure applied to cropland) is also available or can be estimated from available data that is monitored.

In contrast to cropland, Canada does not yet have a working system for estimating C sequestration on its extensive permanent grasslands. A potentially feasible system is one based on combining information from remote sensing with C change estimates related to state and/or changes in apparent grassland utilization and state. This system will require validation from a network of carefully designed experiments to capture SOC change that occur over decade or less.

Canada's investments in MRV of SOC status of agricultural land has enabled more informed decision making regarding soil management practices and policy. We believe that the existing and potential Canadian systems from MRV of SOC change on agricultural land should be widely applicable to countries like Canada where the area of agricultural land is relatively large compared to the size of national economy and so where it is extremely difficult to economically justify monitoring by direct measurement of SOC change.

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1.27 | 4 PER 1000 SOIL CARBON SEQUESTRATION

Budiman Minasny[1], Alex. B. McBratney[1*], Brendan P. Malone[1], Denis A. Angers[2], Dominique Arrouays[3], Adam Chambers[4], Vincent Chaplot[5], Zueng-Sang Chen[6], Kun Cheng[7], Bhabani S. Das[8], Damien J. Field[1], Alessandro Gimona[9], Carolyn Hedley[10], Suk Young Hong[11], Biswapati Mandal[12], Ben P. Marchant[13], Manuel Martin[3], Brian G. McConkey[2], Vera Leatitia Mulder[14], Sharon O'Rourke[15], Anne C. Richer-de-Forges[3], Inakwu Odeh[1], José Padarian[1], Keith Paustian[16],Genxing Pan[7], Laura Poggio[9], Igor Savin[17], Vladimir Stolbovoy[18], Uta Stockmann[1], Yiyi Sulaeman[19], Chun-Chih Tsui[6], Tor-Gunnar Vågen[20], Bas van Wesemael[21], Leigh Winowiecki[20]

[1] Sydney Institute of Agriculture, The University of Sydney, New South Wales, Australia.
[2] Agriculture and Agri-Food Canada, Canada.
[3] INRA Orléans, InfoSol Unit, Orléans, France.
[4] USDA-Natural Resources Conservation Service, USA.
[5] Laboratoire d'Océanographie et du Climat, Paris, France.
[6] Department of Agricultural Chemistry, National Taiwan University, Taipei, China Taiwan.
[7] Nanjing Agricultural University, Nanjing 210095, China.
[8] Agricultural & Food Engineering Department, Indian Institute of Technology Kharagpur, India
[9] The James Hutton Institute, Craigiebuckler, AB15 8QH, Aberdeen, Scotland (UK)
[10] Landcare Research, New Zealand.
[11] Rural Development Administration (RDA), Republic of Korea.
[12] Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India
[13] British Geological Survey, Keyworth, UK.
[14] Université Libre de Bruxelles, Brussels, Belgium.
[15] University College Dublin, Republic of Ireland.
[16] Colorado State University, Fort Collins, CO 80523, USA.
[17] People's Friendship University of Russia, Moscow, Russia.
[18] V.V. Dokuchaev Soil Science Institute, Moscow, Russia.
[19] Indonesian Agency for Agricultural Research and Development, Indonesian Ministry of Agriculture, Bogor, Indonesia.
[20] World Agroforestry Centre (ICRAF), Nairobi, Kenya
[21] Université catholique de Louvain (UCL), Louvain-la-Neuve, Belgium.
* Presenting author

ABSTRACT

The 4 per 1000 initiative aims to demonstrate that agricultural soils can play a crucial role in tackling food security and climate change. It intends to increase global soil organic matter stocks by 4 per 1000 per year as a compensation for the global emissions of greenhouse gases by anthropogenic sources. This paper surveyed the soil organic carbon (SOC) stock estimates and sequestration potentials from 20 regions in the world. This global snapshot showed that most countries demonstrated efforts and scopes for soil carbon sequestration. The potential to increase SOC is mostly on managed agricultural lands. Under best management practices, 4 per 1000 or even higher sequestration rates can be accomplished. High SOC sequestration rates can be achieved for soils with low initial C stock, and at the initial five years of the implementation of best management practices. Areas that have reached SOC equilibrium will not be able to increase their sequestration rate. The challenge for cropping farmers is to find disruptive technologies that will further improve soil condition and deliver enhanced soil carbon. As a strategy for climate change mitigation, soil carbon sequestration buys time over the next ten to twenty years whilst other effective sequestration and low carbon technologies become viable.

INTRODUCTION

The COP21 or 21st Conference of the Parties to the United Nations Framework Convention on Climate Change in Paris (November 30 to December 11, 2015) produced the Paris Climate Agreement on the reduction of climate change, limiting global warming to less than 2 Celsius degrees (C°) compared to pre-industrial levels and to pursue efforts to limit the increase to 1.5 C°. At the same time, the French Minister of Agriculture Stéphane Le Foll also initiated the '4 per mille Soils for Food Security and Climate' programme. The 4 per 1000 initiative aspires to increase global soil organic matter stocks by 4 per 1000 per year as a compensation for the global emissions of greenhouse gases by anthropogenic sources. It was supported by almost 150 signatories (countries, regions, international agencies, private sectors and NGOs). The 4 per 1000 rate is not a fixed target but is meant to demonstrate that a small increase in the soil carbon stock of agricultural soils can offset greenhouse gas emission and contribute to improving soils condition and agricultural production. Stakeholders commit in a voluntary action plan to implement good farming practices that maintain or enhance soil carbon stock on agricultural soils and to preserve carbon-rich soils.

This paper brings together SOC experiences from 20 regions of the world (New Zealand, Chile, South Africa, Australia, Tanzania, Indonesia, Kenya, Nigeria, India, China Taiwan, South Korea, China Mainland, United States of America, France, Canada, Belgium, England & Wales, Ireland, Scotland, and Russia). We surveyed the soil carbon stock estimates of each region and asked whether the 4 per 1000 initiative can be adopted.

RESULTS AND DISCUSSION

Soil carbon demonstrated a high spatial variation with increasing variation from field to regional, continental, and global extent. SOC stock varies with latitude and longitude with greater stocks at higher latitudes, decreases in the mid-latitudes, and increases in the humid tropics. Fig. 1 shows an estimate of global topsoil C stock based on legacy soil information and digital soil mapping techniques.

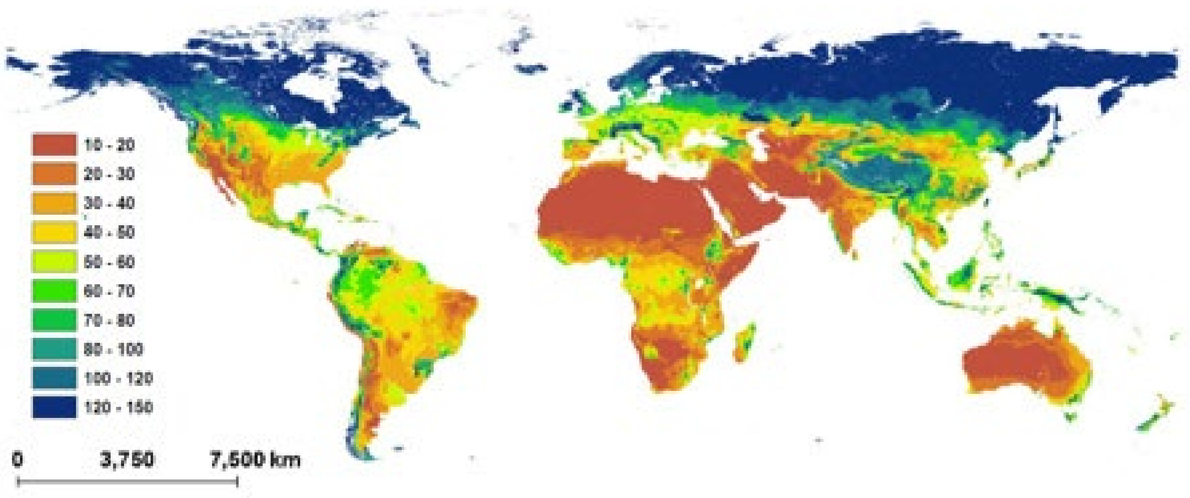

Fig 1: Global soil C stock (0-30 cm) in tonne C per ha.

We surveyed SOC sequestration potential from 20 countries and regions as a global snapshot of soil carbon conditions. Most countries are optimistic on the 4 per 1000 initiative and demonstrated efforts for soil carbon sequestration. Some countries (e.g. Australia & USA) have large agricultural areas with great potential to increase SOC stock, while in other countries, the total area available for cropping is limited (e.g. Belgium, S. Korea). In regions with high inherent SOC content, it may prove difficult to further increase their SOC levels. Conversely, in regions with low (inherent) SOC (e.g. India), it can also

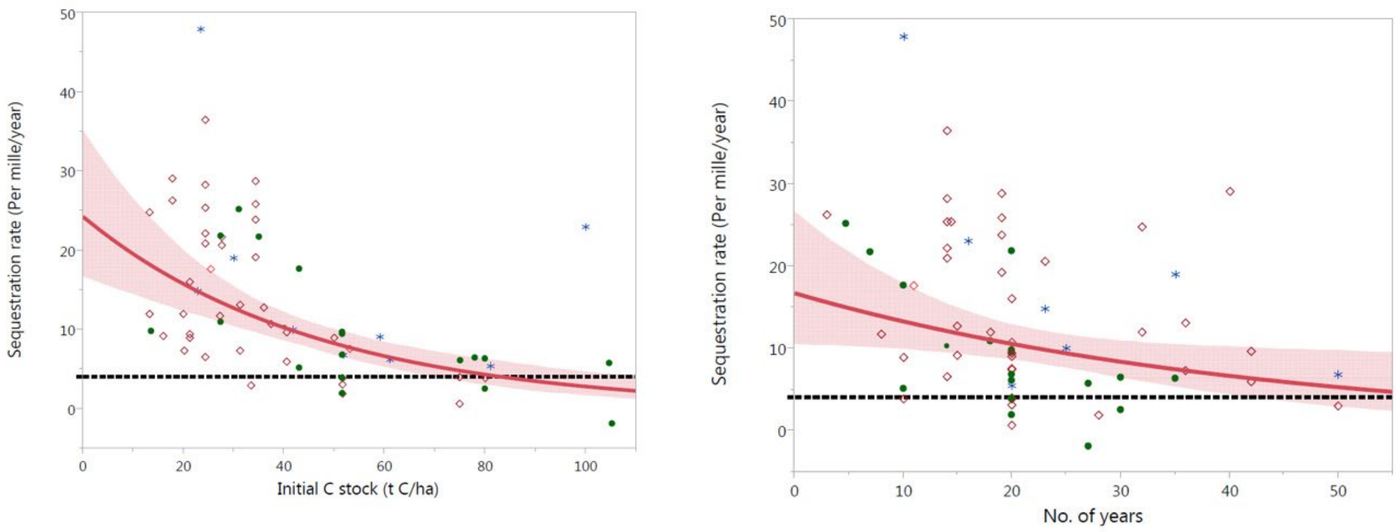

Fig 2: SOC sequestration rates in per 1000 based on studies in 20 regions of the world as a function of initial SOC stock and number of years since management practices been applied. The red curve is a regression model fitted to the data, the dotted line is the required 4 per 1000.

CONCLUSIONS

The 4 per 1000 initiate, for the first time, sets a global goal to promote good soil management that can help mitigate climate change. The top 1 m global agricultural soils hold about 480-790 Gt of C, and increasing SOC stocks for all of these areas by 4 per 1000 (between 2-3 Gt C per year) can offset about 20-35% of global greenhouse gases emission. Global studies showed that there is some scope to increase SOC. In addition, the initiative is an opportunity to implement a sound and credible soil carbon auditing protocol for monitoring, reporting, and verifying SOC sequestration which can be fit into national GHG inventory procedures.

As a strategy for climate change mitigation, SOC sequestration should be implemented immediately. It buys time over the next ten years whilst other effective sequestration and low carbon technologies will become viable.

Advancement in 4 per 1000 requires collaboration and communication between scientists, farmers, policy makers, and marketeers. Farmers and land managers primarily apply management practices to improve their soil's condition and, in doing so, contribute to the sequestering of SOC and mitigating climate change. Scientists provide innovation that can result in greater SOC sequestration, and SOC functioning. Scientists also develop new technologies in measurement, mapping, and auditing to verify SOC sequestration, which is expected by the market to provide confidence in investment. Farmers' SOC sequestration effort provides compliance to the policy makers. This has to be integrated with institutional regulations and policies that facilitate market-based approaches, such as C trading.

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1.28 | USING REMOTE SENSING AND GIS TECHNIQUES FOR PREDICTING SOIL ORGANIC CARBON IN SOUTHERN IRAQ

Ahmad S. Muhaimeed[1,2], Auras M. Taha[3] and Haleima A. Almashhadani[2]

[1]Baghdad University , Iraq
[2]Expert of soil science – ITPS
[3]Green Kassim University, Iraq

INTRODUCTION

Soil organic matter is a major source of Nitrogen used by crops and at any given time, 95 to 99 percent of the potentially available nitrogen in the soil is in organic forms, either in plant and animal residues, in the relatively stable soil organic matter, or in living soil organisms, mainly microbes such as bacteria. Data on field soil total organic carbon and Nitrogen content is important for determining existing C : N ratios to guide optimal rates of nitrogen fertilizer application. Because laboratory measurement of C is expensive and time-consuming, the total number of samples that can be analysed is limited and therefore hinders the characterization of soils and their spatial variation at broader scales (Bouma, 2001; Mermut and Eswaren, 2001; Salehi, *et al.,* 2003). Hence, there is a need for reasonable landscape and regional-scale estimations of C based on limited numbers of samples distributed across an area of interest which can be done by using remote sensing and GIS techniques (Zhu, 2000). The present study aimed to develop remote sensing and GIS based methods to predict the spatial distribution content of soil organic carbon for soils of the study area in Sothern Iraq.

METHODOLOGY

The study area was selected in the region of Al-Kufa city, Al-Najaf province of southern Iraq. The study area characterized by a hot desert climate (Koppen-Geiger BWh) dominated by recent undeveloped soil od Fluvents salt affected dry soils of Salids. 35 sites across the 27,664 ha study area, representing key variations in topography, crop types and soil types were selected for field sampling of surface horizons (0 - 25 cm depth)(Figure 1). Laboratory analysis for the target soil properties including soil organic carbon, and other physical and chemical soil properties using common laboratory analysis methods following USDA (2004) and Klute (1986).Year 2015 March 23, for LANDSAT OLI images of the study area, obtained from the USGS EROS Centre, were used to calculate a range of indices from the distributed spectral values for evaluation; including SAVI, EVI, and GDVI (Table 1). Statistical correlations were applied between soil organic carbon, measured soil properties and indices to determine the best-performing models for prediction SOC. The prediction accuracy of SOC was verified by comparing the predicted and measured values using 35 randomly selected field observations. Then the best fitting models developed using the statistical correlation (Equations 1) was used to study the correlation between the predicted and the laboratory determined values of SOC.

$$SOC = 32.588 + 8.495\ln(SAVI) - 57.965(SAVI) \dots\dots\dots \qquad \dots\dots R^2 = 0.934^{\circ\prime\circ 1} \qquad equ: 1$$

**significant at the 0.01 probability level

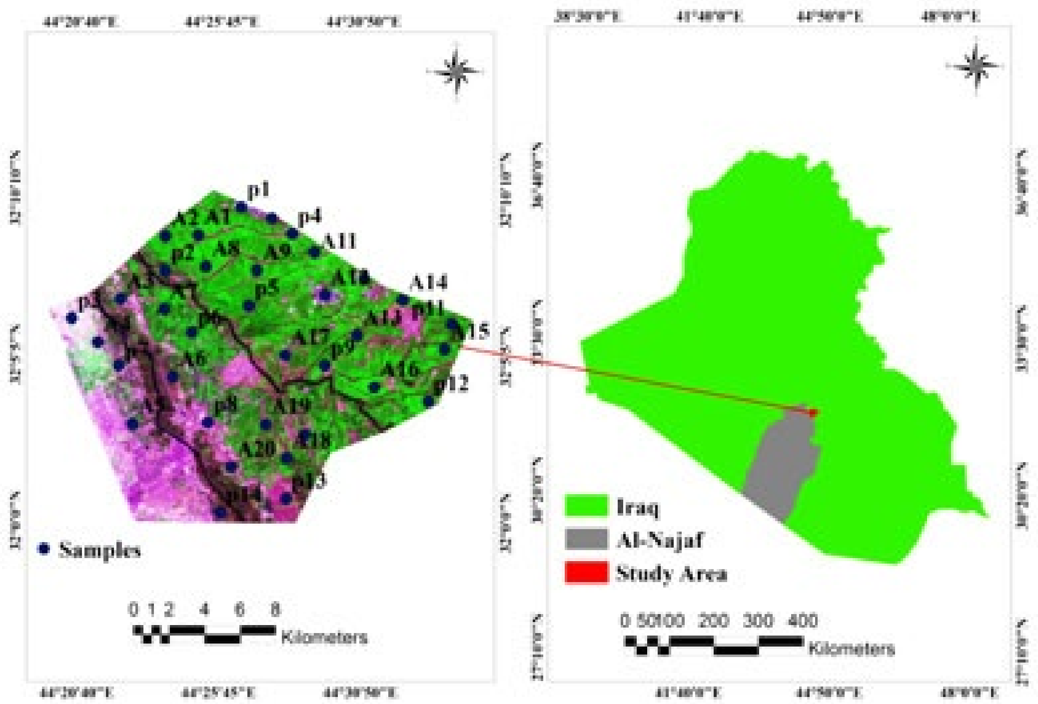

Figure 1: Location of the study area and the selected study sites.

Table 1: Formulae of the vegetation indices

Index	Full Name	Formula	References
SAVI	Soil-Adjusted Vegetation Index	$\frac{(1+L)(\rho_{NIR}-\rho_R)}{(\rho_{NIR}+\rho_R+L)}$ Low vegetation, L = 1, intermediate, 0.5, and high 0.25	Huete (1988)
EVI	Enhanced Vegetation Index	$G * \frac{(\rho_{NIR}-\rho_R)}{(\rho_{NIR}+C1*\rho_R-C2*\rho_B+L)}$ ρ_B = reflectance of blue band, G = 2.5, C1 = 6, C2 =7.5 and L = 1	Huete et al. (1997)
GDVI	Generalized Difference Vegetation Index	$\frac{\rho_{NIR}^n-\rho_R^n}{\rho_{NIR}^n+\rho_R^n}$ n is power number, an integer of the values of 1, 2, 3, 4... n.	Wu (2012)

Note: ρ_{NIR} and ρ_R are respectively reflectance of the near infrared (NIR) and red (R) bands; ρ_B = and ρ_{MIR} are respectively that of blue band and of the middle infrared band (like TM band 5)

RESULTS AND DISCUSSIONS

Prediction of SOC:

The results of laboratory measurement of some soil properties indicate that the content of OC in the study soils are very low, ranging from 0.69 to 7.55 gm/kg with mean value of 5.79 gm/kg and standard deviation of 2.05 gm/km .The best developed statistical model (Equation 1) was used to predict the content of SOC in the study area. The relationships between measured versus predicted content for SOC are shown in Figure 2 .The results show very strong correlation between the measured content of SOC and the predicted with $R^2 = 0.9531$ ($p < 0.01$). The regional map for spatial distribution of SOC in the surface soils horizon of the study area was developed by using the best fitting model (Equation 1), as shown in Figure 3. The result show three classes for the level of SOC. Class 3 (> 7.5 gm/kg SOC) was the most dominant and occupied 38.68 % of the total study area. These areas were the most productive agriculturally and also had low salinity levels. Class 1 (< 5 gm/kg SOC) covered 24.22 % of the total area and associated with high salinity levels, and located within low topographic location near to the Tigris river, with poor drainage.

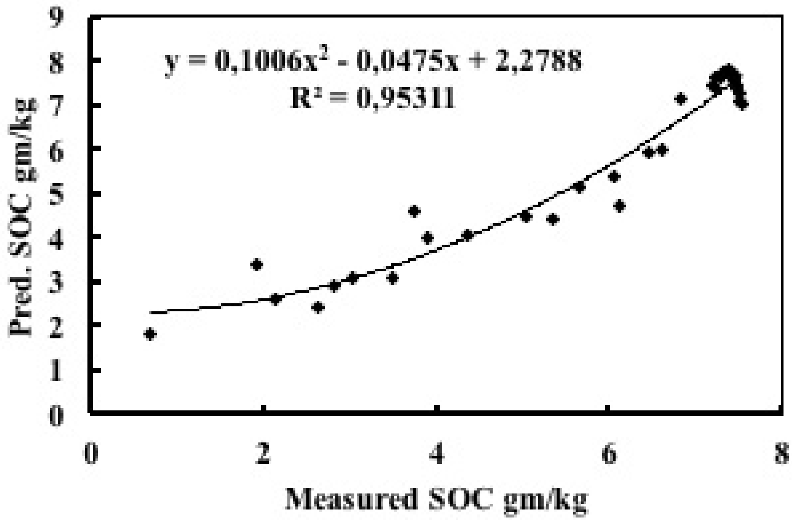

Figure 2: Relationship between measured and predicted content for SOC (gm /kg) in the Surface horizon of the study area

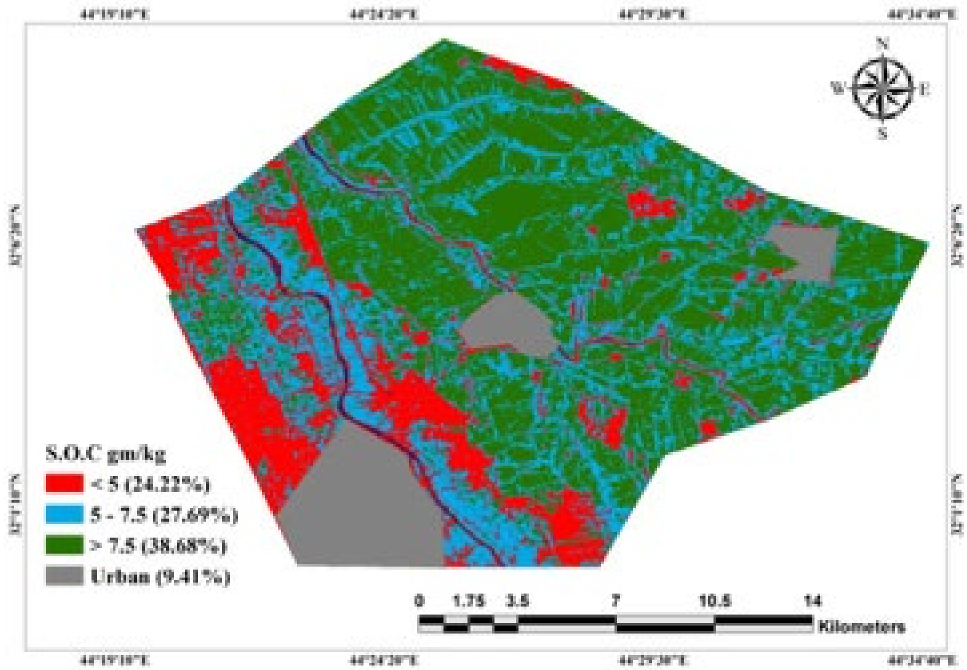

Figure 3 :Spatial distribution pattern of the predicted soil organic carbon content (gm/km) in the surface horizon of study area.

The results revealed that SOC in the study area varied closely with salinity levels and crop types. The results demonstrate the successful approach of using statistical correlation models derived from spectral indices processed from LANDSAT multispectral indices for a region of interest to predict spatial variations of SOC, while maintaining 'ground-truth' accuracy by laboratory analysis of samples collected from the field.

CONCLUSION

The modelled variations corresponded well with the expected factors affecting SOC which were land cover, parent material and soil salinity. Total SOC showed strong negative correlation with salinity ($R^2 < 0.9$, $p > 0.01$). The results demonstrate the successful approach of using statistical correlation models derived from spectral indices processed from LANDSAT multispectral indices for a region of interest to predict spatial variations of SOC, while maintaining 'ground-truth' accuracy by laboratory analysis of samples collected from the field. The results of this study can be used to develop statistical model which best fitting to developed the general map for spatial distribution of SOC in Iraqi soils.
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1.29 | DEVELOPMENT OF A SOIL ORGANIC CARBON BASELINE FOR OTJOZONDJUPA, NAMIBIA

Ravic Nijbroek[1*], Bas kempen[2], John Mutua[1], Mats Soderstrom[3], Kristin Piikki[3], Simeon Hengari[4], Amon Andreas[5]

[1] International Center for Tropical Agriculture (CIAT), r.nijbroek@cgiar.org
[2] World Soil Information (ISRIC)
[3] Swedish University of Agricultural Sciences
[4] Windhoek Research and Data Analysis Consultants (WRaDAC)
[5] Ministry of Environment and Tourism, Namibia
* Presenting author

ABSTRACT

Land Degradation Neutrality (LDN) has been piloted in 14 countries and will be scaled up to over 120 countries. As a LDN pilot country, Namibia developed sub-national LDN baselines in Otjozondjupa Region. In addition to the three LDN indicators (soil organic carbon, land productivity and land cover change), Namibia also regards bush encroachment as an important form of land degradation. We collected 219 soil profiles and used Random Forest modelling to develop the soil organic carbon stock baseline. Values range between 0.53 and 4.27 kg/m^2 in the sandy Otjozondjupa soils. LDN baselines were integrated into other national planning processes to add value to LDN products. Analyses of the relationship between soil carbon and land cover change, especially from grassland to bushland, increased the usefulness of soil carbon maps for the Integrated Regional Land Use Planning process. Local ownership of LDN baseline development, from data collection to digital soil mapping, was crucial for local stakeholders.

Keywords: LDN, soil organic carbon, Namibia, Otjozondjupa, bush encroachment, land use planning

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Land degradation is a global problem with serious economic, social and political consequences. The Economics of Land Degradation (http://www.eld-initiative.org/) project estimates that over 50% of the world's croplands and pasturelands are moderately to severely degraded. The United Nations (UN) estimates that 75% of forest lands are degraded and the rate of forest degradation is almost equal to that of deforestation (FAO, 2015). Economic losses from soil degradation are over $10 trillion, or around $1000 per capita, globally. As the global population increases by 2 billion in the coming 34 years and as diets change, the pressure on land resources will increase.

Given the severity of land degradation, there is renewed focus on restoration and sustainable land management (SLM) activities globally. Programs such as 20 by 20, which aims to restore 20 million hectares of degraded land by 2020 in Latin America, and AFR100, which aims to restore 100 million hectares of degraded land by 2030 in Africa, are working to mobilize resources and attract private sector investors for restoration activities. The Sustainable Development Goals (SDGs) also focus on this issue and SDG15.3 reads: 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.

The concept of Land Degradation Neutrality (LDN) receives much support from the UN Convention to Combat Desertification (UNCCD), and it has been piloted in 14 countries in 2015 while it is being scaled up to over 120 countries (that are parties to the Convention) in 2017. The geographic focus in Namibia, one of the 14 pilot countries that developed LDN baselines, was on the Otjozondjupa Region which has an area of approximately 105,000 square kilometres with a total population of less than 142,000 people. One of the reasons why this region was selected was because Namibia plans to integrate LDN into other national planning processes. The Integrated Regional Land Use Planning (IRLUP) process was planned to start in August 2016 which made the selection of Otjozondjupa ideal. This paper discusses the development of the Soil Organic Carbon (SOC) baseline, one of the three LDN indicators, focusing on method selection, capacity building, and key lessons learned.

METHODOLOGY

The process for LDN baseline development had two phases. During phase 1, a Synthesis Report ((Aynekul *et al.*, 2017) was written to provide a thorough review of methodologies currently available for the three LDN indicators: Soil Organic Carbon (SOC), Land Productivity or Net Primary Productivity (NPP) and Land Use and Land Cover Change (LUC). The LDN process also allows for countries to select a fourth indicator if land degradation is not sufficiently captured by these three indicators. In Namibia, Bush Encroachment (BE) is a problem with significant economic impacts. Therefore, a baseline for bush density was also developed. During a first workshop in Windhoek in February 2016, local stakeholders were guided through different exercises to define selection criteria for LDN methods (e.g. cost or accuracy), apply weights to these criteria, and make a final selection.

During Phase 2, a training workshop was held with potential field staff and representatives from local communities in Otjozondjupa focusing on sampling design and data collection. Participants were trained to collect soil samples at 0-30cm, 30-100cm and a bulk density core at 15cm. We used a freely available SOC map from ISRIC (www.soilgrids.org), Google maps, and local knowledge of the region to plan the data collection. We furthermore balanced data collection for SOC with data collection for the LUC and BE baselines.

After the data were analyzed, several digital soil mapping methods were tested to find the best possible fit for a SOC baseline at 250m resolution. By using the existing SoilGrids map for designing data collection as well as using it as a covariate in the modeling, we wanted to test different ways to easily improve on the freely available SoilGrids with minimal cost. A third workshop was completed with participants from the private sector, local universities and different government offices, all people who had been identified as most likely to provide support to the Ministry of Environment and Tourism (MET) in future monitoring and reporting for LDN. In addition, we took part in IRLUP planning meetings to explain how the LDN baselines could be used for this process.

RESULTS

During the first workshop, participants stressed that the selected LDN methodology needed to be locally "owned". This requirement for local ownership implied several things. First, soil data were analyzed at the Ministry of Agriculture, Water and Forestry (MAWF) in Windhoek. This meant that the Walkley-Black method was used rather than a more precise alternative, such as infrared spectroscopy, which was not locally available. Second, the digital soil mapping technique needed to match local capacities or these capacities needed to be developed. We tested Regression Kriging, Random Forest and Gradient Boosting to develop the final SOC and a survey of workshop participants revealed that capacity was lacking. We provided a one-week training in these approaches, as well as a training in R and GIS. Last, participants of the first workshop wanted the LDN baselines to be useful for the IRLUP process. The proposal we made to the MET was discussed with members of the IRLUP process before it was approved.

The task of planning field work was especially challenging due to the size of the area, time and budget constraints, and a lack of available data on existing road networks. Data were collected during the dry season from April 11 to June 3, 2016. A field team of Namibian nationals aimed to collect 325 soil profiles and were able to reach 237 locations, resulting in 219 useable soil profiles. The final SOC baseline map (Figure 1) was produced using Random Forest modeling and shows a range of values from 0.53 - 4.27 kg/m^2 in Otjozondjupa.

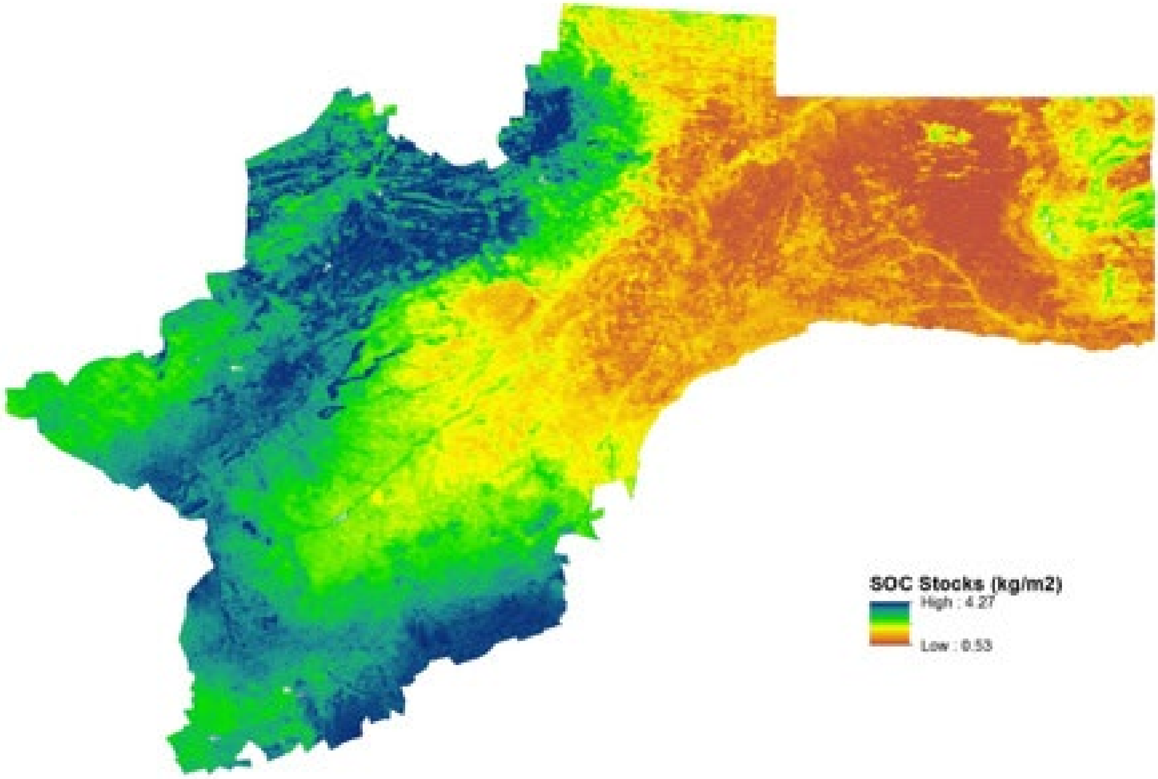

Fig. 1: Soil Organic Carbon stocks (0 – 30cm) for Otjozondjupa, Namibia. Total stock = 2,835 tons.

DISCUSSION

Participants in Namibia were much more concerned with local ownership of the LDN process then we expected. The synthesis study, for example, includes the following criteria that need to be evaluated in the selection of a methodology:

- Ability to assess the indicator of interest at a relevant spatial scale that capture landscape variabilities
- Ability to detect changes in indicators at appropriate spatial scale, and with appropriate temporal resolution
- Cost-effectiveness
- Transparency of methods, high accuracy, consistency, and reliability
- Accessibility, now and in the future, for monitoring and evaluation
- Comparability between regions and nations
- Capacity and acceptance of local and national partners to implement the methodology and integrate with ongoing national processes

Only the last point in this list mentions local acceptance but here it is formulated more with regards to finding agreement or consensus, not necessarily with respect to acceptance for ownership. This point also combines the ability of the method to be integrated with ingoing national processes, and this should probably be a point in itself given the importance in Namibia.

During the digital soil mapping training, for which participants reported that they had a background in GIS, R, statistics or a combination, we conducted a survey to gage whether participants understood what is meant by the fourth bullet: transparency of methods, high accuracy, consistency, and reliability. The answers showed that there was a wide range in understanding of these concepts. This is another indication that understanding of methodologies for developing LDN baselines, including the SOC baseline, requires further investigation in terms of how criteria or communicated and explained.

While there has been much debate regarding the selection of the three LDN indicators (LUC, NPP and SOC), our experience in Namibia shows that it is crucial that the value of these indicators is understood beyond the LDN process in order transition towards a degradation-neutral world. Showing the value and practicality of SOC is especially difficult due to the slow nature of the variable. This is further exacerbated by the relatively low SOC values in sandy soils.

In Namibia, for example, it was important to link SOC, as well as the other LDN indicators, to the locally more important concern for bush encroachment to show the value of the LDN indicators. One approach was to show that areas that converted from the more desirable grassland to bushland had lower SOC values (1.28 kg/m^2) then either areas that converted from bushland to grassland (1.59 kg/m^2) or areas that remained grassland (1.67 kg/m^2) from 2000 to 2016. We also showed that areas which are becoming bush encroached (measured by the density of small bushes less than 1.5m in height) are actively replacing grasslands and have a negative correlation with SOC. On the other hand, once land is encroached by mature bushes (greater than 1.5m), SOC tends to increase again probably due to density of the root system. While this is seemingly desirable in terms of carbon sequestration, in Namibia this has the unfortunate effect of much higher transpiration from deeper roots that can lower the water table compared to grassland systems (Colin Christian & Associates, 2010).

CONCLUSIONS

The LDN framework provides a good opportunity to take stock of the world's soil carbon resources, and work within national environments to stop the loss of soil carbon and reverse land degradation more generally. Many countries lack good data on soil carbon stocks and we successfully developed a SOC baseline at the sub-national level in Namibia. The baseline was just the first step however. It was critical to then link this baseline to other national planning processes, in our case the politically supported Integrated Regional Land Use Planning process. By showing the relationship between land cover change and soil carbon, especially with respect to areas that are converting from more desirable grasslands to bush encroached lands, we captured the attention of the IRLUP team.

There are many factors that influence the development of a SOC baseline including sampling design and cost of data collection, laboratory methods for analyzing soil samples, digital soil mapping techniques, etc. Further research is needed to make sure that relevant decision makers understand the nuance of the differences in choices. Even if this is clear, however, it may be the case that the most important criterion is that the process can be locally controlled from start to finish, and this requires a much greater investment in capacity building.

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1.30 | QUANTIFICATION OF SOIL CARBON IN ITURI FOREST, DEMOCRATIC REPUBLIC OF CONGO

Nsalambi V. Nkongolo*, Jean-Jacques K. Mbuyi, Michel W. Lokonda

Institut Facultaire des Sciences Agronomiques (IFA) de Yangambi, BP 1232 Kisangani, Democratic Republic of Congo, E-mail: nsalambi.nkongolo@gmail.com

ABSTRACT

Reliable estimates of soil organic carbon (SOC) stocks in natural and managed ecosystems are needed for global SOC models. We assessed SOC stocks and other nutrients in soil surface layer (0-10 cm) at Lenda1-Forest Dynamic Plot, Ituri Forest, Democratic Republic of Congo. Soil samples were collected along a 20 m x 20 m grid in a 10 ha plot. Eighty soil samples were collected using a 10 cm height and 10 cm diameter's auger. Samples were air-dried and brought to Harvard Forest, Harvard University for analysis. Results showed that SOC ranged from 7.80 to 77.10 g kg^{-1} with a mean of 17.97 g kg^{-1}. SOC was variable (CV= 62.265%) and best fitted to a Gaussian variogram model (A_0 = 460 m; R^2 = 0.83). Interpolated map showed that SOC decreased with altitude. SOC was also significantly correlated with other soil nutrients and soil physical properties. Soil organic carbon density (SOC_D) ranged from 14.55 to 130.65 tons C ha^{-1}. Overall, the 0-10 cm layer of this 10ha plot sequesters between 145.50 to 1306.50 tons C with an average of 296.50 tons C. More studies are needed to quantify SOC in deeper soil horizons (20-100 cm) of this 10 ha plot.

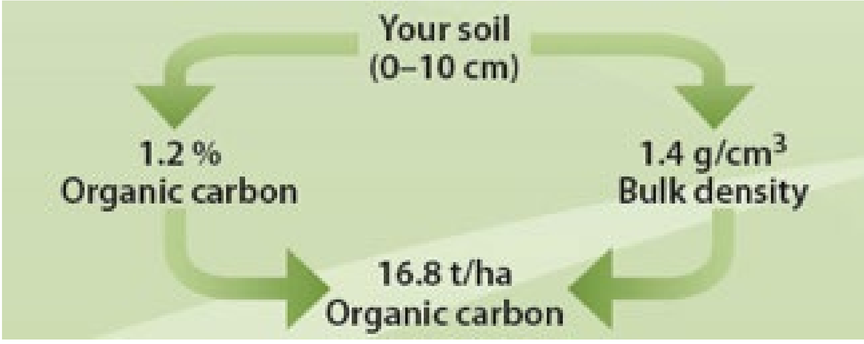
Keywords: *Soil carbon density, carbon sequestration, forest, Democratic Republic of Congo*

INTRODUCTION

Promoting carbon sequestration to offset atmospheric carbon dioxide by offering some sort of incentives via direct payments or carbon credits is a current topic of interest. However, several questions arise as to what is the best way to determine the quantity and quality of carbon in soils? How much carbon can a soil sequester? How fast can that carbon be sequestered? How stable is soil carbon? What proportion of soil carbon is labile and how much is recalcitrant? Is soil carbon in forests different than that in agricultural soils? Does our focus on soil carbon sequestration as an atmospheric offset prevent us from recognizing the other ecosystem services it provides? To address these questions, inventories of soil C concentrations are needed for constant monitoring of current C status and potential for sequestration. The objective of this study was to assess the status of soil carbon and other nutrients in Ituri Forest, Democratic Republic of Congo.

METHODOLOGY

This study was conducted at Lenda 1 Forest Dynamics Plots (FDP) in the Okapi Faunal Reserve (OFR), Ituri Forest, Democratic Republic of Congo. Lenda-1 Forest Dynamics Plot is located at the north of Lenda2, at 1° 19' N latitude and 28° 38' E longitude. The average annual rainfall at the Okapi Faunal Reserve administrative center is about 1600 mm, with a maximum of 2100 mm and a minimum of 1300 mm. The dry season lasts 3-4 months. The average annual maximum temperature is 25° C. The topography of the area is gentle, with occasional rolling hills containing exposed patches of shallow rocky soil (Torti *et al.*, 2001). Plots are located approximately 750 m above sea level and the elevation range from 700 to 850 m. Surface soil samples (0-10 cm depth) were collected along a 20 m x 20 m grid in the 10 ha plot. A portable GPS receiver (Garmin GPSmap 60s) was used to record the coordinates of each sampling location. Eighty soil samples were collected using a 10 cm long and 10 cm diameter soil sampler, giving a soil volume of 785 cm^3 per sample. Soil samples were air-dried and brought to Harvard Forest, Harvard University for analysis of soil organic carbon and other nutrients. Soil organic carbon density (SOCD) was calculated according to Pluske, Murphy and Sheppard as showed below :



i.e. 10,000 m^2 in one hectare x 0.1 m soil depth x 1.4 g/cm^3 bulk density x 1.2 % = 16.8 t/ha.
Authors: **Wayne Pluske** (Nutrient Management Systems), **Daniel Murphy** (The University of Western Australia) and **Jessica Sheppard** (Avon Catchment Council).
Source: http://www.soilquality.org.au/factsheets/organic-carbon

RESULTS

Soil bulk density (BDY) was within the range of normally reported values and varied between 0.92 to 1.89 g/cm^3 with an average of 1.69 g/cm^3 (Table 1) Its standard deviation was 0.17 g/cm^3 with a coefficient of variation (CV) of 9.88%. Soil organic carbon (SOC) ranged from 7.80 to 77.10 g kg^{-1} with a mean of 17.97 g kg^{-1}. It had high variability with a coefficient of variation (CV) of 62.265% and was best fitted to a Gaussian variogram model with a range of spatial variability (A_0) of 460 m and a coefficient of determination (R^2) of 0.83.

Table 1. Summary of simple statistics for soil bulk density and soil chemical properties

Variable	Mean	SD	C.V.	Minimum	Median	Maximum
BDY (g/cm3)	1.69	0.17	9.88	0.92	1.73	1.89
SOC (gkg-1)	1.80	1.13	62.65	0.78	1.53	7.71
N (%)	0.19	0.12	64.94	0.09	0.16	0.86
C/N	9.38	0.97	10.30	7.20	9.35	11.78
OM (%)	4.68	2.81	60.06	2.28	4.00	20.56
SOCD (tons/ha)	29.61	16.39	55.36	14.55	25.06	130.65

BDY = Soil bulk density, SOC = Soil organic carbon, N = Soil nitrogen, C/N = Carbon to Nitrogen ratio, OM = Organic matter and SOC_D = Soil organic carbon density.

An interpolated map was produced and showed that SOC decreased with altitude. SOC was also significantly correlated with other soil nutrients and soil physical properties. Soil organic carbon (SOC) was significantly and positively correlated Ca, P, Na, Fe, Cu, Mn, but the highest correlation was with Zn ($p = 0.0001$, $r = 0.64$). It was also negatively correlated with S, Al and elevation. Significant correlations were also found between soil carbon and soil physical and thermal properties. Soil organic carbon density (SOC_D) ranged from 14.55 to 130.65 tons C ha^{-1} with an average of 29.61 tons C/ha.

DISCUSSION

The coefficient of variation for soil bulk density was less than 20%, implying that there was less variability and that BDY was well measured. Therefore, any effect of BDY in overestimating SOC can be ruled out. The results of this preliminary study also show the potential for soil carbon sequestration in this 10 ha pristine forest plot, dominated by *Gilbertiodendron dewevrei*. Soil organic carbon averaged 29.61 tons /ha in the 0-10 cm layer in Ituri Forest. This value seems to suggest greater SOC storage in Ituri Forest as compared to nearby forest of the same region. In fact, although they sampled in different forests and higher soil layer, but in the same province, Doetterl *et al* (2016) reported SOC values of 23.10 Mg C/ha in Yoko Forest and 55.70 Mg C/ha in Yangambi Forest for the 0-30 cm depth. Our results for a third of their sampling depth shows higher values of SOC.

CONCLUSION

It is suggested the study be pursued to include deeper soil layers (20-100 cm) for a better assessment of soil organic carbon in Ituri Forest, Democratic Republic of Congo

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1.31 | ECOLOGICAL STOICHIOMETRY ALONG URBAN-RURAL LAND-USE GRADIENTS IN SOUTHEASTERN NIGERIA

*C.I Obi
Department of Soil Science and Technology, Federal University of Technology, Owerri, P.M.B 1526 Owerri, Imo State, Nigeria. +2348032687760. innocentck@yahoo.com

ABSTRACT

The inter-link in soil biogeochemical reactions made the study of soil ecological stoichiometry an important necessity. The study was carried out in Imo state, a southeastern part of Nigeria, to assess the soil carbon stock as a key element of the soil ecology. Three urban-rural gradients were delineated for the study, viz; urban soils, suburb soils and rural soils. Three pedons were dug, described and sampled at each of these areas using the guidelines of FAO (2006). Soil samples were prepared in the laboratory and analyze for its properties. Among the ecological stoichiometry, soil organic carbon was given an important priority because of its chelation with other elements. Results showed that the soil carbon stock (SCS), available phosphorous and bulk density were asymmetric in their distribution (Skewness = -1.07, 1.05, -1.47 for SCS, P and bulk density respectively) only in the suburb areas. Moisture content, hydraulic conductivity and K varied highly (CV ≥ 45% ≤ 150%) in most of the soils, base saturation, Mg, Ca, organic carbon, Nitrogen, clay and silt varied moderately (CV ≥ 17% ≤ 39%) while the bulk density, ECEC, exchangeable acidity, P, pH and sand had a low variability (CV ≥ 3% ≤ 13%). Soils in the rural areas had the greatest carbon pool (mean SCS = 1.65 Mg C ha^{-1}) followed by suburb (mean SCS = 6.59 Mg C ha^{-1}) and then urban (mean SCS = 8.63 Mg C ha^{-1}). The study of soil carbon stock at various depths in the respective land use gradients showed a greatest difference having at least 4 Mg C ha^{-1} greatest pool in the rural soils than the other two areas.

Keywords: Stoichiometry, ecology, soil carbon stock, land use, biochemical reactions

INTRODUCTION

More recently, scientists have concentrated efforts in their study of ecological stoichiometry, especially the most dynamic elements in the soil. Most researchers (example Mulvaney *et al.*, 2007; Christoph *et al.*, 2013) have considered carbon and nitrogen sequestration, and phosphorous distribution (Osodeke *et al.*, 2006) in soils around the world which dominate the soil ecology. In our study of ecological stoichiometry, carbon, nitrogen, sulphur and phosphorous are very important because during the decay and synthesis of organic matter in the soil, transformation and mineralization of these elements which chelates as compounds are usually involved. Because of our advancing land-use, it is not clear for example how carbon sequestration may change in response to the changing land use. Sterner and Elser (2002) stated that ecological stoichiometry implied that plant communities with low biomass carbon to nutrient ratio have fast turnover rates, high nutrient cycling and low carbon sequestration while that with high biomass carbon to nutrient ratio have slow turnover rates, slow soil nutrient cycling and high carbon sequestration in organic soils.

The transformation of landscapes from non-urban to urban land use has the potential to greatly modify soil carbon (C) pools and fluxes (Pouyat *et al.*, 2002). They stated that for urban ecosystems, very little data exists to assess whether urbanization leads to an increase or decrease in soil C pools. Urban areas play a significant role in the global carbon cycle as source of carbon emission due to the effects of urban sprawl against other land use types. It is expected that by 2030, an additional 1.2 million square kilometers of land will be converted to urban land use which is expected to result in a loss of carbon storage in natural vegetation of about 138 PgC (Seto *et al.*, 2012). During the decomposition of organic matter, mostly made up of C, nitrogen is usually mineralized. Because of the inter-link in biochemical reactions between C, nitrogen and phosphorous, the study is thus necessary for a proper understanding of ecological stoichiometry, especially carbon, in our ecosystem. One of such stoichiometry that signifies the breakdown of carbon in the soil is given thus; $CO(NH_2)_2 + 2H_2O \rightarrow (NH_4)_2CO_3$. In this research, carbon was given an important priority and was converted to a proper SI unit for a good understanding of the concentrations sequestered. Leaf litter from trees and shrubs are mainly the organic matter components of natural soils. Organic matter is usually decomposed by soil inhabiting organisms and the nutrients and energy they contain are released for utilization by the organisms themselves or the vegetation. Soils in urban and peri-urban areas are interrupted from the cycles by various factors; leaf litter is often swept up as trash, or very little litter falls on urban soils because of the low amount of biomass produced by the plants. Assessment of sequestered carbon and other ecological stoichiometry along urban and rural gradients are important to be able to give an account of changes in carbon pool with consequent land use change since carbon has been recorded as the most important element to sequester if we can check the global climate change.

The objective of the study was therefore to use and detect the soil carbon stock as a key element of the ecology in defining soils that were highly sequestered with carbon and other ecological stoichiometry along urban-rural gradients.

MATERIALS AND METHODS

Description of the Study Site

The study was conducted in three urban-rural gradients namely; urban, suburban and rural soils. Soils were delineated in this order based on ongoing activities and evidence of changing land uses. Soils in the urban areas had some parts with gullies as a limitation, the suburb soils were mainly used for arable crop production while that of the rural had thick vegetation that were made up of shrubs and trees. The whole study areas were located in Imo State, a Southeastern part of Nigeria. Imo state is located approximately between longitudes 6˚50'E and 7˚25'E and latitudes 4˚45'N and 7˚15'N. The state lies within a tropical climate characterized by rainy season (February/March – November) and dry season (November – February/March). Annual rainfall in the state ranges from 3000 mm along Atlantic coast to 2000 mm in the hinterland. Average annual temperature of the state ranges from 25 to 27˚C.

Soil Sampling and Laboratory Analysis

Soil samples were collected from three pedons in each of the areas; urban, surburban and rural. Soils profiles were described and sampled according to the guidelines of FAO (2006). Soil samples were collected from the bottom-most horizon to the topmost to avoid contamination of soils from horizons. All the sampled soils were bagged in fresh clean polythene bag and were prepared for analyses in the laboratory by air drying and sieving using a 2mm sieve.

Standard routine methods were used in the laboratory to analyze, with the inclusion of other physical properties, the important elements that are active in the soil ecological stoichiometry. Particle size was analyzed using the Bouyoucous hydrometer method (Gee and Or, 2002). Bulk density was determined using the core method as described by Blake and Hartge (1986). Moisture content was obtained gravimetrically by the simple oven drying method. Hydraulic conductivity was determined using the constant head permeameter method as described by Topp and Dane (2002). Exchangeable base cations (Ca, Mg, K, and Na) were extracted with 1 N NH_4OAc (pH 7) (Thomas, 1982). Exchangeable calcium and magnesium were determined by ETDA complexio-metric titration while exchangeable potassium and sodium were determined by flame photometry (Jackson, 1962). Exchangeable acidity was determined by titration method (Mclean, 1982). Effective Cation Exchange Capacity (ECEC) was obtained by the summation of all exchangeable cations. Base saturation was calculated as a percentage of the value of the summation of exchangeable bases over cation exchange capacity. Soil organic carbon was analyzed by Walkley and Black wet digestion method (Nelson and Sommers, 1982). Soil carbon stock was calculated using a mathematical formula; soil carbon stock = percentage organic carbon × bulk density × soil depth (Batjes, 1996). Soil pH was measured potentiometrically in both water and 0.1 N KCl at the soil-liquid ratio of 1:2.5. Total nitrogen was determined by micro Kjedahl digestion method (Bremner and Mulvaney, 1982) and available phosphorous was determined by Bray II method (Olsen and Sommers, 1982).

RESULTS AND DISCUSSION

Table 1 shows result of the descriptive statistics of the soil properties of the studied soils. The normality of distribution of the measures of central tendency of the soil properties was mostly symmetric in the urban soils with the exception of clay, K, exchangeable acidity and moisture content. In the suburb soils, the distribution of soil carbon stock, bulk density, hydraulic conductivity and phosphorous were as well asymmetric. It was obvious that the changing land use gradient from urban to a suburb affected the carbon stock of the latter soils (mean = 6.59 Mg C ha^{-1}) because of the trending presence of organic matter as we travel in space off from the urban areas. According to Craul (1985) soils in urban and peri-urban areas are interrupted from the cycles by various factors; leaf litter is often swept up as trash, or very little litter falls on urban soils because of the low amount of biomass produced by the plants. This was not the case for the suburb soils. The trending presence of organic matter that affected the carbon stock of the suburb soils as well affected the phosphorous contents (mean = 23.39 g kg^{-1}) which could be because of the availability of phosphorous from the organic phosphates. In the rural soils, most of the soil properties were neither skewed nor kurtous with the exception of phosphorous, Ca, Mg, K, Na and bulk density. The distribution of the carbon stock of the rural soils were not skewed but kurtous which could be adduced to availability of more carbon pool (mean = 8.63 Mg C ha^{-1}) in the whole area as a result of the thick vegetation made up of trees and shrubs. The soil properties varied in the areas. Moisture content, hydraulic conductivity and K varied highly (CV ≥ 45% ≤ 150%) in most of the soils, base saturation, Mg, Ca, organic carbon, Nitrogen, clay and silt varied moderately (CV ≥ 17% ≤ 39%) while the bulk density, ECEC, exchangeable acidity, P, pH and sand had a low variability (CV ≥ 3% ≤ 13%). Soil carbon stock varied moderately in the suburb and rural soils. The carbon stock (SCS) in the rural soil was highest (mean SCS = 1.65 Mg C ha^{-1}) followed by suburb (mean SCS = 6.59 Mg C ha^{-1}) and then urban soils (mean SCS = 8.63 Mg C ha^{-1}) in that order.

Figures 1 give the graphs of soil carbon stocks against depths in the urban-rural land use gradients. It could be seen that at the depth of 20 cm, soil carbon stock in the rural soils (8.5 Mg C ha^{-1}) were highest when compared among the other gradients. When monitored at the depth of 40 cm, the carbon stock in all the areas neared equals (8.0 Mg C ha^{-1} - 8.2 Mg C ha^{-1}). This could be because the land use in the urban and suburban areas had not so deteriorated the carbon pool in these areas. The soil carbon stock showed a great difference having at least 4 Mg C ha^{-1} greater pool in the rural soils than the other two areas.

CONCLUSION

Most of the soil properties of the three land use gradients had a symmetric distribution. The changing land use of the suburb soils might have resulted to the asymmetric distribution of the soil carbon stock, phosphorous and bulk density in the areas. The rural soils had the greatest carbon pool which affected the availability of phosphorous in a direct proportion. Ecological stoichiometry has had a diverse study; its importance is in the mitigation of the global climate change and for exactitude in soil management.

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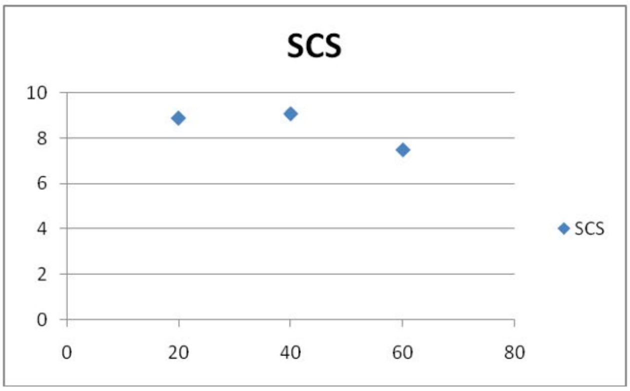
Table 1: Descriptive Statistics of Soil Properties of the Studied Areas

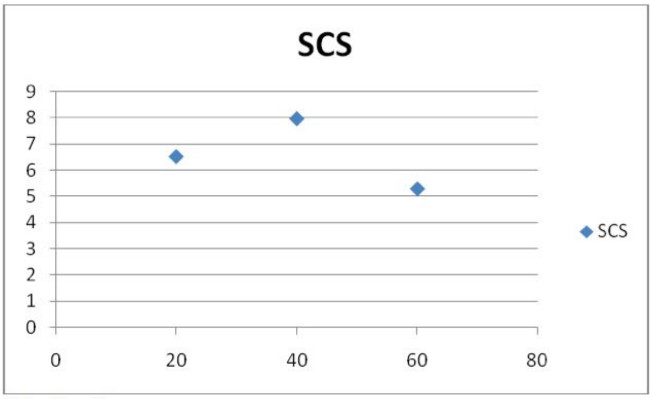
Variable	Urban Soils	Mean	SD	Min.	Max.	CV	Skew-ness	Kurto-sis	Sub-urb soils	Mean	SD	Min	Max	CV	Skew-ness	Kurto-sis
Sand (gkg-1)		792.67	26.46	766.00	846.00	3.34	0.88	0.73		786	43.59	726.00	846	5.55	0.19	-1.27
Silt (gkg-1)		58.89	22.61	30.00	90.00	38.39	0.18	-1.17		65.56	16.67	40.00	80	25.42	-0.75	-0.99
Clay (gkg-1)		140.27	55.37	10.40	184.00	39.47	-1.91	3.83		148.4	46.67	74.00	194.00	31.44	-0.46	-1.44
pH H2O		5.02	0.27	4.60	5.50	5.34	0.35	0.23		4.57	0.26	4.20	5.10	5.76	0.78	0.95
pH KCl		3.93	0.27	3.50	4.40	6.85	0.19	0.09		3.54	0.31	3.00	4.00	8.71	-0.21	-0.09
P (mgkg-1)		21.42	2.78	18.60	25.60	12.96	0.76	-1.51		23.39	3.73	18.60	31.20	15.94	1.05	1.59
N (%)		0.07	0.01	0.05	0.09	19.80	-0.13	-0.78		0.07	0.02	0.05	0.10	21.56	0.27	-0.51
OC (gkg-1)		8.70	1.55	6.40	11.20	17.84	0.0005	-0.58		9.20	2.24	6.20	13.00	24.40	0.53	-0.55
Ca (Cmolkg-1)		1.50	0.27	1.10	1.93	17.89	-0.02	-0.57		2.46	0.53	1.80	3.40	21.46	0.49	-0.67
Mg (Cmolkg-1)		1.89	0.56	1.00	2.80	29.53	-0.10	-0.09		1.56	0.57	0.80	2.40	36.80	-0.12	-1.39
K (Cmolkg-1)		0.98	0.44	0.40	2.00	45.10	1.62	3.99		0.08	0.01	0.07	0.11	16.86	0.64	-0.54
Na (Cmolkg-1)		0.08	0.01	0.06	0.10	16.36	0.60	0.91		0.09	0.02	0.06	0.12	20.86	0.48	0.21
EA		0.08	0.01	0.07	0.10	11.76	1.47	3.28		1.19	0.18	0.88	1.48	14.71	-0.15	0.39
ECEC (Cmolkg-1)		1.22	0.14	1.04	1.48	11.57	0.74	0.03		5.38	0.95	4.21	6.91	17.60	0.17	-1.32
BS (%)		4.24	0.87	3.01	6.03	20.51	0.86	1.68		76.70	7.21	64.85	87.26	9.40	-0.24	-0.90
BD (gcm-3)		69.75	9.23	50.83	82.75	13.23	-0.86	1.46		1.27	0.60	0.02	1.83	47.13	-1.47	1.47
HC (cm-min-1)		0.12	0.06	0.04	0.24	50.96	0.58	-0.01		0.07	0.08	0.0003	0.21	109.28	1.17	0.003
SCS (Mg C ha^{-1})		1.65	0.24	1.17	1.90	14.52	-0.99	0.72		6.59	3.25	0.16	10.79	49.28	-1.07	0.89
MC (g/g)		0.19	0.28	0.01	0.81	150.72	1.77	2.31		15.01	5.49	9.20	25.1	36.59	0.64	-0.57
	Rural soils															
Sand (gkg-1)		827.11	35.51	776.00	886.00	4.29	0.21	-0.48								
Silt (gkg-1)		47.78	14.81	30.00	70.00	31.01	-0.11	-1.30								
Clay (gkg-1)		125.11	31.80	84.00	164.00	25.42	-0.19	-1.56								
pH H2O		5.07	0.34	4.70	5.70	6.62	1.04	0.19								
pH KCl		4.06	0.36	3.60	4.80	8.90	1.10	1.32								
P (mgkg-1)		25.4	4.72	20.60	35.60	18.57	1.33	1.94								
N (%)		0.09	0.02	0.07	0.12	18.61	0.13	-0.82								
OC (gkg-1)		11.03	2.33	8.00	14.80	21.08	0.31	-1.03								
Ca (Cmolkg-1)		3.29	0.63	2.60	4.80	19.26	1.93	4.55								
Mg (Cmolkg-1)		2.68	0.32	2.00	3.10	11.78	-1.28	2.19								
K (Cmolkg-1)		0.10	0.01	0.09	0.13	13.64	1.28	0.83								

Na (Cmolkg-1)		0.19	0.26	0.08	0.88	140.48	2.98	8.95								
EA		0.94	0.22	0.52	1.20	24.03	-0.80	-0.34								
ECEC (Cmolkg-1)		7.11	0.74	5.97	8.67	10.43	0.81	2.25								
BS (%)		86.43	4.09	79.89	94.00	4.74	0.41	0.54								
BD (gcm-3)		1.36	0.51	0.82	2.54	37.35	1.63	3.62								
HC (cm-min-1)		0.06	0.04	0.002	0.14	61.77	0.64	0.93								
SCS (Mg C ha^{-1})		8.63	2.19	5.36	12.95	25.40	0.65	1.09								
MC (g/g)		14.44	4.59	10.00	23.20	31.79	0.74	-0.12								

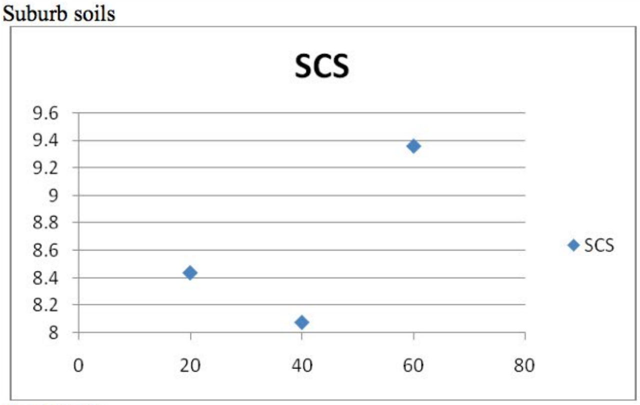
SD- Standard Deviation, CV- Coefficient of Variation, OC- Organic Carbon, EA- Exchangeable Acidity, ECEC- Effective Cation Exchange Capacity, BS- Base Saturation, BD- bulk density, HC- Hydraulic Conductivity, SCS- Soil Carbon Stock, MC- Moisture Content.



Urban Soils



Suburb soils



Rural Soils

Figure 1: Graphs of Soil Carbon Stock against depths in the various land use gradients

1.32 | USING INFRARED SPECTROSCOPY FOR DETECTION OF CHANGE IN SOIL PROPERTIES IN SELECTED LANDUSES IN MT. MARSABIT ECOSYSTEM, NORTHERN KENYA

C.A. Ouko[1] and N. Karanja[2],

[1]*Centre for Training and Integrated Research in ASAL Development (CETRAD)*

P.O. Box 144, Nanyuki, Kenya.

[2]*Department of Land Resource Management and Agricultural Technology, University of Nairobi P.O Box 29053, Nairobi, Kenya.*

Corresponding author Email: oukoca@gmail.com/oukoca@yahoo.co.uk

ABSTRACT

The conversion of forest to smallholder cropland is one of the most common type of land use change in the tropics. Forest margin cultivators respond to deteriorating soil fertility and declining crop yield by cultivation on the forest margins in an attempt to create "*new*" fertile cropland. A critical constraint to managing soils in sub Saharan Africa is poor targeting of soil management interventions. This is partly due to lack of diagnostic tools for screening soil condition that would lead to a robust and repeatable spatially explicit case definition of poor soil condition. The objectives of this study was to evaluate the ability of near infrared spectroscopy to detect changes in soil properties.

The effects of forest conversion and subsequent cultivation on carbon stocks and soil properties were monitored in demarcated land use types (forest, cropped and pasture land) along transects within the Mt. Marsabit ecosystem in northern Kenya. Total carbon ranged between 1.99 – 17.74 gkg^{-1} in the forest, 1.17 – 3.08 gkg^{-1}cropped 1.62 – 4.77 gkg^{-1} pasture land use systems. The soil properties total carbon, total nitrogen, pH, exchangeable magnesium, calcium and CEC were significantly lower ($P \leq 0.001$) in cropped and pasture compared to forest and their variations were successfully predicted ($r^2 > 0.76$) using near infra red spectroscopy (NIRS) is high prediction accuracy. The spectral separability of the three land use systems offers promise for an approach that utilizes NIRS for monitoring changes in soil properties. The study concludes that reflectance spectroscopy is rapid and offers the possibility for major efficiency and cost saving, permitting spectral case definition to define poor or degraded soils, leading to better targeting of management interventions.

Key words: **Spectral detection, reflectance, soil properties, land use systems**

1.33 | GLOBAL SPACE-TIME SOIL ORGANIC CARBON ASSESSMENT

José Padarian [1], Uta Stockmann [1], Budiman Minasny [1], Alex B. McBratney [1,*]

[1] Sydney Institute of Agriculture, The University of Sydney, New South Wales, Australia
* Presenting author: Alex.McBratney@sydney.edu.au

ABSTRACT

We mapped how soil carbon changes with time globally. We used a two-stages modelling approach, combining a statistical model based on environmental covariates and a mechanistic model which predicts soil C changes via landcover change, precipitation and temperature. The results successfully captures the effect of human pressure on natural environments and the subsequent loss of soil organic carbon with a prediction accuracy comparable with other digital soil mapping exercises. This work demonstrates the need to monitor and predict soil C change with time, and highlights the need of long term studies to unveil complex interactions in space-time.

Keywords: Soil security, Food security, Digital Soil Mapping, Google Earth Engine

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Soils fulfil a myriad of essential ecosystem functions, they are the foundation for producing food and fibre, store and filter water and also play a key role in the carbon cycle. The importance of the soil resource for human life and the need for its sustainable management have been a worldwide focus. A key driver for this recognition and increased public awareness was the declaration of 2015 as the International Year of Soils by the United Nations General Assembly (A/RES/68/232). "We need healthy soils to achieve our food security and nutrition goals, to fight climate change and to ensure overall sustainable development." (José Graziano da Silva, FAO Director-General).

Soil properties that can be used as indicators to detect substantial decline of the soil's condition have been discussed within the Soil Quality concept (Karlen *et al.*, 2001) and within the wider Soil Security framework (McBratney *et al.*, 2014). Soil organic carbon fits well into the role of being a universal indicator for soil security as it is somehow known to the global population (Koch *et al.*, 2013). It is therefore used here as a proxy to diagnose the condition of the soil resource.

Soil organic carbon is a key component of functional ecosystems and has been specifically linked to biological activity and agricultural productivity (Stockmann *et al.*, 2013). Soil organic carbon has also become important as it can play a crucial role in climate change mitigation, through the offset of atmospheric CO_2.

Here, we quantitatively assessed the condition of our world soils, employing a unique spatial and temporal assessment of global soil organic carbon dynamics (including the distribution of SOC with depth). Such an assessment allows us to identify critical changes of the soil resource through time in light of land use change and changes in temperature and rainfall patterns, and will enable us to pinpoint regions of the world where the soil resource is at risk to fulfil its fundamental ecosystem functions.

METHODOLOGY

We performed a multiple-stage modelling, a combination of statistical and mechanistic inference. In brief, at the first stage we generated a baseline C map for the year 2001. To account for the C changes with time, on the second stage we performed a "landcover tracking" routine starting from our baseline, to establish where and when landcover changes occur, the nature of the changes, and how long the new landcovers persist.

Stage 1: SOC baseline generation
We based the first stage of our space-time modelling on the *scorpan* regression kriging approach (McBratney *et al.*, 2003), where a soil attribute (i.e.: SOC) is a function of a series of soil forming factors which are represented by environmental

covariates. In a digital soil mapping framework, these covariates are usually in the form of raster images. In this study we used the following set of covariates: a digital elevation model (Danielson and Gesch, 2011) and its derived slope, long-term mean annual temperature (MAT) and total annual precipitation (TAP) (Hijmans *et al.*, 2005), and land cover. To link the environmental covariates with the SOC content we used the CART algorithm (Breiman *et al.*, 1984).

Stage 2: Landcover tracking
We used the MODIS Land Cover Type product (MCD12Q1), which provides annual global land cover information at a 500 m resolution, from the year 2001 until 2013 (which is constantly updated), using five global land cover classification systems. In this study we used the International Geosphere Biosphere Programme (IGBP) classification system (Belward, 1996).

We analysed each raster image since 2001 and kept track of all the landcover changes to establish if in any of the consecutive steps a positive or negative SOC concentration change would occur. The changes in SOC follow the dynamics described in the following Section.

Soil organic carbon dynamics

Magnitude of change: $\tilde{m}$

When a landcover change occurs, it triggers a series of events leading to changes in the properties of the affected system, including SOC content. These changes usually happen over a period of time until the system reaches a new equilibrium. In this work we rationalise that these equilibrium states are related to the mean SOC content of each landcover. We also consider that landcover conditions change between climatic contexts, and to account for this difference we used the Köppen-Geiger climate classification scheme (Peel *et al.*, 2007) to group our observations.

Rate of change: $\tilde{r}$

The transition between the initial and the new system equilibrium state happens over a period of time, and together with the magnitude of the change, the rate for that change to occur is also dependant on temperature and water availability.

The temperature dependence (*vt*) is characterised by $e^{-E/k\,(T+273.15)}$, which is also known as the Arrhenius function (Arrhenius *et al.*, 1915), where *E* corresponds to an "activation energy", *T* is the MAT in Celsius, and *k* is the Boltzmann's constant (8.65×10^{-5} eV K^{-1}). By modifying the activation energy, this equation can be used to: a) describe SOC gains based on the temperature dependence of Rubisco carboxylation (E ≈ 0.32eV), or b) describe SOC losses based on the temperature dependence of processes governed by respiration (E ≈ 0.65eV).

The dependence on precipitation (*vp*) is described by a logistic function

$$vp = \frac{1}{1 + e^{0.003\left(pp - \frac{11401}{5}\right)}}$$

where *pp* is the total annual precipitation in mm. In this model, at low precipitation SOC flows are negligible (Ewing *et al.*, 2008), and after certain amount of water has been stored in the soil, its influence can be dismissed if we assume free-draining conditions. Similar logic has been used by Van Veen and Paul
(2011) who used soil moisture deficit as a reduction factor to simulate SOC dynamics in grassland soils.
The combination of both *vt* and *vp* yields to a normalised rate-modifying factor $\tilde{r}$,

$$\tilde{r} = \frac{r}{r_{max}}$$

$$r = vt * vp$$

where represents the value for the maximum temperature (32° C) and precipitation (11,401 mm) present on the covariates rasters (5.43 × 10−6 and 2.02 × 10−11 for gains and losses, respectively).

Shape of change: $\tilde{s}$

To account for SOC accumulation we generated a sequence of weights $\tilde{s}_{gain}$ using a logistic function, the length and shape of which depend on the value of the normalised rate-modifying factor $\tilde{r}$. A logistic function is a common form to describe growth. The Richard's equation (Richards, 1959), and Gompertz's function (Gompertz, 1825) are some examples. This type of function has also been applied to predict growth in forest ecosystems (Botkin, 1993; Pacala *et al.*, 1993), and crops (Yin *et al.*, 2003).

To simulate the SOC loss mechanism we used an exponential-decay function to generate a sequence of weights $\tilde{s}_{loss}$, which also depends on $\tilde{r}$. This type of curve has been widely used to describe SOC decomposition (Covington, 1981; Poeplau *et al.*, 2011).

By combining magnitude, rate and shape, it is possible to assess the differences in SOC for any given location after a landcover change.

RESULTS AND DISCUSSION

The numerical performance of our model is consistent with similar studies performed at national and global extent, with mean R^2 and RMSE values for the top soil around 31.59%, and 6.68% (SOC) respectively.

With our approach it is possible to predict SOC content for any given year between 2001 and 2013 (and further when new MODIS images become available), and by comparing multiple images it is possible to assess the change is SOC. Fig. 1 shows an example for Rondonia State in Brazil where anthropic pressure has led to expansion of agricultural land, and to deforestation. Similar results were obtained in many areas of the world (Fig. 2), highlighting the importance of landcover change as a driving force.

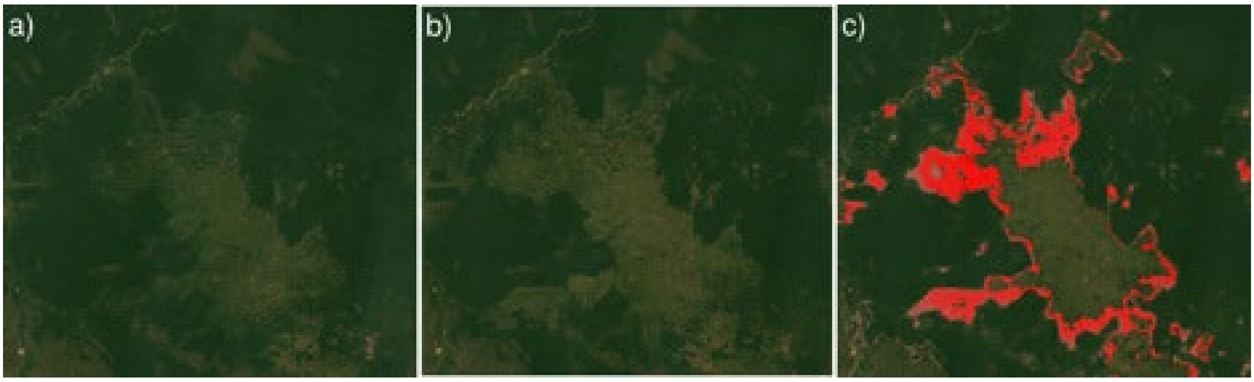


Fig. 1: Topsoil SOC loss in Rondonia State, Brazil. a) Satellite image for the year 2001; b) satellite image for year 2013; c) soil SOC for the year 2013 as compared to 2001, where red represent SOC loss.

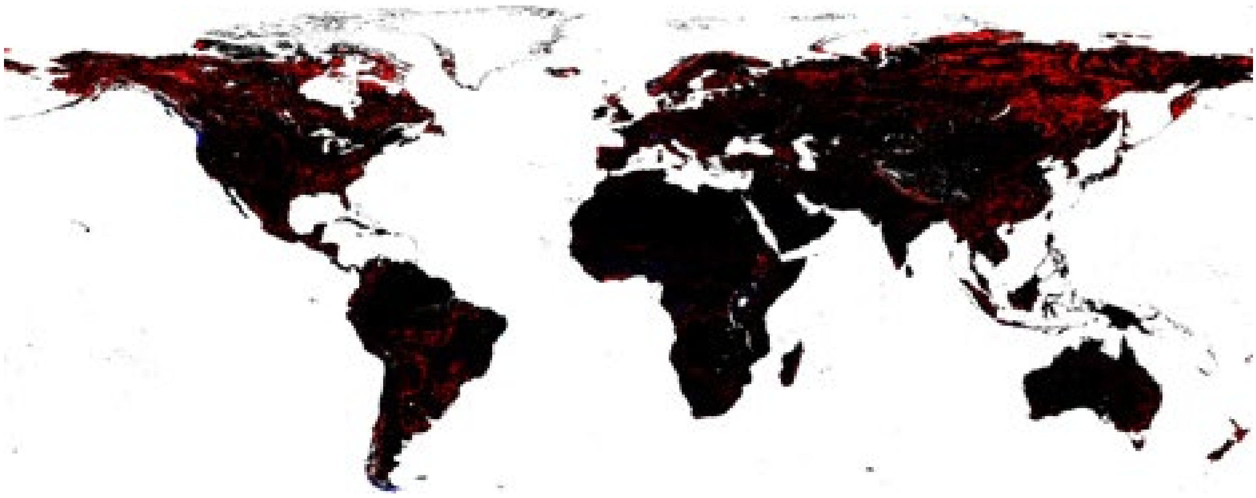


Fig. 2: Global topsoil SOC loss between 2001 and 2013.

Our approach clearly identify areas where SOC loss due to landcover change are expected. We did not find evidence of changes due to climate change in our data, and as a consequence, we ignored its effect, even if the mechanistic part of our model takes in account temperature and precipitation. We believe this is mainly because the low amount of soil chronosequence data in our dataset, and we stress the need to perform such studies in different bio-climatic regions.

Another important factor to consider is the uncertainty of the model. Our methodology assess the uncertainty levels of the modelling component, but has not considered the uncertainty of the MODIS imagery, which has a classification accuracy of around 75%. This inaccuracy leads to a general overestimation of the SOC loss, especially in boreal areas, according to our visual evaluation of the maps.

CONCLUSIONS

The proposed approach successfully captures the effect of human pressure on natural environments and the subsequent loss of soil organic carbon (SOC).

This work would not be possible without the collaboration of organisations who decided to share their soil data with us. Even if we assembled a relatively big dataset, most of the limitation of our model are defined by the absence of data, in particular in areas like peatlands, and other non-agricultural areas, and more specifically the lack of long term studies data to unveil the effect of persistent landcovers and climate change.

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1.34 | FIELD SCALE MAPPING OF SOIL CARBON STOCK WITH LIMITED SAMPLING BY THE USE OF PROXIMAL SENSORS

Priori S.[1*], Fantappiè M.[1], Lorenzetti R.[2], Pellegrini S.[1], Costantini E.A.C.[1]

[1]CREA, Council for Agricultural Research and Economics; Firenze (Italy), simone.priori@crea.gov.it
[2] Università del Molise, Dip. di Agricoltura, Ambiente, Alimenti; Campobasso (Italy)

ABSTRACT

High-precision maps of soil features, namely texture, soil organic carbon, gravels, allow monitoring the effects of specific agricultural managements on carbon stock spatial variability. At a field-scale the assessing of soil spatial variability can be improved by using proximal sensors, which permit a quick and cheap recording of data with a high spatial density.
Aim of the present work was to test the combined use of two proximal sensors, namely visible-near infrared (Vis-NIR) spectrometer and passive γ-ray spectrometer, to obtain high detailed maps of soil carbon stock at a depth of 0-30 cm (CS_{30}), using a limited number of sampling sites per field (around 1 per hectare). CS_{30} maps were interpolated within surveyed fields using Geographically Weighted Multiple Regression (GWMR). The accuracy of CS_{30} predicted maps allows monitoring of the effects of agricultural management and soil erosion on the soil carbon pool and its spatial variability.

Keywords: mapping, spectroscopy, geostatistics, erosion, management, Sicily, Italy.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Assessment of soil spatial variability at high-detail can be very useful to comprehend the effects of management and/or erosion on soil services in all the parts of the field or basin. However, mapping soil features at high detail usually has high cost, is time-consuming for high number of sampling, and the results are often questionable. The use of proximal sensors allows a quick and cheap recording of data with a very high spatial density. Although soil features predicted by proximal soil sensing may be less accurate than conventional methods, the collection of larger amounts of spatial data using quicker, cheaper, and simpler techniques makes their use very efficient (Viscarra Rossel *et al.*, 2009).
The aim of the present work was to test the combined use of two proximal sensors, namely visible-near infrared (Vis-NIR) and passive γ-ray spectrometers, to obtain high detailed maps of soil C stocks at a depth of 0 to 30 cm (CS_{30}) using a limited number of sampling sites per field, which were around 1 sample per hectare.
Over the past 30 years, Vis-NIR diffuse reflectance spectroscopy (Vis-NIR DRS) has proven to be a quick, cost-effective and non destructive method to predict several soil features, in particular soil organic carbon (SOC), water content, texture, and carbonates (Viscarra Rossel *et al.*, 2009; Stenberg *et al.*, 2010). The accuracy of SOC determination by Vis-NIR DRS was slightly lower than that obtained by Walkley-Black and TOC analyser, but the unitary cost was €0.96 with Vis-NIR, versus €2.56 with Walkley-Black and €15.15 with TOC analyser (O'Rourke and Holden, 2011). Vis-NIR DRS could be used both in laboratory and in field, the latter using rugged spectrometers and equation to correct spectra for soil moisture.
The use of passive γ-ray spectrometry for mapping radionuclide concentrations in soils and rocks has been used since the 1960-70 for mineral exploration and geological mapping, but in the last decade it has been also used for soil mapping and agricultural purposes (Van der Klooster *et al.*, 2011; Dierke and Werban, 2013; Priori *et al.* 2014). Such methodology can provide high-precision maps of topsoil spatial variability (0-30 cm), in particular related to mineralogy, texture and stoniness.

METHODOLOGY

Study area
The study area was situated in the western part of Sicily (southern Italy) in the "European Soil region 62.2", described as hills of Sicily on clayey flysch, limestone, sandstone, and coastal plains with Mediterranean subtropical climate (Costantini *et al,*

2013). The fields surveyed during this work had a surface ranging between 2 and 6 ha, and they were dislocated into nine areas, cultivated with extensive row-croplands. The parent materials of the experimental fields included clays, silty-clays and marls clayey-silty deposits of marine origin (Miocene-Pliocene), as well as clayey-calcareous flysches and calcarenites of Cretaceous-Paleogene. The soils of the areas generally showed high clay content and carbonates, and they were classified as *Vertic Calcisols, Calcaric Vertisols, Calcaric Cambisols, Fluvic Cambisols* and *Calcaric Regosols*.

The proximal soil survey by γ-radiometrics and the soil sampling were carried out in the middle of April 2013 and 2014, in very similar climate and soil moisture conditions (about 15-20 dag·kg^{-1}). The sensor used for such survey was "The Mole", a commercial γ-ray spectrometer with a CsI-crystal of 70x150 mm (Van Egmond *et al.*, 2010). The sensor was carried within the fields in a dedicated backpack and it was connected to a GPS and a rugged laptop, which recorded coordinates and γ-ray spectra (about one spectra/second). The total count of γ-ray (TC) and the nuclide concentrations (^{40}K, ^{238}U, ^{232}Th) were interpolated by ordinary kriging to obtain grid maps at 1 m spacing.

Simultaneously with the y-radiometric surveying, 208 soil samples (0-30 cm deep) were collected using a regular grid sampling pattern, with a frequency of 8 samples per hectare.

The samples, previously dried and 2-mm sieved, were scanned by Visible-Near Infrared Diffuse Reflectance spectroscopy (Vis-NIR DRS), using a Fieldspec 3 Hi-Res® (ASD Inc., Boulder, CO), which has bands ranging between 350 and 2500 nm. White referencing was carried out every 10 soil samples, using a Spectralon® panel.

The commercial software Unscrambler X (CAMO software AS., Oslo, Norway) was used for spectra pre-processing (Multiplicative Scatter Correction, first derivation, head and tail spectra removing) and modelling. The models used to predict soil features by Vis-NIR DRS need careful selection of the calibration dataset, which should be large (several hundreds or thousands of samples) and representative of the prediction dataset (Stenberg *et al.*, 2010).

The selection of the soil samples, analysed by conventional laboratory analysis, and then used for calibration set, was carried out after grouping through cluster analysis. The most representative sample of each cluster, which was the sample with the lowest Euclidean distance for that cluster, was selected for calibration. The number of samples that we decided to use for calibration was 1 per hectare, with a minimum of 3 samples per study area.

Therefore, from the total amount of 208 samples, only 32 samples were selected for calibration set. Other 36 samples were selected for validation of PLSR model, and other 36 samples were used to validate the final maps of carbon stock. The three subsets of samples were analysed with laboratory conventional method. Clay and sand content were analysed by pipette method, and SOC was analysed by Walkley-Black method and converted to International Organization for Standardization standard (ISO 14235).

Other 53 soil spectra of our own spectral library, already analysed and belonging to the same Soil Region and parent material, were extracted. Therefore, the complete calibration dataset include 85 soil samples with high pedological and lithological similarity.

Partial Least Square Regression (PLSR), implemented in Unscrambler X, was used to develop calibration models to predict CS_{30} of the fine earth ($CS_{30}f$) from Vis-NIR DRS spectra. The model efficiency was calculated with the external validation set of 36 samples, by coefficient of determination (R^2), root mean square error of the prediction (RMSE), and the residual prediction deviation (RPD).

$CS_{30}f$ values were corrected for the gravel content, according to IPCC LULUCF guidelines (IPCC, 2003).

Afterwards, the interpolation of CS_{30} at each site was carried out through Geographical Weighted Multiple Regression (GWMR), using as covariates the γ-ray maps (total counts and radionuclides concentration).

The final validation of the CS_{30} maps were carried out using the other 36 independent data points analysed by standard laboratory methods.

RESULTS

Total counts (TC) of γ-ray spectroscopy varied between 170 and 520 Bq·kg^{-1} and had a mean standard deviation within each site of about 22 Bq·kg^{-1}. Some fields showed higher spatial variability, mainly due to the presence of strongly eroded areas characterized by thin soils, high stoniness, and scarce soil organic matter. ^{40}K radionuclide showed mean values between 27.2 and 41.8 Bq·kg^{-1}, which are comparable with the mean values measured in calcareous and clayey parent materials in a previous work (Priori *et al.*, 2014). ^{232}Th and ^{238}U showed low values in all the studied areas.

Calibration set using for $CS_{30}f$ prediction by Vis-NIR DRS showed mean and standard deviation values of 4.92 and 1.31 $kg\cdot m^{-2}$, respectively. PLSR model of $CS_{30}f$ showed its best efficiency using 6 principal components, which explained 86.6% of the total variance. The coefficient R^2 of the model was 0.86 and the RMSE was 0.43 $kg\cdot m^{-2}$. The external validation set of 36 samples showed a coefficient R^2 of 0.77, RMSE of 0.67 $kg\cdot m^{-2}$, and RPD of 2.06 (Fig.1b). Although the RMSE did not point out very high precision, the errors can be considered acceptable, considering the high standard deviation of the $CS_{30}f$.
Relationships between CS_{30} (after correction for gravel content) and γ-ray spectroscopy data provided general low correlations. This result justified the use of a non-stationary regression method, such as geographical weighted regression, calculated in each study area, separately.
The interpolation of CS_{30} (Fig. 1a), carried out within each area through the Geographical Weighted Multiple Regression (GWMR), provided maps with acceptable accuracy (R^2 between 0.76 and 0.93). The validation of the CS_{30} maps with the external set of the 36 samples, showed R^2 of 0.69, RMSE of 0.59 $kg\cdot m^{-2}$ (Fig. 1c), and RPD of 1.93.

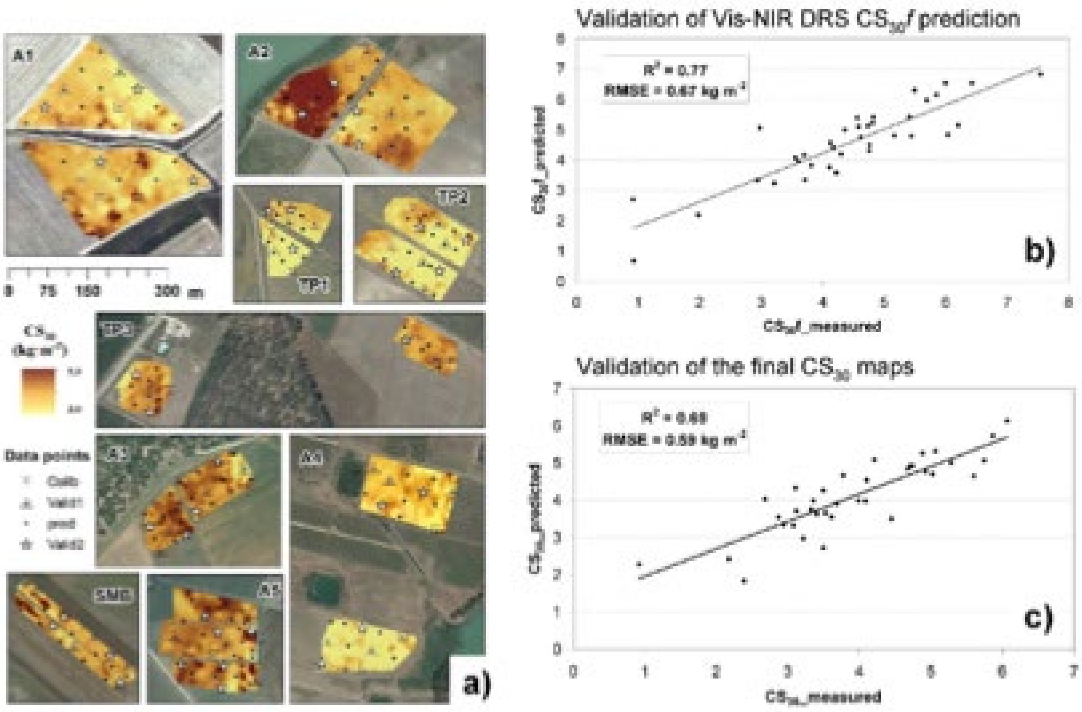

Fig. 1: Predicted maps of carbon stock CS30 with calibration and validation sites (a). On the right, the validation results of carbon stock of the fine earth (< 2mm, CS30f) predicted by Vis-NIR DRS (b) and the final validation of the maps after geographical weighted multiple regression, using ·-ray maps as covariates (c). The images and the results of this work was already published in Priori et al. 2016.

DISCUSSION

The research work demonstrates that working out a predictive model to estimate directly soil carbon stock by Vis-NIR DRS is possible, and the obtained accuracy of the model is good, even if the number of samples for calibration was limited (n= 32). A limited number of samples to calibrate a reliable PLSR model was possible since other similar soils were recorded in our own spectral library. Vis-NIR DRS allowed to save the laboratory analysis cost of 176 samples. According to the cost estimation of O'Rourke and Holden (2011), the total savings to calculate $CS_{30}f$ were about 9.80 € per sample**.**
The general correlation between γ-ray data and soil features showed some significant, but low, relationships for SOC, clay, sand, gravel, and CS_{30}. This means that some correlations between γ -ray spectroscopy data and soil features exist, but the relationships are strongly site-specific. For this reason it was impossible to apply a general regression model to predict maps of CS_{30} using γ-ray data covariates, and it was impossible to calculate covariogram because of scarcity of datapoints per field. The use of Geographical Weighted Multiple Regression (GWMR) exceeded these problems, by the application of spatial weights to the regression.
The validation carried out within each field showed higher accuracy in two fields (A1 and TP1), whereas other two fields showed the lowest accuracy (A2 and SMB). This was mainly due to very few samples that had high error of prediction, due to unknown causes. Actually, radionuclides in the agricultural soils are influenced by several factors not always clear, including water chemistry, relocation of soil because of land leveling or erosion, accumulation of fertilizers, and other chemical pollution.

CONCLUSIONS

The paper shows an innovative methodology to interpolate soil organic carbon stock at high-detail within arable fields, coupling two methodologies of soil proximal sensing, namely Vis-NIR and γ-ray spectroscopy. The methodology described in this work makes use of a limited number of samples per field, around 1 per hectare, saving time and money for laboratory analysis.

The accuracy of CS_{30} maps allows the use of such maps for several purposes, like comparing the effects of different soil management strategies in agriculture and monitoring the effects of soil erosion on soil carbon pool.

The methodology proposed in this paper constitutes an innovation, but the use of γ-ray spectroscopy as covariate to interpolate carbon stock needs additional studies.

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1.35 | CORRELATION BETWEEN SOIL ORGANIC CARBON AND LAND USE, SLOPE CLASS AND SOIL TEXTURE IN CHAING RAI PROVINCE OF THAILAND

Sasirin Srisomkiew[1*], Pitayakon Limtong[1], Supawat Chaikasem[2]

[1][Land Development Department, sasirin_ldd@hotmail.com and pitaya49@msn.com]
[2][Kasetsart University, Sriracha Campus, supawat.ch@ku.th, Faculty of International Maritime Studies]

ABSTRACT

The main aim of this research is to understand soil carbon stock dynamic in soil for various factors affecting it and analyses degradation of land. We present the degradation of land based on soil carbon stock with various factors affecting its content while emphasizing on the guideline to analyses land degradation and proper management of the area with low carbon stock using various degradation maps.

Keywords: Land degradation, Soil erosion, Soil organic carbon, land use, slope class, soil texture

INTRODUCTION

Soil organic carbon (SOC) content is an important component of soil nutrient and the most important elements in the soil system whose loss lead to soil degradation in which soil erosion is found to be the major cause of SOC loss (Jia, He and Wei, 2007). Land use change (LUC) is a main factor influencing content and quality of SOC. Moreover, conversion of arable land into grassland leads to increasing of SOC as higher input of plant and root residues in grassland soils is stabilizing SOC stock in the top soil (Jafarian and Kavian, 2012). Conversion of grassland to cropland was a dominant driving factor responsible for carbon sources, and the recovery of grass cover from cultivated lands enhanced SOC sinks, but the magnitude of sequestration may depend on specific management measures (Tan *et al.*, 2005). The conversion of desert steppe to arable land led to increases in SOC content and storage with SOC stock in arable land increased after abandonment. Moreover, the trend for loss of carbon storage change resembled that for the SOC storage after land use conversions. There were significant differences in SOC content at the 0–10 cm depth in the conversion from arable land to artificial grassland and at the 20–40 cm depth in the conversion from desert steppe to artificial woodland, the SOC content did not change significantly following LUC (ZHANG *et al.*, 2012). Crop cultivation led to decrease in SOC content with effect on land use on soil carbon content limited to the upper 20 cm depth while the texture effect is found all along the soil profile influencing the soil organic carbon stock. In addition, cultivation influences the texture by deepening the particulate component as near-surface level becomes more particulate and advisable for organic matter mineralization (Touré *et al.*, 2013). However, SOC content decreased with depth at all topographic positions with clay fraction increased with the depth [6].

Globally, LUC can cause a change in soil carbon stock with an overall average across all land use change examined, land use conversions had significantly reduced soil carbon stock. The LUC decreased soil carbon, however, the reverse process usually increased soil carbon stocks and vice versa (Deng *et al.*, 2016). Soil Organic Matter (SOM) has a positive correlation with soil texture. The amount of SOC in soil depends on vegetative growth or soil cover which includes agricultural activity whereas there were no correlation between SOM with the soil depths (Azlan *et al.*, 2012). SOC stocks differ significantly between soil types in the topsoil as texture has a strong impact on SOC stocks suggesting soil type to be used as a principal predictor of SOC stocks (Ciric *et al.*, 2013). Soil erosion is one another major factor of loss of SOC as soil erosion transported plenty of sediment and associated organic carbon. Significant linear relationships were observed between SOC loss and sediment loss which indicated that the loss amount of predicted by transported sediment. Soil type has a great impact on SOC loss through influencing sediment erosion pattern and the SOC content in original soils (Li *et al.*, 2016a). The effect of SOC concentration is more vital than that of the amount of eroded sediment on the total SOC loss for soils if the SOC content is large enough. Significant correlations between sediment and SOC losses were observed, and such correlations became relatively close if the organic matter content of the soil was low. SOC loss depended more on flow dynamics if the clay content was low, and it could be well predicted by flow velocity and slope. For soil with a high clay content, total SOC loss could be simply predicted by slope, and geomorphology was identified as the only direct cause (Li *et al.*, 2016b). In addition to the land use effect on the SOC, (Dang *et al.*, 2014) examined effects of climate and land use changes on SOC storage on the Loess Plateau of China in the context of multiple global changes by using an integrated ecosystem model.

In this research, we choose the location which is in the north of Thailand in the province name Chaing Rai. This area is mostly mountainous with high slopes. However, farmers still use the area for cultivation which risks soil erosion, soil surface loss and water runoff. It has become the region with the severest cases of soil erosion of top soil in the upper part of watershed areas, which affects extensively this area and lower area. This causes degradation in physical, chemical and biological aspects of soil properties, including the wider degradation of the environment in both on site and off site areas.

PROBLEM STATEMENT

Chaing Rai has a complex slope with slops at more than 35% and different soil types. Erosion is the main problem including risk for landslide and floods. It is well known that the soil in this area is not suitable for agriculture, but there is still demand to use the area for agriculture as the plain areas are limited which leads to deforestation and changes to forest land to plant field crop/ monoculture. In addition, soils in lowland areas have low fertility. Therefore, it is necessary to leads efforts on effective intervention related to the measurement of soil conservation, soil management and selecting plants to grow properly.

Main Objectives

The main objective of this research work is to understand the soil carbon stock dynamic in the complex geographical. In this work, we present the change in soil carbon stock based on its land use variation i.e. whether it is agricultural field, forest, grassland and find the relationship between it. In addition, we assess the slope of the region and find its effect on the soil carbon stock. Finally, we study the soil type and find its relationship with soil carbon stock. Following is the specific objective of this research.

a. To investigate the development of Geographic Information System (GIS) for analyze and visualize soil organic carbon (SOC), soil stock class and map
b. To evaluate the correlation between soil carbon stock, land use variation, land slope and soil texture/soil series

The scope of this research work is to find the factor that is more prevalent in loss in soil carbon stock dynamic and propose recommendation to manage the soil so that these losses could be minimize.

THE STUDY AREA AND METHODOLOGY

The study area is the Chaing Rai province which is located at the north of Thailand. Chaing Rai has the total area of 1,157,759 hectares (ha). Topographically, the Chiang Rai province has a mixed geographic relief with small plateaus as well as plains along the river. The land use is categorized into cropland 589,840 ha (50.95%), forest 451,450 ha (38.99%), settlement 60,916 ha (5.26%), wetland 33,136 ha (2.86%), grassland 19,740 ha (1.71%) and others land use 2,677 ha (0.23%). In terms of soil series category, 51 different soil series type is available in this province for which the soil organic carbon value ranged from 9 to 28. The study area is in characteristically tropical savanna climate zone with high average relative humidity.

Statistical analyses were carried out using the computing environment R version 3.3.2 (R Programe). The correlation analysis between soil organic carbon with the land use, slope as well as the soil texture/soil series. Significance of the correlation test and variance were used to evaluate relationship between the soil organic carbon and the factors affecting it.

RESULTS AND DISCUSSION

The research is conducted following the considering the UNCCD protocol and using its factor to evaluate correlation with soil carbon stock. The consideration is taken for the land use and land cover. As shown in Fig. 1(a)-1(c), soil carbon stock in agricultural area is lower than that of forest or grassland which can cause land degradation in those agricultural areas. The change from agricultural area to the forest, the soil carbon stock will increase. In addition, if the land has higher slope without any conservation system, there is high risk of loss of soil and consequently the loss of soil carbon stock causing the land degradation in the slope area. Finally, considering soil texture, if the soil is sandy then carbon stock has relatively lower value with higher land degradation as compared to clay soil which has relative high carbon stock.

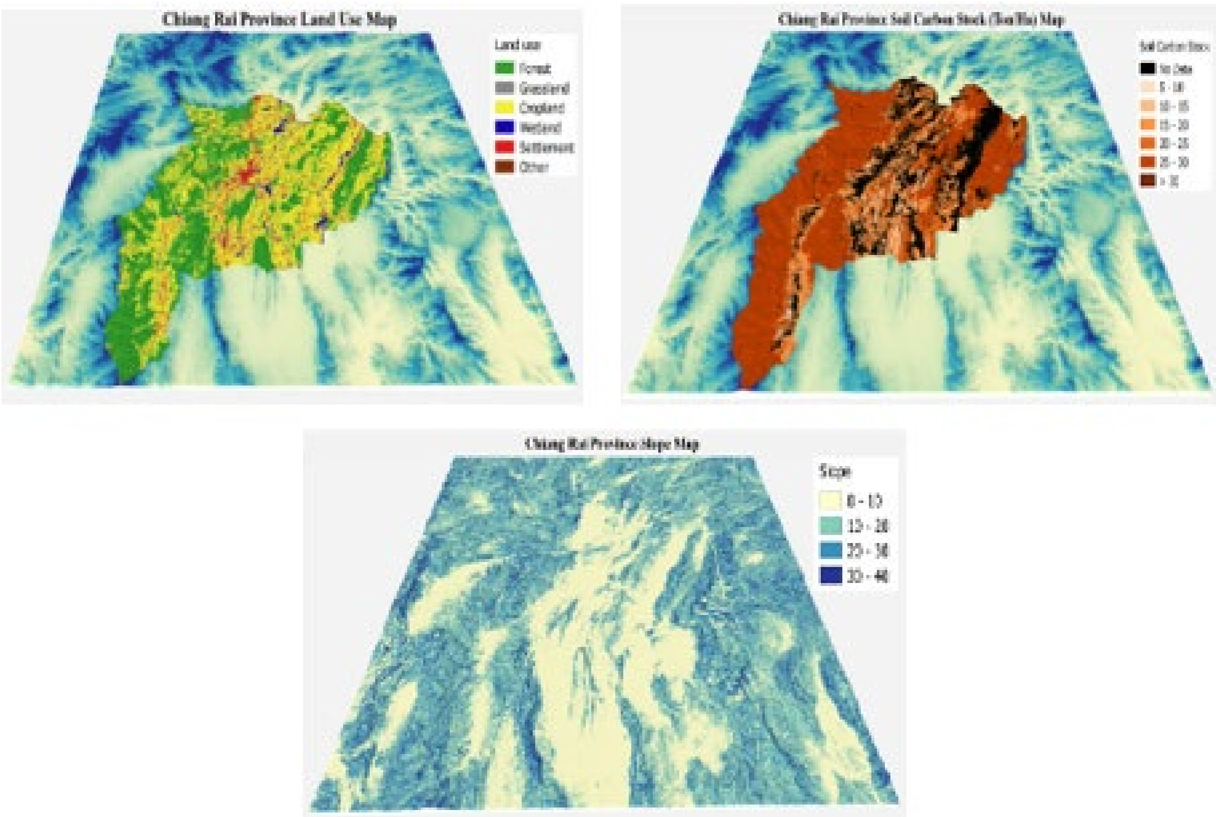

Fig. 1: Chaing Rai Province (a) Land use (b) Soil carbon stock (c) Slope map

CONCLUSIONS

Land degradation and soil erosion is the major cause of SOC loss. GIS was used to establish land use, soil carbon stock and slope potential map of Chiang Rai province, Thailand, with the aim of the study is to evaluate the soil carbon stock dynamic in soil with various factors affecting it and analyses land degradation. This study developed GIS as a tool for building the map and integrating them to establish the SOC loss map and proposed proper management to the study area with low carbon stock using various land degradation maps.

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1.36 | CALCULATING CHANGES IN SOIL ORGANIC CARBON IN JAPANESE AGRICULTURAL LAND BY IPCC-TIER 3 MODELING APPROACH: USE OF MODIFIED ROTHAMSTED CARBON MODEL

Yasuhito Shirato[1]

[1]Institute for Agro-Environmental Sciences, NARO, Tsukuba, 305-0035 Japan. yshirato@affrc.go.jp

ABSTRACT

Changes in total soil organic carbon (SOC) stock (at 0-30 cm depth) of entire Japanese agricultural land was calculated from 1970 to 2050 by using the Rothamsted carbon (RothC) model. At first, the RothC model was validated by using long-term field experiments and then modified respectively for Andosols and for paddy soils, by taking unique properties of these soils into account. Next, a calculation system of agricultural SOC in Japan was developed by linking these modified versions of the RothC model with spatial datasets such as weather, soil, land use, agricultural activities. This system is now used in the National Inventory Report (NIR) of Japan. CH_4 and N_2O emissions were also calculated at the country-scale for considering trade-off between SOC sequestration and other greenhouse gas (GHGs) emissions. Changes in SOC derived from monitoring project was compared with modelling results. Link between monitoring and modelling studies is needed to fill the gap between model and monitoring results.

Keywords: carbon sequestration, climate change, mitigation, modeling, soil organic matter

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Better agricultural soil management has huge potential to mitigate GHG emissions. Modelling approach is useful in estimating this potential at a country scale. Increasing carbon inputs to soils enhance soil C sequestration but it may increase other GHGs (CH_4 and N_2O) emissions. It is therefore important to evaluate total GWP (Global Warming Potential) for each management option by taking this trade-off into account. We have developed a country-scale simulation system of SOC and GHGs for reporting to NIR and to evaluate GWP of several future agricultural soil management scenarios as well as future climate change scenarios. Our objective was to evaluate how agricultural management options can affect SOC sequestration and other GHG emissions at a country scale.

METHODOLOGY

At the first step, the RothC model was tested against long-term experimental data sets in Japanese agricultural lands. The RothC model could adequately simulate changes in SOC contents with time in non-volcanic upland soils (Shirato and Taniyama, 2003) without any modification or calibration to the original RothC model (Coleman and Jenkinson, 1996). The original RothC model, however, underestimated SOC in Andosols (volcanic ash-derived soils) and in paddy soils. We then modified the model for Andosols (Shirato, Hakamata and Taniyama, 2004) and for paddy soils (Shirato and Yokozawa, 2005) by taking unique mechanisms of soil C dynamics in these soils into account, and could have much improved fit between model and observation (Fig. 1).

Next, a calculation system of SOC at the country scale was developed (Yagasaki and Shirato, 2014a), b) by linking the RothC model with spatial data sets such as weather, soil properties, land use, and other activity data (the amount of C input to soils by crop residue and organic manure) including different agricultural management scenarios in future: BAU (Business as Usual) scenario and C sequestration scenarios in which 10% increase the amount of C input to soils. The initial soil C value was set at 1970 for each of spatial simulation unit (100 m grid). Changes in SOC was then calculated until 2050 by applying three different versions of the RothC model (the original RothC, the modified version for Andodols and that for paddy soils) depending on land use and soil type, and by adding different input data derived from weather, soil type, land use and agricultural management scenario in future. Two different climate change scenarios (MIROC-H and FGOALS) (Okada *et al.*,

2009) were used in simulating future period to consider the effect of weather condition on SOC.

For evaluating trade-offs between SOC sequestration and other GHGs, N_2O was calculated from CO_2 emission calculated by the RothC, C/N ratio of soils and the amount of N fertilizer inputs by using empirical equation, which relates N_2O to mineral N in soils, proposed by Mu *et al.* (2008). CH_4 emissions from paddy soils were calculated by emission factors derived from the DNDC-Rice model (Katayanagi *et al.*, 2016). Fossil fuel consumption by agricultural machineries, plastic films, fertilizers, pesticides etc. were calculated, too.

RESULTS

The total amount of topsoil (0-30cm) organic C in Japanese agricultural lands tended to decrease over time. As to agricultural management scenarios, 10%- increasing- C input to soils resulted in higher amount of SOC (i.e. lower CO_2 emission from SOC) but increased both of CH_4 and N_2O at the same time. Other mitigation options such as extending mid-season drainage for rice CH_4 and decreasing N inputs of chemical fertilizer for N_2O, however, could offset these increased GHGs by increasing C inputs to soils.

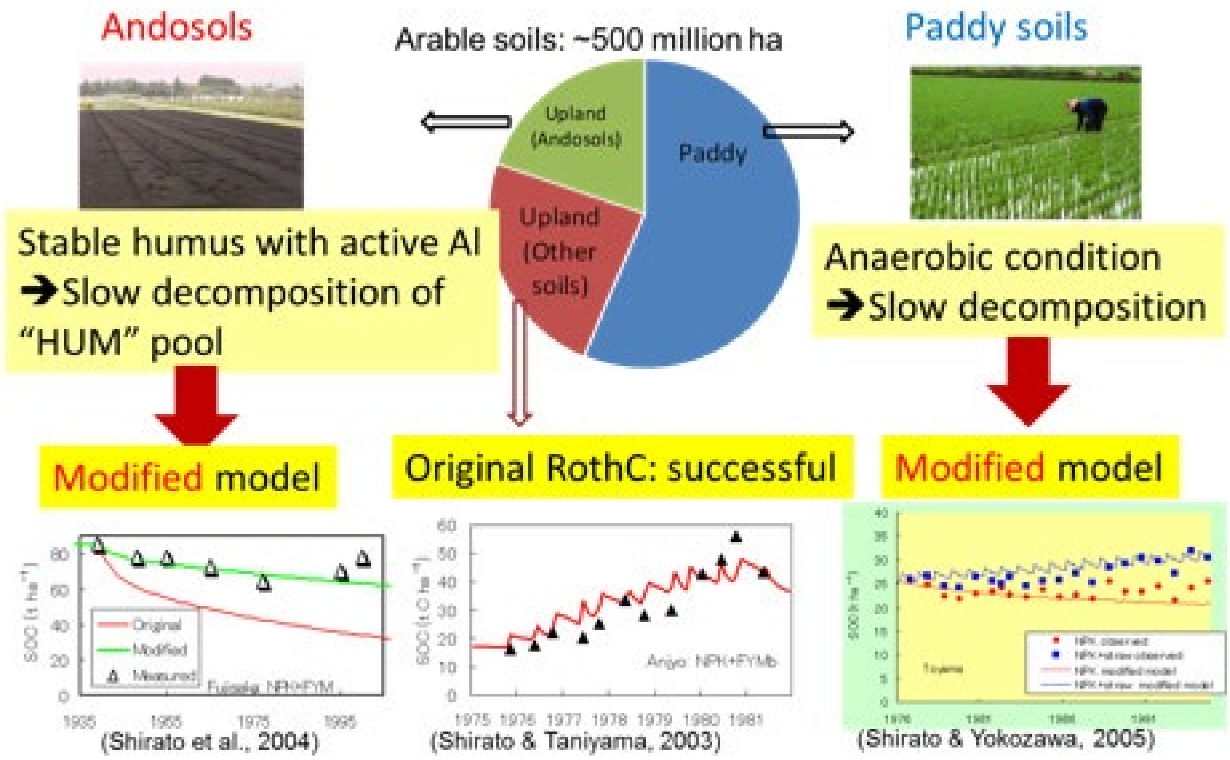

Fig. 1: Validation and modification of the RothC model in Japan. Country scale calculation system switches these three versions (The original RothC, Andosols version and paddy soil version) depending on soil type and land use.

DISCUSSION

Trade-off between other GHGs emission
Our results show that increasing C inputs to soil is effective for enhancing SOC sequestration at country-scale, and accompanying increment of other GHGs (i.e. trade-off) can be offset by other options such as better paddy water management and effective N fertilizer managements. Modeling approach is effective to evaluate total GWP of management options at a country scale for future projection.

Comparison between modeling results and monitoring-based estimation of SOC
The IPCC Tier 3 modeling approach with the use of modified RothC model is currently used in Japanese NIR as explained above. This modeling approach has an advantage that model can be used for future projection as well as current inventory reporting. On the other hand, we have an agricultural soil monitoring system in Japan. It had ca. 20,000 stational monitoring

points from 1979 until 1998 and each point was surveyed in every five years. After that, number of monitoring points has been decreased and it is ca. 4,000 points and every four years of soil survey at present. SOC data obtained from these monitoring points can be used for validating the results of SOC stock change estimated by the modeling approach. However, these monitoring points are not randomly distributed and it makes difficult the direct use of the results of this monitoring project into NIR or model validation. Because these monitoring sites might be biased to "progressive" farmer and have higher organic inputs to soils, SOC in monitoring sites were possibly higher than RothC-simulated one, which support our speculation. We have further analysis to fill this gap between monitoring sites and average farmers.

CONCLUSIONS

The calculation system by linking models with spatial datasets of mode inputs at a country scale is effective both for reporting for NIR and future projection of mitigation potential. Trade-off between soil C sequestration and other GHGs emissions can be evaluated at a country scale with this system. On the other hand, the importance of national-scale soil monitoring projects should be noted because a model has to be always validated by measured data. Linking modeling to monitoring studies is critically important.

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1.37 | CAN GLOBAL SOIL ORGANIC CARBON MAPS BE USED IN POLICY DECISIONS ON PRACTICAL AGRICULTURAL MANAGEMENT?

Söderström M.[1,2*], Piikki K.[1,2]

[1]International Center for Tropical Agriculture (CIAT), Kenya
[2]Swedish University of Agricultural Sciences (SLU), Sweden

ABSTRACT

Decreasing soil fertility – with insufficient soil organic carbon (SOC) content being a key driver/indicator –pose major limitations to crop growth and food security. Improved agricultural soil management will have two mutual benefits: increased soil fertility and (possibly) climate change mitigation. The challenges related to management of the SOC pool are global, the policy is large-scale but any required actions are local and need to be site-specific in order to be efficient. For this, adequate decision support is needed but often lacking. There is a multitude of global efforts to derive such decision support in the form of digital soil maps/soil geodatabases of SOC. One should be aware that high spatial resolution and missing or questionable validation statistics not representative for the intended use can be misleading. The present study, exemplified with data from Rwanda, concludes that global SOC datasets should not be used as decision support for policymakers without prior validation in the area of interest. In case the dataset in question is not found adequate, downscaling/local adaptation through multiscale data fusion may be a viable option.
Keywords: Downscaling, Digital Soil Map; Rwanda; SoilGrids, Soil organic carbon; SOC sequestration; Validation; Water Land and Ecosystems (WLE).

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Digital soil mapping (DSM) is currently carried out in many parts of the world and at different scales, including continental and global scales (e.g. Arrouays *et al.*, 2014; Hengl *et al.*, 2016; Minasny and McBratney 2016; Stoorvogel *et al.*, 2016). In essence, DSM aims at determining soil variation in relation to the landscape by finding measurable proxy variables for the soil property of interest and developing quantitative (spatial or non-spatial) models for prediction of the target soil property. Development of global and continental soil databases will change the manner in which soil data can be included in, for example, the decision-making processes in society at large e.g. by the FAO. Soil organic carbon (SOC) content is one of the most important indicators of soil condition. SOC stocks are currently a much discussed topic in both science and politics across a multitude of scales. O'Rourke *et al.* (2015) reviewed SOC stock science and policy and found that most scientific work is aimed at understanding the biophysical processes governing SOC content at small scales, from particles to landscapes, whereas policy work is predominantly aimed at larger (even global) scales. The authors concluded that attempts to characterise the greatest risks to SOC stocks require data spanning a number of scales and that science and policy need to be integrated across multiple scales. The overall aim of the present study was to assess the possibilities of utilising data from the global SoilGrids database of ISRIC (Hengl *et al.,* 2016) at two different levels of relevance in the practical application of overall decisions on SOC soil management aiming at SOC sequestration and restoration of fertility – both at the farm level and at local administrative Sector units – exemplified with extensive ground truth data in Rwanda in central Africa. The full study was reported in Söderström *et al.* (2016).

METHODOLOGY

SoilGrids (ISRIC – World Soil Information, Wageningen) is currently the most detailed (in terms of spatial resolution; 250 × 250 m^2) global soil database. It includes predictions on SOC content as well as a number of other soil properties, e.g. texture, bulk density, pH and cation exchange capacity (CEC), at up to seven soil depths (0, 5, 15, 30, 60, 100 and 200 cm). The basis for the predictions in Africa is a set of about 28 000 soil observations distributed throughout the continent, combined with a set of covariates (Hengl *et al.*, 2016).
For the purposes of the present study, two independent datasets of agricultural land in Rwanda were compared with SOC data from SoilGrids to assess the usefulness of SoilGrids for SOC mapping at three scales: averages for country, sector

administrative units, and smallholder farms.

All data used represented the SOC content in the topsoil. We used 800 soil analyses distributed over agricultural land in Rwanda (about 1.2 million ha) as the "ground truth". Each sample represented one smallholder farm of ~ 0.5-1.0 ha. In addition we had another independent reference dataset consisting of 100 soil analyses from similar smallholder farms randomly distributed over Rwanda.

Averages for the administrative sector units were judged as being a suitable working level from an advisory service perspective and also a potentially realistic unit size for use of the SoilGrids data. Administrative sectors are the third level of administrative subdivision in Rwanda. They differ in size, but on average they cover about 50 km^2. There were 392 sectors part of which was classified as agricultural land.

Regression kriging (Odeh *et al.*, 1995) was used in order to investigate whether it was possible to apply a simple approach to locally adapt, or downscale, the SoilGrids SOC maps using a number of available local soil analyses. Comparisons between independent observations and predicted values in different types of maps were done to validate the different mapping methods. The coefficient of determination (r^2), which the correlation between map data and ground truth can be inferred and the mean absolute error (MAE), which is a measure of the error magnitude, were used for validation.

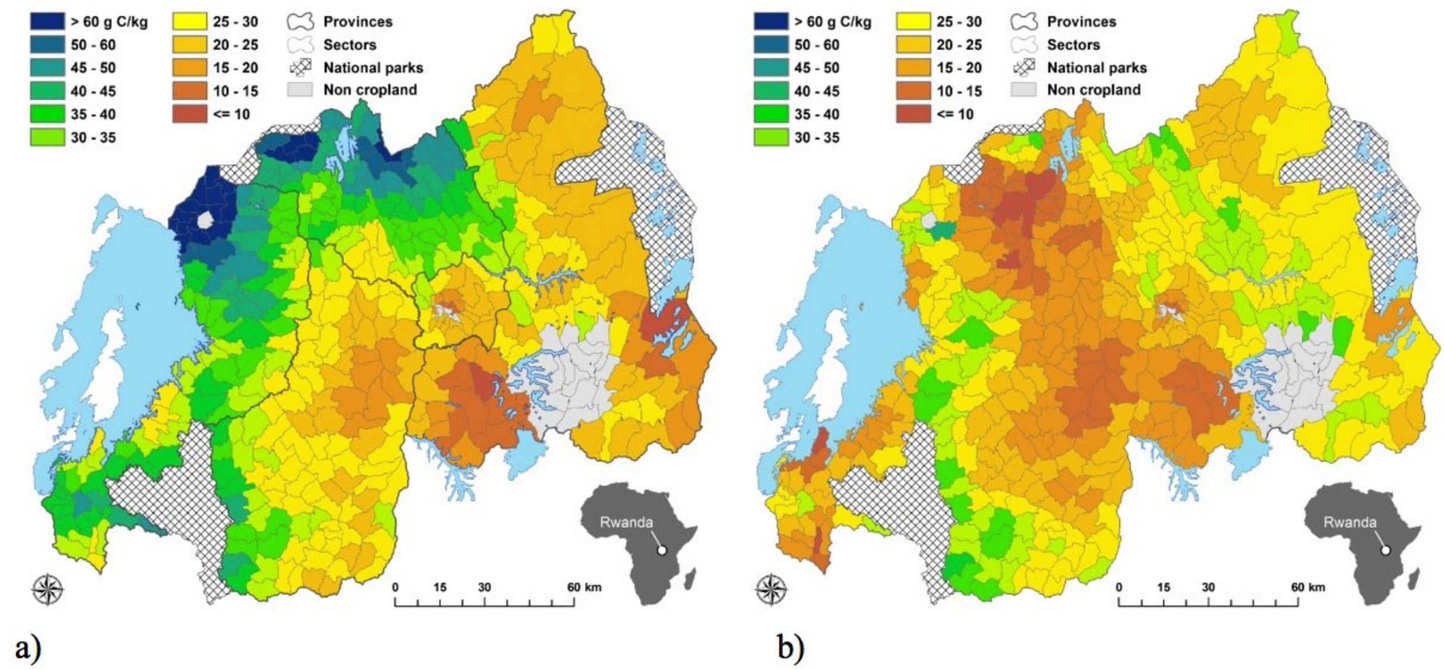

Fig. 1: Soil organic carbon (SOC) content in agricultural land in different administrative sectors of Rwanda. Sector averages of SOC content estimated from a) SoilGrids, b) Downscaling SoilGrids with 100 local soil samples using regression kriging. This procedure for local adaptation considerably improved the SoilGrids map (Söderström et al. 2016)

DISCUSSION

Digital soil mapping has revolutionized the manner in which detailed maps of soil properties can be produced. By combining soil reference data with detailed data sets of auxiliary information in predictive modelling, maps of soil properties covering vast areas can be generated. From a non-experienced user's perspective, or indeed from the perspective of developers of guidelines and policies, it may be reasonable to believe that information derived from renowned research organizations can be trusted and applied. Defourny *et al.* (2012) reported that in many global land-cover applications, the quality and accuracy of the land-cover maps used are not considered. Instead, it is up to the potential user to assess whether the map is appropriate for the application. It has been reported that more than one-third of 90 DSM studies included in a review (Grunwald, 2009) were not validated at all. In addition, validations can easily be misunderstood and misinterpreted since reported uncertainties heavily depend on the manner in which the validations were performed. We have shown that SOC in the topsoil as portrayed in the SoilGrids database was poorly correlated to independent extensive datasets covering the agricultural land of Rwanda ($r^2 = 0.05$; MAE 13 g C kg^{-1}). However, through combining a reasonably low number of local soil samples with the SoilGrids database it was possible to downscale the SoilGrid database to perform better. The same approach was tested also in other areas in western Kenya and northern Namibia and the results (to be published) follow the same trend.

CONCLUSIONS

We conclude that use of global soil databases on SOC should not be applied for regional or local estimates without any reference samples with which to compare. High spatial resolution in a continental data set can be misleading; it is normally only the framework upon which the predictions are made, rather than the resolution of potential applications. In order to prevent inadvertent misuse of published soil data, the DSM community must help users assess whether the map data are appropriate for their intended use. Validations should challenge the predictions – this is unfortunately often not the case. If a large-extent map is found to be too coarse for a specific application (e.g. estimates of SOC sequestration), downscaling and local adaptation may be possible if a number of additional soil observations are available. We recommend further studies on approaches for local improvement of global and continental data sets and call for innovative ideas on how map uncertainties can be made accessible and understandable to general users.

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1.38 | THE PERFORMANCE OF PORTABLE MID-INFRARED SPECTROSCOPY FOR THE PREDICTION OF SOIL CARBON

Soriano-Disla, J.M[*,1,2]., Janik, L.J[1]., McLaughlin, M.J[1,3].,

[1]CSIRO Environmental Contaminant Mitigation and Technologies Program, CSIRO Land and Water, Waite Campus, Waite Road, Urrbrae, 5064, South Australia, Australia.
[2]Sustainable Use, Management and Reclamation of Soil and Water Research Group (GARSA). Department of Agricultural Science and Technology, Universidad Politécnica de Cartagena. Paseo Alfonso XIII 48, 30203, Cartagena, Spain.
[3]Soil Science, School of Agriculture, Food and Wine, University of Adelaide, Waite Campus, Waite Road, Urrbrae, 5064, South Australia, Australia.

ABSTRACT

This study sets out to test the performance of portable mid-infrared (MIR) spectroscopy for the prediction of soil C and its related soil attributes across a range of soils. One objective of this study was to assess the influence of conventional laboratory SOC analysis error in the prediction performance from MIR multivariate modeling. A further objective was to evaluate the accuracy of the infrared predictions using a selection of different multivariate MIR models
For this assessment, 458 soils from Australia were scanned with a portable MIR spectrometer and partial least squares regressions (PLSR) applied for the prediction of total carbon (TC) and SOC using measured and calculated data. Three modeling approaches (PLSR, LOCAL and Neural Network) were developed and compared for their prediction performance of three soil attributes (cation exchange capacity, pH and clay content) which are related to SOC. Our results supported the hypothesis that the MIR regression method represents a viable alternative for the prediction of soil C and related parameters. Our results also demonstrate the importance of having highly reliable analytical data for the success of MIR regressions. In terms of model optimization, the LOCAL method resulted in the most successful approach. This method might be better suited than global PLSR for routine predictions of soil properties in large and diverse spectra libraries using infrared spectroscopy.

Keywords: chemometrics, mid-infrared, organic carbon, soil, spectroscopy

INTRODUCTION

Soils play a vital role to life on earth and soil organic carbon (SOC) is one of the most important components responsible for a number of their ecosystem services (FAO, 2015; FAO and ITPS, 2015). Soil organic carbon in soil is characterized by its large variability, spatially and down the profile. This, linked to the existence of different crop types and highly variable seasonal conditions, implies that management responses need to be targeted to each particular situation. Such management strategies require a high spatial density of soil analytical data (Nocita *et al.*, 2015) that traditional laboratory approaches (e.g. wet chemistry analyses) are unable to provide cheaply and quickly
Mid-infrared (MIR) soil spectroscopy is an attractive alternative. It is rapid, cheap and accurate and portable versions can be used directly in the field (Soriano-Disla *et al.*, 2014; Nocita *et al.*, 2015). The technique relies on the interaction of infrared light with soil compositional components, and the characteristics of the resulting soil spectrum which is unique to each soil and provides information about its composition (Nguyen *et al.*, 1991). The technique is well suited to the study of SOC and other related key soil attributes, such as particle size, cation exchange (CEC) and pH, using multivariate regression (Janik *et al.*, 1998).
Despite these advances, there are still very few studies which evaluate the performance of portable MIR instruments for the prediction of SOC. In order to derive the best possible regression models, there is a need to choose high quality analytical data produced by a trusted laboratory by consistent analytical methods. The precision and accuracy of the reference method is crucial, since the error of the predictive multivariate models depends heavily on the reference data from conventional laboratory analysis. It is also important to
test different chemometric approaches.

The main objective of this study was to test the performance of a portable MIR instrument for the prediction of soil C and to evaluate the influence of reference analytical error on the accuracy of the predicted SOC values. It was also an objective of the article to test the influence of different multivariate models on the accuracy of the predictions of related key soil attributes.

METHODOLOGY

Soil samples and analysis

The samples used in this study were obtained from the Australian CSIRO National Soil Archive (CNSA, http://www.clw.csiro.au/aclep/archive/). The final selection comprised 80 soil profiles (n = 458 samples) from South Australia (66 %) and New South Wales (34 %;). Soil samples were dried at 40°C and sieved < 2 mm. Samples were sourced from variable depths, most of the samples (n = 315) represented the first 100 cm, the rest (n =143) representing depths from 100 to 180 cm.

The following properties were determined by the methodology described in Rayment and Lyons (2011): cation exchange capacity, 1M ammonium chloride; pH, 1:5 soil/water suspension; soil organic carbon, Walkley and Black ($SOC_{W\&B}$); particle size distribution (only clay presented as being representative); total carbon, Leco dry combustion (TC).

Descriptive statistics for the properties analysed were: CEC (N = 458, mean±SD = 22±10 $cmol^+$/kg, range = 1-48 $cmol^+$/kg), pH (N = 439, mean±SD = 7.9±1.3, range = 4.4-10.3), SOC (N = 308, mean±SD = 0.45±0.58 %, range = 0.02-4.90 %), clay (N = 451, mean±SD = 40.5 ±15.7 %, range = 2.0-80.2 %), TC (N = 457, mean±SD = 1.63±1.64 %, range = 0.04-9.18 %).

There were concerns about the validity of the reference $SOC_{W\&B}$ data. A substantial number were only estimated, leaving only about 300 samples for this analyte with real analytical data. For this reason, it was necessary to have a more reliable determination of SOC calculated (SOC_{calc}) as follows:

- Spectra scanned with a benchtop Fourier-Transform (FT-IR) instrument (Frontier, Perkin Elmer) were used for the assessment of inorganic carbon (IC) from the prediction of $CaCO_3$. A previously developed model using archival data (0-50 % $CaCO_3$ and two spectral ranges specific for carbonate response around 2500 cm^{-1} and 1800 cm^{-1}) were used for predictions.
- Negative predictions of IC were reported to be zero.
- The IC values were then subtracted from TC to calculate the SOC. Negative values of SOC were considered to be zero.
- The calculated SOC values (SOC_{calc}) were used to derive PLSR regressions from the MIR spectra and compared with those previously developed by using $SOC_{W\&B}$ as the reference data.

Mid-infrared scanning and chemometrics

Samples were scanned with a Fourier-Transform infrared (FTIR) portable spectrometer (ExoScan 4100, Agilent, USA) in the frequency range 6000–650 cm^{-1}. For each sample, four replicate scans were recorded using a diffuse reflectance (DRIFT) accessory with a resolution of 8 cm^{-1}, and scanning time of 15 s. A coarse-grained silicon carbide (SiC) reference disc (assumed to have a reflectance $R_0 = 1$) was used as the background.

Only the MIR range (4000-750 cm^{-1}) was considered because the energy of the instrument is optimised for that region. Partial least square regressions (PLSR) were developed following de-trending correction in the selected spectral range. For model development, 25 % of the samples were randomly selected and set aside (prediction set). The remaining 75 % were used for model calibration by leave-one-out cross-validation and selection of the optimum number of factors. These models were then tested on the prediction set. The performances of the models were evaluated in terms of the root means square error of the prediction (RMSEP), coefficient of determination (R^2), and the ratio of the standard deviation of the reference values to the RMSEP of the prediction (RPD) (Williams, 1987). In general, models with high values of R^2 and RPD are preferred and indicative of good prediction performance (conversely, models with RPD and R^2 values below 1.5 and 0.5 considered poor or unreliable; Sudduth & Hummel 1996).

All the transformations and model development were carried out by Unscrambler X 10.3 (Camo, Norway).

We also tested the influence of different multivariate models on the accuracy of the predictions of related key soil attributes. We first tested if PLSR model performances were affected by using different software packages. Partial least squares regressions performed with Unscrambler were compared with those provided by WinISI (Foss, Denmark). The WinISI algorithms M-PLSR and LOCAL were also tested. This latter method is able to adapt to unknown sample variability by searching in the spectral library for the most similar samples. Model development and validation were performed following the approach explained above. Models were tested for the prediction of key properties which are related to SOC such as CEC, clay or pH. In addition, the Neural Networks (NN) algorithm (WinISI) was also tested for such properties. The specific NN method does not have the option to predict unknowns so only cross-validation is presented.

Performance of portable mid-infrared spectroscopy for the prediction of soil carbon and influence of the accuracy of reference data

A high predictive performance was obtained for TC (RMSEP = 0.30 %, R^2 = 0.94, RPD = 4.1) but lower accuracy for SOC (RMSEP = 0.31 %, R^2 = 0.67, RPD = 1.8). Reasons for a less successful performance for SOC seem related to a) inaccuracies of the reference analytical data, and to b) the very limited concentration range, which made the model more influenced by analytical error.

Following the concerns raised by the $SOC_{W\&B}$ data, we decided to "calculate" SOC using infrared spectroscopy. The calculated SOC values (mean = 0.5 %, median = 0.4 %, range = 0-3.9 %) were similar to those provided by the W&B method. The spectroscopic model using OC_{calc} from the subtraction of TC and predicted IC was considerably better than the one produced by using reference W&B data (see Figure 1), which confirmed the concerns about the W&B determination. This was despite issues with the prediction of samples with $SOC_{W\&B}$ values near zero, which were randomly predicted positively or negatively. This seems to be related to uncertainties in the TC determination used for the calculation of SOC. Thus, and with this infrared application, we were able to confirm the issues regarding the W&B determination, and to have new SOC data for all samples (W&B only available for around 300 samples).

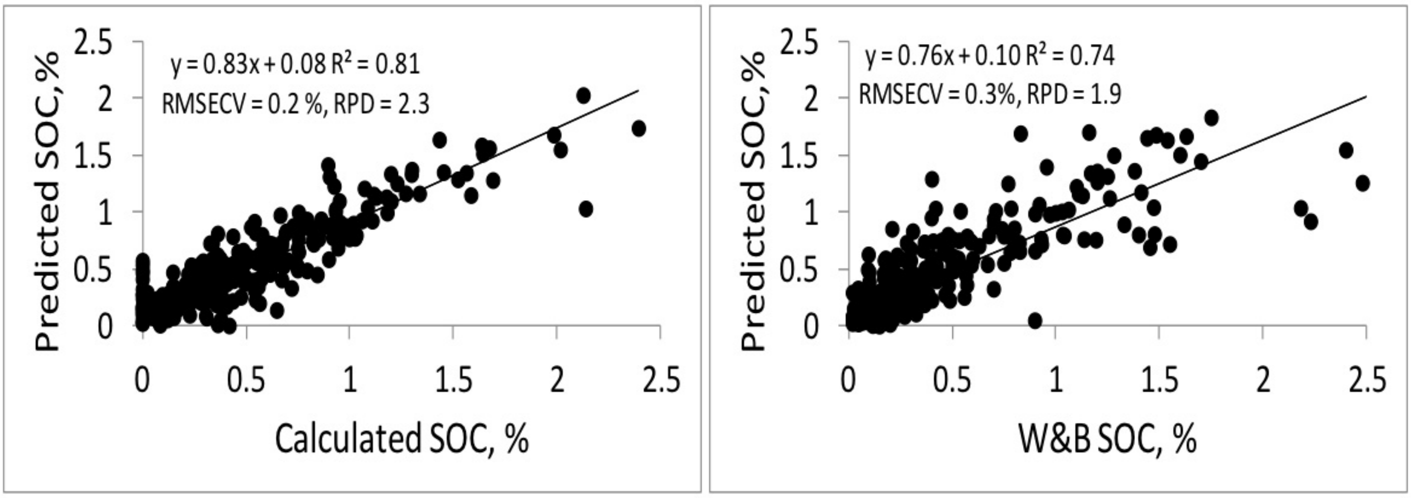

Figure 1. Reference vs. partial least squares regression predicted soil organic carbon using calculated (left) and Walkley & Black (right) data. Results shown for models developed by cross-validation (N = 308).

Assessment of different multivariate models for the prediction of soil properties

A summary of the regression statistics is presented in Table 1. Among the PLSR models, those developed by the Unscrambler software were the most successful, possibly due to the use of different modeling settings. Cross-validation and prediction performances were generally similar. M-PLSR only improved cross-validation performance but not predictions.

The intended application of the MIR technique is to predict "any" unknown soil sample. To make this possible, we need to make sure that the variability of these unknown samples are well represented within the calibration set. In a scenario of predicting samples which are highly variable, both spatially and temporally, global PLSR may not be the best option. In global PLSR methods (the most widely used multivariate algorithm), a single set of soil spectra and corresponding data are used to derive a calibration model. Such models need to be occasionally updated with new uncharacteristic or outlier samples, a non-trivial task. In these cases we may need "adaptive" methods, such as the so-called, "LOCAL", a local calibration PLSR method. This technique is well suited for that purpose, attributed to: 1) no requirement for updating calibrations when new soils are incorporated in the calibration method; and 2) the fact that this method only uses samples that are spectrally similar to unknowns being predicted, expected to result in more accurate predictions and more efficient routine analyses.

Preliminary results for the prediction of CEC, clay and pH using LOCAL, with spectra scanned by Exoscan, showed similar or better results compared to global PLSR. This represents an important advance, especially when using a larger number of samples and in a scenario of large spatial and temporal variability. Neural Networks were not better than PLSR or LOCAL approaches.

Table 1. Summary statistics1 for different multivariate modeling using Exoscan spectra

Method	Analyte	Conc. Range	R2	RMSECV
Unsc PLSR CV	pH (1:5 w)	4.4-10.3	0.80	0.6
WinISI PLSR CV	pH (1:5 w)	4.4-10.3	0.84	0.5
WinISI MPLSR CV	pH (1:5 w)	4.4-10.3	0.89	0.4
WinISI LOCAL CV	pH (1:5 w)	4.4-10.3	0.83	0.5
WinISI NN CV	pH (1:5 w)	4.4-10.3	0.79	0.6
Unsc PLSR CV	CEC (cmol+/kg)	1-48	0.83	4.3
WinISI PLSR CV	CEC (cmol+/kg)	1-48	0.85	4.0
WinISI MPLSR CV	CEC (cmol+/kg)	1-48	0.88	3.7
WinISI LOCAL CV	CEC (cmol+/kg)	1-48	0.84	4.1
WinISI NN CV	CEC (cmol+/kg)	1-48	0.85	4.0
Unsc PLSR CV	Clay (%)	2.0-80.2	0.72	8.3
WinISI PLSR CV	Clay (%)	2.0-80.2	0.75	7.9
WinISI MPLSR CV	Clay (%)	2.0-80.2	0.88	3.7
WinISI LOCAL CV	Clay (%)	2.0-80.2	0.75	8.0
WinISI NN CV	Clay (%)	2.0-80.2	0.74	8.1
Method	Analyte	Conc. Range	R2	RMSEP
Unsc PLSR Pred	pH (1:5 w)	4.5-10.0	0.82	0.6
WinISI PLSR Pred	pH (1:5 w)	4.5-10.0	0.80	0.6
WinISI MPLSR Pred	pH (1:5 w)	4.5-10.0	0.82	0.6
WinISI LOCAL Pred	pH (1:5 w)	4.5-10.0	0.84	0.5
Unsc PLSR Pred	CEC (cmol+/kg)	1-46	0.84	4.4
WinISI PLSR Pred	CEC (cmol+/kg)	1-46	0.83	4.6
WinISI MPLSR Pred	CEC (cmol+/kg)	1-46	0.83	4.5
WinISI LOCAL Pred	CEC (cmol+/kg)	1-46	0.83	4.4
Unsc PLSR Pred	Clay (%)	5.0-69.3	0.77	7.5
WinISI PLSR Pred	Clay (%)	5.0-69.3	0.75	7.9
WinISI MPLS Pred	Clay (%)	5.0-69.3	0.75	8.0
WinISI LOCAL Pred	Clay (%)	5.0-69.3	0.79	7.2

[1]Summary statistics: Coefficient of determination (R^2), root mean square error of the cross-validation (RMSECV), root mean square error of the prediction (RMSEP)

CONCLUSIONS

This study has showed that MIR portable spectroscopy represents a viable and practical alternative to traditional techniques for the determination of soil carbon and related soil properties. In terms of prediction accuracy, aspects related to the reference analyte accuracy play a very important role. Calculation of SOC from reference TC and predicted IC values yields better infrared predictive models than those using reference $SOC_{W\&B}$ data.

The optimization tests have proved that, for being successful in the development of infrared model development for prediction purposes, it is crucial to select samples for calibration which adequately represent the variability of the expected unknowns. In this regard, sample specific method, which select samples based on their spectral characteristics, are the best suited. This is, for example, the case of adaptative methods such as LOCAL. In terms of model optimisation, LOCAL resulted in the most successful approach. This method might be better suited, than traditional PLSR, for future routine predictions of soil properties in large spectra libraries using infrared spectroscopy.

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1.39 | UPDATE ON CANADA'S CONTRIBUTION TO THE GLOBAL SOIL ORGANIC CARBON MAP

Chuck Bulmer[2], Jean-Daniel Sylvain[4], Julien Beguin[5], Brandon Heung[7], Robert MacMillan[8], Glenn Lelyk[1] Asim Biswas[6], Angela Bedard-Haughn[3], Margaret Schmidt[7], David Paré[5], Brian Titus[5], Bert VandenBygaart[*1]and Scott Smith[1]

[1]Science and Technology Branch, Agriculture and Agri-Food Canada, Ottawa, bert.vandenbygaart@agr.gc.ca
[2]BC Ministry of Forests, Lands and Natural Resource Operations
[3]Dept of Soil Science, University of Saskatchewan
[4] Ministère des Forêts, de la Faune et des Parcs Quebec
[5]Canadian Forest Service, Natural Resources Canada
[6]School of Environmental Science, University of Guelph
[7]Dept of Geography, Simon Fraser University
[8] LandMapper Environmental Solutions

ABSTRACT

The Scientific and Technical Committee of the Canadian Digital Soil Mapping Working Group has taken on the task of producing the soil organic carbon map for Canada following the specifications outlined by the Global Soil Partnership. The working group is a collaborative of soil scientists from multiple government agencies and universities from across Canada with an interest in improving digital information in the realm of soil science, soil survey and interpretation. The concept is to use a bottom-up approach whereby digital soil maps with FAO specified soil organic carbon attributes are created by regional contributors using a range of methods. We will compile these regional contributions using an ensemble forecast to produce national soil map(s). Our work will use, as a base layer, soil organic carbon values derived through polygon averaging and disaggregation of legacy soil survey maps. This base layer will be upgraded through the integration of information from new maps produced through inference models calibrated from point datasets at regional scales. We plan to use model averaging to combine the attribute data derived from legacy soil maps and from our point datasets to produce our final product.

Keywords: soil carbon, digital soil mapping, Canada, disaggregation, model averaging

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The Scientific and Technical Committee of the Canadian Digital Soil Mapping Working Group (CDSM-WG) has taken on the task of producing the soil organic carbon map for Canada following the specifications outlined by the Global Soil Partnership. The working group is a collaborative formed within the Canadian Society of Soil Science and is composed of members from multiple government agencies and universities from across Canada. The CDSM-WG is a community of practice, where individual scientists with shared interests work together to advance common goals in the area of digital soil mapping. In this particular case, the focus is on the production of soil organic carbon maps using a range of innovative approaches including digital terrain analysis, machine learning, and knowledge extraction from legacy soil survey maps. We will utilize an existing soil organic carbon map for Canada (Tarnocai and Lacelle, 1996) derived from the Soil Landscapes of Canada map series at 1:1,000,000 scale to serve as the basis four base layer for a global predictor for our soil carbon.

METHODS

Our methods are currently being developed since the project is in its early stages. The concept for our new mapping is to use a bottom-up approach wherein digital soil maps and soil organic carbon attributes are created by regional contributors using a range of methods (Fig 1). In some cases, collaborators have been, or will be, working on a provincial basis, as is the case in British Columbia (Bulmer *et al.*, 2014), Alberta, Saskatchewan, and Quebec or on an ecological region of the country such as the Boreal Forest (Mansuy *et al.*, 2014) .

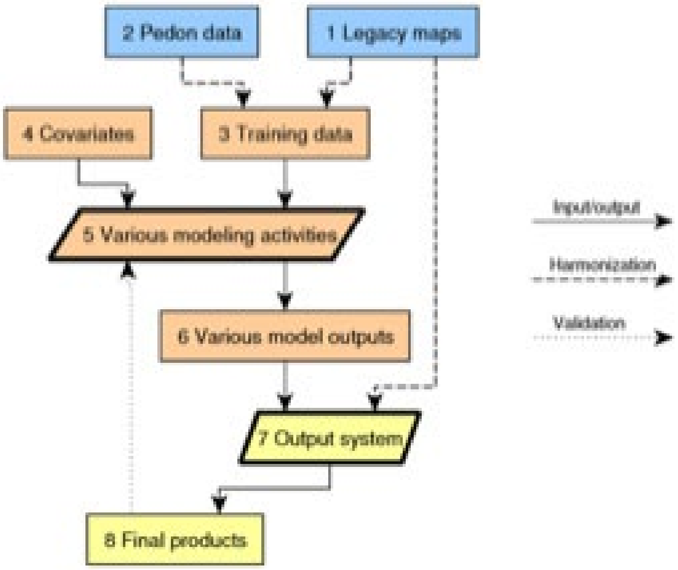

Fig. 1: A conceptual model for collaboration in map production was distributed in a flow chart format and reflected much of the discussion about how the Working Group expects to collaborate.

All of the regional contributions will require considerable effort to compile and harmonize available point profile (pedon) data in order to compute estimates of soil carbon stock individual soil types. It will also be necessary to compute a full suite of gridded covariates (DEM derivatives, climate, vegetation, parent material, remotely sensed imagery, etc) along with mask files of wetlands, urban areas, water bodies, snow, ice, and rock. The tools for making statistical predictions include neural network, support vector regression, Random Forest, Bayesian approaches and regression kriging. We will test the DSMART tool (Odgers *et al.*, 2014) to disaggregate soil survey maps where that approach is required.

The following are some details of the proposed regional/provincial approaches.

British Columbia

Two approaches will be followed in the province of British Columbia (BC). The first will be based on point data (>10,000 profiles) extracted from several sources, primarily from the BC Soil Information System, that will provide reasonable coverage of the province. Compiling, editing, and formatting of these pedon datasets represents a significant undertaking but one that will facilitate on-going digital soil mapping efforts in the province. These point data together with covariates from several provincial sources will form the basis for statistically-driven predictions of soil carbon. A second approach will be to disaggregate existing legacy soil maps, principally the Soil Landscapes of Canada map for BC at 1:1,000,000 scale. Attributes for map unit components will be extracted from the National Soil Database. Some components will require new data to be assigned in order to calculate the required soil organic carbon stocks for the 1 km spatial resolution.

Alberta

Similar to BC, two approaches will be followed for the province of Alberta. The first task will be to extend and modify the existing 1: 100,000 scale regional soil mapping for the province and then use data held in provincial and national soil databases to calculate carbon stock values for each named soil component within map units. These values will be combined and summarized using polygon averaging. Where feasible, map unit polygons may be disaggregated by allocating individual soil components to different landform positions within each polygon. A final map would be produced by a vector to raster conversion of soil carbon stock estimates at 100 m grid size and then generalized to report carbon stock at the 1 km spatial resolution.

A second approach based on statistical modeling will be employed using all available point data for the province. Point data and covariates will be made freely available, and volunteered efforts will be solicited to create and apply DSM models to point data and covariates to predict soil organic carbon stock at 100 m for all of Alberta. These results will then be generalized and assembled at a 1 km spatial resolution for Canada.

Quebec

The approach is to make predictions entirely from point data. For the agricultural region, point data from the Canadian Soil Information System will form the basis to train the prediction model(s) used. For the forested region of Quebec, point data held by various forestry agencies from some 9,600 inventory plots will be used, along with other point data. In forested areas, national and provincial soil databases will be used to define relationships between predicted carbon stock values and soil attributes of texture, color, depth and pH. A hydrologically corrected DEM based on the digital surface model of SRTM at a 40 m resolution will form the spatial base for the modeling approaches described previously. The final product will be generalized to 1 km spatial resolution.

Boreal Forest region

The Boreal Forest region of Canada extends across the country at latitudes between 48°N in eastern Canada up to 65°N in western Canada (Fig 2). For this region, predictions will be generated from point data contained within the National Soil Carbon database and the National Forest Inventory database together providing around 3,000 high quality pedon records that contain SOC values. This work will be conducted at 250 m resolution, using a range of national scale covariates and DEM where the final product will be generalized to the 1 km spatial resolution.

Fig2. Highlighted area on the map of North America shows the extent of the Boreal Forest region in Canada.

Aggregating the inputs

We envisage an ensemble approach for aggregating the contributions received from the regional projects to compute final results for the national map. While the specific approach for aggregation is still being developed, the core concept of our methodology will be to first perform an objective assessment of model errors. Following this, either a simple weighting of the contributions or a more sophisticated approach will be used to combine all predictions into a single value with corresponding error estimates for each grid cell in the final map This 'output system' will be developed in such a way that it not only leads to the best prediction for any particular location, but it will also provide an important and objective source of feedback for the regional contributors. This provides the means to continuously improve estimates of carbon as new information comes available in the future.

Validation

The validation process for predicted map values will be done separately at regional and national levels. The accuracy for regional contributions will be reported using four metrics; determination coefficient (R2), mean error (ME), root mean squared error (RMSE) and bias. Two approaches will be used to report accuracy; k-fold cross-validation and/or bootstrapping procedures. The working group will provide a test dataset that will be used to provide an independent assessment of the errors for each regional contribution. This will also be useful to compare the applicability of individual covariates, inference models and maps.

DISCUSSION

In regions where soil survey map disaggregation or point-based predictions are not possible, we will have to rely on gridded datasets that exist for the arctic and sub-arctic regions of Canada (Hulervig *et al.,* 2014) and for much of the agricultural region of the country (Hempel *et al.*, 2012). These have been derived through weighted averaging of component attribute values from legacy soil survey map polygons. While useful to fill gaps in our coverage, these reported values are not spatially explicit (many adjacent cells have the same value) nor do they currently include any measures of uncertainty. Compiling a comprehensive gridded soil organic carbon map for all of Canada with a land area greater than 9 million km^2 spanning climatic regimes from temperature to polar will present many challenges. In particular, the dynamic 'forest floor' layers of decomposed and semi-decomposed organic matter (i.e. the F and H layers) that overlie the mineral soil material in our forests are an important carbon pool in our forests that can respond quickly to impacts like harvesting or fire and therefore it is essential that global mapping approaches take account of it effectively. The extensive peatlands and permafrost-affected soils in Canada's north contain very large carbon stocks and unusual organic carbon depth profiles. Finally, in agricultural regions, changing land management practices and soil redistribution have altered soil organic carbon concentrations in the upper soil horizons of cultivated soils in the time since the legacy soil surveys were conducted many decades ago. Correctly quantifying the carbon stocks in all of these different soil environments will be critical to generating enhanced, scientifically-credible soil carbon maps.

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1.40 | SPATIAL DISTRIBUTION OF SOIL ORGANIC CARBON STOCKS IN SERBIA

*Dragana Vidojević [1], Maja Manojlović[2], Aleksandar Đorđević[3], Ljiljana Nešić[2] & Branislava Dimić[1]

[1]Environmental Protection Agency, dragana.vidojevic@sepa.gov.rs; branislava.dimic@sepa.gov.rs;
[2]Faculty of Agriculture, University of Novi Sad, maja.manojlovic@polj.uns.ac.rs; nesiclj@polj.uns.ac.rs;
[3]Faculty of Agriculture, University of Belgrade, adjsoils@eunet.rs;

ABSTRACT

Spatial distribution of soil organic carbon (SOC) were investigated in the soils of the Republic of Serbia. The database included a total of 1,140 soil profiles which corresponded to 4,335 soil horizons. To establish the relationship between organic carbon content and soil type, a soil map of Serbia was adapted to the WRB classification and divided into 15,437 polygons (map units). We calculated the SOC stock values for each reference soil group based on mean values of SOC at 0-30 and 0-100 cm and their areas. The largest SOC stocks for the soil layers 0-30 cm were found in Cambisol 194.76 x 10^{12} g and Leptosol 186.43 x 10^{12} g, and for the soil layers 0-100 cm in Cambisol 274.87 x 10^{12} g and Chermozem 230.43 x 10^{12} g. Based on the size of the reference groups, total area of Republic of Serbia, and the mean SOC values for each reference group, we calculated the total SOC stocks. The obtained values for the soil layers 0-30 cm and 0-100 cm amounted to 705.84 x 10^{12} g and 1,159.55 x 10^{12} g, respectively.

Key words: Organic carbon stocks, map unit, soil group, SOC content, Republic of Serbia

INTRODUCTION

This paper presents spatial distribution of organic carbon stocks in the soils of the Republic of Serbia. The assessment was based on long-term research data and data from Soil Information System of Environmental Protection Agency (Vidojević and Manojlović, 2010). Estimation of organic carbon stocks in the soil is important for Republic of Serbia for several reasons. Of the total territory of Republic of Serbia, 65.6% are agricultural land and 32% are forest land (State of Soil in the Republic of Serbia for 2012, 2013). Considering the vital importance of organic carbon for the functioning of ecosystems, its effect on soil structure and soil water capacity, and its role in numerous chemical and physical soil properties, it is important to establish its baseline status in order to be able to monitor its variations over time. The assessment of organic carbon stocks was made in soil layers 0-30 cm and 0-100 cm and it was based on soil type.

METHODOLOGY

Study location

The assessment of organic carbon stocks in the soils of the Republic of Serbia was carried out in the period 2009-2013. Organic carbon stocks in the soils of the Republic of Serbia were calculated on the basis of the mean values for each WRB reference soil group. Organic carbon stocks were calculated for the area of 77,474 km^2, i.e., for the territory of Republic of Serbia excluding Kosovo and Metohija Province (Statistical Yearbook of the Republic of Serbia, 2010). The territory of Kosovo and Metohija Province was excluded from calculation because of unavailable data.

Soil database

In the period 2009-2011, a database was established which served as the basis for further research. Its objective was to collate all available data and to adapt them to fit the base. Presently, the database includes a total of 1,140 soil profiles which involve 4,335 horizons. Data that comprise the database for analytical study were collected in the period 1962-2010.
The soil map of Serbia shows that the reference groups Histosol, Anthrosol, Calcisol, Podzol, Phaeozem and Umbrisol are distributed over a limited area in the country, totaling 3.58%. The most extensive groups are Cambisols (27.99%), Chernozems (17.68%) and Leptosols (15.9%) (Vidojević *et al.*, 2015).

Calculation of organic carbon stocks per WRB reference groups

Using Soil Map of Serbia, areas of the main WRB reference soil groups were defined. Total values of organic carbon stocks for these reference groups were calculated on the basis of the mean values of organic carbon content at 0-30 cm and 0-100 cm and the area of each reference group. The database does not contain the results for organic carbon stocks in the following reference groups: Anthrosol, Calcisol, Histosol, Phaeozem, Podzol and Umbrisol. These groups cover a total area of 276,991 ha, which represents 3.57% of the territory of the country. For the calculation of organic carbon stocks in these groups, we used values which represented the arithmetic means for all reference group at 0-30 cm and 0-100 cm expressed in t ha^{-1}. The mean values for the main reference groups were 89.60 t ha^{-1} and 145.69 t ha^{-1} for the depths of 0-30 cm and 0-100 cm, respectively.

Organic carbon stock at 0-30 cm per reference group was calculated according to the following formula:

SOC 30 cm (t) = Σ {(ẋ) mean value of organic carbon content per reference soil group at 0-30 cm (t ha^{-1}) x area occupied by reference group (ha)}

Organic carbon stock at 0-100 cm was calculated according to the following formula:

SOC 100 cm (t) = Σ {(ẋ) mean value of organic carbon content per reference soil group at 0-100 cm (t ha^{-1}) x area occupied by reference group (ha)}

RESULTS

The calculated data indicated that there existed a great variability in the content of organic carbon among the reference soil groups. The highest mean values of organic carbon content were found in the reference group Leptosol - 151.33 t ha^{-1} and 178.95 t ha^{-1} for the depths of 0-30 cm and 0-100 cm, respectively (Vidojević *et al.*, 2012). The analysis of the coefficients of variation indicated that the mean values were not sufficiently representative for that group (CV > 50%). The lowest mean values of organic carbon content were found in the reference group Arenosol - 41.78 t ha^{-1} and 96.03 t ha^{-1} for the depths of 0-30 cm and 0-100 cm, respectively. The analysis of the coefficients of variation showed that the mean values were sufficiently representative for this group (CV <50%). The research showed that the values of organic carbon content had highest variability in the reference groups Leptosol and Regosol.

The result obtained on the basis of the compound area of the reference soil groups and the area of Republic of Serbia (77,474 km^2) indicated that the organic carbon stocks at 0-30 cm and 0-100 cm were 705.84 x 10^{12} g and 1,159.55 x 10^{12} g, respectively.

DISCUSSION

The map of organic carbon distribution per soil type, at 0-30 cm, showed that largest organic carbon stocks were present in Central Serbia (southern part), predominantly in the reference group Leptosol (Fig. 1). In that reference group, the content of organic carbon at 0-30 cm ranged from 11.06 to 527.22 t ha^{-1}, with the mean value of 151.33 t ha^{-1}. At 0-100 cm, the values ranged from 11.06 to 658.40 t ha^{-1}, with the mean value of 178.95 t ha^{-1}. The soils in this reference group are shallow, so that the values of organic carbon content to the depth of 100 cm represent in fact the value for the entire profile. The reference group Cambisol occupies the largest area in Central Serbia (37.76%). The values of organic carbon content for this reference group, at 0-30 cm, ranged from 20.44 to 347.62 t ha^{-1}, with a mean value of 89.81 t ha^{-1}. The coefficient of variation was 59.40%. The values of organic carbon content at 100 cm ranged from 25.74 to 398.43 t ha^{-1}, with the mean value of 126.75 t ha^{-1}. The coefficient of variation was 49.54%. In the north of the country, in Vojvodina Province, the region with the most intensive agricultural production, the organic carbon content at 30 cm was mostly low, amounting to 1.93%. The most common soil type in this part of the country is Chernozem, which covers 57.9% of the area. The values of organic carbon content for this reference group, at 30 cm, ranged from 7.89 to 133.51 t ha^{-1}, with the mean value of 73.82 t ha^{-1} (Vidojević *et al.*, 2016). The organic carbon content at 100 cm ranged from 24.21 to 341.37 t ha^{-1}, with the mean value of 168.20 t ha^{-1}. The obtained values indicated that chernozems have a greater depth of the humus horizon (Ah), which went up to 100 cm, then Cambisols with the humus horizon up to the depth of 60 cm.

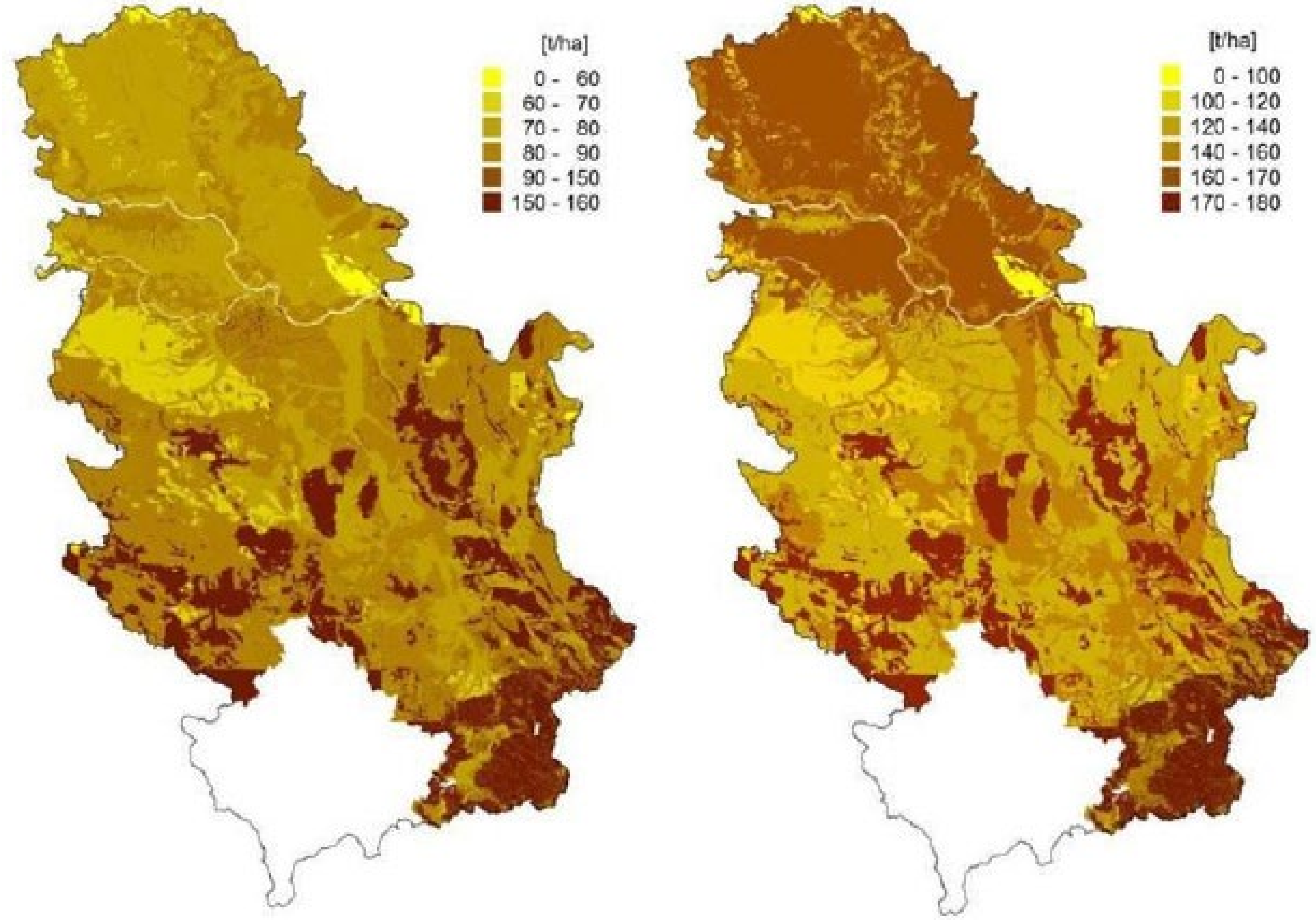

Fig. 1. SOC stocks distribution by soil type, to the depths of a) 0-30 cm and b) 0-100 cm (Vidojevi· et al., 2015)

Chernozem and Gleysol, the two most common soil reference groups in Vojvodina Province, which occupy 76.03% of the area, were found to have larger organic carbon stocks than Cambisol, the most common soil reference group in Central Serbia. The Chernozem soil in Russia was reported to contain 290 t ha^{-1} of organic carbon at 0-100 cm (Mikhailova and Post, 2006), while a study in Bulgaria showed 142 t ha^{-1} (Filcheva *et al.*, 2002). Chernozem in Vojvodina Province, which had developed on loess terraces, has the mean organic carbon content of 151 t ha^{-1} at 0-100 cm (Belić *et al.*, 2013).

CONCLUSION

According to the analysis of the soil map, the soils of Serbia were found to store 705.84 x 10^{12}g (Tg) of organic carbon at 0-30 cm and 1,159.55 x 10^{12} g (Tg) at 0-100 cm. The spatial distribution of organic carbon stocks and its variability is caused by various factors, such as clay content, land use pattern, altitude, and climate. In general, the distribution of the content of organic carbon at 0-30 cm showed higher values in Central Serbia, where forestland occupied a larger area than agricultural land.

Republic of Serbia has a variety of soils which differ in profile structure and depth. In the case of the reference soil groups with the profile depth less than 100 cm, the content of organic carbon was still presented for the depth of 0-100 cm although it was not true for the actual situation.

As the data for organic carbon content come from a total of 1,140 soil profiles, we believe that the results of the this study are accurate and reliable. This study is the first comprehensive assessment of organic carbon stocks in the soils layers 0-30 cm and 0-100 cm done in the Republic of Serbia. The compilation of data on organic carbon stocks and its distribution in the different soil reference groups is the first step in the evaluation and monitoring of changes of organic carbon stocks in the soils of Serbia.

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1.41 | TOWARDS REALISTIC AND FEASIBLE SOIL ORGANIC CARBON INVENTORIES: A CASE OF STUDY IN THE ARGENTINEAN SEMIARID CHACO

Villarino, Sebastián Horacio[1, 2,*], Studdert, Guillermo Alberto[2], Laterra, Pedro[1, 3]

[1] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)
[2] Unidad Integrada Balcarce, Facultad de Ciencias Agrarias (UNMdP) - Estación Experimental Agropecuaria Balcarce (INTA)
[3] Fundación Bariloche
* presenting author with an asterisk

ABSTRACT

Soil organic carbon (SOC) is the main terrestrial carbon reservoir. The development of reliable tools for SOC stock monitoring at large scale is fundamental to face climate change. The IPCC carbon inventory method is based on three tiers. The higher the tier, the greater the estimation accuracy, but also the need for resources. Argentinean Semiarid Chaco (ASC) is a deforestation hotspot. In order to improve SOC stocks estimations in that region, we developed a Tier 2 (T2) following a proposed approach for regions with information limitations. The RothC model was used to derive SOC change factors and empirical data was used to estimate SOC under native forest (SOCref). Selected models to predict stock change factor for cropland (Fc) and for grassland (Fg) showed very good fit ($R^2 = 0.89$ and $R^2 = 0.90$, respectively). Hence, SOC changes simulated with RothC could be predicted with linear models. The stock change factors (Fc and Fg) for forest to cropland and forest to grassland conversions were always less than 1. This indicates that deforestation, whether for grassland or cropland land use, decreased SOC stocks. We proved that T2 based on RothC simulations approach could be applied in ASC, a region with information limitations.

Keywords: IPCC, Tier 2, Greenhouse gas, Land use change, deforestation.

INTRODUCTION

The most important anthropogenic greenhouse gas (GHG) is the CO_2, and its main sources from human activity are primarily from fossil fuel emissions and secondarily from net land use change emissions (IPCC, 2013). Soil organic C (SOC) stock is the main terrestrial C reservoir and land use change generate CO_2 fluxes from soil to atmosphere (Lal, 2011). Thus, in the context of international policy agendas on GHG emissions mitigation, the development of reliable tools for SOC stock monitoring at large scale is fundamental (Lal, 2011).

The Intergovernmental Panel on Climate Change (IPCC) developed a C inventory method (IPCC-CIM) to estimate CO_2 emissions from soil (IPCC, 2006). The IPCC-CIM is based on three tiers. The higher the tier, the greater the accuracy of the outputs, but also the need for knowledge and information (IPCC, 2006). Tier 1 (T1) is easily applicable but, unfortunately, its estimates showed a very poor match with observed data at regional scale (Berhongaray and Álvarez, 2013; Villarino *et al.*, 2014). On the other hand, Tier 2 (T2) and Tier 3 development require the availability of much more information resources and, therefore, they would be feasible only in special and limited cases.

In response to T1 limitation, Villarino *et al.* (2014) proposed a T2 based on simulations performed with the RothC model (Coleman and Jenkinson, 1996). By using this approach, a significant improvement was obtained over T1 for Argentinean Pampa Region with very little demand for additional information (Villarino *et al.*, 2014). In regions where information about SOC stock relations with land use changes is scarce, the development of a T2 based on that proposed estimation mechanism, could be a good option to improve SOC stock estimations using the IPCC-CIM.

In South American Semiarid Chaco has occurred the highest rate of subtropical forest loss in the 21st century (Hansen *et al.*, 2013), and approximately 62% of this region is located in Argentinean Semiarid Chaco (ASC) (Vallejos *et al.*, 2014). The ASC region is a vast plain of about 29 Mha located at north-central Argentina. Native vegetation of this region is mainly a xerophytic forest. Deforestation rates in the ASC have increased exponentially since 1976, reaching a maximum value (2.5 % yr^{-1}) between 2006 and 2012 (Vallejos *et al.*, 2014). The main goal of this work was to test the suitability of the IPCC T2 based on RothC simulations (Villarino *et al.*, 2014) to estimate SOC stocks along land use change in ASC.

METHODOLOGY

The T2 developed was based on Villarino *et al.* (2014) proposal (Eq. 1):

$$SOC = SOCin \times Fi \quad \text{(Eq. 1)}$$

where SOC is the estimated SOC stock (Mg ha^{-1}), SOCin is the initial SOC (Mg ha^{-1}), Fi is the stock change factor for the i-th land use (i.e. cropland or grassland).

Forty counties belonging to ASC were evaluated in 1976, 1996 and 2012. Land use change was classified into seven categories: forest remaining forest, forest to cropland, forest to grassland, cropland remaining cropland, cropland to grassland, grassland remaining grassland and grassland to cropland. Forest change area was obtained from remote sensing estimations (Vallejos *et al.*, 2014) and cropland area was taken from the Argentinean Integrated Agricultural Information System (SIIA, 2015). It was assumed the area that is not neither cropland nor forest, is grassland.

The SOC stock under native forest (SOCref) was estimated with linear models that predict SOCref as a function of soil sand content and mean annual precipitation. Data for model fitting was obtained from soil samples (Villarino *et al.*, 2017) and from climate (Bianchi and Cravero, 2010) and soil maps (INTA, 1990; Angueira *et al.*, 2007).

The stock change factor for croplands (Fc) and for grasslands (Fg) were developed from SOC simulations with RothC model. For cropland simulations, 11 hypothetical crop rotations that included cotton, maize, soybean, sunflower, and wheat were defined for the ASC, based on querying to local experts. These rotations were simulated with three rotation yield levels and under two tillage systems (full tillage and no-till). Carbon inputs were estimated from crop yields. The RothC model simulates SOC stock change under full tillage. To simulate no-till system, soil surface condition was loaded in the model as permanently covered. For grassland simulations, we assumed that dry matter (DM) productivity of grasslands was 4.6, 5.7, and 6.7 Mg DM ha^{-1} when mean annual precipitation of the county was between 487-642 mm, 643-797 mm, and 798-875 mm, respectively (De León, 2004).

All scenarios were simulated at 0-30 cm soil depth, under three soil clay percentage levels (3%, 13 % y 20 %), and during 10, 20, 30, 40, and 50 years. The average age of a new grassland or cropland area within a period was calculated as the difference between the ending and the starting years of the period divided by two (Villarino *et al.*, 2014). The starting points for croplands simulations were forest at equilibrium, estimated with the inverse mode of RothC model and for grassland simulations were five initial SOC stocks obtained from cropland simulations (55, 42, 36, 30, and 18 Mg C ha^{-1}). With all possible combinations, 2970 data of Fc and 675 data of Fg were obtained. Then, multiple linear regression models were fitted to predict Fc or Fg using soil clay content (g 100 g^{-1}), cotton, maize, soybean, sunflower, and wheat proportions (%) in the rotation, weighted average yield (average of each crop yield weighted by the proportion of each one in the rotation), initial SOC stock, elapsed time under cropland or grassland, tillage system, and DM production level as predicting variables. Finally, the best model was selected through graphical analyses of the residuals and the highest R^2 criterion.

RESULTS

Selected models to predict Fc and Fg showed very good fit (R^2 = 0.89 and R^2 = 0.90, respectively, Table 1). Hence, SOC changes simulated with RothC could be predicted with linear models (Table 1).

Table 1: Summary of fitted linear models to predict stock change factor for croplands (Fc) and for grassland (Fg)

Response variable	Predictor variable	Estimated parameter	Standard error	p-value
Fc	Intercept	5.422	0.307	<0.000001
	Clay (g 100 g-1)	0.001352	0.000136	<0.000001
	Time (yr)	-0.00788	0.000102	<0.000001
	Soybean (%)	-0.04536	0.003065	<0.000001
	Maize (%)	-0.04549	0.003065	<0.000001
	Wheat (%)	-0.04302	0.003054	<0.000001
	Sunflower (%)	-0.04436	0.003089	<0.000001
	Cotton (%)	-0.04568	0.003071	<0.000001
	Weighted yield (Mg ha^{-1})	0.04594	0.001176	<0.000001
	SOCi (Mg ha^{-1})2	-0.000058	0.000001	<0.000001
	NT	0.05165	0.003589	<0.000001
	Time (yr) * NT	0.001962	0.000135	<0.000001
Fg	Intercept	1.312	0.01957	<0.000001
	Time (yr)	0.00779	0.000466	<0.000001
	SOCi (Mg ha^{-1})	-0.02081	0.000844	<0.000001
	SOCi2 (Mg ha^{-1})2	0.000204	0.00001	<0.000001
	DM-5.7	0.05383	0.0045	<0.000001
	DM-6.7	0.1058	0.004522	<0.000001
	Clay (g 100 g-1)	0.007798	0.001287	<0.000001
	Clay2 (g 100 g-1)2	-0.000156	0.000056	0.00526
	Time (year) * SOCi (Mg ha^{-1})	-0.000262	0.000013	<0.000001

SOCi: initial soil organic carbon. NT, DM-5.7, and DM-6.7 are categorical variables. For croplands under no-till (NT) system, NT = 1, and under full tillage NT = 0. For grasslands, when dry matter (DM) production is 4.6 Mg DM ha^{-1}, DM-5.7 = 0 and DM-6.7 = 0, when DM production is 5.7 Mg DM ha^{-1}, DM-5.7 = 1 and DM-6.7 = 0, and when DM production is 6.7 Mg DM ha^{-1} DM-5.7 = 0 and DM-6.7 = 1. The asterisk (*) indicates interactions between predictor variables. The adjusted R^2 of Fc and Fg models were 0.89 and 0.90, respectively.

The stock change factors (Fc and Fg) for forest to cropland and forest to grassland conversions were always less than 1. This indicates that deforestation, whether for grassland or cropland land use, always decreased SOC stocks (Fig. 1). The Fg for forest to grassland conversion was between 0.87 and 0.88 and the Fc for forest to cropland conversion was between 0.77 and 0.91 (Fig. 1). The Fc for cropland remaining cropland was always lower than the Fg for grassland remaining grassland (Fig. 1). This means that cropland remaining cropland loss more SOC proportions than grassland remaining grassland.

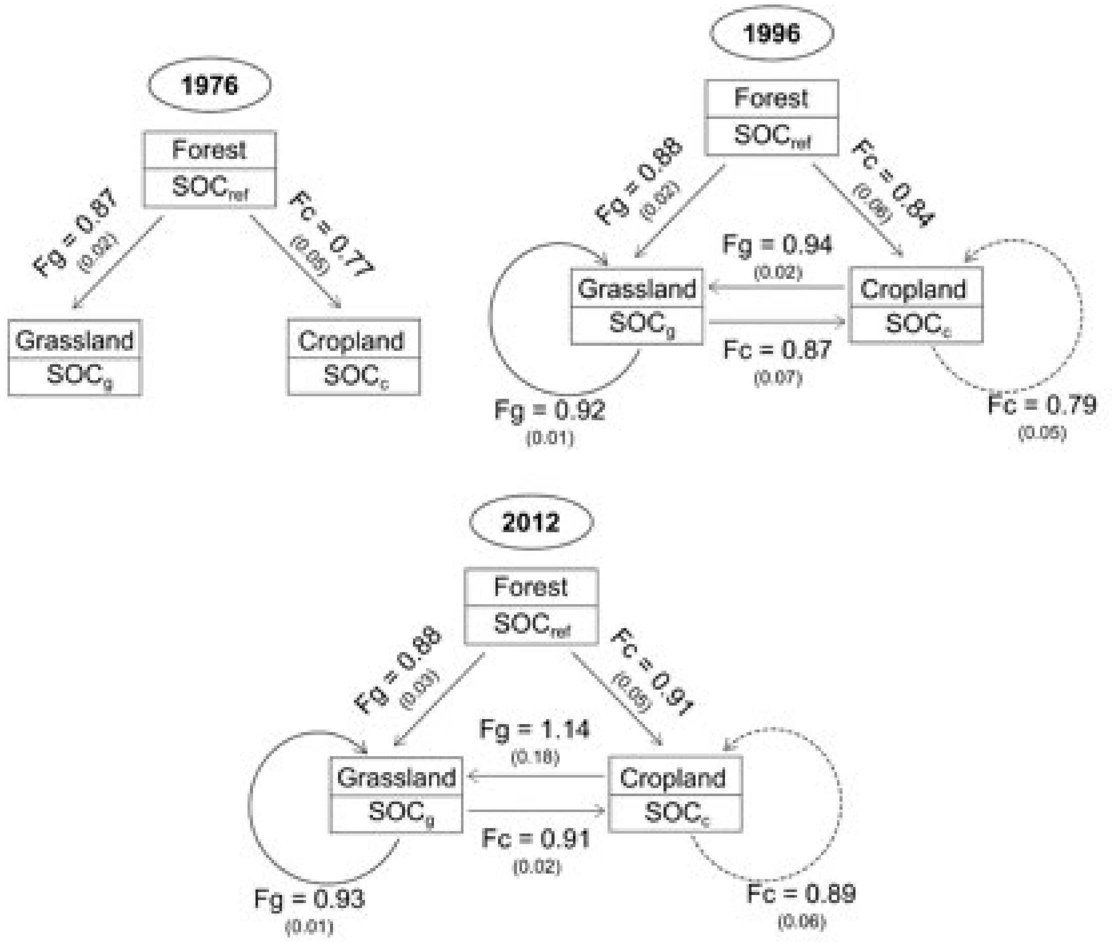

Fig. 1: Stock change factors for croplands (Fc) and for grasslands (Fg) used to estimate soil organic carbon changes in grassland (SOCg) and cropland (SOCc) for each evaluation year (bold number inside ovals). Circular arrows indicate grassland remaining grassland (solid) and cropland remaining cropland categories (dashed). SOCref: soil organic carbon under forest. Number between brackets are the standard deviation.

The highest SOCref stocks were estimated for the north-east and south-east, whereas the lowest SOCref stocks were estimated for the center-east of the ASC. Between 1976 and 2012, the average SOC stocks were estimated as maintained similar to SOCref in north and south of ASC, whereas a tendency to SOC decrease was estimated in the central ASC (Fig. 2).

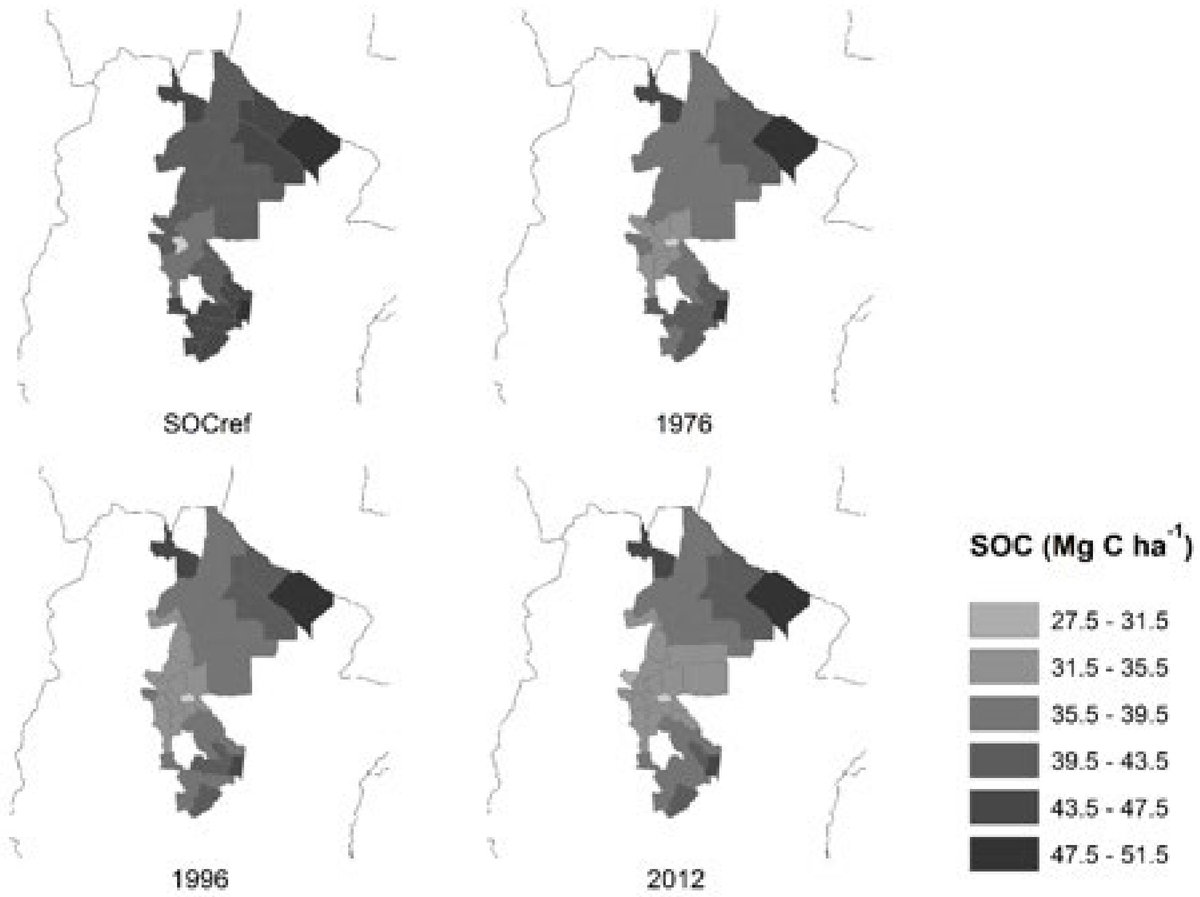

Fig. 2: Soil organic carbon under forest (SOCref) and average soil organic carbon (SOC) stocks in the Argentinean Semiarid Chaco counties in 1976, 1996 and 2012.

DISCUSSION

The Fc for forest to cropland conversion grew from 1976 through 2012 (Fig. 1). This could be explained by the model parameters in the Fc model (Table 1). The positive value of weighted yield parameter (Table 1) indicates a positive correlation between SOC stocks and crop yields, and these last grew from 1976 to 2012 (SIIA, 2015). On the other hand, switching from full tillage to no-till strongly affects SOC dynamics and, in many situations, causes a SOC accumulation near soil surface (West and Post, 2002). In agreement with this, the estimated parameter for no-till was positive (Table 1). No-till system was introduced in the 1990s. Hence, this tillage system change led to an increase in Fc in 2012.

For 16, 10 and 8 yr under cropping after deforestation, Fc's of 0.75, 0.85 and 0.90, respectively, were estimated in ASC from observed data (Villarino *et al.*, 2017). The Fc's estimated in this work for these cropping ages were 0.77, 0.84 and 0.91 (Fig. 1). Therefore, there is a high degree of agreement between studies. The Fg for forest to grassland conversion was between 0.87 and 0.88. Caruso (2008) studied 11 sites in ASC where forest changed to grassland, and the average SOC change under grassland was -24% (Fg = 0.76). However, this average resulted from an extremely high range, with a maximum of 6% (Fg = 1.06) and a minimum of -43% (Fg = 0.57). In other ASC sites, Ciuffoli, (2013) observed -30 and -10 % SOC changes for 4 and 31 yr since forest to grassland conversion, respectively (Fg between 0.7 and 0.9). Hence, these studies (Caruso, 2008; Ciuffolli, 2013) suggest that forest to grassland conversion leads to highly variable SOC changes. Nevertheless, the Fg's estimated in this work (Fig. 1) have a moderate degree of agreement with the observed values (Caruso, 2008; Ciuffolli, 2013).

CONCLUSIONS

In this work we proved the IPCC T2 based on RothC simulations approach (Villarino *et al.*, 2014) could be applied in ASC, a region with information limitations. The estimated stock change factors of T2 were similar to the reported in other studies carried out in ASC. We encourage to countries or regions that are using T1 due to data limitation to derive a similar T2 method using our proposed approach.

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1.42 | STRENGTHS AND WEAKNESSES OF A BOTTOM UP APPROACH IN ESTIMATING SOIL ORGANIC CARBON: AN EXPERIENCE IN THE VARIED ITALIAN SCENERY

I. Vinci [1*], F. Fumanti [2], P. Giandon [1], S. Obber[1]

[1] ialina.vinci@arpa.veneto.it, ARPAV (Veneto Region Environmental Protection Agency), Via S.Barbara 5 TV – Italy
[2] ISPRA (Italian National Institute for Environmental Protection and Research), Via V. Brancati 48 Rome - Italy

ABSTRACT

A first attempt to provide consistent information about soil organic carbon stock in Italy was made through a pilot project set up by the National Institute for Environmental Protection and Research in Italy (ISPRA), involving regional soil services. Aim of the project was the exploitation of the most updated and detailed available information, through local expertise, in order to give reliable answers to the urgent need of information on soil, at national and European level, providing an harmonized and shared tool, according to the bottom-up approach. The common infrastructure for data sharing, consisted of a 1 km^2 reference grid and an exchange format for storing data and metadata, simplifying harmonization and up-scaling issues, easy to query and update, ensuring consistency with European standards and procedures. Main issues in SOC assessments were bulk density evaluation, comparability of analytical methods and of different spatial distribution modelling.

Keywords: soil organic carbon assessment, soil bulk density, harmonization

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Since soil is a non-renewable resource increasingly under pressure, there is an urgent need for consistent and reliable information. Since the comparability of information on soils is limited, often based on few data, collected using different methodologies (Sulaeman *et al.*, 2013), the Institute for Environmental Protection and Research has financed and started the SIAS project to develop a new approach that exploits the more updated and detailed information on soil and the expertise available at local level to build reliable indicators on some soil threats at national level. This pilot project has been focused on soil erosion and loss of organic matter, as these were two of the main threats identified by the European Commission in the Thematic Strategy for Soil Protection and Proposal for a Framework Directive (COM 2006, 231 and 232; European Commission, 2006). Partners of the project were 16 Regional Soil Survey Services out of 20 regions, that contributed defining methodology, elaborating soil data and assessing soil indicators for their own region, under the technical coordination of the Environmental Protection Agency of the Veneto Region. Other partners were CRA-RPS (Research Centre for the study of plant-soil relationship), and the Land Management and Natural Hazards Unit of JRC, for implementing the methodology of up-scaling data, ensuring consistency with European standards and procedures.

METHODOLOGY

Every Regional Soil Survey Service has been asked to participate in defining an exchange format at first, and later in filling the format in, concerning the soil indicators and all related information (metadata).
To overcome harmonization problems, it has been decided to assess and present output data on a reference grid, with a common coordinate reference system, setting up a common infrastructure for data sharing. The reference grid has been built following the recommendations of the INSPIRE Directive (European Parliament, 2007). For SIAS project, a 1 km grid was chosen, seeming a good compromise between information quality, operability and goals of the project.
To collect pixel data and meta-information, an exchange format was set up jointly by the working group; the format was then developed as a database. Information about soil organic carbon stock was stored as well as some data quality indicators, shared by the working group, both as quantitative indexes of data availability in the pixel and as specific confidence levels in each pixel.
Special emphasis of the project lays on exploitation of local expert judgement ("bottom-up" approach) so that local experts can

follow the most adequate assessment procedures up to their judgement, as long as procedure paths were recorded into metadata that was the project value-added information.

Organic carbon stock (t ha^{-1}) has been calculated for 0-30 cm, 0-100 cm and for holorganic layers, through the following formula, applied for each profile or Soil Typological Unit (STU):

$$O.C. = \sum_{1}^{n} o.c. * b.d. * depth * \frac{(100 - sk)}{100}$$

where:
O.C.= profile/STU organic carbon content (t ha^{-1});
o.c.= horizon organic carbon content (%);
b.d.= fine earth bulk density of the horizon (g cm^{-3});
depth = horizon depth (cm) within the given section;
sk = horizon rock fragment content (%);
n = number of horizons within the given section.

In order to have a comparable assessment, organic carbon data obtained by means of local analytical methods have been converted into ISO method results, according to specific regression functions. These were developed thanks to results of a ring test worked out among several public Italian laboratory for soil analysis. Concerning bulk density, both measured data and pedotransfer function (PTF) were used; some regions used original PTFs calibrated on own measured dataset (Ungaro *et al.*, 2005a), the other ones used literature PTFs.

To assess organic carbon content within the pixel, different pathways have been followed, as every Regional Soil Service could choose the most suitable one for its specific situation:

- by means of a soil map, calculating the weighted average of STUs in the SMU (soil mapping unit), or the average of single profiles in the SMU;
- using geostatistical analysis, usually by means of kriging with varying local means calibrated on SMUs (Ungaro *et al.*, 2005b; Deutsch and Journel, 1998; Goovaerts, 2001).

As final step, organic carbon stock within the pixel has been intersected with a land-cover map, Corine Land Cover or more detailed regional map, to obtain the final value of t ha^{-1}, subtracting no-soil surfaces.
All information (analytical-measurement methods, PTFs and regressions used, data time span, spatialization and up-scaling methods, land-cover scale and year) has been recorded in the metadata section of the exchange format.

RESULTS

The project started in 2008 but not all regions could take part, as some lack a regional soil service.
Organic carbon stocks for 0-30 cm for 17 regions out of 20 are shown in figure 1. The approaches used for organic carbon stock evaluation were different in different regions, sometimes even in different areas of the same region. In areas where a soil map was available, carbon stock could be calculated by means of weighted average of STUs in the SMU or as average value of observations within the SMU.
Where more detailed maps were available, observation density higher and local expertise adequate geostatistical analysis could be applied for data spatialization (kriging with varying local means calibrated on functional groups of STUs), requiring data such as single observation organic carbon percentages, measured bulk density (where available) or estimated bulk density calculated by means of pedotransfer-functions (e.g. in Veneto and Emilia Romagna alluvial plain).
Graphs in figure 2 shows mean carbon stocks of 10 out of 20 regions. Average SOC in plain areas goes from 34 to 60 t ha^{-1} in the 0-30 cm section, with the lowest values in southern Italy (34 t ha^{-1}) and the highest (51-60 t ha^{-1}) in the north (Po plain). Average SOC in the 0-100 cm section ranges from 78 to 154 t ha^{-1} in the plain, with the same geographical trend. In the Alps SOC is quite variable, going from 59 to 103 t ha^{-1}, on average, for the 0-30cm section, and from 87 to 160 t ha^{-1}, for the 0-100cm. Central and southern mountain areas (Appennini) have average contents of 50-58 t ha^{-1} within 30 cm and 95-114 t ha^{-1} within 100 cm.

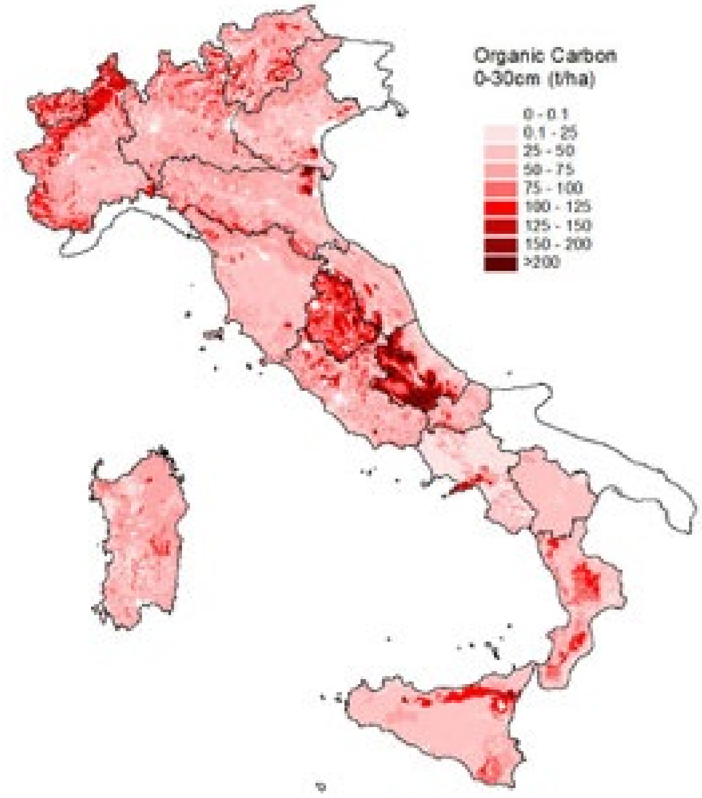

Fig. 1: 0-30 cm SOC (t ha^{-1}) in 17 regions out of 20.

DISCUSSION

Different problems were faced during the project. In the beginning, partner involvement has not been easy, since interest and various region know-how was quite different. Bulk density assessment turned out to be a weakness point, since different PTFs often give very different results, strongly depending on the environment where they have been developed and calibrated. Several regions had large datasets of measured bulk densities that were used to develop local PTFs that turned to be useful also to other regions with similar environments.

Once the common infrastructure has been shared and accepted, all regions had to face different technical problems. Know-how seemed to vary a lot among regions, so that a main group of more expert regions acted as technical guide for other, less experienced, regions.

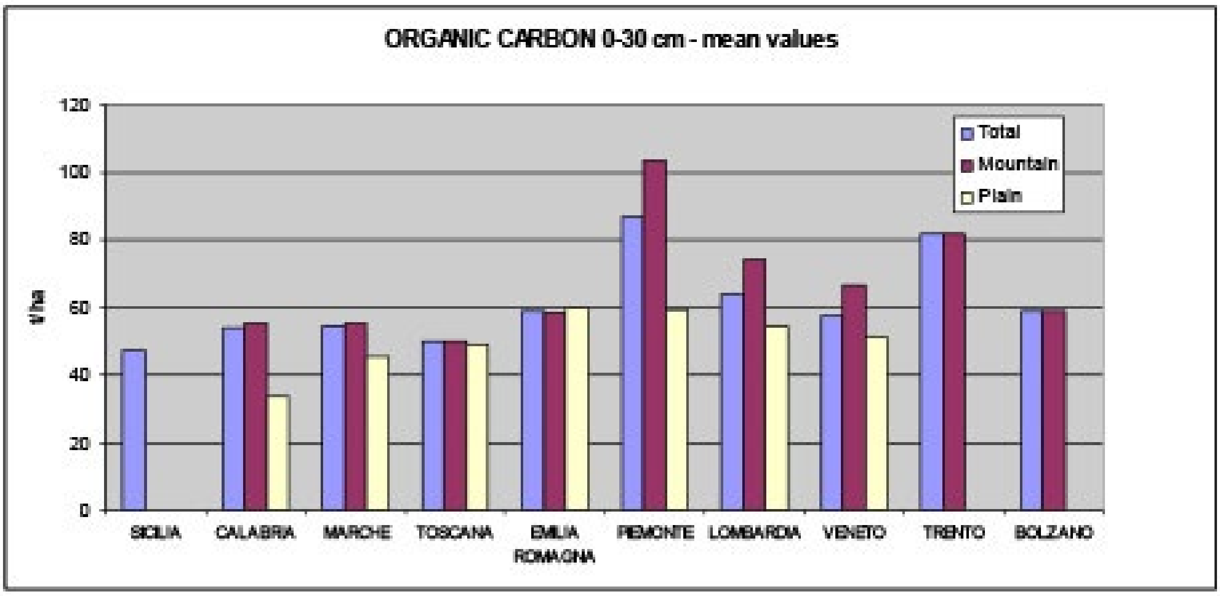

Fig. 2: Mean 0-30cm SOC values in the most representative regions (t ha^{-1}).

CONCLUSIONS

At the end outputs of 17 out of 20 regions were available, giving not a complete picture, but far enough to face main correlation and harmonization issues. Bulk density PTFs, locally developed or available in literature, together with comparability of different methods of soil laboratory analysis and different methods of data spatialization were the main issues. 1 km pixels seemed to be a suited tool for representing SOC indicator.

SIAS project was the first Italian attempt to provide consistent information about soil organic carbon stock. It has also provided, according to the bottom-up approach, an harmonized assessment tool for exploitation of local expertise, that can guarantee the use of the most up to date information and the more reliable assessment, and can be used to work out a national shared result, coherent with European and international standards. The project suffered from an insufficient financing and from the varied Italian scenery, where regional soil survey services are entrusted to the good will of the individual regions, lacking a regulatory framework at national level.

Within a second phase of the project with a major investment, a further step should be to face harmonization problems, i.e. gain a better comparability of results and smoothen differences due to diverse assessment methodologies.

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1.43 | OVERVIEW OF THE RAPID CARBON ASSESSMENT PROJECT: DESIGN AND CONTERMINOUS U.S. SUMMARIES

Skye Wills[1*], Terrance Loecke[2], Stephen Roecker[3]

[1]National Soil Survey Center, Natural Resource Conservation Service, United States Department of Agriculture
[2]University of Kansas
[3]Natural Resource Conservation Service, United States Department of Agriculture, Indianapolis, IN.
Presenting author* skye.wills@lin.usda.gov

ABSTRACT

Soil organic carbon (SOC) is an important component of soils, landscapes, ecosystems and global carbon cycles. The RaCA project was designed to capture the range and total amount of soil organic carbon across the CONUS with information about variability and uncertainty. A multi-level stratified random sampling scheme was created to maximize geographical and spatial sample coverage, to maximize the number of conditions represented, and to give a framework for aggregating information into regional areas. At each site, 5 pedons were sampled to a depth of 100cm. Bulk density was measured where possible to 50cm and modeled for all other samples. SOC was measured as the difference between combustion (total) carbon and a calcimeter measure of inorganic carbon. Carbon stocks were then calculated using the fixed depth increment approach for 5cm, 30cm and 100cm. The overall distribution of SOC pedon stocks was skewed with an average 78.1 Mg ha^{-1} and very few high values 4000 Mg ha^{-1} to 100cm depth. The weighted mean stocks for CONUS were calculated to be 12.3 stdev 2.6, 43.5 stdev 2.2 and 73.5 stdev 2.2 Mg ha^{-1} for 5cm, 30cm and 100cm respectively. Region and land use/cover averages follow expected trends. Regions with cool wet climates have the highest mean SOC stocks (up to 181.7 Mg ha^{-1} to 100cm) while the lowest regions (as low as 25.9 Mg ha^{-1} to 100cm) have hot dry climates. Wetlands have the highest (260 Mg ha^{-1} to 100cm) values of SOC stocks while rangelands (areas managed for grazing with no agronomic inputs) have the lowest stocks (50.6 Mg Mg ha^{-1} to 100cm). The statistical framework of the RaCA project allows for statistically valid calculations of average and total stocks with known error and uncertainty. It also allows for comparisons between land use/cover types and regions.

Keywords: Soil Organic Carbon, Carbon Stocks, Carbon Mapping

INTRODUCTION

Soil organic carbon (SOC) is an important component of soils, landscapes, ecosystems and global carbon cycles. SOC influences soil physical, chemical and biological properties which are important to multiple ecosystem services including food production, hydrology and nutrient cycling (Adhikari and Hartemink, 2016; MEA, 2005).

METHODOLOGY

The Rapid Carbon Assessment (RaCA) project was designed to capture the range and total amount of soil organic carbon across the CONUS with information about variability and uncertainty. A multi-level stratified random sampling scheme was created to maximize geographical and spatial sample coverage, the number of conditions represented, and give a framework for aggregating information into regional areas. The complete relevant project population includes all lands for which the U.S. Soil Survey (SSURGO) maps had been created in the conterminous United States as of January 2012 (Soil Survey Staff, 2013).

The first-level strata were based on the Soil Science Division's major land resource area (MLRA) regions for logistical reasons. Within each of the 17 RaCA regions, sampling was further stratified by information related to soils and land use-land cover. Soils were grouped with an algorithm (Wills *et al.*, 2013) by expected SOC stocks (total mass of carbon to a depth of 1 meter). Land use-land cover (LULC) classes were developed to coordinate with classes and definitions of the National Resources Inventory (NRI) (USDA, 2007) and to associate with classes from the national land cover dataset (NLCD) (Fry *et al.,* 2011). The combination of SSURGO soil groups and NLCD LULC classes was termed LUGR and a gridded/raster version was used to spatially weight and map SOC stock coverage (Fig 1).

Within the region and soil group - LULC strata, the NRI sampling framework (Nusser *et al.*, 1998) was used to distribute samples. The primary sampling units of NRI are arranged randomly within geographic strata in a way that provides complete coverage of the CONUS. For each selected site, five pedons were sampled in a fixed arrangement; one pedon was located in the center of the plot and the others 30m away in each cardinal direction (occasionally modified somewhat based on accessibility and conditions).

Each pedon was described and assigned a likely taxonomic class and soil series given the information available. Minimum required information for each horizon included: horizon designation, depths, color, texture, rock fragment modifier (percent coarse fragments by volume), redoximorphic features, and structure (where possible). Small pits were excavated to a depth of 50 cm or to a root-limiting layer, such as bedrock or cemented soil, and probes or augers were used to sample 50 to 100cm. Samples were collected from the surface to a depth of 5 centimeters and from 5 to 100 cm centimeters by genetic horizon. Volumetric samples were collected for samples from the surface to a depth of 50 cm in the most appropriate manner. Samples were labelled, sealed in air-tight bags, and transported to the regional soil survey office for processing.

All mineral samples were scanned using a LabSpec 2500 visible-near infrared (VNIR) Spectrometer. Each region had an identical VNIR and measured both reference samples and high/low quality control samples to maintain consistency and comparability across regions. Both Sequeira *et al.* (2014a) and Wijewardane *et al.* (2016) present models that can be used to predict SOC from the RaCA scans. Organic horizon samples and samples from central pedons were sent to the Kellogg Soil Survey Laboratory.

Soil organic carbon was taken as the difference between total carbon (measured by combustion) and inorganic carbon (measured as calcium carbonate equivalence) according to the Soil Survey Laboratory Methods Manual (Burt *et al.*, 2004). Bulk density was calculated for all samples with sample volume and modelled using the random forest approach described by Sequeira *et al* (2014b) using generalized horizon designation, textural class, depth for each sample and neighboring sample data. In this implementation, two models were created: one for organic samples (horizon master nomenclature 'O') and another 'overall' model for mineral samples.

Initial SOC stock calculations were completed for those samples with laboratory SOC data using the fixed depth increment approach (Ellert *et al.*, 2008) to depths of 5, 30, and 100cm. Summaries were done on log transformed values. After aggregating pedons by classes, all values were weighted based on the extent using LUGR (combination of soil and land use/cover) and then back-transformed for presentation. Thus the number reported represent geometric means. All calculations were done in R (R Core Team, 2016) and maps were made with ArcGIS (ESRI Inc. Redding, CA USA). A full description of the sampling scheme, sample collection instructions, bulk density modeling and R scripts used in analysis can be found at the Rapid Carbon Assessment website https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054164/.

RESULTS AND DISCUSSION

Calculating accurate stock summaries is complicated by the distribution of SOC concentrations and stocks across pedons. SOC concentrations ranges from in 20 - 55% in O horizons to below detection limits (< 0.0001%) in some E and C horizons. The overall distribution of SOC pedon stocks is skewed with an average 78.1 Mg ha^{-1} and very few high values 4000 Mg ha^{-1} to 1m depth. The weighted mean stocks for CONUS were calculated to be 12.3 stdev 2.6, 43.5 stdev 2.2, and 73.5 stdev 2.2 Mg ha^{-1} for 5cm, 30cm and 1m respectively.

Wetlands have consistently higher levels of SOC stocks across depth increments evaluated. For all LULC classes, the majority of carbon is stored within the upper 0 – 5 cm of the soil with only small differences between them (Fig 2). Wetlands store more carbon with depth than other land use-land cover types. Near the surface (0 – 5cm), forest lands (27.8 Mg ha^{-1}) have SOC stocks nearly as great as wetlands (34.2 Mg ha^{-1}). At greater depths however, wetlands (260 Mg ha^{-1} to 1m) have more than twice the carbon stocks of other LULC classes (50 - 102 Mg ha^{-1} to 1m) and account for almost 30% of the carbon stocks while only covering 5% of CONUS. Rangelands (areas managed for grazing with no agronomic inputs) have the lowest stocks at all depth increments (50.6 Mg ha^{-1}).

Regional distributions of SOC stocks support expected trends (Fig 1). Stocks were greatest in those regions with cool wet, climates and lowest in hot, dry climates. Shows the distribution of SOC stocks mapped using soil group and LULC classes. Several known geographic features are clearly visible, even when they cross regions used for sample stratification and aggregation. The sand hills are visible near the center of CONUS with noticeably low SOC stock values. The Sand Hills are a surficial geomorphic unit of eolian deposits (Ahlbrandt *et al.*, 1980) characterized by shallow, poorly developed soils. Their low SOC stock content is expected. Conversely, very high values are apparent in wetlands present in wet humid portions of the southeast, in coastal wetlands along the east coast and in closed depressions in the north-central portion of CONUS.

CONCLUSION

The RaCA project collected soil organic carbon stocks across CONUS at one point and time. The sample sites were spread across all land use and soil conditions in this area. The statistical framework allows for comparisons between land use/ cover types and regions. It will also allow for statistically valid calculation of total stocks with known error and uncertainty.

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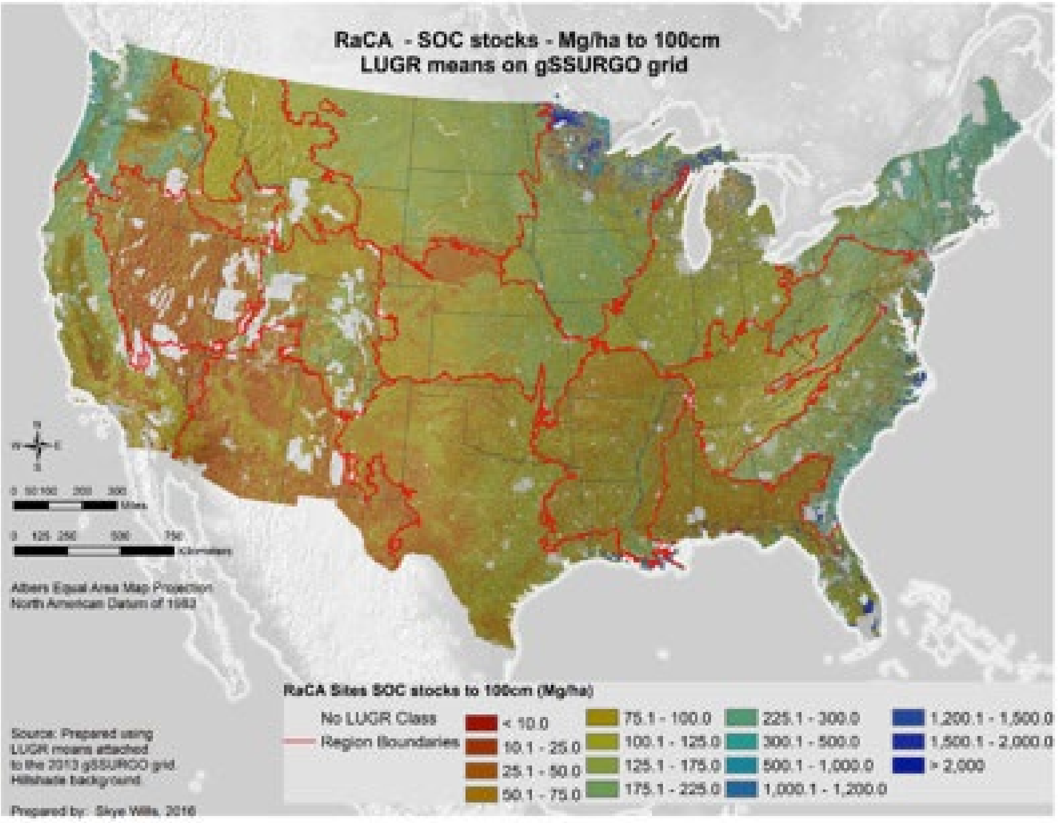

Fig. 1. Soil organic carbon stocks for the conterminous United States produced using RaCA protocols.

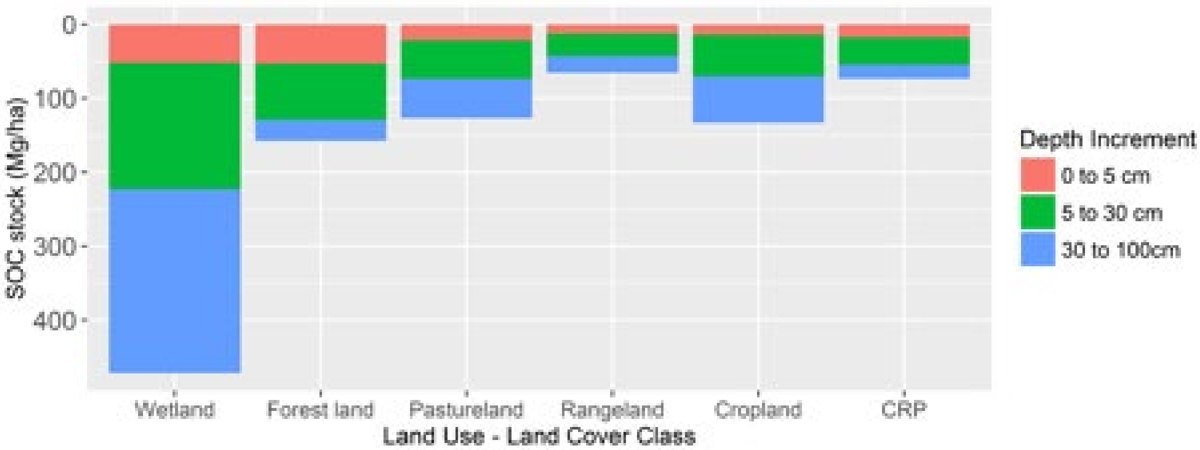

Fig. 2. Soil organic carbon stocks for the conterminous United States produced using RaCA protocols.

1.44 | SPATIAL ASSESSMENTS FOR THE MAPPING AND MONITORING OF SOIL ORGANIC CARBON: USING STAKEHOLDER ENGAGEMENT PROCESSES

Tor-Gunnar Vågen[1], Leigh Ann Winowiecki[2*], Constance Neely[3], Sabrina Chesterman[4], Mieke Bourne[5]

[1*]World Agroforestry Centre (ICRAF), t.vagen@cgiar.org, Nairobi, Kenya
[2]World Agroforestry Centre (ICRAF), l.a.winowiecki@cgiar.org, Nairobi, Kenya
[3]World Agroforestry Centre (ICRAF), c.neely@cgiar.org, Nairobi, Kenya
[4]World Agroforestry Centre (ICRAF), s.chesterman@cgiar.org, Nairobi, Kenya
[5]World Agroforestry Centre (ICRAF), m.bourne@cgiar.org, Nairobi, Kenya

ABSTRACT

Land degradation impacts the health and livelihoods of about 1.5 billion people worldwide. Given that the state of the environment and food security are strongly interlinked in tropical landscapes, the increasing need for land for food production, urbanization and other uses pose several threats to sustainability in the long term. There is increasing recognition that more integrated approaches to ecosystem health assessments are needed to meet the targets of the 2030 Agenda, including SDG 15.3. In addition to systematic and reliable biophysical and socio- economic assessments, stakeholder engagement with evidence is crucial. This paper demonstrated the integration of land and soil health maps with socio-economic datasets into an online, open-access the Resilience Diagnostic and Decision Support Tool using the SHARED approach in Kenya. This highlights the utility spatial assessments of SOC for monitoring of LDN compliance, understanding the drivers of SOC dynamics, and inclusion in stakeholder decision-making. The main objectives of this paper were to: 1) demonstrate the application of a systematic approach for land health assessments, including spatial mapping of soil organic carbon; 2) demonstrate the operationalization of interdisciplinary framework for assessing ecosystem health; and 3) showcase the application of evidence-based tools for stakeholder engagement using the SHARED approach.

Keywords: soil organic carbon, stakeholder engagement, remote sensing

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The 2030 Agenda, including multi-lateral environmental agreements and the Sustainable Development Goals (SDGs), has set the stage for greater appreciation and understanding of the complex nature and interaction among issues facing society. SDG 15 calls for the protection, restoration and promotion of sustainable use of terrestrial ecosystems, sustainably managed forests combatting desertification, halting and reversing land degradation and halting biodiversity loss. At their core, Land Degradation Neutrality (LDN) and SDG 15 necessitate healthy ecosystem function and resilient landscapes which underpin healthy economies and societal well-being. Because these aspects are intrinsically inter-related, decisions around soil and land cannot be taken in isolation. Achieving the associated targets, requires a) a robust evidence base for measuring and monitoring land health indices and associated land management practices; b) local and policy level awareness of the importance of land health in supporting multiple sectors; c) local capacity to implement the monitoring and assessments of these indicators; and d) mechanisms for integrated, cross-sectoral coordination and inclusive, multi-stakeholder collaboration for prioritizing actions to achieve impact.

Many assessments of land health suffer from (i) disagreements about the definition of land degradation/ land health; (ii) a conundrum of indicators that are often not feasible to measure and hence operationalize, and (iii) a lack of rigorous science-based analytical frameworks. Indicators are critical when assessing environmental conditions and progress made towards the mitigation or avoidance of land degradation, but they are also important to effectively communicate information both to stakeholders such as farmers or advisory services, and to policy makers. Indicators for assessment and monitoring of land health should be a) science based; b) readily measurable (quantifiable); c) rapid; d) based on field assessment across multiple scales (plot, field, landscape, region) and e) representative of the complex processes of land degradation in landscapes. Furthermore, there is a critical need for efforts to operationalize monitoring frameworks for assessment of land health, including robust analytical frameworks that explicitly incorporate scale dependencies.

The Land Degradation Surveillance Framework (LDSF) is an example of a method that has been applied in a number of projects in the global tropics to provide more rigorous, science-based, assessments of land degradation risk and status, as well as soil health (Vågen *et al.*, 2013c). An important indicator of soil health is soil organic carbon (SOC), and field datasets collected using the LDSF have been used to provide spatially explicit assessments of land degradation processes such as soil erosion and SOC, among other soil properties across landscapes (Vågen *et al.*, 2016; Vågen, Davey and Shepherd, 2012; Winowiecki, Vågen and Huising, 2016; Winowiecki *et al.*, 2016). These assessments can be used to inform spatially explicit land and soil health monitoring systems, which are critical in order for countries to avoid land degradation, or to restore already degraded ecosystems. Combining systematic data collection efforts with rigorous analytical frameworks, evidence-based approaches have the opportunity to engage stakeholders with interactive online user-friendly platforms to inform national and international policy makers.

Within this context, the engagement of stakeholders becomes an important element to prioritize investment strategies for accelerating sustainable development goals. The Stakeholder Approach to Risk-informed and Evidence-based Decision-making (SHARED) emerged in response to this need and was developed around a number of key factors, steps and principles, including: a) advancing a holistic or systems view to raise awareness on the integrated nature of environmental, social, cultural and economic dimensions and causal relationships; b) establishing a clear understanding of the influencing factors of human and group decision making including stakeholder analysis; c) facilitating different government sectors and multi-stakeholder platforms of diverse societal sectors; d) collectively articulating mutually agreed, desired sustainable development outcomes and indicators building upon fundamental ecosystem services and nested within national and global goals, e) generating evidence and experience and tailoring tools in a readily consumable way problem solving and options identification, f) testing options based on collectively defined criteria, including risks and potential synergies and g) designing option implementation with monitoring and evaluation and co-learning feedback into the process.

This paper demonstrates the integration of land and soil health maps with socio-economic datasets into an online, Resilience Diagnostic and Decision Support Tool in Kenya. The main objectives of this paper were to: 1) demonstrate the application of a systematic approach for land health assessments, including spatial mapping of soil organic carbon; 2) demonstrate the operationalization of interdisciplinary framework for assessing ecosystem health; and 3) showcase the application of evidence-based tools for stakeholder engagement using the SHARED approach.

METHODOLOGY

This paper uses data from a network of Land Degradation Surveillance Framework (LDSF) (Vågen *et al.*, 2013) sites in the global tropics. The LDSF was designed for practical and cost-effective soil and ecosystem health surveillance, and for mapping soil organic carbon (SOC) and soil erosion prevalence, in particular (Vågen *et al.*, 2013; Vågen *et al.*, 2012; Vågen and Winowiecki, 2013; Winowiecki *et al.*, 2016). The framework is also designed for monitoring changes over time, and provides opportunities for targeting improved soil management and land restoration activities. Specifically, the LDSF systematically assesses several ecological metrics simultaneously at four different spatial scales (100 m^2, 1000 m^2, 1 km^2, 100 km^2), using a spatially stratified, hierarchical sampling design (Vågen *et al.*, 2013). The LDSF also applies the latest soil infrared (IR) spectroscopy technologies in analysis of SOC and other soil properties, which are cost effective and hence allow for the scaling of soil measurements.

About 21,000 georeferenced soil samples were analyzed for SOC at the ICRAF Soil and Plant Diagnostics Lab in Nairobi, Kenya. A subset consisting of 70% of the samples were used to develop a predictive model for SOC based on remote sensing data from the MODIS platform in the current study. The accuracy of the prediction model was assessed using the remaining 30% of the samples, representing an independent validation or test dataset. The prediction model was applied to an annual composite MODIS image for 2012 and a map of SOC stocks was generated for Kenya.

ICRAF GeoScience Lab is actively developing interactive dashboards as a data-driven platform to integrate existing and new data and to provide robust data management and graphical tools to allow users to interact with these data in a meaningful way. The Landscape Portal (landscapeportal.org) is ICRAF's interactive online spatial data storage and visualization platform. It comes with a rich set of features to store, document, search and retrieve, and visualize spatial data and maps. By applying advanced data visualization and actionable data, these dashboards help facilitate communication of data and analysis between scientists and stakeholders. This will then allow for interrogation of evidence and increase the rate of discovery and help contextualize the data used. The dashboards are designed as an integrated part of the SHARED approach, which ensures that the tools developed are firmly embedded in a strong facilitation process. Recently, the created an interactive dashboard for Turkana County in Kenya, the Resilience Diagnostic and Decision Support Tool was developed.

To foster the innovation required for land health assessments, we use the Stakeholder Approach to Risk-informed and Evidence-based Decision-making (SHARED) approach to shape and embed evidence into inclusive negotiation and decision-making processes. SHARED is a comprehensive framework tailored to specific decision needs; it brings together processes, evidence and tools to shift the decision paradigm towards more inclusive, inter-sectoral and inter-institutional integration to tackle complex decisions and achieve desired outcomes. This targeted facilitation ensures cohesive communication across multiple institutions, political levels and knowledge systems to build capacity and the evidence-base as a continuously linked process, within the same development outcome pathway. At the national level, the SHARED approach has been used in collaboration with Kenya's Ministry of Environment and Natural Resources and the Ministry of Agriculture, Livestock and Fisheries to synthesise the evidence of 44 integrated crop-livestock-tree system projects to develop recommendations for climate-resilient approaches (Chesterman and Neely, 2015) and to directly inform the drafting of Kenya's National Climate Change Policy Framework (Neely, 2014).

RESULTS

Soil organic carbon (SOC) stocks were mapped for Kenya at 500m spatial resolution (Figure 1) and used to estimate SOC stocks for the country (Minasny *et al.*, 2017). Based on this analysis, Kenyan soils store approximately 2.4 Gt carbon (C) in topsoils at 0 to 30 cm depth, on average. The lowest estimated C stocks are found in arid and semi-arid regions of the country, as expected. Higher SOC stocks are found in sub-humid and humid parts of the country, such as in the central highlands and in western parts of the country, with the highest SOC stocks found in forest systems, such as around Mt Kenya, the Aberdares, the Mau Forest Complex and Kakamega forest. Also, wetland ecosystems are critical SOC pools in Kenya and in much of East Africa, including inland riverine and palustrine wetland systems. In the drylands, such wetland systems are critical for SOC stocks, frequently reaching between 80 and 100 at 0 to 30cm depth. Other wetland systems, many of them under threat, such as around the Rift Valley lakes and lacustrine wetlands along Kenya's coast are also examples of ecosystems that are critical for C storage in the country.

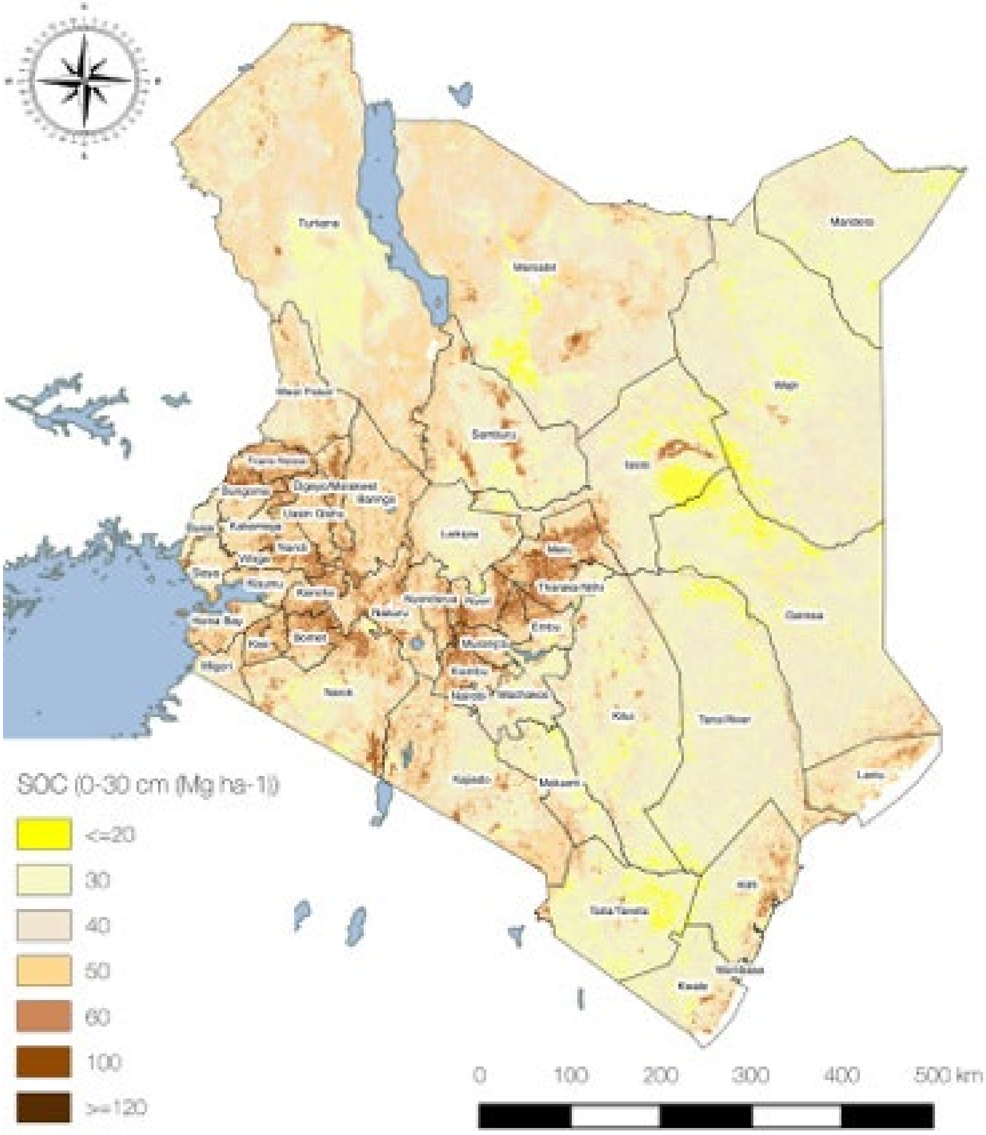

Figure 1. Soil organic carbon (SOC) stock map of Kenya at 500m resolution (for 2012).

DISCUSSION

Through the application of systematic field and lab measurement protocols, spatial assessments of SOC can be made at multiple spatial scales with unprecedented accuracy and spatial coverage. Figure 1 shows estimated SOC stocks for Kenya for the year 2012 (Vagen *et al.*, in prep). As is evident in this map, SOC stocks are low, particularly in degraded areas of the arid- and semi-arid (ASAL) regions of the country. Without such spatial assessments, the distribution of degraded areas and the severity of the degradation both remain poorly understood, hampering efforts to restore SOC and soil health. Further, by systematically assessing land health at scale, restoration efforts can also be scaled appropriately through assessments of the actual restoration potential of a given area.

CONCLUSIONS

Decision support tools increase the utility of soil and land health assessments by providing users with both interactive dashboards that allow them to map and interact with data and analytical tools for land health diagnostics and targeting of interventions. Through the application of open source platforms and tools, the use of evidence in land health management can also be effectively mainstreamed. In the context of the SHARED approach, this process is enhanced through structured stakeholder engagement and co-learning.

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1.45 | SOIL SPECTRAL LIBRARIES FOR MONITORING AND REPORTING ON SUSTAINABLE DEVELOPMENT GOAL INDICATORS IN NORTHERN GREECE

Nikolaos L. Tsakiridis[1], Nikolaos Tziolas[2], George Galanis[3], Eyal Ben-Dor[4], George C. Zalidis[2, 3,*]

1 Automation and Robotics Laboratory, Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Thessaloniki 54214, Greece; Tel.: +302310996377; E-mail: tsakirin@ece.auth.gr
2 Laboratory of Remote Sensing, Spectroscopy, and GIS, Faculty of Agriculture, Aristotle University of Thessaloniki, Thessaloniki 54214, Greece; Tel.: +302310991779; E-mail: ntziolas@agro.auth.gr, zalidis@agro.auth.gr
3 Interbalkan Environment Center, 18 Loutron Str., Lagadas, Greece; Tel.:+302394023485; E-mail: info@i-bec.org
4 The Remote Sensing Laboratory, Department of Geography and Human Environment, Tel-Aviv University, P.O. Box 39040, Ramat Aviv, 69978 Tel-Aviv, Israel; Tel.: +972036407049; E-mail: bendor@post.tau.ac.il

ABSTRACT

In this paper, we present a case-study of utilizing vis-NIR spectroscopy to estimate the content of Soil Organic Carbon (SOC) remotely in Northern Greece. In this agricultural area, SOC plays a pivotal role in the physical, chemical, and biological function of the soils and hence requires rapid and in situ analysis. 474 Entisol soil samples were collected from the two top soil horizons. The wet analytical evaluation of SOC using the Walkley-Black method yielded an average of 0.6599%, with a standard deviation of 0.3908%. The reflectance spectra of these soils were acquired across the vis-NIR region (350-2500 nm) in the laboratory using a standardization protocol. For the chemometric analysis, three pre-processing methods were considered, namely the absorbance transformation, the continuum removal, and the first-derivative. We used two state-of-the-art machine learnings algorithms (Partial Least Squares Regression and Cubist), to estimate the SOC from the spectra. The best results were achieved using the first derivative, by the Cubist algorithm, where an RMSE of 0.1174% was achieved. These results indicate that precise mapping of SOC can be achieved with vis-NIR spectroscopy, facilitating the regular updating of SOC maps for sustainable agriculture, in line with the Sustainable Development Goals 2.4 and 15.3.

Keywords: soil spectral library, soil spectroscopy, soil organic carbon, precision agriculture, vis-NIR spectroscopy, reduced input agriculture

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Soil Organic Carbon (SOC) plays a crucial role in agro-ecosystem function, influencing the productive potential of the soil and water holding capacity. The United Nations Statistical Commission's Interagency and the Expert Group on Sustainable Development Goals (SDGs) Indicators agreed on "Proportion of agricultural area under productive and sustainable agriculture" and "Proportion of land that is degraded over total land area" as indicators to monitor the SDG 2.4 and 15.3 targets, respectively. Reliable, accurate and timely information of SOC stocks at a variety of scales, would help for monitoring and reporting progress towards the implementation of the SDG targets.

However, many countries have significant gaps and great level of fragmentation in infrastructure to monitor and report these indicators. Building capacity in this regard, provides essential knowledge to farmers, environmental policy makers and regional stakeholders, enabling enhanced decision making and effective management of natural resources.

The purpose of this paper is to highlight the use of vis-NIR spectroscopy to accurately estimate the SOC of soil samples in a regional soil spectral library and simultaneously overcome the shortage of soil data in Greek territory. In particular, only few and sporadic spectra have been recorded in the latest attempt for the development of a global soil spectral library (SSL) (Viscarra Rossel *et al.*, 2016), as well as in the European LUCAS spectral library (Tóth, Jones and Montanarella, 2013).

Recently, soil spectroscopy has emerged as a fast, simple, and relatively inexpensive way to estimate the physical and chemical properties of soil samples (Nocita *et al.*, 2015). Among the most commonly employed applications of soil spectroscopy, is the estimation of SOC (or soil organic matter), which has proven to be accurately estimated.

Several papers have already assessed SOC from spectra, but the models are not robust and it is essential to generate different models for each area. This is mainly because SOC is a complex material composed of varying molecules, strongly dependent on the environmental conditions within the field in question.

The objective of this work is thus to assess the ability of vis-NIR spectroscopy to accurately estimate SOC using a vast soil spectral library generated recently in Greece and demonstrate its potential usage. The derived models can be used to map the SOC of the entire region without the necessity to measure SOC directly in the laboratory and save time and money. To this end, two state of the art machine learning algorithms were used to correlate the input vis-NIR spectra with the observable values of SOC. The predictive accuracy of the derived models was investigated, to identify the best model.

METHODOLOGY

Initially, a soil spectral library was developed comprised of 474 Entisol soil samples (~250g) from soil horizons A (0-30 cm) and B (30-60 cm). These soil samples were collected from the agricultural lands surrounding the Nestos river delta, in the Eastern Macedonia and Thrace region, located in northern Greece. The Nestos river delta spans a region of roughly 300 square kilometers. From 235 different sampling points both layers A and B were sampled, while from 4 sampling points only the top layer was sampled.

The collected samples were subsequently divided into two equal parts. The first half was sent to a chemical laboratory, which measured SOC using the Walkley-Black method, and yielded an average of 0.6599%, while the standard deviation was 0.3908%. The distribution is positively skewed (1.03). The second half of the soil sample was air dried, and gently crushed to pass through a <2 mm sieve. It was subsequently placed into a dark chamber, and its reflectance spectrum in the vis-NIR region (350-2500 nm) was collected. The PSR+ spectrometer from Spectral Evolution was used, which covers the 350-2500 nm range using a spectral resolution of 3 nm at 700 nm, 8 nm at 1500 nm, and 6 nm at 2100 nm. It further provides a data output with a 1nm sampling resolution. A standardization procedure was applied to correct from potential nonsystematic and systematic spectral variations (Kopačková and Ben-Dor, 2016).

Initially, the 5 first principal components (explaining 99.53% of the variance) of the reflectance spectra were used, in order to calculate the Mahalanobis distance of each spectrum. Using the cumulative chi-squared distribution, and by applying a threshold of 97.5%, 27 outliers were identified and removed from the dataset. Thus, the soil spectral library considered in this study was comprised of a total of 447 soil samples.

The recorded reflectance spectra were then pre-processed using the following independent methods: 1) the (pseudo) absorbance transformation (log(1/reflectance)), 2) the continuum removal of the reflectance spectra, and 3) the first-derivative of the reflectance spectra using a Savitzky-Golay filter of width 7. To these 4 datasets (including the initial reflectance spectra), two algorithms were applied, namely Partial Least Squares Regression (PLSR), and the Cubist algorithm (Quinlan, 1993) to correlate the input spectra with the output SOC. The R package caret (Kuhn, 2008) was used to apply these algorithms.

Two sets of experiments were considered. Initially, a 5-fold cross-validation experiment was conducted. Thus, one fold was kept for testing the performance of the model, and the rest 4 folds comprised the training set. This was repeated 5 times, with each of the fold used once as a testing test. For each training dataset, an internal repeated 10-fold experiment (with 5 repetitions) was used to determine the based parameters of the algorithms (the latent variables for PLSR, and the number of committees and neighbors for Cubist).

In the second set of experiments, the dataset was split into two parts using the Kennard-Stone algorithm (Kennard and Stone, 1969); 2/3 of the dataset were used to build the model, and 1/3 to validate it. The distance metric used was the

Mahalanobis distance computed over the principal components' space. Once again, to select the optimal set of parameters for both the algorithms, a repeated 10-fold experiment was conducted.

To compare the generated models, the following measures were calculated in the independent test set (y_i is the SOC of the i-th sample, $\widehat{y_i}$ is the predicted SOC for the i-th sample, and $\bar{y}$ is the mean SOC of all samples):

$$R^2 = 1 - \frac{\sum_i (y_i - \widehat{y_i})^2}{\sum_i (y_i - \bar{y})^2}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (y_i - \widehat{y_i})^2}{N}}$$

RESULTS

The performance of the algorithms using as predictors the different sources is presented in Table 1. We note that for the cross-validation experiment, the average results in the testing (prediction) dataset across the folds are presented. For PLSR, the average number of latent variables (LV) is also given. Furthermore, for the Cubist algorithm the average numbers of committees and neighbours are depicted. The results of the best model for both experiments and both algorithms were derived using as a source the first derivative of the reflectance spectra. The models developed by Cubist tend to be more accurate, with an average RMSE of 0.1718 compared to an average RMSE of 0.2377 for the first experiment, and an average RMSE of 0.2410 compared to an average RMSE of 0.2467 when Kennard-Stone was used. With an RMSE of 0.1174 the model created by the Cubist algorithm using the first derivative spectra as the predictors, exhibit the best predictive accuracy.

5-fold cross-validation

	PLSR			Cubist			
	2	RMSE	LV	2	RMSE	Committees	Neighbours
Reflectance	0.6053	0.2460	10.2	0.7977	0.1761	18.0	0.0
Absorbance	0.6359	0.2363	13.0	0.7714	0.1872	18.0	5.4
Continuum Removed	0.6192	0.2416	13.2	0.7220	0.2064	16.0	0.0
First derivative	0.6638	0.2270	11.4	0.9102	0.1174	16.0	9.0

Splitting with Kennard-Stone

	PLSR			Cubist			
	2	RMSE	LV	2	RMSE	Committees	Neighbours
Reflectance	0.6081	0.2450	10	0.6147	0.2430	20	0
Absorbance	0.5770	0.2537	10	0.6024	0.2469	20	0
Continuum Removed	0.5914	0.2471	12	0.6043	0.2463	20	0
First derivative	0.6216	0.2409	9	0.6613	0.2279	20	9

Table 1: Results of the derived models for both set of experiments

DISCUSSION

The above results underscore the fact that vis-NIR spectroscopy can effectively estimate the SOC content. The significant difference between the models generated by PLSR and Cubist is attributed to the fact that Cubist employs boosted regression trees, i.e. an ensemble of models, each creating local models, while in contrast PLSR is a single global model. Moreover, the 5-fold cross-validation experiment generated better results over the use of the Kennard-Stone algorithm. This is attributed to the following reasons: a) when a 5-fold cross-validation experiment is considered, more percentage of the dataset is used in each fold to build the model (80% compared to 66.6%), thus more variance is covered, and b) the Kennard-Stone algorithm has been shown to not always optimally represent the initial vis-NIR distribution (Ramirez-Lopez *et al.*, 2014).

CONCLUSIONS

By utilizing vis-NIR SSLs and deploying state-of-the-art machine learning methods, essential information can be extracted in order to promote the development of an integrated Nexus framework, supporting the strengthening of capacities in the areas of food security monitoring and adaptation to climate change.

Forthcoming relevant activities and outcomes envisaged will be in the direction of extending, improving and strengthening the vision for a global SSL. Especially, in less developed countries, where monitoring systems for SOC, spanning from the absolute absence of monitoring capacities to the execution of timely and high cost field campaigns.

A further step that could be conducted, to ascertain that the model is working correctly, is to compare the spectral assignments of the model with the spectral regions that SOC influences the most, as reported in the literature. In this context, the encoded information could be the basis for new developments based on Micro Electro Mechanical Systems technology, in order to revolutionize the agricultural sector by providing more cost-efficient and targeted tools.

As future work, using the best model created, it would be possible precisely map the SOC of the region using only the vis-NIR spectra of the soil samples. A common spectral library enabling data interoperability and comparability, might help to regularly update digital soil mapping products with better resolution.

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1.46 | ESTIMATION OF SOIL ORGANIC CARBON STOCKS IN THE NORTHEAST TIBETAN PLATEAU

Ganlin Zhang, Renmin Yang

State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Soil Science, Nanjing 210008, China
E-mail: glzhang@issas.ac.cn

ABSTRACT

Soil organic carbon in cold areas is more vulnerable to climate change and my form a positive feedback to air temperature increase. In the Tibetan Plateau, alpine grassland is the most widespread ecosystem and plays an important role in the storage of SOC. Therefore, there is a need for accurate estimate of soil organic carbon (SOC) stocks for understanding the role of alpine soils in the global carbon cycle.

The study area is located in the northeast of the Tibetan Plateau (ca. 30000 km^2). We tested a method for mapping digitally the continuous distribution of the SOC stock in three dimensions. First, a step-wise exponential depth function was defined to describe SOC depth distribution, with four parameters. This depth function integrated the spatial distribution of the "mattic epipedon" which is a special surface horizon with intensive roots. Such topsoils rich in organic matter. It usually leads to a sharp decrease in SOC contents with depth. Consequently, a monotonic decreasing function may result in an unrealistic distribution of SOC in the mattic epipedon because of high SOC content in topsoils. Second, a combined model of classification and regression analysis in random forest was applied for mapping parameters of soil depth functions using environmental covariates across the study area. Third, SOC stocks were predicted by using soil depth functions at each location.

The defined soil depth function provided a mean R^2 of 0.91 between the observed and fitted SOC content at calibration sites. Prediction models resulted in high prediction accuracy. The mean RMSE value of independent validation was 0.94 kg m^{-2}. By applying the predicted parameters of soil depth functions, we mapped the spatial distribution of SOC stocks across the study area. An average SOC stock in the mattic epipedon was estimated to be 4.99 kg m^{-2} in a mean depth of 14 cm. The average stock for the 0-30 cm layer was 5.54 kg m^{-2}, that of 6.11 kg m^{-2} for the 0-50 cm layer and 6.89 kg m^{-2} for the 0-100 cm layer. The amounts of SOC in the mattic epipedon, the upper 30 cm and 50 cm accounted for about 21 %, 80 % and 89 %, respectively, of the total SOC stock in the upper 1 m depth. By investigating the mattic epipedon, we were able to quantify the role of such an uppermost soil layer in storing SOC. Information on this layer is valuable for mapping the realistic distribution of SOC stocks in the Tibetan grasslands. Compared with previous estimates, our approach resulted in more reliable predictions.

THEME 2

MAINTAINING AND/OR INCREASING SOC STOCKS (FOSTERING SOC SEQUESTRATION)

2.1 | DEEP PLOUGHING MINERAL SOILS FOR SOC SEQUESTRATION

Viridiana Alcántara Cervantes[1,2*], Axel Don[2], Reinhard Well[2], Florian Schneider[2], Rolf Nieder[3]

1Food and Agriculture Organization of the United Nations, viridiana.alcantara@fao.org
2Thünen Institute of Climate-Smart Agriculture
3Technical University Braunschweig, Germany

ABSTRACT

Subsoils hold a large potential to store additional soil organic carbon (SOC) because of the large number of unsaturated mineral surfaces and environmental conditions that impede SOC decomposition. However, measures for enhancing SOC storage commonly focus on topsoils. This study assessed the long-term storage and stability of SOC in topsoils buried in arable subsoils by deep ploughing, a method of full-inversion tillage for breaking up hardpans and improving soil structure to optimize crop growing conditions. Beside translocating SOC formed near the surface into the subsoil, SOC-poor subsoil material is mixed into the 'new' topsoil by deep ploughing. Deep-ploughed croplands represent unique long-term in situ incubations of SOC-rich material in subsoils. In this study, we sampled five loamy and five sandy soils in Germany that were ploughed to 55–90 cm depth 35–50 years ago. Adjacent, similarly managed but conventionally ploughed subplots were sampled as reference. The deep-ploughed soils contained on average 42 ± 13% more SOC than the reference subplots. On average, 45 years after deep ploughing, the 'new' topsoil still contained 15% less SOC than the reference topsoil, indicating long-term SOC accumulation potential in the topsoil. A global meta-analysis of field trials examining the effect of deep ploughing on crop yields revealed 21% (14%–27%; 95% CI) higher yields after deep ploughing sites with root restricting soil layers. On sites without root restricting soil layers, the effect of deep ploughing on crop yields was highly variable. It can be concluded that deep ploughing can meliorate sites with root restricting soil layers while sequestering SOC by enlarging the storage space for SOC-rich material.

Keywords: subsoils, deep plowing, deep tillage, long-term field trials, SOC burial

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Even with a low SOC content, subsoils generally store more SOC than topsoils because mass of subsoils is generally many times higher than topsoil mass. Over 70% of the global SOC stocks are stored below 30 cm (Batjes, 2014). Especially because of the low SOC contents of subsoils, their potential to store additional SOC has been emphasized (Rumpel, Chabbi and Marschner, 2012). Subsoil SOC is considered to be highly stable because SOC radiocarbon age generally increases with depth (Gleixner, 2013). It has been widely suggested that subsoil has great potential to store additional SOC than topsoil (Lorenz and Lal, 2005) because of the large number of unsaturated mineral surfaces (Beare *et al.*, 2014) and environmental conditions that slow down SOC mineralisation, e.g. more constant moisture and temperature regime or oxygen limitation (Rumpel and Kögel-Knabner, 2011).

Subsoils have a yet untapped potential to contribute to SOC sequestration in managed soils and play an important role in climate change mitigation. Burial of SOC-rich soil material has been often recognised as an important element of terrestrial SOC sequestration (Chaopricha and Marín-Spiotta, 2014; Doetterl *et al.*, 2016). In this study we evaluated the option of actively burying SOC-rich soil material through deep ploughing and its effects on SOC stocks.

METHODOLOGY

Ten field sites were selected in which one part was deep-ploughed with a special mouldboard plough 36 to 48 years prior to sampling and the rest of the field was not deep-ploughed, serving as a control. The sites were located in Germany. Initially, the field trials were set up by the local Chamber of Agriculture between 1965 and 1978 as practice trials on different farmers' field sites.

Along the border of the deep-ploughed part of each site, we identified a deep-ploughed plot and a directly adjacent control plot in the non-deep-ploughed part of the field site. Each plot was 20 m by 40 m large. At five of the sites the soil texture was loamy and at the other five sites it was sandy. Deep ploughing depth was between 55 and 90 cm (Fig. 1). Peatlands and soils influenced by groundwater were excluded from the study.

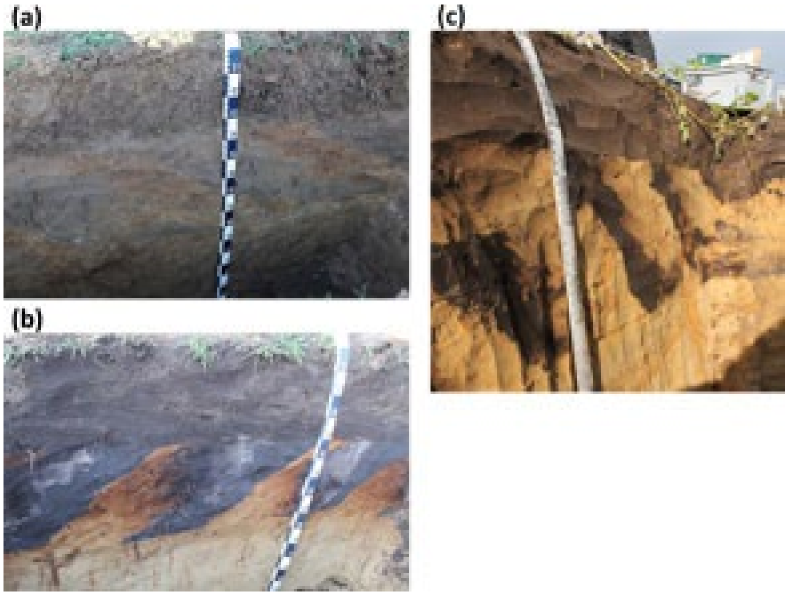

Fig. 1: Deep-ploughed soil profiles at a) one loamy site in Salzgitter-Ohlendorf, Germany, b) one sandy site in Hemmelsberg, Germany and c) one sandy site in Essemühle, Germany. Source: (Alcántara et al., 2016)

In order to account for subplot scale heterogeneity, 20 core samples were collected in the deep ploughed subplot and 15 in the reference subplot, using a soil auger (60 mm inner diameter; Nordmeyer Geotool GmbH, Berlin, Germany) driven by an electric jackhammer (Wacker EH 23, Wacker Neuson, Munich, Germany). The sampled depth increments included: i) the current ploughed horizon, ii) subsoil down to deep ploughing depth, iii) deep ploughing depth + 10 cm and iv) non-deep-ploughed subsoil down to 100 cm.

Core samples were dried at 65°C to constant mass and sieved to <2 mm. An aliquot of each sieved sample was milled in a planetary ball mill and analysed by dry combustion for total C and total N (TruMac CN LECO, St. Joseph, MI, USA). Samples with a pH value of >6 were analysed for carbonates after ignition of the sample at 450`C for 16 h in a muffle kiln. SOC content was then calculated by subtracting carbonatic C from total C. SOC Stocks for each depth increment were calculated according to (Poeplau, Vos and Don, 2017). To evaluate the overall effect of deep ploughing on SOC stocks, a linear mixed effects model was fitted by restricted maximum likelihood with tillage as a fixed effect with two levels (deep-ploughed vs. reference) and a nested random effect (sites nested within substrates 'loam' and 'sand'). One variance term per tillage substrate combination was applied using package *nlme* (Pinheiro *et al.*, 2016) in R. The p-value was obtained by conducting an F-Test with the Anova function (Chambers and Hastie, 1992).

In addition to the analysis of the effect on SOC stocks, the effect of deep ploughing on crop yields was assessed by a meta-analysis. For this, the Web of ScienceTM was screened combining following keyword searches: "yield", "deep ploughing", "subsoil" and/or "deep tillage". Only articles written in English or German were considered. German literature was complemented by scientifically sound grey literature from the 1960s to 1980s. Experimental sites were classified based on the presence of root restricting soil layers, namely either physical or chemical barriers for vertical root growth, which were either removed or disrupted by deep ploughing to >20 cm depth. Relative yield increase (*RY*) was calculated as the ratio between the yield on the deep ploughed plot ($Yield_{Deep}$) and the yield of its respective control ($Yield_{Control}$) in the same unit using the formula (Rosenberg, Rothstein and Gurevitch, 2013):

$$\ln(RY) = \ln\left(\frac{Yield_{Deep}}{Yield_{Control}}\right)$$

Further methodological details are documented in an article currently under review (Schneider *et al.*, 2017). The search resulted in 779 yield comparisons between deep ploughing and ordinary control tillage at 29 experimental sites. Most of the observations derived from short-term field studies documenting the effect of deep ploughing on the productivity of cereals (479 observations) and roots/tubers (217 observations) grown in temperate latitudes. About 20% of the observations derived from sites with root restricting soil layers (mostly dense clay or compaction).

RESULTS

Deep ploughing significantly increased SOC stocks in the long-term ($p<0.01$). On average, the SOC stocks were 42±18 Mg ha^{-1} higher in the deep-ploughed than in the control plots (Fig. 2).

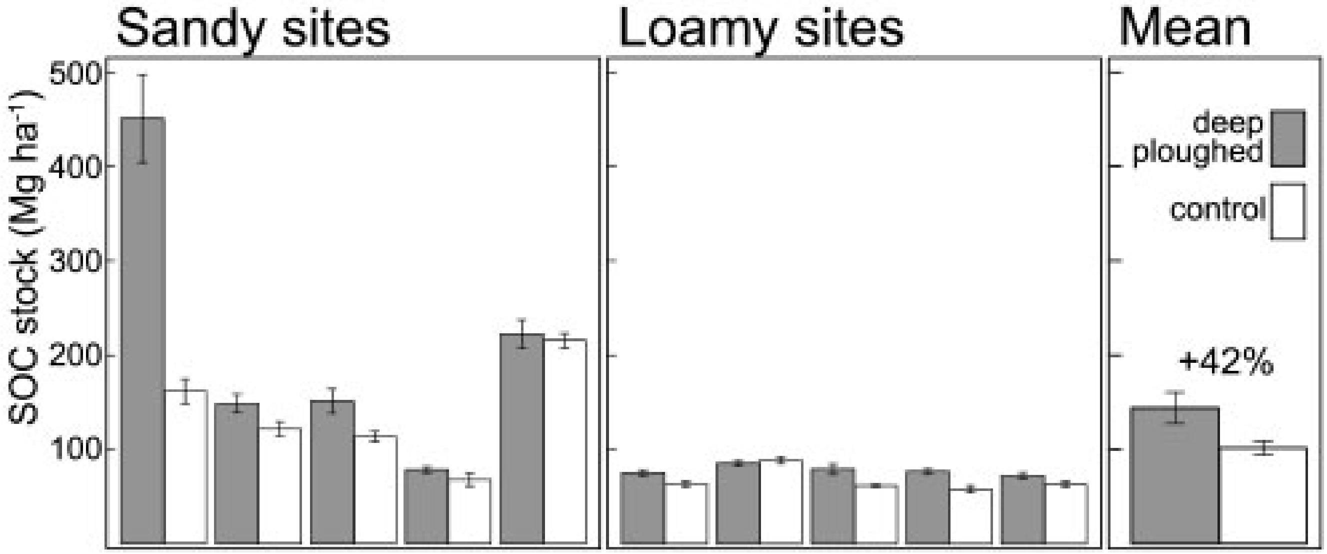

Fig. 2: SOC stocks down to 100 cm in deep-ploughed and control plots as determined from core sampling. Bars represent standard errors of the mean (n = 5 at each subplot and site). Source: (Alcántara et al., 2016)

The contribution of the subsoil (below the current plough horizon) to total SOC stocks in the reference soils was 23±3% at the sandy sites and 27±4% at the loamy sites. In the deep ploughed subplots, subsoil SOC contributed 45±8% and 38±4% to the total SOC stocks (0-100 cm) for sandy and loamy sites, respectively, indicating increased importance of the subsoil for SOC storage. After 45 years on average, the SOC stocks in the topsoil of the deep-ploughed subplots were 4 to 22% lower than in the reference topsoils. After the deep ploughing event, the new topsoil of the deep ploughed fields accumulated on average 0.4±0.1 Mg SOC ha^{-1} yr-1.

On average, deep ploughing slightly increased crop yields (+6%). However, this effect was not significant because of the large variability in the results (Fig. 3a). In about 40% of the observations yields were negatively affected by deep ploughing. Especially soils with > 70% silt content or poor nutrient availability in the newly established topsoil were prone to yield losses after deep ploughing. However, on sites with root restricting soil layers, deep ploughing significantly increased yields (Fig. 3b).

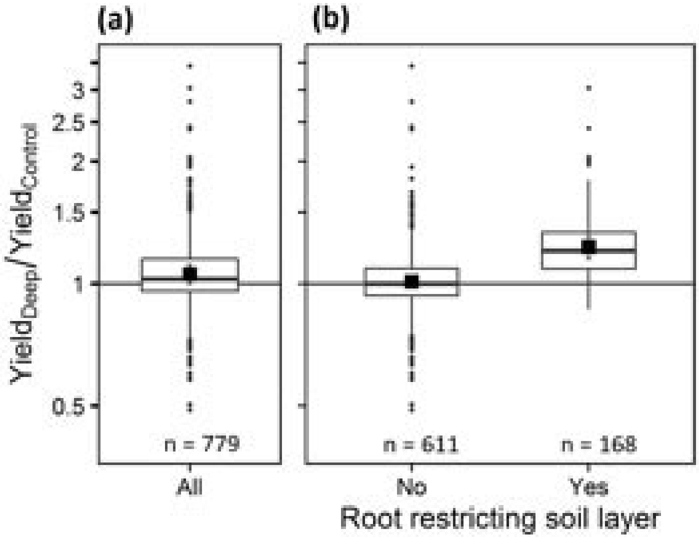

Fig. 3: Effect of deep ploughing on crop yield as derived from the meta-analysis (box plots and mean ± 95% confidence intervals). Values > 1 illustrate higher yields on deep ploughed plots compared to adjacent conventionally tilled control plots. (a) Overall effect on crop yield. (b) Effect on crop yield depending on the presence of a root restricting soil layers.

DISCUSSION

The impact of the active burial of large amounts of SOC on long-term C sequestration was found to depend on two main key aspects: (1) the stability against complete mineralisation of buried SOC in subsoil and (2) the additional SOC enrichment in the 'newly formed topsoils'. Since subsoil SOC stocks were higher in deep ploughed than in control plots at all study sites, it can be concluded that the decomposition of SOC at greater depth is hampered enabling a large degree of preservation. The currently largely debated factors that account for long-term stability of subsoil OC are:

- interaction with the mineral phase, such as clay and poorly crystalline minerals (Kleber *et al.*, 2005), which protects SOC against oxidative destruction (Rumpel and Kögel-Knabner, 2011),
- low probability of a decomposer to meet an SOC particle due to low SOC concentration (Don, Rödenbeck and Gleixner, 2013), i.e. low microbial density together with low microbial diversity (Agnelli *et al.*, 2004; Ekschmitt *et al.*, 2008),
- physical protection of occluded particulate OC in aggregates and microaggregates (Moni *et al.*, 2010; Rasmussen, Torn and Southard, 2005),
- low nutrient availability (Fierer *et al.*, 2003; Garcia-Pausas *et al.*, 2008),
- higher chemical recalcitrance of root derived C compared to litter derived C. Root input has been identified as one of the main sources for subsoil OC (Rasse, Rumpel and Dignac, 2005),
- missing availability of fresh C with a high bioenergetic yield (Fontaine *et al.*, 2007) and
- accumulation of chemically recalcitrant black C in subsoil horizons (Chabbi, Kögel-Knabner and Rumpel, 2009; Dai *et al.*, 2005), among others.

Although SOC is accumulated in the "newly formed" topsoil over time with the continuous, subsequent plant growth on top of the deep ploughed soil, at the sites studied, significant differences in topsoil SOC stocks between the non-deep-ploughed reference and deep-ploughed soil persisted even 48 years after the deep ploughing event. These results underscore, that while SOC losses may be very quick, SOC accumulation is regularly slow. Moreover, for topsoils, which are close to SOC saturation, further SOC sequestration potential can be tapped when exploring the subsoil resources.

Despite its potential for SOC sequestration, deep ploughing might only be applied on a larger scale if it does not impair soil fertility. Our meta-analysis suggests that deep ploughing often decreases nutrient availability in the topsoil, which warrants higher fertilizer application rates in the first years after deep ploughing. In soils with labile soil structure, e.g. soils from loess, deep tillage seems to decrease the plant-availability of nutrients and water stored in the subsoil which can be detrimental for crop growth. However, on sites with < 70% silt content and root restricting soil layers, deep ploughing has a large potential to meliorate the sites by facilitating deeper rooting and increasing crop yields (Schneider *et al.*, 2017). This could in turn promote SOC sequestration even further through enhanced allocation of C into greater soil depth and increased C input through crop residues.

CONCLUSIONS

Deep ploughing can be regarded as a feasible measure to bury SOC-rich topsoil thus sequestering SOC in subsoils because of their preservation at greater depth. The accumulation of SOC in the "newly formed" topsoil is the key factor for a full-profile enhancement of SOC stocks. Since this study was only conducted in Germany assessing two soil types, application in other soil types and climatic zones requires further research. Especially in soils with root restrictive layers and sandy soils, the effects of deep ploughing on SOC stocks and yield enhancements seem very promising.

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2.2 | FACTORS LIMITING SOC SEQUESTRATION BY NO-TILLAGE IN MEDITERRANEAN AGROECOSYSTEMS

Jorge Álvaro-Fuentes[1*], Daniel Plaza-Bonilla[1], José Luis Arrúe[1], Carlos Cantero-Martínez[2]

[1]Estación Experimental de Aula Dei, Spanish National Research Council (CSIC), Zaragoza, Spain

[2]University of Lleida, Lleida, Spain

[*]Contact email: jorgeaf@eead.csic.es

ABSTRACT

In Mediterranean areas, soil organic carbon (SOC) sequestration following the adoption of no-tillage (NT) may be affected by certain factors. In this study, the next three factors are presented and reviewed: (i) sequestration duration; (ii) soil depth distribution; and (iii) climate change impact. Sequestration duration was determined in a NT chronosequence established in 1990 in a conventional tillage field. Changes in SOC distribution along the soil profile were evaluated in three long-term tillage experiments established in 1987, 1989 and 1990, respectively. Climate change impact on SOC storage was evaluated with the Century model together with climate outputs from four climate change scenarios. The chronosequence showed that about 80% of the total SOC gained during the first 20 years after NT adoption occurred during the first 11 years. Furthermore, the three long-term tillage experiments showed that SOC gains under NT decreased with soil depth. The simulation of climate change conditions revealed that NT responded differently to climate change depending on the scenario selected. According to the findings of this study, the three factors reviewed should be taken into account in order to maximize the SOC sequestered and to evaluate the success of NT as a mitigation option in Mediterranean agroecosystems.

Keywords: Soil organic carbon sequestration; No tillage; Mediterranean agroecosystems; sequestration duration; climate change.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

In Mediterranean conditions, agriculture production is dependent on soil water availability for crop growth. Scarce annual rainfall together with high evaporation losses limit crop yields and determine the economical profit of the farm. Managing agricultural soils for soil water conservation has been a main motivation in these areas in which traditional practices based on intensive tillage and cereal monocultures have been carried out during decades. In certain Mediterranean areas, however, signs of change are being seeing in the practices adopted by farmers. In particular, the adoption of less disturbing tillage techniques is gaining popularity in some areas. These techniques have resulted interesting in terms of operation costs, reducing labour hours and tractor use, and also improving soil water conservation leading to the concomitant increase in crop yield and water use efficiency when intensive tillage is suppressed (Lampurlanés *et al.*, 2016). The increase in crop growth derived from the adoption of reduced tillage (RT) or no-tillage (NT) techniques may also have a significant impact on soil organic carbon (SOC) stocks in these areas. Under NT crop residues are left on soil surface and slowly incorporated into the soil resulting in the build-up of SOC in surface soil layers. In Mediterranean areas this C enrichment process following the adoption of NT could be altered under certain situations limiting the potential of this technique for SOC sequestration and, thus, for atmospheric CO_2 mitigation. According to this, in this study we reviewed the factors limiting NT to sequester SOC in Mediterranean agroecosystems. The next three main factors are presented in this paper: (i) sequestration duration; (ii) soil depth distribution; and (iii) climate change impacts.

METHODOLOGY

Data presented in this study were obtained from different experimental fields and also from the use of modelling tools. All the experimental fields were located in a representative Mediterranean area located in NE Spain (Ebro river valley) where climate is characterized by low annual precipitation (250-450 mm) and mean annual temperatures ranging from 13 to 15 ºC. In this area, the most frequent soil types are Aridisols, Inceptisols and Entisols (Álvaro-Fuentes *et al.*, 2011). Typical crops include winter cereals (mainly barley and wheat), grapes, olives and almonds.

Sequestration duration was determined in a chronosequence established in 1990 in a conventional tillage (CT) field in which mouldboard ploughing had been the main tillage implement for more than 40 years. From 1990 to 2010, different proportions of the CT field were converted to NT in different years. Thus, in 2010, the chronosequence included four NT areas with four different durations: 1, 4, 11 and 20 years and a remaining CT area (Álvaro-Fuentes *et al.*, 2014). In summer 2010, SOC and soil bulk density were measured by triplicate in each chronosequence phase and at four soil depths (0-5, 5-10, 10-20 and 20-30 cm).

Changes in SOC distribution along the soil profile were evaluated in three long-term tillage experiments established in Selvanera (SV), Peñaflor (PN) and Agramunt (AG) in 1987, 1989 and 1990, respectively (Álvaro-Fuentes *et al.*, 2008). The three experiments differed among them in the type of CT implement (subsoiling in SV and mouldboard ploughing in PN and AG) and mean annual precipitation (475, 330 and 270 mm in SV, AG and PN, respectively). In summer 2015, soil bulk density and SOC concentration were measured in the 0-5, 5-10, 10-20, 20-30 and 30-40 cm soil depths, to calculate SOC contents.

Climate change impact on SOC storage was evaluated with the Century model (Parton, Stewart and Cole, 1988) together with climate outputs from the next two climate models: ECHAM4 and CGCM2, both forced with two IPCC scenarios (A2 and B2) (Álvaro-Fuentes and Paustian, 2011). The model was run during 90 years and the SOC predicted at the end of the simulation period was compared to the initial SOC level.

RESULTS

SOC sequestration duration

The chronosequence showed that about 80% of the total SOC gained during the first 20 years after NT adoption occurred during the first 11 years (Table 1). During the first 5 years, annual SOC sequestration rate was 0.42 Mg C ha^{-1} yr^{-1}. However, during the last 9 years (from year 11 to 20) SOC sequestration rate dropped to 0.02 Mg C ha^{-1} yr^{-1}. It is important to clarify that the annual SOC rate was calculated considering the change in SOC measured in the CT plot during the 20 years of chronosequence.

Table 1: Soil organic carbon (SOC) stocks in the 0-30 cm soil layer in the different no-tillage (NT) chronosequence phases: 0-NT, 0 years under NT; 1-NT, 1 year under NT; 4-NT, 4 years under NT; 11-NT, 11 years under NT; 20-NT, 20 years under NT (Álvaro-Fuentes et al., 2014).

	0-NT	1-NT	4-NT	11-NT	20-NT
SOC stock (Mg ha^{-1})	33.0	33.2	35.1	37.7	38.8

SOC distribution with depth

In the three tillage experiments presented in Table 2, SOC gains under NT decreased with soil depth. The greatest amount of SOC sequestered was observed when only the upper 5 cm soil layer was considered. However, when the entire soil profile sampled (0-40 cm) was evaluated, NT only increased SOC levels in two out of the three field experiments, with SOC gains below 7%. In the SV site, indeed, SOC showed lower SOC contents in NT compared with CT when the entire 0-40 cm soil layer was considered (Table 2).

Table 2: Percentage of SOC gain in no tillage (NT) vs. conventional tillage (CT) in three long-term experiments (SV, Selvanera; AG, Agramunt; and PN, Peñaflor). Positive or negative values denote SOC gains or losses, respectively.

Soil depth (cm)	SV	AG	PN
0-5	40	128	71
0-10	15	90	48
0-20	-1	40	24
0-30	-9	12	13
0-40	-12	1	6

Climate change impact on SOC sequestration

Depending on the scenario selected, NT responded differently to climate change. Compared with the baseline scenario (current climate conditions), the annual SOC sequestration rate in NT slightly increased in the two CGCM2 scenarios (from 0.44 Mg C ha^{-1} yr^{-1} under baseline to 0.46 Mg C ha^{-1} yr^{-1} under climate change) but it decreased in the two ECHAM4 scenarios (from 0.44 Mg C ha^{-1} yr^{-1} under baseline to 0.38 Mg C ha^{-1} yr^{-1} under climate change), which corresponded to the climate scenarios with the greatest decrease in precipitation and the greatest increase in temperature predicted. Accordingly, the SOC contents at the end of the simulation period (i.e., 90 years) were 74.9, 76.0, 76.0, 70.2, 69.0 Mg C ha^{-1} in the baseline, CGCM2-B2, CGCM2-A2, ECHAM4-B2, ECHAM4-A2, respectively (data not shown).

DISCUSSION

Despite NT has been recognized as an effective strategy to increase SOC stocks in Mediterranean agroecosystems, some aspects may limit its potential to sequester SOC as it has been demonstrated in this study. In our experiment, SOC increased over the first 20 years after NT adoption, similar to the findings reported by West and Six (2007), who concluded that climate, soil properties, land-use history and management mainly controlled sequestration duration. Tillage also impacted SOC allocation along the soil profile. The three long-term experiments selected in this study showed a decrease in SOC differences between NT and CT with soil depth. This finding has been discussed in several review papers (e.g., Baker *et al.*, 2007; Powlson, Whitmore and Goulding, 2011). Angers and Eriksen-Hamel (2008) recommended to sampling below 30 cm depth when NT is compared to CT. Finally, the Century ecosystem model predicted a significant impact of climate change on the ability of NT to sequester SOC in Mediterranean systems. The sign of the impact could vary depending on the final degree of future climate variation. The scenarios that promoted the highest rainfall reduction (ECHAM4 scenarios) resulted in the lowest sequestration rates due to their impact on crop growth and C inputs incorporated in the soil. However, climate change scenarios with small rainfall reductions (CGCM2 scenarios) had little impact on C inputs and they could even increase SOC sequestration rates compared with the baseline scenario due to a reduction in the decomposition rates (Álvaro-Fuentes and Paustian, 2011).

CONCLUSIONS

No tillage (NT) is an interesting option to sustain farm productivity and to decrease labour hours. Moreover, NT adoption is generally related to the increase of SOC stocks and, in turn, to the soil sink capacity to decrease atmospheric CO_2 concentration. In this study, we have identified three main factors that may limit the potential for SOC sequestration in Mediterranean soils: the sequestration duration, the distribution of SOC along the soil profile and the impact of climate change on SOC sequestration. These three factors should be taken into account in order to maximize the SOC sequestration and to evaluate the success of NT as a mitigation strategy in Mediterranean agroecosystems.

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2.3 | CARBON SEQUESTRATION BY AN ACCELERATED COMPOST IN AN ALFISOL

AyanfeOluwa O. E.[1*], O. O. AdeOluwa[2] and V. O. Aduramigba-Modupe[3]

[1]ayanfeoluwaolufemi@gmail.com, Federal College of Agriculture, Ibadan, Nigeria
[2]Department of Agronomy, University of Ibadan, Ibadan, Nigeria
[3] Institute of Agricultural Research and Training, Moor Plantation, Ibadan.

ABSTRACT

Compost has the potential to trap carbon in the soil while supplying nutrients needed for the crop. This study investigated the carbon sequestration potential of different rates of a commercial accelerated compost (Gateway Organic Fertilizer) in an Alfisol in two years. The treatments laid out in Randomized Complete Block Design with three replications were accelerated compost (AC) at the rates of 0, 60, 90, 120, 150 and 180 kgN/ha. Mineral fertilizer (NPK 15-15-15) and conventional compost (CC), both at 60 kgN/ha, were checks. Post residual cropping soil samples (6 months after application) were analysed for organic carbon and data analysed using standard error of means. In 2013, the carbon sequestered was in the order of 90 kgN/ha AC;111%) > 150 kgN/ha AC;102% > 60 kgN/ha CC;66% > 180 kgN/ha AC;55% > 60 kgN/ha AC;45% > 120 kgN/ha AC;38% > 60 kgN/ha NPK;24%. In 2014; 60 kgN/ha AC;58% > 180 kgN/ha AC;53% > 90 kgN/ha AC;34%) > 120 kgN/ha AC;22% > 150 kgN/ha AC;13% > 60 kgN/ha CC;9% > 60 kgN/ha NPK;2%). It could therefore be concluded that the shortness in maturity of the AC used for this study does not limit its carbon sequestration potential.
Key words: Accelerated compost, organic wastes, carbon sequestration, climate change, mitigation strategies, Alfisol

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Agriculture has a great potential to reduce the build-up of greenhouse gases in the atmosphere thereby mitigating climate change (Paustian *et al.*, 2006). This is possible by promoting the use of organic wastes into organic fertilizer for crop production, thereby facilitating the composting of organic materials that would have been burnt, thus, storing the carbon that have being trapped from the atmosphere during photosynthesis into the soil (Fliessbach *et al.*, 2009; UNFCCC, 2007; Lal, 2004).

Recent development had shown that composting process could be accelerated by speeding up the rate of the biological decomposition of organic material through the artificial introduction of some microorganisms, or by manipulating the temperature. Compost made within a relatively short period of about three weeks instead of the conventional three month period of maturity are referred to as accelerated compost (Rotor, 2008). This technology; acceleration of composting, therefore, has the tendency to increase the availability of compost for farmers while encouraging the trapping of more carbon in the soil and mitigate the effect of climate change. It will also accelerate the handling of high volume of waste being generated thereby enhance the management of waste and promote healthy environment (Laine-Ylijoki *et al.*, 2005). However, the concern is what will be the implication of reduced composting time on the carbon sequestration ability of the compost. Alfisols constitutes 9.7% of the global soil, based on soil order (Blum and Swaran, 2006). This work therefore investigated the carbon sequestration by an accelerated compost on an Alfisol using maize as the test crop.

METHODOLOGY

The experiment was carried out on an Alfisol at the experimental site of the Federal College of Agriculture, Ibadan, Nigeria, 7˚22.5′ N and 3˚50.3′ E in both year 2013 and 2014. The total land area for the experiment each year was 360 m^2. The experiment was made up of a total of 24 experimental units with plot size of 3.3 m^2, a spacing of 0.5 m between plots and 1 m between the blocks. The pre planting/pre-applied soil analysis showed that the Alfisol was very low in N (0.4, 0.9 g/kg), P (8, 4 mg/kg) and organic carbon (7.2, 9.1 g/kg), and marginal in K (0.4, 0.4 cmol / kg) in both 2013 and 2014 trials, respectively, while the textural class was loamy sand. The chemical composition of the accelerated compost (AC) and conventional compost (CC) used for this study is shown in the Table.

The treatments laid out in Randomized Complete Block Design with three replications were AC at the rates of 0 60, 90, 120, 150 and 180 kgN/ha. Mineral fertilizer (NPK 15-15-15) and CC, both at 60 kgN/ha, were checks. Soil samples were collected from treated plots after the residual cropping and analysed for organic carbon using the dichromate wet oxidation method (Nelson and Sommers, 1996), and the data analysed using standard error of means. The amount of carbon sequestered in the soil by each treatments was calculated as the surplus of the soil organic carbon (SOC) relative to the control (no soil additive) treatment.

Table. Chemical composition of the compost used for the study

Parameter	pH (H_2O)	Total Carbon	N	P	K	Ca	Na	C:N ratio	Fe	Cu	Mn	Zn
		-------------------- (g / kg) -----------------							------------- mg / kg -------- ---			
AC	5.9	150	10.9	10	3	140	1	14	1321	61	405	146
CC	9.7	170	12	8	17	240	4	14	6053	11	393	1.5

AC; accelerated compost, CC; conventional compost

RESULTS

The result of the soil organic carbon and the carbon sequestration in the two years of trials is shown in the Figure. In 2013 trial, the result showed that 90 kgN/ha AC treated soil resulted into the highest mean value of SOC (37.2 t/ha), which was not significantly ($p<0.05$) different from the 150 kgN/ha AC (35.6 t/ha). Ranked next was the 60 kgN/ha CC (29.2 t/ha), followed by the180 kgN/ha AC (27.2 t/ha) which was not significantly different from the 60 kgN/ha AC (25.6 t/ha). The next in the rank was the 120 kgN/ha AC (23.8 t/ha), followed by the 60 kgN/ha NPK (21.8 g t/ha) while the control treatment gave the lowest significant value (17.6 t/ha). The carbon sequestered in the treated soils was in the order of 90 kgN/ha AC (111 %) > 150 kgN/ha AC (102 %) > 60 kgN/ha CC (66 %) > 180 kgN/ha AC (55 %) > 60 kgN/ha AC (45 %) > 120 kgN/ha AC (38 %) > 60 kgN/ha NPK (24 %). It could be noted that the organic carbon sequestered in the 60 kgN/ha AC treated soil (45 %) was almost double that of the 60 kgN/ha NPK (24 %).

In 2014 trial, the result showed that 60 kgN/ha AC treated soil (29.0 t/ha) resulted into the highest mean value of SOC, which was not significantly ($p<0.05$) different from the 180 kgN/ha AC (28.2 t/ha). Ranked next was the 90, 120 and 150 kgN/ha AC (24.6, 22.4 and 20.8 t/ha respectively) followed by the 60 kgN/ha CC (20 t/ha). The 60 kgN/ha NPK and the control treatment resulted into the least significant mean value of 18.8 and 18.4 t/ha respectively. The carbon sequestered was in the order of 60 kgN/ha AC (58 %) > 180 kgN/ha AC (53 %) > 90 kgN/ha AC (34 %) > 120 kgN/ha AC (22 %) > 150 kgN/ha AC (13 %) > 60 kgN/ha CC (9 %) > 60 kgN/ha NPK (2 %). It could be noted that the highest organic carbon sequestered in 60 kgN/ha AC treated soil (58 %) was about 6.5 fold that of the 60 kgN/ha CC (9 %).

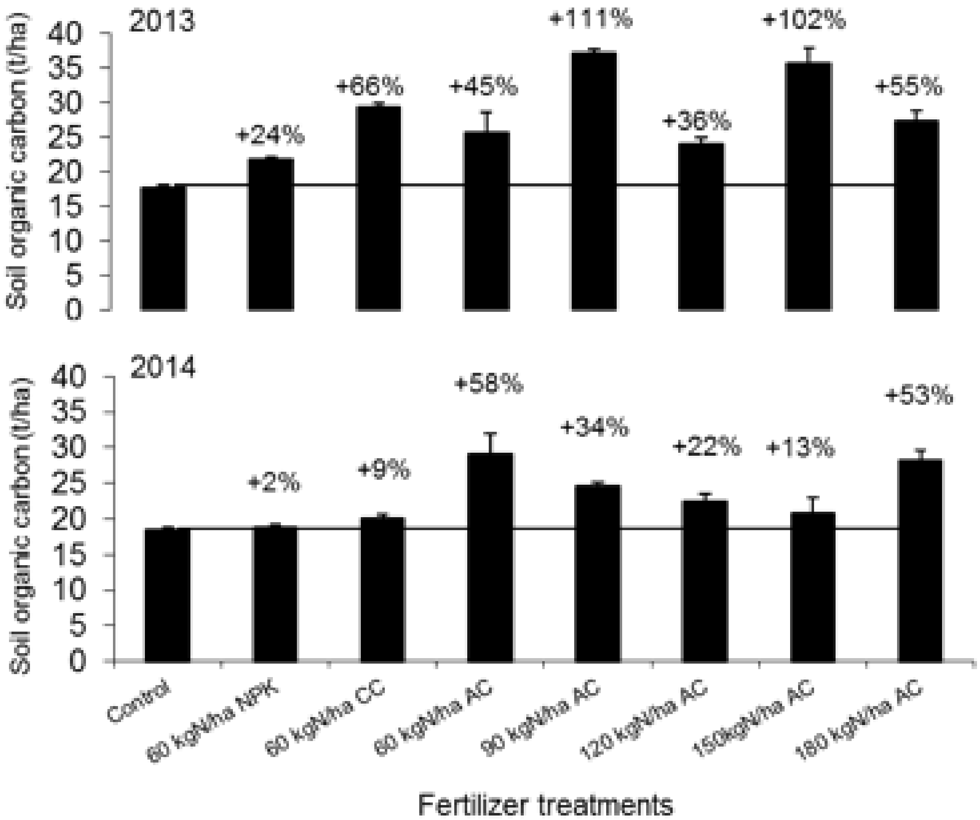

Figure. Effects of the application rates of accelerated compost on the soil organic carbon and carbon sequestration after the residual cropping

NPK, NPK 15-15-15; AC, Accelerated Compost; CC, Conventional Compost

Bar is Standard error of mean

The line across bars indicates the surplus SOC in all treatments relative to the Control

DISCUSSION

This result showed that both the accelerated and conventional composts treated plots in this study sequestered more carbon than the NPK 15-15-15 mineral fertilizer plot. This concur with the reports of Adeyemo and Agele S.O. (2010); Šimon and Czakó (2014) that composts improved the soil organic carbon. This result substantiates the submission of Luske and Van Der Kamp (2009) as well as Eifion (2009) that the organic carbon contained in composts will be sequestered into the soil when applied as a fertilizer. The result further substantiates the reason while UNFCCC has included composting as an official method for greenhouse gas emission reduction projects (UNFCCC/CCNUCC, 2007). It also confirmed the position of Lal (2004) that agricultural soils are a major potential carbon sink that may be used to mitigate climate change.
The result also showed that the AC at 60 kgN sequestered more carbon than the CC at the same rate in the 2014 trial. This showed that the shortness in the duration of composting for accelerated compost does not pose limitation to its carbon sequestration ability.

CONCLUSIONS

This result of this finding revealed that the accelerated compost used for this study sequestered carbon comparable to the conventional compost in the two years of trials. It could therefore be concluded that while accelerated compost increased the chances of availability of compost for crop production, the shortness in its maturity does not limit its carbon sequestration potential. Thus, the adoption of accelerated composting technology should be encouraged to enhance the availability of organic fertilizers for farmers' use, thereby promote the sequestration of carbon in the soil.

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2.4 | LONG-TERM FERTILIZATION IMPACTS ON TEMPERATURE SENSITIVITY OF SOIL ORGANIC CARBON DECOMPOSITION UNDER WHEAT BASED CROPPING SYSTEMS

Avijit Ghosh[1], Ranjan Bhattacharyya[2*], B.S. Dwivedi[3], M.C. Meena[4], B. Aggarwal[5], R. Agnihorti[6]

[1]ICAR-Indian Agricultural Research Institute, New Delhi, 110 012, India. E-mail: avijitghosh19892@gmail.com
[2]ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India. E-mail: ranjanvpkas@gmail.com
[3]ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India. E-mail: bsdwivedi@yahoo.com
[4]ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India. E-mail: mcmeena@gmail.com
[5]Birsa Agricultural University, Kanke, Ranchi 834 006, Jharkhand, India. E-mail: bkassac@gmail.com
[6]National Physical Laboratory, New Delhi 110 012, India. E-mail: rajagni9@gmail.com

ABSTRACT

Understanding temperature sensitivity of soil organic carbon (soc) decomposition (q10) from bulk soils and aggregates of long-term fertilized plots is imperative to forecast soil c dynamics. We evaluated the impacts of 43 and 44 years of fertilization under wheat (triticum aestivum) based cropping system on q10 in an alfisol and inceptisol, respectively. Bulk soils as well as macro- and micro-aggregates of 0-15 (topsoil) and 15-30 cm soil layers were incubated for 24 days at 25oc and 35oc. Results revealed that cumulative SOC mineralization (ct) of bulk soils with npk + fym and npk treated plots were similar but significantly higher than unfertilized control plots in both soil types. In topsoil, npk + fym plots had ~10 and 26% greater q10 values of macro- and microaggregates than npk in alfislol and similar results were observed in inceptisol. Activation energies required for bulk soil c mineralization was ~2 and 3 times higher in npk + fym and npk + l plots, respectively, compared with unfertilized control plots in alfisol. Thus, long-term npk + fym (in both soils) and npk + l applications (in alfisol) have great potential for less proportional SOC decomposition than npk or unfertilized control plots under a temperature rise.
Keywords: Soil organic carbon mineralization, Macroaggregates, Microaggregates, Q_{10}, activation energy, C decay rates, temperature rise, Inceptisol and Alfisol

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Understanding the impact of elevated temperatures on rates of soil organic matter (SOM) decomposition in diverse soil systems is critical to our knowledge of soil C dynamics and this will assist estimation of future global SOC stocks. Different kinetic properties of SOM components provide obstacles to the understanding of thermal stability of SOC decomposition (Davidson and Janssens, 2006). As predicted by Arrhenius, if differences in decomposition rates are entirely due to activation energy (as a measure of the energy required for decomposers to access the material), temperature sensitivity should increase with the organic matter 'recalcitrance' (Davidson and Janssens, 2006). Thus, stable compounds in soils are associated with higher activation energies, as they are less reactive to a temperature rise. But SOC decomposition is also regulated by long-term management practices, as well as by soil aggregate sizes (Manna *et al.*, 2013). Substrate quantity and quality and microbial activities within different soil fractions influence temperature sensitivity. Hence, there is a need to study the effects of aggregate size and long-term fertilization on Q_{10} and activation energy (Ea) in different soils and production systems.

Thus, studying temperature impacts on soil C decomposition as affected by fertilization could provide interesting data for assessing the impacts of integrated nutrient management (INM) on climate change mitigation potential. The hypothesis was that fertilization significantly affects C mineralization and Q_{10} from bulk soils and their aggregates, and INM requires more Ea to mineralize C than NPK or unfertilized control plots (due to probable presence of more recalcitrant C and thus agreeing to the carbon quality-temperature (CQT) hypothesis), even after a heat wave. The CQT hypothesis has not been tested for short heat waves, which are predicted to regularly recur under climate change scenarios (Nianpeng *et al.*, 2013).

The objectives were: (i) to evaluate the rates of SOC decomposition in bulk soils and their aggregates as affected by 43 and 44 years of continuous fertilization in wheat-based cropping systems in an Alfisol and Inceptisol and (ii) to assess the temperature sensitivity of SOC decomposition from bulk soils and their aggregates.

METHODOLOGY

Study sites and experiment details

The study was conducted in tow long-term fertility experiments of Ranchi (Alfisol) and New Delhi (Inceptisol), India. The latest cropping systems were soybean (*Glycine max*)-wheat and maize (*Zea mays*)-wheat in Alfisol and Inceptisol, respectively. The treatments in Alfisol (since 1972) were: no mineral fertilizer or manure (control), 100% recommended dose of nitrogen (N), N and phosphorus (NP), N, P and potassium (NPK), NPK + lime at 0.4 Mg ha^{-1} (NPK + L), 150% recommended NPK (150% NPK), and NPK + FYM at 10 Mg ha^{-1} (NPK + FYM). In Inceptisol, all but NPK + L treatments were there (since 1971). These were arranged in a complete randomized block design with three replications. Other details of experimentation and crop management practices of Alfisol can be found in Ghosh *et al.* (2016) and that of Inceptisol in Purakayastha *et al.* (2008).

Soil sampling, processing and bulk density determination

In April 2015, triplicate soil samples were collected after wheat harvest from the individual plots from two depth layers (0-15 and 15-30 cm). Samples were bulked and then divided into three subsamples. One portion was air-dried, ground in a wooden mortar and with a pestle, and sieved to pass through a 4.75-mm sieve (bulk soils). The second subsample was passed through a 4.75 mm sieve and used for aggregate separation. Processed soil samples were used to determine soil chemical and physical properties.

Soil aggregate separation

A sub-set of samples of the 0-15 and 15-30 cm layers from the second soil sample-set were taken for soil aggregation related studies. Aggregate-size separation was performed by a wet sieving method to obtain three aggregate fractions: (i) 250 to 4750-µm (macroaggregates; MA), (ii) 53 to 250-µm (microaggregates; MI), and (iii) <53-µm (silt- plus clay-size particles).

A*nalyses of soil C pools*

The labile SOC concentrations of bulk soils and aggregates were determined by the modified Walkley–Black method using 18.0 M H_2SO_4 (Chan, Bowman and Oates, 2001). Total C concentrations of bulk soils and aggregates were analysed using an isotopic ratio mass spectrometer (IRMS) (Delta V plus; Thermo) coupled with an Elemental Analyser (Owens and Rees, 1989) in a continuous flow mode. Inorganic C concentrations were subtracted from total C concentrations to obtain total SOC.

Carbon mineralization study

Carbon mineralization studies of bulk soils (BS), MA and MI were conducted at two temperatures (25 and 35°C), set in laboratory incubators, for 24 days. Three replicates of 25 g soil samples from each treatment were placed in 250 ml jars (along with two blanks) with alkali traps. Evolved CO_2 was trapped by 10 ml 0.5 N NaOH (in the alkali trap) and measured at each sampling date (Day 2, 4, 7, 10, 17 and 24). The amounts of CO_2 trapped were determined by back titration of the 0.5 N NaOH with 0.5 M HCl at pH 8.3 in the presence of $BaCl_2$. The CO_2 fluxes were measured and details can be seen in Ghosh et al. (2016). An exponential model (Stanford and Smith, 1972) was used to determine C loss with time:

$$C_t = C_o (1-e^{-Kct}) \quad (1)$$

where C_o represents the labile pool, and C_t is the pool of C mineralized at time t, with decay rate Kc.

Vant Hoff factor (Q_{10}) was calculated using the following formula (Janssens and Pilegaard, 2003):

$$Q_{10} = \{(\text{Rate of C mineralization at 35°C}/\text{Rate of C mineralization at 25°C})\}^{(10/T_2-T_1)} \quad (2)$$

Activation energy was calculated using the Arrhenius equation (Hamdi *et al.*, 2013):

$$Ea = R^* \ln (Q_{10}) / \{(1/T_1)-(1/T_2)\} \quad (3)$$

where R = 8.314 j/mol; T_1 and T_2 are temperatures indicating the 10°C temperature range (T_1 = 25°C, T_2 = 35°C).

Statistical analyses

All data were analysed using ANOVA for a randomized block design. Tukey`s test of honest significant difference was used as a post hoc mean separation test (P <0.05) using SAS 9.3 (SAS Institute, USA).

RESULTS

In Inceptisol, plots under NPK + FYM had ~18 and 136% higher total SOC concentration than NPK plots in topsoil (Table 1). In Alfisol, plots with NPK + L, 150% NPK and NPK treatments had similar total SOC concentrations. In soil surface of Alfisol, cumulative SOC mineralization (C_t) at 25 and 35°C and Q_{10} values of bulk soils with NPK + FYM and NPK plots were similar, but were significantly higher than control plots (Table 1). However, in Inceptisol, NPK + FYM treated plots had significantly higher C_t of bulk soils than NPK. In Alfisol, NPK + FYM treated plots had ~10 and 26% greater Q_{10} values of macro- and microaggregates than NPK (Table 2). But, in Inceptisol, NPK + FYM treated plots had similar Q_{10} values of macro- and microaggregates to NPK. Bulk soils of NPK + L plots had higher Q_{10} values than NPK + FYM plots in both surface and sub-surface soil layers, indicating long-term NPK + FYM application acted as energy barriers to SOC decomposition and had considerable potential in having less proportional (to its total SOC) SOC decomposition under increased temperatures. Overall, long-term NPK + FYM and NPK + L applications have great potentials in having less proportional SOC decompositions than NPK, 150% NPK or unfertilized control plots under a temperature rise in Alfisol and the same is true for NPK + FYM versus NPK or 150% NPK in Inceptisol.

Table 1. Total soil organic carbon, cumulative soil organic carbon mineralized (Ct), and Q10 in bulk soil and in soil aggregates as affected by 43 years of fertilization under a wheat based cropping system in an Alfisol of 0–15 cm soil depth (Source: Ghosh et al., 2016)

Treat-ments	Total SOC (g kg-1)			C_t (mg 100 g-1)						Q_{10}		
				25oC			35oC					
	BS	MA	MI	BS	MA	MI	BS	MA	MI	BS	MA	MI
Control	3.1b (5.0d)	4.8cd (4.4c)	3.0e (16.8c)	33.9c	20.1d	22.9d	35.9d	21.2d	28.1e	1.07d	1.06c	1.25d
N	3.1b (8.8c)	4.6d (6.8c)	3.3e (16.3c)	40.4bc	27.2c	23.9d	44.7c	29.6d	29.3e	1.12c	1.09c	1.24d
NP	3.6b (8.4c)	4.9cd (12.3b)	4.0d (17.5c)	49.0b	38.5b	38.3c	56.3b	44.6c	47.2d	1.18c	1.18b	1.26d
NPK	3.8b (16.2ab)	5.3c (14.3b)	4.6bc (22.0b)	70.3a	64.6a	51.6b	84.4a	76.1b	66.7c	1.24b	1.21b	1.33c
150% NPK	4.3b (17.9ab)	5.6bc (13.9b)	4.8b (24.2b)	70.0a	65.4a	65.6a	85.8a	76.6b	85.8a	1.26a	1.20b	1.37b
NPK + FYM	6.0a (15.0b)	6.9a (21.9a)	5.7a (39.3a)	68.0a	64.7a	53.1ab	81.0a	83.3a	83.3a	1.22b	1.33a	1.67a
NPK + L	4.0b (19.6a)	6.0b (21.6a)	4.4c (23.5b)	64.6a	61.5a	57.7ab	80.6a	78.7b	75.2b	1.29a	1.33a	1.36b
Mean	4.0 (13.0)	5.4 (13.6B)	4.3 (22.8A)	56.6	48.8A	44.7B	66.6	58.6A	59.4A	1.19	1.20B	1.35A

() Data in parentheses indicate activation energy values (kJ mol^{-1}). Means with same lower-case letters within a column are not significantly different at P <0.05 according to Tukey's HSD test. Significant (P <0.05) effects of macroaggregates versus microaggregates for each parameter (mean of all treatments) are denoted by different upper-case letters in the last row. BS = Bulk soil; MA = Macroaggregates; MI = Microaggregates.

Table 2. Total soil organic carbon, cumulative soil organic carbon mineralized (Ct), and Q10 in bulk soil and in soil aggregates as affected by 43 years of fertilization under a wheat based cropping system in an Inceptisol of 0-15 cm soil depth.

Treat-ments	Total SOC (g kg-1)			C_t (mg 100 g-1)						Q_{10}		
				25oC			35oC					
	BS	MA	MI	BS	MA	MI	BS	MA	MI	BS	MA	MI
Control	3.29d (5.1e)	4.12f (13.3d)	2.98e (5.3d)	41.87d	21.98c	20.22	44.29d	25.85e	21.55d	1.07e	1.19c	1.07d
N	4.05c (9.1d)	4.98e (15.8c)	3.78d (10.3bc)	49.86d	29.73c	34.06b	55.15c	35.99d	38.36c	1.13d	1.23bc	1.14c
NP	3.93c (13.3c)	6.25d (20.8a)	4.66c (14.9ab)	60.54c	42.04b	38.53b	69.50b	53.84c	45.83b	1.19c	1.31a	1.22ab
NPK	6.57b (16.5b)	7.64c (16.3b)	5.38b (14.2ab)	78.31b	64.35ab	42.19ab	93.93ab	77.70b	49.83b	1.24b	1.24b	1.20b
150% NPK	7.02b (18.3a)	8.61b (15.2bc)	6.35a (14.5ab)	77.90b	65.44ab	46.94a	95.56a	78.23b	55.73ab	1.27a	1.22bc	1.21b
NPK + FYM	7.82a (15.6b)	9.10a (16.3b)	6.69a (17.0a)	83.88a	70.18a	49.85a	99.97a	85.03a	60.94a	1.23bb	1.24b	1.25a
Mean	5.45 (13.0)	6.78A (16.3A)	4.97B (12.7B)	65.39	48.95A	38.63B	76.40	59.44A	45.37B	1.19	1.24A	1.18B

BS = Bulk soil; MA = Macroaggregates; MI = Microaggregates.

Means with same lower-case letters within a column are not significantly different at P <0.05 according to Tukey's HSD test.

() Data in parentheses indicate activation energy values (kJ mol^{-1}).

DISCUSSION

Less proportional carbon mineralization from NPK + FYM treatment may be due to the formation of compounds which are resistant to microbial action (Cotrufo *et al.*, 2013). Thus, this study highlights consideration of the role of microbial diversity and matrix stabilization within bulk soils and aggregates to understand temperature sensitivity of SOC decomposition (Jagadamma *et al.*, 2014). Thus, the results indicate complex role of P and microbial diversity in Inceptisol and sesqui-oxides and matrix stabilization in Alfisol. Abnormally high Ea in macroaggregates of NP treated plots of Inceptisol could be explained by the highest enrichment factor of SOC within macroaggregates indicating protection of C, whereas high Ea in macroaggregates of sub-surface depth of NPK + FYM could be due to high recalcitrant C (>52%). In Alfisol, at surface depth low Ea in NPK + FYM treated plots than NPK + L and NPK may be due to very low SOC enrichment factor in aggregates.

CONCLUSION

Among all practices, NPK + FYM application not only had highest SOC accumulation, but also could have less SOC losses under elevated temperatures and hence could be recommended.

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2.5 | AGRICULTURAL PRACTICES THAT STORE ORGANIC CARBON IN SOILS: IS IT ONLY A MATTER OF INPUTS ?

Claire Chenu[1*], Rémi Cardinael[1,2,3], Bénédicte Autret[4], Tiphaine Chevallier[2], Bertrand Guenet[5], Cyril Girardin[1], Thomas Cozzi[1], Hélène Guiller[1,3], Bruno Mary[4].

[1] UMR Ecosys, INRA-AgroParisTech, Thiverval Grignon, France

[2] UMR Eco&Sols IRD-INRA-Supagro Montpellier, Montpellier, France

[3] UMR Aida, CIRAD-INRA, Montpellier, France

[4] UR AgroImpact, Laon, France

[5] UMR LSCE, CEA-CNRS-UPMC, Saclay, France

ABSTRACT

Agricultural soils have a high C sequestration potential because of their generally low SOC stocks. Here we investigated the effect of alternative cropping systems, conservation agriculture (i.e. no tillage and permanent cover crop) and silvo-arable agroforestry on SOC stocks using long term experiments of 16 and 18 years in France. We measured increased SOC storage in the surface soil layer (0-30 cm) compared to the reference situations. While there was no difference in SOC mineralisation rates, the OC inputs were considerably increased in the alternative cropping systems, due to the associated vegetation (cover crops, trees). This suggests that practices that increase C inputs to soil through additional biomass production would be more effective to store C in soil than practices, such as no-tillage, that are assumed to reduce soil organic matter mineralisation rates.

Keywords: soil, organic carbon, agroforestry, no tillage, conservation agriculture

INTRODUCTION

Increasing the world soils carbon stocks by a factor of 4 per mille annually would compensate the global annual CO2 emissions from fossil fuel. This statement, which is the core of the initiative launched by the French government at the COP21, has been translated at the local scale with an aspirational target of an annual 4 per 1000 increase of soil organic carbon (SOC) stocks. Compared to forest and pasture soils, agricultural soils have a higher SOC storage potential, because they are often characterized by low SOC contents (Paustian *et al*., 2016) and increasing their OC content is associated with benefits in terms of soil properties and ecosystem services. In this context, estimates of the effect of current or innovative cropping practices and systems are particularly needed (Paustian *et al.*, 2016; Stockmann *et al*., 2013).

Changes in SOC stocks at the plot scale are the result of a balance between input flows - i.e. fresh plant biomass inputs or organic wastes addition into soil-, and output flows which result mainly from mineralisation. The former are potentially increased by cropping practices such as intercropping, cover cropping, planting trees and hedges as well as importing organic wastes. The later are potentially decreased by reduced tillage, which avoids a de-protection of soil organic carbon (Six *et al*., 2000) (Balesdent *et al*., 2000). Here, we investigated how alternative cropping practices and systems in annual cropping modified SOC stocks and to which extent it was explained by variations in OC inputs or in losses by mineralisation.

METHODOLOGY

We quantified, under temperate conditions, the additional C storage related to the implementation of cropping systems that are recognized to be in the framework of agroecology: conservation agriculture on the one hand and agroforestry on the other hand. These studies were based on long-term experiments (LTE). At La Cage site, in the Paris area, a 16-years old LTE allowed to compare a conservation agriculture system (i.e. no tillage with permanent soil coverage with an associated plant, fescue or alfalfa) to a conventional one on luvisols. At Restinclières LTE in southern France, a 18-year-old silvo-arable agroforestry system associating hybrid walnut trees and durum wheat was compared to a conventional cropping system on fluvisols. The main crops were cereals in both cases. SOC stocks were measured on an equivalent soil mass basis down to 30 cm in the La Cage site (Autret *et al*., 2016) and down to 1m in the Restinclières site (Cardinael *et al*., 2015). Organic inputs were quantified at both sites by measuring yields. At La Cage published data were used to estimate belowground crop inputs and crop growth allometric equations to estimate the biomass of the cover crops. At Restinclières, in the agroforestry system, leaf litter, fine root senescence and tree row herbaceous vegetation inputs were measured. Soil sampled 0-30 cm, sieved to 5 or 10 mm, was incubated in the lab to measure SOC mineralisation kinetics The evolution of SOC stocks was modelled at La Cage using a 2 pools model, AMG (Saffih-Hdadi and Mary, 2008) and compared to measured SOC stocks.

RESULTS

Both systems allowed for a net storage of C in soils, which were, for the equivalent of the 0-30 cm tilled layer, of + 0.55 ± 0.16 t ha^{-1} yr^{-1} for conservation agriculture and of + 0.25 ± 0.03 t ha^{-1} yr-1 for the agroforestry system compared to the reference conventional system (Table 1). Inputs of OC to soil were increased by about 32% (+1.32 t C ha^{-1} y^{-1}) in the conservation agriculture system and by 40% (+1.11 t C ha^{-1} y^{-1}) in the agroforestry system, compared to their respective references (Figure 1). There was no significant differences in the basal respiration (expressed as % of total SOC) between soil in conservation agriculture or agroforestry and their respective references. The model AMG successfully described the evolution of SOC stocks at La Cage LTE and the same mineralization rate of SOC could be used in both the conventional tilled soil and the un-tilled soil in conservation agriculture.

La Cage	Depth	ESM	Conventional		Conservation agriculture					
	(cm)	(t ha^{-1})	SOC stocks (t C ha^{-1})							
1998	≈ 0-10	1300	12.8	±1.0	13.4	±2.5				
	≈ 0-30	4300	40.4	±3.5	41.9	±8.7				
2014	≈ 0-10	1300	13.1	±1.2	21.5	±2.9				
	≈ 0-30	4300	41.7	±4.2	51.9	±6.6				
Restinclières	Depth	ESM	Control		Tree row		Inter-row		Agroforestry	
	(cm)	(t ha^{-1})	SOC stocks (t C ha^{-1})							
2013	≈ 0-8	1000	9.3	±0.1	21.6	±1.0	9.8	±0.4	11.7	±0.3
	≈ 0-28	4000	35.8	±0.2	52.8	±1.4	37.9	±0.6	40.3	±0.5

Table 1. Soil organic carbon stocks in the La Cage and Restinclières long term experiments. Data reprinted from (Autret et al., 2016) (La Cage) and (Cardinael et al., 2015) (Restinclières)

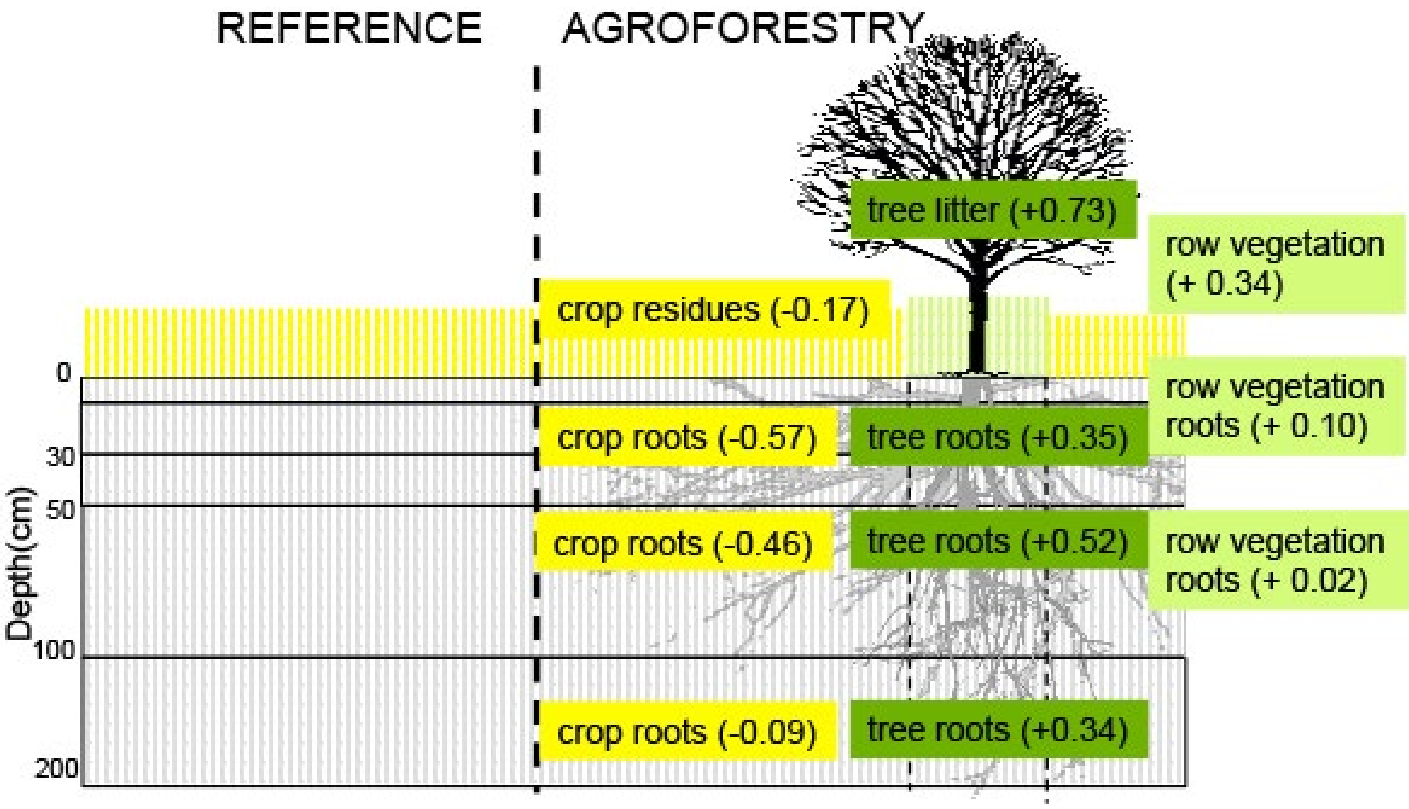

Figure 1. Measured differences in fresh organic carbon inputs from the vegetation to soil in the agroforestry plot at Restinclières, compared to the reference plots. All values are in tC ha^{-1} y^{-1} and only average values are presented here.

DISCUSSION

Both alternative cropping systems studied here led to increased SOC stocks, at rates above an annual 4 per 1000 increase. The results are in line with estimates proposed in a recent French national assessment concerning the potential of different agricultural practices to reduce greenhouse gas emissions *(Pellerin et al.*, 2015).

Here, we hypothesised that SOC stocks would increase in the alternative cropping systems because of (i) increased OC inputs due to increased biomass production thanks to the associated vegetation, i.e. cover crops, trees, tree row herbaceous vegetation and (ii) decreased OC outputs due to decreased mineralisation because of no tillage, on the whole surface area of the plot in the conservation agriculture system, or in the tree rows in the agroforestry plot. We found that OC inputs to soil were strongly increased in the alternative cropping system. We did not measure soil respiration in situ, but in vitro measures of SOC mineralisation showed no differences and the modelling exercise suggested that mineralization rates were not affected by the absence of tillage. Thus we did not verify our second hypothesis.

The present results then suggest that increased C inputs to soil through additional biomass production would be more effective to store C in soil than practices, such as no tillage, that are assumed to reduce soil organic matter mineralisation rates. This was also suggested by the (Pellerin *et al.*, 2015) study, in which cover crops between cash crops, hedges, agroforestry, cover crops in vineyards and orchards or buffer grass strips were found, based on a literature review for French pedoclimatic conditions, to store more carbon than no tillage or superficial tillage practices.

Indeed, while no tillage has been one of the most important agricultural practices sought to increase SOC, its effect on SOC stocks has been scaled down in the last years, especially based on meta-analyses (Angers and Eriksen-Hamel, 2008; Luo *et al.*, 2010; Virto *et al.*, 2012). These showed that relative increases in SOC stocks under no tillage are often restricted to superficial soil layers and are extremely variable across soil types and climates. Further (Virto *et al.*, 2012) found that that crop C inputs differences was the only factor significantly and positively related to SOC stock differences between no tillage and inversion tillage, explaining 30% of their variability.

This questions our understanding of the effect of no tillage on soil organic matter dynamics. In the absence of tillage, more organic matter has been shown to be physically protected from biodegradation, because of a more aggregated soil and a less frequent disruption of the aggregates (Six *et al.*, 2000). In addition, under temperate conditions as here, moister and cooler conditions in no till soils should also decrease mineralization rates (Balesdent *et al.*, 2000). However, less residue incorporation in the absence of tillage could also lead to less physical protection and less SOC stabilization in subsoil layers (Gregorich *et al*., 2009). A better mechanistic understanding of the complex effects of no tillage on soil organic matter dynamics is needed to reconcile process oriented studies with field scale monitoring of SOC stocks.

CONCLUSION

One major outcome of the study is that it suggests that to increase soil organic carbon stocks it is probably more effective to increase carbon inputs into the soil than to attempt to reduce outputs. All the practices increasing primary production can be mobilised here: planting of ligneous plants in combination (hedges, agroforestry), replacing bare soil with plant cover, either in space (intercropping) or time (cover crops).

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2.6 | CONSERVATION AGRICULTURE, AN OPTION FOR CARBON SEQUESTRATION IN SOIL. CASE STUDY IN GUANTÁNAMO, CUBA.

Marianela Cintra Arencibia *[1], Oneyda Hernández Lara[2], Teudys Limeres Jiménez[1]

[1] Institute of Soils - UCTB Guantánamo, Cuba. E-mail: grupoinv@suelos.gtm.minag.cu
[2] Institute of Soils, Havana, Cuba. E-mail: hernandezo@isuelos.cu

ABSTRACT

During 3 years, a demonstrative area was monitored in the southwest part of Guantánamo province, Cuba, for the implementation of Conservation Agriculture technology, with the objective of validating the technology transfer to the country. Laboratory analysis were used to evaluate soil moisture, organic matter content, pH, electrical conductivity and bulk density; in order to corroborate the results obtained by the Visual Evaluation of Soils (VES). An increase of moisture retention in the soil profile of 20% was achieved, up to a depth of 60 cm. The decrease of the bulk density was verified in 10%, which reflects the decrease of the compaction and benefit of other properties. The organic matter in the soil showed improvement in 30%, increasing in turn, the carbon sequestration. Improvement in soil structuring and increase in soil biological activity were verified. These results are still within the ranges determined at the beginning of the system, but show signs of ecosystem recovery and the feasibility of technology transfer as a measure to Climate Change adaptation.
Keywords: Conservation agriculture, climate change.

EXTENDED ABSTRACT

INTRODUCTION

Global warming is due, to a large extent, to the high concentrations of CO_2 in the atmosphere; and soil is naturally, a large reservoir of organic carbon. It must therefore to be considered as a way of retaining carbon to prevent it from being released into the atmosphere. The production of organic materials varies according to the ecology of the specific medium. In general, management practices that increase soil organic carbon also reduce erosion, increase production, and improve natural resources (Espinoza, 2005).

Just as the soil is over, provides a medium in which the plants grow, in turn, they protect the soil from erosion. Human activity is breaking this relationship. At some point in the last century, with the intensification of agricultural activity, soil erosion began to exceed the rate of soil formation in large areas. The secret to avoid soil erosion is to not allow it to be unprotected, ensuring that the surface is always covered with plants or with a mulch of those same plants.

Conservation Agriculture (CA) is based on three fundamental principles: crop rotation, permanent land cover and minimum or zero tillage and is a technology widely recognized as a viable concept for the practice of sustainable agriculture, increasing the levels of soil matter and with it, the available organic carbon as an energy source, adding or releasing N to or from the soil through the symbiotic fixation of the N_2 of the atmosphere, breaking the cycle of some pests and diseases that can appear in the crop systems, improving the structure of the soil, retaining soil moisture, and reducing the energy needed for cultivation, among other benefits.

METHODOLOGY

The experience was developed during 3 years in the Malabé farm, of 4 ha, belonging to the CCS Enrique Campos of Guantánamo municipality, southwest of the province of the same name, in Cuba, on a typical Salinized Fluvisol soil (Hernández *et al*., 1999), Typical Ustifluvent (USDA, 1992) loamy clay texture, located between the coordinates North 156.450 - 156.650 and East 667.400 - 667.500. In order to perform this work, was used the basic soil map 1:25 000. Periodic soil samples were taken at a scale of 1: 5000 for the determination of chemical analyzes: (pH in H2O by the potentiometric method (Soils Institute, 1985), percentage of organic matter by Walkley - Black method (Soils Institute, 1985) and electrical conductivity in automated paste to determine soil salinity which became saturation extract from the conversion factor for light soils (Rivero *et al*., 1998)) and physical analysis (soil moisture up to 60 cm in depth and apparent density). In addition, Visual Evaluation of Soils (VES) (Shepherd *et al*., 2006) was used to corroborate the analytical results obtained.

RESULTS AND DISCUSSION

Initially the study area was under the technology of traditional agriculture, being carried out all the corresponding agricultural activities like, for example, tillage, furrow, pass of step, crossing and seeding. In cultivated soils, the greatest contribution of carbon comes from harvest residues, hence the need for technological change that favors adaptation and / or mitigation of the effects of climate change, through CA. The term organic matter refers to the total amount of all the organic carbon contained in the soil. The main chemical element of all that content is carbon, hence the terms organic matter and carbon are used indiscriminately (Goddard *et al*., 2008).

In the initial physical - chemical characterization of the soil the pH values varied between 7.70 and 8.80, from slightly to medium alkaline, obtaining, as average, 8.18, medium alkaline; Organic matter averaged 1.9%, classified as low; and the electrical conductivity in the saturation extract ranged from 0.88 to 1.31 $dS.m^{-1}$, with mean values of 1.05 $dS.m^{-1}$, which classified the soil as No Saline. The apparent density was determined, with a value of 1.35 $g.cm^{-3}$, classified as medium to high. The values of humidity were between 12 and 17%, the average being 14.5%, to a depth of 60 cm.

Considering international experience accumulated on the implementation of CA system that proposes to obtain positive results between the 3 and 5 years after introduction, the demonstration area was monitored and these parameters were monitored during 3 years, maintaining a rotation in the system with crops like sorghum, beans, maize and squash, fundamentally.

The average values of pH obtained were kept within the initial range, that is, from slightly to medium alkaline, but with a slight decrease to 7.7; an average of 2.5% of organic matter was obtained, showing an approximate increase of 30% with respect to the initial values, although it remains classified as low. Martínez et al. (2008) refer that organic matter in the soil affects the pH of the soil due to the various active groups that contribute acidity levels, to the cation exchange capacity and the nitrogen content present in the organic residues contributed to the soil. The electrical conductivity showed similar behavior, maintaining the classification of soil as No Saline.

The apparent density decreased 10% (1.22 $g.cm^{-3}$) classified as medium to high, showing a decrease in compaction and a benefit of other important physical properties (structural stability, porosity, infiltration velocity), which ratifies the thesis that the recovery of a soil is much slower than its destruction. Carter (2002) cited by Martínez *et al*. (2008) argues that the maintenance of adequate levels of organic matter in the soil contributes to decrease the apparent density and resistance to soil compaction.

Cairo (1982), showed that the increase of organic matter increases notably the stability of the aggregates, the porosity and consequently the permeability of the soil.

An increase in moisture retention in the soil profile of 20% was observed, allowing a more rational use of irrigation throughout the cycle. Karenski (1975), Geigel (1977) and Goddard *et al.* (2008), pointed out that the annual biomass contribution, besides protecting the soil from surface runoff with the layer that forms, increases water retention 3.15 times, which implies a considerable increase in infiltration capacity and decrease the loss of soil by trawling.

Through the VES, the soil structure was improved, with the presence of macro and micro pores, increased biological activity of the soil with the presence of earthworms in the first 20 cm of the soil and the formation of galleries. In the same way a better development of the root system could be appreciated. This corroborates the fact of the increase of the organic carbon in the soil, essential for the biological activity of the soil. The presence of these soil organisms allows the decomposition of organic residues actively participating in the cycles of many elements used by plants; in addition, they participate in the formation and stabilization of soil structure and porosity (Martínez *et al*., 2008).

There is also sufficient evidence in the literature that traditional agriculture lowers soil carbon and supports the increase of new and improved forms, such as CA, to preserve or increase the storage of organic matter in the soil, which allow better control of the carbon balance on the planet.

CONCLUSIONS

Soil, although the monitored properties present non-significant improvements, because their evaluation remains in the ranks characterized at the beginning of the system, showed signs of recovery in a fragile, difficult to manage ecosystem and the feasibility of Conservation Agriculture technology transfer. It is important to note that the increase of organic content in the soil, understood as organic carbon, favored the chemical, physical and biological properties evaluated in the demonstration area by means of Conservation Agriculture.

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2.7 | SOIL ORGANIC CARBON IN MEDITERRANEAN CROPPING SYSTEMS AND THE INFLUENCE OF CLIMATE CHANGE ON SOIL PHYSICAL QUALITIES

Pellegrini S.[1], Agnelli A.E.[1], Andrenelli M.C.[1], Barbetti R.[1], Lo Papa G.[2], Madrau S[1], Priori S.[1], Costantini E.A.C.[1*]

[1]CREA, Council for Agricultural Research and Economics. Firenze (Italy), edoardo.costantini@crea.gov.it

[2] University of Palermo

[3] University of Sassari

(*)Presenting author

ABSTRACT

Many soil properties are deemed to change significantly in response to climate change. However, soil management has been demonstrated to potentially cause much larger effects on soil features, thus there is the need to understand the interactions between climate and management on soil variations in the different cropping systems. This research work was aimed at estimating the climate change impacts on soils under main Mediterranean cropping systems. To this aim, we decoupled the impact of climate from that of agricultural husbandry through investigating the soil-climate interactions in four areas, where specific soil types and cropping systems were placed along well defined climosequences of the past (1961-1990), present (1981-2010) and future (2021-2050). Soil C stock, bulk density, available water capacity, erodibility, crusting and compaction susceptibility, and erosion rate, were the variable of interest. Soil profiles analysed in the past were re-sampled and re-analysed. The interaction between climate, soil type, and specific soil quality differed between the studied cropping system. Andosols under olive trees resulted the most vulnerable soil type, that is, easily sensitive to climatic variations, while Vertisols of Sicily under cereal system showed to be the most affected to future climate change.

Keywords: SOC, climosequence, cropping systems, Mediterranean, climate change, Luvisols, Andisols, Vertisols, Italy

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Agricultural production is dramatically affected by climate variability and changes (Lal, 2004; Lobell, Schlenker and Costa-Roberts, 2011; Parry *et al.*, 2004). Producers, land managers, and other decision makers need information about the effects of climate changes on cropping systems, to develop mitigation and adaptation strategies, and policy measures (Olesen and Bindi, 2002). Due to the great variability of climate and soil cover, however, adaptation measures should be tailored according to specific conditions, to be really effective (Thornton *et al.*, 2009).

Although land use and management changes are expected to play a greater role than climate changes on soil properties and functions (Fantappiè, L'Abate and Costantini, 2011; Lal *et al.*, 2011), projected climatic conditions are considered to jeopardize several soil qualities and functions (Lal, 2004). Soil organic matter and its components, including biological activity, are the most sensitive and dynamic properties and therefore privileged indicators for monitoring land degradation processes, as well as adaptation and restoration strategies, also because they affect many other chemical, physical and hydrological soil properties and qualities (Costantini *et al.*, 2016; Kirschbaum, 1995). Soil physical and hydrological characteristics, in spite of being mainly indirectly related to climate changes, are of particular interest, for their paramount importance in shaping soil services (Powlson *et al.*, 2011).

Soil organic matter content (SOM) variations observed along climatic gradients (climosequence) can provide information about potential fluctuations in past or future climatic scenarios.

This research work was aimed at estimating the climate change impacts and vulnerabilities of soils under main Mediterranean cropping systems. To this aim, we decoupled the impact of climate from that of agricultural husbandry through investigating the soil-climate interactions in specific soil types and cropping systems placed along well defined climosequences of the past (1961-1990), present (1981-2010) and future (2021-2050).

METHODOLOGY

Cereal monocultures on Vertisols (CV) of Sicily (about 354,000 ha), permanent pastures and meadows on sandy loam Luvisols (PL) of Sardinia (169,000 ha), olive tree cultivation in medial Andosols (OA) of Campania (4,000 ha), and forage and livestock production on loamy Luvisols (FL) of Po Plain (150,000 ha) were the Mediterranean cropping systems that we selected for the investigation. These are among the most characteristic and widespread cultivations in the agricultural areas of Mediterranean countries and, at same time, among the least affected by the dynamic of land use and management; therefore, their soils were expected to reflect better than others the possible modifications caused by climate changes.

The test areas were placed and dimensioned so to encompass well-characterized climates and transition environments within a cropping system, cultivated on the same soil type. The areas were all located in Italy, spanning from the 37° to the 46° parallel north, including the main climatic conditions of Mediterranean agricultural soils, namely, Mediterranean sub-oceanic, sub-continental, and subtropical (Costantini and Lorenzetti, 2013). The considered time series were the 1961-1990 30-year period, selected as the baseline climate by most authors (e.g., IPCC, 2006), named period 1, the decade closest to the present climate (1981-2010, period 2), and the future climate projection (2021-2050, period 3).

The sampling sites in each study area were selected from the national soil database (CNCP), taking all the georeferenced soils profiles located along a climatic gradient, belonging to the same soil typology, placed on similar morphological position and parent material, and under the same cropping system. As a whole, 59 sites were identified, sampled in the time period from 1960 to 2000. The sites were re-sampled in 2010-2011, to check the occurred changes in soil characteristics. To improve the spatial representativeness of the soil-climate relationship, the sample size of all climosequences was increased, and further 55 sampling sites were selected and investigated. The permanence along time of the same crop system in each sampling site (old and new) was checked through a multi-temporal remote analysis.

Physical and chemical characterization of the surface soil layer (0-30 cm) was made according to internationally recognized analytical methods: pH, electrical conductivity (EC 1:2.5), total organic carbon (TOC), total nitrogen (N), total limestone ($CaCO_3$), bulk density (BD) and plant available water capacity (AWC). The soil particle size distribution was determined by the Sedigraph X-ray attenuation method (Andrenelli, Fiori and Pellegrini, 2013). Soil data were used to estimate soil carbon stock and several physical qualities, namely, bulk density, available water capacity, erodibility (Torri, Poesen and Borselli, 1997), crusting and compaction susceptibility (Vignozzi *et al.*, 2007), and erosion rate.

Fig. 1: study areas and climatic regimes

Several climatic indices were calculated on a 30 km grid and downscaled to 500 m using DEM and distance from the sea as covariates. Future climate was inferred for four stations placed inside the studied areas according to Tomozeiu *et al.* (2010) and related to SOC variations.

RESULTS

The Index of de Martonne (P/T +10; IDM) resulted the most correlated to SOC among the studied climatic indices and was taken as a reference for the next elaborations. The IDM values in the investigated areas in the first (1961-1990) period resulted generally lower than the second (1980-2010), pointing to a significant increase in aridity, apart from Sicily, where it increased. The linear relationships between IDM and SOC found in the first (1961-1990) and second (1980-2010) period resulted both statistically significant in each studied area. The correlation in the two periods was not significantly different, therefore we could assume that the influence of climate on SOC content is relatively stable, and could be applied to future climatic scenarios. The estimated climatic condition during the third period (2021-2050) pointed to a significant increase in temperature in the four areas, but with variable rainfall regime. Therefore, aridity was deemed to severely increase in Sicily but lower in Po Plain, whereas Sardinia and Campania did not show important variations.

The relationship between IDM and soil qualities were all significant, except for bulk density and available water capacity, but rather different between the four soil types. Andosols under olive trees were the most vulnerable, that is, easily affected by small climatic variations, while Vertisols under cereals resulted relatively more resilient to future climate change.

Applying the relationship between IDM and SOC in each area to the future climatic scenario, we obtained the estimation of the future SOC content in the studied cropping systems. The projected value of SOC and climatic parameters allowed to calculate the future values of the considered soil qualities.

Table 1: Descriptive statistics (mean values and std deviation) of IDM index and main soil functions related to the organic carbon content and erosion rate by RUSLE model for the three compared decades (1961-1990, 1981-2010 and 2021-2050).

Decade	Cropping system*	IDM	C stock (kg m-2)	K	**Compaction susceptibility (dimensionless)**	Crusting susceptibility (dimensionless)	Erosion rate (Mg ha^{-1} y^{-1})
1961-1990	CV	21.8 (2.1)	5.21 (0.33)	0.0284 (0.000093)	1.783 (0.016)	0.922 (0.012)	30.3 (25.4)
	PL	20.4 (2.0)	3.49 (0.27)	0.0379 (0.000338)	1.805 (0.015)	1.683 (0.036)	4.0 (7.3)
	OA	42.2 (3.7)	6.52 (0.59)	0.0345 (0.001122)	1.656 (0.021)	1.256 (0.046)	20.7 (17.5)
	FL	41.4 (4.4)	3.07 (0.32)	0.0413 (0.00028)	1.879 (0.020)	2.014 (0.048)	30.5 (30.7)
1981-2010	CV	23.1 (2.1)	5.96 (0.40)	0.0283 (0.000094)	1.744 (0.017)	0.894 (0.013)	33.7 (27.8)
	PL	19.4 (1.8)	3.49 (0.27)	0.0379 (0.000355)	1.804 (0.016)	1.681 (0.038)	3.7 (6.8)
	OA	35.6 (2.3)	5.68 (0.32)	0.0362 (0.000619)	1.697 (0.016)	1.343 (0.035)	17.5 (14.8)
	FL	36.0 (2.3)	2.88 (0.33)	0.0413 (0.000282)	1.884 (0.021)	2.025 (0.052)	25.6 (25.1)
2021-2050	CV	19.7 (1.8)	5.29 (0.36)	0.0285 (0.000072)	1.774 (0.016)	0.916 (0.012)	31.8 (26.4)
	PL	20.2 (1.9)	3.49 (0.28)	0.0378 (0.000378)	1.797 (0.016)	1.665 (0.039)	4.2 (7.5)
	OA	33.7 (3.0)	5.32 (0.43)	0.0367 (0.000772)	1.711 (0.022)	1.370 (0.044)	18.3 (15.5)
	FL	41.5 (4.4)	3.71 (0.65)	0.0405 (0.000691)	1.835 (0.036)	1.909 (0.089)	27.8 (27.4)

* CV: cereal monocultures on Vertisols of Sicily, PL: permanent pastures and meadows on sandy loam Luvisols of Sardinia, OA: olive tree cultivation in medial Andosols of Campania, FL: forage and livestock production on loamy Luvisols of Po Plain.

DISCUSSION

In the future scenario of generalized temperature raising, but regionally variable rainfall distribution, the cereal cropping system on Vertisols of Sicily results to be the most affected. In fact, the soil C stock reduction here is estimated to be larger than 11%. The SOC content decline shows a clear influence on all soil physical qualities and, in particular, causes an increase of the compaction and crusting susceptibility, as well as of the erodibility index. In spite of that, the marked decrease in precipitation will produce a significant lowering of the soil erosion losses, which however will remain higher than tolerable rate.

The Andosols of Campania under olive tree cultivation, showed modifications only second to those of cereals on vertisols, for all the considered soil qualities.

The slight aridity decrease that was estimated to occur in Sardinia will produce no increase in SOC content and C stock of sandy loam Luvisols under pastures and meadows. The climatic improvement however will be only marginally reflected in an improvement of soil physical qualities. The erosion rate instead is deemed to increase notably, although the grass cover that characterize the land use, as a consequence of the augmented precipitation.

The elaborations depict a very dissimilar scenario for the fodder and livestock cropping system of Po Plain. The decreased aridity is going to induce a distinct increase of the SOC content and C stock of loam Luvisols, and a consequent improvement of their physical qualities. On the other hand, the expected increase in rainfall will produce an erosion rate more than 8% higher, which will not be set off by the improvement of soil physical conditions.

CONCLUSIONS

The foreseen climate change will produce in the soils of the years 2021-2015 important modifications, not only related to soil organic matter. Actually, changes in erosion rate will on average exceed carbon stock variations. Also crusting susceptibility results to vary markedly, in dependence of soil organic carbon. It must be stressed, however, that local variations will be surely greater than the general trend. Therefore the study points to strong interactions between climate change, soil type, cropping system, and specific soil quality.

The results of this study suggest that the implementation of conservative practices, such as conservation agriculture, are particularly to be encouraged for Andosols under olive tree and Vertisols under cereal cultivation. The study also demonstrates that soil climosequences can be recommended to relate soil qualities variations to climatic changes.

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2.8 | BIOCHAR AS A STRATEGY FOR SUSTAINABLE LAND MANAGEMENT AND CLIMATE CHANGE MITIGATION

Annette Cowie[1*], Lukas Van Zwieten[2], Bhupinder Pal Singh[2], Ruy Anaya de la Rosa[3]

[1]University of New England, Armidale, NSW Australia; UNCCD Science Policy Interface; annette.cowie@gmail.com

[2]NSW Department of Primary Industries, NSW Australia.

[3]Starfish Initiatives, Armidale, NSW Australia

ABSTRACT

Biochar could play a role in sustainable intensification and climate smart agriculture, through its capacity to enhance land productivity, build soil carbon, contribute to climate change mitigation via multiple mechanisms, and strengthen resilience of agricultural systems. Biochar is produced by pyrolysis, in which biomass is heated under oxygen limitation. Biochar properties depend on the biomass source, pyrolysis conditions and post-production treatments. Biochar is most beneficial in rehabilitating degraded lands and improving low-fertility soils with defined constraints to production. While carbon stabilisation is certain, other impacts of biochar vary widely and benefits are not universally observed. Biochars should be engineered to address specific soil/crop constraints in each target application. Enriched biochar, produced by adding minerals during pyrolysis and/or reacting the biochar with organic matter and minerals, has been shown as an effective fertiliser. Limitations to up-scaling biochar systems include constrained biomass availability particularly in drylands, high capital costs, lack of large-scale production facilities, and lack of awareness of the potential benefits and best methods for biochar utilisation. Risks associated with biochar include production in unsafe, polluting facilities; unsustainable harvest of biomass; and poor quality control. These risks can be managed through certification of biochar products, training and development of knowledge-sharing platforms to communicate best practice in production and use of biochar.

Keywords: Carbon sequestration; resilience; climate smart agriculture; life cycle assessment; greenhouse gas emission, soil health.

EXTENDED ABSTRACT INTRODUCTION

Feeding the world's growing population, expected to reach 9 billion by 2050, will be a major challenge, particularly under the influence of climate change and escalating land degradation. In addition, there is increasing competition for land for productive purposes (animal feed, fibre, timber), for urban expansion, transport infrastructure and mining, and for biodiversity protection and recreation.

Increasing food production while per capita resources are decreasing will require increased intensity of production, which may have undesirable environmental consequences if achieved through increased use of chemical fertilizers, agricultural chemicals and irrigation. It is critical that sustainable intensification practices are employed, focusing on efficient use of water, nutrients and land; protection of soil resources; and minimizing off-site impacts on natural and human systems.

Biochar could make an important contribution to sustainable intensification, while improving soil health. Furthermore, biochar offers benefits for climate change mitigation and adaptation. This paper summarises recent findings on the benefits and limitations of biochar in sustainable land management.

ROLE OF BIOCHAR IN CLIMATE CHANGE MITIGATION

Biochar is organic matter that is carbonized by heating in an oxygen-limited environment, and used as a soil amendment. Biochar can be produced from a wide range of organic sources including crop and forest residues, food processing waste, urban green waste, bio-solids, algae and animal manures.

The carbonization process stabilizes the carbon (C) in the biomass. Thus, biochars are relatively resistant to decomposition and therefore provide a long-term C store. Biochars have different properties depending on the feedstock, the conditions of production and post-production treatment: biochars produced at higher temperature, and from woody material tend to have greater stability than those produced at lower temperature, and from manures (Singh *et al*., 2012). Biochar stability is influenced by soil properties at the site of application, being further stabilized by interaction with clay minerals and native soil organic matter (Fang *et al*., 2015). Biochar stability has been estimated to range from decades to thousands of years, for different biochars in different applications (Weng *et al*., 2015; Singh *et al*., 2015).

Application of biochar may further enhance soil carbon stocks through "negative priming", in which plant-derived carbon is stabilized through sorption of labile C on biochar, and formation of biochar-organo-mineral complexes (Keith *et al*., 2011; Weng *et al*., 2015). Conversely, turnover of native soil carbon may increase ("positive priming") due to enhanced soil microbial activity induced by small amounts of labile C in biochar, but this effect is small and short-lived compared to the stabilization of biochar carbon and negative priming effects in the long-term (Singh and Cowie, 2014). Negative priming has been observed particularly in clay-dominated soils (Weng *et al*., 2015; Whitman *et al.,* 2015).

Biochar can provide additional climate change mitigation benefits through:

- Lower nitrous oxide (N_2O) emissions from soil: a meta-analysis showed an average decrease in emissions from soil of 54% (Cayuela *et al*., 2014). Processes involved in this response include decrease in substrate availability for denitrifying organisms, driven by the molar H/C ratio of the biochar (Cayuela *et al*., 2015). Recent studies have improved understanding of the processes involved, and increased ability to predict the likely impact based on biochar characteristics, soil type and environment. Decrease in N_2O emissions from agricultural soils could be important for intensive broadacre and horticultural cropping systems with high N fertilizer inputs, particularly where irrigated, or for manure feedstocks where emissions from manure processing (Agyarko-Mintah *et al*., 2016) and application can be reduced.
- Reduced fertilizer requirements: there is substantial evidence that biochar reduces the requirement for fertilizer, due to reduced losses of nutrients through leaching and/or volatilization. This is particularly important for nitrogen (N) fertilizer, the production of which is a greenhouse gas (GHG)-intensive process.
- Avoided emissions from decomposition of organic wastes that are instead used for biochar, such as manure that would otherwise be stockpiled, crop residues that would be burned or processing residues that would be landfilled.

Biochar is a potential "negative emissions" technology: the thermochemical conversion of biomass to biochar slows mineralization of the biomass, delivering long term C storage; gases released during pyrolysis can be combusted for heat or power, displacing fossil energy sources, and could be captured and sequestered if linked with infrastructure for carbon capture and storage (Smith, 2016).

ROLE OF BIOCHAR IN SUSTAINABLE LAND MANAGEMENT

Biochar can contribute to sustainable land management through the following documented benefits:

- Increased yields: biochars have variable impacts on yields, depending on the feedstock, properties of receiving soil and the target crop, and negative responses are sometimes seen (Macdonald *et al*., 2014). Yield benefits are generally greatest in poor soils, especially light-textured acidic or degraded soils. Meta-analyses show that the average yield response is +10% (Jeffrey *et al*., 2011). Identifying soil constraints and addressing these with appropriate biochar is essential to obtain a positive outcome.
- Improved nutrient use efficiency: biochars can enhance retention of N and availability of phosphorus (P) in soils with high P fixation capacity, potentially reducing fertilizer requirements. Furthermore, biochar produced from nutrient dense feedstocks, such as poultry litter, can substitute chemical fertilizer.
- Management of heavy metals: application of biochar can reduce availability of heavy metals, thus providing an affordable means of remediating contaminated soils, and enabling the continued utilization of such soils for food production.
- Improved water holding capacity: biochar could limit plant water stress in sandy soils by improving the soil's water holding capacity (Basso *et al*., 2013).

Biochar systems can deliver a range of other co-benefits, such as waste management, destruction of pathogens and weed propagules, avoidance of landfill, improved ease of handling, management of odors, reduction in environmental N pollution, protection of waterways and soil remediation.

RISKS AND CONSTRAINTS TO BIOCHAR UP-SCALING

The following issues have been identified:

- Limitations of biomass availability: in dryland developing countries, biomass is utilized for fuel, feed and soil protection, and there is rarely surplus that could be used for biochar. Nevertheless, conversion from inefficient fuelwood use to efficient biochar stoves could allow biochar production, while also reducing indoor air pollution.
- Risk of unsustainable harvest of biomass: unless controlled, biomass could be harvested unsustainably, with negative implications for C stocks, biodiversity and local communities. Purpose-grown biomass for biochar production may be a viable land use on marginal or contaminated lands that are not suited for cropping. However, if practiced on productive land, there is a risk of indirect land use change that should be quantified, and policies should be introduced to minimize this risk.
- Risk of polluting production methods: to ensure that biochar production does not contribute to air pollution and methane emissions, it is critical that biochar is produced in a facility that captures or combusts the gases released during pyrolysis. The heat produced through combustion of pyrolysis gases can be used as renewable energy. Biochar production can occur at scales ranging from cookstoves to large engineered industrial plants.

POTENTIAL CONTRIBUTION TO CLIMATE CHANGE MITIGATION

Studies of the life cycle climate change impacts of biochar systems generally show emissions reduction in the range 0.4 -1.2Mg CO2-e Mg^{-1} (dry) feedstock. The proportion of C sequestered and GHG emissions avoided varies widely between biochars, soils and target crops. For example, biochar applied to wheat grown in a sandy soil in a temperate environment could give 32-62% lower abatement than the same biochar applied to maize grown in a clayey soil in a subtropical environment (Cowie and Cowie, 2013).

A global analysis in which sustainability constraints were applied to protect against food insecurity, loss of habitat and land degradation, found that annual net GHG emissions could be reduced by up to 3.7 - 6.6Pg CO_2-e per year (7 to 12% of 2012 anthropogenic GHG emissions), with total net emissions over the course of a century reduced by 240 – 475Pg CO_2-e. (Woolf *et al.,* 2010).

NOVEL BIOCHAR FORMULATIONS

Much of the research into biochar has utilized high doses – e.g. ≥10 t ha^{-1} – of raw biochar. However, high rates of application may be prohibitively expensive for many land holders. Improved understanding of the chemical reactions occurring at the biochar surface has led to design of enriched biochar, produced through mixing biomass with minerals prior to pyrolysis, or composting biochar with manure and ash. These nutrient-enhanced biochar formulations can be effective in stimulating plant growth and/or immobilizing heavy metals at much lower application rates (Joseph *et al*., 2013).

CONCLUSIONS

Application of biochar as a soil amendment has been trialed in a wide range of agricultural systems, on various field crops and pastures around the world. Studies have found that biochar can improve plant yields, enhance soil water holding capacity and reduce fertilizer requirements, though results vary widely between different biochars, soil types, climates and target crops. Biochars should be designed to address specific soil constraints.

There are a range of mechanisms by which biochar can deliver GHG mitigation: the most important, and best understood, are stabilization of C in biomass feedstock (delaying significantly the decomposition of biomass), and displacement of fossil fuels with the combustible gases or bio-oil which are co-products of biochar production. Other mechanisms that can contribute to mitigation include lowered N_2O emissions from soil; reduced fertilizer manufacture; enhanced growth; reduced fossil fuel use in irrigation and cultivation; and avoided emissions from biomass decomposition. Recent evidence indicates that biochar can stabilize C inputs to soil from plants, thus increasing soil C stocks beyond the C applied in biochar.

Biochar is thus a technology that can simultaneously enhance soil productivity, and contribute to climate change mitigation and sustainable development. It is therefore well-suited as a strategy for sustainable land management and climate smart agriculture.

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2.9 | THE POTENTIAL OF REDUCING TILLAGE FREQUENCY AND INCORPORATING PLANT RESIDUES AS A STRATEGY FOR CLIMATE CHANGE MITIGATION IN SEMIARID MEDITERRANEAN AGROECOSYSTEMS

Almagro, M[1]., Garcia-Franco, N[2]., de Vente, J[*1];Boix Fayos, C[1].; Diaz-Pereira, E[1]; Martínez-Mena, M[1].

1. CEBAS-CSIC; almagromaria@yahoo.es;Campus Universitario de Espinardo 30100, Murcia (Spain)
2. TUM School of Life Sciences Weihenstephan, Technical University of Munich, Freising, Germany

ABSTRACT

Here, we assess the effects of different soil management practices (conventional tillage, reduced tillage, reduced tillage plus green manure, and no tillage) on soil CO_2 flux dynamics and carbon sequestration in two organic rainfed almond (*Prunus dulcis* Mill.) orchards under semiarid conditions. Soil CO_2 flux, temperature, and moisture were measured monthly over two-three years, and shortly after tillage operations. The soil aggregation distribution (including micro-aggregates occluded within macro-aggregates) and associated organic carbon content were measured after four years of implementation. No significant differences in CO_2 emissions among the soils subjected to the distinct management practices were observed at either site. Moreover, improved soil management practices enhanced the organic carbon content in aggregates of all sizes and modulated the response of soil CO_2 flux to temperature and moisture in these semiarid Mediterranean agroecosystems. According to our results, soil CO_2 flux under the conventional tillage treatment was more sensitive to temperature increments than with the reduced tillage treatments, indicating that bare soils will be more vulnerable to mineralization with global warming. However, plant residues incorporation promoted soil aggregation and organic carbon preservation, making soils more resilient to abrupt changes in temperature and moisture.

Keywords: Improved soil management; Green manure; Almond orchards; Soil CO2 emissions; Carbon sequestration; Occluded micro-aggregates.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The importance of improved soil management practices in the mitigation of the current atmospheric CO2 increase through the enhancement of soil organic carbon (SOC) levels has long been recognised (Aguilera et al. 2013), but a proper understanding of the response of Mediterranean soils to climate change and their mitigation capacity, if managed sustainably, is still lacking. Despite much research on soil CO2 flux dynamics in relation to improved soil management in Mediterranean and other dry environments (Abdalla et al. 2016), few studies have been conducted in woody cropping systems (but see Montanaro et al. 2016) and it is not yet clear which factors control the total amount of carbon released to the atmosphere and its implications for the SOC balance. The main purpose of this study was to compare the soil CO2 flux dynamics and carbon sequestration performance of several soil management practices differing in tillage frequency and plant residue management, for two organic rainfed almond orchards with similar climatic conditions but different land management history. Specifically, we aimed to: i) characterize the short-term response of soil CO2 flux to tillage operations and its implications for annual soil CO2 emissions; ii) assess the effect of improved soil management practices on SOC stabilization; and iii) examine if the response of soil CO2 flux to soil temperature and water content varies among soil management practices. We expect that the adoption of improved soil management practices will enhance the carbon sequestration capacity of Mediterranean agricultural soils. We also hypothesize that changes in soil environmental conditions driven by improved soil management will modulate the response of soil CO2 flux to increments in soil temperature and moisture fluctuations, making Mediterranean agricultural soils more resilient to the forecasted climate change.

METHODOLOGY

The rates of soil CO2 emission to the atmosphere were measured in situ with a Licor 8100 closed chamber system (LI-COR, Lincoln, NB, USA). For each management practice treatment, four PVC circular collars (5 cm deep, 10 cm in diameter) were inserted into the soil surface in the inter-tree locations, 3.5 m from the tree trunks. Simultaneously with the soil CO2 flux measurements, the soil temperature (T) and volumetric soil water content (SWC) were measured at the 0-12 cm depth interval, adjacent to each soil collar. Soil temperature was automatically recorded with a LI-8100 soil temperature probe, and soil water content was measured using a FDR soil moisture sensor (HOBO event, 12 cm in length, Massachusetts, USA). The total plant biomass production – green manure or spontaneous annual and perennial grasses – was collected in May from four quadrants (1 m x 1 m) placed randomly for each management treatment. Soil samples were collected from the plow layer following crop harvest in November 2012, four years after the management practices were implemented. Aggregate-size separation was carried out on each soil sample using a modified wet-sieving method adapted from Elliott (1986).] A series of three sieves (2000, 250, and 63 μm) was used to obtain four aggregate size classes: (i) large macro-aggregates (LM; > 2000 μm); (ii) small macro-aggregates (SM; 250-2000 μm); (iii) micro-aggregates (m; 63-250 μm); and (iv) silt plus clay-sized particles (s + c; < 63 μm). The protected micro-aggregates contained within the small macro-aggregates (SMm) were obtained using the micro-aggregate isolation method described by Six et al. (2000) and Denef et al. (2004). The organic carbon (OC) concentration was analyzed separately for each water-stable aggregate-size class, as well as for the micro- within macro-aggregates, using the elemental analyzer mentioned above, after soil carbonates had been eliminated using 2 M HCl. The SOC stocks (g m^{-2}) were calculated as a product of the OC concentrations, soil bulk density (corrected for rock fragments), and depth of the plow layer for each management treatment and site.

RESULTS

Soil CO2 flux rates in all management treatments varied significantly during the year, following changes in soil temperature during the fall, winter, and early spring, or changes in soil moisture during late spring and summer. Repeated-measures ANOVA revealed no significant differences in the soil CO2 flux rates among management practices throughout the study period at either site. The flux rates increased significantly shortly after the winter and spring tillage operations at Burete, but they levelled-off one (in winter) or three (in spring) days after tillage. Immediately after the winter tillage, soil CO2 flux increased by 60% on average for the reduced tillage (RT) and green manure (RTG) treatments. In spring, soil CO2 flux increased by 68% and 46% on average for the RTG and RT treatments, respectively, during the first two days following tillage. The responses of soil CO2 flux to temperature were similar among the soil management practices during the growing period. However, the response of soil CO2 flux to soil moisture was affected by the soil management during the dry period. In particular, suppression of tillage led to a lower basal soil CO2 flux rate and less responsiveness to soil moisture fluctuations at Burete, while soil CO2 flux under the green manure treatment appeared to be less responsive to soil moisture fluctuations at Alhagüeces. The suppression of tillage increased the proportion of large and small macro-aggregates but did not enhance the OC content of any aggregate size. However, green manure incorporation increased the proportion of small macro-aggregates and micro-aggregates occluded within the small macro-aggregates (SMm), while enhancing the OC content in all aggregate sizes. At Alhagüeces, reduced tillage frequency combined with the incorporation of plant residues increased the proportion of micro-aggregates occluded within small macro-aggregates (SMm). In addition, the RT and RTG treatments gave a greater OC content in most aggregate sizes, with the exception of the silt plus clay fraction, compared to the CT treatment.

Table 1. SOC stocks, percentage of SOC change among control and improved soil management practices after four years of their implementation, carbon respired from soil , organic carbon mean residence time (MRT, yr-1), and plant residue inputs, for each management practice and site.

Site	Treatment	SOC stock (g m-2)	ΔSOC (%)	C respired (g m-2 yr-1)	MRT (SOC:C respired)	Plant inputs (g m-2 yr-1)
	RT	2517	nd	492	5.1	78.6
Burete	RTG	3703	47	492	7.5	128.8
	NT	2544	1	405	6.3	120.7
	CT	4223	nd	399	10.6	negligible
Alhagüeces	RT	5448	29	469	11.6	173.6
	RTG	5551	31	439	12.6	174.4

RT: reduced tillage; RTG: reduced tillage plus green manure; NT: no tillage; CT: conventional tillage; nd: not determined. SOC stocks at Burete were estimated based on an equivalent soil mass-depth basis.

DISCUSSION

The magnitude and duration of soil CO_2 peaks upon tillage vary depending on the prevailing soil environmental conditions and the legacy effect of historical management (Calderón et al. 2000). At our study sites, both the magnitude and duration of the soil CO_2 peaks after tillage were similar to those observed elsewhere (Abdalla et al. 2016) and did not significantly affect the annual CO_2 emissions of our semiarid Mediterranean agroecosystems.

At Burete, green manure incorporation had enhanced the OC content in all aggregate sizes (by 48% on average) without increasing soil CO_2 emissions to the atmosphere (compared to RT). By contrast, the suppression of tillage did not enhance the amount of OC stored in the soil compared to that of the RT treatment despite greater annual plant biomass inputs and somewhat lower amounts of carbon released to the atmosphere annually for the former treatment (Table 1). At Alhagüeces, contrary to what has been reported previously, reducing the tillage intensity did not decrease the amount of carbon released annually to the atmosphere. However, the SOC content was increased by 41% on average by both reduced tillage treatments at this site. It can be explained by the greater carbon inputs resulting from the incorporation of plant residues over the four years for both reduced tillage which promote soil aggregation and the physical protection of OC by aggregates (Garcia-Franco et al. 2015).

Soil management modified the response of soil CO_2 flux to temperature and moisture. During the growing period, soil CO_2 flux was more responsive to temperature under conventional tillage than under both reduced tillage treatments, despite the lower SOC content in the former at Alhagüeces. This pattern has been observed previously in other semiarid agroecosystems (Li et al. 2013), and highlights both the importance of plant covers in buffering the response of soil CO_2 flux to increased temperature through shading, and the fact that OC is physically protected by newly formed aggregates under the RT and RTG treatments. Contrastingly, bare soils are directly exposed and therefore would be much more susceptible to mineralization with the forecasted increase in temperature.

At Burete, however, soil under no tillage showed the lowest basal CO_2 flux rates and less responsiveness to soil moisture fluctuations during the dry period. These results are consistent with previous studies reporting lower soil CO_2 flux rates under NT and are explained by: i) the low-quality organic matter inputs (i.e., higher C:N) returned to the soil from its perennial plant cover, compared to the annual plant cover present in the reduced tillage treatments (Table 1); ii) plant residues left on the soil surface, rather than incorporated into soil by plowing, are less susceptible to decomposition (Almagro and Martínez-Mena, 2014); and iii) changes in soil environmental conditions (Martínez-Mena et al. 2013) that limit microbial activity.

CONCLUSIONS

Tillage operations had a rapid but short-lived effect on soil CO_2 flux rates, with no significant influence on the annual soil CO_2 emissions. Although four years may not be enough to assess changes in SOC, the results from this study suggest a trend towards enhancing SOC sequestration by reducing tillage frequency and incorporating plant residues into the soil in these semiarid Mediterranean agroecosystems. Our results also

show that improved soil management can modulate the response of soil CO_2 flux to temperature and moisture in semiarid Mediterranean agroecosystems. For the conventional (intensive) tillage treatment, soil CO_2 flux was more sensitive to temperature increments than under the reduced tillage treatments, indicating that bare soils (including fallow fields) will be more vulnerable to mineralization as global warming proceeds. However, plant residues incorporation promoted soil aggregation and organic carbon preservation, making soils more resilient to abrupt changes in temperature and moisture. These findings also emphasize the need for results derived from longer-term studies (> 10 years), as well as studies at larger spatial scales representing a wide range of climatic conditions, to fully understand the mitigation potential of improved soil management practices in semiarid agroecosystems under climate change.

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2.10 | LOSSES AND REDISTRIBUTION OF ORGANIC CARBON BY EROSION IN FRAGILE AGRICULTURAL AND RESTORED CATCHMENTS

Boix Fayos, C[1], de Vente, J[1*], Nadeu, E[1], Almagro, M[1], Pérez-Cutillas, P[2], Navas, A[3], Gaspar, L[4], Martínez-Mena, M[1]

1. Soil and Water Conservation Group, CEBAS-CSIC, Campus Universitario de Espinardo 30100, Murcia (Spain)
2. Department of Geography, University of Murcia, Campus de la Merced, 30100, Murcia (Spain)
3. Experimental Station Aula Dei, EEAD-CSIC, Spanish Research Council, 1005 Avda. Montañana, Zaragoza, Spain.
4. Environmental Science Program, University of Northern British Columbia, 3333 University Way, Prince George, British Columbia, V2N 4Z9, Canada.

ABSTRACT

Although large efforts are being made to understand the flow paths of OC at the catchment scale, studies carrying out estimations of redistribution of organic carbon by lateral flows at this scale are still scarce. Particularly little is known on how organic carbon is redistributed on fragile environments with a variety of lithologies, combined land uses (large agricultural areas adjacent to large reforested areas) and ephemeral hydrological and sedimentological pulses, typical of Mediterranean conditions. The objective of this work was to estimate the organic carbon redistributed by lateral flows in representative Mediterranean catchments, highly disturbed by agricultural terraces, land levelling for agriculture, reforestation and construction of check-dams, with erodible lithologies and shallow soils.

A general estimation of total organic carbon redistributed by lateral flows was carried out in two medium sized catchments (2000-5000 ha) in SE Spain, with contrasting climatic conditions (semiarid versus subhumid). Existing data on the mass of sediments behind check-dams, organic carbon concentration of soils and sediments, and spatial information were combined to estimate organic carbon redistributed by erosion processes on both catchments. The results show that sediments had organic carbon concentrations similar to those of agricultural soils but much lower than those of forest and shrubland soils. Overall, a loss of more than 10% of the superficial soil carbon stock can be attributed to erosion processes during studied period (20-30 years), with an annual rate of 0.4% for both studied catchments. It was estimated that between 60-70 % of the organic carbon redistributed by lateral fluxes was redeposited within the fluvial system, with different residence times depending on the fluvial dynamics, and the rest was exported downstream or lost by mineralization. These results point out the need to protect soil organic carbon resources in active fluvial environments of such fragile ecosystems. This can be achieved, for instance, by stabilizing organic carbon in soils and sediments and decreasing connectivity of rich-carbon soils with channels.

Keywords: organic carbon redistribution, lateral fluxes, catchment scale, restored lands, reforestation, check-dams, soil carbon yield.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Lateral flows of sediment are affected by agricultural management practices and by land use changes (Van Oost *et al.,* 2007; Martinez-Mena *et al.*, 2008; Quijano *et al.*, 2016), which influence runoff production, soil stability, sediment detachment and available SOC in the soil surface, having thus an influence on the SOC detached and transported (Martínez-Mena *et al.*, 2012; Nadeu *et al.*, 2015; Quijano *et al.*, 2016). Multiple experiences at plot and field scales reported selective erosion of fine particles and enrichment of SOC in sediments compared to the original soils (Starr *et al.*, 2000; Martínez-Mena *et al.*, 2012). However, the redistribution of organic carbon by lateral flows at the watershed scale seems to be much more complex with interference of other ecogeomorphological processes (Boix-Fayos *et al.*, 2015).

In addition to the factors and mechanisms mentioned above, redistribution of organic carbon by lateral flows at coarser scales can be affected by fluvial processes, complex erosion patterns (gully, channel and bank erosion) and by transport and post-depositional processes in sediments (Van Hemelryck *et al.*, 2011; Boix-Fayos *et al.*, 2015). The catchment scale research on this matter could identify organic carbon sinks providing insight on opportunities for carbon sequestration through sediments management.

Therefore to close carbon budgets at the catchment scale, it is crucial to understand how organic carbon moves with sediments along fluvial paths (Hoffmann *et al.*, 2013). However, although large efforts are being made to understand the flow paths of OC at the catchment scale, the studies carrying out estimations of global redistribution of organic carbon by lateral flows at this scale are still scarce. Particularly, little is known on how organic carbon is redistributed on fragile environments with a variety of lithologies, combined land uses (large agricultural areas adjacent to large reforested areas) and ephemeral hydrological and sedimentological pulses, typical of Mediterranean conditions. The objective of this work was to estimate the organic carbon redistributed by lateral flows in two representative Mediterranean catchments, highly disturbed by agricultural terraces, land levelling for agriculture, reforestation and construction of check-dams, with erodible lithologies and shallow soils.

STUDY AREA AND METHODOLOGY

Research was carried out in two catchments (Cárcavo and Rogativa) in SE Spain, representing medium mountain Mediterranean environments with a variety of land uses, mainly agriculture and reforested land, and different climatic conditions. Both catchments had large extensions dedicated to agriculture in the 1950's (40-50 % of their catchment area), however socioeconomic evolution of the area led to a large abandonment of agricultural activities in the second half of last century. Besides, large reforestation works and hydrological control works were carried out in order to prevent flooding and siltation of water reservoirs downstream of each catchment. Both catchments have experienced a greening up effect in the last decades, due to natural and induced reforestation (>50 % of forest in the drainage area nowadays). The Cárcavo catchment has more arid conditions, with 279 mm of precipitation per year, an extension of 2732 ha, and a lithology of marls, limestones and Quaternary deposits. In the 1980's a net of 36 check-dams was constructed to prevent floods. The Rogativa catchment has subhumid conditions with 530 mm of precipitation per year, a mixed lithology including marls, sandstones and limestone. It has an extension of 4770 ha and in the 1970's a net of 58 check-dams was constructed mainly to prevent siltation of the downstream Taibilla reservoir.

In both areas an extensive research has been carried out in the last decade on land use changes, erosion processes, fluvial dynamics and organic carbon redistribution by lateral fluxes (Boix-Fayos *et al.*, 2007, 2009, 2015; Castillo *et al.*, 2007; Nadeu *et al.*, 2012, 2015; Nadeu, 2013). From this research data bases on different sediment, soil and erosion processes information were available. The research methodology combined fieldwork (sampling sediments at subcatchment level, sampling soils and geomorphological mapping), laboratory analysis (physicochemical characteristics of sediments and soils) and spatial GIS analysis of catchment and subcatchment areas. In this work we use the total sediment masses retained in the check-dam network of both catchments (Castillo *et al.*, 2007; Boix-Fayos *et al.*, 2007), the organic carbon data of soils and sediments and spatial data extracted for catchment areas (Boix-Fayos *et al.*, 2015 and Boix-Fayos *et al.*, 2017).

We estimated the total organic carbon (TOC) redistributed (TOC_{red}) by lateral flows at the catchment scale both for Cárcavo and Rogativa catchments, recalculating values after Nadeu (2013), and using her same approach, by:

$$TOC_{red} = 0.26 \times TOC_{red} + 0.20 \times TOC_{red} + \sum TOC_{CD} + \sum TOC_{exp}$$

Where 0.26 was extracted from modelling exercises at the subcatchment level in the Rogativa catchment and represents the fraction of sediment that it is redeposited at the hillslopes after initial erosion (Nadeu *et al.*, 2015), 0.20 was extracted from literature review representing the fraction of soil organic carbon that is mineralized during transport and deposition processes (van Hemelryck *et al.*, 2010). TOC_{CD} represents total organic carbon stored in alluvial wedges behind check-dams and TOC_{exp} represents organic carbon exported downstream check-dams, being both estimated from the volume and the density of sediments retained by check-dams and the trap efficiency of those as in Boix-Fayos *et al.* (2009).

RESULTS

In both catchments, organic carbon concentration of sediments in the fluvial system and stored in alluvial wedges at check-dams is significantly lower than the soil organic carbon concentration of forest and shrubland soils (Table 1). On average, sediments in both catchments contain a 43% of the organic carbon of forest soils (Table 1). However, organic carbon concentration is higher in sediments than in agricultural soils, although without significant differences between both groups. The specific soil carbon yield estimated at the catchment scale is similar for both areas (0.040 tn ha^{-1} yr^{-1} and 0.037 tn ha^{-1} yr^{-1} for Cárcavo and Rogativa catchment, respectively).

Table 1. Indicators of the Total Organic Carbon concentration, stored and exported in the Cárcavo and Rogativa catchments

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	TOC	TOC	TOC	Soil	TOC buried	TOC exported	Specific soil carbon
Land use	forest	agricultural	Sediments	TOC	check-	downstream	yield (SCY)
pattern	soils	soils	0-100 cm	stock	dams	check-dams	catchment
	g kg-1	g kg-1	g kg-1	5 cm	tn	tn	tn ha^{-1} yr-1
				tn ha^{-1}			
Cárcavo							
1981	15.2 ± 9.35a	4.4±1.06b	6.6b	7.3	677.65	45.156	0.040±0.047
Rogativa	18.82 ±						
1974	5.37a	8.12 ± 3.20b	11.7b	9.31	1654.18	502.29	0.037±0.045

a,b show significant differences between groups of samples according to Kruskal-Wallis test at $p < 0.005$.

Total organic carbon removed by erosion processes represented an 11.37% of the superficial 5 cm soil stock in 21 years for the Cárcavo basin, and a 10.60 % of that for the Rogativa basin in 27 years. The rate of TOC soil loss with respect to the original soil stock was 0.54 % per year in Cárcavo and 0.39 % in Rogativa basin. From the organic carbon redistributed by lateral fluxes, 69% and 61% was redeposited within the fluvial system in Cárcavo and Rogativa, respectively, with different residence times depending on the fluvial dynamics, while the rest was exported downstream or lost by mineralization.

DISCUSSION

The sediments circulating in the Cárcavo and Rogativa fluvial systems are on average impoverished in TOC, when compared to the values reported for eroded sediments obtained at smaller scales in erosion plots (Quinton *et al.*, 2006; Martinez-Mena *et al.*, 2008). This can be explained by the different erosion processes mobilizing sediments at different spatial scales (Boix-Fayos *et al.*, 2009; Nadeu *et al.*, 2012). At the hillslope scale, sediments impoverished in TOC are found occasionally when compared to reference sites, but sediments enriched in TOC are also found due to high burial efficiency (Wang *et al.*, 2015). At the catchment scale, both sediments impoverished in TOC with respect to catchment soils (Boix-Fayos *et al.*, 2015; Ran *et al.*, 2014) and sediments enriched in TOC associated with the suspended load (Rhoton *et al.*, 2006) have been reported.

The sources of sediments and how sediments are connected to the fluvial channel and transported seem to have a key role in determining the enrichment or depletion of OC in sediments with respect to the catchment reference soils (Nadeu *et al.*, 2012). The specific carbon yield (or TOC erosion rate) in the studied catchments are lower than the ones reported for humid ecosystems - such as 0.07 Mg ha^{-1} y^{-1} (Smith *et al.*, 2005) and 0.113 Mg ha^{-1} y^{-1} (Izaurralde *et al.*, 2007), but the same to the value (0.04 Mg ha^{-1} y^{-1}) reported by Doetterl *et al.* (2012) derived from the modelling of eroded pastures worldwide. It is also close to the one reported by Ma *et al.* (2016) (0.032Mg ha^{-1} y^{-1}), in their study of diverse reforested areas. Those authors considered that reforestation was not an optimal solution of land restoration in their area in terms of soil loss and C sequestration.

CONCLUSIONS

In fragile Mediterranean environments with active geomorphological processes, despite restoration activities (reforestation and hydrological control works), erosion processes caused the loss of more than 10% of the superficial soil carbon stock during the studied period (20-30 years). At this catchment scale, sediments flowing within the fluvial system have similar concentrations of organic carbon than agricultural soils of the catchments. Losses of soil organic carbon due only to lateral fluxes represent a rate of at least 0.4% per year in both studied catchments, without taking into account losses of organic carbon due to other processes (as land use conversions and land management practices). Those results point out the need to protect soil organic carbon resources in active fluvial environments of those fragile ecosystems, for instance with measures for stabilizing organic carbon in soils and sediments and decreasing connectivity of rich-carbon soils with fluvial channels.

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2.11 | LAND MANAGEMENT IMPACT ON OIL ORGANIC CARBON STOCKS – WHAT DO WE REALLY KNOW?

Axel Don*
Thünen Institute of Climate-Smart Agriculture, Branschweig, Germany, axel.don@thuenen.de

Agricultural management and land use deplete soil organic carbon stocks with global impact on the soil carbon cycle. However, there are several management options in agriculture that aim at recovering the lost carbon and aim to sequester additional carbon. We reviewed several of these options performing quantitative meta analysis in order to compile existing knowledge on their impact on soil organic carbon stock. Land use change from grassland to croplands had the strongest impact on total soil carbon stocks with 30 to 40% less carbon in tropical and temperate croplands as compared to grassland. Our result revealed that measures that increase the carbon input to the soil are the most effective to enhance soil organic carbon stocks. Regular growing of cover crops during winter season and subsequent use a green manure could increase soil carbon stocks by 300 kg ha^{-1} a^{-1}. In contrast, reduced or no-tillage did not significantly increase soil carbon stocks in temperate soils but only redistributed carbon in the soil profile. Moreover, no-tillage increased nitrous oxide emissions which strongly affected the greenhouse gas balance of no-tillage fields as compared to conventional tilled fields. Agricultural measures to enhance soil organic carbon should aim at synergies with other soil functions.
Keywords: land management, land use change, no tillage, cover crops, organic fertilisation

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

With the four per mille initiative of the French Ministry of Agriculture launched at the COP21 in Paris 2016, new attention has been paid to the role of soil organic carbon in the global carbon cycle. Soil carbon sequestration may be an option to mitigate climate change but in agriculture soil organic carbon may be also a key to increase and sustain soil fertility and resilience of soils against climate change and climate extremes. Agriculture, thus, obtained the chance to switch from a major emittent of greenhouse gases to providing a possible solution for increasing atmospheric carbon dioxide concentrations through soil carbon sequestration. However, there are many unsettled expectation how adapted farming practice can enhance soil carbon. In order to substantially support the global aims of reduced greenhouse gas emissions via soil carbon sequestration enhanced quantitative knowledge I required how different land management option impact on soil organic carbon stocks. Thus, the aim of our research during the last 10 years was to compile this knowledge in several quantitative meta analysis.

METHODOLOGY

We compiled data on soil organic carbon stocks after a certain land-management treatment and reference soil organic stocks from more than 1100 sites covering the globe with almost all climate regions. The following management options were assessed in detail:

1.) Land use change (mainly cropland – grassland and forest conversions)
2.) Cover crops
3.) Reduced and no-tillage
4.) Bioenergy production with perennial bioenergy crops.

Drivers that explain the various effects of land management on soil carbon at the different sites were compiled and statistical analysis was used to relate them to the land use and management effects.

RESULTS

Results of or analysis are presented in several published papers. Land use change effects in the tropical and temperate zone are strong with highest soil carbon losses if native tropical forest is converted to cropland (Don *et al.* 2011). In the temperate zone soil organic carbon reacts much sower upon land use changes. Thus, it may take more than 100 year after land use change until a new steady state is reached (Poeplau *et al.* 2012). Cover crops increase the carbon input to the soil without compromising external biomass resources. With around 300 kg ha^{-1} a^{-1} cover crops are a very effective measure to increase soil carbon on croplands (Poeplau and Don 2015). The effects of reduced or no-tillage on soil carbon stocks are less clear that

often discussed. We did not detect any significant soil carbon sequestration rate with reduced or no tillage in temperate soils. Even the oldest field trials revealed inconsistent results. However, increased nitrous oxide emissions due to reduced tillage may turn greenhouse gas balance of no-tillage into negative. Opposing to reduced tillage we also assessed the impact of deep tillage down to 100 cm and it long term effect on total soil carbon stocks. Surprisingly we found more than 40% higher soil carbon stocks several decades after the deep ploughing event (Alcantara *et al.* 2016).
We also explored new management techniques such as plantations of Miscanthus or short rotation coppice for bioenergy production. Such perennial crops partly also increase soil carbon stocks (Poeplau *et al.* 2014, Don *et al.* 2012, Walter *et al.* 2015).

DISCUSSION

Soil organic carbon management is challenging with only selected methods being promising options to enhance soil organic carbon stock. These options should be also applied and evaluated site specifically. Not all management option can be applied to all soil types in all climate region thus requiring increased knowledge transfer to the management decision makers, the farmers.

CONCLUSIONS

Soil carbon sequestration should be one out of several measures to combat climate change. However, in order to implement agricultural soil carbon management, our abilities need to be increased to better site specifically predict the effects of different land use management options. With our extensive meta-analysis on different land use and management options with contributed to compile scattered knowledge into a more comprehensive picture.

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2.12 | EFFECTS OF LAND USE/LAND COVER ON AGGREGATE FRACTIONS, AGGREGATE STABILITY, AND AGGREGATE-ASSOCIATED ORGANIC CARBON IN A MONTANE ECOSYSTEM

Tshering Dorji[1*], Inakwu O. A. Odeh[2], Damien J. Field[3]

[1] National Soil Services Centre, Ministry of Agriculture and Forests; Bhutan

[2 & 3] Department of Environmental Sciences, Faculty of Agriculture and Environment, The University of Sydney, Biomedical Building C81, Central Avenue, Australian Technology Park, Eveleigh, NSW 2015, Australia

ABSTRACT

This study investigated the effects of land use/land cover (LULC) on aggregate fractions, aggregate stability, and aggregate-associated organic carbon (AAOC) in a montane ecosystem of Bhutan. The soil aggregate samples were collected from the genetic 'A' horizon and were wet sieved into large macroaggregates (> 2.0 mm), small macroaggregates (0.25-2.0 mm), microaggregates (0.053-0.25 mm), and mineral fraction (< 0.053 mm). The AAOC of each aggregate fraction was determined to assess their role in soil aggregation. Under all LULC types, the large macroaggregates accounted for 86 to 93% of the total aggregates except under dry land (64%) and paddy land (35%). The aggregate stability under different LULC types decreased in the order of fir forest > shrubland > grassland > orchard > blue pine > broadleaf > mixed conifer > dry land > paddy land. The AAOC of the large macroaggregates constituted for about 76-90% of the total AAOC under all LULC types except for dry land (65%) and paddy land (38%). Among the soil and other environmental variables, the AAOC of the small and large macroaggregates, LULC type, and AAOC of the microaggregates significantly influenced soil aggregate stability. The quadratic correlation of mean weight diameter (MWD) with the large macroaggregate AAOC depicted upper threshold of SOC to enhance soil aggregate stability.

Keywords: Aggregate stability; mean weight diameter; soil organic carbon; land cover; Himalaya

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Land use/land cover change is one of the main anthropogenic factors affecting the soil carbon dynamics and contributes to climate change. Unsustainable land use/management also contributes to rapid release of soil carbon into the atmosphere through destruction of soil structure. Soil organic carbon (SOC) is the key binding agent in soil aggregate formation. It reduces aggregate wettability and enhances mechanical strength of the soil aggregates. In turn, the stable aggregates physically protect SOC from microbial degradation and increase the SOC residence time in the soil (Six *et al.*, 2002; Daynes *et al.*, 2013; Stockmann *et al.*, 2013).

Soil aggregation may be variably influenced by diverse plant species under different land use/land cover (LULC) types due to difference in their organic matter (OM) inputs. As such, the variation of soil aggregate stability under different LULC types could be attributed to difference in aggregate-associated organic carbon (AAOC) of different aggregate fractions. However, the effects of LULC and other environmental variables on soil aggregate fractions, aggregate stability, and AAOC are not fully investigated and understood in the Himalayan region due to limited studies.

Therefore, this study was aimed to: (i) investigate the effects of LULC on aggregate-size distribution, aggregate stability, and AAOC; (ii) assess the relative importance of different soil and environmental variables on aggregate stability and AAOC; and (iii) examine the role of AAOC in aggregate stability in a montane ecosystem of Bhutan.

METHODOLOGY

The study was undertaken in western part of Bhutan (27°04.87' to 27°38.28' N and 89°14.03' to 89°35.82' E) with altitude ranging from 1769 m to 5520 m above mean sea level. The dominant LULC types at the site include mixed conifer (36%), blue pine (24%), broadleaf (8%), fir (5%), shrubland (14%), grassland (3%), dry land (rain-fed agriculture) (4%), paddy land (2%), and orchard (1%). Soil samples were collected from the genetic 'A' horizon of the predetermined sampling sites using conditioned Latin Hypercube sampling design (Minasny and McBratney, 2006). Bulk soil samples were analyzed to determine the C concentration, pH, and particle sizes, while air-dried soil aggregate samples (3-5 mm) were sieved through a nest of sieves with different sieve sizes (i.e. 2.0, 0.25, and 0.053 mm) to determine the aggregate size distribution and aggregate stability. Based on the proportion of different aggregate fractions, the mean weight diameter (MWD), an index for aggregate stability, was calculated according to Kemper and Rosenau (1986). The AAOC of each aggregate fraction was analyzed using the isotopic ratio mass spectrometry (IRMS). One way analysis of variance (ANOVA) followed by the *post-hoc* Tukey-Kramer HSD test ($\alpha = 0.05$) was performed to investigate the significance of differences of aggregate-size distribution, aggregate stability, and AAOC of different aggregate fractions under different LULC types. Further, the relative importance of various soil and environmental factors affecting aggregate stability and AAOC of different aggregate fractions was assessed by using the "importance" function in the random forest package in *R* following Akpa *et al.* (2014).

RESULTS

The large macroaggregates (> 2.0 mm) constituted the highest proportion (> 86%) of the total aggregates followed by the mineral fraction (< 0.053 mm), small macroaggregates (0.25-2.0 mm), and microaggregates (0.053-0.25 mm) under all LULC types. The proportion of large macroaggregates was significantly higher ($p < 0.05$) than other aggregate fractions under all LULC types except under paddy land. Among different LULC types, the proportion of large macroaggregates under all forest types, shrubland, and grassland was significantly higher ($p < 0.05$) than under different agricultural lands. However, the proportion of small macroaggregates, microaggregates, and mineral fraction was significantly higher ($p < 0.05$) under paddy land and dry land than under other LULC types except for the small macroaggregates and microaggregates under dry land from fir, broadleaf, grassland, and orchard.

The aggregate stability, as indicated by the MWD, decreased in the order of fir > shrubland > grassland > orchard > blue pine > broadleaf > mixed conifer > dry land > paddy land. The high value of MWD is indicative of stronger soil aggregation and more aggregate stability. Although MWD varied among LULC types, only the MWD under dry land and paddy land was significantly lower ($p < 0.05$) than under other LULC types. Similar to the variation of MWD, the AAOC in the large macroaggregates under different LULC types decreased in the order of fir > broadleaf > mixed conifer > grassland > shrubland > blue pine > orchard > dry land > paddy land. While the large macroaggregate AAOC under fir, broadleaf, and mixed conifer was significantly higher ($p < 0.05$) than under dry land and paddy land, the AAOC of the small macroaggregates and microaggregates was significantly higher ($p < 0.05$) under dry land and paddy land than under other LULC types except for dry land from orchard, grassland, broadleaf, and fir.

In terms of the relative importance, the small and large macroaggregates, LULC type, and AAOC of the microaggregates were found to be the most important variables affecting aggregate stability. And for the AAOC of the different aggregate fractions, LULC type, bulk density, cation exchange capacity (CEC), and pH were the most important variables. When MWD was plotted with AAOC of the large macroaggreagate, a quadratic relationship was depicted indicating the upper threshold of SOC to enhance the aggregate stability.

DISCUSSION

The relatively high proportion of large macroaggregates (>2.0 mm) under different forest types, shrubland, grassland, and orchard could be attributed to their high OM input, slow decomposition, organo-mineral complexation, and less soil disturbance compared to dry land and paddy land. Further, the hydrophobicity in forest soils might have also protected and enhanced soil aggregation to form larger macroaggregates by increasing cohesiveness and decreasing dispersion of soil aggregates (Bronick and Lal, 2005). On the contrary, the significantly high ($p < 0.05$) proportion of other aggregate fractions under dry land and paddy land could be due to disaggregation of large macroaggregates from cultivation (Kumari *et al.*, 2011) and low SOC content to bind and form large macroaggregates. The combination of large and small macroaggregates as macroaggregates (> 0.25 mm) in this study, accounted for 50 to 93% of the total aggregates which is similar to the results (54 to 80%) reported by Kumari *et al.* (2011).

The high aggregate stability under different forest types, shrubland, grassland, and orchard could be due to their high OM input from the aboveground biomass (Blanco-Canqui and Lal, 2004) which provides mulching effect and better habitat for soil meso- and micro-fauna and flora to improve soil aggregation. The hydrophobic property of the forest soils must have also enhanced the aggregate stability. Our result agrees with Shrestha *et al.* (2007), which reported higher aggregate stability under forest than under rain-fed upland and paddy land. Under different agricultural lands, orchard had significantly high ($p < 0.05$) aggregate stability than under dry land and paddy land and this could be attributed to good groundcover, extensive root system, high OM input, and limited soil disturbance under orchards. The significantly high ($p < 0.05$) aggregate stability under dry land compared to paddy land could be due to the former's close proximity to the farmhouse which receives relatively more organic manure than paddy land. Further, paddy land is subjected to deliberate flooding, plowing, and puddling resulting to destruction of soil structure and low aggregate stability.

The significantly higher ($p < 0.05$) AAOC in the large macroaggregates than in all other aggregate fractions across all LULC types could be because the large macroaggregates constituted for more than 90% of the total aggregate fraction except under dry land and paddy land. This is in line with the results reported by Kumari *et al.* (2011) and Huang *et al.* (2014) under different tillage and land use systems. The significantly high ($p < 0.05$) AAOC of the large macroaggregates under forest, shrubland, and grassland could be due to their high OM input, slow decomposition, and formation of organo-mineral complexes compared to other LULC types. The significant influence of AAOC of large and small macroaggregates and AAOC of microaggregates on aggregate stability further confirmed the important role of SOC in soil aggregation. However, the quadratic correlation of MWD with AAOC of the large macroaggregates indicates the upper threshold for SOC to enhance aggregate stability. This agrees with the result reported by Saha *et al.* (2011).

CONCLUSIONS

This study investigated the effects of LULC on aggregate stability and AAOC, and the latter's role in aggregate stability under a montane ecosystem of Bhutan. The aggregate-size distribution was dominated by the large macroaggregates under all LULC types except under dry land and paddy land. Similar to the proportion of large macroaggregates under different LULC types, the aggregate stability also decreased in the order of fir > shrubland > grassland > orchard > blue pine > broadleaf > mixed conifer > dry land > paddy land indicating a strong influence of LULC types. The large macroaggregate AAOC constituted the bulk of the total SOC (>76%) under all LULC types except under dry land (65%) and paddy land (38%). The results showed that LULC and AAOC of different aggregate fractions have significant influence on soil aggregate stability. Likewise, the AAOC of different aggregate fractions greatly vary under different LULC types indicating its strong influence. The quadratic correlation of aggregate stability (MWD) with AAOC of the large macroaggregates suggests an upper threshold for SOC to enhance aggregate stability. Overall, the results indicated a complex interrelation of aggregate stability and AAOC with LULC and other soil and environmental factors, and needs further investigation to better understand their intrinsic relationships particularly in a fragile and very dynamic landscape like in the Himalayas.

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2.13. | APPLICATION OF THE FAO EX-ACT TOOL FOR CARBON BALANCE ACCOUNTING IN THE AGROECOSYSTEMS OF TAJIKISTAN

*Olga Golubeva[1], German Kust[2], Murod Ergashev[3],Olga Andreeva[4]

[1]Environmental Land management proj., CEP, Tajikistan; Moscow University PhD student. golubeva190@gmail.com
[2]World Bank, Consultant; Moscow Lomonosov State University, Professor. gkust@yandex.com
[3]Environmental Land management project, Committee for Environmental Protection, Tajikistan. soil_m@rambler.ru
[4]Moscow Lomonosov State University, Associate Professor. andreevala@yandex.ru

Abstract

The FAO Ex-ACT tool was applied for the calculation of the carbon balance in the agro-ecosystems of Tajikistan. This method allows to make decisions on the use of low-carbon (low-emission) technologies in the agricultural sector. There were studied about 800 micro-projects implemented by local communities in the three macro-regions: Moist and semi-dry highlands; Moist foothills, and Dry downlands. It is shown that the Ex-Act can successfully define the groups of sustainable land management mini-projects by using the "carbon balance" criterion. According to this criterion the activities implemented by local communities in the highlands, are 10 times more effective than those in the lowlands. The highest specific efficiency for the formation of carbon stocks in soils and of the long-term sequestration in the above-ground biomass (per unit area) is typical for pasture management projects, horticulture, and deforestation control. Infrastructure projects (roads, greenhouses, etc.), on the contrary, contribute to increased CO_2 emissions and necessarily require appropriate compensatory measures.

Keywords: Ex-ACT, carbon balance, agricultural ecosystems, sustainable land management

INTRODUCTION, SCOPE AND MAIN OBJECTIVES.

There is no uniform opinion among scientists how to consider the role of agricultural sector in the carbon balance. Apparently, the most likely opinion should be considered that the various agricultural branches and technologies can contribute to both the emissions of greenhouse gases (GHG) and to reduce them. The last is linking with the absorption of carbon by formation of the soil humus (long term storage), and with the accumulation of the slowly mineralized biomass of wood and/or industrial crops.

For decision-makings on the use of low-carbon (low emission) technology in the agricultural sector it is important to know their effectiveness and the overall carbon balance, taking into account the above-ground and below-ground carbon pools in the complex of interrelated activities of the agricultural cycle. There is no single mechanism designed at the moment taking into account the absolute values of GHG emissions and carbon accumulation in agriculture, but there are mathematical models to assess the main trends in the carbon balance change within different land use and land management methods and approaches. The Ex-ACT modelling tool developed by FAO to assess the carbon balance is among these models, and is based on the 'estimated quantities' in agricultural and forestry projects ((Bernoux et al., 2010; Ex-ante Carbon-balance Tool - Ex-ACT). The method was used in our study to assess the "low-emission" efficiency of small-scale testing projects on sustainable land management. These projects are implementing in Tajikistan with the support of the World Bank, GEF and the Pilot Program for Climate Resilience within the project "Environmental land management and improving people livelihoods in rural areas". In the future, it is assumed that the carbon balance criterion will be used to recommend the most efficient technologies for dissemination. The tool can also be useful for the selection of project activities that provide the greatest benefits in economic terms and climate change mitigation, and evaluation results can be used during the financial and economic assessment of the projects (Cerri et al., 2010).

Thus, the purpose of our study was solved with the help of two interrelated tasks: (a) using the criterion of "carbon-reduction" to conduct a comparative assessment of agricultural technologies and complex of economic activities potentially considered to be sustainable in different natural and socio-economic conditions of a particular country; (b) to evaluate the

possibility of using the Ex-ACT method to assess the perspectives of the carbon balance control at the level of communities and small farmers.
It is also important to note that the Ex-ACT method demonstrated good results in more than 20 project sites in Africa, Asia-Pacific and Latin America, but in Central Asia this tool was used at such a large scale for the first time.

METHODOLOGY

In total the Ex-ACT method was used for processing the information about 800 local projects implementing in the rural area Tajikistan in 2015-2016. We studied not only technologically different projects (cereal plants production, water management and irrigation, cattle breeding, pasture management, horticulture, road and canal rehabilitation, soil protection and eroson control, creenhouses, biofuel and alternative energy sources, etc.), but also compared the carbon balance of the similar activities implementing in different biophysical and economic conditions. In this respect, Tajikistan is very attractive country, because different natural zones are presented here: from high mountains with predominantly pastoral use, to the foothills with a rapidly developing horticulture and rainfed agriculture on slopes, upto the lowlands with well developed but devastated irrigation systems, where the current active search for effective cost-effective crop rotation (to replace the pre-existing monoculture of cotton using a water and soil conservation techniques) are taking place. The complexity as a combination of multicultural planting in the farms with cattle breeding is the main feature and at the same time a basis of the small private farms in Tajikistan. In combination with different climatic conditions a variety of impacts contributing to the carbon footprint provides a good platform for testing the functionality and applicability of the Ex-ACT method.
The Ex-ACT tool is a system for accounting carbon stocks and their changes in per unit area or yield, measured in equivalent tonnes of CO_2/ha per year. The carbon balance is calculated as the difference between the two scenarios of the development: "with" and "without" project activities. The Ex-ACT is based on the Microsoft Excel platform and consists of a number of modules, which describe the main directions of the agricultural and forestry sectors in terms of the carbon balance components, and works on the principle of "black box": after data entry in the relevant cells the output is the value of the carbon balance taking into account the capitalization time (we used the 20-years period). The main advantage of this approach is that it is accessible by trained users, who do not necessarily have a deep knowledge of the mechanisms of the carbon balance in the upper and below ground ecosystems (such as farmers, governmental field officers, NGOs, and others.). Therefore, the profile-based questionnaire was developed to collect primary data, where local farmers inserted the necessary information. Thereafter, it was checked for consistency and entered into a database for the purpose of further calculations. The coefficients used in some of the Ex-ACT modules were also checked (to be modified if need) on the basis of field and laboratory studies of the carbon balance in randomly selected sites.

RESULTS

The application of the Ex-ACT tool for small areas (less than 1 hectare) it was discovered that the sensitivity of the method is low, because the values of the carbon balance do not exceed tenths or even hundredths tonnes of CO_2. In these cases the combination of similar projects in one can help, or alternatively more details in the description of the project are required, which is often beyond the scope of a standard questionnaire.
With these modifications the results obtained characterize the project activities as positive in terms of reducing carbon emissions. The most effective is the horticulture development (more than 34% of the total project activities, leading to carbon sequestration), the second is the perennial planting (about 24%), and the third is the rehabilitation of irrigation systems and canals, especially in arid regions (about 19 %).
More detailed results are given in the tables. Effective interventions are characterized by a negative carbon balance (absorption and long-term carbon sequestration), inefficient are characterized by positive balances (emission into the atmosphere).

Macro-Region	Number of subprojects	Gross carbon balance	Average carbon balance per project	% of the total carbon balance	Carbon balance per year
Moist and semi-dry highlands (Tavildara and Jirgatol districts)	186	-42083	-226	63	-2077

Moist foothills (Baljuvon and Khovaling districts)	218	-12987	-60	19	-641
Dry lowlands (Farkhor and Kulob districts)	380	-11702	-31	18	-578
Total	784	-66771	-85	100	-3296

Table 1: Carbon balance in the project's macroregions

Type of activity	Macroregion	Sequestration: t CO2-eq per hectare		
		Maximum	Mean	Minimum
Deforestation control	Midlands	-458	-255	-54
	Lowlands	-363	-312	-210
Horticulture	Highlands	-355	-176	-16
	Midlands	-183	-151	-64
	Lowlands	-153	-135	-92
Perennial mea-dows and pasture management	Highlands	-233	-63	-20
	Midlands	-44	-42	-32
	Lowlands	-26	-22	-16
New technologies for crop production	Highlands	-54	-39	-7
	Midlands	-54	-48	-44
	Lowlands	-30	-15	-4
Rehabilatation of irrigation canals	Highlands	-20	-19	-15
	Lowlands	-57	-24	-16
Water management	Highlands	-20	-19	-16
	Midlands	-21	-19	-17

Table 2: Specific carbon balance for some key activities

DISCUSSION

The data obtained show that although the investments in the micro-projects are of the close scale, but in different macro-regions and invested in the development or application of different technologies they have different results in the carbon deposition: almost 60% of the effective carbon sequestration accounts for sustainable land management activities implemented in the highlands, primarily due to the micro-projects in horticulture and pasture management. Specific efficiency of the micro-projects evaluated by the carbon absorption criterion is almost 10 times higher in the highlands than in the valleys with irrigated agriculture. This is largely due to the fact that the local communities in the highlands invest the bulk of funds for the projects directly contributing to improving the state of natural resources (soil, forests, alpine meadows, pastures), and in the valleys farmers mostly invest in infrastructure projects (roads, greenhouses, water facilities and channels).

The specific values of carbon emissions (equivalent tonnes CO_2/ha per year.) are of particular interest. The data clearly shows that the most effective measures for carbon storage are: deforestation control, horticulture, and pasture management. The stabling activities and infrastructure development and rehabilitation as well as greenhousing promote the largest carbon emissions.

CONCLUSIONS

The results suggest that the mathematical models underlying the method of Ex-ACT are able to adequately describe the carbon fluxes within different land-use types, and can used for the planning of environmentally effective activities in different biophysical conditions.
The method helped to determine these most effective activities in the region (by the criterion of the annual carbon emission): deforestation control, horticulture, and pasture management. The stabling activities and infrastructure development and rehabilitation as well as greenhousing promote the largest carbon emissions.
Among the local communities, who have been granted an independent right to choose the direction of the project activities, the most effective in the development and application of low-emission and low-carbon technologies are those who live and operate in high-altitude regions. Their efficiency is 10 times higher compared with those communities living in low-lying valleys.

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2.14 | REGENERATIVE DEVELOPMENT TO REVERSE CLIMATE CHANGE: QUANTITY AND QUALITY OF SOIL CARBON SEQUESTRATION CONTROL RATES OF CO_2 AND CLIMATE STABILIZATION AT SAFE LEVELS

Thomas J. Goreau[1]

[1]Soil Carbon Alliance, Goreau@bestweb.net, 37 Pleasant Street, Cambridge, MA, USA

ABSTRACT

Today's CO_2 atmosphere concentrations will lead to devastating increases in global temperatures and sea level over the thousands of years that cold deep ocean waters warm up, even if no more fossil fuel CO_2 is added. Long-term impacts shown by climate records are much greater than IPCC projections, which are politically mandated to only include short-term initial responses. They ignore 90% or more of the long-term climate impacts that will affect future generations for millions of years unless CO_2 is rapidly reduced to pre-industrial levels, giving policy makers a false sense of security. Even complete emissions reductions cannot remove the existing CO_2 excess already in the atmosphere, only increased carbon sinks can do so, and only soil has the capacity to store it in time to avert runaway climate change. CO_2 can be reduced to safe levels in decades if 1) current carbon farming sequestration practices are applied on a large scale, 2) lifetime of soil carbon storage is increased with biochar, and 3) with large scale restoration of coastal marine wetland peat soils, especially using new electrical stimulation methods. Regenerative Development strategies to reverse climate change by increasing soil and biomass carbon need to be implemented by UNFCCC.
Keywords: CO2 sequestration, soil carbon, lifetime, burial rates, stabilization time, reversing climate change, regenerative development

Introduction, scope and main objectives

Climate change strategies claiming that 2 degrees C warming or 350 ppm are "acceptable" sentence coral reefs and low lying countries to death. Corals are already at their upper temperature limit (Goreau & Hayes, 1994). The last time global temperatures were 1-2 C warmer than today, sea levels were 6-8 meters higher, equatorial coral reefs died from heat, crocodiles and hippotamuses lived in London, England, yet CO2 was only 270 ppm (Goreau, 1990; Koenigswald, 2006, 2011).

CO2 in the atmosphere (>400ppm) is already way above the pre-industrial (270ppm) levels consistent with modern global temperature and sea level, and millions of years of ice core and deep sea climate records show that current atmospheric CO2 levels will lead, over thousands of years, to steady state global temperatures and sea levels around 17 degrees Celsius and 23 meters higher than modern levels (Goreau 1990, 2014; Rohling *et al.*, 2009).

It takes thousands of years for this response to happen to the CO2 already in the air because the deep ocean, which is around 4 degrees Celsius and holds nearly 95% of the heat in the earth climate system, takes 1600 years to turn over, and until the deep ocean warms up we won't feel the full effect at the surface. This time lag is ignored in IPCC projections. Once the earth enters a super Greenhouse, like those the last time when CO2 was last 400 ppm millions of years ago, temperatures and sea levels were indeed around 17 celsius and 23 meters higher respectively (Rohling *et al.*, 2009). The excess CO2 (and temperatures) will take from hundreds of thousands of years to millions of years to be finally buried in sediments and geologically removed from the system (Goreau, 1995). The oceans cannot serve as a major sink without turning them into dead zones stinking of hydrogen sulfide and devoid of life above bacteria.

However, there is a vastly faster biological short-circuit to the slow geological burial of CO2, namely rapid enhancement of biomass and soil carbon sinks, especially in the tropics, which could stabilize CO2 at safe levels rapidly (Goreau, 1987, 1990, 1995, 2014). Worldwide we have already lost about half the carbon in the Earth's living biomass, and about half the carbon in soils that have been converted to farming and grazing, but restoring these natural CO2 sinks ("Geotherapy") can absorb excess fossil fuel carbon at the lowest cost.

MAIN OBJECTIVES

1) Identify scientifically-sound safe CO2 levels from climate records

2) Determine how quickly CO2 can be stabilized to prevent extinction of coral reefs and flooding of low-lying coasts, based on quantity and quality (long-lived fraction) of soil carbon sequestration and global atmospheric CO2 input-output models.

3) Identify the specific methods and locations for the fastest and most effective reduction of CO2 to safe levels.

METHODOLOGY

The rate at which CO2 can be stored in soil can be done depends on the quantity and quality (in terms of lifetime) of carbon sequestration, and the target. The "safe" CO2 target in terms of global temperature and sea level changes is identified as preindustrial CO2 levels from nearly a million years of Antarctic Ice Core, fossil coral, and deep sea sediment climate records. IPCC model projections are not used because they seriously under-estimate long term impacts due to use of the wrong time horizons for calculating impacts. Steady-state temperature and sea level for TODAY'S 400 ppm CO2 level are around 17 degrees C warmer and 23 meter higher than now (Rohling *et al.*: 2009; Goreau, 1990, 2014), and it takes thousands of years for the deep ocean to warm up, only then we will feel full impacts. IPCC estimates don't include this lag.

To meet global Geotherapy goals of restoring planetary life support systems to health, not only is increased soil carbon storage needed in every terrestrial habitat and ecosystem, but increases in soil carbon storage lifetime will also be essential. We calculate here how long it takes to reduce atmospheric CO2 to safe preindustrial levels and show the results graphically as a function of the global increase in net carbon burial on the land surface (the soil carbon sequestration quantity parameter), and as a function of the fraction of long-lived carbon that does not decompose (the soil carbon sequestration quality parameter).

RESULTS

Current agricultural practices only return about one ton of carbon per hectare per year, and very little of this, perhaps 1% is long lived, so typical practices would take thousands of years to drawdown the excess, coral reefs will die, and coasts flood. On the other hand, best practice carbon farming is capable of burying tens of tons per hectare per year (Toensmeier, 2016), and using biochar up to tens of percent of soil carbon can be long lived, which would allow the dangerous excess CO2 to be removed in decades, and

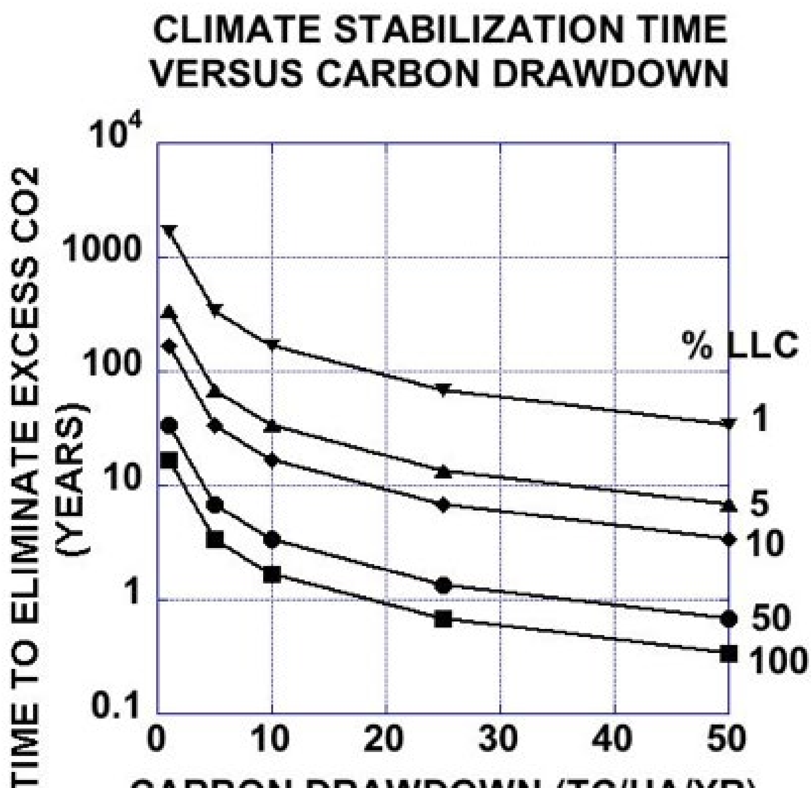

FIGURE 1. Time to eliminate dangerous excess carbon versus rate of carbon drawdown for various percentages of long lived carbon (Goreau, 2016).

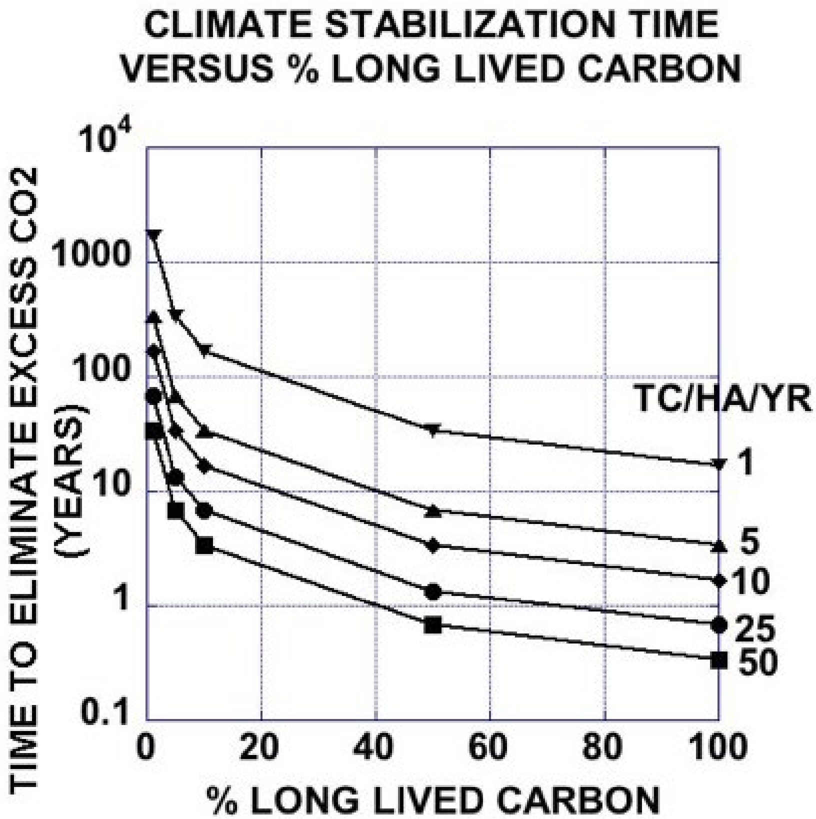

FIGURE 2. Time to eliminate dangerous excess carbon versus percentages of long lived carbon for various rates of carbon drawdown (Goreau, 2016).

DISCUSSION

Two critical leverage points can greatly increase soil carbon lifetime: biochar and marine wetlands. If properly made and applied, Biochar can be applied to any soil, is resistant to decomposition, and lasts centuries, millennia, or even millions of years in the soil, while retaining soil water and nutrients for plants and increasing soil fertility, and providing carbon-negative renewable biomass energy (Lehmann & Joseph, 2009). Biochar can be applied to any soil and is best made from invasive weeds preventing ecosystem recovery. Biochar energy is renewable and carbon negative. Biochar greatly increases soil nutrient and water holding capacity, but is effective only if mature and charged with minerals from rock powder and compost. Raw biochar inhibits growth. Those using raw biochar instead of mature biochar get negative results instead of positive ones.

Soil has nearly 5 times more carbon than atmosphere or biomass, with around half in wetlands, the richest carbon soils. Wetland soils have about half of global soil carbon, with highest carbon content of all soils because lack of oxygen severely inhibits decomposition. Marine wetland soils (salt marsh, sea grass, mangroves) occupy less than 1% of the earth surface, but hold about a half of wetland carbon and a quarter of global soil carbon (more than the atmosphere or biosphere), and account for about half the carbon deposition in the ocean. Newly developed methods now allow rapid regeneration of marine wetland soils and carbon storage, which will be one of the most effective soil carbon sinks for the cost and area required, while providing valuable benefits for shore protection and fisheries habitat.

Marine wetlands, mangroves, salt marshes, and sea grasses, covering around 1% of Earth's surface hold more carbon than the atmosphere, burying around half the carbon in the ocean. Marine wetlands are the most rapidly vanishing ecosystems, their restoration would provide largest carbon sinks in the smallest areas for the least costs, restoring critical fisheries nurseries and protecting coastlines from erosion. Most efforts to restore marine peat soils fail because new plants wash away before their roots can grow. These problems are overcome with Biorock electric stimulation methods, allowing sea grass, salt marsh, and mangroves to be grown where all other methods fail, and expanding carbon-rich ecosystems seawards where they are rapidly eroding away (Goreau, 2014).

CONCLUSIONS

Using known and proven regenerative methods could prevent runaway climate change within decades if governments are serious about funding rapid action. Failure to do so means runaway climate change (the equilibrium temperature and sea level for today's CO_2 concentration of 400 parts per million is around +17 degrees C and +23 meters higher than today's levels) that will last for millions of years before they go away as the dangerous excess carbon from fossil fuels is gradually buried in marine sediments. Such runaway climate change will guarantee extinction of coral reef ecosystems, which are already are at their upper limit, have mostly died from high temperature in recent years, and can take no more warming, while causing billions of refugees to flee flooded islands and coasts. Those changes are what fossil fuel "business as usual" inevitably commits the world to unless regenerative development is systematically and urgently applied to reverse climate change.

Regenerative development strategies increase soil carbon storage to reverse climate change and stabilize CO_2, temperature, and sea level at safe levels within decades. Emissions reductions alone cannot reduce CO_2 to safe levels on any time scale. Carbon farming can store CO_2 excess within decades, and produce carbon-negative sustainable energy, if long lived carbon is increased. Carbon farming can stabilize CO_2 in decades if quality and quantity of carbon farming practices are increased. Failure will result in runaway climate overshoot that could last millions of years. The longer action is delayed, the more difficult and costly stabilization will be, until it finally becomes impossible.

Two strategies maximize soil carbon sequestration cost-effectiveness: biochar and marine wetlands: biochar carbon is stable for thousands to millions of years, whereas marine wetland peats are the richest soils in carbon because lack of oxygen prevents decomposition. Regeneration of mangroves, sea grass, and salt marsh peats could sequester the needed carbon in around 1% of the earth's surface.

The Regenerative Development to Reverse Climate Change strategy of the Commonwealth Secretariat, 52 countries and 2.5 billion people, which will be proposed at UNFCCC in December 2017, aims to solve the problem of runaway climate change for future generations by large-scale increase of biomass and soil carbon sinks.

Current state-of-the-art of carbon farming and soil sequestration (Toensmeier, 2016) can draw down the dangerous CO_2 excess in decades only if implemented immediately, but delay in doing so will require increased lifetimes of soil carbon storage in order to do the job, cost more, be slower, and allow greater damage from climate change. The techniques to solve the problem are all available, all that is needed to implement them is intelligent, informed, educated, and far-sighted global leadership.

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2.15 | THE EFFECT OF FOREST HARVEST ON SOIL CARBON: A GLOBAL META-ANALYSIS

Rob Harrison,[1,2*], Jason James[1], David Butman[1], Cole Gross[1], Irae Guerrini[2]

[1]University of Washington, School of Environmental and Forest Sciences, Box 352100, Seattle, WA 98195
[2] Universidade Estadual Paulista, Departamento de Solos e Recursos Ambientais, Botucatu, SP, Brazil

ABSTRACT

Forest soils represent a substantial portion of the terrestrial carbon (C) pool, and changes to soil C cycling are globally significant not only for C sequestration but also for sustaining forest productivity and ecosystem services. To quantify the effect of harvesting on soil C, we used meta-analysis to examine a database of 945 responses to harvesting collected from 112 publications from around the world. Harvesting reduced soil C, on average, by 11.2%. There was substantial variation between responses in different soil depths, with greatest losses occurring in the O horizon (-30.2%). Much smaller but still significant losses (-3.3%) occurred in top soil C pools (0-15 cm depth). In very deep soil (60-100+ cm), a significant loss of 17.7% of soil C in was observed in harvested soils. The response of soil C to harvesting varies substantially between soil orders, with greater losses in Spodosol and Ultisol orders and less substantial losses in Alfisols and Andisols. The publications in this analysis were highly skewed toward surface sampling, with a maximum sampling depth of 36 cm, on average. Sampling deep soil represents one of the best opportunities to reduce uncertainty in our understanding of the response of soil C to harvest.

Keywords: Forests; Deep soil; soil organic matter; meta-analysis; soil orders; forest management

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Forest ecosystems contain 1240 Pg C, which represents as much as 80% of aboveground terrestrial C and 70% of soil organic C (Batjes, 1996; Dixon *et al.*, 1994; Jobbagy and Jackson, 2004; Prentice *et al.*, 2001). The net balance of soil C in forests relies upon large input rates (61.4 Pg C year^{-1}) and respiratory losses (60 Pg C year^{-1}), which represent a substantial yearly turnover in the soil C pool (Schimel, 1995). By decreasing detrital inputs and increasing respiratory outputs, forest harvest and land-use change can have substantial impacts not only on ecosystem function, but atmospheric chemistry and global climate.

Deep soils store substantial quantities of C with as much as 38% of soil C found below 1 m, globally (Batjes, 1996). While it has traditionally been assumed that this millennially-aged, deep soil C is minimally responsive to human activities, it has been shown that this deep soil C responds just as much to warming (Fang *et al.*, 2005) and the introduction of fresh, labile materials (Fontaine *et al.*, 2007) as surface soil. In addition to direct losses of C through in situ respiration, advances in freshwater research suggest that substantial quantities of soil C are mobilized to streams, rivers, and lakes, constituting a second pathway for soil C mineralization to the atmosphere (Bianchi *et al.*, 2013; Raymond and Bauer, 2001).

Recent estimates of the transfer of C from terrestrial systems to freshwaters has more than doubled from 0.9 to 1.9 Pg C year^{-1} (Cole *et al.*, 2007). Moreover, as the extent of human disturbance increases, the age of riverine dissolved organic matter also increases in watersheds around the globe (Butman *et al.*, 2015). This gives credence to the hypothesis that mobilization of soil carbon to freshwater through human activities represents an additional source of fossil carbon to the modern carbon cycle.

Currently, protocols for ecosystem C monitoring poorly assess soil C. In many protocols, soil C is either limited to surface sampling (20 cm), not required, or excluded entirely (Buchholz *et al.*, 2014). Inclusion of soil C in ecosystem models is also crucial. For example, the payback period for C when substituting forest bioenergy for coal increased by 25 years when soil was included (Zanchi, Pena and Bird, 2012).

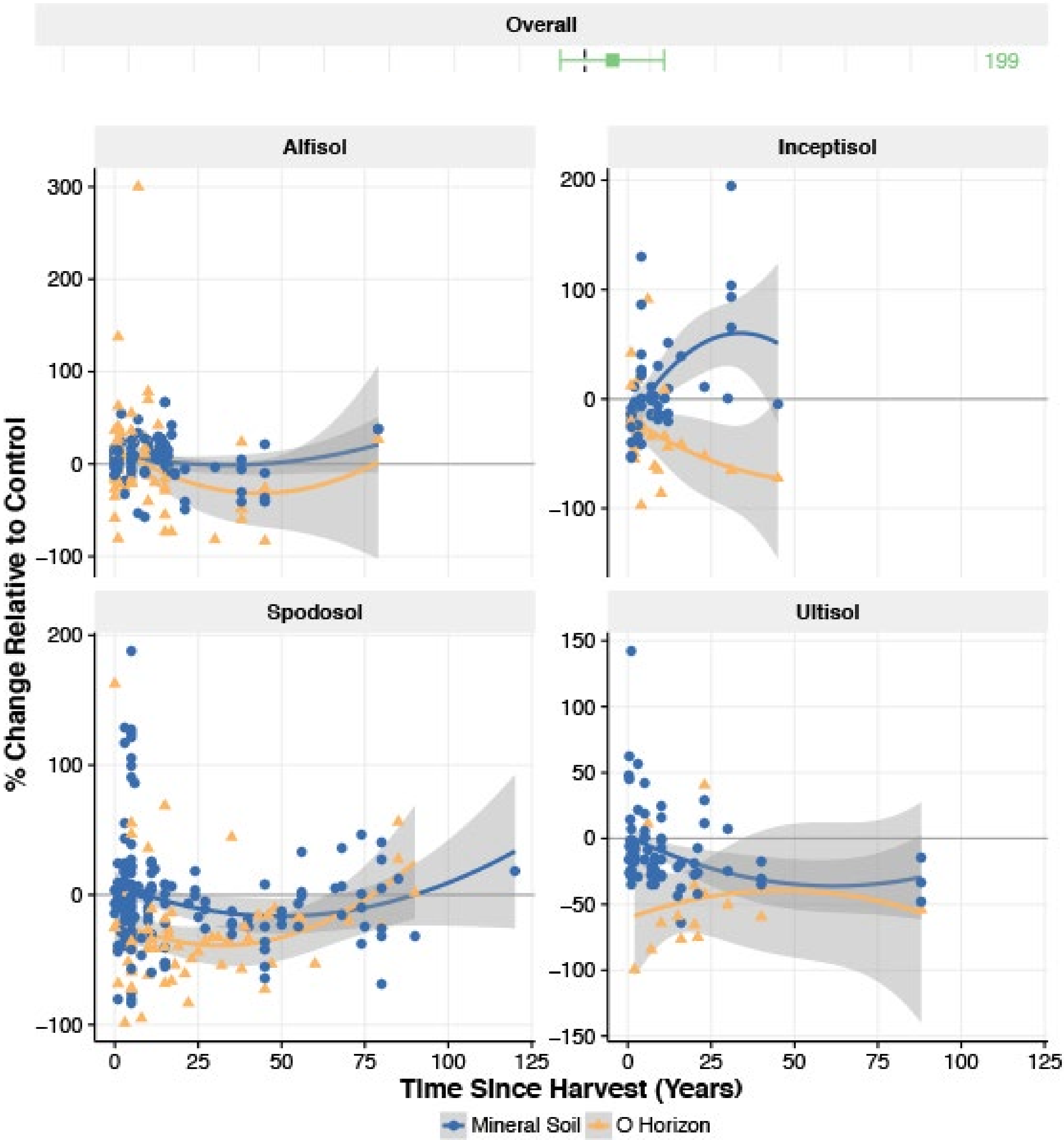

Fig. 2: Temporal patterns in both O horizon (yellow triangles) and mineral soil (blue circles) C pools for Alfisol, Inceptisol, Spodosol, and Ultisol orders. Other orders are not show due to inadequate sampling over time. Regression lines show trends with time using a second order polynomial (Time + Time2). For the overall model, F=9.205 on 7 and 532 degrees of freedom, Adj. R2 = 0.1, p < 0.0001. Reproduced from (James and Harrison, 2016).

DISCUSSION

These results suggest that much additional research is necessary to fully understand the effect of forest harvest on soil C, globally. Due to the sheer size of the forest soil C pool, small relative changes in soil C can result in large absolute losses of C either to the atmosphere or freshwater systems. While this meta-analysis shows a significant and substantial loss in very deep soil, the small number of observations in the literature suggest that substantially more observations need to be made in field research plots in a variety of soil types around the world.

In general, sharper losses occur quickly in O horizons, while mineral soils may continue to lose C over 25 years after harvest. Despite greater losses in C, O horizons recover more quickly that mineral soils to disturbance. In Spodosols, O horizons recovered around 75 years after harvest, while mineral soil C pools took 85-100 years to recover. For Inceptisols, there is insufficient data to calculate a full recovery period. However, little sustained loss in mineral soil is evident in these soils, while O horizon losses continued for at least 45 years post-harvest. The response to harvest was most muted in Alfisols, with mineral soils retaining C over time and O horizons recovering within 50-75 years after harvest.

CONCLUSIONS

Forest soils represent the majority of soil C on the planet, and this C is sensitive to human management efforts. Consequently, utmost care should be taken to utilize less intensive management practices where possible and to carefully consider the soil when designing national policies for bioenergy and forest products. Conclusions and recommendations from this analysis:

- For modeling: surface and deep soil should be included in carbon balance assessments and ecosystem C models
- For monitoring: in addition to gathering sufficient samples to overcome spatial heterogeneity, long-term monitoring efforts should include some ongoing deep sampling (1+ m). Insufficient sampling of deep soils is one of the largest gaps in global soil C data.
- For reporting: national assessments of soil C should report the depth of soil sampled, bulk density measurements, and C pool size rather than concentration alone.

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2.16 | INFLUENCE OF NITROGEN FERTILIZER APPLICATION ON ORGANIC CARBON CONTENT OF UNDERUTILIZED VEGETABLE GROWN SOILS IN SOUTHWESTERN NIGERIA

Idowu M. K[*1]., Oyedele, D. J.[2] and Oladele, A. O[3].

[1]*Department of Soil Science and Land Resources Management, Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. E-mail: midowu@oauife.edu.ng; Phone No.: +2348038272331*
[2]*Department of Soil Science and Land Resources Management, Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. E-mail: d_oyedele@yahoo.com; Phone No.: +2348052153111*
[3]*Department of Soil Science and Land Resources Management, Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. E-mail:, Phone No.: +2347032707918*

ABSTRACT

The study examined the effect of fertilizer microdosing on organic carbon content of three underutilized vegetables grown soils of southwestern Nigeria in 2016. The study was a 2 x 2 x 5 arranged in a split- split plot design and replicated four times. The main plot was the two locations. The sub plot was two times of nitrogen application and the sub-sub plot was nitrogen application at 0, 20, 40 and 60 kg N ha^{-1} plus 5 ton ha^{-1} of organic fertilizer (OF) (3.5%), and 80 kg N ha^{-1} without OF. *Solanum macrocarpon, Telfairia occidentalis and Amaranthus viridis* were used. Soil organic carbon was determined prior and after the experiment. The average native soil organic carbon were 25.3 gkg^{-1} and 8.5 gkg^{-1} for Ilesa and Ogbomoso, respectively. Application of nitrogen increased SOC in Ogbomoso compared with the control for all the vegetables while a reduction in SOC was obtained at 80 kg ha^{-1}in Ilesa for *S. macrocarpon*. The study concluded that addition of N reduced organic carbon decomposition in the derived savanna and application of 20 kg N ha^{-1} plus 5 ton ha^{-1} of organic fertilizer was optimal for sustaining soil organic carbon for vegetable production in southwestern Nigeria.
Keywords: Soil organic carbon, agroecological zones, time of fertilizer application

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Soils of sub-Saharan Africa (SSA) are highly weathered and predominated by low activity clays such as kaolinites. Soil organic matter acts as a store house for plant nutrient and helps to sustain soil physical properties under intensive cultivation (Idowu and *et al.*, 2014). There is a wild gap between the actual and obtainable crop yields in both SSA and Nigeria in particular, which has been associated with the prevailing poverty level amongst the small-holder farmers. The average fertilizer use in SSA estimated at 10 kg ha^{-1} is the lowest in the world. Inorganic fertilizers are too expensive for the resource-poor farmers. However, fertilizer microdosing is a technology that has been examined for maize production in East Africa and recommended for reducting fertilizer investment. The technology has not been tested on vegetables and on response of soil organic carbon with N addition. Information on effect of N addition on soil organic carbon has been inconsistent, while some authors reported that N addition suppressed soil respiration and enhanced soil organic carbon, others observed the opposite. The main objective of this study was to examine the influence of nitrogen fertilizer rate on soil organic carbon with a view to establish the optimal nitrogen fertilizer application for vegetable production in rainforest and derived savanna agroecological zones of southwestern Nigeria.

METHODOLOGY

Description of the study area

The study was carried out in two locations: Ilesha which lies within Latitude 7° 38' 36" N and Longitude 4° 45' 40" E in Osun State and Ogbomosho which lies within Latitude 8° 6' 35" N and Longitude 4° 18' 41" E Oyo State. The locations represented the rainforest and derived savanna agroecological zones, respectively. Bulk Soil sample was collected at 0-15 cm depth before planting.

Experimental design

The study was a 2 x 2 x 5 arranged in a split- split plot design and replicated four times. The main plot was the two locations: Ilesa in Osun State and Ogbomoso in Oyo State representing rain forest and derived savanna, respectively. The sub plot was two times of nitrogen application, at planting and 14 days after planting, and the sub-sub plot was five rates of nitrogen application consisting of 0, 20, 40 and 60 kg N ha with basal application of 5 ton ha of organic fertilizer (OF) (3.5%), and 80 kg N ha without basal OF. *Solanum macrocarpon, Telfairia occidentalis and Amaranthus viridis* were the testing vegetables.

Planting method

The planting method employed for *A. viridis and S. macrocarpon* was by drilling, and each plot was divided into six rows with spacing of 0.5 m in-between the rows. Four (4) spoonful seed and eight (8) spoons of dry fine sand were added together in a dry deep plastic container and mixed thoroughly. The mixture was evenly spread per row on each plot. *Telfairia occidentalis* was planted at spacing of 0.75 m × 0.50 m per stand making a crop density of 25 stands per plot.

Data collection

Vegetables were harvested at five weeks after planting and thereafter harvested every two week for two times. Soil samples were collected for determination of soil organic carbon after the third week of harvesting the vegetables. Soil organic carbon was determined using the potassium dichromate method of Walkley-Black (1934) described by Sparks (1996).

Data analysis

Data were subjected to analysis of variance. Means were separated using Duncan's multiple Range test at 5% level of probability using SAS software

RESULTS

The results showed that agroecology had a significant influence on native soil organic carbon (SOC) content (Table 1). The native soil organic carbon was 25.3 g kg $^{-1}$ and 8.5 g kg $^{-1}$ for Ilesa and Ogbomoso, respectively. Soil organic carbon content was decreased after crop harvest in Ilesa while an increase in he values were obtained in Ogbomoso, compared with the control. Time of N addition had no effect on SOC in the two locations. Addition of N increased SOC with or without basal organic fertilizer application compared with the control. The average mean for SOC range from 16.2 g kg^{-1} to 20. 2 g kg^{-1} for Ilesa and 6.9 g kg $^{-1}$ to 8.5 g kg^{-1} for Ogbomoso. The vegetable yield in Ogbomoso was higher than in Ilesa (the results are not shown).

Table 1: Effect of Nitrogen Fertilizer Application on Average Soil Organic carbon

	Solanum macrocarpon		***Telfairia occidentalis***		***Amaranthus viridis***	
	Ogbomoso	Ilesa	Ogbomoso	Ilesa	Ogbomoso	Ilesa
	<--------------------		gkg^{-1}		-------------------->	
Native SOC	6.0	26.4	7.0	15.9	8.1	20.0
Nitrogen kg ha^{-1}						
0	4.1	26.6	6.2	17.2	4.0	14.1
20	6.4	23.8	6.4	15.3	6.2	15.6
40	7.9	28.2	6.8	16.8	5.9	19.4
60	7.3	16.6	8.4	15.9	8.0	21.4
80	9.1	16.6	14.6	16.1	9.1	15.3
Mean	6.9	20.2	8.5	16.2	6.7	17.1

DISCUSSION

Agroecology had a prominent effect on native soil organic carbon and the response of organic carbon to N addition (Table 1). Soil organic matter consists of an accumulation of undecomposed or partly decomposed roots, stems, and leaves of higher plants, and residues of worms, arthropods, bacteria, algae, and fungi. The dead remain of these materials added to the soil are converted into dark coloured complexes known as humus. According to Aduayi (1985), it is conventional to aim at soil organic matter of between 15 to 50 g kg^{-1} to maintain soil fertility. Native soil organic carbon was 25.3 and 8.5 in Ilesa and Ogbomoso, respectively, within the medium fertility class (Sobulo and Adepetu, 1987). Higher soil organic carbon in the rainforest could be due to higher amount of rainfall in the agroecology. Rainforest zone contains more moisture which supports thick vegetation (Adepetu, 2014). After crop harvest, soil organic carbon increased in the derived savanna with a decline under rainforest with exception of *Telfairia occidentalis*. These results can be explained by the report of Tonitto *et al.* (2013) that although studies have identified the importance of N additions in suppressing soil respiration and enhancing soil organic carbon, early experimental works have shown that litter quality strongly affected rates of litter mass loss, with decomposition varying inversely with litter lignin:N ratios. It was also reported that liter quality in terms of lignin, hemi-cellulose, and cellulose composition is a defining characteristic of the response of litter decomposition to N. Our study confirmed higher rate of organic carbon decomposition in the rainforet., due to higher microbial activities. In order to encourage application of inorganic fertilizer by farmers, fertilizer microdosing technology should be promoted.

CONCLUSIONS

The study concluded that application of 20 kg N ha^{-1} plus 5 ton ha^{-1} of organic fertilizer is optimal for sustaining soil organic carbon for vegetable production in rain forest and derived savanna of southwestern Nigeria. Promotion of production of good quality organic fertilizers from abundant organic materials in the region is essential.

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2.17 | SOIL MACROFAUNA AND THEIR ROLE IN SOIL REMEDIATION

Kokhia Mzia

Institute of Zoology, Ilia State University, 3/5 K. Cholokashvili Ave., 0162, Tbilisi, Georgia;
mzia.kokhia@iliauni.edu.ge

ABSTRACT

For the first time about the terricolous invertebrates role in soil formation process pay attention Charles Darwin, in 1837 when he made a presentation about earthworms and their vital activities.

Nowadays, the comprehensive investigation of the functional importance of each group of soil inhabitants is a necessity to create a coherent picture of their participating in soil formation processes.

This is especially relevant taking into account modern problems of the protection of natural resources, including one of the most important parts of it - the soil cover.

The main goals of this work are:

► to define species composition, horizontal and vertical distributions, seasonal dynamics in soil layers.

► to study of trophic structures and soil inhabitants' role in decomposition of plant remains

► to study nutritional and energetic requirements of soil saprophagous of High Mountain meadows and their role in decomposition and mineralisation of plant residues.

The investigation of soil invertebrate's metabolism and productivity in soil zoology are connected with the quantitative estimation of the soil saprophagous' role in the humification and mineralisation processes of plant residues. The definition ratio of phytosaprophage's feeding activity showed high food assimilability (60-70%). We consider the improved food assimilability for invertebrates from the alpine pastures as an adaptation of saprophagous to pessimal habitat conditions.

Keywords: Soil, macrofauna, sapropages

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Georgia is among the 34 Hot spots of world biodiversity. Particularly it concerns to the soil fauna, which is comparatively weak studied. The soil inhabitant's role in the soil structure, water movement, nutrient dynamics, and plant growth is a very important. They are not essential to all healthy soil systems, but their presence is usually an indicator of a healthy system. The most of them have performed the several significant functions.

Georgia is the country in the Caucasus, lying between western Asia and Eastern Europe. It is bounded to the west by the Black Sea, to the north by Russia, to the south by Turkey, and to the south-east and east by Armenia and Azerbaijan. The area is largely montane to high-montane and represented by high mountain ranges of the Greater and Lesser Caucasus. Therefore the soil condition and its fertility are very important and have a decisive importance for the proper development of the country, agriculture and industry. The climate of Georgia is quiet diverse but largely mild to warm, considering the small size of country. There are two main climatic zones, roughly corresponding to the eastern and western parts of the country. **The main objective** of our study was a detailed study of the quantity and the main groups of soil invertebrate inhabitant in the target region.

SOIL MACROFAUNA & SOIL FORMATION

The climatic conditions and their variations have a significant impact on the soil inhabitants. The soil structure and formation of its humus horizon significantly depends on a vital activity of soil macrofauna. The activity of soil inhabitants determines the rate of plant residues destruction and their mineralisation, and accordingly the rates of turnover of organic compounds. The character of plant litter destruction, its structure and humus horizon formation entirely depends on the action of soil inhabitants (Kokhia, 2011, 2016; Kokhia *et al*., 2015). In trophic structure of macrofauna complexes prevalence of saprophagous is obviously expressed. Earthworms, millipedes, larvae of some dipterans and etc. are the active destroyers of the plant residues. Naturally, in meadow soils the basic food resource for these saprophagous was the remains of roots, and for millipedes - decaying parts of plants. Among larvae also there were the representatives of saprophytic complex, namely – larvae of lamellicorn bugs. In the investigated pasturage plots there were a considerable quantity of bugs and dung beetles.

Fig. 1. Soil Map of Georgia (Urushadze, 1999)

THE DOMINANT GROUPS OF SOIL MACROFAUNA

The goal of this research was to study the high mountain soil fauna of different regions of Georgia to make the comparison of soil fauna composition.
The major groups of soil fauna in the pilot sites of studied regions are invertebrates-saprophages which occupy the leading position in the soil formation processes. The table presents the main groups of soil inhabitants in the region.

Macrofauna	Quantity					
	I		II		III	
	%	Ind/m2	%	Ind/m2	%	Ind/m2
Lumbricidae	50.1	344	67	219	31.4	266
Myriapoda	27	188	1.5	5	50.6	429
Insecta	22.5	155	31.5	103	18	153
Total		687		327		848

Table 1. Main groups of soil inhabitants

METHODOLOGY

Study the species composition of high mountain ecosystems'soil inhabitants, their distribution and trophic structure standard methods applied in soil zoology were used (Striganova, 1987). To collect and determine the dominant species of soil invertebrates was used the manual method. A role of soil invertebrate-saprophagous was shown in plant litter destruction processes, in the enhancement of biological cycle of high mountain ecosystems and in the maintenance of soil natural fertility.

A complex research of high mountainous ecosystems and components, their vital activities were investigated in two High Mountainous - Southern and Eastern Regions of Georgia. The investigation was carried out in alpine zone, low grass pastures and in the forestry areas of Georgia. The basic groups of high mountain meadows invertebrate-saprophagous (millipedes, earthworms, insect, etc.) were determined.

The depth of distribution of representatives of macrofauna was up to 50 cm in all three plots. The most densely populated were the upper horizons of the soil, up to30 cm, there were only individual species of larvae of weevils and lamellicorns, which met deeper.

RESULTS

Research showed a leading position of earthworms on selected plots. It should be noted that in depression a number of macrofauna representatives were several times less in comparison with raised sites. In our opinion, the cause of reducing of saprophagous abundance was the high humidity of soil that was showed by the presence of hygrophilous species of macrofauna such as earthworms and by the complete absence of steppe specie *Nicodrilus jassyensis* (Michaelsen, 1891) on the plots. The stability of the soil macrofauna structure greatly depends on pasture loading. An excessive overgrazing of pastures often leads to unrecoverable results which can be revealed with tamping and packing of soil and destruction of plant cover. All of it showed the importance of active involving in soil forming processes of the faunistic complex. The seasonal distribution of the main soil inhabitants is presented in the Table 2.

Plots / Months	Ind/m2		
	I	II	III
V	128	2	203
VI	348	-	1206
VII	86	2	112
X	192	10	198
Total	754	14	1719

Table 2. The seasonal distribution of the main soil inhabitants

WHAT CAN BE DONE FOR SOIL REMEDIATION?

To increase the soil fertility is very important selection and usage of fertiliser and green manuring which strengthens and enriches the soil with organic matters.

Among the measures to improve the condition of pastures is remarkable the regulation of the load on pastures – numbers of grazed cattle and sheep, to avoid disordered and a chaotic overloading of pastures. The most damage with erosion grass covering soil needs a longer rest period.

Soil inhabitants have an important role in the soil forming process; hence we consider the necessity of preservation of soil invertebrates' biodiversity.

The improvement of the soil productivity due to active organic fertilizers will be possible by introducing vermiculture.

The development of vermitechnology gives a possibility to grow up the soil productivity (Scheu, 2003).

The most damage with erosion grass covering soil needs a longer rest period.

Soil inhabitants have an important role in a soil forming process; hence we consider the necessity of preservation of soil invertebrates' biodiversity.

CONCLUSIONS

- As it was expected the meadow soil macrofauna significantly differ from forests' soil macrofauna. It was mostly observed in dominant groups. As for main groups, they were unchangeable. In all height levels and in all associations the earthworms have the dominating position, though in other groups among them the insects and diplopods were in small quantities. It was due to earthworm density of soil invertebrates that was quite high, especially in the lower alpine zone (1250-1300 m asl).
- The occupancy level of soil with invertebrates (macrofauna) in low grassy meadows of the subalpine belt of the Greater Caucasus differed significantly in various variants of meadow habitation (55-850 ind. /m^2). The basic amount difference of soil invertebrates also depended on the peculiarities of a mesorelief in the range of one plot.
- In an animal population of the Greater Caucasus subalpine meadow the dominant were the groups of millipedes (*Diplopoda*) and in some regions - wood lice (*Oniscoidae*), earthworm (*Lumbricus*). The soil saprophagous made up 50-80% in the trophic structure of the animal population. In these ecosystems, the main current of energy is directed through the detritus food chain.
- In the subalpine meadow, the main mass of invertebrates was concentrated in the upper soil horizon (0-10 cm), and on the surface of the soil under coverings, also. The most intense number of animals was concentrated at the edge of slide rocks that proved the rule of the ecotone effect. It was detected, a tendency of transition of soil animals to inhabitance on the surface of the soil at big heights. In this case, the main limiting factor was warmth deficiency in the soil, increasing with the height.
- The detection of the reading of food activity among the representatives of the eight species of
- phytosaprophages (wood lice, diplopods, dermapterans) showed the high degree of food assimilability (60-70%), which was carried out with the gravimetrical method. The similar value of food assimilability ratio was observed in the inhabitants' of tundra and arid landscapes with the shortened period of food activity. The increased food assimilability in invertebrates from high mountain meadows is considering as an adaptation of saprophages to pessimal habitation conditions.
- It was discovered that in subalpine meadow, the soil invertebrates' saprophagous took an active part in the decomposition of terrestrial grass liter that forwarded its fast and complete mineralisation, facilitating the biological cycle of high mountain ecosystems.

ACKNOWLEDGEMENTS

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2.18 | ESTIMATION OF THE SOIL CARBON SEQUESTRATION IN A FOUR YEAR ROTATION MANAGED WITH CONVENTIONAL AND CONSERVATIVE METHODS

Lorenzo D'Avino[1], Giovanni L'Abate[1](*), Francesca Chiarini[2] , Federico Correale[2], Francesco Morari[3]

[1] Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria
Centro di ricerca per l'agrobiologia e la pedologia (CREA-ABP), Firenze
[2] Veneto Agricoltura, Azienda Regionale per i settori agricolo, forestale e agroalimentare, Legnaro (PD)
[3] Università degli studi di Padova, Dipartimento Agronomia Animali Alimenti Risorse Naturali e Ambiente (DAFNAE)

ABSTRACT

In three Veneto Agriculture experimental farms a three-year monitoring has been conducted. It involved the collection of a data set with 564 georeferenced sampling points with both soil and crop residues samples (epigeal and ipogeal) related to 32 plots extended about 1.5 hectares each. The conservative rotation included the use of cover-crops. In addition to residual biomass and the mean annual air temperature of the station, soil organic carbon, bulk density, coarse materials, clay content and total carbonates were considered. Those data allowed for developing of a mineralization index (MI) characterizing different soils. Data and rotations allowed for the defining different scenarios and the estimation the soil organic carbon after 20 years. The model provides for average MI soils a loss of SOM in conventional soils. The use of digestate determines credits for two farms. The contribution of organic fertilizers, increasing the mineralization, is particularly suitable in soils with low MI. This tool could enable quantifying C credits that could be paid to farmers. Estimations could provide guidance to the objective of the yearly increase of the C 4 ‰, proposed by the Climate Change Paris Conference of 2015.

Keywords: carbon sequestration scenarios, culture system, carbon dynamics, farming system, agroforestry

EXTENDED ABSTRACT

Soil organic carbon (SOC) sequestration estimation is decisive in a Life Cycle Assessment to provide the agricultural phase. However, the limited availability of data often does not allow the application of simulation models of the SOC dynamics in daily or monthly steps.

The aim of this work was to implement a physically based, simplified computational model, which provides guidance on how to increase the sequestration of SOC in the agricultural top-soil horizon (0-30 cm). Taking into account both site-specific characters an the culture system, established knowledge and analytical monitoring data have been implemented. The Hénin-Dupuis model (Tirado *et al*, 2013; Castoldi & Bechini, 2006; Mary & Guerif, 1994) has provided the conceptual basis, by annual application of the constants (k1 and k2) estimations in a complex cultural system.

In three Veneto Agriculture experimental farms a three-year monitoring has been conducted. It involved the collection of a data set with 564 georeferenced sampling points with both soil and crop residues samples (epigeal and ipogeal) related to 32 plots extended about 1.5 hectares each.
The conservative four-year rotation (no till) included the use of cover-crops (in green), in particular: 1st year Zea mays L. cv korimbos; 2nd year Hordeum vulgare L. + Vicia sativa L. - Glycine max (L.) Merr cv Demetra; 3rd year Triticum aestivum L. cv aubusson - Sorghum bicolor; 4th year Brassica napus L. cv excalibur - Sorghum bicolor; 5th year H. vulgare + V. sativa - Z. mays (repeated 4 times from 2nd year up). In addition to residual biomass and the mean annual air temperature of the station, soil organic carbon, bulk density, coarse materials, clay content and total carbonates were considered. Processing these data and rotations allowed for the creation of different scenarios for each plot and the estimation the soil organic carbon after 20 years.

To evaluate the amount of organic carbon of each soil that is potentially mineralized each year per unit volume was estimated, for each analyzed soil, the mineralization index (MI) at time t0 calculated and soils with greater and lesser MI identified.

Three scenarios with annual pace have been compared: Conventional intensive management; Full replacement of mineral nitrogen with digestate from energy crops and industrial products; No tillage with cover crops. Digestate from energy crops and industrial products has defined by Bezzi & Regazzoni, 2014, has an efficiency of 45% (DM 25/02/16), biological stability similar to compost (Tambone *et al*, 2010), and increased mineralization; In no tillage cover crops are dried and / or shredded and mineralization results reduced.

Estimates of SOMBIL model were compared with the measured SOC values in 2012, 2013 and 2014, and with those obtained from the IPCC model (2006), which estimates the increase in SOC with decades step. The model estimates the carbon dynamic, however, the time interval of three years is excessively reduced and the values of SOC results extremely variable. Due also to the variation of soil bulk density, the estimates of the soil carbon stock after 4 years is far more accurate. An exception is the Vallevecchia farm (particularly in no till plots) where the clay fraction also contains carbonate rocks (dolomite and calcite, Piccoli *et al*, 2016). The protection of the mineralization induced by carbonates seems overestimated by the model, suggesting a possible adjustment in the case of carbonate rocks in clay fraction.

Estimated values were validated with the observed values after three years of experimentation, resulting compatible with the variability of data and allowing for model calibration. Burial of all crop residues would allow a substantial maintenance of carbon stocks, even in conventional farming scenarios, except for soils characterized by a high rate of mineralization, in which, according to the model, there would be depletion. Conservative scenarios instead show a general increase in organic SOC after 20 years.
This tool could enable quantifying SOC credits that could be paid to farmers. Already implemented, site-specific assessments on conservative agricultural practices are: compost or digestate intake, and agroforestry practices. Finally the thus obtained estimations could provide guidance to the objective of the yearly increase of the SOC 4 ‰, proposed by the Climate Change Paris Conference of 2015.

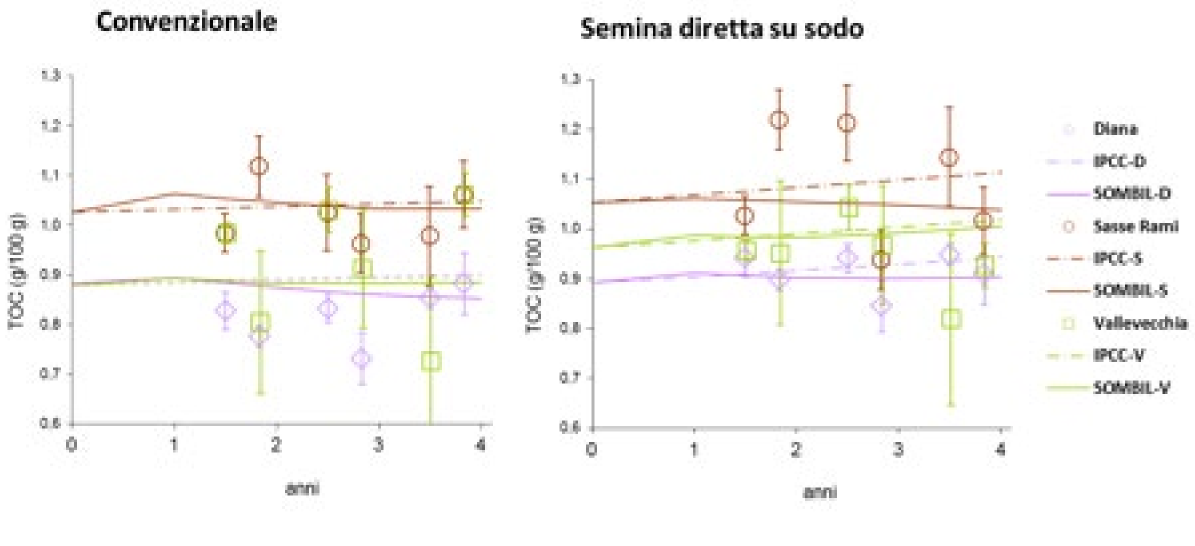

Fig. 1: Comparing the carbon stock predicted by the model and observed (bars: standard and dashed error, standard deviation)

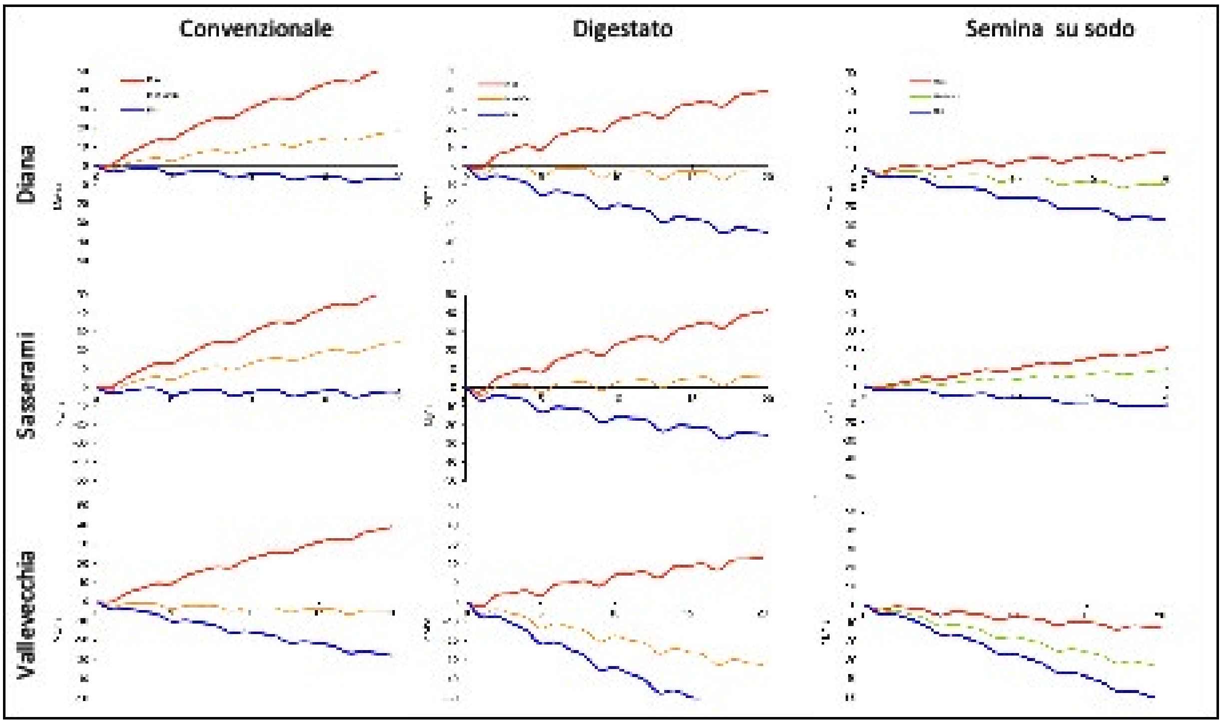

Fig. 2: Estimate of the SOC sequestration (<0) or the emissive character (> 0) of soils with mineralization potential maximum, medium and minimum in the different scenarios

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2.19 | SIGNIFICANT OFFSET OF LONG-TERM POTENTIAL SOIL CARBON SEQUESTRATION BY NITROUS OXIDE EMISSIONS IN THE EU

Emanuele Lugato[1*], Arwyn Jones[1], Adrian Leip[1] and Luca Montanarella[1]

[1]European Commission, Joint Research Centre (JRC), Directorate for Sustainable Resources, Via E. Fermi, 2749, I-21027, Ispra (VA), Italy – emanuele.lugato@ec.europa.eu

ABSTRACT

International initiatives such as the '4 pour 1000' are strongly promoting carbon (C) sequestration in soils, particularly in the agricultural sector where targeted management can mitigate greenhouse gas emissions. Changes in soil organic turnover have many feedbacks on the coupled nitrogen cycle, therefore any variation in soil nitrous oxides (N_2O) emissions could potentially offset or enhance any C sequestration actions. However, large-scale and dynamic temporal quantification of CO_2 and N_2O soil fluxes to guide policy-making decisions are still lacking. Here we ran a biogeochemistry model on approximately 8,000 soil sampling locations from the most extensive land use/soil inventory framework for the EU, to assess the net CO_2 equivalent (CO_2eq) flux associated with representative mitigating agricultural practices. We showed that practices based on integrated crop residue retention and lower soil disturbance did not increase N_2O emissions as long as C accumulation was continuing. By 2100 the N_2O-induced soil C sequestration offset (NCO) was 24%. The introduction of N fixing cover crops allowed higher C accumulation over the first 20 years but, beyond 2080, NCO values were over 100% even after reducing mineral N fertilizations proportionally. We conclude that significant CO_2 sequestration can be achieved in the initial 20-30 years of any mitigation scheme but, afterward, N inputs should be controlled through appropriate management.

Keywords: Carbon sequestration, N_2O emissions, agricultural soil, GHG, mitigation

2.20 | TEMPORAL VARIATIONS IN SOIL ORGANIC MATTER CONTENT OF DIFFERENT LAND USE TYPES IN SOUTH WEST NIGERIA

Mesele Samuel Ayodele[1*], Adigun James Kehinde[2]

[1]Federal University of Agriculture Abeokuta Nigeria, ayodelemesele@hotmail.com; +2348057646091

[2] Federal University of Agriculture Abeokuta Nigeria, Adigun.james@gmail.com

*the presenting author

ABSTRACT

A study was conducted to test the effect of different land use types on the organic matter content of soil. The treatments comprised four land use types which were: forest (secondary forest), natural grassland, notill farmland (5 years of conservation tillage), and conventionally tilled farmland (5 years of continuous plough and harrow cropland). The results demonstrated a significant variations (P<0.05) in soil organic matter of the land use types at different soil depths. At the 0 – 5 cm soil depth, there was a similarity in the soil organic matter content of the secondary forest, natural grassland, and the notill farmland. However, as the depth of sampling increased to 30 cm soil depth, there exist a significant different with the secondary forest having the highest organic soil matter followed by the natural grassland. Generally, there was a decrease in soil organic matter with increase in the depth of soil sampling. While the soil organic matter of notill farmland at the 0-5 and 5 -10 cm soil depths were significantly higher than those of the conventionally tilled farmland, there exist no considerable differences in the soil organic matter content of the two land use types at 20-30 cm soil depth.

Keywords: soil organic carbon, land use, Nigeria, forest, conservation farming

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Soil organic matter content is a function of organic matter inputs (residues and roots) and litter decomposition (Bell *et al*., 1999). It is related to moisture, temperature and aeration, physical and chemical properties of the soils as well as bioturbation (mixing by soil macrofauna), leaching by water and humus stabilization (organomineral complexes and aggregates). Land use and management practices also affect soil organic matter. Soil organic matter – the product of litter and crop residue biological decomposition – affects the chemical and physical properties of the soil.

Many common agricultural practices, especially ploughing, disc-tillage and vegetation burning, accelerate the decomposition of soil organic matter and leave the soil susceptible to wind and water erosion (Brown *et al*., 2003). However, there are alternative management practices that enhance soil health and allow sustained agricultural productivity. Conservation agriculture encompasses a range of such good practices through combining no tillage or minimum tillage with a protective crop cover and crop rotations. The objective of this study was therefore to evaluate the temporal variations in soil organic matter of different land use types.

METHODOLOGY

The study was conducted at the experimental farm of the Federal University of Agriculture Abeokuta, Nigeria. Four treatments which comprised of different land use types were evaluated in the study. The land use types were: 1. secondary forest – the initial vegetation has been replaced by secondary forest. And this area has been under forest for over a decade. 2. Natural grassland – this area contain grasses with very few and scattered woody species. This Area has maintained this condition for over a decade with no history of cultivation at least for a decade. 3. No-till farmland – this is a farmland that has maintained 100 % soil cover with a variety of improved agronomic practices such as crop rotation, intercropping among others for about five years. 4. Conventionally tilled farmland – this is an area that has been under continuous cultivation for the last five years. The method of land preparation has been predominantly plough and harrow. The area is grown with maize season after season though with NPK fertilizer application. Soil samples were taken with the aid of an auger at 0 -5, 5 -10, 10-20 and 20-30 cm soil depth on each land use type. The organic carbon using Walkley and Black method (Nelson and Sommers, 1982).

RESULTS

Effect of land use types on soil organic matter is presented in Figure 1. There was no significant difference (P >0.05) among the soil organic matter values of the forest, natural grassland and notill farmland. However, these three land use types were significantly different in their soil organic matter values with respect to the conventionally tilled farmland. Soil organic matter shows a gradual decline with increasing sampling depth on all the land use types (Figure 2). The decline was more on the conventionally tilled farmland than others.

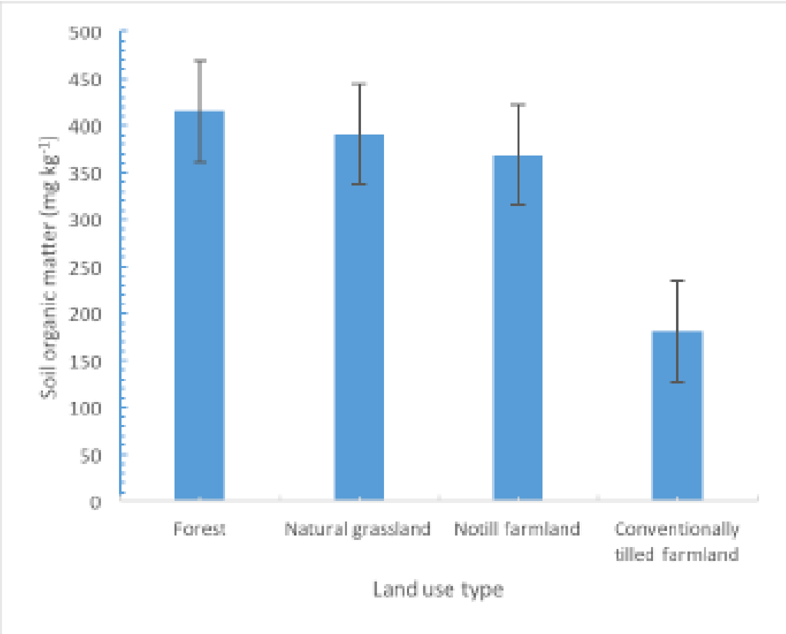

Fig. 1: Effect of land use types on soil organic matter

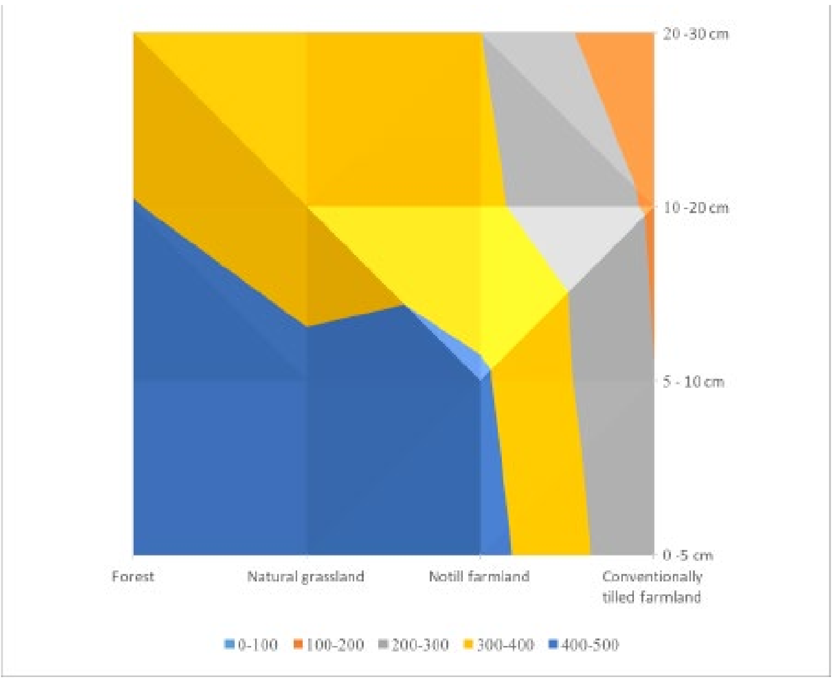

Fig. 2: Variation of soil organic matter with soil depth on different land use types

DISCUSSION

Land use types have profound influence on the soil organic matter content. Notill farmland mimic ecological land use such as forest and natural grassland land particularly with reference to its soil organic matter content at the topsoil (0-5cm). With increasing soil depth, there exist a difference in the soil organic matter content of all the land use types. As expected, the conventionally tilled farmland had the least soil organic matter both at the topsoil and at the subsoils. With appropriate land use types, farmland could mimic natural or semi-natural ecosystems, thereby enhancing not only the sustainability of soil resources but of agricultural productivity.
Since the maintenance of soil organic matter is a major challenge in tropical agro-ecosystems due to the rapid decomposition rates, practices such as notill that are able to maintain their soil quality in a way similar to the natural systems are preferable. This system provides a win –win approach, soil quality is maintained while at the same time agricultural productivity is enhanced.

CONCLUSIONS

Soil organic matter varied with land use types. After five years of cultivation, Notill farmland, soil organic matter similar to forest and natural grassland. Notill system of farming is therefore an ecological system that provides a win-win approach of soil and crop productivity.

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2.21 | ECOLOGICAL INTENSIFICATION INCREASES SOIL C STOCKS VIA CHANGES IN CROP RESIDUE TRAITS

Pablo García-Palacios[1], Andreas Gattinger[2], Helene Bracht-Jørgensen[3], Lijbert Brussaard[4], Filipe Carvalho[5], Helena Castro[5], Jean-Christophe Clément[6,7], Gerlinde De Deyn[4], Tina D'Hertefeldt[3], Arnaud Foulquier6, Katarina Hedlund[3], Sandra Lavorel[6], Nicolas Legay[6,8,9], Martina Lori[2], Laura Martínez[4], Pedro Martins da Silva[5], Adrian Muller[2,10], Eduardo Nascimento[5], Filipa Reis[5], José Paulo Sousa[5], Rubén Milla[1*]

[1]Departamento de Biología y Geología, Física y Química Inorgánica y Analítica, Área de Biodiversidad y Conservación, Universidad Rey Juan Carlos, 28933 Móstoles, Spain

[2]Research Institute of Organic Agriculture, 5070 Frick, Switzerland

[3]Department of Biology, Lund University, 223 62 Lund, Sweden

[4]Department of Soil Quality, Wageningen University, P.O. Box 47, 6700 AA, Wageningen, The Netherlands

[5]Centre for Functional Ecology, Department of Life Sciences, University of Coimbra, 3000-456 Coimbra, Portugal

[6]Laboratoire d'Ecologie Alpine, UMR 5553 CNRS-UGA-USMB, Université Grenoble Alpes, BP 53, 38041, Grenoble Cedex 09, France

[7]CARRTEL, UMR 0042 Université Savoie Mont-Blanc - INRA, 73376 Le Bourget-du-Lac, France

[8]Ecole de la Nature et du Paysage, INSA CVL, 41000 Blois, France

[9]CNRS, CITERES, UMR 7324, 37000 Tours, France

[10]Institute of Environmental Decisions IED, Federal Institutes of Technology Zurich ETHZ, 8092 Zurich, Switzerland

ABSTRACT

Increasing soil C sequestration in croplands can make an important contribution to mitigate climate change. Ecological intensification (EI) practices such as organic farming (OF) enhance soil C stocks compared with conventional farming (CF). Differences in soil C inputs are not enough to explain such pattern, since higher C stocks are found in organic farms with low manure rates, and plant residues are likely lower under OF. Thus, altered soil C losses (e.g. organic matter decomposition) between farming systems may drive higher soil C stocks and sequestration rates in OF compared with CF. Here we assess whether intraspecific changes in crop residue traits key for decomposition drive soil C sequestration responses to OF, by coupling global meta-analyses addressing OF vs. CF, with mechanistic field experiments across six European EI sites. The positive OF effect on soil C sequestration at global scales was dependent on the crop leaf N concentration. Across the European sites, intraspecific changes towards crop residue lability (e.g. high leaf N) in conventional intensification was related with higher SOC stocks in ecological vs. conventional intensification. A trait-based framework of crop residues and their intraspecific changes with management is fundamental when evaluating the ecosystem services delivered by ecological intensification.

Keywords: ecological intensification, organic farming, soil carbon, plant traits, crop residues, carbon sequestration

Extended Abstract

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The decline in soil C stocks typically found after agricultural conversion is a major challenge for agriculture, since croplands occupy 40 % of earth land surface and soils store the largest amount of terrestrial C (Lal, 2004). Increasing C sequestration in agricultural soils is thus an important goal to mitigate climate change (Smith *et al*. 2014), but also to enhance soil fertility and yields via increased organic matter pools (Drinkwater *et al*. 1998). Ecological intensification (EI) advocates maintaining food provision while reducing environmental impacts of high-inputs conventional farming by optimizing key ecosystem services such as soil C sequestration. A recent meta-analysis found that organic farming, a widespread EI practice (ref), increases soil C stocks even after controlling for the higher C inputs (e.g. manure) applied compared to conventional farming (Gattinger *et al*. 2012). Interestingly, such increase in soil C stocks goes in opposite direction to the lower soil C gains via crop residues, as yield is usually 20-25% lower in organic farms (Seufert *et al*. 2012, Ponisios *et al*. 2014). However, soil C losses mechanisms, such as reduced crop residue decomposition under organic than under conventional farming, remain unexplored. Here, we tested the hypotheses that (1) crop residue traits are as important as fertilization inputs and climate to determine soil C storage responses to organic farming; and (2) that EI enhances soil C storage by reducing crop residue quality (high leaf litter C:N ratios and low N concentration).

METHODOLOGY

To test our first hypothesis we improved the literature review of Gattinger *et al*. (2012) with recent studies addressing soil C sequestration rates and crop residue traits data (leaf N and P concentration, and leaf-dry matter content). Pairwise field comparisons of organic vs. conventional (synthetic fertilizer and/or pesticides) farming systems addressing changes in soil C stocks (Mg C ha^{-1}), soil C sequestration rates (Mg C ha^{-1} yr-1), and soil respiration (mg C-CO2 kg soil-1 d-1) were evaluated with meta-analytical techniques. The relative importance of crop residue traits, external C and N inputs, and climate was assesses using structural equation modelling.
To test our second hypothesis we built a network of European agricultural sites across different land-use types and climatic conditions comparing ecological intensive vs. conventional farming systems. Crop residue (leaves and leaf litter) and soil were harvested at each site to measure several plant chemical traits and soil C stocks. The effect size of EI on crop residue traits was used to predict the effect size upon soil C stocks.

RESULTS

Effects of organic farming on soil C storage:
Averaged across all studies, organic farming significantly increased soil respiration, C stocks and C sequestration rates compared with conventional farming. This positive effect was still significant even in studies where the amount of organic fertilization was below inputs that could have been produced theoretically at the respective organic farm (zero net input organic systems).
Drivers of soil C storage responses to organic farming:
Management and fertilization intensity were the major driver of SOC stocks and C sequestration rates responses to organic farming (Fig. 2). Nevertheless, crop residue traits played an important role as well. Crops with high LDMC were related with lower organic farming effect sizes on SOC stocks ($r = -0.18$), while crops with high leaf N concentration promoted a higher effect size on soil C sequestration rates ($r = 0.20$).
Predicting soil C storage responses to ecological intensification using crop residue traits:
Crop residue traits shifted considerably between ecological and conventional intensification plots across all European sites. Specifically, more than half of the variation (55%) in the effect size of EI on SOC stocks was best explained by responses of crop residue C:N ratio and N concentration to management. Increases in litter C:N ratio but decreases in litter N under ecological intensification were related with higher SOC stocks in this particular management scenario.

DISCUSSION

Soil C storage is higher under organic than under conventional farming across biomes and land-use types. This result is not consistent with the generally lower C gains (e.g. crop yield) and C losses (e.g. soil respiration) found in organic farming systems, and is not entirely due to the higher C inputs applied (e.g. manure). Interestingly, our results indicate that crop residue traits are important drivers of soil C stocks and C sequestration responses to organic farming. Reduced crop residue quality (e.g. higher leaf litter C:N ratio and N concentration) promoted higher soil C stocks under ecological intensive than under conventional farming. Global increases in soil C storage under ecological intensification practices such as organic farming may be a consequence of both higher C inputs applied, but also shifts in crop residue traits towards higher recalcitrance (e.g. high leaf litter C:N ratio) and hence lower organic matter decomposition rates and soil C losses.

CONCLUSIONS

We conclude that consistent global-scale increases in soil C storage found under ecological intensification practices such as organic farming are a consequence of the higher C inputs applied (e.g. manure), but it is also due to shifts in crop residue traits towards higher crop residue recalcitrance and hence lower litter decomposition rates and soil C losses. Our results highlight the importance of using a trait-based framework when addressing the ecosystem services delivered by ecological intensification, which is fundamental to identify mechanisms promoting global food security with sustainable agriculture.

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2.22 | INVESTIGATIONS ON CARBON-STRUCTURE-RELATIONS IN AGGREGATED SOILS SUBJECTED TO DIFFERENT TILLAGE INTENSITY

A.Mordhorst[1*], R. Horn[1]

[1]Institute for plant nutrition and soil science, Christian-Albrechts-University Kiel, Olshausenstr. 40, 24118 Kiel, a.mordhorst@soils.uni-kiel.de

ABSTRACT

Aim of this work was to prove changes in carbon-structure-relations by investigating the impact of disruptive forces of tillage activities and mechanical loading on the spatial distribution of soil organic carbon (SOC) inside large macroaggregates (5 – 20 mm across) and CO_2-release of intact soil cores (236–471 cm³). Undisturbed samples were taken from the topsoil of loamy sand field plots under no-tillage (NT), reduced tillage (CONS) and conventionally ploughed (CT). Air-dried aggregates were peeled from the outside (exterior region) to the inside (interior region) using the SAE method from Park and Smucker (2005).

The effect of tillage intensity on the spatial distribution and stabilization of SOC was confirmed within macroaggregates irrespective of aggregate size class. With increasing tillage intensity (NT < CONS < CT) aggregates were less stable and their SOC content was found to be depleted in aggregate exterior compared to interior layers. This led averagely to a 2/3 higher SOC stock (0–20 cm soil depth) in macroaggregates under NT compared to CT. At the bulk soil scale a high susceptibility against SOC losses due to mechanical loading was observed, that varied with soil strength and as consequence on soil management indicated by a higher CO_2-release under CT.

Keywords: Soil organic carbon, tillage systems, CO_2-release, mechanical loading, soil strength, aggregate peeling, conservation tillage, large macroaggregates

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Combating climate change needs abilities of mitigating anthropogenic CO_2-emissions from arable soils. Implementation of alternative management strategies with lower disturbance intensity compared to conventional ploughing (CT) is stated to increase the soil organic carbon pool (SOC) of arable topsoils by 0.2 ± 0.13 t/ha/year (Arrouays *et al*., 2002, Mordhorst, 2013). Inside of intact aggregates organic substrates are physically protected against microbial attack since microorganisms as potential decomposers can´t access these pores or they are inactive under limited environmental conditions such as oxygen, water and energy supply. Physical inaccessibility of SOC is known to be an effective mechanism to sequester carbon at different size and time scales (Balesdent *et al*., 2000, Six *et al*., 1998, Young and Ritz, 2000). Soil management influences structure formation processes and the associated physical carbon protection in aggregates. Hence, the susceptibility against SOC losses is related to stress-induced changes in aggregation and internal pore structures, and depends therefore on the mechanical strength properties (Horn and Smucker, 2005).

Aim of this work was to prove related changes in carbon-structure-relations by investigating the impact of disruptive forces of tillage activities or mechanical loading on the SOC distribution inside aggregates and CO_2-release at different scale sizes: the *bulk soil scale* using intact soil cores as well as the *aggregate scale* using intact macroaggregates (5 – 20 mm across). It was hypothesized, that the spatial SOC distribution and stabilization potential within these macroaggregates is controlled by soil management, for example by soil tillage intensity (conventional ploughing and conservational/no-tillage systems). Secondly, it was expected that the SOC loss potential (CO_2-release) is dominated by the soil strength (stability of aggregates) depending on soil tillage frequency.

METHODOLOGY

Undisturbed soil cores (236 and 471 cm³) and soil blocks (1000 cm³) were collected from a topsoil of field plots of a loamy sand texture (59% sand, 28% silt, 13% clay) at a Danish Research Station (mean annual temperature of 7.7 °C, annual rainfall of 560 mm). Field plots have been subjected to different tillage treatments for 9 years before sampling. A no-tilled (NT), reduced tilled (harrowed down to depth of 8–10 cm: CONS) and conventionally ploughed (CT) Stagnic Luvisol (FAO, 2006) from glacial till was sampled in inter-traffic line zones.
For investigations on the aggregate scale, field moist soil blocks taken from 0–10 and 10–20 cm depths were gently fractionated into the aggregate-size classes (AS class) 5–8, 8–12, 12–20 mm by manually breaking larger fragments along their weakest rupture planes. After air-drying, single aggregates from each AS class (n = 10) were separated into three concentric layers of equal solid mass ratio representing the exterior, transitional and interior aggregate region using the SAE method developed by Park and Smucker (2005b). In addition, aggregate volume was measured for whole aggregates and after removing the exterior and transitional concentric layer using a Pyknometer (Geopyc 1360, Micromeritics). Soil organic carbon (SOC) was measured for each concentric layer by dry combustion at 1200°C (Coulomat 702, Fa Ströhlein instruments) as well as total Kjeldahl N using a Flow-Injection Analyzer.
The mechanical stability of these aggregates was derived from (a) their Erosive strength (E_s) calculated from abrasive forces, which were required for peeling the aggregates from the outside to the inside, and (b) their tensile strength (Y) using the Crushing Test according to Dexter and Kroesbergen (1985).
CO_2-release was determined at the bulk soil scale for undisturbed soil cores taken from 10 – 15 cm depth (n = 6), which were pre-drained to field capacity (-6 kPa) prior laboratory measurements. CO_2-changes due to soil structure deformation by mechanical load application (max. 400 kPa) were measured dynamically using the Gas Flow Compaction Device as well as statically in terms of basal respiration rates using an alkali CO_2 trap inside of respiration chambers.

RESULTS

At the *aggregate scale*, the effect of tillage intensity on the spatial distribution and stabilization of SOC was confirmed within macroaggregates of almost all tested AS classes: With increasing tillage intensity (NT < CONS < CT) aggregates were less stable (lower E_s and Y) and their SOC content was found to be depleted in aggregate exterior compared to interior layers in both depths. Fig. 1 shows a lower amount of SOC of exterior regions for 2/3 of CT aggregates compared to their interior layers. In contrast, SOC was relatively enriched in aggregate exterior regions for >80 % of aggregates from all AS classes under NT. Additionally, significantly higher C/N ratios in exterior layers compared to interior were observed for NT aggregates in both depths, opposite results were found for CT and CONS treatments. Although accumulation of SOC under NT was limited to 0–10 cm soil depth, the SOC stock within these macroaggregates was almost 2/3 as large increasing averagely from 15 t/ha (CT) to 26 t/ha (NT) summed up for 0 – 20 cm depth.
At the *bulk soil scale*, we could confirm the strong impact of structural deterioration by exceeding internal soil strength on changes in CO_2-release. In fact, primary reduction in CO_2-release by soil compaction was not persistent over time, because increasing carbon losses (CT > CONS > NT) compared to the initial state (without compaction) were found when the soil was re-equilibrated to field capacity (-6 kPa) again. This demonstrates a varying high susceptibility against SOC losses due to externally mechanical impacts depending on soil strength and as a consequence on soil management.

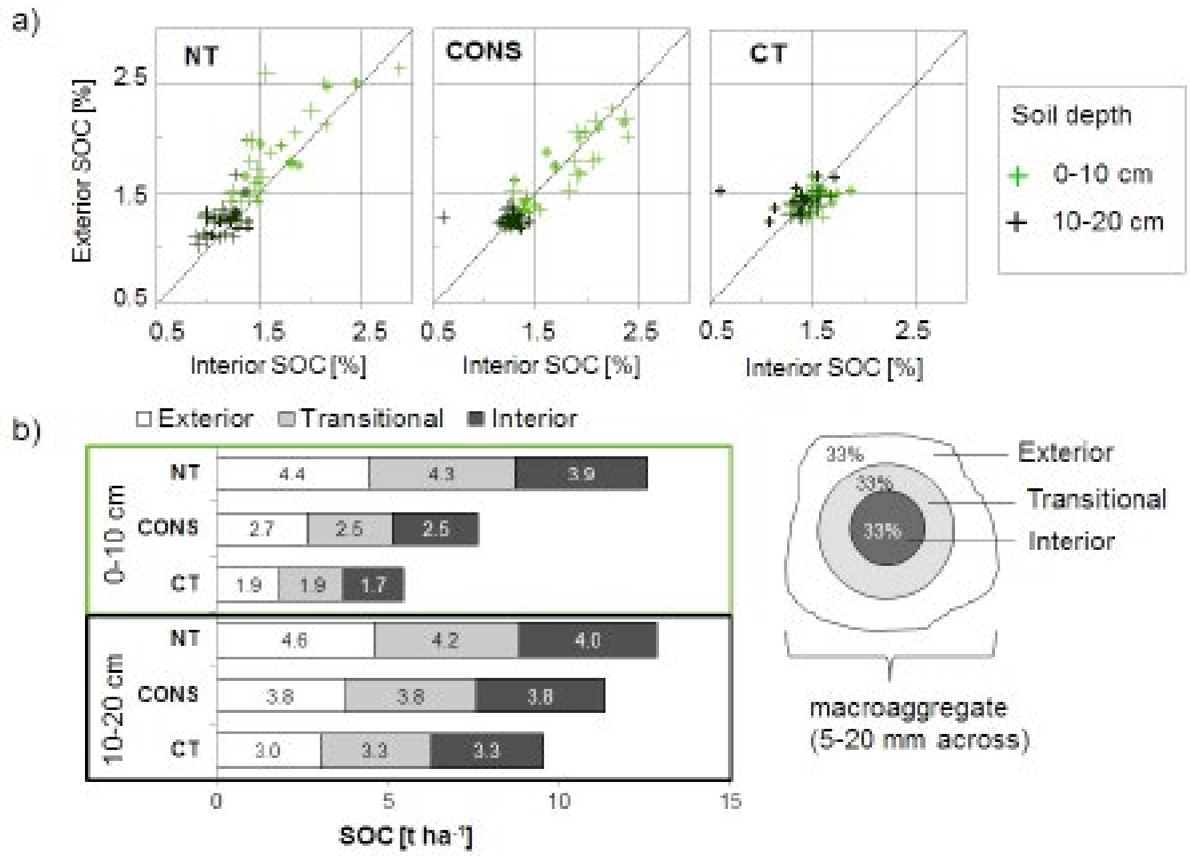

Fig. 1: Relation between exterior and interior SOC within macroaggregates (5-20 mm across) from 0-10 and 10-20 cm sampling depth of a sandy-loam Stagnic Luvisol (published in Mordhorst, 2013) (a) and calculated mean SOC stocks of concentric aggregate layers (b) depending on tillage intensity (CT = conventional ploughing, CONS = Reduced tillage (harrowing 8-10 cm), NT = No-tillage).

DISCUSSION

Higher depletion of SOC at exterior regions with increasing tillage intensity (NT < CONS < CT) suggests higher microbial decomposition rates through the enhanced aeration of interaggregate pores. Accumulation of SOC in the outer skin of aggregates has repeatedly been observed for aggregates of equal size order (e.g. Park and Smucker, 2005a; Urbanek *et al*., 2011). Such gradients may be promoted by carbon depositions onto aggregate surfaces derived from roots or fungal hyphae which are likely dominated between aggregates (Kavdir and Smucker, 2005). Higher N content and lower C/N ratio of exterior regions under CT suggest higher microbial biomass and higher microbial activity (Park and Smucker 2005a).

The establishment of SOC gradients within aggregates possesses a great potential for SOC sequestration, but requires that aggregate turnover-rate is low and the internal aggregate porosities increase over time in order to expand the SOC storage towards interior regions (Park and Smucker, 2005). In this way, Park *et al* (2007) demonstrated the formation of preferential diffusion path ways in microfissures for transporting DOC from exterior to interior regions, which are yet free of potential decomposers. As the aggregate turnover rate is lowest under NT and aggregates were stable, it is conceivable that such diffusion processes were responsible for the absolutely higher SOC contents in interior regions of NT compared to CT aggregates (Fig. 1a). In contrast, tillage-induced loss of aggregate stability, indicated by lower erosive and tensile strengths, likely prevents the establishment of concentric gradients from outer to inner regions. Results indicated the importance of minimizing aggregate turnover rates for improving carbon sequestration.

Otherwise, when aggregates were destroyed by mechanical loading (according to agricultural field traffic), the SOC sequestration potential was diminished again. The increase in CO_2-release after re-equilibrating a compacted soil to field capacity (-6 kPa) was presumably related to changes in microbial activity, originating from enhanced energy supply following structural rearrangement by mechanical and hydraulic stresses. Since ploughing promotes the incorporation of freshly organic residues to deeper soil regions compared to CONS and NT, highest CO_2 losses were found for CT soil cores from 15 cm depth.

CONCLUSIONS

The strong response of tillage practices on aggregate strength and SOC distribution inside aggregates affecting the SOC sequestration potential in soils was confirmed. Results underpin the importance of minimizing macroaggregate turnover being essential for the formation of stable macroaggregates and the establishment of SOC gradients from the exterior to interior aggregate regions. Investigation of carbon-structure relations on that scale size (mm to cm) has proven to be valuable for evaluating the effect of management (e.g. soil tillage systems) on the susceptibility against mechanical load applications and accompanied CO_2-release that diminishes the carbon sequestration potential again.

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2.23 | EFFECTS OF DIFFERENT THINNING INTENSITIES ON SOIL CARBON STORAGE IN PINUS LARICIO FOREST (APENNINE, SOUTH ITALY).

Muscolo A*., Settineri G., Mallamaci C., Attinà E., Sidari M.

Dipartimento di Agraria, Università Mediterranea, Feo di Vito-89122-Reggio Calabria, Italy
Email: amuscolo@unirc.it

Thinning, reducing tree density and altering microclimate and organic matter budget, can affect soil carbon (C) and soil ecosystem functioning; however, changes in soil C, soil microbial biomass (MBC) and its activity after thinning are not well elucidated. This study investigated, in a Pinus laricio L. Poiret forest, how thinning of different intensities (no thinning, TO; 30% thinning, T30; 60% thinning, T60; clear cut CC) affected soil biological properties, organic matter trend and carbon storage. Results showed that soil carbon content and C/N ratio were significantly higher in T60 than in T0, T30 and CC. Under T60, the soils had the highest enzymatic activities, MBC, and colonies of fungi and bacteria. 60% thinning with lower density of trees compared to control and higher ones compared to CC and T30 determined regimes of light, temperature and humidity at soil level, that increased herbaceous vegetation diversity promoting an increase in soil microbial biomass, overall in bacteria responsible for the production of enzymes involved in carbon transformation. Humification indices confirmed that humification process prevailed in T60 with consequent carbon storage. This study shows that T60 is a sustainable forest management practice improving soil quality and C storage already after few years of treatments.
Keywords: pine forest, soil biochemical parameters, carbon storage, thinning

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Forests act as a natural storage for carbon at the global scale, contributing approximately 80% of terrestrial aboveground, and 40% of terrestrial below-ground carbon storage. The relatively rapid change in the status of forests– from a steady state of minimal CO_2 emission/sequestration to major CO_2 emitter – during this time period may offer a cautionary tale of how quickly the source/sink status of large-scale forest C stocks can change. Our understanding of how forest management influences standing C stocks, however, is limited because many forest C studies have focused on quantifying trends in unmanaged forests. Among silvicultural practices, thinning, reducing tree density and altering microclimate and organic matter budget, can affect soil carbon (C) storage and soil ecosystem functioning. In Italy, thinning of pine forests is the most effective silvicultural treatment to enhance the ecological value of these stands; however, changes in soil C, soil microbial biomass and activity after thinning in pine forests are not well elucidated yet. Our objectives were to understand how thinning affects the dynamic of total carbon in forest ecosystem as well as each of its component pools. We estimated carbon stocks in Pinus laricio stands, evaluating carbon pool dynamics in forest subject to different thinning intensities (0, 30 and 60%) and clear cut over two contrasting seasons (winter and summer), to verify if the environmental conditions affect in short term soil carbon pool. Our aim was to identify the silvicultural practice that increased carbon storage in pinus forest. Our hypothesis-driven research was that increasing thinning intensities physico-chemical, microbiological and biochemical properties of soil related to soil quality and fertility decreased.

METHODOLOGY

The study area was located in 60-years-old *Pinus laricio* stands in Aspromonte Mountain (Calabria, South Italy). The soils were classified according to the IUSS WRB (2006) as Humic Cambisols. The thinning intensities were 30% (30% plants removed, T30), 60% (60% plants removed, T60), clear cutting (100% plants removed, CC), and a control (no thinning, T0). Soil samples (0-30 cm) were randomly taken after removing the litter layers. Soil chemical and biochemical analyses as well soil microbial biomass, fungi and bacteria colonies were detected as reported in Sidari *et al*. (2008); Muscolo *et al*. (2010); Sidari *et al*. (2010).

RESULTS

Results showed that soil carbon content and C/N ratio were significantly higher in T60 than in T0, T30 and CC. Under T60, the soils had the highest enzymatic activities, MBC (Tables 1). 60% thinning with lower density of trees compared to T0 and higher ones compared to CC and T30 determined regimes of light, temperature and humidity at soil level, that increased herbaceous vegetation amount and diversity promoting an increase in soil microbial biomass, overall in bacteria responsible for the production of enzymes involved in carbon transformation. Humification indices confirmed that humification process prevailed in T60 with consequent carbon storage (Table 1). This study shows that T60% is a sustainable forest management practice able to improve in parallel soil quality and C storage already after few years of treatments.

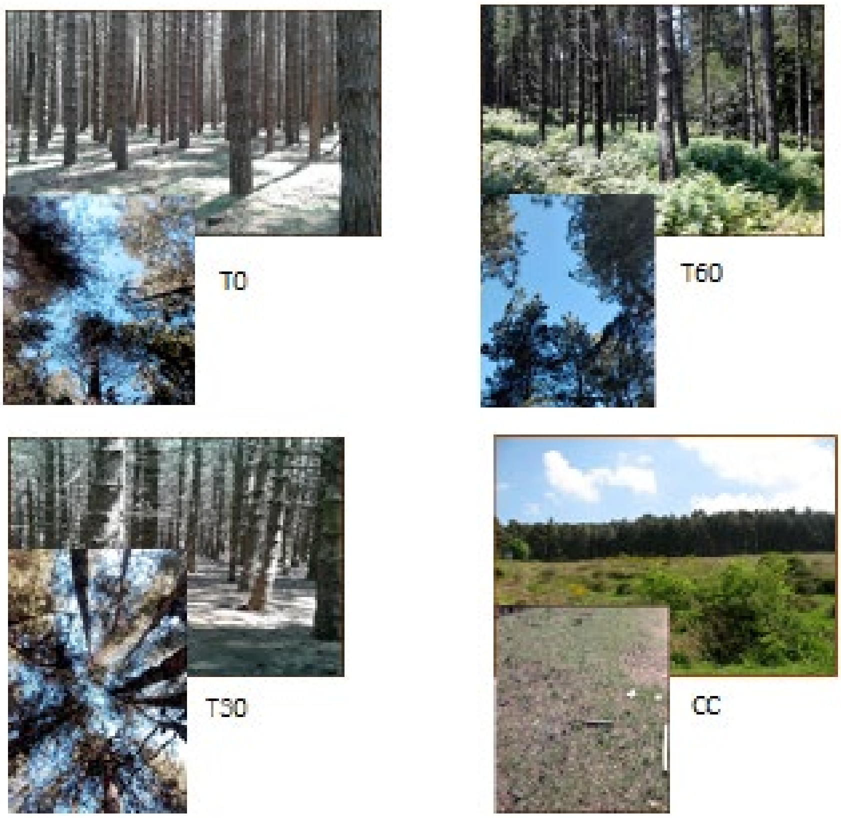

Fig. 1: Different thinning intensities: no thinning (T0), 30% thinning (T30), 60% thinning (T60) and clear cut (CC)

Table 1: Chemical and biochemical soil analysis: organic matter (OM%), total nitrogen (N%), C/N ratio, fluorescein diacetate (FDA, µg fluorescein g·1soil h·1), protease (PROT, µg tyrosine g-1 dry soil 2h-1), catalase (CAT, µmol O2 g-1 soil min-1), dehydrogenase (DHA, µg TTF g-1 h-1), microbial biomass C (MBC, mg C g-1 dry soil), water soluble phenols (WSP, µg TAE g-1 dry soil), cation exchange capacity (CEC, meq 100g-1 dry soil), humic acid/fulvic acid (HA/FA), humification index (HI), humification rate (HR, %), humification degree (DR, %) under Pinus laricio plantation differently managed: thinning 0%, control; thinning 30%,T30; thinning 60%, T60 and clear cut, CC.

Season		OM	N	C/N	FDA	PROT	CAT	DHA	MBC	WSP	HA/FA	HI	HR	DR
	T30	18.35 b	0.63c	16.5b	58.52b	80.35b	1.69b	7.36b	7574b	200a	1.42a	0.24c	63.5b	80.5b
	T60	24.21a	0.72a	19.5a	71.92a	90.90a	1.88a	11.15a	7997a	200a	1.17c	0.16d	77.0a	85.9a
Summer	CC	16.86c	0.62b	15.8b	53.18c	76.07c	1.13c	6.23c	6810c	195a	1.43a	0.37a	56.7c	73.1c
	T0	7.68d	0.37d	12c	45.86d	68.22d	0.74d	5.89d	6378d	200a	1.25b	0.26b	58.5c	79.1b
	T30	14.49b	0.69b	12b	53.25b	59.86b	1.32b	3.77b	6800b	233a	1.96a	0.33b	58.8c	75.2c

Winter	T60	15.54a	0.70b	13a	61.80a	63.01a	1.41a	4.40a	7550a	222a	1.22d	0.14d	75.3a	87.5a
	CC	13.48c	0.83a	9d	50.10c	56.81c	1.03c	2.24c	6352c	228a	1.67b	0.24c	63.3b	80.7b
	T0	12.32d	0.67b	11c	42.85d	52.79d	0.94d	1.93d	6027d	229a	1.58c	0.38a	53.5d	72.1c

DISCUSSION

Natural processes of C sequestration in terrestrial ecosystems (e.g. soils, vegetation, wetlands) contribute to increased biomass, improved soil health and function. Thereby these processes enhance the resilience of ecosystems and the adaptation of these systems to climatic disruptions with the attendant changes in temperature, precipitation and frequency and intensity of extreme event. Most soils under the managed ecosystems contain a lower SOC pool than their counterparts under natural ecosystems, Thus,

soil C sequestration can be reached through the adoption of sustainable management practices. Simultaneous examination of changes in SOM fractions and soil biological properties represents an important beyond the insights it gives into the contribute of forest management on C cycle (Sicardi *et al*. 2004; Sidari *et al*. 2005). Under 60% thinning the soils had the highest amount of microbial biomass and bacteria. These results qualitatively demonstrated a microbial diversity-SOM dynamics relationship. The lower density of trees compared to control forest determined different regimes of light, temperature and humidity at soil level, increasing herbaceous vegetation and its diversity undergrowth with the production of litter easily degradable, which in turn promoted an increase in soil microbial biomass and overall in bacteria amount. All the humification parameters indicated that 60% thinning was the silvicultural practice to adopt for increasing soil carbon storage.

CONCLUSIONS

In short, we found that 60% thinning was the silvicultural practice to adopt for increasing carbon storage in coniferous soil. Our study provides scientific information for predicting the consequences of current management practices for future forest productivity, and understanding how ecological processes interact with human interventions to influence soil carbon storage. The results of our research are important for land managers policymakers, carbon accountants, and scientists working on a variety of forest-related issues.

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2.24 | INCREASING SOIL ORGANIC CARBON AND ENHANCING SOIL MOISTURE HOLDING CAPACITY THROUGH TANK SILT APPLICATION TO ADAPT CLIMATE CHANGE

R Adhinarayanan

Programme Leader DHAN Foundation,

1A, Vaidhyanathapuram East, Kennet Cross Road, Madurai – 625016 Tamil Nadu, India aadhi@dhan.org

ABSTRACT

Climate change pose serious negative impact on farming communities in India in the form of variations in seasonal rainfall and rainy days. The drastic reduction of organic carbon in the soil due to over use of inorganic fertilizer and top soil erosion in rainfed lands highly challenging the farmers to ensure crop productivity hence the soil moisture holding capacity reduced at alarming level. The change in the onset of monsoon and increased dry spell resulted drying of early stage crops in dryland rainfed farming. Farmers have no other option than farming resowing the seeds with increased cost of cultivation due to less moisture in the soil. To enhance the organic carbon content and soil moisture retention capacity an action research has been undertaken in semi-arid tropics with the support of GIZ in Madurai district. Indigenous practice of tank silt with combination of goat/sheep penning were applied. It increases the moisture holding capacity of the soil. Over all, this intervention increased the physical and chemical properties of soil in the treatment plots compare with control and water storage capacity in the traditional water bodies (tank).

Keywords: Tank silt, climate change, dry spell, organic carbon, moisture holding capacity

1. INTRODUCTION

Climate change is a reality in many parts of the globe and it posing serious negative impact on farming communities in India in the form of variations in seasonal rainfall and rainy days. Especially, rainfed lands are facing challenges like season change (*pattam mattram)* and increased dry spell could not provide adequate moisture for crops resulted crop failure and re-sowing of crops. The continued increased use of chemical fertilizers on land resulted changed the soil physical and chemical properties and made it hardening of top soil. As a result of this the soil not able to absorb rain water to its full capacity, in-turn the water runoff eroded the top soil. The reduction of soil organic matter and moisture holding capacity increased the risk of small and marginal farming communities and increased the cost of cultivation. This leads the farmers to avoid cultivation of their land and reduced the employment through farming, food and nutritional insecurity in the villages.

2. STUDY AREA

To address the soil moisture holding due to climate change a demonstration were conducted in T.Kallupatti (77.89^0 E longitude and 9.75 ^{0} N latitude) block of Madurai district, Tamil Nadu. Where soil type of the land is broadly classified by the local communities are *"pottal"* (clay with less moisture holding and fertility) and "*karisal"* (black cotton soil with high moisture holding capacity and good fertility). 55 percent of the agriculture lands soil type is *pottal* is weakness for their cultivation and it requires more input cost for the crop cultivation. The effect of climate change join with the non-climatic factors of soil management significantly reduced the soil moisture holding capacity, which is crucial factor of crop success in rainfed dry lands. Indigenous practice of application of tank silt @ 50 Cubic Metre per acre with combination of goat/sheep penning were applied. Tank silt has significant amount of organic carbon (0.89), 50 Cubic meter of tank silt changed the organic carbon content of soil ranges from 0.03 to 0.40.

3. TANK SILT APPLICATION – ADAPTATION TO CLIMATE CHANGE

Tank silt is a fine soil runs through runoff during rainfall from catchment area along with dried leaves, crop debris deposited as sediment in the tank water spread area and decomposed over a period time. This process enriches the soil organic content. Upto 2-3 feet sediment (tank silt) excavated and transported to agricultural field and spread in the filed and incorporated during ploughing practice is called tank silt application.

Excavated tank silt of 50 Cubic metres (25 tractor tipper load) was applied to rainfed farm lands. Tank silt was applied to agriculture fields for 105 farmers in 104 acres.

The tank silt was applied to the lands to change the physical characteristics of soil and nutrient enhancement too. Out of 31 samples studied, 6 samples were detailed analyzed for five times to see the changes like pH, Electrical Conductivity, Organic carbon.

- Tank silt was primarily applied to the *pottal* lands (73 acres for 74 farmers) which have low water holding capacity and saline nature and *Karisal (*31 acres for 31 farmers).
- Through this tank silt excavation 5200 Cu.M of additional water storage is created in Kilankulam tank. The pits are filled in the first rain and this storage acts as a dead storage and useful for the livestock and ground water recharge.

Pilot project implemented period has consecutive drought. The average annual rainfall of T.Kallupatti block is 806 mm. Analysis of long term rainfall data (1901-2004) shows that the district receives rainfall during NE monsoon (47%), SW monsoon (32%), summer (17%) and winter (4%). Out of the total rainfall, July to Sep month rainfall decides the farming because of rainfed farming. Generally during these period 258 mm rainfall received and it is highly sufficient for carry out all agriculture activities. But in the study period, pilot project area received 128 mm (15.9 %) and 94.5 mm (11.72 %) against the normal annual rainfall in the year 2012 and 2013 respectively.

Temperature

High temperature experienced only in the months of April, May and June. Now the high temperature is continuing upto August month. Also the temperature increased one to two degrees more compare with last 40 years. (Maximum 42 degree Celsius). Increased hot weather on crops requires more wetting/moisture to complete the crop cycle otherwise the crop is damaged (crop yield decrease or total crop failure)

The variation in the Southwest monsoon is 18.20% for 2013 and 2014. It clearly shows that climate is changed in rainfall aspects. Over all gap in the rainfall for year 2012 is 396 mm (49.13 %) and for 2013 is 313.40 mm (38.88 %). With this deficit rainfall the farmers have carried out their rainfed agriculture. It is very good opportunity to see the adaptation activities performance in the field.

4. RESULTS OF THE ACTION RESEARCH

Table-1 Multiple uses of tank silt application

Water storage	Nutrient cost	Adaptation
50,000 litres in tank	Nitrogen - INR.71	Physical properties of soil positively changed
Increase moisture holding	Phosphorous -	Change of pH 0.5 to 1.0
capacity	INR.32.50	
Increased rate of ground	Potash –INR. 324	Reduction and control of GHG emission by not
water recharge		using inorganic fertilizer
	INR..427.50	

4.1 Tank silt application and organic carbon availability of soil

Tank silt has significant amount of organic carbon (0.89), 50 Cubic meter of tank silt changed the organic carbon content of soil ranges from 0.03 to 0.40. It increases the moisture holding capacity of the soil.

Table-2 . Soil organic carbon analysis

After	Before	Change
0.69	0.29	0.4
0.37	0.34	0.03
0.36	0.27	0.09
0.31	0.2	0.11
0.29	0.13	0.16
0.31	0.19	0.12

4.2 Tank silt application on soil Electrical Conductivity

It increases the moisture holding capacity of the soil. The field continuously irrigated by using ground water having salinity and excess use of inorganic fertilizer leads to increase in EC value of soil. Application of tank silt has resulted in reduction of EC in all agriculture fields. The reduction of EC ranges from 0.02 to 1.21. The yield of crops increased to 50 to 60 percentage in the deficit rainfall season compare with normal yield.

4.3 Tank silt application effect on crop yield

Table 3 - Tank silt application effect on crop yield

Crop	Control	Normal	Treatment	Increase of yield compare with normal %
Barnyard millet	100	700	1400	200
Maize	909	1400	1067	76
Paddy	2448	2880	3500	122
Pearl millet	328	600	417	70
Cotton	70	350	222	63
Chilly	100	650	625	96

CONCLUSIONS

Tank silt application is a cost effective adaptation technique to climate change and environmental friendly having multiple benefits

Government has to analyze silt and declare tank wise nutrient status and potential tanks for tank silt application for farm lands

Tank silt to be considered as a substitute for the chemical fertilizer and subsidy given to fertilizers need to be allocated for tank de-silting and recycling of nutrients to farm lands.

Traditional wisdom of farmers should be documented and scientifically evaluated and recommended for policy at state and national level.

2.25 | REGENERATIVE ORGANIC FARM MANAGEMENT PRACTICES MITIGATE AGRO-ECOSYSTEM VULNERABILITY TO CLIMATE CHANGE BY SEQUESTERING CARBON AND BUILDING RESILIENCE

Kristine Nichols[1*], Emmanuel Omondi[1], Andrew Smith[1], and Jeff Moyer[1]

[1]Rodale Institute, 611 Siegfriedale Road, Kutztown, PA, USA 19530

ABSTRACT

Rodale Institute, a solutions-based non-profit U.S. research, outreach and education institution, has been conducting side-by-side research trials comparing organic or conventional management practices since 1981. The grain production system, Farming Systems Trial (FST), was started in 1981 while the Vegetable Systems Trial (VST) was initiated in 2016. The primary goal of both FST and VST is to quantify the impacts of farm management practices on the linkages between soil health and human health. Measurements of soil biological, chemical, and physical parameters have been and are continuing to be made in conventional and organic plots. Over the 34 years of management history in FST, soil organic carbon (SOC) levels have increased from 2.0% to 2.5% and the depth of the A horizon has increased by 2 to 10 inches in the organic systems compared to the conventional systems. In addition, the organic plots are more resilient to climatic uncertainty and have higher yields during drought years. Finally, organic systems are less energy intensive and emit lower amounts of greenhouse gases. Hence regenerative organic systems are productive systems providing nutrient dense grains and vegetables and mitigating agro-ecosystem vulnerability to climate change by sequestering carbon and building resilience.
Keywords: Carbon sequestration, Farming Systems Trial, Organic, Regenerative, Resilience, Vegetable Systems Trial

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

For many generations, conventional, agro-chemical-intensive farming practices were responsible for feeding global populations. However, today, farmers not only need to meet the demand for increased production but also to improve the soil health in order to sustain those yields for generations and to ensure that the food they grow is nutrient dense. The extensive use of agro-chemicals and GMO varieties in conventional farming has degraded soils reducing productivity, water quality, the plants' ability to extract the nutrients needed to maintain personal health, and ecosystem services. Conventional farming systems increase nitrate leaching, phosphorus run-off and pesticide exposure. Biologically-based alternatives to synthetic chemical pesticides will be used for weed and insect pest management and thereby improve farm worker safety by eliminating toxic pesticide exposure. Ultimately reductions in soil health have contributed to a decline in the nutrient density of the soil, which decreases nutrient bioavailability to grain and vegetable crops (Ikemura and Shukla, 2009). Unlike conventional, agro-chemical intensive farming, organic farming practices regenerate soil by reducing tillage, increasing crop diversity through long crop rotations and the extensive use of cover crops, and fertilizing with manure and compost. These practices elevate soil organic matter levels and enhance soil biological activities.

In response to these issues, Rodale Institute designed two long-term research studies comparing organic and conventional systems side-by-side. Since 1981 this comparison has been conducted in a grain cropping systems trial (FST) while last year the VST began. The goals for both these studies were to:

1. Improve the nutrient density (or increase the amount of nutrients per calorie) of crops, hence food quality;
2. Reduce environmental and health risks in agriculture particularly through the use of pesticides;
3. Improve productivity, soil health, water quality, protection of natural resources, and the quality of life for farmers, their employees, and the farm community;
4. Adapt to and mitigate climate change;
5. Reduce fertility and pest management costs; and
6. Increase net farm income.

Project objectives were to:

1. Compare the effect of organic and conventional farming systems on crop nutrient profiles, including minerals, crude protein, beta-glucans, lipid-soluble and water-soluble vitamins as well as soil quality.
2. Measure the pesticide contamination levels in leachate and crops in organic and conventional systems.
3. Quantify carbon storage levels, greenhouse gas emissions, and adaptability to climatic uncertainty.

METHODOLOGY

Experimental Design:
Farming Systems Trial: Three grain cropping systems - manure organic, legume organic, and synthetic agro-chemical conventional system – have been compared in FST since 1981. The **Manure Organic** system represents an organic dairy or beef operation. It features a long rotation including both annual feed grain crops and perennial forage crops with fertility provided by leguminous cover crops and periodic applications of composted cow manure. The diversity of the rotation and stimulation of the soil biological community through the use of compost are the primary lines of defense against pests. The **Legume Organic** system represents an organic cash grain system. It features a mid-length rotation consisting of annual grain crops and cover crops, and its fertility is leguminous cover crops with the rotation diversity and enhancement of soil biology through the use of legume cover crops providing the primary lines of defense against pests. This system will be used as a check to compare a standard organic system using only cover crop-based soil additions to the manure-based organic systems. The **Synthetic Conventional** system represents the majority of grain farms in the U.S. It has a short rotation of corn and soybeans and relies on synthetic nitrogen for fertility, and weeds are controlled by synthetic herbicides selected by and applied at rates recommended by Penn State University Extension. In 2008, each of the three systems was modified to include tilled and rotational no-till systems to conform to the current global trend of reducing tillage in agricultural systems. The no-till organic systems utilize cover crops and our innovative no-till roller/crimper to manage weeds while conventional system utilizes synthetic herbicides. GMO varieties of corn and soybean were also introduced in the conventional systems to emulate the majority of conventional farmers.

Vegetable Systems Trial: Four vegetable cropping systems – organic reduced tillage, conventional reduced tillage, organic black plastic mulch, and conventional black plastic mulch – are being established in this trial. The **Organic Reduced Tillage** system will utilize a rolled down cover crop as a green manure and a weed barrier as surrogate to herbicide application. Crops in the organic and conventional reduced tillage system will be planted using a no-till planter or transplanter. The **Conventional Reduced Tillage** system will have a cover crop burned down with herbicides in spring. Some crops, such as potatoes, may require tillage for planting and harvesting and therefore the reduced tillage systems will not be completely no-till. The **Organic Black Plastic Mulch** system will consist of a plowed down cover crop in the spring with black plastic mulch laid shortly after plow down. Harvest will be followed by removal of black plastic and cover crop establishment. The **Conventional Black Plastic Mulch** system will consist of a plowed down cover crop in the spring with biodegradable black plastic mulch laid shortly after plow down and incorporated into the soil following harvest. Within the organic and conventional plasticulture system, the goal is season extension or double cropping within a single growing season for maximum profitability.

Soil Sampling Protocol: In both FST and VST, chemical, physical and biological soil quality parameters were measured on surface and deep core soil samples. These parameters include soil pH, soil organic matter percentages, total carbon and nitrogen levels, macro- and micronutrients, cation exchange capacity, bulk density, aggregate stability, microbial biomass, microbial community structure, water infiltration rates, and compaction.

RESULTS

In FST, combined grain yields of corn, soybean, wheat, and oats, averaged between 1986 and 2014, between the three cropping systems show no significant difference in combined. Organic systems perform especially well during years of drought. During a 5-year period between 1988 and 1998 when total rainfall from April to August was less than 14 inches (compared to 20 inches in normal years), average corn yields were 31% (115 bushels per acre) greater than conventional system (86 bushels per acre). In both 2015 (Fig. 1) and 2016, the organic systems were more productive than the conventional system. This performance may be attributed to greater soil organic matter (SOM) in organic systems. Soil organic matter in tilled manure organic systems increased from 3.3% in 1981 to about 4.5% in 2014 representing a net increase of 27%. In the conventional system, SOM changed from 3.3% to 3.6% – a net increase of only 8%. In addition to increases in SOC with organic management, the depth of the A horizon increased by 2 to 10 inches compared to the conventional system (Fig. 2). Soil samples in 2015 from the organic treatments had higher soil carbon and nitrogen concentrations while 2014 oat grain samples had higher B vitamin levels, micronutrient content and crude and total proteins.

Fig. 1: In 2015, organic corn in the Farming Systems Trial was resilient against drought and yielded 18.6% more than corn in adjacent conventional plots.

DISCUSSION

Increases in soil organic matter make agro-ecosystems more resilient against climatic variability because SOM holds water (Hudson, 1994; Johnson *et al*., 2005) and stimulates biological activity to form soil aggregates which keep water in the root zone. During drought years in the 1990's and 2015-2016, the impact of higher than normal precipitation in spring followed by a long dry spell in late summer and fall was seen in corn plants from an organic legume treatment and an adjacent conventional treatment. Because of this precipitation pattern, it is likely that nitrate and phosphate fertilizers applied in the spring to the conventional treatment ran off the field and low soil moisture content later in season reduced nutrient flow which contributed to drought stress. Soil healthy was also linked to the nutritive quality grains illustrating that organic systems produce healthier soil and food.

CONCLUSIONS

Healthy soils created by biologically-based, regenerative organic management practices sequester more carbon to deeper depths than chemically managed soils. By stimulating higher levels of activity in the soil microbiome, soil organic matter becomes biologically, chemically and physically occluded increasing soil organic carbon concentrations in surface soils increasing the depth of the A horizon. These processes enhance soil aggregation leading to improved soil structure, tilth, and productivity. Biologically active soils provide nutrients to plants on demand making them more resilient and to resist pests, so farmers can reduce pesticide applications. This combined with reducing the cost of fertilizers while maintaining or even increasing yields offers huge economic gains for the producer. The organisms present in healthy soil live in synergy with each other, creating a soil food web that breaks down residue, fixes nitrogen, metabolizes phosphorous into plant-available forms, strikes a balance between beneficial and predatory insects, builds soil organic matter – or carbon – and even filters water and neutralizes pollutants.

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2.26 | LAND USE CHANGES ON SOIL CARBON DYNAMICS, STOCKS IN EASTERN HIMALAYAS, INDIA

Dhermesh Verma[1], B.P. Bhatt[2], Brajendra[3], Ranjan Bhattacharyya[4] and Lehar Jyoti[5]

[1]Head: ICT, Remote Sensing & GIS, AgriNet Solutions, India. verma.dharmesh@gmail.com

[2]Director, ICAR Research Complex for Eastern Region, Patna, Bihar, Indiadrbpbhatt.icar@yahoo.com

[3]Principal Scientist, Indian Institute of Rice Research, Rajendranagar, Hyderabad, India. birju1973@gmail.com

[4]Sr. Scientist, CESCRA, Nuclear Research Laboratory Building, Indian Agricultural Research Institute, Pusa, New Delhi, 110 012, India ranjan_vpkas@yahoo.com

[5]*ICAR Research Complex for NEH Region, Umiam, Meghalaya, India*

Presenting Author: Dhermesh Verma, verma.dharmesh@gmail.com

We evaluated four different land use systems for their potential of soil organic matter (SOM) dynamics in an acid soil of the eastern part of the Indian sub-Himalayas. Mean (of 0-30 cm soil layer at 10 cm interval) bulk density value was highest in the plots under Guava (Psidium guajava) based agro-forestry system (AFS; 1.03 Mg m^{-3}) and was lowest in Alder (Alnus nepalensis) based AFS (0.95 Mg m^{-3}). Plots under hedge and Alder based AFS had about 62 and 59% higher SOC concentrations compared with the control plots (mean of three soil layers = 16.0 g kg^{-1}) in the 0-30 cm soil layer. Again, plots under guava based AFS had similar SOC concentration to the control plots in that soil layer. For all land use systems (except for the control plots), SOC contents in the 10-20 cm depth was significantly higher than in the 0-10 and 20-30 cm soil layers, indicating the importance of the middle layer for SOC sequestration. The particulate organic matter–C (POM-C) content closely followed similar trend to SOC content in different soil depths and land use systems. This conclusively proved that different AFS systems had significant roles in SOC retention. As hedge and Alder based AFS had significantly higher SOC stock and POM-C than the Guava based AFS and the control plots, the former management practices are recommended for better soil carbon retention (and thus for mitigation of global warming) in the Indian sub-Himalayas.

Keywords: **SOC, particulate organic C, C sequestration, Agro-forestry system**.

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The extent and degree to which Soil Organic Matter is bound to inorganic mineral particles regulate its dynamics (Barrios *et al*., 1996). Carbon present in particulate organic matter (POM) can build up fast under management practices that reduce soil disturbances. This fraction (POM) can also present an initial indicator of changes in C dynamics and total SOC under different land management practices (Bhattacharyya *et al*., 2009). A loss of soil organic carbon (SOC) due to unsuitable land use and management practices can deteriorate soil quality (Lal, 2004). On the other hand, proper land use and management practices can lead to increased SOC and improved soil quality that can mitigate atmospheric CO_2 rise (Lal, 2004). The present study was carried out to ascertain the effects of growing different hedgerow species on SOC contents and to estimate the relative advantage of growing these plants over a control plot in terms of total SOC stocks in the 0 to 30 cm soil depth in the eastern part of the Indian Himalayas. The specific objective was to study the impacts of different AFS on the selected SOM fractions (POM-C and SOC) in the surface soil layer after five years of land management practices in an acidic soil of the Eastern sub-Himalayas. The main hypothesis was that the plots under AFS would have significantly higher SOC content and its labile pools in the 0-30 cm soil layer compared with the control plots, as the added biomass by the trees would have notable impacts in the plots under AFS.

METHODOLOGY

Site

The experimental site is located between 25°39" 25°41"N latitude to 91°54"-91°63"E longitude. Triplicate soil samples from all plots from 0-10, 10-20 and 20-30 cm depths were collected from one location each under all hedge species using a core sampler. Representative sub-samples were taken to determine various physico-chemical properties using normal protocols (Page *et al*., 1982).

Soil organic matter fractionation study

Particulate organic matter was measured following the method depicted by Cambardella and Elliott (1992), with a little modification (Six *et al*., 2002). In brief soil samples were dispersed in 100 mL 0.5% sodium hexametaphosphate solution by shaking for 15 h using a reciprocal shaker. The soil suspensions were passed through a 0.05 mm screen. All materials left on the screen, termed the POM fractions. These fractions were oven-dryed at 60 °C for 24 h and then transferred to glass beakers and weighed. Sub-samples of whole soils and the POM fractions were ground and analyzed for total C using the dry combustion method (Nelson and Sommers, 1982).

Fresh soil was used for determining the microbial biomass C (MBC) using a modified chloroform fumigation extraction method (Witt *et al*., 2000). Soil samples were fumigated with chloroform and reserved in dark at 25°C for a day. Organic C concentrations in fumigated and unfumigated soils were extracted with 0.5 M K_2SO_4 solutions and C concentrations were measured using $K_2Cr_2O_7$. The soil extracts were digested at 150 °C for half-an hour together with 0.01 N $K_2Cr_2O_7$, 98% H_2SO_4 and 88% H_3PO_4. After cooling the soil extracts were treated with 0.01 N $Fe(NH_4)(SO_4)_2$ in 0.4 M H_2SO_4. Soil MBC was calculated using the subsequent formula:

$MBC = (ECF-ECU)/K_C$

where, ECF and ECU are organic C extracted from fumigated and unfumigated soils, respectively. The value of K_C was assumed as 0.45 (Witt *et al*., 2000). The SOC/N pools for a specific depth were computed by multiplying the SOC/N pools (g kg^{-1}) with bulk density (Mg m^{-3}) and depth (m) .

Leaf litter was collected from Alder and Guava based AFS (three years old) and hedge species (one year old). The biomass production in each species was recorded using simple quadrate method. Litter samples were oven dried at 65 °C. Nitrogen content in the foliage was determined by micro-Kjeldahl method.

Statistical analysis

We analysed soil properties using ANOVA for a randomized block design (with four treatments and three replications). Tukey's honestly significant difference test was used as a *post hoc* mean separation test ($P <0.05$) using SAS 9.1 (SAS Institute, Cary, North Carolina, USA). Statistical analysis were carried out at all depths within a land use and the differences were considered significant when $P < 0.05$. Linear regression was used to find relationships between SOC and POM-C, MBC and SOC and MBC and MBN. Correlation coefficient was also observed for the relationships between SOC fractions and different soil parameters.

RESULTS

Soil bulk density

Mean bulk density in the plots under Guava based AFS (1.03 Mg m^{-3}) was significantly higher than the Alder based AFS (0.95 Mg m^{-3}) (Table 1). Irrespective of the land use systems, soil bulk density augmented with soil depth. Soil bulk density values for different depths between and among the AFS systems were non-significant. However, down the profile bulk density values increased due to more compaction in the soil strata.

Carbon fractions and stock of the agro-forestry systems

Plots under hedge based AFS had about 63 and 62% higher mean (of three soil layers) SOC content (25.9 g kg^{-1}) compared with the Guava based AFS and control plots, respectively (Table 1). Plots under Alder and hedge based AFS had similar mean SOC values and had higher SOC contents in the sub-surface soil layer than the surface layer (0-10 cm). Similar trend was observed for the mean SOC stock/content values. Mean SOC stock was highest in the plots under hedge based AFS. Plots under Hedgerow based system had about 21% higher SOC content in the 10-20 cm soil layer than the 0-10 cm soil layer (24.3 Mg ha^{-1}). Similarly, for the Alder based system, the sub-surface (20-30 cm) layer had about 22% higher SOC than the 0-10 cm soil layer (Table 1).

Plots under the hedge and Alder based AFS had significantly higher POM-C values than the control plots (Table 1). Like total SOC, plots under Guava based AFS and control treatments had similar POM-C concentrations, and the plots under the hedgerow and Alder based AFS had similar POM-C contents (Table 1). The middle layer of all land use systems contained significantly higher POM-C stock than the surface layer (Table 1). Perusal of the data obtained for SOC revealed that among all AFS, mean soil C content was highest in the plots under hedge based AFS that was significantly higher than control plots. About 71 and 28% higher MBC content was observed in the plots under Alder based AFS compared with the control (211 mg kg^{-1} soil) and hedge based AFS plots (281 mg kg^{-1} soil) . However, MBC content of Guava based AFS and control plots were similar . Similar results were obtained for MBN content of the soils. Hedge based AFS system was found to have significantly higher MBN content in soils than control plots. Highest microbial biomass N (13.41 mg kg^{-1}) was observed in Alder based AFS followed by hedge based AFS (10.6 mg kg^{-1}) and Guava based AFS (6.52 mg kg^{-1}). Significantly higher soil MBN content was also observed in the plots under Alder based AFS than control plots.

DISCUSSION

Changes in SOC content

Significant variations in SOC among treatments designate that soil C can be increased by converting cropped lands (without trees) to agroforestry intervention. Plots under high pruned biomass led to more accumulation of SOC, in turn, increase MBC content. Carbon accumulation to soils through pruned biomass of hedge encouraged microbial activities, as evident from the MBC contents of soils under the AFS. Application of pruned biomass leaf-litter resulted in less MBN content because of elevated C:N ratios, that reduced the mineralization process. Soil organic in the 0–10 cm soil layer in the plots under hedge based AFS was 35% higher compared with the control plots (Table 1). Similarly, (i) Somarriba *et al*. (2013) found cocoa trees accrued 9 Mg C ha^{-1} (18% of aboveground biomass-C) in central America; (ii) Malhi *et al*. (2002) found a 114% higher soil C in the topsoil under a 30-year old hedge based AFS plots compared with plots under an adjacent cultivated field in Canada; (ii) Malhi *et al*. (2002) observed that SOC retentions decreased with increasing soil depths (for instance, C increases were 10.5 and 8.2%, respectively, over control plots in the 0-10 and 10-20 cm soil layers). They also found that the variations among soils under hedge-based and Alder-based AFS were not significant. Fontaine *et al*. (2007) also observed SOC accumulation and stability in the 10-20 soil layer. However, unlike the results of Malhi *et al*. (2002) and Bronson *et al*. (2004), the results of this study showed that total soil N content was significantly higher in hedge based AFS compared with in the control plot soils only in the top 0-10 cm. The little time-lag (five years) of this experimentation after plantation of the hedge based AFS may have limited SOM accumulation (Payan *et al*., 2009). Additionally, SOM spatial distribution could also influence the results**.**
Furthermore, higher root biomass inputs onto the control plots relative to that applied to the hedge based AFS plots most likely reduced SOC and total soil N variations in soil surface. Higher levels of SOC contents in the plots under AFS systems over control was mainly due to the accumulation of biomass, leaf litter-fall and root biomass accumulation (especially in the sub-surface layers). Guava based AFS systems are known to have less biomass compared with hedge and Alder based AFS, resulting less SOC retention. Climate, plant nutrient contents, soil texture, soil structure and the time lags since the land use change was performed are the governing factors of soil C accumulation under different land use and management practices (Liang *et al*., 2003). Although impacts of several resource conservation practices (conservation tillage, organic farming and balanced fertilization) on SOC retention in the Indian Himalayas have extensively been evaluated, effects of agroforestry systems on SOC pools have rarely been studied in the Indian Himalayas. Hence, this study is one of the novel works that would provide soil carbon retention potential of the acid soils of the Indian Himalayas.

Alterations in SOC fractions

Particulate organic matter-C can serve as a functional part of soil quality index and is a insightful indicator of land management outcomes on SOC (Su *et al*., 2007). It is lost from soils under grassland upon transformation into any AFS intervention. In this experiment, a greater amount of POM-C was observed in hedge and Alder based AFS soils than in soils of Guava based AFS, and there was a greater variations in POM-C under the hedge/Alder based system relative to the mean (of other AFS systems) POM-C (Table 2). These results suggest that the accrued organic C occurred also in POM fraction in these acid soils. Therefore, perennial vegetation should be maintained for a long time period to increase the slow and passive pools of SOM, apart from the known benefit that the atmospheric CO_2 is also fixed in the aboveground biomass. However, it is needed to be noticed that if the increased POM-C was transitory or permanent.

We also observed that POM-C was higher in the plots under hedge-based AFS compared with the Alder-based AFS, especially in the surface soil layer (Table 2). The C sequestration potential of any soil is reliant upon its C saturation level, which is the highest amount of C associated with silt and clay particles (Six *et al*., 2002). The results showed that the amounts of POM-C was on average 9.7 Mg ha^{-1} soil in the 0-30 cm soil depth layer plots under hedge based AFS

Greater SOC and POM-C in the plots under hedge/Alder based AFS soils compared to the Guava based AFS and control plots can be due to many factors. These are: (i) a long growing season and a more wide root network is observed under hedge based AFS has compared with the annual crops; (ii) this along with decreased soil disturbances and augmented residue returns (after cutting three to four times each year), resulted a greater C sequestration rate; (iii) Additionally, variations in water and wind erosions may also affect the differences in SOC concentrations among different land use treatments (Su *et al*., 2004). Thus, in these highly erodible and acidic soils, the conversion of lands (with a double cropping) to a hedge based AFS should be widely used to improve soil health and sequester SOC.

Relationships among soil organic matter parameters

Microbial biomass carbon is a good indicator of soil quality. Different stakeholders are genuinely interested in getting straight forward assessment of soil quality parameters in the field for easy on farm assessment of soil quality. In the present study following relationships can be obtained for AFS:

Relationship between MBC (mg kg^{-1}) and SOC (g kg^{-1}) in AFS

MBC = 79.40 x SOC + 118.4 (1)

Relationship between POM-C (g kg^{-1}) and SOC (g kg^{-1}) in AFS

POM-C = 0.415 x SOC - 0.147 (2)

Relationship between MBN (mg kg^{-1}) and MBC (mg kg^{-1}) in AFS

MBN = 0.038 x MBC - 0.52 (3)

Many researchers (Jenkinson and Ladd, 1981; Leita *et al*., 1999) observed linear relationships between MBC and SOC in temperate agro-ecosystems. However, these results are novel for this region and this can very well describe the related phenomena for sub tropical to tropical agro-ecosystems. Thus, the relationship obtained was different for different soil parameters. This conclusively proved that different AFS are affecting SOC pools significantly.

CONCLUSIONS

Conversion of fallow to hedge based AFS resulted in greater SOC and total N build up in the 0-30 cm layer in these acid soils of the Indian Himalayas. Organic C under hedge based AFS also increased (relative to crop soils) at the 0–10 and 10–20 cm depths and the variations were always appreciable. Soil C/N ratios tended to increase in the plots under hedge based AFS than control soils. Alterations in POM-C values were higher compared with those in total N or SOC concentrations after five years of land management practices. The soils have enormous potential for SOC sequestration and conversion of crops to hedge-based AFS could be one of the efficient approaches to improve C retention in this region. Significant variations were observed for 0-10 cm depth and 10-20 cm depth and 20-30 cm depth. Irrespective of the soil depths, POM-C stock values were non-significant down the profile in all the AFS. Significant variation for SOC stock was obtained for 0-10 cm and 10-20 cm depth, between 10-20 and 20-30 cm depth in all agroforestry systems. For all land use systems (except for the control plots), SOC contents in the 10-20 cm depth was significantly higher than in the 0-10 and 20-30 cm soil layers, indicating the importance of the adopted land use systems on SOC sequestration (as SOC in the middle layer is less liable to be lost by erosion and biochemical processes). As hedgerow and Alder based AFS systems had significantly higher SOC content and higher labile pools (POM-C and MBC) compared with the Guava based AFS and the control plots, the earlier management practices are recommended for soil carbon retention (and thus for maintaining soil quality) in the acid soils of the Indian Himalayas. This is one of the rare studies that evaluated rate of soil carbon retention by different agroforestry systems in the Indian Himalayas.

Table 1. Effects of various agro-forestry systems on mean (± SD) soil organic carbon concentration and content in the Indian sub-Himalayas

Farming system/soil depth	Total SOC (g kg-1)	**Soil bulk density (Mg m-3)**	**Total SOC content (Mg ha^{-1})**
1. Hedge based AFS			
0-10 cm	24.8 ± 3.6B	0.98 ± 0.03B	24.30B
10-20 cm	28.9 ± 3.9A	1.02 ± 0.03AB	29.48A
20-30 cm	24.1 ± 3.2B	1.05 ± 0.03A	25.31B
Mean	25.9 ± 3.6 a	1.00 ± 0.03 a	25.9 a
2. Alder based AFS			
0-10 cm	24.1 ± 3.2B	0.93 ± 0.02B	22.41B
10-20 cm	24.4 ± 3.5B	0.95 ± 0.02AB	23.18B
20-30 cm	27.9 ± 3.6A	0.98 ± 0.02A	27.34A
Mean	25.4 ± 3.4[a]	0.95 ± 0.02b	24.13 a
3. Guava based AFS			
0-10 cm	18.4 ± 2.3[a]	1.01 ± 0.01B	18.54[a]
10-20 cm	15.7 ± 2.0B	1.02 ± 0.01B	16.01B
20-30 cm	13.3 ± 2.1C	1.06 ± 0.01A	14.10C
Mean	15.8 ± 2.2b	1.03 ± 0.01a	16.24 b
4. Control (without a tree)			
0-10 cm	16.3 ± 1.9A	0.99±0.02B	16.14B
10-20 cm	14.7 ± 1.9B	1.01±0.02B	14.85B
20-30 cm	16.8 ± 2.0A	1.07±0.02A	17.98A
Mean	16.0 ± 1.9c	1.02±0.02a	16.32 b

Values followed by similar uppercase letters within a column for a particular land use system are not significant at P <0.05. Means of different land use systems within a column followed by similar lowercase letters are not significant at P <0.05.

Table 2. Effect of various agroforestry systems on mean (± SD) total N and particulate organic matter-carbon contents in the Indian sub-Himalayas

AFS system/ Soil depth (cm)	**POM-C (g kg-1)**	**Total N (g kg-1)**	C/N Ratio	**POM-C/SOC**	POM-C Stock (Mg/ha)
1. Hedge based AFS					
0-10	8.5 ± 1.2B	2.0 ± 0.1A	12.4 ± 1.2B	0.34 ± 0.02A	8.33C
10-20	11.3 ± 1.4A	1.9 ± 0.1A	15.2 ± 1.5A	0.39 ± 0.02A	11.3[a]

20-30	8.9 ± 1.0B	1.8 ±0.1A	13.4 ± 1.2B	0.37 ± 0.02A	9.35B
Mean	9.2 ± 1.2 a	1.9 ± 0.1 a	13.7 ± 1.3 b	0.36 a	9.66 a
2. Alder based AFS					
0-10	9.2 ± 0.8B	1.7 ± 0.1B	14.2 ± 0.4A	0.38 ± 0.01A	8.56B
10-20	10.4 ± 0.9[a]	1.8 ± 0.2B	13.5 ± 0.4A	0.43 ± 0.01A	9.88A
20-30	8.8 ± 0.8B	2.1 ± 0.2A	13.3 ± 0.4A	0.31 ± 0.01B	8.62B
Mean	8.6 ± 0.8a	1.9 ± 0.2a	13.6 ± 0.4b	0.34a	9.02 a
3. Guava based AFS					
0-10	4.2 ± 0.6B	1.1 ± 0.1 A	16.7 ± 0.6A	0.23 ± 0.04B	4.24B
10-20	4.8 ± 0.5A	0.9 ± 0.1B	17.5 ± 0.5A	0.30 ± 0.04A	4.90A
20-30	3.9 ± 0.4B	0.8 ± 0.1B	16.6 ± 0.6A	0.30 ± 0.04A	4.13B
Mean	4.6 ± 0.5 b	0.9 ± 0.1 b	17.0 ± 0.5 a	0.29 b	4.42 c
4. Control (without a tree)					
0-10	4.0 ± 0.5B	1.9 ± 0.1A	8.5 ± 0.8B	0.25 ± 0.01B	3.96C
10-20	5.6 ± 0.6AB	1.5 ± 0.1B	9.8 ± 0.9A	0.38 ± 0.01A	5.66B
20-30	6.1 ± 0.7A	1.6 ± 0.1B	10.4 ± 0.9A	0.37 ± 0.01A	6.53A
Mean	4.9 ± 0.6b	0.17±0.0a	9.5 ± 0.9c	0.31 ± 0.0b	5.38 b

Values followed by similar uppercase letters within a column for a particular land use system are not significant at $P < 0.05$ according to Tukey's HSD test. Means of different land use systems within a column followed by similar lowercase letters are not significant at $P < 0.05$ according to Tukey's HSD test.

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2.27 | FAMILY COFFEE FARMERS IMPROVE MOUNTAIN SOILS

Alberto Pascual Q[1]

[1]Non-Governmental (NGO) Fundación CoMunidad / apascual@mail.com / www.fcomunidad.org
Alberto Pascual Q

ABSTRACT

Located in the highlands of the Panamanian Central Cordillera in the Santa Fe district of Veraguas province, the 72 636 ha Santa Fe National Park has proven critical for conveying the need for investment in the conservation and sustainable management of natural resources. It belongs to the Mesoamerican Biological Corridor, a highly biodiverse region that encompasses seven Central American countries and Mexico. In addition, it contains a strategic water reservoir for the major human settlements of the country, and the water streaming from its watershed and the related rivers has great potential to generate hydropower. Thanks to the elevation and steepness that characterize the geomorphology of the park, all the springs of the major rivers originating within the protected area may potentially generate renewable energy.
The non-governmental organization (NGO) Fundación CoMunidad works with family farmers engaged in small-scale coffee production in the protected area and its surroundings. A buffer zone outside the natural park is a forested area with trees such as Cedrela odorata and Cordia alliodora up to 30 m high and an understorey with many fallen leaves. Hence, this area is a productive system with natural or significant spontaneous woody vegetation. These lands are suitable for the production of coffee, and their humid tropical climate also allows for the production of complementary crops such as citrus, beans and vegetables. With constant rain throughout the year and favourable soil features, the area also has good agricultural potential for various forest and fruit plantations.

Keywords: Family Farmers, Coffee, Ecosystem Services, Climate Change, Latin America and the Caribbean, Resilient.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The production of shade-grown coffee is key to the conservation of mountain ecosystems. In Panama's Santa Fe National Park, coffee is a traditional crop and one of the main income sources for many family farmers who live in the protected park area and its surroundings. The cultivation of shade-grown coffee ensures environmental, polyculture and agroforest biodiversity, contributes to soil conservation and plays a crucial role in mitigating and adapting to climate change.

The park has mountain ranges with narrow valleys and elevations ranging from 600 to 1 400 masl. Mountains slopes are steep, especially in the southern section of the Santa Fe National Park and its buffer zone, and soils are thin with good internal drainage. The predominant soils of this mountain region have a pH that tends to range from acidic (< 6.5) to very acidic (4.5). This is because the rainfall has historically induced a strong phenomenon of nutrient leaching and soils are exposed to wind erosion and other atmospheric agents.

METHODOLOGY

The work of family farmers engaged in shade-grown coffee generates multiple benefits due to the use of native species, soil conservation and improvement practices, reduced dependence on petrol and derivatives through agro-ecology, practice of polyculture and silvopastoralism, terraced coffee plantations and crop rotation. One of the salient features of the traditional farming systems is their high degree of biodiversity thanks to polyculture and agroforestry. Diversified systems support several ecosystem services such as soil carbon sequestration, regulation of the hydrological cycle, provision of habitat for natural pollinators and control of pests and diseases through natural enemies. All this, in turn, promotes dietary diversity and improves the long-term productivity of soils, even with low levels of technology and limited resources.

RESULTS

The techniques the family farmers have implemented for shade-grown coffee have reduced soil erosion and nutrient loss, while also respecting the ground cover, the trees and their extensive root systems which are key elements for agriculture to conserve and improve soils in mountain.

Photo 1: [Coffee / Alberto Pascual Q]
Photo 2: [Family Farmer / Alberto Pascual Q]

DISCUSSION

All components and joint actions of this project are framed and legitimized within the Management Plan of the Santa Fe National Park published in September 2014 by the Panamanian Ministry of the Environment which calls for: • reducing the pressure on natural resources by promoting sustainable production techniques, restoring degraded areas, strengthening local capacities, income generation and use of native species, identifying crops that are suitable to the park's soil and overall improvement of livelihoods; • promoting understanding and analysis of the human-environment interaction in the park and its buffer zone, with special emphasis on indigenous communities; • promoting knowledge sharing on the biophysical, ecological and cultural features of the region; • ensuring participative management of the park involving local communities, institutions, NGOs

CONCLUSIONS

In this framework, Fundación CoMunidad works with local producers to establish shade-grown coffee as a finished brand product. This has potential to open new markets, build public and private partnerships, and identify new strategic partners, always ensuring sustainable use of natural resources and soils conservation and improvement within the Santa Fe National Park and its buffer zone.

2.28 | ASSESSING THE POTENTIAL OF SOIL CARBON SEQUESTRATION IN AFRICAN SOILS

Razafimbelo T. M[1*]., Bernoux M.[2], Badiane Ndour N.Y.[3], Barthès B.[4], Masse D.[4], Sabir M.[5], Aholoukpe H.[6], Amadji G.[6], Balarabe O.[7,8], Hien E.[9], Koné A.[10], Abgassi A.[11], Sall S.[12], Andriamananjara A.[1], Razakamanarivo H.[1], Blanchart E.[13], , Albrecht A.[4], Guibert H.[8], Brossard M.[4]

[1]Université d'Antananarivo, Laboratoire des RadioIsotopes, Route d'Andraisoro, Antananarivo, Madagascar, tantely.razafimbelo@gmail.com

[2]FAO, Mitigation of Climate Change in Agriculture (MICCA) Programme, Rome, Italy.

[3]ISRA, Laboratoire National de Recherches sur les Productions Végétales, Dakar, Senegal

[4]IRD, UMR Eco&Sols, Montpellier, France

[5]ENFI, Salé, Maroc.

[6]INRAB, Centre de Recherches Agricoles Plantes Pérennes, Cotonou, Bénin.

[7, 8] IRAD, Maroua, Cameroun

[8]Cirad, AIDA, Montpellier, France

[9]Université de Ouagadougou, Ouagadougou, Burkina Faso

[10]Université Nangui Abrogoua, Abidjan, Côte d'Ivoire

[11]Université de N'Djamena, Département de Géologie, N'Djamena, Tchad.

[12] Université Gaston-Bergé, Saint-Louis, Sénégal

[13]IRD, UMR Eco&Sols, Antananarivo, Madagascar

ABSTRACT

African soils are high weathered with low nutrients content and more sensitive to erosion. These edaphic constraints are exacerbated by climate change impacts and lead to soil degradation. However, soil is the main support of agricultural activities, which are the main resources for African countries. The use of sustainable practices as conservation agriculture, agroforestry systems, crop rotation or association can be cited as one of the solution to restore soil and to increase their agricultural productivity. This study aimed to highlight the potential of soil carbon sequestration (SCS) of some sustainable agricultural practices in African countries which was studied by the "Soil Carbon or Sustainable agriculture in Africa" network (or CaSA network). Results showed that depending of the climate, soil and practices, SCS can vary for 0 to 1.8t C.ha^{-1}.year^{-1}. However, in general SCS are higher in the context where there are many C inputs and in clayey soils in humid climates. This study also showed the importance of soil carbon stocks variability in the African which can make difficult the assessment of the SCS values and have then to be taken into account in the future.

Keywords: Sustainable agriculture, Agricultural practices, Madagascar, Benin,

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

African soils are very diverse and varying from sandy soils as Arenosol to very clayey soils as Ferralsol or Gleysol. However, they are in majority composed by high weathered soil and characterized by low nutrients content and their sensitivity to erosion (Bationo et al., 2006). These edaphic constraints are exacerbated by the human pressure and climate change and increase pressure on soil and its degradability.

Soil carbon sequestration (SCS) by increasing soil organic matter in soil can be one of the best ways to restore these degraded soils and to maintain soil fertility in Africa. It can also help on the limitation and preservation of soils from erosion by increasing soil structural stability. Soil organic matter or carbon is the main driver of many reactions and processes in soils and it it is the guarantee of the safety of ecosystemic services provided by soils. Among of the potential agricultural techniques for soil carbon sequestration, there are conservation agriculture, agroforestry systems, crop rotation, or some traditional techniques as Zaï practices or half-moon holes. This paper aimed to highlight the potential SCS of some of these practices in African areas. Results presented in this study are coming from research studies of CaSA (Soil Carbon sequestration in Sustainable agriculture in Africa) network.

METHODOLOGY

Some data from studies on SOC where selected in order to represent the possible range of SCS according the existing practices. Four main practices among the sustainable practices studied by CaSA team members were selected:
- Conservation agriculture in Madagascar (Razafimbelo et al., 2010), in which climate (humid tropical and subtropical), soils (Cambisol, Fluvisol, Ferralsol) , crops (maize or rice as main crop) and fertilizer uses were studied on different tropical soils,
- Zai practices in Burkina Faso (Masse et al., 2011): Zaï was studied on Acrisol by its comparison with conventional tillage (No Zai). Zaï is a traditional practice used in the Sahelian area to restore degraded soils or topsoils with physical properties that are unsuitable for traditional tillage practices,
- Legume use in Benin (Barthes et al., 2004), where the *Mucuna pruriensis* after a maize crop in the year rotation was studied, on a Nitisol (sandy textured),
- Organic fertilizers in Madagascar (Rafolisy et al., in prep.), where different types of organic fertilizers as manure, urban organic waste and compost were tested on a Ferralsol (clay textured).

RESULTS AND DISCUSSION

For CA, SCS is very different according climate, soil and practices (Table 1). SCS is quite higher in Humid climate than in subtropical climate. In the humid tropical climate, Gleysoils showed a higher value of SCS, might be due to their localisation in downslope where soils are often saturated by water and this might lead to a lower rate of SOM mineralisation. For tropical climate, the differences with Ferralic Cambisol and Fluvisol are due to the facts that Fluvisols are located in downslopes and are then richer in soil nutrients. Therefore, the production of biomass was higher and this can lead to a higher amount of SCS than Ferralic Cambisol. For the Subtropical climate, the Ferralsol 3 had a high content of clay with a SC of 0.32 MgC.ha.yr. This is due to the original high level of SOC content in this soil (more than 50g.kg^{-1}) (Razafimbelo et al., 2010) which have some andic properties. For plant effect, rice lead to a slight higher SCS than maize due to its higher biomass inputs.

For Zai practices, Masse et al. (2011), in Figure 1 showed that there was no significant difference in the SOC content of the topsoil under conventional tillage and in zaï plots due to the high variability of SOC content. However, the SOC tended to be higher in the zaï holes than in control without Zaï (No zaï) and SOC tended to be increased with the duration. The SOC was greater under the holes than between holes. According their study, a previous study showed that zaï encouraged biological activity, particularly termite activity, improving soil porosity and water infiltration.

For the legume use, the mucuna led to a high rate of SOC sequestration of 1,35 Mg/ha/yr, due mainly to the high mucuna biomass that was returned into soil but also to the legume effect on maize biomass production.

The comparison of the 3 organic inputs : manure, compost (build from vegetation residues) and organic urban waste (from the compositing of urban organic waste) showed different values of SCS (Table 1). However, because of the high level of field SOC variation, there were no significant increase of SOC, but a trend of increase was observed. In this case, we observed that the use of the studied organic fertilizers maintained then soil organic carbon in soil. Even if the increase of SOC was not significant, a trend can be observed and it is sure that use of organic fertilizer led at least to a maintain of SOC.

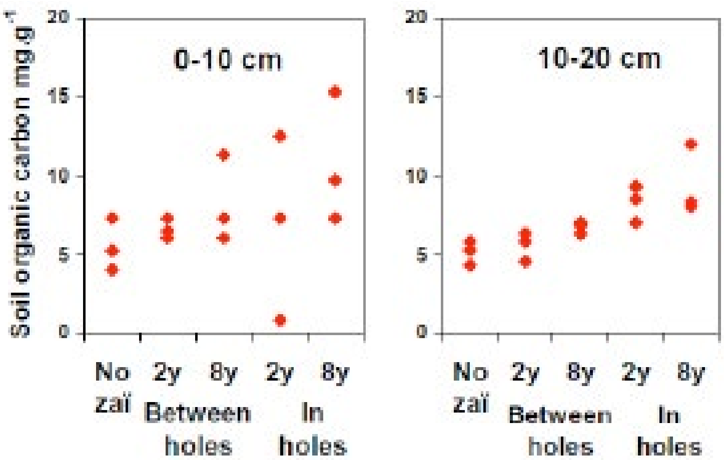

Fig. 1: Soil organic carbon content in Zai practices (Masse et al. 2011)

Table 1: Soil carbon sequestration (SCS) in (MgC.ha^{-1}.yr-1) in conservation agriculture, legume use and organic fertilizer inputs.

Techniques	Soil type	Clay (%)	Main crop	Legume	Fertilizer inputs	SCS	References
Conservation agriculture (Madagascar)							
Humid	Gleysoil	20	Rice	Stylosanthes1	No	0.80	Razafimbelo et al. (2010)
Tropical	Gleysoil	20	Rice	Stylosanthes	Mineral	1.82*	Razafimbelo et al. (2010)
	Ferralsol 1	45	Rice	Stylosanthes	No	0.53	Razafimbelo et al. (2010)
	Ferralsol 2	30	Rice	Stylosanthes	Mineral	0.00	Razafimbelo et al. (2010)
Tropical	Cambisol	20	Maize	Vigna2	Manure	0.14	Razafimbelo et al. (2010)
	Cambisol	20	Maize	Vigna	Manure + Mineral	0.22	Razafimbelo et al. (2010)
	Fluvisol	15	Rice	Vigna	Manure	0.73*	Razafimbelo et al. (2010)
	Fluvisol	15	Rice	Vigna	Manure + Mineral	0.60	Razafimbelo et al. (2010)
Subtropical	Ferralsol 3	65	Maize	Soybean	Manure + Mineral	0.32	Razafimbelo et al. (2010)
Legume Use (Benin)							
	Nitisol	Sandy loam	Maize	Mucuna	-	1.35*	Barthès et al. (2004)
Organic Fertilizer inputs (Madagascar)							
	Ferralsol	40	Maize	-	Manure	0.16	Rafolisy et al., in prep
	Ferralsol	40	Maize	-	Urban Organic Waste	0.61	Rafolisy et al., in prep
	Ferralsol	40	Maize	-	Compost	0.75	Rafolisy et al., in prep

*Significant differences [1] *Stylosanthes guyanensis* [2] *Vigna unguiculata*

These comparative studies imply that many parameters have to be taken in account in SCS measurement and the more important of them was the definition of the reference and the improvement of the method for assessing the field variability of SOC measurement. The SCS of the studied technologies in this paper are in line with Marks et al. (2009, modified from Lal 2004) findings which showed that the potential C sequestration by improved technologies (Table 2). SCS are higher in humid tropical climate than in subarid climate. These potentials are in general, depending on the techniques, varying from 100 to 400 kgC/ha/year, and we found in this study the important effects of other factors as soils and practices. Effectively, SCS is the balance of C inputs and outputs, and these two factors play some important roles on SCS by controlling the carbon mineralization (soil texture) and by increasing the C in soil by the increase of plant biomass and enhancing biological activities and improving soil physical properties.

CONCLUSIONS

This study showed that the amount of SCS is different according the practice or technologies, but also according the climate, soil types and texture which are the main drivers of SCS. SCS values in African agriculture landscape are in general affected by high variabilities and need an improvement of the SOC measurement in these areas. Sustainable practices exists in Sub-Saharan Africa and have to be taken into account as an option for soil restoration and for a sustainable production in Africa.

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2.29 | LE CARBONE ORGANIQUE DU PARK AGROFORESTIER À BASE D'ACACIA ET DU NIÉBÉ À N'DOUNGA, AU NIGER.

Addam Kiari Saidou[1*], Abdou Latif Yussouf[2] et Ambouta Jean Marie Karim[2]

1, Institut National de la Recherche Agronomique du Niger, Niamey Niger et auteur correspondant

2, Faculté d'Agronomie, Université Abdoumoumouni de Niamey au Niger.

kaddam2001@yahoo.fr

Des investigations ont été menés à N'Dounga, une commune de Niamey dans le département de Kollo, entre 2°18'28'' de longitude Est et 13°25'00''de latitude Nord, le climat dans cette zone est de type sahélien. Dans la station forestière, abritant plusieurs espèces d'arbres dont Acacia senegal, des échantillons du sol ont été prélevés, sous houppiers de 3 classes d'arbres isolés et des arbres groupés. Le dispositif est un block complet randomisé comprenant cinq traitements (arbre isolé de]4 ; 5], arbre isolé de]3 ; 4] et de]2 ; 3] m de rayon de houppier, houppier groupés et témoin, sans arbre). Ces échantillons ont été analysés pour le carbone organique.

Les résultats obtenus ont montré des différences significatives entre les traitements. Des différences au sein des parcelles sous houppier, la comparaison des moyenne indique que les teneurs en carbone et matière organique sont plus élevées au niveau du traitement arbre 1, suivies du traitement arbre 2 ensuite des arbres groupés et du traitement arbre 3.

En effet étant isolés les uns des autres, contrairement aux arbres groupés, les pieds d'arbres individuels semblent mieux développés, et présentent donc plus de possibilité d'apport de litière. Ceci expliquerait les teneurs observées sous ces traitements. Par ailleurs, le niébé évoluant sur le terrain sans arbre n'est pas touché par l'effet d'ombrage et profite d'une bonne photosynthèse pour non seulement bien fixer l'azote atmosphérique mais aussi contribuer au carbone organique du sol.

Mots clés *: Sol pauvre, carbone organique, Niger, Acacia, Niébé.*

ABSTRACT

Investigations have been carried out in N'Dounga, a commune of Niamey in the department of Kollo, between 2 ° 18'28 '' east longitude and 13 ° 25'00 '' north latitude, the climate in this zone is of Sahelian type. In the forest station, harboring several species of trees including Acacia senegal, soil samples were collected, under crowns of 3 classes of isolated trees and grouped trees. The design is a randomized complete block comprising five treatments (Isolated tree of 4; 5], isolated tree of] 3; 4] and 2; 3] m of radius, grouped crown and control, without tree). These samples were analysed for organic carbon.

The results obtained showed significant differences between the treatments. Differences within the crown plots show that the average comparison indicates that the carbon and organic matter contents are higher in the tree 1 treatment, followed by the tree 2 treatment, then the grouped trees and the tree 3 treatments.

In fact, isolated from each other, unlike the grouped trees, the individual tree feet seem to be better developed, and thus present more possibility of litter production. This would explain the levels observed under these treatments. Moreover, the cowpea evolving on the ground without trees is not touched by the effect of shade and benefits from a good photosynthesis not only to fix the atmospheric nitrogen but also to contribute to the organic carbon of the soil.

Key words: *Poor soil, organic carbon, Niger, Acacia, Cowpea.*

2.30 | AGRICULTURAL LONG-TERM FIELD EXPERIMENTS AS A BASIS TO MONITOR SOIL ORGANIC CARBON

Taru Sandén[1*], Georg Dersch[1], Andreas Baumgarten[1], Heide Spiegel[1]

[1]Austrian Agency for Health and Food Safety (AGES), Department for Soil Health and Plant Nutrition, *taru.sanden@ages.at, Spargelfeldstrasse 191, A-1220 Vienna, Austria.

ABSTRACT

Improved management practices such as minimum tillage, crop residue incorporation or compost amendments are expected to increase soil organic carbon (SOC) contents, but the effects of those interventions cannot be demonstrated without long-term monitoring. Long-term field experiments (LTEs) enable thorough investigation of a particular improved management practice over time. When experiments from different regions with varying climate and soils are monitored, upscaling of results becomes possible. Austrian Agency for Health and Food Safety (AGES) manages ca. ten long-term experiments across Austria, of which four will be reported here. The selected LTEs include a tillage trial (Fuchsenbigl), two crop residue incorporation trials (Rutzendorf and Rottenhaus), and a compost trial (Ritzlhof). Most of the improved management practices resulted in significant increases in SOC concentrations, after 24, 30, 26, and 21 years of practice, respectively. Minimum tillage had the highest SOC concentration in Fuchsenbigl, crop residue incorporation in Rutzendorf and Rottenhaus, along with organic waste compost and sewage sludge compost in Ritzlhof. We conclude that these improved management practices represent possible ways to increase SOC concentrations in agricultural soils. Future research should also study greenhouse gas emissions, in order to investigate the whole carbon cycle of the monitored long-term field experiments.

Keywords: Soil organic carbon (SOC), long-term experiments, agriculture, Austria, monitoring network, demonstration of improved management practices, field experiment, evidence-based research

INTRODUCTION

Agricultural long-term field experiments (LTEs) hold a key to understanding how the improved management practices such as different tillage practices, crop residue incorporation or compost amendments affect soil organic carbon (SOC). LTEs are living laboratories that enable researchers and policy-makers to gain a deeper understanding of the trends and dynamics of change, rather than a short snapshot of the situation. LTEs indeed enable to monitor changes in specific soil functions, such as carbon storage, which is often said to be challenging (Sachs *et al*., 2010; Baveye *et al*., 2016). Feasibility assessment of initiatives such as the ´4 per mille Soils for Food Security and Climate´ (Minasny *et al*., 2017) could also benefit from LTE databases.

Thus, this study was designed to investigate the long-term effects of three improved management practices, namely different tillage practices (Fuchsenbigl), crop residue incorporation (Rutzendorf and Rottenhaus) and compost amendments (Ritzlhof), on soil organic carbon concentrations, after 24, 30, 26, and 21 years of practice, respectively.

METHODOLOGY

Long-term field experiments

The Austrian Agency for Health and Food Safety (AGES) is running approximately ten long-term field experiments with different improved management practices in Austria, of which four were selected for this study. Table 1 gives an overview of the selected LTEs. The treatments in the selected field experiments were:

Fuchsenbigl:

- Minimum tillage (MT): plots were treated with a rotary-driller without any primary treatments before sewing to a depth of 5-8 cm.

- Reduced tillage (RT): plots were treated with a cultivator in autumn to a depth of 15-20 cm.
- Conventional tillage (CT): plots were treated with regular mouldboard ploughing to a depth of 25-30 cm.

Rutzendorf:
- Crop residue incorporation (CRI): all crop residues were incorporated in treatments with four phosphorous (P) fertilisation stages (0,33,66,131 kg P ha^{-1} y^{-1})
- Crop residue removal (CRR): all crop residues were removed in treatments with four P fertilisation stages (0,33,66,131 kg P ha^{-1} y^{-1})

Rottenhaus:
- Crop residue incorporation (CRI): all crop residues were incorporated in treatments with four phosphorous (P) fertilisation stages (0,33,66,131 kg P ha^{-1} y^{-1})
- Crop residue removal (CRR): all crop residues were removed in treatments with four P fertilisation stages (0,33,66,131 kg P ha^{-1} y^{-1})

Ritzlhof:
- Control: no fertilisation
- Urban organic waste compost (OWC): compost corresponding to 175 kg N ha^{-1} was applied to the fields annually, except in 2004, 2008, 2010 and 2012.
- Green waste compost (GWC): compost corresponding to 175 kg N ha^{-1} was applied to the fields annually, except in 2004, 2008, 2010 and 2012.
- Cattle manure compost (MC): compost that contained straw bedding impregnated with liquid and solid manure corresponding to 175 kg N ha^{-1} was applied to the fields annually, except in 2004, 2008, 2010 and 2012.
- Sewage sludge compost (SSC): compost from anaerobically stabilized sewage sludge corresponding to 175 kg N ha^{-1} was applied to the fields annually, except in 2004, 2008, 2010 and 2012.

Table 1: AGES long-term experiments (LTEs) in Fuchsenbigl, Rutzendorf, Rottenhaus and Ritzlhof.

	Fuchsenbigl	Rutzendorf	Rottenhaus	Ritzlhof
Improved management practice	Minimum tillage and reduced tillage	Crop residue incorporation	Crop residue incorporation	Compost amendments
Start year of the experiment	1988	1982	1986	1991
Experimental design	Randomised block design	Randomised block design	Randomised block design	Randomised block design
Meters above sea level	136	151	262	280
Mean annual rainfall (mm)	529	540	836	753
Mean annual temperature (°C)	9.4	9.1	8.5	8.5
Soil type (IUSS, 2015)	Haplic Chernozem	Calcaric Phaeozem	Gleyic Luvisol	Cambisol
pH ($CaCl_2$)	7.6	7.5	6.6	6.8
Texture (%sand/silt/clay)	37/41/22	26/52/23	7/77/16	14/69/17

Soil sampling and characteristics

Soils were sampled and analysed after harvest in 2012. Approximately 10 random soil cores from each treatment plot at 0-25 cm (except 0-10 cm, 10-20 cm and 20-30 cm in Fuchsenbigl) depth were collected and bulked. The samples were sieved to <2 mm, air-dried and stored at air temperature prior to the analyses. Total carbon (C) concentrations of the soil samples were analysed by dry combustion in a LECO RC-612 TruMac CN (LECO Corp., St. Joseph, MI, USA) at 650°C (ÖNORM, 2013).

Statistical analyses

The statistical analyses were performed using the IBM SPSS Statistics 20 software package. The effects of different management practices for each field experiment separately were investigated with analyses of variance with Tukey´s significance test ($p < 0.05$) as a *post hoc* test.

RESULTS AND DISCUSSION

The beneficial effects of minimum tillage, crop residue incorporation and compost amendment are well known (Hernanz *et al*., 2002; D´Hose *et al*., 2014; Lehtinen *et al*., 2014) and our results confirm previous studies. The long-term improved management practices resulted in distinctly different SOC concentrations in the different field experiments in 2012 (Table 2). In Fuchsenbigl, minimum tillage resulted in significantly higher SOC concentrations at 0-10 cm soil depth, whereas at the deeper soil depths no significant differences were observed between the management practices. This is in line with results published previously from the experiment (Spiegel *et al*., 2007) as well as by other authors (Mrabet *et al*., 2001). Crop residue incorporation, in both Rutzendorf and Rottenhaus, increased the SOC concentration significantly (22.00 and 9.29 g kg^{-1}, respectively) compared to the crop residue removal treatments (20.58 and 8.43 g kg^{-1}, respectively). Similar increases in SOC concentration were also observed in Lehtinen *et al*. (2014) when data from numerous European LTEs investigating the effects of crop residue incorporation were studied. Of the four different compost amendments in Ritzlhof, urban organic waste compost and sewage sludge compost resulted in significantly higher SOC concentrations (14.00 and 14.75 g kg^{-1}) compared to the control treatment (11.85 g kg^{-1}) that didn´t receive any fertilisation. This confirms results from a review by Diacono and Montemurro (2010), even though the increases in our study were not as high.

Table 2: Means (standard deviations, n=3, n=16, n=16, n=4, respectively) of soil organic carbon (SOC) in Fuchsenbigl, Rutzendorf, Rottenhaus and Ritzlhof, in 2012. Different letters indicate significant differences between the management practices at the p < 0.05 level, separately for each site. MT denotes minimum tillage, RT reduced tillage, CT conventional tillage, CRI crop residue incorporation, CRR crop residue removal, control no fertilisation, OWC urban organic waste compost, GWC green waste compost, MC cattle manure compost, and SSC sewage sludge compost.

Fuchsenbigl		Rutzendorf		Rottenhaus		Ritzlhof	
SOC (g kg-1)		SOC (g kg-1)		SOC (g kg-1)		SOC (g kg-1)*	
n = 3		n = 16		n = 16		n = 4	
0-10 cm		0-25 cm		0-25 cm		0-25 cm	
MT	20.17 (1.16)b	CRI	22.00 (0.64)b	CRI	9.29 (0.49)b	control	11.85 (0.97)a
RT	16.00 (1.73)a	CRR	20.58 (0.48)a	CRR	8.43 (0.34)a	OWC	14.00 (1.02)b
CT	16.20 (0.75)a					GWC	13.55 (0.82)ab
10-20 cm						MC	12.88 (0.81)ab
MT	16.33 (0.45)a					SSC	14.75 (1.00)b
RT	16.30 (0.87)a						
CT	16.20 (0.61)a						
20-30 cm							
MT	15.40 (1.44)a						
RT	15.77 (0.67)a						
CT	16.73 (0.72)a						

*values from Lehtinen *et al*., 2016

CONCLUSIONS

These four long-term field experiments demonstrate the importance of long-term monitoring sites in following the development of soil organic carbon. The beneficial effects of minimum tillage, crop residue incorporation, urban organic waste compost and sewage sludge compost were shown as increased soil organic carbon concentrations. However, monitoring of greenhouse gas emissions on the same sites would be recommended in order to further investigate the carbon sequestration potential of the selected improved management practices. We conclude that these long-term field experiments are important monitoring sites that could in the future be included in evidence-based assessment of initiatives such as the ´4 per mille Soils for Food Security and Climate´.

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2.31 | A NOVEL APPROACH FOR ON-FARM ASSESSMENT, PREDICTION AND MANAGEMENT OF SOC

Vinayak S. Shedekar[1*], Rafiq Islam[2]

[1]The Ohio State University, shedekar.1@osu.edu, 1864 Shyville Rd, Piketon OH 45661 (USA)* [2] The Ohio State University, islam.27@osu.edu 1864 Shyville Rd, Piketon OH 45661 (USA)

ABSTRACT

Soil organic carbon (SOC) management is gaining importance in the grain producing regions of the Midwestern US. With the renewed emphasis on Soil Health by US agencies, farmers are realizing the importance and potential of SOC management. However, few tools and techniques are available for rapid,

reliable, and in-field assessment and prediction of SOC stocks in response to different management practices. While the policy framework for SOC management may benefit from the vast availability of research data and complex simulation models, on-farm decision making lacks accessibility to these resources. The complex and highly technical nature of scientific information sometimes limits the ability of farmers to comprehend and make relevant decisions. We review the existing tools and techniques that have proven their superiority and applicability, and demonstrate a novel approach that integrates these tools and techniques into a decision framework for SOC assessment, prediction, and management at farm-scales.

Keywords: *Soil Organic Matter, Residue Management, Soil Quality, Active Carbon, Carbon Modeling*

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Maintaining a healthy and productive soil is the foundation of sustainable agriculture. The term "soil health" is gaining more prominence than the conventional concept of "soil quality". Soil health not only relates to the physical, chemical and biological properties of soil, but also to its functionality and productivity (Doran et al. 1996). Assessment of soil health or overall soil quality typically involves a comprehensive assessment of soil physical, chemical, and biological properties. Commonly accepted indicators of soil health include a combination of: microbial biomass C and N, soil respiration, enzyme activity, macro-aggregate stability, water retention, infiltration, pH, Electrical Conductivity, Cation Exchange Capacity, potentially mineralizable N, plant available nutrients, and active and passive pools of soil organic matter (SOM) (Allen et al. 2011).

Soil testing laboratories serving farmers typically assess SOM using loss of mass on ignition method (Stevnson, 1994). The SOC can then be estimated based on the stoichiometric percentage of carbon (58%) in the SOM. Although several methods exist to quantify different fractions of SOM, the active fraction, and total SOC are considered to be composite indicators of soil health (Alllen et al. 2011). While the SOM is composed of both active and passive pools, each pool makes its particular contribution towards soil quality according to chemical composition and lability, physico-chemical stability, and turnover rates (Stevenson 1994). Maintaining the active (or labile) carbon (active C) pool is important to ensure greater biological diversity, and recycling of essential nutrients in soil. While, the more passive fractions are important with respect to buffering capacity, water and nutrient holing capacity of the soil. Thus, a better understanding of both active- and passive pools of SOM induced by the impact of land-use changes may serve as a guide to evaluate overall soil health and soil quality. An average farmer is limited by resources and technical knowledge to conduct a comprehensive soil health assessment.

Furthermore, a soil health assessment report that involves numerous soil physical, chemical, and biological properties becomes difficult to interpret for farmers. The traditional fertility recommendations do not provide guidelines for managing, maintaining, and/or improving overall soil health by addressing any or many of these indicators. Thus, farmers are left to their own intuition and experience to make future management decisions with respect to agronomic practices as well as soil management. A framework that integrates a rapid, reliable field-assessment technique with a decision support tool that may help predict soil health/quality responses to future management practices is virtually non-existent. The objective of this study is to assess and demonstrate the feasibility of SOC, and its active fraction as a core indicator of soil quality, and develop a framework for a decision support tool for on-farm assessment, prediction, and management of SOC.

METHODOLOGY

A field test for active SOC:

A colorimetric test based on dilute (0.02 M) solution of slightly alkaline potassium permanganate ($KMnO_4$) that reacts with most readily available (active) forms of SOC is one of the most reliable, rapid and easy to adopt methods (Islam and Sundermeier, 2008; Weil et al. 2003). In the simplified method, slightly alkaline dilute solution of $KMnO_4$ reacts with most of the active fractions of SOM, changing the deep purple color of the solution to a light pink color. The lighter the color of the $KMnO_4$ solution after reacting with soil, the greater the amount of active C. The test involves mixing 0.02 M $KMnO_4$ with air-dry soil, 2 minutes of shaking, allowing 10 minutes for settling, and finally comparing the resulting color with a simple color chart calibrated for active C concentrations (Fig. 1).

Fig. 1 Field kit for in-situ active C test (https://go.osu.edu/SoilTestKit)

A tool for simulating SOC dynamics:

Over the past 30 years, several models, such as CENTURY, CANDY, DAISY, CQESTR, and Roth-C have been developed to assess C and nutrient turnover in agricultural systems (Jenkinson 1990; Smith et al. 1997). Most of these models are data intensive, require extensive training and local calibration, and were not designed to assess soil health. We developed the “OSU SOM Calculator”, a spreadsheet tool to predict long term SOM dynamics in response to different agricultural management scenarios (Shedekar, et al. 2016). The SOM Calculator consists of a user-friendly interface, with options to select crop rotation, management practices (tillage type, cover crops, drainage, manure application etc.), and residue removal rates. Based on these inputs, the calculator uses first order decay functions for calculating annual changes in SOM over short- and long-term. The effects of different management practices are incorporated using data from long-term research experiments, and a heuristic approach. The calculator further predicts active and passive fractions of SOM, CO_2 sequestration, and overall soil quality based on a soil health index.

Derivation of soil health index:

A soil health index (SH_{index}) is derived, using deductive and inductive additive approach (Aziz et al. 2013), that considers “higher or lower values of crop or soil properties (selected by a principal

component analysis) are better indicators of soil health”. Normalized values of each property are then summed and averaged into a single integrator, viz. SH_{index}. The SH_{index} ranges from 0 (extremely poor soil health) and 1 (Excellent soil health).

RESULTS

Validation of field-test kit for active SOC:

The results of validation of field-kit for active C, compared to laboratory based protocol have been presented in detail by Islam (1997) and Weil et al. (2003). The $KMnO_4$-based laboratory technique was found to be to be rapid, highly reliable and repeatable. The active C measured using this test was found to be sensitive to management effects, and more closely related to biological soil properties, such as respiration, microbial biomass and aggregation. Furthermore, the field-kit for in-field assessment of active C showed a strong correlation ($R^2 = 0.98$) with the laboratory based protocol over a wide range of soils (Weil et al. 2003; and Islam, 1997). These results demonstrate the reliability of the field-kit for in-situ testing of active C.

Validation of SOM calculator:

The SOM calculator was tested for its prediction accuracy using data from 12 different field experiments, representing a range of soils, tillage practices, crop rotations, and management practices in Michigan, Illinois and Ohio (Shedekar et al. 2016). A comparison of predicted values of SOM versus the observed amounts showed a good agreement between the predicted and observed data, with a coefficient of determination (R^2) of 0.937 and other statistically derived performance indices (Nash-Sutcliffe efficiency 0.93, Root Mean Square Error 0.13, Percent bias -1.6).

Relationship between SOC, active C and soil health index:

We have developed empirical relationships between the SOC and SH_{index} and active C and SH_{index} for a range of soils, agronomic practices, and regions. A regression analysis based on more than 3000 soil samples from different regions shows that total SOC and active C can be used as reliable indicators of overall soil health and overall soil quality (Anonymous, 2016; Aziz et al. 2013; Weil et al. 2003). Furthermore, studies also suggest that a strong correlation exists between the total SOC and active C in most agricultural soils (Lucas and Weil, 2012). Thus, with a reliable estimate of total SOC and active C in a soil, it is possible to estimate the overall soil health.

Framework for a soil health decision support tool:

A framework is developed to integrate the field assessment technique for active C with the OSU SOM Calculator into a decision support tool that may assist in management of soil health (Fig. 2). The field-kit helps establish a reliable baseline with respect to active C, and total SOC. The SOM calculator can then help compare different future management scenarios and predict their effects on SOM dynamics over short- to long-term. The predicted quantities of total SOC and active C can then be used as input
parameters in the empirical models for SH_{index} that can further estimate the overall soil quality and soil health. The final module of the system may help estimate the effect of change in soil quality and soil
health on relative yields using regional empirical relationships between the SH_{index} and yields (Knight et al. 2013). The developed framework is currently being evaluated for the Midwestern region of United Sates, and the results of evaluation will be presented at the Global symposium on SOC.

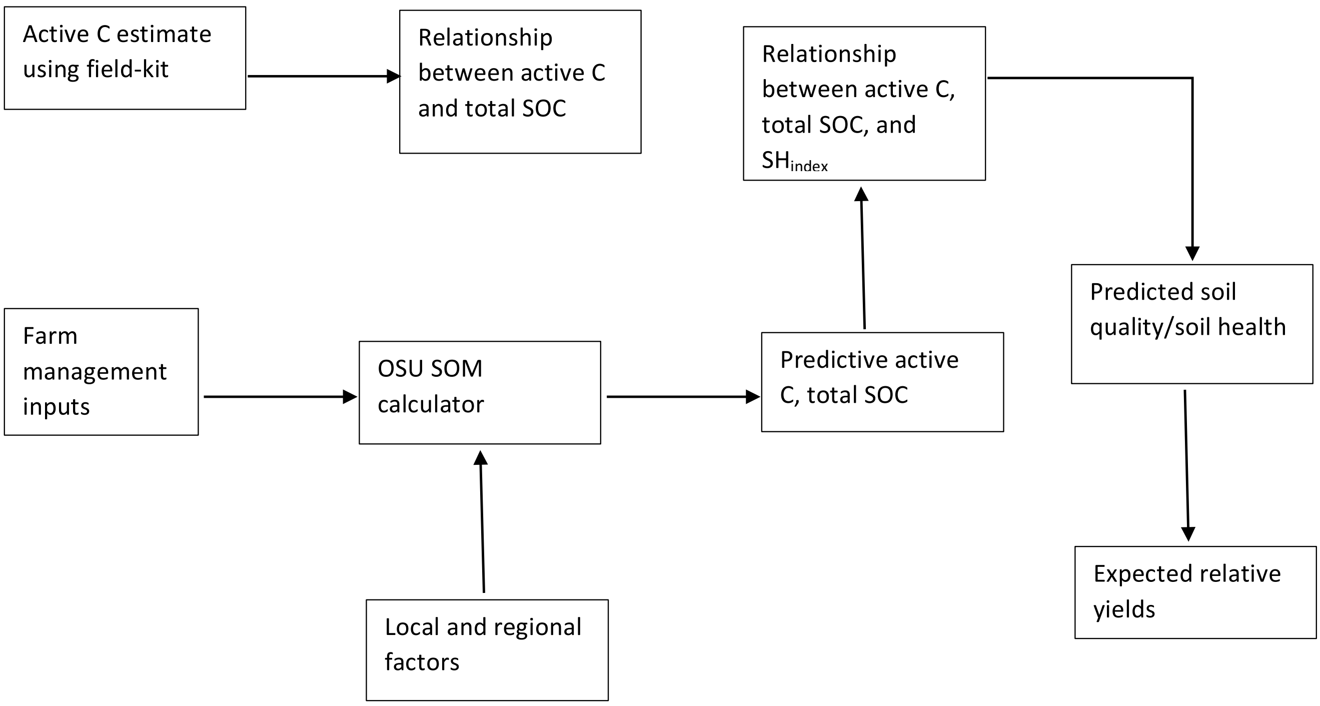

Fig. 2 Framework for a soil health decision support tool

DISCUSSION

Unlike policy framework, the farm-scales management of SOC involves several local decision variables that relate to natural factors (e.g. soil type) as well as management options (e.g. tillage versus no-tillage, crop rotation, cover crops). Thus, a farm-scale decision support tool that takes into account these local factors becomes imperative. However, results of such regional/local systems may or may not be comparable at global scales due to multiplicity of input and output variables. The framework developed in this study provides an effective tool for management of SOC at local/regional scales, while the assessment technique (field-kit for active C) ensures its global relevance outside the system boundaries. The system can also be a valuable teaching tool for crop consultants and educators.

CONCLUSIONS

While the policy framework for SOC management may benefit from the vast availability of research data and complex simulation models, on-farm decision making lacks accessibility to these resources. The complex and highly technical nature of scientific information sometimes limits the ability of farmer to comprehend and make relevant decisions. This study demonstrates development of a framework that integrates science-based reliable techniques and tools for on-farm assessment, prediction and management of SOC. This framework can be applicable to any region after a regional validation of individual components

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2.32 | CROP YIELDS, SOIL ORGANIC CARBON, AND GREENHOUSE GAS EMISSIONS: TRADE-OFF LESSONS FROM A LONG-TERM EXPERIMENT IN WESTERN KENYA

Kihara J., Paul B. and Sommer R.,

A better understanding of the multiple influences of land management on soil fertility, food security and potential contribution to global climate change mitigation is important especially in sub-Sahara Africa (SSA) where the need and potentials for agricultural intensification are high. Such understanding is constrained by scarcity of co-located and long-term data. In this study, we assessed synergies and tradeoffs between productivity, soil organic carbon (SOC) build up and nitrous oxide (N_2O) emissions and intensities from a set of best bet integrated soil fertility management options based on 26 seasons (13 yrs) of agronomic data. These are from two experiments located in sub-humid tropical Western Kenya. SOC contents declined in the long-term trials in all the management practices, yet no decline in crop yield over time was observed. Within individual seasons, SOC content affected crop productivity within specific strata/management levels and a few seasons only. Also, while N_2O emissions were elevated with increased N-fertilization, these on the one hand were partially offset by reduced losses of SOC, while on the other hand productivity and profitability increases were observed. In smallholder systems of SSA, where food security is a key goal, managing such trade-offs with climate change mitigation is a delicate balance.
Keywords: Soil fertility, agricultural intensification, climate change mitigation

2.33 | SOIL ORGANIC CARBON STABILIZATION IN COMPOST AMENDED SOILS

Riccardo Spaccini *[1,2], Alessandro Piccolo[1,2]

[1]riccardo.spaccini@unina.it; CERMANU Università di Napoli Federico II, via Università 100 80055 Portici NA (IT)

[2]Dipartimento di Agraria, Università di Napoli Federico II, via Università 100 80055 Portici NA (IT)

ABSTRACT

The molecular characteristics and the hydrophobic properties of natural organic matter represent a driving force in the long term stabilization of soil organic carbon. Laboratory incubations and field experiments were carried out to evaluate the effect of humified composts on the biochemical stability of soil organic components. Humic extracts and bulk composts were able to promote a stable incorporation of labile compounds in the humic hydrophobic domains thereby strengthening the incorporation of OC in soil size fractions and reducing the OC mineralization. The comparison of different soil organic matter managements in three agricultural soils, provided sound indications that soil amendment with mature hydrophobic green compost promote a significant incorporation of added organic materials in bulk soils and soil aggregates allowing a larger organic carbon stabilization in respect to conventional organic management practices

Keywords: SOC stabilization, compost, humic substances, hydrophobic protection

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The soil organic carbon (SOC) represent the largest reservoir in the global carbon cycle of terrestrial biosphere pools, accounting for 1500-1770 Pg, as compared to C stocks of vegetation (450-650 Pg) and fossil fuels (1000-1940 Pg. Despite the unavoidable uncertainties and approximations in the estimate of total SOC stocks for different geographical areas and land uses, global soil carbon levels of cultivated lands have decreased historically and continue to decline. Even though the term C sequestration is considered not adequate for the definition of the whole range of SOM managements (Powlson, Whitmore and Goulding, 2011), there is an increasing shared consensus on the powerful role of long term SOC stabilization for the maintenance and improvement of OC stocks in croplands and forest systems. The current conceptual depictions of SOC accumulation, are inclined to support the major role of physical protection mechanisms on SOM stabilization (Six *et al.*, 2002). The current techniques for SOC sequestration, rely on the application of minimum or no tillage intervention, coupled with crop rotation, green manure and mulching treatments, that imply the slacken of aggregate dynamics, the incorporation of fresh OM in undisturbed soil aggregates with a decrease of OC losses through lower exposition to microbial decomposition (Green Carbon Conference, 2014).

Complementary sustainable SOM managements for OC sequestration in cultivated soils are focused on the molecular characteristics and biochemical stability of SOM components (Song *et al.*, 2013). A determinant role in SOC sequestration is assigned to humified organic matter which is the most abundant and persistent pool of SOM, and represents the principal potential sink of OC in the biosphere. The current acknowledged representation of soil humus is based on a self-assembled supra-molecular associations of heterogeneous molecules, deriving from the selective degradation of plant residues and OM inputs, integrated by the incorporation of microbial by-products (Piccolo, 2002). The multiple components are held together by weak dispersive forces that stabilizes the supra-molecular structures in a high pliable assembly of contiguous hydrophilic and hydrophobic domains. The progressive accumulation of hydrophobic and recalcitrant molecules in the humic superstructures constitute the most hydrophobic environment in soil, tightly impermeable to aqueous solvent irrespective to solution pH (Masoom *et al.*, 2016). This hydrophobic barrier may hence provide a biochemical hindrance to microbial decomposition thus developing a dynamic mechanism of hydrophobic protection toward the more biolabile organic compounds released in soil solution by crop residues, plant roots exudates and microbial degradation of crop biomolecules.

Therefore a rising attention is focused on promising SOM managements based on the improvement of quantity and quality of soil humic materials, carried out with the use of highly humified OM inputs such as compost (European Commission, 2011). The mature compost is an important reservoir of humic substances that may effectively support the SOC sequestration in agricultural soils. The objective of the present work is to provide evidence on the effectiveness of humified composts in the incorporation and stabilization of SOM. Here we report the results of different laboratory tests and field experiment on the SOC sequestration provided by hydrophobic protection of mature composts and compost humic substances.

METHODOLOGY

- Experiment 1. In a laboratory incubation experiment, a labile 13C-labeled 2-decanol (13C 2dec.) was partitioned in two water dissolved humic acids, extracted from lignite (HAL) and compost (HAC), of different hydrophobicity as determined by NMR spectroscopy. A soil sample was incubated for three months with the following treatments: control; soil+13C-2 dec. alone; soil+HAL/13C-2dec., soil +HAC/13C-2dec. for a total of 36 bulk soil samples (4 treatment, 3,times, 3 replicates). The soils were sampled at initial incubation (t0), after 2 weeks (t1) and after 12 weeks (t2).

The residual 13C-OC content was determined in bulk soils, particle-size fractions and soil humic substances by Gas Chromatography Isotope Ratio Mass Spectrometry

- Experiment 2. In one year laboratory test, a sandy-loam (P) and silt-loam (L), soils were incubated with the following treatments: P or L= no addition (control); AG1/AG2= addition of polysaccharides corresponding to 2,000 kg $ha^{-1}$and 10,000 kg ha^{-1}; HAL/HAC= humic acids from lignite and composts, corresponding to 900 kg ha^{-1}; CMP= compost corresponding to 10 ton. ha^{-1}. Beside these six control treatments, the samples were treated with the two rates of AG (AG1 and AG2) both before and after each single addition of HAL, HAC, and CMP, for a total of 12 additional treatments. Measurement of OC content in samples was conducted at the following sampling dates: t0=at the start of the incubation; t1=after 2 weeks; t2=after 33 weeks; t3=after 52 weeks.

- Experiment 3. Within a three-years field trials, three agricultural soils were subjected to the following SOM managements: TRA (Traditional)=ploughing at 35 cm depth, followed by surface harrowing with addition of mineral fertilizers; MIN (Minimum tillage)=no ploughing, with addition of mineral fertilizers; GMAN (Green manure)= as TRA treatment with Leguminous crops interlaced between two main annual cycles and used to totally or partially replace nitrogen fertilizer; COM-1/COM-2 (Compost)=as the TRA plots with addition of hydrophobic mature green compost corresponding to 2.7 and 5.4 ton.ha^{-1} of OC

The SOM stabilization was evaluated with the following analyses: TOC content and Thermochemolysis-Gas Chromatography Mass Spectrometry (THM-GC-MS) of bulk soils and water stable aggregates.

RESULTS AND DISCUSSION

Experiment 1 The result of 13C-OC distribution showed that biolabile 13C-labeled 2-decanol was protected from mineralization when incorporated into the hydrophobic domains of the added HAs. At the end of incubation, the residual 13C-labeled OC recovered in bulk soil was equal to 28, 45, and 58% of the original content for samples containing the labeled alcohol alone or with HA-L and HA-C, respectively. The distribution of 13C-OC among soil particle sizes indicated that the protection was most effective in the finer soil fractions revealing a large incorporation promoted by hydrophobic humic acids in the silt- and clay-sized particles (Table 1). This finding confirms the importance of associations between fine textural fractions and microbially recalcitrant OM and suggests that SOM accumulation due to hydrophobic protection preferentially occurs within organo-mineral association of finer soil particles. In all soil treatments the added labelled decanol was also incorporated in the native SOM pools, with a larger partition observed in soil sample with compost HA.

Table 1: Variation of total organic carbon (TOC) and 13C-labelled organic carbon (13C-OC) in the bulk soil and sum of particle-size fractions with incubation time andsoil treatment (from Spaccini et al., 2002)

Treatments	t^a	Bulk soil[b]				Sum of fractions[b]					
		TOC[c]		^{13}C-OC		TOC[c]		^{13}C-OC			
		%	δ‰	%TOC	mg	%	%tot	2000 < μ > 0.1		< 0.1 μ[d]	
								mg	%tot[e]	δ‰	mg
Control	t_0	1.8	−26.3*a*			1.43	79.4			−25.0	
	t_1	1.7	−26.2			1.35	79.4			−25.3	
	t_2	1.5*a*	−26.3*a*			1.42	94.6			−25.2	
^{13}C-2 dec	t_0	1.8	−13.9*b*	0.47*ab*	10.2*a*	1.49	82.7	3.14*a*	30.8	49.0	6.94
	t_1	1.7	−18.5	0.29	6.0	1.37	80.6	3.60	59.5	14.0	2.40
	t_2	1.3*b*	−21.3*d*	0.19*c*	2.9*c*	1.28	98.5	1.90*c*	64.5	9.0	0.90
^{13}C-HAC	t_0	1.9	−13.4*c*	0.46*a*	10.4*a*	1.50	78.9	3.40*a*	32.4	52.9	7.0
	t_1	1.8	−14.4	0.42	9.1	1.50	83.3	3.70	40.6	49.0	5.30
	t_2	1.7*c*	−20.8*e*	0.20*d*	4.2*d*	1.61	94.7	3.80*d*	90.4	−16.4	0.38
^{13}C-HAL	t_0	1.8	−13.5*b*	0.50*b*	10.8*b*	1.44	80.0	4.21*b*	39.0	40.7	6.60
	t_1	1.7	−13.9	0.49	10.2	1.47	86.5	5.12	50.2	38.8	5.15
	t_2	1.7*c*	−18.9*f*	0.30*e*	6.1*e*	1.72	100	5.94*e*	96.0	−18.2	0.21

Experiment 2 The humified organic materials added to soils, were capable to reduce the biological mineralization of labile polysaccharides due to progressive interaction with the humic domains of added exogenous organic matter. The main difference in OC retention was observed among treatments when

mixtures of stable organic matter (CMP, HAC, HAL) were added with labile material (AG) in both P and L soils, regardless of the order of addition. Both bulk compost and HAC treatment induced progressive significant decrease of OC losses, at subsequent incubation time, in the two soils, with a final larger OC preservation in the sandy-loam soil. The soil treatment with compost CMP or humic acid from compost HAC progressively increased the overall OC sequestration, retaining at the end of incubation from 120% to 160% of the initial OC content in respect to control soil. A lower OC sequestration was shown by all samples at the higher polysaccharides rate. In this case, treatments with CMP increased OC retention during incubation time, up to 110% and 120% of the initial OC content, while the retention exerted by HAC and HAL was in the range of 85–76% and 58–53%, respectively, of the initial OC content. The results showed that the soil addition with compost may effectively stabilize the labile organic matter entering the soil by incorporation into stable humified organic matter.

Experiment 3 After three year of SOM managements, the minimum tillage showed a final positive increase of TOC in respect to traditional ploughing, only in a silty-loam soil, while the overall larger variability in SOC content shown by both conventional SOM managements GMAN and MIN, throughout the experimentation period and all experimental sites, suggests that these practices were not able to persistently stabilize OC. Conversely, notwithstanding an initial priming effect and a consequent decrease in SOC content observed in two experimental sites in the first year, the soil amendment with hydrophobic mature composts (COM-1 and COM-2) produced a significant stabilization of SOM revealing a persistent incorporation of SOC in both bulk samples and soil aggregates. Depending on soil bulk densities of different experimental sites, the field plots added with compost were able to maintain in all the ploughed horizons (0.30 m), a significant percentage of cumulative added OC, that ranged from the 52 to 63% and from the 50 to 80%, for the low and high doses of compost addition respectively. This data corresponded to a stable OC incorporation of 2.1 to 4.1 Mg ha^{-1} year^{-1}, that represented on average about the 75% of annual OC additions (2.7 and 5.4 Mg OC ha^{-1} year-1).

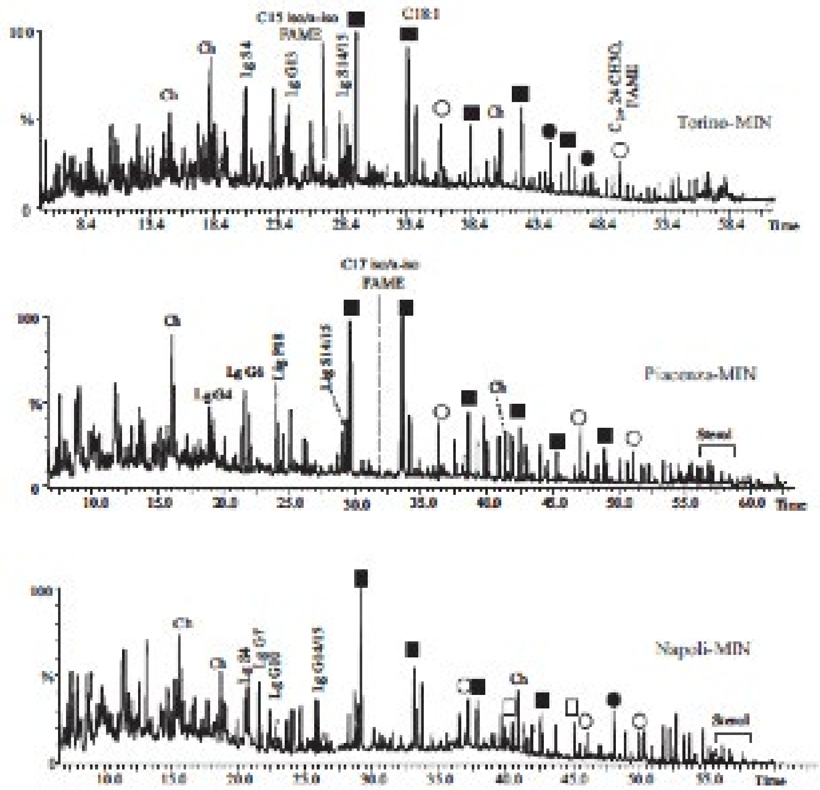

Figure 2 Representative total ion chromatograms of thermochemolysis products released from soil samples
(●) alcohol; Ch, carbohydrate;
(□) alkyl-dioic acid DIME;
(■) FAME; (○) hydroxy-FAME;
Lg, lignin.

The molecular characterization of SOM by THM-GC-MS analyses (Figure 2) revealed an effective incorporation of hydrophobic organic components from compost materials into bulk soils and water stable aggregates of each experimental sites. Increasing amounts of lignin components, fatty acids, *n*-alkanes and various biopolyesters derivatives such as long chain hydroxy-alkanoic and alkane-dioic acids were found in all compost amended soils. Moreover the inclusion of stabilized OM was indicated by the calculation of structural indices associated with the decomposition of lignin monomers. The aldehydes and benzoic acids forms of guaiacyl and syringyl lignin structures result from the progressive oxidation of lignin monomers. Conversely the corresponding homologues, holding integer methoxylated side chains, are indicative of unaltered lignin components, which retain the propyl ether intermolecular linkages. The ratio of relative amounts of oxidized acidic structures over those of the corresponding unaltered monomers are useful indicators of the bio-oxidative transformation of lignin components. The steady larger values found in both MIN and GMAN treatments and the corresponding progressive decrease of decomposition index in compost amended plots, further highlight the modification of SOM quality and the SOC stabilization promoted by the humified mature composts.

CONCLUSIONS

The results of laboratory and field experiment suggest that hydrophobic protection and the accumulation of alkyl and aromatic hydrophobic compounds, such as lignin and lipid components, may effectively contribute to OC accumulation in soil. The soil amendment with humified mature compost may be exploited to improve the biochemical stability of SOM, reduce the OC mineralization of the labile organic matter pools thus improving the OC stabilization and the sequestration potential of agricultural soils

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2.34 | LIFE CARBONFARM PROJECT: TECHNOLOGIES TO STABILIZE SOIL ORGANIC CARBON AND FARM PRODUCTIVITY, PROMOTE WASTE VALUE AND CLIMATE CHANGE MITIGATION

(LIFE12 ENV/ IT 000719)]

Riccardo Scotti[1], Chiara Bertora[2], Vittoria Pastore[3], Martina Antonucci[4], Catello Pane[1], Stefano Gaudino[2],Alessandro Persiani[3], Roberto Sorrentino[1], Vincenzo Di Meo[4], Carlo Grignani[2], Massimo Zaccardelli[1], Giuseppe Celano[5], Riccardo Spaccini[4]*

[1]CREA-Centro di Ricerca per l'Orticoltura, Via dei Cavalleggeri 25, 84098 Pontecagnano, SA (IT)

[2]DISAFA Università degli Studi di Torino, Largo Paolo Braccini 2, 10095 Grugliasco, TO (IT)

[3]DICEM Università degli Studi della Basilicata, Via San Rocco 3, 75100 Matera, (IT)

[4]CERMANU Università di Napoli Federico II Via Università 100 80055 Portici NA, (IT) *riccardo.spaccini@unina.it

[5]DIFARMA Università degli Studi di Salerno, Via Giovanni Paolo II, 132 84084 Fisciano, SA (IT)

The LIFE CarbOnFarm project focus on the application of sustainable soil managements in agro-ecosystem based on the application of high quality composts derived from the recycling of local available agricultural biomasses. The main objectives are the improvement in quantity and quality of soil organic carbon, the restoration of biological properties, the maintenance of crop productivity, the decrease of energetic inputs, the control of soil green house gases emissions. These methodologies are applied at field scale, in five different farming systems in Italy. After two year of project activities sounds indications were obtained on the effective contribution of humified composts to soil fertility and crop yields.

The analyses of compost from agricultural biomasses revealed a large content of humified hydrophobic molecules, associated with a suppressive properties and biostimulation activity. The amended plots of each experimental site promoted a significant increase of SOC with an incorporation of exogenous OM in bulk soils and soil aggregates and limited effect on GHG emissions. The addition of OM inputs showed an overall improvement of soil biological activities, thereby producing also positive effects on crop productivity

Keywords: SOM management Compost quality, SOC characterization GHG emission, Crop productivity

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Soil organic matter (SOM) is the key compartment for the maintenance of soil fertility, acting as driving force for the overall sustainability of agro-ecosystems. The lowering content of SOM related to deforestation, land uses, agricultural managements, is acknowledged among the main factors affecting the observed loss of soil properties and crop productivity (European Commission, 2011; UNFCCC, 2015). An additional side effect of SOM losses is represented by the contribution to the greenhouse gases (GHG) emission from soils. The historical global SOC losses mainly associated with decomposition of OM inputs and mineralization of soil humus, account for 136±50 Pg, while the current annual fluxes are rounded up to 1.1 Pg yr-1 (IPCC, 2013).

The restoration of soil organic carbon (SOC) level in croplands is hence regarded as an updated and topical challenge for the sustainable development of agro-ecosystems (European Commission, 2010). An increasing effort is dedicated to support the adoption of adequate and suitable SOM managements aimed to revert the trend of SOC decline and enhance the potential of cultivated soils to become an effective sink of OC (Paustian, Rumpel and Pan, 2014; Young *et al.*, 2007). The use of recycled agricultural biomasses for SOM managements represent a powerful and viable method to improve the SOC, restore the soil fertility and warrant a suitable crop productivity (Bertora *et al.*, 2009; Scotti *et al.*, 2016).

The LIFE+ CarbOnFarm project (www.carbonfarm.eu) attempt to promote the application of sustainable practices for SOM managements in agro-ecosystems. The project strategies approach the environmental problems related to the decrease of SOC content in agricultural areas of Mediterranean countries, which are among the chiefly target objectives advised by EU Soil Thematic Strategy. The goal is the restoration of SOM level and functions in agricultural soils, attained through the valorisation of local recycled agricultural biomasses with high quality composts. The project strategies are applied at farm scale in five project sites, located in Piemonte and in Campania regions in Italy, reproducing the local farming systems. Different compost are applied, depending on the local availability of organic waste and biomasses. In farm sites of Piemonte, the compost is

produced from the solid fraction of anaerobic digestion of cattle slurry (solid digestate), while in Campania the compost is obtained by the farm biomasses and residues with *on-farm* composting facilities.
The improvement of SOC, the characterization of compost quality control of GHG emission and evaluation of crop productivity are the main concerned objectives. Here we present the intermediate results after two year of project activities

METHODOLOGY

Project sites and experimental set up

Piemonte:

- Public farm of Tetto Frati University of Torino (TF). Soil texture: loamy Cropping system: maize Compost type: solid fraction of anaerobic digestion of cattle slurry. Twenty-four randomized plots (60 m^2 each one) with 6 treatments and 4 field replicates: **0N**=no Nitrogen, mineral P and K; **TRA**= mineral fertilization (N, P and K); **CMP-B**/**CMP-A**=1000 and 2000 kg of C ha^{-1} with compost; **SS-B** /**SS-A**=1000 and 2000 kg of C ha^{-1} with fresh solid digestate

- Commercial Farm Grandi (GR). Soil texture: sandy loam. Cropping systems: open field horticultural crops. Compost type: solid fraction of anaerobic digestion of cattle slurry. Twenty-four randomized plots (28 m^2 each one) with 6 treatments and 4 field replicates: **0N**= no Nitrogen, mineral P and K ; **TRA=**mineral fertilization (N, P and K); **CMP-B/ CMP-A**=1000/2000 kg of C ha^{-1} with compost; **SS-B** and **SS-A**= 1000 and 2000 kg of C ha^{-1} with fresh solid digestate

Campania

- Public farm of Castel Volturno University of Napoli (CV). Soil texture: clay loam. Cropping system: maize. Compost type: on-farm compost from cattle+buffalo manure and maize straw. Twelve randomized plots (50 m^2 each one) with 3 treatments and 4 field replicates: **TRA**=mineral fertilization (N and P); **CMP-B/CMP-A**=compost addition (10/20 t ha^{-1}) + P

- Commercial farm Idea Natura (ID). Soil texture: clay loam Cropping systems: horchards (peach, kiwi). Compost type: on-farm green compost from farm residues (horticultural crops, trimming, woody residues). Eighteen randomized plots for each systems (900 m^2 each one): two compost types: **S** summer and **W** winter; three level of compost: **0**= control (mineral fertilizers N, P, K), **1**=lower (10 t ha^{-1}), **2**=higher (20 t ha^{-1}); 3 field replicates

- Commercial farm Prima Luce (PL) Soil texture: clay loam. Cropping system: open filed horticultural crops. Compost type: *on-farm* green compost from farm residues (horticultural crops, trimming, woody residues). Twelve randomized plots (280 m2 each one) with 4 treatments and 3 filed replicates: **0N=**control no fertilization; **TRA=**traditional organo-mineral fertilizer (N= from 50 to 200 kg ha^{-1}, depending on the crop); **CMP-B/CMP-A=**on-farm green compost 10/20 tons ha^{-1}

Analyses

- **Compost quality**: C, N, and P contents, pH, EC; biological assays: phyto-toxycity, suppressivity; microbiological characterization coupled with metagenomic approaches; solid state Nuclear Magnetic Resonance (13CCPMAS NMR); Thermochemolysis Gas Chromatography Mass Spectrometry (THM-GC-MS); laboratory analysis of GHG emission from composts; 13C isotopic analyses

- **Soil**: soil aggregate stability; TOC, N content in bulk soils and soil aggregates; 13C isotopic analyses; THM-GC-MS and 13C CPMAS NMR; field GHG analyses with Photoacustic Field Gas Monitor (Figure 1); phospholipids fatty acids (PLFA); soil microbial respiration, biological activities and metagenomic analyses using T-RFLP technique

- **Crops**:

- maize and vegetables: photosynthetic status; above-ground biomass: crop yields; N and P contents
- peach and kiwi: size, weight, dry matter, firmness, colour (peach), soluble solids, acidity, N, polyphenols, antioxidant activity

RESULTS AND DISCUSSION

Compost: the characterization of organic materials revealed the attainment of highly humified mature composts characterized by the selective preservation of stable hydrophobic components represented by lignin compounds, plant and microbial lipids and plant bio-polyesters.

The biological assays showed a significant microbial activity in all biomasses as measured by total respiration and hydrolase activity. The innovative metagenomic analyses indicated that composts were characterized by a variable suppressive activity, and biochemical stimulation depending on molecular composition. The first outcomes indicate that *Streptomyces* can play a determinant role for the suppressive propriety of composts, and strengthen the working hypothesis that the phenolic components related to lignin derivatives positively affect the biological activity (Martinez-Balmori *et al.*, 2014). Also the different combination of hydrophobic fraction and bio-labile components (carbohydrates, peptide derivatives) act as important modulator in the bio-activity displayed by the humified fraction of composted biomasses.

SOC: after two year of SOM managements an average improvement of SOC content was found in field plots with organic amendments of each project sites. The widespread increase of TOC found in both bulk soils and size-aggregates ranged from 0.4 to 2.0 g kg^{-1}, depending on soil type and dose of organic amendment. The molecular characterization showed that the SOM managements produced an overall increase in the yields of both stable hydrophobic aliphatic and lignin components derived from added OM (Table 1), which are currently associated with the humification processes and stabilization mechanisms of SOC (Song *et al.*, 2013). The 13C-OC isotopic distribution further confirmed the incorporation of exogenous OC in soil aggregates.

The analyses of PLFA revealed a steady increase of microbial biomass in all OM amended field plots of TF, GR and CV, while specific larger yields of PLFA derivatives from mycorrizhal fungi in CMP-A and SS-A treatments of TF and GR project sites. Also in the PL soil an improvement of metabolic activity in CMP-A treatment was stressed by the observed increase of the microbial community efficiency, as summarized by the biodiversity Sannon's index and AWCD (average weight color development) indicator

Table 1 Example of composition and yields (μg g-1) of main SOM compounds identified by THM GC MS at 2 year for field treatments at GR and TF project sites

	GR Field treatments 2nd year								TF Field treatments 2nd year					
Compounds	t0	Trad	0N	SSB	SSA	CmpB	CmpA	t0	Trad	0N	SSB	SSA	CmpB	CmpA
Fatty acids $C_{12}\div C_{28}$	4465	4276	4125	4612	4575	4563	4596	3063	3020	2990	3190	3220	3330	3410
Bio-polyesters (cutin and suberin) $(C_{16}\div C_{22})$	1039	972	1020	1084	1087	1114	1140	635	513	545	660	740	726	753
Alkanes $(C_{25}\div C_{31})$	95	82	79	95	97	108	110	89	60	80	95	85	100	120
Alcohols $(C_{16}\div C_{26})$ & Phytosterols $(C_{28}\div C_{30})$	167	145	139	180	185	207	215	162	143	133	189	153	206	217
Total alkyls	5766	5475	5363	5971	5944	5992	6061	3949	3736	3748	4134	4198	4362	4400
Guaiacyl	195	192	185	208	225	227	232	127	142	128	118	147	187	205
$(Ad/Al)_G$b	3.2	3.4	3.6	3.2	3.1	3.2	3.1	4.4	4.3	4.2	4.1	4.0	3.9	3.9
(Γ_G)b	3.4	3.9	3.8	3.3	3.2	3.1	3.2	3.0	3.2	3.0	3.1	2.8	2.9	2.8
p-Hydroxyphenyl	181	152	172	206	232	245	256	64	58	55	64	72	71	74

Syringyl	164	170	154	189	196	194	205	174	185	174	177	202	215	208
$(Ad/Al)_S$b	4.0	3.9	3.8	3.9	3.8	4.1	3.9	3.5	3.4	3.5	3.4	3.0	3.1	3.1
(Γ_S)b	3.2	3.1	3.3	3.1	3.0	3.1	2.9	3.8	3.9	4.1	3.7	3.6	3.5	3.8
Total lignin	540	514	511	603	653	666	693	365	385	357	359	421	473	487

[a] Total range varying from Ci to Cj; b Lignin structural indexes: $(Ad/Al)_G$=G6/G4; $(Ad/Al)_S$=S6/S4; (Γ_G)=G6/(G14+G15); (Γs)=S6/(S14+S15).

Figure 1. GHG field sampling system

<u>GHG emissions</u>: the soil laboratory incubation performed to evaluate the GHG emissions (N2O, CO2 and CH4) for different organic materials used in soil amendments, highlighted the decrease of specific emission of all composts in respect to either mineral fertilizers (e.g. urea) and to fresh solid digestate, thereby supporting the advantage of SOC stabilization attained with the composting process. The field measurements revealed a slight increases of CO2 emissions from compost treatments in bare soils, that were nullified however by the almost matched larger values found during the crop cycle

<u>Crops:</u> averaged larger yields were found, in compost amended plots, for the horticultural crops at both GR and PL sites, without differences in nutrient uptakes (N, P). Significant improvements for compost treatments were shown in orchard systems for either yield or quality, suggesting a positive effect of humified compost on plant physiology. The main increase were related, for W1,2 and S1,2 soil managements, to global yield, dry matter, total polyphenol and soluble solids in kiwi system, while, for peach fruits significant increase were observed for average yield/plant (+47-100 %), average yield/ha (+60-100%), total dry matter and N contents.

CONCLUSIONS

The soil treatment with humified composts from agricultural biomasses produced the incorporation of stable exogenous OM components, in bulk soil and soil aggregates of different soil types. After two year of SOM managements, positive effect were noticed on SOC distribution, biological activity, GHG emission and crop productivity, thereby further supporting the role of mature compost as viable way to meet the requirements of sustainable development in agro-ecosystems while linking SOC management, GHG mitigation and maintenance of crop yields

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2.35 | FOLLOW UP OF THE STATUS OF THE WORLD'S SOIL RESOURCES REPORT 2015. GLOBAL MANAGEMENT OF SOIL ORGANIC MATTER (SOM)

Miguel A. Taboada[1]

1[INTA, CIRN, Institute of Soils; CONICET. taboada.miguel@inta.gob.ar (*)]

ABSTRACT

Follow up of the Status of the World's Soil Resources Report 2015. Global management of Soil Organic Matter (SOM)

Soil organic matter (SOM) declines have been identified as a main threat for soil quality, so that increasing SOM levels represents a major part of the solution to various environmental concerns related to climate change and food production. The impact of different initiatives, practices and actions undertaken by different stakeholders involved in SOM management was assessed on the basis of reviewing recent scientific literature (focus on review articles) and responses to a stock template. Main drivers of SOM inputs and storage in soil are soil texture and clay percentage, soil type, climate and vegetation residues. Different authors found about 2.0 Mg C ha^{-1} as a minimum annual C input to maintain critical soil functions and/or stop further soil C losses. Field practices to reduce soil disturbance (zero tillage and others) may increase SOM content and improve topsoil quality, but their potential to mitigate climate change may be overestimated. Practices aiming to increase soil carbon stock including crop rotations, cover crops, afforestation and manuring, among others, generally have positive impact on SOM. Different land policies are being implemented at international or national level to protect the soils and increase soil C stocks.

Keywords: [soil organic matter, soil carbon stocks, C drivers, zero tillage, climate change mitigation, crop rotations, afforestation, land policies]

EXTENDED ABSTRACT

INTRODUCTION AND OBJECTIVES

Increasing soil organic matter (SOM) represents a major part of the solution to various environmental concerns related to climate change and food production. The "Global Management of Soil Organic Matter (SOM)" was one of the specific working groups (WG) tasked to closely follow up on the four main priorities for action identified in the SWSR (FAO and ITPS 2015). This priority of action aims to list, review and/or evaluate the impact of different initiatives, practices and actions undertaken by different stakeholders involved in SOM management with the aim of improving soil functions, soil fertility, structural stability and movement of water in agroecosystems and ecosystems. This includes any practice, initiative and action aimed at carbon sequestration in soil profiles and SOM maintenance or recovery.

METHODS

a) review of recent scientific literature, with the focus on review and meta-analysis articles published after 2013; and b) responses to a stock template previously submitted to ITPS members and members of Regionals of the Global Soil Partnership (GSP), soil scientists and policy-makers.

RESULTS

A. Drivers of SOM inputs and storage in soils

SOC accumulation depends on a range of factors, such as amount and type of residues added to soil, initial SOC content, soil material and topographic position, and climate. Figure 1 shows a proposed graphic of potential saturation curve, achievable curve and critical curve for the amount of organic C in agricultural soils (Stockmann *et al*. 2013). Initial increased in SOC following a change in management are rapid, and then slow and reach a new quasi-equilibrium at some point.

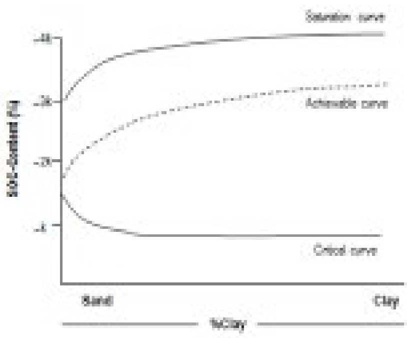

Fig. 1. Notional saturation, achievable and critical curves of SOC accumulation as a function of soil texture. Here, k is a site- or region-specific proportionality constant that depends on a variety of interacting factors (e.g. climate, soil material and topographic position). Redrawn from Stockmann et al (2013).

Soil type, climate, vegetation indices and terrain attributes, and non-complexed clay are good predictors of SOC (Apka *et al*. 2016; Merante *et al*. 2017). Potential to sequester SOC varied from 0.2 to 30.8 Mg C ha^{-1} (Apka *et al*. 2016). In wheat systems in China an average C input of 2.1 Mg C ha^{-1} yr^{-1} was enough to stop soil C loss and to maintain SOC (Wang *et al*. 2015; 2016).

B. SOC management practices effects on soil C storage

Soil conservation practices may reduce soil disturbance (e.g. zero and reduced tillage) and/or increase soil carbon inputs (e.g. cover crops, crop rotations, residue management). Zero and reduced tillage increased SOC from 0,04 to 0,45 Mg C ha^{-1} yr^{-1} in different countries and regions, as a function of crop rotation, cover crops and residue returns. Climate change mitigation of 24% to 31.3% by zero tillage alone or combined with different rotations or integrated productions was found in South America and China (de Moraes Sá *et al*. 2017; Du *et al*. 2015). However, soil C is not necessarily increased, but redistributed or stratified at surface (Merante *et al*. 2017). Other authors alert on an overestimated impact of zero till farming on climate change mitigation because limited C inputs (Olsson 2013, Powlson *et al*. 2014, Cheesman *et al*. 2016; VandenBygaart. 2016). Organic farming not always give climatic change benefit through soil carbon sequestration either (Gattinger *et al*. 2012; Leifeld *et al*. 2013).

Zero tilled cover crops (catch crops and green manures) can sequester between 0.10 and 1 Mg ha^{-1} per year of SOC relative to zero-till without cover crops, depending on cover crop species, soil type, and precipitation input (Blanco-Canqui 2013; Lugato *et al*. 2015; Poeplau and Don 2015; Rimski-Korsakov *et al*. 2015; Raphael *et al*. 2016; Merante *et al*. 2017). Crop rotations including legumes (e.g. vetch) and meadow grasses can increase SOC by 0.17 Mg C ha^{-1} yr^{-1} (Merante *et al*. 2017). Intercropping can sequester 184 +/- 86 kg C ha^{-1} and 45 +/- 10 kg N ha^{-1} and have an average of 23% greater total root biomass with respect sole crops (Cong *et al*. 2015).

In England total C stocks (Mg ha^{-1}, 1 m depth) in grasslands were 10.7% greater at intermediate than at intensive management, which equates to 10.1 Mg ha^{-1} in surface soils (0–30 cm), and 13.7 t ha^{-1} in soils from 30 to 100 cm depth (Ward *et al*. 2016). Grazing effects on SOC are site-specific because of rainfall, soil texture, grazing intensity and grassland composition (C3 vs. C4) effects (McSherry *et al*. 2013).

Up to 2.2 Pg C (1 Pg = 1015 g) may be sequestered above- and belowground over 50 years in agroforestry systems (Lorenz and Lal 2014). Largest carbon sequestration was found after croplands and with conifer species planted (Bárcena *et al*. 2014). Carbon stocks can be increased by 200–500% in forest floors and by 40–50% in top mineral soil by tree species change (Vesterdal *et al*. 2013).

Land use change to biofuel feedstock production impacts on SOC is highly dependent on the specific land transition, with overall 6–14% SOC gains after cropland conversions and carbon losses of 9-35% after of grassland or forest to corn (without residue removal) or poplar caused significant carbon loss (Qin *et al*. 2016).

C. Land use policies

Land policies promoting land use changes to perennial vegetation were implemented in some countries and regions, such as the "Evergreen" system in Austria, the Grain to Green Program (GGP) in China, and soil erosion control in Songliao Watershed, China, and different laws or regulations in Uruguay, Honduras, Mexico, Senegal, among others. In China, the GGP soil carbon stocks (0-100 cm) initially decreased and then recovered after 5 years coincident with vegetation restoration. Converted areas from croplands to forests could sequester 110.45 Tg C by 2020, and 524.36 Tg C by the end of this century (Deng *et al*. 2014; Liu *et al*. 2014). Initial low carbon sequestration was also observed after abandonment in agricultural fields of the former Soviet Union, but carbon uptake increased significantly after approximately 10 years at a rate of 0.75 t C ha^{-1} yr^{-1} after an average of 14 years of abandonment (Schierhorn *et al*. 2013; Kämpf *et al*. 2016).

At a global scale, the French government launched the "4 per 1000" initiative" at the COP21 in Paris. An annual growth rate in SOC stock of 4‰ should be achieved to stop the present increase in atmospheric CO_2, bymeans of conservation tillage, agroforestry and intercropping, among others (Minasny *et al*. 2017).

SUMMARY

SOC sequestration is driven by different factors, such as soil texture, clay percentage and type, soil type, climate, amount and quality of residues. Critical SOC levels were established as a function of these factors.

SOC is positively affected by a range of management practices, such as zero- and reduced tillage, crop rotations including legumes and meadow grasses, cover crops, conversion to pastures, grasslands and afforestation, and rangeland management. There is a need to be more realistic about both the benefits and disadvantages of these practices on climate change mitigation.

Different land policies implemented at global, national or regional scale have demonstrated their potential to recover SOC and stop soil degradation.

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2.36 | URBAN SOILS AS HOTSPOTS OF ANTHROPOGENIC CARBON ACCUMULATION.

Viacheslav Vasenev*[1], Yakov Kuzyakov[2]

[1][RUDN University, Moscow, Russia, vasenyov@mail.ru]*

[2] [Georg-August-University, Göttingen, Germany, kuzyakov@gwdg.de]

ABSTRACT

Urban soils and cultural layers accumulate carbon (C) over centuries, however, processes and mechanisms leading to high C accumulation in urban soils remain unknown. The processes specific for C accumulation in urban soils were analyzed and the C sequestration rates were assessed based on the data from 118 cities worldwide. For the whole range of climatic conditions, 1.5-3 times higher C content and much deeper C accumulation in urban soils resulted in 3-5 times larger C stocks compared to natural soils. Soil organic carbon (SOC) and black carbon (BC) increased with latitude, whereas soil inorganic carbon (SIC) was less affected by climate. The city size and age were the main factors controlling intra-city C stocks with higher stocks in small cities compared to megapolises, and in medieval compared to young cities, whereas the inter-city variability was dominated by functional zoning. Substantial amounts of SOC, SIC and N were sequestered for long-term in the subsoils, cultural layers and sealed soils, underlining the importance of these 'hidden' stocks for C assessments. Despite small city areas, urban soils are hotspots of long-term belowground C sequestration worldwide, and the importance of urban soils will increase in future with global urbanization.

Keywords: Global change, Urbanization processes, Cultural layers, Subsoil carbon, Anthropogenic processes, Pyrogenic carbon, Xeno-carbon, Carbon accumulation rate.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Urbanization increases the importance of urban ecosystem components and raises the environmental relevance of urban soils from local to regional and global levels. Urban soils provide important functions and ecosystem services. The research clearly showed one of the ecosystem services of urban soils: the C sequestration.

METHODOLOGY

We collected data on organic (SOC), inorganic (SIC), black (pyrogenic) (BC) and N contents and stocks in urban soils from 100 papers. The database (770 values on SOC, SIC and BC stocks from 118 cities worldwide) was analyzed considering the effects of climate and urban-specific factors: city size, age and functional zoning. The processes specific for C accumulation in urban soils were analyzed and the C sequestration rates were assessed. Urban soils were compared with their natural counterparts. Natural soil types based on the Harmonized World Soil Database v 1.2 (HSWD; Fischer et al., 2008) and dominating in the 10 km buffer surrounding a city were selected as a counterpart for comparison

RESULTS

The estimated C stocks in urban soils were 3-5 times higher than in natural soils and were based on long-term accumulation of four C forms: SOC, SIC, BC and Xeno-C. Climate was the main contributor to the variance of SOC stocks in the topsoil, whereas the city area and age mainly affected SOC stocks in subsoil and cultural layers. Topsoil urban SOC for cold and temperate Zones was higher than those in tropical and arid zones. The topsoil SIC stocks were highest in arid and cold zones. BC stocks in temperate climates were almost 10 times larger than in cold and arid zones. SOC stocks significantly increase (r = 0.61, R^2 = 0.38, p<0.05) in 0-10 cm of urban soils from tropics (~20 °) towards high latitudes (60-70 °). The pattern was similar to the SOC distribution in upper 10 cm in natural soils for the same range of latitudes (ISRIC-WISE Dataset, Batjes, 2008), but the correlation for the natural soils was weaker (r = 0.46, R^2 = 0.21, p<0.05). Thus urban topsoil in tropics and arid climates (20-30 ° latitudes) contained less SOC, whereas in temperate and cold climate SOC contents and stocks were substantially higher compared to natural soils (Fig. 1)

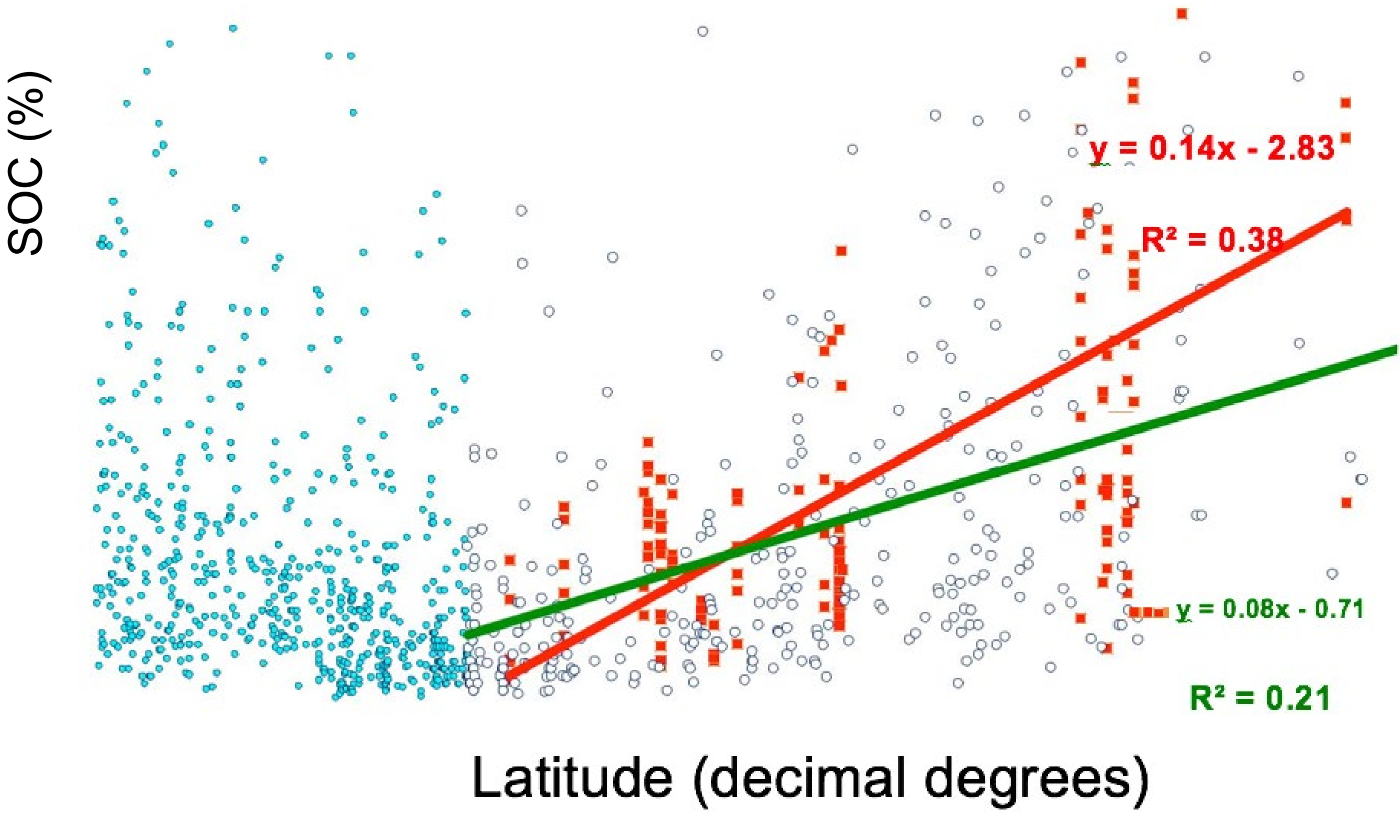

Fig. 1: Zonal patterns in SOC content in urban and natural topsoil (0-10 cm).

The inter-city variability of C stocks was dominated by functional zoning: large SOC and N stocks in residential areas and large SIC and BC stocks in industrial zones and roadsides were similar for all climates and for cities of various size and age. Substantial amounts of SOC, SIC and N were sequestered for long-term in the subsoils, cultural layers and sealed soils, underlining the importance of these 'hidden' stocks for C assessments. Long-term C inputs from outside the cities and C accumulation coincided by upward soil growing of 50 cm per century result in continuous accumulation of 15-30 kg C m^{-2} per century in urban soils and cultural layers.

DISCUSSION

Much higher C stocks in urban compared to natural soils are explained by the specific anthropogenic and natural processes and mechanisms, contributing to fast C accumulation in urban areas. These mechanisms include 1) C inputs from suburban-areas (e.g. transfer of food, wood and raw materials), 2) C provisioning and redistribution inside the city (e.g. xenobiotics, soot and charcoal) and 3) *in situ* transformations (e.g. sealing, over-compaction and water-logging). Upward growth of urban soils over a long period results in very deep cultural layers with very high C accumulation. Urban soils grow upward for about 50 cm per century corresponding to C accumulation rate of 20-30 kg C m^{-2} per century. This results in SOC stocks in 200 cm depth in soils of medieval cities which are higher than the maximal SOC stocks in Chernozems and Phaeozems - natural soils with highest C stocks. Such high rates of C accumulation in urban soils highlight their potential to mitigate climate change despite their comparatively small area.

CONCLUSIONS

Urbanization is one of the most important components of Global Change and its rates are faster than of the other components. Consequently, the importance of urban soils as omnipresent part of the cities will increase in future. Therefore, urban soils should be considered not only as the stocks of waste and pollutant accumulations (as in the most studies), but having a broad range of ecosystem function, one of them - long term C sequestration, which is much higher than in natural soils.

2.37 | DYNAMICS OF SOIL CARBON SEQUESTRATION UNDER OIL PALM PLANTATIONS OF DIFFERENT AGES

*Brahene, Sebastian Wisdom[1], Owusu-Bennoah, Emmanuel[2], Abekoe, Mark Kofi[3]

[1]FAO Regional Office for Africa, Accra, Sebastian.Brahene@fao.org or wisneb@yahoo.com Tel. :(+233) 277146372
[2]Department of Soil Science, University of Ghana, Legon, eowusubennoah@gmail.com
[3]Department of Soil Science, University of Ghana, Legon, k_abekoe@ug.edu.gh

ABSTRACT

Farming system transformations such as replacing forests with oil palm have generated some arguments owing to the perceived negative impacts of oil palm on the environment. A change in management practices such as heaping of pruned branches could increase carbon stocks. The objectives of this study were to assess soil carbon content, stocks and dynamics over time in oil palm plantations. Oil palm plantations of five different ages were chosen based on similar land history fairly located at the bottom slope. On the same farm two different samples were taken; first within alleys; and secondly under heaped pruned branches. A control was selected from a forest reserve. The carbon content determined showed that organic carbon under alleys fairly decreased with age whiles that under prunnings increased. Carbon stocks calculated followed a similar pattern. The use of carbon saturation deficit showed how much carbon each age group needed to add in order to attain equilibrium. The closest was the 20-25 years group under prunnings indicating a positive feedback compared to the rest when pruned materials were added. In conclusion oil palm plantations have the ability to sequester carbon when residue materials in the form of pruned palm fronds are well managed.

Keywords: oil palm, prunning, heaps, alley, carbon, sequester, decomposition.

INTRODUCTION

Tackling climate change demands special attention to agriculture since growing of crops and raising of farm animals contribute an estimated 10-12% of anthropogenic greenhouse gas emissions globally (Smith *et al.* 2008). Farming system transformations in the humid tropics involving the replacement of forests with cash crops have also generated a lot of controversies with respect to CO_2 emission. For example the large scale cultivation of oil palm has been implicated as one of the major causes of substantial gas emission and often irreversible damage to the natural ecosystem.

In the Eastern Region of Ghana some farmers have engaged in converting primary and secondary forests into oil palm plantations. The farmers engage in periodic prunning and the heaping of palm fronds in between the rows of plants during the growth of the crop. Information on the impact of this management practice especially on organic matter and its constituent carbon (C) in Ghana is scarce.

According to Youl (2009) a change in any management practices leading to an increase in C stocks (sink) represents a means to reduce CO_2 concentration in the atmosphere which is responsible for the increase of the earth's surface temperature (GIECC, 1997).

The objectives of this research were: (1) to assess soil C content and stocks under pruned heaps in already established oil palm plantations of different maturity ages; (2) to examine the dynamics (changes) in soil C stocks over time under pruned heaps in these oil palm plantations.

MATERIALS AND METHODS

As a way of transposing space for time, plantations of different ages were looked at and compared with a system in its native state by identifying a suitable chronosequence and a representative control site all within a semi-deciduous rain forest.

Private oil palm plantations owned by local farmers within the Kwaebibirim District of the Eastern Region, Ghana, were selected with a reference soil, (uncultivated forest soil) taken from the Forest and Horticultural Crops Research Centre, Okumaning, Ghana within the same district.

These oil palm farms were at different maturity ages from very young ones of about three months old to farms as old as twenty-five years. Sampling of farms begun with creating five clusters according to age of oil palm plantation into which various farms were grouped. A total of fifteen farms were selected for sampling with three farms representing each age group as replicates. The sites selected were oil palm farms established at the valley bottom along a typical catena. The dominant soil at this location is Oda Soil Series classified as *Aeric Endoaquent* (Owusu-Bennoah *et al.*, 2000). Soils were sampled from a depth of 0-10 and 10-20 cm. The various age groups considered were 0-5, 5-10, 10-15, 15-20 and 20-25 years. Sampling was preceded by marking out an area 25m by 25m. These sampling plots contained both alleys between rows of palm trees and pruned and heaped palm fronds within the palm rows. Core samplers were driven into the ground to take undisturbed soil samples within the alleys and under heaped branches for bulk density analysis. Sampling under the prunnings was done carefully especially under old heaps since there was the need to distinguish the top layer from the decomposed material sitting just above it. Soils from the sampled spots from each farm were put together to obtain a composite sample. A sub-sample was taken, air dried, crushed and sieved through a 2 mm sieve and processed for laboratory analyses. Bulk density, particle size analysis (Bouyoucos Hydrometer, Day (1965)), pH (Electrometric), Organic Carbon (Wet Oxidation, Walkley and Black (1934)), Total Nitrogen (Kjeldahl Digestion, Bremner (1960)), Exchangeable bases and CEC (1M Ammonium acetate solution at pH 7.0) were among the properties determined. Carbon stocks for each layer i.e. 0-10 and 10-20 cm were determined on the fine earth fraction after bulk density and C content had been determined on the soils using the formula below: C stocks ($Mgha^{-1}$) = , where ρb- Bulk density a- Area of a hectare, d- Sampling depth (Youl *et al.* 2011). Carbon saturation deficit was calculated from stocks for each of the layers using:
Csatdef = , where Cref- Carbon stock in reference soil and Corg -Current carbon stock in sampled soil under oil palm (van Noordwijk *et al.* 1997). Genstats (12^{th} Edition) and Minitab (16^{th} Edition) were used for computer analyses. Separation of means was done using the Least Significant Difference (LSD) method. All tests were conducted at 5% significance level.

RESULTS AND DISCUSSION

Prunning and heaping of palm fronds by the farmers starts after the initial 5 year period of the establishment of the plantation and so serves as the basis for tracking C dynamics. The results for the reference and the 0-5 years shows what exists in the natural vegetation and moments after conversion and so may not be key in comparison.
A general increase in bulk density (BD) with depth was observed under prunnings and alleys which was attributed to the increasing clay content with depth (Brahene *et al.* 2015). The primary objective of tracking soil C stocks in the top 20 cm over time (25 years) under oil palm was met. Results in Tables 1 and 2 show that conversion leads to a dramatic loss in soil C stocks of around 45% in the top 10 cm irrespective of heap or alley location. The difference between the 0-5 years and the uncultivated was significant with a substantial amount of C present on the soil surface after initial removal of vegetation. With the 0-5 years serving as a reference for the cultivated fields a notable drop in OC within the first 5 years was seen as has been reported in other studies by Guo and Gifford (2002). The subsequent drop in OC beyond 10 years was gradual when compared to preceding years as has been observed in a similar study. In the 10-20 cm layer, loss was 50-60% with lower decline under residue heaps. Organic C was about 40% higher in the 0-10cm than the 10-20 layer across all the age groups. There was a consistent increase in OC of about 4.2% with age up to 20 years under heaps. Beyond 20 years the increase observed was significant and was about 24% of the OC determined for the 15-20 years period. Although significant litter was present on the forest floor the OC determined was 40.7 g C/kg soil for the 0-20 cm which was relatively low as has been reported by Nye and Greenland (1962) for humid tropical soils. The OC content for soils within the alleys followed a similar trend as that under prunnings except that there was a significant decline beyond 20 years.

Table 1 Bulk density, C content and stocks for 0-10 and 10-20 cm layers under oil palm heaps.

No.	BD (Mgm^{-3}) 0-10 cm	OC (%) 0-10 cm	C Stocks (Mgha^{-1}) 0-10 cm	Csatdef (gkg^{-1}) 0-10 cm	BD (Mgm^{-3}) 10-20 cm	OC (%) 10-20 cm	C Stocks (Mgha^{-1}) 10-20 cm	Csatdef (gkg^{-1}) 10-20 cm	∑stocks (Mgha^{-1})
1*	1.36a	25.5d	34.7f	-	1.46b	15.2a	24.9d	-	- 59.6
2*	1.24c	22.3c	27.7g	-	1.48b	11.0d	16.3e	-	- 44.0
3*	1.34a	14.6ae	19.6a	43.7a	1.43b	8.42b	12.1b	51.5b	31.7
4*	1.18c	15.6a	18.4a	47.0ab	1.40abe	8.68b	12.2b	51.1b	30.6
5*	1.21c	16.6a	20.1a	42.2a	1.36abe	10.8d	14.7c	41.0ac	34.8
6*	1.15d	22.0c	25.2d	27.5d	1.34ae	13.1e	17.6e	29.4de	42.8

*1= Uncultivated; 2= 0-5 years; 3= 5-10 years; 4= 10-15; 5= 15-20 years and 6= 20-25 years Means without the same letter are significantly different C_{satdef} = Carbon saturation deficit ∑stock= C stocks in 0-10 cm layer + C stocks in 10-20 cm layer

Table 2 Bulk density, C content and stocks for 0-10 and 10-20 cm layers under alleys.

No.	BD (Mgm^{-3}) 0-10 cm	OC (%) 0-10 cm	C Stocks (Mgha^{-1}) 0-10 cm	Csatdef (gkg^{-1}) 0-10 cm	BD (Mgm^{-3}) 10-20 cm	OC (%) 10-20 cm	C Stocks (Mgha^{-1}) 10-20 cm	Csatdef (gkg^{-1}) 10-20 cm	∑stocks (Mgha^{-1})
1*	1.36a	25.5e	34.7e	-	1.46b	15.2a	24.9f	-	59.6
2*	1.24c	22.3f	27.7g	-	1.48b	11.0d	16.3a	-	44.0
3*	1.36a	13.7a	18.6a	46.4c	1.49b	6.49b	9.65b	61.1b	28.3
4*	1.33a	14.3a	19.1ac	46.0ac	1.44c	6.83b	9.82b	60.5b	28.9
5*	1.28d	16.9c	21.5c	38.8a	1.51b	9.52d	14.4d	42.3a	35.9
6*	1.35a	13.0a	17.5a	49.3c	1.52b	8.68d	13.2d	46.9ac	30.7

*1= Uncultivated; 2= 0-5 years; 3= 5-10 years; 4= 10-15; 5= 15-20 years and 6= 20-25 years Means without the same letter are significantly different C_{satdef} = Carbon saturation deficit ∑stock= C stocks in 0-10 cm layer + C stocks in 10-20 cm layer

Carbon stocks in soils from uncultivated, prunnings and alleys followed a similar trend as C content. Under residue heaps significant improvements in C stocks in the top layer are discernible after 20 years but not in the alleys, even though the upper layer was significantly higher than the lower layer. In the 10-20 cm layer improvements in SOC are discernible after 15-20 years already both with and without heaps. The C stocks measured under pruned heaps for the 0-5 years was significantly higher than that for the 5-10 years. Beyond 10 years it decreased marginally at a rate of 1.22 % but increased by 8.46% for the 15-20 years and further by 20.24% to attain the 25.2 Mg C/ha observed under the 20-25 year group. When C stocks for both layers were summed up, it was observed that soils under prunnings had higher values than the alleys particularly for the 20-25 year group, giving a value of 59.6 Mg C/ha.

The Csatdef calculated increased initially up to 10 years and decreased gradually at 10.2 % until a further decrease of about 34.8% was observed for 20-25 years for the upper layer under pruned fronds. In the lower layer significant differences were observed among some age groups. The Csatdef in the 0-10 cm layer under alleys showed relatively higher values for the deficit. For the 10-20 cm layer very high values of about 61% were noted with the trend being similar to those of the upper layer within the alleys. The results of the present study seem to suggest that the soil under the prunnings for 20-25 years would require less organic matter for the 0-10 cm layer than those within the alleys to reach the OC level of the reference. The 20.3 % obtained for the 0-5 years has shown that although the soil lost some C due to removal of vegetation, decomposition of litter and in some cases burning, good management practices could restore such a soil to its equilibriumIt can be seen that the presence of pruned materials influenced C stocks in the upper layer of soils under prunnings compared to the same layer under alleys with significant differences. In addition to the annual increases in stocks under prunnings, some organic materials are still present on the farm at various stages of decomposition serving as a means to trap and hold C and other gases (released via decomposition).

CONCLUSIONS AND RECOMMENDATION

The Carbon saturation deficit (Csatdef) proved useful and could be used for future studies. Based on the Csatdef, the higher the index the more OC is needed to sequester C.

From sequestration point of view, materials with high C:N ratios (Brahene *et al.* 2015) are good since they would persist longer in soil and so contribute to C storage. Quantifying the effects of individual management practices such as prunning and heaping of fronds and their combinations on C sequestration is vital for improving the potential of oil palm farming systems to sequester C. The practical implications of this research would be to encourage prunning and heaping of palm fronds within rows of palm trees at well designated spots continually; an action which would not only return some nutrients to the soil but would with time contribute to C build-up in soils.

The study recommends further research into improvement in the decomposition of oil palm residue to enhance the fertility of the mineral soil.

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2.38 | MANURE APPLICATION INCREASED GRAIN YIELD AND SOIL ORGANIC CARBON ACROSS CHINA'S AGRICULTURAL LAND

Guiying Jiang[1], Wenju Zhang[1], Minggang Xu[1*], Jinzhou Wang[1], Daniel V. Murphy[2]

[1]National Engineering Laboratory for Improving Quality of Arable Land, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, PR China. Contact: Prof. Minggang Xu, Email: xuminggang@caas.cn; Tel: +8610-8210-5636

[2]Soil Biology and Molecular Ecology Group, School of Geography and Environmental Sciences, Institute of Agriculture, University of Western Australia, Crawley, Western Australia, 6009, Australia. Contact: daniel.murphy @uwa.edu.au

ABSTRACT

Application of manures to soil has declined globally due to increased availability of inorganic fertilizers; which have a key role in feeding the growing population. Here we used a combination of long-term field trial data (22-32 years, 20 sites) and both climate change and soil organic carbon (SOC) models to quantify the importance of manure application to grain yield and SOC sequestration across China's agricultural soils (122 M ha). During the past three decades inorganic fertilizers (37-450 kg N ha^{-1} yr^{-1}) have increased grain yield (91-183%) but with little contribution to SOC sequestration (4-17%). In contrast manure (2010 rates; 0.4-4.0 t C ha^{-1} yr^{-1}) when applied with inorganic fertilizer provided a small benefit to grain yield (6-19%) but doubled SOC sequestration (8-41%). Modelling to the end of this century predicted that an additional 0.23 t C ha^{-1} yr^{-1} can be derived from these levels of manure use (manure-C retention coefficient=10%) compared to 0.53 t C ha^{-1} yr^{-1} for inorganic fertilizer only; an average 43% more SOC is sequestered when inorganic fertilizer used in conjunction with manures. We conclude that the use of manures with inorganic fertilizers is essential for soil to maintain the dual functions of increased food production and SOC sequestration.

Keywords: Soil organic carbon sequestration, cropland, manure application, chemical fertilizers, Long-term fertilization, China

EXTENDED ABSTRACT

INTRODUCTION AND MAIN OBJECTIVES

China has 20% of the world population but only 8% of the total arable land and uses more inorganic fertilizer than any other country; accounting for 90% of the global increase in use and consuming 36% of total global production. Between 1980-2010 there was a six-fold increase in inorganic fertilizer use in China (with a co-incident rapid decline in manure application to agricultural land since 1997. While grain yields doubled over this period soil organic carbon (SOC) stocks only changed slightly; with a general decrease in arid/semi-arid regions and increase in humid/semi-humid regions. If China continues to maintain self-sufficiency in food production, then arable lands will need to increase productivity without causing loss of SOC and associated problems of soil degradation and greenhouse gas (GHG) emissions.

Soils in China account for 7 to 12% of the global SOC stock under arable production systems. This SOC stock reflects additions of organic waste to agricultural soils over a period of thousands of years aiding the stabilization of SOC. Use of inorganic fertilizers in the absence of organic amendments can cause losses of SOC with an associated increase in CO2 emissions and nutrient release. This is exemplified in the ancient Loessial soils in China where the decomposition rate of SOC was 21% faster when inorganic fertilizer is applied alone than with manure. As such, our aim was to quantify the contribution of manure application to gain crop yield and SOC sequestration in agricultural soils across China. This was achieved through use of climate and field trial data to measure long-term historical yield and SOC values and to use this date to calibrate climate change (Hadley Center Global Environmental Mode-Earth System, based on RCP4.5 scenario) and SOC models (Roth-C) to predict the future contribution of manure to SOC stocks by the end of the century.

METHODOLOGY

Field trial sites

Our study consisted of 20 long-term experimental trial sites (22-33 years duration) located across China on either upland soils (Wheat or Maize) or on paddy-upland rotation soils (Rice-Wheat rotation). The climate at these sites ranged from arid to semi-humid and from mild temperate to subtropical. Annual mean temperature ranged from 1.5°C in the northeast to 18.3 °C in the southern region, annual precipitation ranged from 131 mm in the northwest to 1653 mm in the southern region, and evaporation was 2-15 times greater than precipitation. Field trial sites represented the major arable land soil types and cropping systems (Since the soil types are complex, just descript in the text, no table to present) within the northeast (Black soil, Dark brown soil), northwest (Grey desert soil, Irrigated desert soil, Dark loessial soil, yellow loessal soil), North China Plain (Fluvo-aquic soil, Loess soil, Shajiang black meadow soil) and southern region (Red soil, Paddy soil, Yellow brown soil, Purple soil) of China.

Experimental design

Field trial treatments consisted of no fertilizer (Control), inorganic fertilizer only (nitrogen (N), phosphorus (P) or/and potassium (K), (NP or NPK), and manure (M) plus inorganic fertilizer (NPM or NPKM). A randomized design was used for all field trial sites (n=20 for field trial location, n=1–4 for within trial plot replicates).

Soil analysis

Composite soil samples (0–20 cm depth) were randomly collected from each plot using push-in soil cores (n=5–10 cores per composite; 5 cm in diameter) during September-October after harvest but before tillage, and then air dried before being sieved (<2 mm) prior to analysis. Soil pH was determined in water (soil:water = 1:1). Soil sub-samples were ground to 0.25 mm for measurements of SOC, total N, total P, and total K. Available N and K were measured following the method of Lu and available P (Olsen-P) by the method of Olsen.

Climate change scenarios

We have previously validated the climate change model for use in Chinese agroecosystems. (There are two climate condition were set: from start year to 2010, the climate parameters (monthly temperature, moisture, and evapotranspiration) used the observed data, from 2011-2099, (1) no climate change, used the average data during experiment of relevant sites; (2) climate change scenario, used the data from climate change model from Hadley Center Global Environmental Mode-Earth System based on RCP4.5 scenario (Representative Concentration Pathway (RCP) 4.5 is a scenario that stabilizes radioactive forcing at 4.5 W m^{-2} in the year 2100 without ever exceeding that value).

RothC model

We used the long-term experimental field trial data sets to validated the accuracy of the Rothamsted carbon (RothC) mode on the sub-set of field trial sites (n=10) where this had not been done previously. The RothC model was able to adequately simulate SOC dynamics in all treatment plots as modeled SOC values fitted well with the observed values during the experimental period. The coefficient of determination (R^2) between observed and modeled SOC contents was 0.92 ($P<0.001$) with a root-mean-square error (RMSE) of 9.71%. Modeled and observed SOC contents showed a declining trend in control plots at most sites. Where plots received inorganic fertilizer only (NP/NPK) modeled SOC values were at steady state or increased slightly, in but obviously increased in plots with organic manure (M, NPM or NPKM, NPM or NPKS). We then used weather files generated from the climate change model scenario as input files to the RothC model to enable future SOC predictions based on climate change.

Manure carbon input scenarios

Since RothC model does not contain the crop-sub model, for plant residues C input, from 2011 to 2099, NPP in NPK and NPKM plots set same as the average of the whole experimental periods. The carbon input scenarios were set as below: (A) under control and NPK plots, from experiment start to 2010, use the original carbon input scenario, from 2011 to 2099, set two C input scenarios: (i) plant residue and manure carbon input were the average one during the experimental period; (ii) plant residue carbon input were the average one during the experimental period and increase the manure C input (NPK+M).(B) Under NPKM plot, from experiment start to 2010, use the original carbon input scenario; from 2011 to 2100, set two C input scenarios: (i) plant residue and manure carbon input were the average one during the experimental period; (ii) plant residue carbon input were the average one during the experimental period and cease the manure C input (NPKM-M).

Statistical analysis

Analysis of variance (ANOVA) and the least-significant-difference (LSD) methods ($P < 0.05$) were applied to compare treatment and manure level on crop yield and SOC sequestration. All statistical analyses were conducted with the software SPSS version 20.0 and Origin profession version 8.5.

RESULTS

The effect of chemical and/or manure fertilizer effect on the grain yield and SOC content

Compared with the control plot, application of inorganic fertilizer with (NPKM) or without (NPK) manure significantly increased gain yield in single-, double-cropping and paddy-upland rotation systems. The manure component also caused a small but significant ($P<0.001$) increase in grain yield during the experimental period; NPKM minus NPK treatments had a mean 10.4, 21.4, 6.0% increase in potential yield in single-cropping, double-cropping and paddy-upland soils, respectively. In contrast to grain yield application of manure significantly increased the SOC in single- (31.1%) and double-cropping system (41.3%) in upland soil, but not in paddy-upland rotation system (7.7%). The interaction effect of chemical fertilizer and manure on SOC improvement in double-cropping system region was higher than that in single-cropping system area.

Maintaining and increasing SOC is a prominent strategy for mitigating atmospheric CO_2 and adapting agriculture to climate change. When applied in combination with inorganic fertilizer the manure component did not contribute appreciably to increased grain yield but caused a large increase in SOC. These findings highlight that a combination of both inorganic fertilizer and organic amendments is required to produce more food from the same available land whilst increasing SOC to enhance soil sustainability, especially in dry land cropping systems.

As expected the amount of C input required maintaining SOC level varied between agro-ecological regions and for cropping system. The amount of C input required to maintain the current SOC level decreased with the annual mean temperature, while there was little effect of annual mean precipitation and evapotranspiration. According to the relationship between SOC change rate and mean annual C input, we estimated the manure required to maintain the current SOC content at each site. The C input required to maintain existing SOC levels was: single-cropping 2.98 t C $ha^{-1}yr^{-1}$, double-cropping 1.01 t C $ha^{-1}yr^{-1}$, and paddy-upland rotation 2.22 t C $ha^{-1}yr^{-1}$. This equated to manure application rates of 17.1, 6.0, and 13.2 t ha^{-1} yr^{-1} in single-, double- and paddy-upland rotation cropping systems, respectively.

Current manure application rates are low (0.4 to 4.0 t C ha^{-1} yr^{-1}) and likely to remain the same unless government policy, focused on use of organic materials to improve soil fertility and GHGs mitigation reverse this trend. The Ministry of Agriculture of People Republic of China have established a new scheme to maintain total inorganic fertilizer use (zero increase) at current levels whilst increasing use of organic materials in agricultural system (i.e. increase the manure application to 40%, straw return to 40%).

The effect of manure application on carbon budget in agricultural system in China

Using current NPP, combined with the no climate change scenario, modelled SOC content to 2099 increased when manure was added with NPK (i.e. NPKM) in all sites; the relative increase of SOC content in 2099 varied from 26% to 150% in single-cropping system area, 39% to 140% in double-cropping system area, and 11% to 61% in paddy-upland rotation system area . It was similar results of the manure effect on SOC content under increased NPP combined with climate change scenario. We estimated that if add locational amount of manure under NPK plot from 2011, there will be 2089.54 Tg and 2493.97 Tg, which accounted for 37% and 27% of the relevant total NPKM SOC can be sequestrated from manure in 2099 under current NPP + no climate change and increased NPP + climate change scenarios, respectively. They were equaled 7661.63 and 9144.56 Tg CO_2 can be mitigated by manure application under these two scenarios in 2099. However, there will be 19584.92 and 19716.43 Tg CO_2 released from the manure application until 2099, which implied that there was 39% and 46% CO_2 released by manure can be sequestrated.

There was no significant relationship between mean annual temperature and precipitation on the annual SOC change during 2011-2099. However, the annual SOC change decreased exponentially with initial SOC concentration and clay content in upland soil and decreased linearly with initial SOC concentration in paddy-upland rotation system area.

In our study, the manure SOC efficiency was ca. 20-30% during the first 18 years (n=20 long-term sites) of field trials. As the capacity of the soil to sequester further C declines so does the manure-C retention coefficient. By 2099 the manure SOC efficiency was not significantly different between the two climate change scenarios and ranged between 8.8-10.3%. Depending on feed-stock and animal species the manure quality varies; material with low C/N ratio have a higher conversion rate to SOC. Here we show that cattle manure had a significantly ($P<0.05$) higher conversion efficiency to SOC that pig and horse manure. This is consistent global data and highlights the preference for cattle manure as a SOC sequestration strategy.

Conclusions

In this study, we qualified that manure when applied combination with inorganic fertilizer, there was little contribution to grain yield (12.6%), but contribute 27.1% to SOC. If we continue use manure with chemical fertilizer at current application rate, there will be increase SOC sequestration of 2493.97 Tg t C, and increase 43% compare to inorganic fertilizer only in the end of this century in arable land in China.

THEME 3

MANAGING SOC IN:

A) SOILS WITH HIGH SOC
(PEATLANDS, PERMAFROST AND BLACK SOILS);
B) GRASSLANDS AND LIVESTOCK PRODUCTION SYSTEMS;
AND
C) DRYLAND SOILS.

THEME 3.1 | MANAGING SOC IN SOILS WITH HIGH SOC (PEATLANDS, PERMAFROST, AND BLACK SOILS)

3.1.1 | PEAT SOIL CARBON MONITORING AND MANAGEMENT IN INDONESIA

Fahmuddin Agus, Maswar, Ratri Ariani, Anny Mulyani, Neneng L. Nurida, Fitri Widiastuti

[1]Indonesian Agency for Agricultural Research and Development, at Jl. Tentara Pelajar No. 12, Bogor 16114, Indonesia

ABSTRACT

Carbon (C) stock and emission of Indonesian peatland is greatly affected by land use change and land management systems. This research was aimed at estimating C stock, peat subsidence and C dynamics related to land use change and management systems. Soil C stock of the country's 14.9 million ha peatland is 24.5±11.2 Pg (mean ± stdev.) as estimated based on mean peat depth of 246±232 cm and C density of 0.057±0.026 g cm^{-3}. Site level peat C loss was monitored using peat subsidence data and the ratio of heterotrophic respiration : subsidence (H/S) of 40% for non compacted peat and 60% for compacted peat. Overall mean subsidence rate for our study's drained peat sites was 4.08±1.75 cm yr^{-1} and mean annual peat C loss was 10.39±3.2 Mg ha^{-1}. Using the IPCC (2014) emission factor default values, and historical land use change spatial data, annual C loss from Indonesia's peat decomposition was around 76.3 Tg in 2000-2003 and was gradually increasing overtime with the larger areas of peatland being drained, reaching about 101.5 Tg in 2013-2015. If the business as usual (BAU) land use change trajectories continues, annual peat C loss will reach 123.9 Tg in 2024-2033 period. Our mitigation scenarios, including no new large scale plantation development on peat and rewetting of degraded peat forests, could reduce up to 19% C loss from peat decomposition relative to the BAU level.

Keywords: Land use, subsidence, heterotrophic respiration, Mitigation scenarios

INTRODUCTION

Monitoring of peat carbon stock and carbon dynamics is important as a basis for developing sustainable use and management of peatland, managing climate-related hazards, and mitigating greenhouse gases emissions. Indonesia has the largest (14.9 Mha) tropical peatland area and several districts have more than 30% peat land relative to the total land area, giving them low flexibility, but to use peatland for livelihood. Therefore the high carbon (C) stock peatland is under high pressures for serving its dual functions: environmental quality protection and economic development.

Under the current social and economic circumstances, winning one function likely sacrifices the other function (Agus et al. 2016). This is because peat soil C is conserved under high water table in natural condition, whilst most of current economic crops produce satisfactorily under drained peat.

The government has launched several regulations for improving peat sustainability, including the suspension of new permits for peatland utilization and the formation of Peat Restoration Agency, mandated for restoring degraded peatland. With these new policies it seems reducing peat soil C loss is more promising. This research was aimed at evaluating the national peat C stock, drained peat subsidence rate, and assessing the rate of peat soil C loss at plot and national scales.

METHODOLOGY

Three main items related to C stock and C dynamics were evaluated in this research. These include estimates of: (i) National level C stock, (ii) Plot scale peat subsidence and C loss, and (iii) National level peat C loss over time.

(i) National level C stock

The national level peat C stock was estimated using the peat depth and area data based on peatland map by Ritung *et al*. (2011). The map divided peat depth classes into 50-100 cm, 100-200 cm, 200-400 cm and >400 cm and estimated total peatland area of Indonesia of 14.9 million ha. It is a refinement of the previous version maps of Wahyunto et al. (2003, 2004 and 2006), by inclusion of more soil survey data of peat distribution and depth and less reliance on satellite imageries. However, estimation of peat depth is more difficult for deep peat which are mostly located remotely around the centre of peat dome. Weighted average peat depth was calculated based on the mid-value of depth classes with the area of each class as the weighting factor. For the >400 cm depth, the average depth is arbitrarily assumed 800 cm, since in some places peat of >1000 cm deep are found.

Peat depth by area provides the peat volume. Peat C density was based on C density of hemic maturity peat of 0.057±0.026 g cm^{-3} as presented in Agus *et al*. (2011). C stock is the product of peat volume and C density.

(ii) Plot scale C loss monitoring

Closed chamber is the most common method for estimating greenhouse gas fluxes and, unlike the Eddy Covariance technique, it has a high flexibility to compare fluxes from different treatments and land cover types. However, soil CO_2 flux is often interfered by root respiration which lead to an over estimate of the true peat C loss through peat decomposition (heterotrophic respiration). Therefore, peat subsidence approach, in combination with the closed chamber and the root exclusion technique, is often used to minimize the effect of root (autotrophic) respiration (e.g. Wakhid *et al*. 2017).

For the current experiment, we have installed 33 pieces of subsidence poles of 6 cm diameter and various length steel pipes. One m top part protrudes above ground and the remaining length penetrates the peat and 1 m bottom penetrates the clay beneath peat layer. The poles were installed at different times starting in April 2012 to Sept. 2013 in Sumatra and Kalimantan on 497±186 cm deep peat. The peat has been drained for about nine years prior to Dec. 2016. Land uses observed with the subsidence poles included oil palm plantation, annual crop, rubber plantation, and shrub. Five poles were also installed in Timika, Papua in April 2014 under sago plantation, but monitoring is less frequent and the data are not presented in this paper.

With the subsidence measurement we have a high certainty of subsidence rate, but estimation of heterotrophic respiration/subsidence (H/S) ratio remains a source of uncertainty. Several values of H/S were introduced, ranging from 25% (Wahid *et al*. 2017), 40% and 60% (Couwenberg and Hooijer 2013), and around 92 (Hooijer et al. 2012). The higher ratios seem more appropriate for mature or compacted peat, while the lower ratios are for newly drained peat. In our case, with nine year period since the drainage systems installed, it seems the H/S ratio of 60% is appropriate for compacted peat such as under oil palm plantation which underwent compaction during land preparation because of use of heavy machineries. The C loss rate value obtained by using this H/S ratio had the closest proximity as those obtained from closed chamber technique. If the peat soil is not compacted during land preparation, the H/S ratio of 40% is more reliable.

Peat C density values were based on measurement of around 1800 samples from Sumatra and Kalimantan by Agus et al. (2011) which ranged from (g cm^{-3}) 0.082±0.035 for sapric maturity peat, 0.057±0.026 for hemic maturity peat and 0.046±0.025 for fibric maturity peat. The first 50 cm layer of peat at our research areas had the maturity closest to hemic and therefore C density of 0.057±0.026 g cm^{-3} was applied. Peat C loss (C_{loss}) through heterotrophic respiration was calculated by:

$$C_{loss} = Sub \times H/S \times C_{density} \times A$$

Where

Sub = Subsidence rate (m yr^{-1})
H/S = Ratio of heterotrophic respiration and subsidence rate (unitless or %)
$C_{density}$ = Carbon density (g cm^{-3} or Mg m^{-3})
A = Area, in this case 10,000 m^2 for estimating annual loss per ha.

(iii) National level peat C loss over time

For the national greenhouse gas inventory, we used the default emission factors of IPCC (Drösler *et al*. 2014). These default values were based on various research in Indonesia and Malaysia using closed chamber and subsidence techniques. As such, this could be assumed qualified for Tier 2 inventory in Indonesia. The IPCC default values were adapted for the 22 land cover types of Indonesia as explained by Agus (http://www.cifor.org/ipn-toolbox/tema-d/).

The activity data were generated from land use change trajectories analyzed from land cover spatial data of Landsat TM provided by the Ministry of Forestry. Sets of 20 x 22 land use change matrices with two to three year intervals from 2000 to 2015 and the projection of land use change beyond 2015 were used. Emission projection was based on the historical land use change of 2006-2015. Projected land use change matrices were generated by the LUMENS program (http://www.worldagroforestry.org/output/lumens). Additive scenarios for mitigation were based on the most rational assumptions taking into account the current national policies on peatland utilization. These include:

BAU = Business as usual, i.e. land use changes continue following the historical trend

Scenario 1 = No plantation expansion on peat primary and secondary forests.

Scenario 2 = Scenario 1 + no plantation expansion on degraded forests.

Scenario 3 = Scenario 2 and rewetting of 40% of remaining degraded forests in two future consecutive nine year periods.

Results

(i) National level C stock

Although in places we found peat with depth of >1000 cm, but the dominant peat depths were 50-100 and 100-200 cm, each shares about 30% of the total peatland area. Those with 200-400 cm depth represents 18%, while the ones with >400 cm depth is 20% of the total peatland area. The deep peat are distributed mainly in Riau, Jambi, and Central Kalimantan. With the above mentioned peat depth distribution we found the country level mean peat depth of 287±326 cm. Our calculation of total peat soil C stock is 24.5±11.2 Pg (mean ± stdev.).

(ii) Plot scale C loss monitoring

Table 1 shows that subsidence ranged from 2.49±0.19 cm yr^{-1} for peat under oil palm plantation in Jambi to 5.15±2.48 cm yr^{-1} for peat under shrub and traditional rubber plantation. The difference is attributable to compaction by buldozers during land preparation for oil palm plantation leading to slower rate of compaction and no such compaction under traditionally managed systems such as for rubber and annual crops or under degraded forests. The overall mean subsidence rate was 4.08±1.75 cm yr^{-1} and mean peat soil C loss due to heterotrophic respiration (decomposition) was 10.39±3.28 Mg $(ha.year)^{-1}$.

(iii) National level peat C loss over time

Agriculture, both large plantations and small scale farmings expanded relatively rapidly on peatland. Most of the current agricultural systems on peat are under drained condition. As long as the drained condition is maintained, expansion of drained agricultural areas translates to increasing rate of C loss from peat decomposition. Fig. 1 shows that C loss consistently increased from 76.3 Tg in the period of 2000-2003 to 101.5 Tg in 2013-2015. The projected C loss keeps increasing, reaching 123.9 Tg in 2024-2033 period under the business as usual (BAU) scenario. The proposed additive mitigation scenarios including no new permit (and hence no clearing and draining) for plantation expansion, and rewetting of part of degraded forests will lead to significant amount of mitigation, which is amounted up to 19% below the BAU level in 2024-2033 period.

Table 1: Peat subsidence rate and estimated carbon loss from heterotrophic respiration for different sites and land uses in Sumatra and Kalimantan

Sites and land uses	Time since drained	N	Peat depth	Subsidence rate	C loss
	(year)		(cm)	cm yr^{-1}	Mg C $(ha \cdot yr)^{-1}$
Rasau Jaya, W. Kalimantan; Annual crop rotation	6	5	379±18	4.71±1.26	10.74±2.86
Pelalawan, Riau; Oil palm	9	5	576±46	2.78±0.37	9.49±1.26
Pelalawan, Riau; Shrub, Rubber	9	6	608±49	5.15±2.48	11.75±5.64

Arang-arang, Jambi; Oil Palm	11	7	224±29	2.49±0.19	8.50±0.66
Jabiren, C. Kalimantan; Rubber	10	10	642±140	4.89±1.45	11.15±3.30
Mean	9	33	497±186	4.08±1.75	10.39±3.28

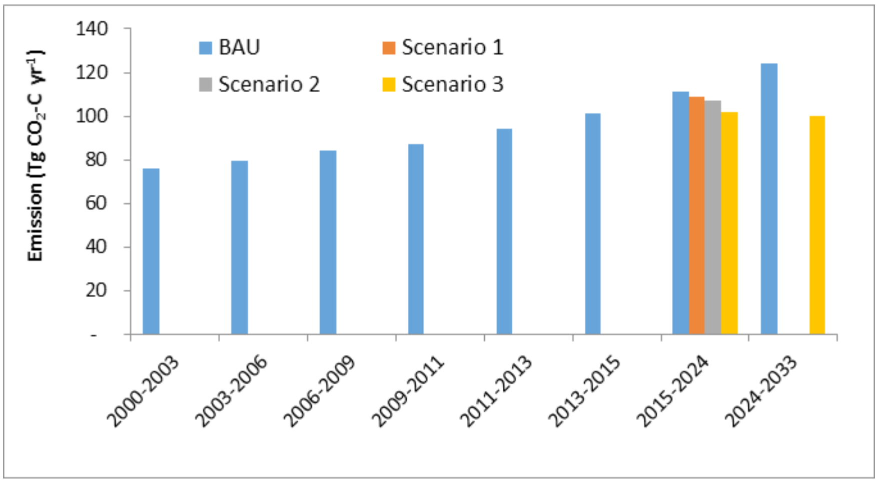

Fig. 1: Annual historical and projected peat carbon loss through CO_2 emissions from soil respiration by time period under the business as usual (BAU) scenario, Scenario 1 (no plantation expansion on peat primary and secondary forests), Scenario 2 (Scenario 1 and no plantation expansion on degraded forests, and Scenario 3 (Scenario 2 and rewetting of 40% of remaining degraded forests in two future consecutive nine year periods)

DISCUSSION

With the total C stock of 24.5±11.2 Pg, each ha of peat has an average of around 1640±750 Mg C; a figure about eight times the amount of aboveground C stock of primary forests (Agus *et al*. 2013). Being a very labile C, when peat forest is drained, the stored C has a high potential to contribute to the national greenhouse gas figure.

Drained peat subsides at a high rate shortly after the drainage system is installed. The mean rate of subsidence under this study was 4.08±1.75 cm yr^{-1}. With time the subsidence tend to decrease (Couwenberg and Hooijer 2013). Assuming the subsidence rate of 4.08±1.75 cm yr^{-1} sustains, one cycle of plantation which is typically 20 years, will undergo the total subsidence of 80 cm. This will have implication to the vulnerability of the land to inundation. At the same time, this also leads to high carbon losses as our data shows in Table 1 and Figure 1. The subsidence will continue until the peat reaches the undrainable level; i.e. when its surface elevation is similar to that of the average water surface elevation of the controlling river .

Several mitigation scenarios, including raising of water table, banning the use of peatland for agriculture, and rewetting the degraded peatland, theoretically plausible. However, the implementation remains challenging as, under the current economic and agronomic systems, most of high value and high market demand crops are suitable under drained systems. For the land owners, conserving carbon without economic compensation will be impossible. Therefore alternative undrained or also called paludiculture systems will only be plausible after the discovery of suitable and economically competitive crops for such systems , or else compensation should be provided to the land holders for conserving carbon.

CONCLUSIONS

The unstable peat carbon needs to be conserved by conserving the remaining forests and raising water table in existing agricultural lands. Rewetting of degraded peatlands is expected to reduce peat carbon loss significantly. However, the success of voluntary rewetting depends on the availability of economically attractive and high market demand crops suitable for undrained (paludiculture) system.

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3.1.2 | DISTRIBUTION OF TROPICAL PEATLAND TYPES, THEIR LOCATING AND CURRENT DEGRADATION STATUS

Alexandra Barthelmes*[1]& Cosima Tegetmeyer[1]

[1] Greifswald Mire Centre, c/o Greifswald University, Germany (contact: alex.barthelmes@greifswaldmoor.de)

ABSTRACT

Peatlands of the Tropics are highly diverse and occur from the coast to alpine altitudes. Natural tropical peatlands are covered by peat swamp forests, wet grasslands, *Papyrus* reeds, mangroves, salt-marshes, and specific high altitude afro-alpine or páramo vegetation. The total area of tropical peatland is estimated to be 30-45 million ha (10-12% of the total global peatland resource). It constitutes one of the largest near-surface pools of terrestrial organic carbon (Sorensen 1993).
Although the exact extent of peatlands in large and partially remote areas is unclear (e.g. western Amazon Basin, Pantanal, Congo Basin, Sudd, Okavango Delta, Ganges Delta), a wealth of information is available to locate the majority of peatlands across the Tropics (cf. Barthelmes *et al*. 2015). We present an overview of tropical peatland types and their distribution based on ecoregions and geospatial data collated in the Global Peatland Database.
The current degradation status of tropical peatlands is addressed in case studies from East Africa, the Ganges Delta and the Guyana shield. Furthermore, we highlight regions where vast areas of undisturbed tropical peatlands (may) occur, and that need protection against land reclamation that involves drainage (e.g. Congo Basin, Zambia floodplains, western Amazon Basin, coastal lowlands of Papua New Guinea).

Keywords: Tropics, peatland types and distribution, peatland mapping, organic soil, utilization pressure, drainage

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Peatlands have become increasingly recognized as a vital part of the world's wetland resources. Peatlands are wetlands where permanently waterlogged conditions prevent the complete decomposition of dead plant material. In peatlands thick layers of carbon rich peat has accumulated over thousands of years which make them to the most space-effective stocks of organic carbon on the planet.
Deforestation and drainage of peatlands stop their ability to sequester carbon and lead to the emission of huge amounts of greenhouse gases (e.g. Hooijer *et al*. 2012). Especially in the tropics, the rising global demand for food, biofuels (e.g. palm oil) and raw materials triggers the development and drainage of peatlands. Overall, an urgent need exists to identify the location of peatlands, to protect them against drainage for decrease greenhouse gas emissions and to prevent peat fires.
Until now, there is no satisfactory pantropical or continental geospatial data on peatland types, their location or distribution available. Therefore, the pantropical inventory of peatlands still depends on the aggregation of existing and new elaborated local, regional and national data.
During the last decades a tremendous amount of regionally or punctual research studies, expedition reports, governmental and NGO information and datasets on peatlands have been elaborated and are increasingly available electronically. A first global overview on peatland extent has been presented by Joosten *et al*. (2009[1]). We now provide a rough geospatial overview of peatland types, their distribution and drainage status across the tropics.

METHODS

We compiled this geospatial overview of tropical peatland types, their distribution and drainage status based on comprehensive information on peatland and landscape ecology, and integrated very different datasets. We mainly used:
1) the global map of 'terrestrial ecoregions'[2],

2) the 'worldwide bioclimatic classification system - Ombrotypes' (1996-2017),

1 https://www.wetlands.org/publications/the-global-peatland-co2-picture/
2 http://maps.tnc.org/files/metadata/TerrEcos.xml

3) the ‘tropical and subtropical histosol distribution’[3] (SWAMP 2016),

4) ‘a new map of standardized terrestrial ecosystems for Africa’ (Sayre *et al*. 2013), and

5) various geospatial data on distribution of peatlands, histosols and organic soils collated in the Global Peatland Database[4].

Moreover, we integrated own geospatial data elaborated in framework of the Global Peatland Database.
Recognizing the vast diversity of definitions and terms for peatlands, we considered all available data that fit into the broad IPCC concept of ‘organic soils’ with 12 percent or more organic soil carbon without a depth criterion (cf. IPCC 2014). This automatically includes all peatlands, histosols, and most other organic soils, and moreover allows the integration of historically grown national or regional datasets.
To roughly estimate the drainage and degradation status of peatland areas we used the ‘global 1-km consensus land cover’ (Tuanmu & Jetz 2014) and the map on the ‘world land stress – anthropic’ from the ‘Plant and soil sciences eLibrary of the university Nebraska[5]. Since the major threat to peatlands is drainage, we furthermore visually assessed the drainage system using available aerial and satellite imagery.

RESULTS

We found that, as everywhere in the World, peat is deposited in the tropics under long-term water saturation of the soil in areas with frequent and excessive rainfall (e.g. in humid tropics) or areas where large amounts of water is available (e.g. in coastal environments), where water is flowing together (e.g. depressions, floodplains), or under cold and humid climates that inhibit the decay of organic matter (e.g. in montane and alpine environments). Natural tropical peatlands are covered by peat swamp forests, palms, wet grasslands, *Papyrus* reeds, mangroves, and specific high altitude afro-alpine or páramo vegetation (Fig. 1). Peat swamp forests of South East Asia prevailed in the public and scientific perception of tropical peatlands during the last two decades. But forested peatlands also cover large areas in the western Amazonas basin, and the Congo Basin, and occur at the West African coast (e.g. in Ghana and Ivory Coast; Asante & Jengre 2012, cf. Barthelmes *et al*. 2015) and in South Africa. Whereas many African peat swamp forests are undrained and not heavily logged so far, the peat rich ‘Sundarbans freshwater swamp forest’ ecoregion in the Ganges delta seem to be completely extinct. Recently increased logging activities in Papua New Guinea may endanger the peatlands of the ‘Southern New Guinea freshwater forest’ ecoregion in next years too.

3 https://data.cifor.org/dataset.xhtml?persistentId=doi:10.17528/CIFOR/DATA.00029

4 http://www.greifswaldmoor.de/global-peatland-database-en.html

5 https://passel.unl.edu/pages/

Fig. # Natural vegetation on tropical organic soils: 1-Papyrus dominated (Okavango Basin, Botswana); 2-grassy vegetation (Kenya); 3-Peat Swamp Forest (Malaysia); 4, 5-grassy vegetation (Uganda and Kenya); 6 - high altitude afro-alpine vegetation (Uganda); 6 - high altitude grassy vegetation (Peru).
(photos: Hans Joosten & Alexandra Barthelmes)

Peatlands in flooded grasslands are widely spread are across the tropics. For example the 'Zambezian flooded grassland' ecoregion that includes e.g. large peatland areas as the Okavango delta (Botswana), and in the Barotse floodplain, the Lukanga and Bangweulu swamps in Zambia. Most of these areas are still undrained or seem to be used only for subsistence agriculture without deep and intensive drainage. Comparable flooded grassland peatlands occur in the 'Sahara flooded grassland' ecoregion (incl. vast *Papyrus* dominated peatlands in the Nile floodplain – the Sudd, in the 'Pantanal' ecoregion (Brazil, Bolivia, Paraguay), and in the 'Humid Chaco region' (Argentina, Paraguay, Brazil). The overall human impact (drainage and

agriculture) seem to be higher in South America than in the African flooded grasslands.
Another distribution center of tropical peatlands are high altitude peatlands that prevail e.g. in the ‘Paramos’ and ‘Wet Puna’ ecoregion in South America, on several East African mountains (e.g. Mount Kilimanjaro, Mount Meru, Mount Ruwenzori, Mount Kenya, the Bale Mountains = ‘alto-tropical moorlands’, cf. Bussmann 2006), and in the ‘New Guinea central mountains’ ecoregion in Papua New Guinea. Degradation hotspot of peat filled mountain valleys on the uplifted flanks of the East African Rift (Lake Victoria region) are Burundi (91% of all peatlands drained), Kenya (45%), and Rwanda (46%), respectively.
Peatlands and organic soils are widespread along the coasts of the humid tropics, e.g. in South America (Guiana shield, Orinoco delta, southern Brazil), in Africa (West Africa, Mozambique, East coast of Madagascar), and Asia (Indonesia, Malaysia, Papua New Guinea, Bangladesh, Sri Lanka). They basically can be divided in peat swamp forests (see above), inter-dune valley bottom peatlands, delta and lagoon peatlands and mangroves of organic soil. Especially in SE Asia, East Africa and southern Brazil these coastal peatlands are widely under drained land use.

DISCUSSION

It is often emphasized that the knowledge especially on tropical peatlands outside SE Asia is rare, and comprehensive, accurate and up-to-date GIS data and remote sensing models are not available.
However, if considering different scientific disciplines, different languages, and different kinds of data, as well as indicative proxy and legacy data, there is a tremendous amount of information available. We used them to roughly deduce the location and distribution of tropical peatlands. The disadvantage of this method is, that this diverse data cannot be easily harmonized and processed automatically, and partly remain expert judgement.
This compilation aims to introduce wide spread tropical peatland types and the range of datasets that can be used to locate and describe them, e.g. for awareness rising, nature protection, or as starting point for high resolution mapping. We focused on geospatial data on ecoregions, bio- geographical or freshwater regions that are nowadays increasingly at available global and continental scale. Unfortunately, their zonation is often based on forest distribution pattern or huge freshwater basins, which makes them not fully operational considering often small and azonal distributed peatlands. Available national and regional datasets on ecoregions, landscapes, bio-geographical regions or vegetation might be used to derive higher resolution coverage on peatland types, and to determine their characteristics, variability and vulnerability to human or climate change disturbance.
We would like to point out, that although the exact extent of peatlands in large and partially remote areas is unclear (e.g. western Amazon Basin, Pantanal, Congo Basin, Sudd, Okavango Delta, Ganges Delta), a wealth of information is available to locate the majority of peatlands across the tropics with reasonable effort and sufficient results e.g. for biodiversity assessments, for developing sustainable land use options or nature protection strategies.

CONCLUSIONS

Considering the tropics as a whole, the current knowledge level is sufficient to identify important countries or regions is terms of peatland occurrence, typology, biodiversity and degradation as starting points for comprehensive peatland inventories for different purposes.
On a national level, for various countries large uncertainties on peatland locations exist. However, for hardly any country lacking knowledge is the bottleneck for starting inventory, assessment and setting monitoring baselines, certainly when the vast range of suitable and already available data is adequately located, provided and integrated.

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3.1.3 | MANAGING OF KARST PEATLAND USE AND POTENTIAL REHABILITATION IN DINARIC REGION

Hamid Čustović[1*], Melisa Ljuša[2], Tomaž Prus[3]

[1][University of Sarajevo, Faculty of Agricultural and Food Sciences, custovic.hamid@gmail.com, +387 33 225 727]
[2][University of Sarajevo, Faculty of Agricultural and Food Sciences, melisa.ljusa@gmail.com]
[3][University of Ljubljana, Biotechnical Faculty, Tomaz.Prus@bf.uni-lj.si]

ABSTRACT

Peatland and wetland sustainable management is one of very important ecological, economical and social issue in the entire Dinaric karst area. As all ecosystems also peatland are exploited to satisfy human needs. In peatlands special relations between water, plants and peat are in force and that makes them very vulnerable. Functions of peatlands exceed plant and raw material production, they important filtering and sink functions as well as many other nonmaterial functions. While their recovering after peat extraction cannot be regarded as a renewable resource and several conventions include statements of their protection.
In this paper some of the suitable measures for the peatland management in the karst field Livanjsko polje (field) in Dinaric Region of Bosnia and Herzegovina (B&H) will be presented and discussed. Livanjsko polje is the largest karst field in B&H, and one of the largest in the world. As of 2008 the field is inscribed in the Ramsar List of Wetlands of International Importance.
Keywords: *karst peatland, peat degradation, peatland rehabilitation,* wetlands*, bogs, fens*

INTRODUCTION

Peatlands are a specific type of wetlands where a substantial accumulation of partially decayed plant remains form peat layers. Peatlands in Russia extend over 57 million of hectares, in Finland almost 9 million, Sweden 6.7, Belarus and Ukraine 3.4, Norway 3, Baltic states 2.2, Poland 1.2 and Ireland 1.3. Only 5% of listed areas in those states are used for peat extraction and more than 60% of the areas are still in natural condition where the peat grows about 0.5 to 1 mm per year.
Rather than bog, karst peat formation corresponds to fen type of wetland which is characterized by an impermeable layer which holds in summer season water table in a level which still enables the fen vegetation to grow. Karst peatlands belong either to permanent wetlands either to seasonal wetlands. This depends on hydrological conditions and water drainage system. Drainage is either natural through sinkholes or artificial through trenches, ditches and canals.
In recent time peatlands acquire interest because of their environmental function as a carbon sink and/or source. Peatlands forms only 3% of the world land area their degradation equal 7% of all fossil fuel carbon dioxide emissions (Boreal Peatland Ecosystems, 2006, Springer). In the context of climatic change certain types of peatlands can become a source of methane and NO_x as well.
Peatlands ecosystems contain disproportionately more organic carbon then other terrestrial ecosystems. While covering only 3% of the World's land area, peatland contain at least 550 Gt of carbon in their peat. This is equivalent to 30% of all global soil carbon, 75% of all atmospheric carbon, equal to all terrestrial biomass, and twice the carbon stock in the forest biomass of the world. This makes peatlands the top long-term carbon store in the terrestrial biosphere (UNDP, 2007).
Peatlands used in agriculture and forestry are less threatened, but peat excavation, water drainage and fire are very serious threats for their existence.
Agricultural use of peatlands usually turns the upper peat layer to muck. Mineralization of peat, which simultaneously accompanies the muck formation, decomposes organic carbon compounds which became strong source of carbon dioxide. Water drainage can lead to similar processes of peat disintegration and muck formation when peat dries out and the surface rewets again even if there is no mechanical influence. Hydrophobic phenomena can occur as well when rewetting starts again and the result is subsiding of the peat layers above ground water table.
Fire heath destroys organisms and ashes can change the ecological characteristics of peat as a growing media of wetland plants.
From the review of available information sources it is very clear that peatlands protection is a worldwide accepted policy statement. At the moment this seems to be a political priority and there are many examples of reclamation, restoration and

rehabilitation projects. General goal of those projects is maintaining biodiversity (Rydin and Sundberg, 2001; Middleton et al., 2006; Stammel et al., 2003; Wheler et al., 2002; Johnson and Valppu, 2003 and many others), preventing greenhouse gasses emissions from peatlands, restoration of peatlands function as a sink of carbon dioxide.
The decisions on management priorities vary of course very much from country to country and depend on environmental, social and economic circumstances of the county.
In B&H there is an outstanding natural phenomenon 46,000 hectares large karst field called Livanjsko polje (Livno field). Since half of its area is regularly flooded, Livno field is actually a combination of wetlands and peatlands and meadows.
Due to presence of carbonates, peatlands of Livanjsko polje belong to extremely rich (peat forming) fen to calcareous tufa-forming fen (Hayek et al., 2006).
Peatlands of karst fields are very fragile. There are actually two separated peatland areas Jagme and Ždralovac. Both are highly degraded. Degradation of Jagme peatland is caused due (too) extensive ameliorations and consequently peat fires. Ždralovac peatland is physically degraded due to peat extraction. Extraction is possible at a lower groundwater table, so peat is dried over the summer time as well. Peat fires have consequently acted as degradation agents in that area too.

METHODOLOGY

Considering the importance of Livanjsko polje, sustainable use as well as its protection, research has been conducted within the UNDP project "Mainstreaming Karst Peatlands Conservation into Key Economic Sectors" (KARST, 2007) in order to identify the problem or the key process responsible for the observed changes in the components of the ecosystem and its functioning.

In respect of local conditions the active excavation field Ždralovac is taken into consideration. Three groups of processes has been identified as follows: biological, hydrological and chemical. Appropriate technical measures have been proposed and discussed. Further different principal management strategies for restorations, namely peat excavation area, burned peat areas and of degraded peat due to ameliorations are described.

RESULTS AND DISCUSSION

Total surface of the active excavation field Ždralovac is 3,615 ha. The present management of hydrological conditions is leading to irreversible changes of phytocoenoses of the area. The abiotic parameters of environment have been severely changed due to peat fires as minerals from the ashes influence the chemical properties. At the moment at least fragments of primary vegetation cover exist and enable a seed bank for future rehabilitation. The term fragment is used because, as it can be seen from Picture 1., Ždralovac peatland is physically untouched due to excavation only in about a half of the area and even for that no available data exist about fire damages.

Figure 1 Peatland natural conditions and excavation area tables, UNDP, 2013

Figure 2 Peatland before processing and packing, H., Čustović, 2012

There are several disturbances that have led to a reduction in scope of function of the Ždralovac peatland ecological system:

- Extraction of peat with the purpose of processing it into the substrate for growing plants;
- Ignition of peatlands;
- Drainage of peatlands due to the construction of drainage canal for its exploitation which caused a reduction in the level of groundwater and consequently increased mineralization, subsidence of peat and change of natural vegetation.

Identified processes can be divided into three groups:

- Biological: extraction of peat, succession of vegetation following the ignition of peat;
- Hydrological: reduction in groundwater levels and shift in wetland vegetation on peatlands; enhanced mineralization of peat; drying up of peat prior to fire outbreaks; changes in the physical properties of peat (compaction, subsidence, occurrence of cracks);
- Chemical: changes in water quality; decomposition of peat.

The exploitation of peat at the site of Ždralovac is unplanned. During the mechanical extraction of peat, thickness of the remaining layer is left uneven and in some places reduced to parent substrate. In most cases the entire layer of peat, down to the parent substrate, is removed without leaving a possibility of re-vegetation or restoration of wetlands vegetation such as reed and sedges. This could account for just a sporadic emergence of reed in the first few years after the exploitation, i.e. link this phenomenon with thickness of the left layer of peat.
An important condition for the renewal of exploitation basins after the extraction of peat is leaving a 20-50 cm thick layer of peat at the bottom of the basin which is in line with good practice of exploitation of this type of peat and which allows spontaneous regeneration of reeds.

However, intensification of drainage caused by the construction of a drainage canal in the area of peatlands Ždralovac has led to a general reduction in groundwater levels and creation of conditions conducive to the succession of wetland vegetation by woody plant species. Draining of peatlands also prolongs dry period and drying up of peat thus increasing peat bog fire hazard. After the fire outbreak comes the accelerated succession of vegetation and the emergence of shrub-like and forest vegetation which suppresses reed. The succession of vegetation is then followed by increased intake of water by woody plants which further reduces the groundwater levels. It has to be noted that this process is first and foremost associated with altered hydrological regime and lowering of groundwater levels as well as with the fact that these species could not emerge in wetland conditions. Therefore, solving the problem of changes in the hydrological regime of peatlands would solve this problem as well.
Following all mentioned above, the first recommendation is to quit the peat excavation as soon as possible. It would be worth to try to invalidate the concession contract.
In case the peat excavation continues severe technical measures to protect the preserved peatlands and to reestablish the conditions for peat formation should be applied:

- At excavation area water tight cassettes should be constructed for keeping the water table of not excavated fields as high as possible. The water pumped necessary for excavation should be returned on the field and not in drainage system.

- Drainage ditches of the area, which not necessary for water runoff from excavation fields, should be closed as much as possible. Many materials are used for that purpose around the world so this measure is not costly at all.

Construction of water barriers are very different. For a concrete area a feasibility study is recommended where the locality of barriers should be defined, their number and construction properties. Generally this should be very low cost measure.
A nursery for reed saplings production from rhizomes should be established. From the excavated fields only rare plant stalks are growing on the natural way and the recovery of the dominant plant species is slow. After the excavating the peat the concessionaire should replant the reed saplings.
Reed replanting should be experimentally tested also on the burned peat areas. A minor experimental field should be established as soon as possible.
The water integral management is a crucial political and professional task. The water needs do not exist only for electricity production, but also the essential needs of natural habitats and agriculture should be fulfilled. There is even not possible to establish a natural friendly land use management system if the water management system stays one-sided.

CONCLUSIONS

Livanjsko polje is one of the largest karst field in the world in which there is more than 10,000 ha of peatland. The devastation of peatland in Livanjsko polje, in particular in Ždralovac location (3,615 ha north-west) which is a subject of the research, is mainly due to excavation of peatland. This area is covered with peat layers more than 2 meters thick. Damage is caused by the construction and operation of drainage channels built to facilitate the peat extraction.
Also, in the same area the devastation is partly due to the construction of melioration channels in its southeastern part, where the peatland has been converted into agricultural land.
A large part of the peatland gets completely drained during dry periods of year. Therefore, the restoration of the groundwater regime has to be implemented in order to avoid further degradation of the peatland and the loss of biodiversity, especially in case of fire.
In the context of the climate change mitigation the water holding capacity of Livanjsko polje soils and sediments should be raised generally (not only in the way of new retentions) as well as the capacity for carbon dioxide sink. A management of raising the amount of organic matter in soils should be established.

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3.1.4 | THE POTENTIAL OF RESPONSIBLE PEATLAND MANAGEMENT TO REDUCE GLOBAL SOIL CARBON LOSS AND GREENHOUSE GAS EMISSIONS

Chris Evans*[1], Sue Page[2], Ross Morrison[3], Rebekka Artz[4], Lahiru Wijedasa[5]

[1]Centre for Ecology and Hydrology, Bangor, LL57 2UW, UK. cev@ceh.ac.uk
[2]Department of Geography, University of Leicester, University Road, Leicester LE1 7RH, UK.
[3]Centre for Ecology and Hydrology, Wallingford, OX10 8BB, UK.
[4]James Hutton Institute, Aberdeen, UK
[5]Department of Biological Sciences, National University of Singapore, Singapore.

ABSTRACT

Peatlands represent the largest single global store of soil carbon. Despite providing a natural long-term CO_2 sink, drainage and conversion to agricultural and silivicultural management of peatlands has converted them into large net contributors to global greenhouse gas (GHG) emissions (~2.5% of all anthropogenic emissions, primarily from Europe and SE Asia). Drainage-based agriculture on peatlands is intrinsically unsustainable, causing oxidative loss of soil organic matter and land-subsidence, which ultimately reduce or negate their value for agriculture. Returning all drained peatlands to their natural wetland function could make a substantial contribution to reducing global GHG emissions, but socio-economic factors – namely the high realisable income from drained agricultural peatlands, intensifying demand for land in regions with growing populations, and lack of adequate financial incentives for conserving or restoring natural peatlands – make such an outcome unlikely in the short to medium term. We therefore consider the potential climate mitigation benefits of the adoption of an interim move towards 'responsible peatland management', which seeks to minimise GHG emissions from areas under ongoing agricultural use via the implementation of higher water level management strategies and alternative crops. We also discuss the possibility to create 'future carbon sinks' by restoring degraded agricultural peatlands to peat-forming systems.

Keywords: Peatlands, responsible management, water table, greenhouse gas emissions, methane

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Peatlands occupy around 4 million hectares of the earth's surface, and hold around one third of all soil carbon. Under natural conditions they can sequester CO_2 continually over millennia, thus having a net cooling impact on the global climate. However, the drainage-based utilisation of peatlands for agriculture, biomass production and peat extraction has converted peatlands into a major source of global anthropogenic CO_2 emissions. This process, which began centuries ago in Europe but accelerated with the onset of pumped drainage in the 20th century, is now increasingly widespread in other parts of the world, notably in the extensive peatlands of Southeast Asia where drained organic soils support economically important crops such as oil palm and Acacia pulpwood plantations. The drainage and cultivation of organic soils was estimated in the last IPCC assessment report (Ciais et al., 2013) to be producing around 0.9 Gt of CO_2 emissions per year from peat oxidation alone, which equates to ~2.5% of *all* anthropogenic CO_2 emissions. Along with this climate impact, oxidation and compaction of drained peat also lead to land subsidence, and eventual wastage of the peat, which increases energy costs for pumped drainage, exacerbates flood risk in low-lying coastal landscapes, and ultimately threatens the long-term viability of agricultural activity in peatland areas. Nevertheless, in the short-term agriculture on organic soils is highly profitable, supporting high-value horticulture and arable agriculture in many areas of Europe, and supporting economic and livelihood development for millions of people in countries such as Indonesia, Malaysia and Papua New Guinea.

Despite some attempts to portray drainage-based peatland agriculture as sustainable, most key peatland actors, including governments and plantation companies, now recognise that this activity is inherently unsustainable (Wijedasa et al, 2016a,b). Furthermore, the growing recognition that conserving peat soil carbon is important not only for the climate but also for the long-term agricultural and economic viability of peatland landscapes presents opportunities for governments, industry and academia to work together towards a mutually beneficial outcome. Attaining such an outcome does, however, require either financial mechanisms to adequately recompense individuals and countries for conserving and restoring peatlands to their natural condition, or the development of land-use practices that support the agricultural use of peatlands under conditions that do not require drainage. The concept of 'paludiculture' (productive wetland agriculture on peatlands) has been developed and demonstrated at the small scale, but as yet the comparatively low economic returns mean that it is difficult for such practices to 'compete' with conventional drainage-based agriculture, either in Europe or in SE Asia. Consequently, we consider whether there may be potential for significant emission reductions through interim measures aimed at mitigating GHG emissions from peatlands under conventional agricultural use. This approach, which has been termed 'responsible peatland agriculture (Clark & Rieley, 2010; Wijedasa et al., 2016a) may not halt emissions from peatlands, but could substantially reduce current emission rates while longer-term solutions are sought. However, such an approach requires a robust evidence base, to enable effective (and scientifically defensible) land-management practices to be put in place. Here, we describe the results of a major UK research programme, which seeks to quantify the controls on GHG emissions from agriculturally managed peatlands, and to identify potential options for emissions mitigation. These results are placed within a wider context of international land-use emissions reporting and global peatland emissions, and used to estimate that likely scale of global GHG emissions reductions that might be achieved via a more towards responsible peatland management.

METHODOLOGY

We describe the results of a UK government-funded three-year integrated programme of GHG and carbon (C) flux measurements at 15 UK peatland sites, ranging from conservation-managed wetland systems to highly modified grassland, cropland and peat extraction sites (for full details, see Evans et al., 2017). Flux towers, static chambers, waterborne carbon and biomass offtake measurements were used to construct full C budgets, and site characteristics including peat depth and chemical properties (C and N content, pH, bulk density), hydrology (water input-output budgets, mean water table depth) and meteorology were also measured. Flux data were analysed against measured site characteristics in order to identify dominant controls on GHG emissions, and results were then evaluated against a wide range of published flux tower-based measurements from temperate and boreal peatland sites. We also used these and other flux data, together with spatial data on peat condition, to develop and apply an IPCC 'Tier 2' approach to estimate the magnitude and sources of peatland GHG emissions at a national level. The identified relationships between peat GHG emissions and controlling factors were combined with the recent IPCC estimate of total GHG emissions from organic soils under cropland and grassland (Ciais et al., 2013) in order to generate an indicative estimate of the magnitude of emissions reduction that could be achieved through altered peatland management.

RESULTS

The UK study sites ranged from strong net CO_2 sinks under wetland conservation management (~5 t CO_2 ha^{-1} yr^{-1}) to major net emission sources (25-30 t CO_2 ha^{-1} yr^{-1}) under cropland. Emissions were very strongly related to mean water table depth (WTD, Figure 1), with no other measured site variable providing significant additional explanation of observed fluxes. Methane fluxes were high at the wetland sites (~4 t CO_2 ha^{-1} yr^{-1} based on a 100 year GWP) but near-zero when WTD was lower than 25 cm. Emission data derived from our data broadly conform to the IPCC's Tier 1 emission factors (IPCC, 2013) but indicate that it is the WTD associated with a land-use activity, rather than the activity per se, that determines emissions. Comparing our results to those obtained from other published flux tower studies suggests that WTD can account for the majority of all variability in peatland CO_2 balance. Other work in both high-latitude and tropical peatlands (Couwenberg et al, 2011) suggests that such relationships are essentially global.

Taking the combined UK/international dataset shown in Figure 1, we were able to simply estimate the reduction in CO_2 emissions that could be achieved by raising mean WTD from 80 cm (a typical value for both temperate and tropical croplands) to 25 cm, for the 250,000 km^2 of cultivated organic soils identified by Ciais et al. According to this analysis, CO_2 emissions could be expected to decline from 25 to 4 t CO_2 ha^{-1} yr^{-1}, equivalent to a reduction in global CO_2 emissions of 0.66 Gt CO_2 yr^{-1}. Since CH_4 fluxes are negligible at WTD > 25 cm, there would be little or no offsetting increase in CH_4 emissions.

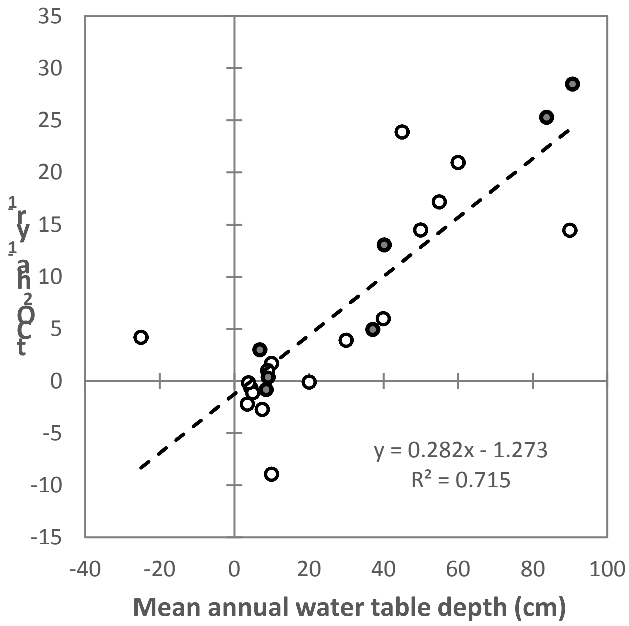

Fig. 1: Observed net CO_2 balance versus mean water table depth for temperate and boreal peatland sites with flux tower data. Filled circles: This study (Evans et al., 2017); Open circles: Other published data.

DISCUSSION AND CONCLUSIONS

Our analysis confirms the overriding importance of water table depth in controlling the C and GHG balance of managed peatlands. Whilst our extrapolation of CO_2 balance data to the global area of cultivated organic soils is inevitably uncertain, it seems clear that there is major potential to reduce global GHG emissions – perhaps by as much as 2%. Whilst this falls short of the cessation of all peatland emissions (and return to net CO_2 sequestration) that could be achieved by full re-wetting and restoration of cultivated organic soils, nevertheless we estimate that perhaps 80% of current emissions could be halted by responsible peatland management practices, whilst continuing to permit economically productive use of these socio-economically important areas. Our results present a challenge to agronomists and the agricultural industry to develop crops, cultivars and management practices that enable economic yields and food security to be maintained under higher water table conditions. For example, it may be possible to maintain biomass and crop yields under shallower water tables if the nutrients supplied through peat oxidation can be replaced by alternative fertilizer sources, without giving rise to large N_2O emissions. Whilst the development of such methods will require the investment of time and resources, and whilst they would still fall short of true sustainability, we argue that responsible peatland management has the potential to make a quantitatively significant, and realistically achievable, contribution to reducing global anthropogenic GHG emissions and rates of soil carbon loss.

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3.1.5 | QUANTIFYING TERRESTRIAL ECOSYSTEM CARBON STOCKS FOR FUTURE GHG MITIGATION, SUSTAINABLE LAND-USE PLANNING AND ADAPTATION TO CLIMATE CHANGE IN THE QUÉBEC PROVINCE, CANADA

Michelle Garneau*, Simon van Bellen

Geotop research center and Département de géographie, Université du Québec à Montréal, Montréal, Québec, Canada. garneau.michelle@uqam.ca

ABSTRACT

Organic carbon (C) stocks have accumulated in boreal peatlands and forest soils since the early Holocene (< 10,000 years BP), actively removing CO_2 from the atmosphere and creating a net cooling effect on global climate over this period. Based on various databases, C stocks of terrestrial ecosystems in the boreal and Arctic biomes of the Quebec province were quantified as part of an evaluation of their capacity to mitigate anthropogenic greenhouse gas (GHG) emissions and estimate their vulnerability with respect to recent climate change and land use changes. The results of this project are contributing to the establishment of the Strategy for Climate Change Adaptation as well as the 2013-2020 Climate Change Action Plan of the Québec Ministry of Environment, which aim to adapt the Quebec society to the effects of climate change and the reduction of GHG emissions. Results show that mean C density in peatlands is 85.5 kg C m^{-2} and decreases with latitude. Mean forest soil C density is 11.7 kg C m^{-2}, of which 57% stored in mineral horizons and 43% in organic horizons. The total boreal Québec peatland and forest soil C stock is quantified at 14.1 Gt, of which 56% is stored in peatlands. Per surface unit, peatlands store seven to eight times more C than forest soils. These ecosystems are less affected by disturbance than forests, hence they deserve particular consideration in conservation policies. In 2013, total anthropogenic emissions in Québec attained 82.6 Mt CO_2-equivalent. The total boreal peatland and soil C stock thus represents about 627 years of anthropogenic emissions at their current rate. Future GHG mitigation policies and sustainable land-use planning should be supported by an increase in investments in peatland, wetland and forest conservation, management and rehabilitation to limit greenhouse gas emissions. Quebec is the first province in Canada that initiated such quantification.

Keywords: boreal, carbon, peatland, forest, soil, ecosystem, Canada

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Organic matter is accumulated in terrestrial ecosystem soils as long as litter production exceeds heterotrophic decomposition. Organic carbon (C) stocks have accumulated in boreal peatlands and forest soils since the early Holocene, actively removing CO_2 from the atmosphere and creating a net global climatic cooling effect over this period. These ecosystems thus have the potential to mitigate anthropogenic greenhouse gas (GHG) emissions but they are also vulnerable to recent climate and land use changes. Here we present the boreal Québec C stock and its spatial distribution obtained using databases of ecosystem type and inventories of C density (kg C m^{-2}). The results of this project are contributing to the establishment of the Strategy for Climate Change Adaptation as well as the 2013-2020 Climate Change Action Plan of the Québec Ministère du Développement durable, Environnement et Lutte contre les changements climatiques (MDDELCC), which aim to adapt the Québec society to the effects of climate change and the reduction of GHG emissions.

METHODOLOGY

Peatlands

A database of 30 deep peat cores was used for multiple regression analysis on six climate-related variables (Garneau *et al.*, 2014; Turunen *et al.*, 2004; Gorham *et al.*, 2003). These variables included mean annual temperature, number of growing-degree days above 0°C, growing-season precipitation, annual precipitation, growing-season average shortwave radiation and growing-season cumulative shortwave radiation. As deep, central peat cores tend to overestimate C density at the scale of the peatland (van Bellen *et al*., 2011), a correction was applied based on an empirical equation. The obtained relationship between C density and selected climate variables was applied to an adapted database of peatland areas from the MDDELCC (Bissonnette and Lavoie, 2015). The total C stock per *natural region* was defined by the product of its mean C density and the total peatland area of each region. The *natural region* classification corresponds to the ecological framework (*CERQ*) of the MDDELCC.

Forest stands

Two databases were used to quantify soil C density (kg C m^{-2}). In the southern part of the boreal biome quantifications were based on a model created from soil survey data (Tremblay *et al*., 2002). For the northern part, data were limited to the inventory from Natural Resources Canada (Siltanen *et al*., 1997). Both C density databases included separate quantification of organic and mineral horizons. Total C stocks were quantified using the spatial database from the MDDELCC.

RESULTS

Peatlands

- C density (kg C m^{-2}) is positively correlated with growing-season cumulative shortwave radiation and precipitation in Québec.
- A model was created with growing-season cumulative shortwave radiation and total precipitation during the growing season as predictors for C density ($r^2 = 0.55$).
- Mean boreal peatland C density is 85.5 kg C m^{-2} and decreases with latitude. This trend is explained by shorter growing seasons in the northernmost regions, with limited biomass productivity. Peatland C stocks are concentrated in the central-western part of the province, south of James Bay, because large areas of peatlands have developed here (Fig. 1).
- Total boreal peatland area is estimated at 92,500 km^2.
- The best peatland C stock estimate is 7.9 Gt C, with a 95% confidence interval of 5.6 to 10.6 Gt C.

Forest stands

- Southern boreal forest stands cover 416,800 km^2 with a mean soil C density of 11.7 kg C m^{-2}, of which 57% is stored in mineral horizons and 43% in organic horizons.
- Northern boreal forests cover 139,700 km^2 with an average C density of 9.4 kg C m^{-2}, of which 59% is stored in the mineral horizons.
- The total boreal forest soil C stock is 6.2 Gt C, of which 4.9 Gt C is contained in the southern boreal forests and 1.3 Gt C in the northern latitudes. The major part of the forest stand soil C stock is located in the southern and eastern regions.
- Mineral horizon C stock is highest in the eastern and southern parts of the province, while organic horizon C stock generally increase with latitude and the presence of closed black spruce stands, with an optimum around 51ºN (Fig. 2).

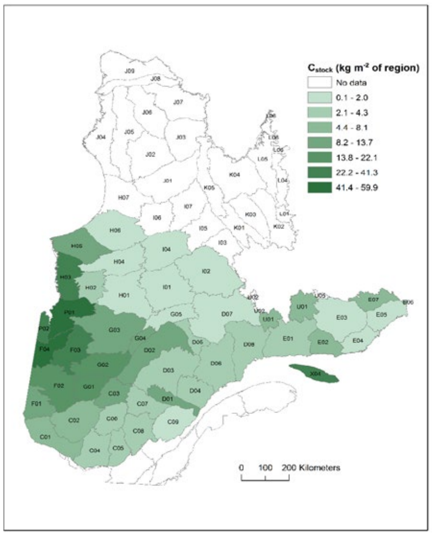

Figure 1: Spatial pattern in peatland C stock, represented by the total peatland C stock per natural region (sensu MDDELCC), divided by its total surface area.

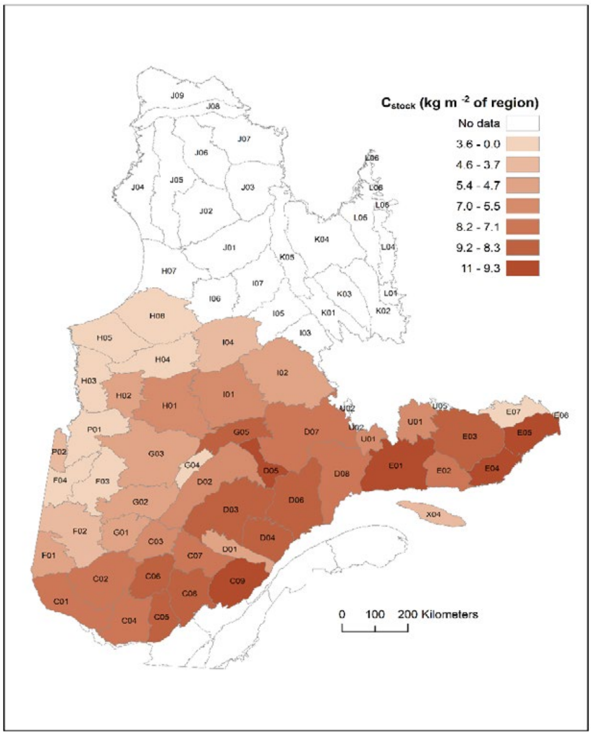

Figure 2: Spatial pattern in total forest soil C stock, represented by the C stock per natural region (sensu MDDELCC), divided by its total surface area.

DISCUSSION

Our quantifications of C stocks show that C density is on average seven to eight times higher in peatlands (85.5 kg C m^{-2}) than in forest soils (11.1 kg C m^{-2}) in boreal Quebec. Climate projections for 2041-2070 by Consortium Ouranos (www.ouranos.ca) suggest warmer and more humid conditions than present in the northern part of the boreal region, but warmer and drier conditions in the southern part (Mearns *et al*., 2009). These trends are likely to affect the evolution of boreal C stocks:

- Increasing summer soil water deficit in southern boreal peatlands may decrease C sequestration because of an increase in decomposition.
- In the northern part of the boreal biome, warmer and more humid conditions may benefit C sequestration, due to longer growing seasons and higher plant productivity.

- Forest stands south of 51°N may risk more frequent burning and larger fires, yet migration of less flammable hardwoods to these regions may attenuate these trends (Terrier *et al*., 2013). C in mineral horizons is relatively immobile, but organic horizons C stocks may be affected by a higher summer water deficit.
- Lower average forest stand age, resulting from more frequent burning, will imply lower total C stocks.

CONCLUSIONS

As stated by IPCC (2013), future GHG mitigation policies and sustainable land-use planning should be supported by more scientific data on terrestrial ecosystem C stocks. The total boreal Québec peatland and soil C stock is quantified at 14.1 Gt, of which 56% is stored in peatlands. Per surface unit, peatlands store seven to eight times more C than forest soils. They are less affected by disturbance than forests, hence they deserve particular consideration in conservation policies. In 2013, total anthropogenic emissions in Québec attained 82.6 Mt CO_2-equivalent (Environment Canada, 2015). The total boreal peatland and soil C stock thus represents about 627 years of anthropogenic emissions at their current rate.

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3.1.6 | RE-WETTING DRAINED PEATLANDS CAN POTENTIALLY REDUCE LARGE GREENHOUSE GAS EMISSIONS

Hongxing He[1*], Åsa Kasimir[1]

[1]Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden; E-mail: hongxing.he@gu.se

ABSTRACT

Drained peatlands are hot spots for GHG emissions, which could be mitigated by rewetting and land use change. We performed an ecological analysis of rewetting drained fertile peatlands in a hemiboreal climate by different land use strategies over 80 years. Vegetation, soil processes and total GHG emissions were modeled using the CoupModel for four scenarios: 1) business as usual – Norway spruce with average groundwater level of -40 cm; 2) willow with groundwater at -20 cm; 3) reed canary grass with groundwater at -10 cm; and 4) a fully rewetted wetland. The predictions were based on previous model calibrations with a number of high resolution datasets consisting of water, heat, carbon and nitrogen cycling. The modelled long term spruce biomass was validated by measured onsite tree ring data. Scenario 1 resulted in a total soil emission (including stored peat depletion $CO_2 + N_2O + CH_4$) of 13.8 Mg CO_2eq ha^{-1} yr^{-1}, and compared with this the scenarios 2, 3 and 4 reduced emissions by 25%, 44% and 7%, respectively. Draining also increases vegetation growth but not as steep change as the GHG emissions increase. We conclude that raising the water table for fertile drained peat soils could significantly reduce GHG emissions. This needs to be considered for land use planning and policy-making.

Keywords: Norway Spruce, Willow, Reed Canary Grass, Wetland, Ground water level, CO_2, CH_4, N_2O

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The land-use sector 'Agriculture Forestry and Other Land Use (AFOLU)' contributes 24% of annual anthropogenic greenhouse gas (GHG) emissions. Of these, one quarter comes from drained peatlands, mainly in the boreal and tropical regions. The Swedish National Inventory Reporting to the UN climate convention (UNFCCC) shows drained peatlands to have emissions about 10 Tg CO_2eq yr^{-1}, almost as high as the road traffic, 17 Tg CO_2eq yr^{-1}.

Several factors have been found to influence the size of the emissions, including the groundwater level, land use intensity, climate zones, and soil fertility. In general, nutrient rich fens with deep groundwater level are larger GHG sources than ombrotrophic bogs with shallow groundwater level, while intensive land use in tropical and/or temperate regions have much higher emissions than extensive land use in boreal regions. For policy introduction it is a need to show potential of emission reductions and other ecosystem gains for a number of rewetting options. Since soil wetness is known as a decisive factor for GHG emissions, from a local management perspective re-wetting drained fertile peatlands is thus a promising mitigation strategy. The central questions were: 1) what is the best possible land use of drained peatlands? and 2) which vegetation type and soil wetness are preferable for low GHG emissions?

METHODOLOGY

We used the CoupModel for analyzing four land use scenarios associated with rewetting fertile drained peatland in hemiboreal climate. Four scenarios were developed, from moderately drained (i.e. groundwater level at around 1) -40 cm, 2) -20 cm, 3) -10 cm into 4) wet soil (i.e. a water level in the soil surface, 0 cm). Since willow and reed canary grass are known to cope wetter conditions better than spruce these were selected as vegetation for scenario 2 and 3 respectively.

The data used for model forcing, parameterization, calibration and validation was obtained from the Skogaryd research catchment (http://gvc.gu.se/english/research/skogaryd), located in the southwest of Sweden (58°23′ N, 12°09′ E), which now has a managed Norway spruce (*Picea abies*) forest 66 years of age. The site has drained fertile peat soil earlier used for agriculture from 1870s until 1951. The ecosystem model CoupModel (available at www.coupmodel.com) was used to simulate the scenarios. First the model was calibrated using high resolution datasets (2007-2009) consisting of net radiation, soil surface heat flow, soil temperature, soil water content, groundwater level, net ecosystem exchange and N_2O emissions

(He et al., 2016a). Modelled long term (1951-2011) spruce biomass prediction was validated by measured onsite tree ring data. The calibrated spruce scenario was used as a base for generating the other scenario simulations (He et al., 2016b). Parameters describing the willow, reed canary grass and wetland characteristics and management regimes are not calibrated against real measured data on this site but are compiled from previous CoupModel applications made elsewhere. For scenario comparison the simulation period was 80 years for all scenarios, which includes a full forest rotation period. Model sensitivities were conducted by varying the groundwater level by ±20 cm, ±10 cm and ±5cm for scenario 1, 2 and 3 respectively.

RESULTS

Over 80 years the simulated annual average aboveground biomass production was for spruce, willow, reed canary grass and wetland: 10.4, 10.0, 11.7 and 4.0 respectively, expressed as Mg CO_2 ha^{-1} yr^{-1} (Fig. 1). The results show the peat to disappear for the first three drained land use options by 11.5, 4.7, 1.1 Mg CO_2 ha^{-1} yr^{-1}, but accumulate by 1.2 Mg CO_2 ha^{-1} yr^{-1} for the wetland scenario (Fig. 1). Simulated N_2O emissions were 2.5, 1.0, 0.2 and 0 also expressed as Mg CO_2 ha^{-1} yr^{-1} for the four scenarios. For CH_4 emissions the spruce scenario had a soil uptake of 0.2 Mg CO_2 ha^{-1} yr^{-1} while the willow, reed canary grass and wetland scenarios emitted methane in the size of 4.6, 6.4 and 14.1 expressed as Mg CO_2 ha^{-1} yr^{-1} respectively (Fig. 2). The total soil GHG emissions for these four scenarios were: 13.8, 10.3, 7.7 and 12.9 Mg CO_2 ha^{-1} yr^{-1}. The results show that when groundwater level is deep CO_2 dominates the emission, and when wet CH_4 (Fig. 2). The relationship between N_2O and the groundwater level is not as clear as for the other gases but for the wetter scenarios N_2O emission was overall low. When adding all three GHG's together the tendency of higher emissions by deeper groundwater level prevails, however high emissions was found for the scenario 4 when the water level was in the soil surface, since this resulted in high CH_4 emissions (Fig. 2).

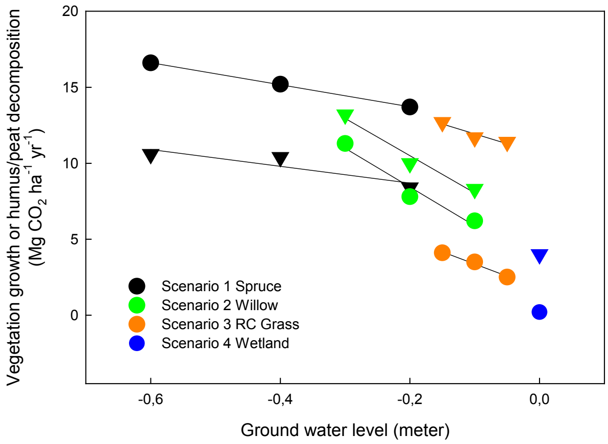

Fig. 1: Sensitivity of mean aboveground biomass growth and peat decomposition to the groundwater level. (▼) Vegetation growth and (●) peat decomposition. Vegetation for the scenarios are; 1) spruce, 2) willow, 3) reed canary grass and 4) wetland mosses.

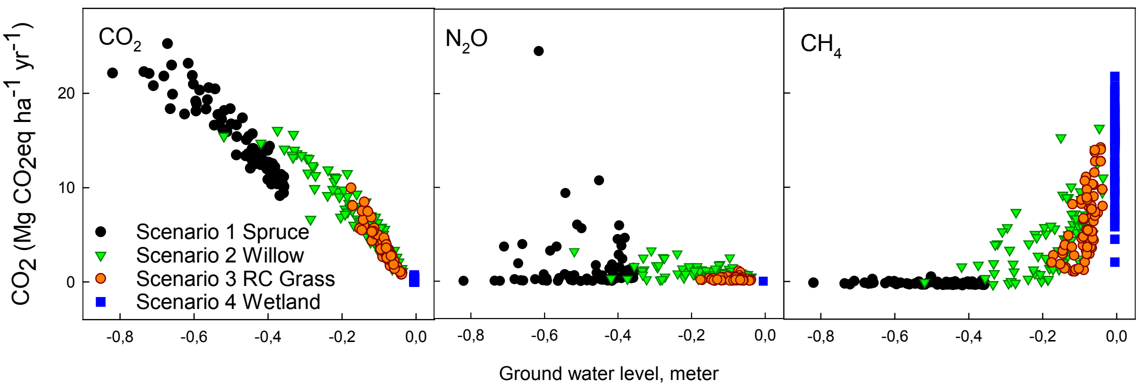

Fig. 2: Annual mean soil flux of CO_2 due to peat decomposition, N_2O and CH_4 for the four scenarios with 1) spruce, 2) willow, 3) reed canary grass and 4) wetland mosses, related to annual mean groundwater level over 80 years.

DISCUSSION

While most of the biomass produced over a century is recycled into CO_2 the peat soil emissions adds GHG into the atmosphere which is distinctive from producing biomass on a mineral soil. Here we found the soil emissions of the scenario with water at -10 cm and reed canary grass to have the least GHG emissions, followed by willow, wetland, and where the spruce forest scenario was the worst with largest soil emissions.

If also including the vegetation growth for a full GHG balance scenarios 2, 3 and 4 resulted in losses of 6.7, 7.0 and 7.2 Mg CO_2eq ha^{-1} yr^{-1} over the 80 years while the losses for the scenario 1 with spruce was lower, 5.5 Mg CO_2eq ha^{-1} yr^{-1} due to not including the final clear cut. After the harvest roots left in the soil will decay with a half-life of 19 years and of the harvested timber we assume 40% used as high quality timber and the rest (60%) as paper or fuel wood, which according to by IPCC guidelines have half-life of 'Harvested Wood Products' 30 years and 2 years respectively. Then it takes only ten more years after spruce harvest for this scenario to show a double loss, 10.9 Mg CO_2eq ha^{-1} yr^{-1}. The harvested willow and reed canary grass are all assumed to be incinerated for bioenergy purpose thus the carbon is released back to atmosphere quickly. It is also possible to consider avoidance of GHG by replacement of products otherwise causing high emissions, like concrete and fossil fuel use. However in a world where we want to avoid further warming we conclude biomass production on peat soils to be harmful for the atmosphere. We must keep the soil carbon in the ground, where peat soils are especially vulnerable for decomposition due to draining. How to best avoid GHG emissions needs more studies, including other plants and management options.

CONCLUSIONS

Compared to a business as usual spruce production on drained peat soil our examples show wetter conditions to mitigate soil emissions. Rewetting the drained peat soils need policy introduction and land use planning for actions reducing GHG emissions.

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3.1.7 | WATER MIGRATION OF SOIL ORGANIC CARBON IN SOILS AND LANDSCAPES IN HUMID FORESTS OF MIDDLE TAIGA (ARKHANGELSK REGION, RUSSIAN FEDERATION).

*German Kust[1], Olga Andreeva[2]

[1]Moscow Lomonosov State University, Dept. of soil erosion and conservation. 119991. Russia. gkust@yandex.com

[2]Moscow Lomonosov State University, Dept. of agroinformatics; Russia. andreevala@yandex.ru

ABSTRACT

The aim of the study was to pay particular attention to the high migration potential of the organic carbon (OC) originated from soils in middle and northern taiga. Only part of the organic carbon of the soil origin is fixed directly in the soil, under certain conditions (in the litter or at the calcareous geochemical barrier), and most of the OC migrate almost unchanged from the lateral runoff into local streams. Thus, the OC of the initially soil origin subsequently redistributes within the watershed by lateral and surface runoff. This makes important to consider the soils of taiga not only as one of the carbon sink, but also as an generator of the OC carrying out and reallocating with river waters. Approximate number of OC actively migrating when filtering through soil profile and then by surface flow to the local water catchments is not less than 400 kg/Ha annually for the study area.

Keywords: soil organic carbon, soluble carbon, soil carbon migration

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

What is the Soil Organic Carbon? It is usually being considered as carbon content in organic horizons of the topsoil accumulated during soil formation due to the processes of humification of the bioorganic residuals of plants (such as tree waste) and soil biota. It is believed that the soil of natural ecosystems may serve as one of the main long-term deposits of carbon sinks, and the carbon content in the soil can be judged on their role in the carbon balance of the related ecosystems. It involves many carbon balance models considering the organic carbon content in the soil in-situ as one of the key components of this balance. However, not all of the soil organic matter (SOM) of soil origin accumulates and/or mineralizes directly in soils. It has long been observed that a significant part of SOM is water-soluble and migrate beyond the soil profile with streams. This forms the distinctive brown color of the surface waters, not only in lentic swamps and lakes, but also in running lakes, rivers and streams. Major chromophores of these waters are usually compounds of organic carbon and iron. The rivers and lakes of the humid landscapes can contain up to 100 mg/l of OC of the type of soil humic acids. In this case waters acquire the color of strong tea (e.g. in West Siberia and Amazon areas).

Some scientists consider that in podzolic soils about 35% of SOM, formed in the forest litter is driven out of the soil profile, and that it is podzolic soils in middle taiga subzone with the most favorable conditions for the mobilization of the SOM and its abiogenic migration.

In this study we aimed to assess how and what quantities of the water-soluble SOM get from the soil into water bodies, and how meaningful are the quantitative conversion of the OC concentration in the waters within local watershed.

METHODOLOGY

We studied the waters sampled in the Kenozero lake area in the Arkhangelsk region of Russia located in between $61^0 57'$ - $61^0 57'$ N, and $38^0 05'$ - $38^0 35'$ W (fig.1).

The surface deposits of the area vary of sedimentary and crystalline origin. The rocks of different ages and composition

from acidic to basic, from the Archean to Fat Kalinin glaciation come to the surface. The depth of Quaternary deposits varies from 0 to 3 meters on carbon plateau and up to 186 meters in the depression of Kenozero lake.
The soil cover is represented by combinations of podzolic soils and podzols (including residual-calcareous), acid and leached brown soils, and peat soils. The forests consist mainly of mixed pine and spruce forests with an admixture of birch and aspen. The hydrography includes more than 300 lakes of mainly glacial origin, with the exception of the biggest Kenozero lake itself. The chemical composition of the surface waters varies from soft (mainly atmospheric and snow-fed) to hard (ground power supply), and rarely alkaline (on calcareous rocks and sediments).

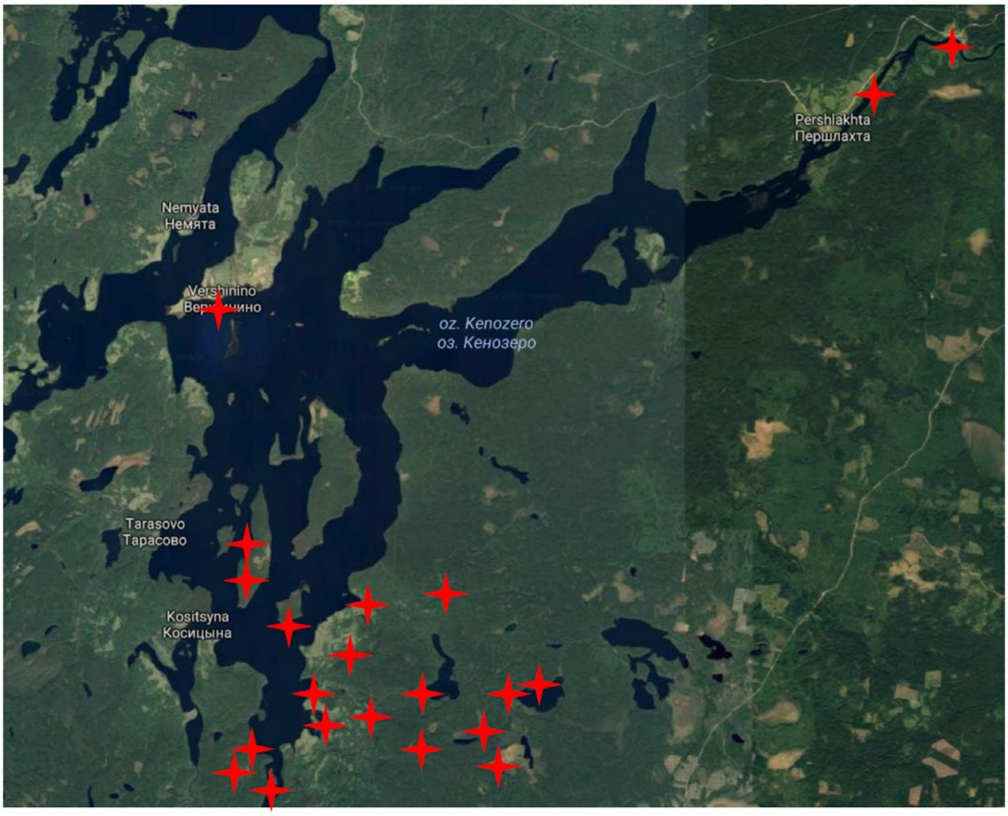

Fig. 1: Location of the testing sites and collecting soil and water samples (based on the Google Earth space imagery scene).

More than 50 water samples were selected and studied from the following sources:

- Soil solution (pressed out) from the surface organic horizons (peat, litter);

- Subsurface water (taken from the vadose or lysimetric vessels installed at 30-40 cm below the illuvial horizon (in the upper part of the horizon C);

- The waters of the surface runoff: streams and small rivers flowing into the Kenozero lake; samples were taken at least 3 times along the stream: near basic soil pits where soil water samples were collected, in the middle reaches, and at the mouth);

- Lake and swamp water: samples were taken close to the shoreline (no more 20 m) at a depth of 1 m to eliminate the influence of precipitation;

- Kena river water flowing out of the Kenozero lake.

Sampling was carried out in July, when the average monthly air temperature of + 17^0C.

1 liter of water was taken for each sample and stored in dark glass bottles, conserved with a few drops of toluene. The total organic carbon (TOC) content were tested in the samples filtered through the “blue ribbon” filter (pore diameter = 2-3 micron) to dispose hard and flaky particles. A part of samples were also filtered through membrane filter (pore diameter < 0.45 micron) to determine the content of dissolved organic carbon (DOC).
Samples were concentrated on the bain-marie to the volumes of 20 ml. The OC content was estimated by the wet oxidation method (Tyurin method with the spectrophotometric end).

RESULTS

The TOC content of the mineral topsoil varies from 0.9 to 2.0% (in litter and peat horizons it reaches 40-50%), abruptly decreasing down the profile. Sometimes an additional maximum of the TOC content (0.3-0.5%) is noticable in the illuvial horizon.
The maximum TOC content was discovered in the soil solutions of pressed from the forest litter, with no relation to the extent of its decomposition, and also in peat: the concentration vary from 180 to 320 mg/l. In the peat maximum values are typical for lowland non-draining locations and relatively low pH values (up to 4.5). For those closely underlined by calcareous rocks and sediments, and pH of the solutions of higher than 5, the TOC concentration in pressed solutions falls sharply (to 30-40 mg/l or less).

The TOC in the samples of lysimetric and vadose waters retain remarkable constancy irrespective of the location of the sampling points and vary in the narrow limits between 94 and 110 mg/l. (The exception is the water samples collected from the damaged ecosystems - in forest cutting and burnt areas. Here, the TOC reaches 150-180 mg/l.) The same range of concentrations as in the lysimetric waters in undisturbed ecosystems is maintained throughout the course of streams and rivers, up to their outfalls in the Kenozero lake, and in the lake itself: from 95 to 107 mg / l. Exceptions are the locations (small lakes and bogs) with the bed underlined by close calcareous rocks and moraines. Here, the TOC concentration falls sometimes to the vanishingly small values. Accordingly, a relatively small TOC content observed in the water sampled at the sources of streams and rivers flowing from such reservoirs, as well as those cutting through calcareous sediments. The water of the Kena river, flowing out of the Kenozero lake, have a lower TOC concentration of about 80 mg/l at the outlet, and less than 70 mg/l downstream.

The DOC concentration in relevant samples is considerably low. In Kenozero lake the DOC content is about 40 mg/l; in vadose and lysimetric water samples it ranges from 10 to 45 mg/l, шт streams and small rivers vary from 7 to 35 mg/l. The reason for such large fluctuations of DOC concentrations in comparison with relatively stable concentrations of TOC in the same samples remains unclear, and probably should be concerned with the peculiarities of biochemical processes in soil and water, and with the formation of different ferro-organic complexes in different conditions.

DISCUSSION

These results clearly highlight several groups of water containing organic matter originated from soil:
A. Water with a OC content up to several hundred milligrams per liter. This group includes the water extracted from the forest litter, and the OC concentration in them hardly reflects soil differences associated with the location/formation on the calcareous rocks. We consider this describe the high independence of the soil forming processes in the topsoil from the chemical composition of underlying rocks in humid climate. All water samples have intensive brown color ("strong black tea").
B. OC content values close to 100$\pm$10 mg/l. This is the largest group among the samples studied, including the water of the Kenozero lake, of streams and small rivers, whose catchment area is confined to non-calcareous rocks, as well as all of the samples of soil vadose. It is also easy to see from the data obtained that the OC concentration in the vadose and lysimetric water hardly reflects differences in parent material. All samples are transparent and have a light brown-yellow color.
C. Water with the OC concentration substantially less than 100 mg/l. This group includes surface water of valley and transition peat bogs serving as a local catchment for landscapes and soils located in the watershed containing calcareous rocks and sediments. These samples are colored from light yellow to yellow.
D. Water with negligible OC content. This group is represented by the samples taken from lakes and some bogs formed on the bed of calcareous rocks and sediments. It includes also the water of streams cutting calcareous moraine and fluvioglacial deposits. These waters are transparent and almost non-colored.
The results obtained describe the following ways of the migration of water-transportable SOM in the test region.
The main source of water-transportable SOM is the forest litter usually overmoistured and having maximum activity of microbiota. The water of the soil vadose (which is the hallmark of the most of the local soils formed on the sediments with binary texture: light sandy loams and loamy sands underlying by heavy loams and clays) and samples from lysimetric pans has less concentration of SOM (about 100 mg/l of TOC). These organic substances can be considered as the most capable for migration. Our study justified that in the absence of geochemical barriers to migration routes of water-transportable SOM, the TOC concentration remains unchanged along all the way from the soil vadose through surface flows until the water entering

the final lake catchment of the area.
Accounting the amount of precipitation in the study area during the season of active biochemical conversion of plant residues by soil microorganisms, a first approximation can be given to calculate the amount of SOM runoff into local catchments, and further to the world ocean. When the amount of precipitation is about 400 mm, falling from May to September, we should expect the removal of at least 40 g TOC from each square meter, which is equivalent to 400 kg/ha of soil organic matter annually.

CONCLUSIONS

1. Differences in parent rocks and differences in soil location in topography hardly affect the content of OC in the water of forest litter and in vadose. In the study area the OC content in litter water is on the average from 200 to 300 mg/l, and in vadose it is 100±10 mg/l.
2. Differences in the parent rocks chemical composition have a significant impact on the further migration of SOM. The water of lakes and bogs formed in the bed of calcareous rocks and sediments contain vanishingly small amounts of OC. Carcareous rocks and sediments also reduce its concentration in the streams' water. This manifests in the presence of illuvial-humus horizons in soil profile and humus covers and films on the surface of soil peds, and on the faces of chalky and dolomite minerals. If non-calcareous rocks dominating in the catchment area, then the differences in the content of OC in the waters of soil vadose and surface flowing streams and small rivers are not detected.
3. Soils are the main source of organic matter actively migrating when filtering through soil profile and then by surface flows to the local water catchments. Approximate number of TOC is not less than 400 kg/Ha annually for the study area.

3.1.8 | EFFECTS OF A RAISED WATER TABLE ON CO_2 AND CH_4 SOIL EMISSIONS AND CELERY YIELD FROM AGRICULTURAL PEAT UNDER CLIMATE WARMING CONDITIONS

Magdalena Matysek*[1], Donatella Zona[2], Jonathan Leake[3], Steve Banwart[4]

[1]University of Sheffield, mjmatysek1@sheffield.ac.uk
[2]University of Sheffield, d.zona@sheffield.ac.uk
[3]University of Sheffield, j.r.leake@sheffield.ac.uk
[4]University of Leeds, S.A.Banwart@leeds.ac.uk

ABSTRACT

Peatlands are globally important areas for carbon preservation: covering only 3% of world's land, they store 30% of total soil carbon. At the same time, peat soils are widely utilised in agriculture: 40% of UK peatlands have been drained for agricultural use and 24% of deep peat area in England is being farmed. One of the most important regions for crop production on lowland peats in the UK are the East Anglian Fenlands (the Fens): an area of drained peatlands in East England. This study was conducted on peat cores excavated from a field in the Fens and focused on the following objectives:

1. To examine effects of climate change-induced temperature rises on celery productivity and peat CO_2 and CH_4 emissions.
2. To find the field water table level that reduces peat emissions of CO_2 and CH_4 while maintaining celery productivity.

The research found higher CO_2 emissions from the elevated (+5°C) temperature treatment and lower CO_2 emissions from the higher (-30cm) water table level, however, noted no effect on CH_4 emissions of any of the treatments. The higher water table decreased aboveground celery biomass. There was no effect of increased temperature on aboveground celery yield.
Keywords: peat; agriculture; greenhouse gases; drainage; climate change

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Peatlands are globally important areas for carbon preservation: covering only 3% of world's land, they store 30% of total soil carbon (Global Environmental Centre, 2008). At the same time, peat soils are widely utilised in agriculture: in Europe 14% of peatland area is under cultivation (Global Environmental Centre, 2008), 40% of UK peatlands have been drained for agricultural use (Dixon et al., 2014) and 24% of deep peat area in England is being farmed (Natural England, 2015).
One of the most important regions for crop production on lowland peats in the UK are the East Anglian Fenlands (the Fens): an area (1,500 square miles) of drained peatlands in East England covering Cambridgeshire, Norfolk, West Suffolk and Lincolnshire (Darby, 1956). Eighty eight percent of the Fenland area is cultivated, sustaining around 4000 farms and supplying 37% of total vegetable production in England (NFU, 2008). The soils of the area are fertile (89% of agricultural land being classified as grade 1 or 2: the highest scores on a six grade scale which describes soil suitability for cultivation in England and Wales) and so crops with high nutritional demands (such as vegetables) tend to dominate (NFU, 2008). It is estimated that Fenland peats store 41 Tg of Carbon, which is lost from the ecosystem at a rate of 0.4 Tg C/yr (Holman, 2009). Despite their economic and environmental importance, Fens are at risk due to continued drainage-induced volume loss of the peat layer via shrinkage, compaction and oxidation, which are estimated to result in wastage rate of 2.1 cm/yr (Holman, 2009).
Manipulation of the water table has the potential to extend the lifespan of the fertile soil of the Fens. The position of water table is often credited to be of key importance in determining the rate of mineralisation of organic matter. The majority of studies on temperate and Northern peatlands demonstrate that a rise in the position of the water table decreases emissions of CO_2 and increases release of CH_4 (Nykanen et al., 1995, Dinsmore et al., 2009, Wilson et al., 2016, Karki et al., 2010, Strack et al., 2004, Hou et al., 2013, Poyda et al., 2016, Regina et al., 2015, Yrjala et al., 2011), although in many instances no link is found between the water table level and emissions of greenhouse gases (Regina et al., 2007, Schrier-Uijl et al.,

2010, Muhr et al., 2011) or a drawdown of the water table results in smaller release of CO_2 Dirks et al, 2000). Despite the importance of preservation of agricultural peats, there is a lack of studies which attempt to find water table level that strikes a balance between crop yield and GHG production. Renger et al. (2002) found that while a water table of -40 cm to -50 cm maximised grass yield on a fen, keeping it at -30 cm is the optimal solution as 90% of productivity is kept and mineralisation is lowered by 30-40% of the maximal value. A similar pattern was reported by Regina et al. (2015) on organic soils cultivated for grass in Finland: they noted a decline of CO_2 and N_2O emissions when water table was raised from -70 cm to -30 cm, although they do not provide biomass data. Nevertheless, the relationship between the position of water table and peat oxidation is not always clear: water table level was found to have no effect on CO_2 emissions (Lafleur et al., 2005) and its lowering from -40 cm to -80 cm resulted in a decreased CO_2 loss (Berglund and Berglund, 2011).

The future of the Fens is overshadowed by another uncertainty: increases in temperature brought by climate change. It is estimated that average global temperature increase expected by the end of this century (relative to 1986-2005) would be within the range of 0.3-4.8°C (IPCC, 2014). Rising temperatures should accelerate the rate of organic matter mineralisation, which will lead to higher emissions of greenhouse gases as well as enhanced plant growth due to better availability of nutrients (Rustad et al., 2001). The effects of higher temperatures on crop growth and greenhouse gas emission have not been properly investigated in the context of peatlands utilised in agriculture.

This study was conducted on peat cores excavated from a field in the Fens and focused on the following objectives:

3. To examine effects of climate change-induced temperature rises on celery productivity and peat CO_2 and CH_4 emissions.
4. To find the field water table level that reduces peat emissions of CO_2 and CH_4 while maintaining celery productivity.

METHODOLOGY

A total of 64 soil cores were collected from a farm in Methwold Hythe, Norfolk. This was done by inserting PVC pipes with a diameter of 11 cm to a depth 60 cm. The PVC pipes were excavated out of the ground, preserving the existing soil structure. The cores (half planted and half unplanted) were subjected to a multifactorial manipulation of:

- Water table at two levels: -30 cm and -50 cm
- Fertilisation: fertilisation with ammonium polyphosphate and lack of fertilisation
- Temperature: ambient and elevated (+5°C).

In order to regulate temperature conditions, the cores were placed in two growth chambers. To simulate the field conditions, the chamber temperature was raised each week from the base temperature of 17°C (22°C in the elevated temperature treatment) until it reached 20°C (25°C in the elevated temperature treatment) in week 6. The temperature, air humidity and PAR settings of this experiment are based on June, July and August readings from the field in years 2013, 2014 and 2015.

CO_2 and CH_4 measurements were taken once a week in weeks 1-11 with an LGR Ultra Portable Gas Analyser GGA-30p. Two custom-made PVC chambers: a transparent (to record fluxes in light) and an opaque (for dark respiration) chamber (both with a volume of 2.8 l) were used to collect soil gas emissions and transfered to the LGR in real time. Each measurement lasted 2 minutes. The fluxes of CO_2 and CH_4 were calculated as described in McEwing et al. (2015).

Statistical analysis was performed using the open source programme R (R Core Team 2016). Linear models and mixed effects models were used to test the effects of water table level, temperature and fertiliser use on celery biomass and emissions of CO_2 and CH_4. The analysis was done in the lme4 package (Bates, Maechler & Bolker, 2014), so as to avoid temporal and spatial pseudoreplication.

RESULTS

The weight of the aboveground fresh biomass was 19% lower from the -30 cm water table treatment as compared with the -50cm water table. Aboveground fresh biomass was not significantly affected by temperature. Dry root biomass was lower in the -30 cm water table treatment by 33% and remained unaffected by temperature.

The CO_2 flux from unplanted cores was 25% higher from the elevated temperature treatment and also 31% higher form the -50 cm water table treatment. CH_4 fluxes were not affected by any of the treatments.

DISCUSSION

Higher CO_2 emissions from the elevated (+5°C) temperature treatment may point to increased rates of organic matter oxidation by soil microorganisms. Temperature increases may enhance the decomposition of organic matter, among other factors, through positive effects on microbial metabolic rate (Ziegler et al., 2013). A number of studies demonstrate that in the agricultural context a water table of -20cm or lower is enough for complete oxidation of methane by methanotrophs (Regina et al., 2015; Karki et al., 2016; Poyda et al., 2016, Renou-Wilson, 2014). The absence of a relationship between water table fluctuations and methane emissions at low water table levels is likely due to the fact that low water tables have no or negligible effect on topsoil water content (Juszczak et a., 2012), which is the key factor in determining methanotrophic activity (Tiemeyer et al., 2016). The lack of response of CH_4 emission to the elevated temperature treatment could be because the difference of 5°C was not enough to significantly affect the production and consumption of CH_4, especially for the values close to the optimal temperature (25°C).

CONCLUSIONS

Raising the water table from -50 cm to -30 cm would depress celery yields, however, it would also decrease the rate of peat wastage. Global warming is likely to increase peat loss via oxidation and unlikely to improve celery yields.

3.1.9 | AN EXPERT SYSTEM MODEL FOR MAPPING TROPICAL WETLANDS AND PEATLANDS

Thomas Gumbricht[1], Rosa Maria Roman-Cuesta[2*], Daniel Murdiyarso[2]

[1]Karttur AB, Birger Jarlsgatan 102b, 3tr, 11420 Stockholm, Sweden
[2]Center for International Forestry Research (CIFOR), P.O Box 0113 BOCBD, Bogor 16000, Indonesia
*presenting author

ABSTRACT

Our understanding of wetlands' services is currently constrained by limited knowledge on their distribution, extent, volume, inter-annual flood variability, and disturbance levels. We here present an expert system to report on wetland and peat areas, depths and volumes, which relies on three biophysical indices that capture three fundamental properties of wetlands: 1. Long-term water supply exceeding atmospheric water demand; 2. Annually or seasonally water-logged soils; 3. A geomorphological position where water is supplied and retained. Tropical and subtropical wetlands cover 4.7 million km^2. In line with current understanding, the American continent is the major contributor (45%) and Brazil, with its Amazonian inter-fluvial region, contains the largest tropical wetland area (800,720 km^2). Our model suggests, however, unprecedented extents and volumes of peat in the tropics, mainly outside Asia: 1.7 million km^2 and 7,268 (6,076-7,368) km3, which more than three-fold current estimates. Unlike current understanding, South America (particularly Brazil) contributes the most to tropical peat area and volume (ca. 44% for both) partly related to some yet unaccounted extended deep deposits but mainly to extended but shallow peat in the Amazon Basin. Asia has a second place (38% for both tropical peat area and volume). Indonesia is the main regional contributor and still the holder of the deepest and most extended peat areas in the tropics. Africa hosts much more peat than previously reported but climatic and topographic contexts leave it as the least peat forming continent.

Keywords: wetlands, peatlands, peat deposits tropics, land use, climate change

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Wetlands play fundamental roles in climate change regulation and mitigation, with unmanaged wetlands being the largest natural sources of methane in the global CH_4 budget (Denman *et al*., 2007; Montzka *et al*., 2011; Melton *et al*., 2013; Petrescu *et al.,* 2015). Their participation is however imprecise due to the considerable uncertainty of fundamental wetland variables such as their global distribution, spatial extent, or their temporal dynamics. Efforts to assess global wetland extents include the Wetland and Wetland CH_4 Inter-comparison of Models Project (WETCHIMP) (Melton *et al*., 2013; Wania *et al*., 2013). Their results concluded that the estimates of wetland area vary ca. four-fold in modelled area simulations (7.1- 26.9 mill km^2), and three-fold (4.3-12.9 mill km^2) in observational mapping (Melton *et al*., 2013). Part of this variability relates to the unstandardized definition of wetlands and the temporality of their inundation patterns (Melton *et al*., 2013; Junk *et al*., 2014; Zhang *et al*., 2016). Peatlands are wetlands and, therefore, suffer from the same problems but their assessment of areas and volumes are complicated by unclear definition of what peats and peatlands are (Page *et al*. 2011; Junk *et al*., 2011), and by a general lack of data due to their complex monitoring requirements (i.e. soil depths, bulk densities, carbon contents) (Joosten *et al*. 2012). The lack of robust validation processes (Page *et al*., 2011) also affect current peat maps, particularly in the tropics. This is problematic since tropical peatlands are an important focus of international concern due to the magnitude of their emissions under intense (van der Werf *et al*., 2008) or even moderate climatic (Gaveau *et al*., 2014) and human pressures (Hooijer *et al*., 2010; Petrescu *et al*., 2015; Turetsky *et al*., 2015). The need for developing robust, comparable, and highly detailed tropical wetlands and peatland maps, could not be more urgent. We here present a novel method for mapping wetland/peatlands in the tropics and subtropics including estimations of their soil depths and volumes, at a spatial resolution of 232 meters. Our goals are 1. To characterize the spatial distribution of wetlands and peatlands in the tropics and subtropics, and 2. To estimate the depths and volumes of peatlands. In this research we define peatlands as areas where soils have a minimum depth of 30 cm and an organic matter content of at least 50 percent (27% of carbon content).

METHODOLOGY

We developed a knowledge-based model to estimate the spatial distribution and extent of wetlands, peatlands, soil depths and volumes. Compared to previous mapping efforts, such as remote sensing or analytical assessments through hydrological models, we develop three biophysical indices from observational data: hydrological wetness, satellite-derived soil wetness phenology, and geomorphology, to capture key properties of wetland/peatland development: i) inter-annual water inputs exceed the atmospheric water demand (i.e. potential evapotranspiration), ii) annually or seasonally wet or inundated soils, and iii) the geomorphology supports water accumulation and wetland development. This approach requires data on i) regional and local water balances, ii) soil wetness and soil wetness phenology, and iii) geomorphology. The three biophysical indices are:

1. Wetland Topographic Convergence Indices (wTCI): We applied a hydrological model to simulate surface runoff, groundwater flow and flooding volumes.
2. Transformed Wetness Index (TWI) and soil wetness phenology: We developed an algorithm for capturing intra-annual variations of soil surface wetness (soils wetness phenology) based on an annual time series of MODIS optical images. Soil moisture phenology was also used to determine periods of inundation and water saturation.
3. Hydrogeomorphological maps and indices: We mapped general landscape geomorphological elements (i.e. plains, valleys, slopes, ridges, etc) using topographic data. Three types of drainages and maps were produced that represent three different geomorphological wetlands: 1. Peat domes (sourced by permanent rivers with high flow), 2. Valley bound wetlands (sourced by smaller streams), and 3. wetlands in plains and open slopes (sourced by permanent rivers.

RESULTS

Our model suggests much larger areas and volumes of peatlands in the tropics than previously reported, with estimates that reach 1.7 million km^2, and 7,268 (6,076-7,368) km3 (Table 1, Figure 1). Most of these estimates correspond to under-reported peatland areas outside Asia. For the same study area than previous reports (i.e. Page *et al*., 2011) our estimates of areas suggest two-fold increases in Asia and almost four-fold increases in South America and in Africa (Table 1). South America (with a tropical area contribution of 46%) and not Asia (36%) holds the largest area of tropical peatland. Brazil (312,250 km^2) and not Indonesia (225,420 km^2) lead the contribution to tropical peatland area. Countries with much larger peat areas than previously reported include Bangladesh, India, Thailand, Viet Nam, Congo DRC, China, Colombia, Brazil and Venezuela. There is a general increase of tropical peat volume in all the continents (Table 1), with South America and Africa having almost ten times more peat volume than previously reported. Asia only sees a two-fold increase. South America (42%) and not Asia (39%) holds the largest peat volume, with Brazil (1,489 km3) holding more volume than Indonesia (1,388 km3). Differences with previous volume reports (i.e Page *et al*. 2011) highlight the so far under-reported contribution of Brazil, Peru, Venezuela, Colombia and Argentina, as well as DRC, China, India or Bangladesh. Asian differences then relate to some unaccounted deep deposits such as those in Indonesian Papua, but mainly to extended but less deep deposits in Bangladesh, Viet Nam, Cambodia, Myanmar, Thailand or Brunei. The situation out of Asia is a combination of some unaccounted very large and very deep deposits (i.e. Congo-DRC, Peruvian peats), and very extended but shallower peats (i.e northern Amazonia). Our model suggests several under-reported peatland hotspots which would require further research and field validation. A non-exhaustive list includes the Amazon Basin (9 different sites); in Argentina the Ibera Wetlands, and la Plata River and tributaries (Paragay and Paraná). In Asia, almost all the river deltas, particularly in Bangladesh, the Mekong and Red Rivers in Viet Nam, the Irrawady river in Myanmar/Burma, the Chao Phraya in Thailand, and the wetlands of the lower Mekong

River in Cambodia). Indonesian Papua hosts large under-reported peat deposits. In African the model highlights the Niger River Delta, the Sudd in South Sudan, and the Cameia wetlands in Angola. Zambia hosts a diversity of locally important peat deposits, among them those in the Bangweulu wetlands. We also see more peat on the Okavango River and on the Cuvette Centrale. In terms of carbon stocks, if we selected standard values for bulk density (0.09 g.cm-3) and for carbon content (56%), we would report 352 GtC of peat soil carbon, more than three times current estimates (88 GtC) (Pag *et al*. 2011).

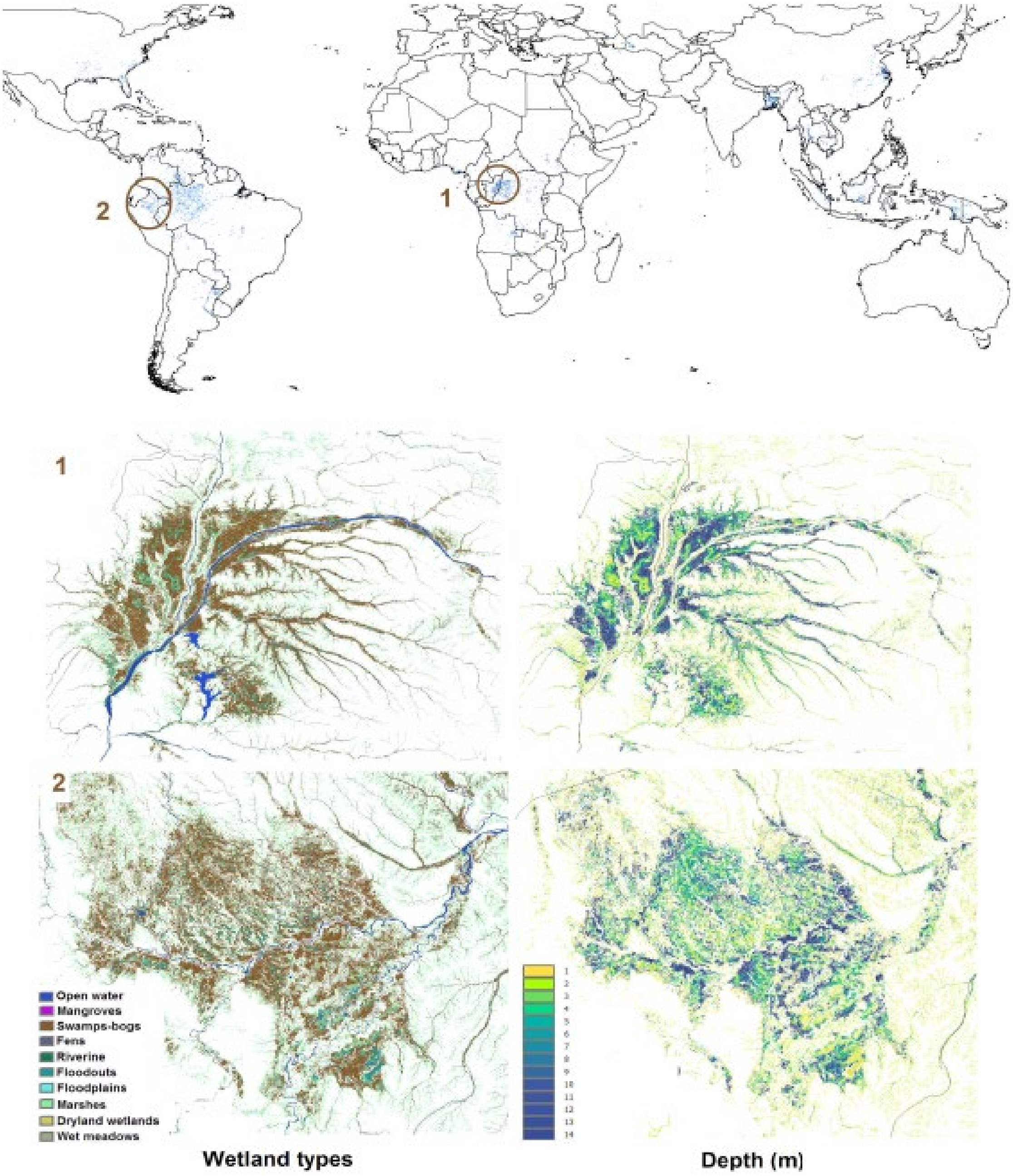

Fig. 1: Distribution of tropical and subtropical peatlands with black circles locating vast peat deposits in (1) the Cuvette Centrale, in the border between Congo and Congo- DRC, and (2) the Pastaza-Marañón in Peru. The lower panels show the detailed wetland composition and depths (m) of these peat deposits as produced by our maps. Source: Gumbricht et al. (2017)

Table 1: Peatland areas, and volumes as reported by Page et al.,(2011) and by this study. M=106, million.
a To allow comparisons, values reported on this row correspond to the same countries as reported by Page et al. (2011) (i.e.58 common countries). See Table S2 in the Supplement for the country list.
b Values reported on this row correspond to the study area of this research, which is larger than Page et al. (2011)'s and covers the tropics and the subtropics (i.e.146 countries). Contributions from Middle-East are not shown (Area: 10,829 (0.6%); Volume: 9 (0.1%); Depth: 1m).
c Asia includes Southeast Asia (Brunei, Indonesia, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand, Viet Nam), other Asia (Bangladesh, China, India, Sri Lanka), and the Pacific (Australia-Queensland, Fiji), as in Page et al. (2011)
d America includes Central and South America.
Source: Gumbricht et al. (2017)

	Total area Mkm^2	Volume km^3	Depth (m)	Continental peatland area (km^2) and contribution (%)			Continental peatland volume (km^3) and tropical contribution (%)		
				Asia[c]	**America**[d]	Africa	Asia	America	Africa
Estimates in Page *et al.*,(2011)	0.44 (0.39-0.66)	1,758 (1,585-1,822)	2.3	254,115 (241,451-347,051) (57%)	130,860 (116,096-175,146) (30%)	55,860 (29,464-135,043) (13%)	1,368 (1,322-1,396) (78%)	252 (228-266) (14%)	138 (70-161) (8%)
This study estimates (study area of Page *et al.*, (2011)[a]	1.5	6,991 (5,765-7,079)	2.5	618,979 (36%)	629,189 (46%)	257,038 (18%)	2,699 (2,209-2,729) (39%)	2,916 (2,414-2,959) (42%)	1,376 (1,142-1,391) (20%)
This study estimates (our total study area)[b]	1.7	7,268	1.8	647,764 (38%)	750,000 (44%)	291,407 (17%)	2,730 (2,376-2,763) (38%)	3,117 (2,350-3,160) (43%)	1,411 (1,213-1,429) (19%)

DISCUSSION

Our peatland data highlight a remarkable misconception of tropical estimates, distributions, and continental contributions to peatland area and volume, mainly due to biased research intensities, which currently highlight Southeast Asian peat deposits as the major tropical contribution (Page *et al*., 2011). Contrarily, the vast and still very inaccessible peatlands of Africa and Latin America remain poorly studied due to logistic (i.e. ground access) and methodological constrains (i.e. cloud persistence for remote sensing, poor climatic data for hydrological modelling), in largely uninhabited regions. As a result, descriptions of vast carbon peats outside Asia are still occurring. This is the case of the Pastaza-Marañon foreland basin in Peru (Lähteenoja *et al*., 2009b; Draper *et al*., 2015) (35,600km^2, up to 9 m deep) and the Congo-DRC peatland reservoir (Dargie *et al*., 2017; Lawson *et al*., 2015) (200,000km^2, up to 7 m deep). Latin America peats overpass the Asian contribution, with Brazil hosting larger areas and volumes than Indonesia, which only but mirrors its role as the largest wetland country in the tropics. This new ranking is certainly an underestimation due to the omission of extended montane peatlands along Latin American mountain ranges. Southeast Asian peatlands will likely remain as the most extensive and deepest tropical contribution (Page *et al*., 2011; Lähteenoja *et al*., 2013) since the Brazilian contribution to tropical peat mostly relates to smaller and shallower peat deposits that add up to large extensions and volumes. African peatlands are the least known (Joosten *et al*., 2012). However, due to climatic and topographic contexts, our results suggest that this continent hosts the lowest peat areas and volumes and suffers from less underestimation than the American continent.

CONCLUSIONS

Our model suggests unprecedented areas and volumes of peatland in the tropics, which more than three-fold current estimates, mainly outside Asia. New peatland hotspots have been identified in the Amazon Basin, in Argentina, Niger, Angola, Bangladesh, and several river deltas in South-East Asia, among others. Latin America, and particularly Brazil, appear as the main contributors to tropical peat. The hypothesis behind our large estimates outside Asia requires field validation but it relates both to yet unaccounted moderately large and deep deposits (i.e. Ecuador), and to extended but shallow deposits in the inter-fluvial Amazonian region that add-up to high areas and volumes. If proven correct, our peatland estimates would also evidence our current misconception of the contribution of tropical peatlands to global carbon budgets.

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3.1.10. | EVALUATION OF ANNUAL CARBON LOSSES DUE TO "SOIL RESPIRATION"

Siabruk Olesya

National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky", Ukraine
e-mail: blakhart.Liss@yandex.ua

ABSTRACT

Currently, the annual increase of CO_2 in the atmosphere is 1,5 ppmv. Carbon emission in the atmosphere is 50% of the greenhouse effect compared to other gases. The additional inflow of carbon dioxide in the atmosphere greatly depends on the intensity of agricultural land use. Quantitative estimation of the impact of these factors makes it possible to anticipate and adjust the intensity of CO_2 emissions from the soil. Therefore, research in this area acquire a special significance due to global climate change. Minor changes in soil carbon content can have a huge impact on the concentration of CO_2 in the atmosphere. For reduction of greenhouse gas emissions and climate change mitigation the carbon sequestration in soil is one of the best options. By the sustainable use the soils have potential for significant sequestration of carbon. The paper presents the modern methods of monitoring the emission fluxes of carbon from the soil using a portable gas analyzer and calculation of the direct loss of carbon from the soil through soil respiration.

Scientific novelty is in the fact that it is expanded the scientific knowledge on the laws of the dynamics of CO_2 emission flow from chernozems under the influence of agricultural use with the background of seasonal fluctuations of hydrothermal conditions; it is defined emission volume of carbon by chernozems typical and podzolic of Left-bank Forest-Steppe of Ukraine during the growing season and developed predictive models of carbon losses at the expense respiration under different weather and climatic scenarios.

The results can be used to improve methods of monitoring emissions of CO_2 from soils on agricultural lands, gradual transition of cadastral evaluation of greenhouse gas emissions on the quantitative and monitoring basis, for constructing mathematical models of forecasting changes in the production of carbon dioxide from the soil under different weather and climatic scenarios and for predicting the impact of new agricultural technologies in carbon balance in the context of sustainable use of soil.

Keywords: soil respiration, loss of soil carbon, method of cultivation, mathematical model

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Soil organic matter is the repository of the largest inventories (1,395.3 Gt) of carbon in terrestrial ecosystems. Thus, the soil cover with its gas function (relative to carbon) performs a critical role in the biosphere support for modern optimal climate. According to various scholars the total annual CO_2 flux from soil surface ecosystems of our planet is estimated at 50 - 77 Gt per year. By increasing soil organic matter in the soil, you can get a higher level of carbon stock (carbon balance). We know that carbon dioxide of atmosphere for about 90% of a soil origin. Since the flow of CO_2 arriving the atmosphere, its emission from the surface of the soil is one of the largest sources of carbon dioxide, minor violations soil respiration on a global scale could lead to serious changes in the concentration of CO_2 in the atmosphere.

According to long-term estimations, the amount of soil carbon that is released around the world in the last century due to adopted agricultural technologies is (136 ± 55) pg (billion tonnes) of carbon. That's about half of all emissions from fossil fuels - (270 ± 30) pg, and cultivation gives carbon emissions at a rate of (78 ± 12) pg and soil erosion - (26 ± 9) pg also it is estimated that in the soil at the expense flora, fauna and terrestrial ecosystems can keep 3 GHG emissions per year (1.41 parts per million of atmospheric carbon dioxide) [Information of Research Institute of Organic Agriculture (FiBL).].

The key factors that determine the level of content of organic carbon in the soil, is the amount of organic residues after harvesting, soil type and its moisture content and methods of cultivation. Optimal conditions for the accumulation of carbon in the soil are a high amount of biomass both ground parts and roots laid in moist soil, where aeration is not limited [Malhanova E.V., 2007]. Thus, the calculation of loss of soil carbon - is a common question that still does not have a single solution.

The objective of our work was to calculate the total emission volume of carbon losses from soil during the growing season in options of different cultivation ways based on observations of the dynamics of soil respiration intensity during the growing season and to build a mathematical model depending CO_2 emissions from hydrothermal conditions of the year.

METHODOLOGY

Research was carried out during 2011-2015 on the chernozems of Left-bank Forest-Steppe of Ukraine. To address the problems in the work there were used methods of instrumental monitoring and statistical and mathematical research. Monitoring the CO_2 emissions from soil was carried out in the field (once a month during the growing season) with simultaneous control of moisture and temperature of the soil.
Instrumental control of carbon dioxide intensity from the soil surface was carried out using a portable gas analyzer «testo 535» from the isolation of the air. The measurements were performed 3-5 times a day with subsequent statistical processing and averaging the results.
The results were proceeded by methods of mathematical statistics using the program Statistica.

RESULTS

Conducted observations show a significant difference between the intensity of soil respiration by systematic plowing and other cultivation methods. In our opinion, this is due to the differences in compaction of the soil, and also indicators of temperature and humidity. This is confirmed by the fact that CO_2 emissions from the soil surface has quite clear daily and seasonal dynamics. According to the results, in the summer can be abrupt (4-5 times) increase in carbon dioxide emissions after rainy periods due to high soil moisture and temperature.
Research by Hu Lifeng has shown even greater difference between different types of soil tillage can be expected in the first 5 days after the conducting, especially on surfaces covered with plant remains [Hu Lifeng et al, 2008]. Concomitant monitoring moisture and soil temperature changes also give an explanation of the difference between the respiration, because in November by direct sowing temperature and soil moisture is higher, which has a positive impact on microbial activity.
Obtained during the vegetation period 2011-2015 data show a significant difference between the intensity of soil respiration in different periods of the year. Adjacent monitoring the temperature and humidity of the soil showed that the latast one is the determining factor an abrupt increased respiration of the soil after heavy rains. After that soil moisture reduced, and by the greatest extent - by plowing and surface tillage and by zero tillage was at the highest.
With the help of the data of intensity of respiration we can calculate the value of the loss of soil carbon. We used the method of mathematical calculations, based on the difference between the average height indicator intensity of soil respiration.
Вирахувавши середню висоту показника дихання між місяцями дослідження (травень-вересень) отримали кількість діоксиду вуглецю, що викидається ґрунтом у атмосферу за вегетаційний період року. Потім, обрахувавши пропорційну частину вуглецю у газі, отримали приблизні втрати вуглецю з ґрунту за рахунок дихання за різних способів обробітку (табл. 1).
We calculated the average height of respiration indicator among monthes of the research (May-September), received the amount of carbon dioxide, emitted into the atmosphere by the soil during the growing season. Then, we calculated proportionate part of carbon in gas , we obtained soil carbon loss from soil due to respiration at different ways of tillage (Table. 1).

Table 1: [Loss of carbon from chernozem typical by different ways of tillage during the growing season]

Options of experiment	Average loss of carbon from soil during the growing season 2011-2015, kg / ha
Plowing	577
Disk plowing	560
Cultivation	578
Direct seeding	613

Observations and calculations show that the most significant is the loss of carbon by using direct seeding, ie without basic tillage. Since the experiment studied only direct seeding as a separate component of technology no-till, because of a lack of mulch on the surface layer the moisture and temperature of soil was different from versions of plowing and cultivation surface. At the same time, by the direct seeding all plant residues remain on the surface, their humification is minimal, which causes greater losses of carbon [Siabruk O.P., 2013].
Among general recommendations to eliminate a possible threat of extreme climate change there are indicated preventive measures of scientific nature: to improve models of predictions of climate, assemble into a comprehensive system the models of predictions of environmental, economic, social and political consequences of climate change, to develop methodology for assessing the vulnerability of the country related to possible climatic changes, and so on. In order to predict climate changes, scientists rely on very complex mathematical models. Models are built on the basis of what has been observed in previous years, and the understanding of the relationship of natural processes occurring on the surface of our planet.
Given that the most relationships in the soil as inert system have nonlinear character, for mathematical modeling in the first approximation quadratic model was used.
Summary of research 2011-2015 as a graphical model is shown in Fig. 1. According to a graph, the sampling of experimental values characterized by a gradual increase of carbon dioxide with increasing temperature at low humidity and significant strengthening of the process in moist soil.

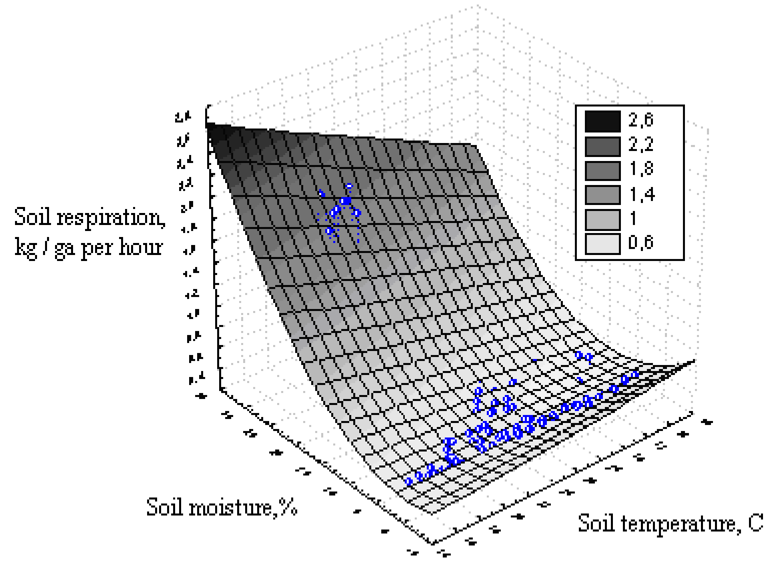

Fig. 1: [Dependence of intensity of CO_2 allocation from the soil on hydrothermal conditions on stationary experiment with soil cultivation]

The equation of this dependence has the form:

$$z = 0,47-0,0048x+0,023y+0,0002x^2-0,0016xy+0,0018y^{2,}$$

where z – intensity of CO_2 emissions from the soil surface, kg / ha per hour;
x – soil temperature, ^oC;
y – soil moisture, %.

DISCUSSION

The foregoing interpretation coincides with the observations of many scientists for changes of humus soil state in the early stages of implementation of no- till technology. In particular, A.D. Balayev with colleagues [Balayev A.D. 2004], believes that systematic use of no- till with the addition of fresh organic matter on the soil surface will not promote its humification and therefore not form enough humic substances. There were no positive changes of humus state under the influence of no-till on chernozem ordinary of Askaniya Research Station of the Institute of irrigated agriculture [Voloshenyuk A.V., Chorniy S.G., 2014], although the intensity of the allocation of CO_2 was higher than traditional cultivation.
It was developed a mathematical model can still be improved and supplemented with new data, but in general can be used to predict the volume of CO_2 emissions from automorphic chernozem under different scenarios of weather and climate warm period. Additionally, it is advisable to introduce an amendment to influence methods of management.

CONCLUSIONS

1. It is proved that by the total amount of CO_2 emissions from chernozem typical direct seeding technology prevails over methods studied basic soil processing (loss of carbon from 525 to 701 kg / ha per year), it is due to higher weediness of crops, better water regime and a total mineralization of plant residues on the soil surface. By disking soil in 10-12 cm annual losses of carbon smallest (497-622 kg / ha). At the same time, systematic plowing over 6 years has led to a reduction of labile organic matter and fulvic acid and reduce potential production capacity for CO_2 in the upper soil surface compared with cultivation and direct seeding technology.
2. Since the method of calculating the balance of carbon in crop rotations does not take into account such factors as the peculiarities of water and temperature conditions of the soil, which significantly affect the processes of mineralization and humification of organic matter, it is proposed to estimation of carbon losses from the soil through periodic observations of the release of CO_2 from the soil and generalization of the results in the annual cycle.
3. There are developed mathematical models of depending on the intensity of emissions from hydrothermal conditions. This allows predicting the volume of CO_2 emissions from automorphic chernozem under different scenarios of weather and climate warm period from generalizing models with the introduction of amendments to the method of soil cultivation, fertilization system and culture, etc.

3.1.11 | UKRAINIAN CHERNOZEMS AS A FACTOR IN GLOBAL FOOD SECURITY AND RESILIENCE OF AGRICULTURE TO CLIMATE CHANGE

Sviatoslav Baliuk[1], Vitaliy Medvedev[2], Anatoliy Kucher[3], Vadim Solovey[4], Arkadiy Levin[5]*, Yuriy Kolmaz[6]

[1] National Scientific Center «Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky» (NSC ISSAR), Director, GSP Focal Point of Ukraine; pochva@meta.ua
[2] NSC ISSAR, Soil Geoecophysics Laboratory; vvmedvedev@ukr.net
[3] NSC ISSAR, Sector of Economic Research; anatoliy_kucher@ukr.net
[4] NSC ISSAR, Soil Resources Department; gruntpokrov@ukr.net
[5] NSC ISSAR, Department of Scientific-Economic Activities, Innovations and Coordination of International Cooperation, Deputy GSP Focal Point of Ukraine; alevin@ukr.net
[6] Ministry of Ecology and Natural Resources of Ukraine, Sector of Land Resources; UNCCD Focal Point of Ukraine; kolmaz@ukr.net

ABSTRACT

The objective of this report was to demonstrate the role of Ukrainian chernozems as a factor in global food security and sustainability of agricultural production to climate change. We used such methods: abstract and logical, monographic, expertise, computational and analytical. The leading role of Ukraine in the formation of global food security is discussed. The report shows the results of preliminary assessment of the Ukrainian soils' contribution into the global soil problem of carbon sequestration. The scale of organic carbon losses due to inefficient use of land is analyzed. The report indicates perspective directions of organic carbon reproduction in the chernozems of Ukraine to support/increase its reserves and provide neutral land degradation. Proposals for future Plans of Actions to increase the capacity to manage reproduction of organic carbon in chernozems of Ukraine are included.
Key words: chernozems, soil organic carbon, humus, food security, land degradation neutrality.

GENERAL INFORMATION ON LAND RESOURCES AND SOIL COVER OF UKRAINE

The total area of Ukraine is 60.35 mln.ha, area of lands - 57.93 mln.ha. Land Fund of Ukraine is divided as follows (Ministry of Ecology and Natural Resources of Ukraine, 2015): agricultural lands - 42.74 mln.ha (arable lands - 32.53; hayfields and pastures - 7.86; fallow lands - 0.25; gardens - 0.89); forest lands - 10.62; wetlands - 0.98; built-up lands - 2.54 mln.ha. Soil cover of Ukraine is very diverse and has up to 1000 kinds of soil. On 2/3 it consists of chernozems soils (about 25.3 ml.ha). At the same time chernozems ordinary cover an area of 10.5 mln.ha, typical - 5.8, southern - 3.6, podzolized - 3.4 and chernozem-meadow soils - 2.0 mln.ha. Also, significant areas are occupied by fertile gray forest soils (4.3 mln.ha), the sod-podzolic soils (up to 3.9 mln.ha), chestnut soils (1.4 mln.ha), brown soils (1.1 mln.ha) and meadow -marsh soils (about 1 mln.ha).

CONTRIBUTION OF UKRAINIAN SOILS IN THE GLOBAL FOOD SECURITY

According to preliminary data, in 2016 Ukraine harvested a record yield of grain and sugar beet. Thus, production of grain and leguminous crops is almost 66 mln.t at average yield is 4.61 t/ha; gross harvest of sugar beet amounted to 13.9 mln.t with the yield of 48.2 t/ha. In recent years Ukraine is confidently among ten largest world producers of major products in agrofood sector, both in terms of gross production and the volume of exports. Thus, in 2014 on the production of sunflower and sunflower oil Ukraine held the 1st place in the world, barley – 3rd; nuts – 4th, maize and honey - on 5th; soy - on 8th and wheat – 9th place. On export of sunflower oil Ukraine occupied 1st place; grain and nuts – 2nd; maize and rapeseed - 3rd; barley – 4th; wheat – 6th place in the world. In 2015/2016 marketing year, according to the Ministry of Agrarian Policy and Food, Ukraine exported 39.4 mln.t of grain (https://delo.ua/business/avtory-rekorda-top-10-krupnejshih-eksporterov-zerna-iz-ukrainy-319734/). These data indicate that Ukraine plays a strategic role in global food market and ensuring global food security.

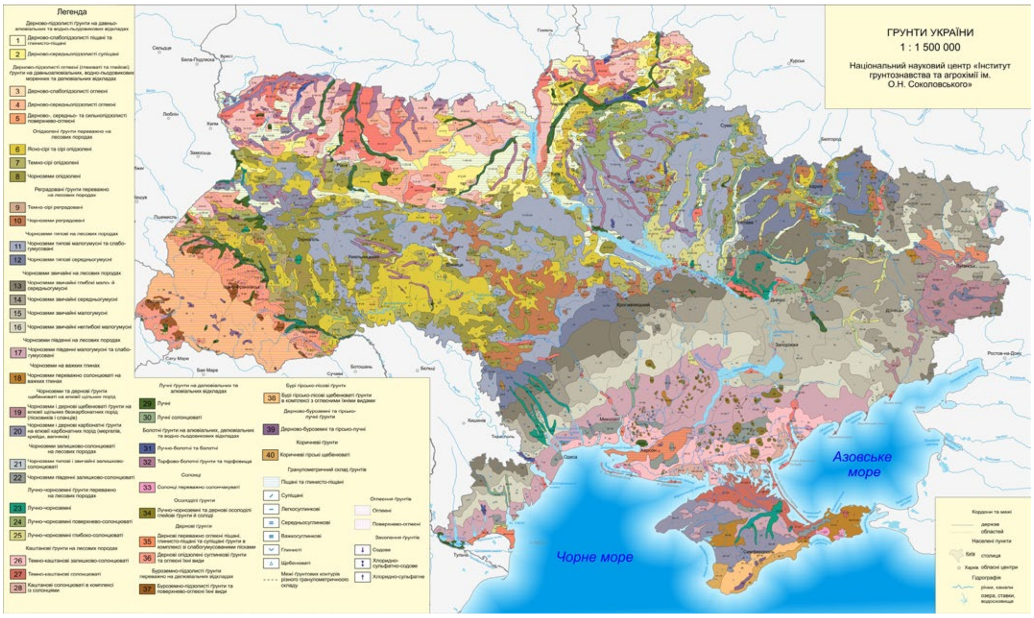

Fig. 1: Soil map of Ukraine 1 : 1 500 000 (NSC ISSAR, 2016)

PRELIMINARY ASSESSMENT OF UKRAINIAN SOILS CONTRIBUTION INTO GLOBAL CARBON SEQUESTRATION

Soils of Ukraine are characterized, in general, by average (2-3%) and high (3-4%) humus content in arable layer (map on Fig.2). Soil area with this content is 16.4 mil.ha, or about half of the arable land. Depth of Ukrainian soil profiles varies very widely and for chernozem soils depending on geographical, climatic and other factors is between 50 and 150 cm (Baliuk, Medvedev and Tararyko, 2010). Stocks of humus (SOC) in the main Ukrainian soils also vary widely: humus 100-720 t/ha, SOC 60-420 t/ha (Tab.1).

According to preliminary expert estimates of NSC ISSAR researchers total SOC stocks in Ukrainian soils are about 7 Gt. This compares with 1/3 of SOC in agricultural soils of EU, which are estimated about 18 Gt in 0-30 cm layer (Joint Research Centre, 2013).

Potential of SOC stock increasing by using the best agricultural technologies and balanced application of fertilizers is quite high. According to expert estimates it can reach 0.1-0.3% for the layer 0-30cm in medium term (5-10 years).

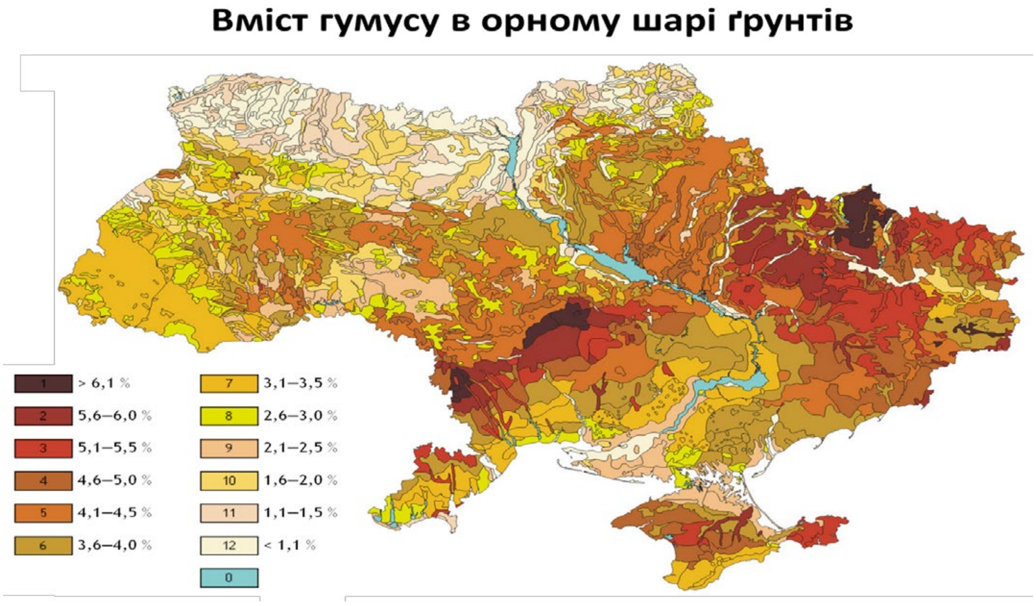

Fig. 2: Humus content in the arable layer of soils of Ukraine (National Atlas of Ukraine, 2007)

Table 1: Stocks of humus and SOC in Ukrainian soils

Type of soil	Humus content in arable layer,%	Humus in profile, t/ha	SOC in profile, t/ha
Chernozems ordinary	3.5-5.7	200-550	116-319
Chernozems typical	2.5-6.0	300-600	174-348
Chernozems southern	3.0-3.5	200-250	116-145
Chernozems podzolized	2.6-4.5	220-350	128-203
Chernozem-meadow soils	3.0-7.2	360-720	209-418
Gray forest soils	1.3-3.5	100-230	58-133
Sod-podzolic soils	2.0-3.7	150-280	87-162

INFORMATION FOR SOC MAPPING

Sources of information about content of humus and SOC on agricultural lands that are currently used for the preparation of SOC Ukrainian maps are:

- Database "Soil Properties of Ukraine", developed by the NSC ISSAR;
- Materials of large-scale soil survey 1957-1961 years;
- Materials of agrochemical certification of agricultural lands;
- Database of ecological and agro-reclamation state of ameliorated soils, developed by the Institute;
- Data of research institutions of various Ministries and Departments and universities;
- Data of stationary field experiments listed in State Register of Ukraine.

SOC data for non-agricultural lands (about 18 mln.ha) are scattered in dozens of organizations from different Ministries.
The Institute carries out all-Ukrainian geo-oriented Database "Soil properties of Ukraine", which by 31.01.2017 contained about 2,000 points on the SOC content. Database replenishment is going on by information available in a variety of "soil" organizations of Ukraine (academic institutions, universities, etc.).
First edition of the National Digital Raster SOC Map of Ukraine for 0-30cm layer with grid 1x1km must be prepared in April 2017 with FAO support.

Loss of humus because of irrational use of land

In Ukraine, since the days of V.V.Dokuchaev there have been conducted numerous researches of organic matter dynamics in soils. They showed that average loss of humus for nearly 130-year period reached 22% in forest-steppe, 19.5% - in the steppe and about 19% - in Polissya regions of Ukraine. Annual humus loss is 550-600 kg/ha and more (Baliuk and Medvedev, 2012; Medvedev, 2009).

According to stationary tests, a long-term plowing and cultivation of soil without adequate fertilizer application leads to significant losses of humus (Table 2) on all analyzed depths - up to 60 cm.

Table 2: Humus content (%) in virgin (non-turf) and plowed chernozems

Depth, cm	Chernozems			
	typical, virgin land	typical, arable land	ordinary, deposit land	ordinary, arable land
0-10	7.76	4.58	4.61	4.25
10-20	6.08	4.55	4.35	4.20
20-30	5.05	4.51	4.28	4.12
30-40	4.79	4.29	3.74	3.48
40-50	4.05	3.85	2.80	2.61
50-60	3.82	3.60	2.65	2.49

The highest humus loss occurred in the 60-80-ies of last century due to increase of sugar beet and maize share in crop rotations. In the following years, level of annual application of organic fertilizers reached 8.4 t/ha and 170 kg/ha of mineral a.m., therefore equilibrium balances of humus and nutrients were reached. Afterwards, fertilization subsequently reduced and the humus balance became negative. In recent years, application of mineral fertilizers increased to 75 kg/ha, but there is no perceptible shift for organic fertilizer. NSC ISSAR research as described in (Oldeman, Hakkeling and Sombroek, 1991) shows that humus loss occurs at 43% of arable land with a speed of up to 620 kg/ha per year (SOC loss 360 kg/ha*year) depending on rotation structure, tillage and standards of organic fertilizers (Baliuk and Medvedev, 2012).

Decrease of humus content is mainly due to following factors (Oldeman, Hakkeling and Sombroek, 1991): high level of plowing (56% of land area); catastrophic reduction in application of organic fertilizers (last 10 years less than 1.0 t/ha is applied instead of recommended 8-14); unbalanced use of mineral fertilizers; violation of cropping patterns; monoculture cultivation, reducing area of perennial grasses and legumes; high intensity of tillage.

MEASURING, MONITORING AND REPORTING ON SOC

Basic method of humus measuring is a modified method by I.V.Tyurin, which is standardized in Ukraine and used in all analytical laboratories.

Today, there is no specialized system of SOC monitoring in Ukraine. However, in Ukraine for more than 50 years agrochemical survey of agricultural land is carried out once every five years according to the method developed by NSC ISSAR. For each field 20 soil indicators are defined, including data on averaged humus content.

Only in the ninth round of 2006-2010, 26 mln.ha of agricultural lands were surveyed which included taking of about 2.7 mln. topsoil samples and preparing more than 450 thousand of agrochemical passports for individual fields (Institute of Soil Protection of Ukraine, 2015). Field passports as legal documents were made for land users and land owners with recommendations how to use and improve soil cover.

SOC MANAGEMENT AT NATIONAL LEVEL

State of legislative provision of issues on soils protection in Ukraine in recent years has improved with the introduction of the Land Code of Ukraine, Laws of Ukraine “On Land Protection” and “On state control over land use and protection”. According to these documents, Government has committed to organize and regulate the use, control and protection of soils. Ukraine as a Party of UNCCD was invited to formulate voluntary targets to achieve Land Degradation Neutrality (LDN) in

accordance with specific national circumstances and development priorities.
Therefore, in accordance with p.206 of Outcome Document of UN Conference on Sustainable Development “Rio + 20” and sustainable development goal 15.3 as set out in UN General Assembly documents from 09.25.2015 №70/1, Cabinet of Ministers of Ukraine adopted National Action Plan to Combat Land Degradation and Desertification 30.03.2016 p. (Cabinet of Ministers of Ukraine, 2016). It provides activities related to the provision of LDN and SOC stock enhancement, in particular:

- development of the law draft “On the protection and preservation of soil fertility”;
- conducting surveys of land in Ukraine;
- conducting soil-agrochemical survey and agrochemical certification of agricultural land;
- development of technologies for balanced use, protection and restoration of land and soil, prevention of their degradation. Creating an open database of soil conservation technologies and best practices;
- improvement of land and soil monitoring system.

It is taken into account that according to decision 15/COP 12, one of the three indicators for assessment of the processes of land degradation is “trend in carbon stocks above and below soil,” as a metric it is adopted SOC stock in soil.
Unfortunately, funding sources for the implementation of this ambitious Plan are not identified today, therefore the Ministry of Ecology and Natural Resources of Ukraine expressed interest to join to the Land Degradation Neutrality Target Setting Programme (LDN TSP) which has been launched by the Secretariat and the Global Mechanism of the UNCCD with support of several bilateral and multilateral partners to assist Country - Parties to the Convention in implementing decision 3/COP12.

SCIENTIFIC SUPPORT OF SOC MANAGEMENT IN UKRAINIAN CHERNOZEMS

The National Academy of Agrarian Sciences of Ukraine at the expense of state funding carries out with a five-year cycle the research programs on Ukrainian soil conservation and improvement of soil fertility. Currently, NSC ISSAR implements National Research Program for 2016-2020 “Soil resources: Forecast of Development, Sustainable Use and Management”. Most of 56 projects of this program in some way aim at improving the fertility of Ukrainian soils, that is, in fact, to maintain and increase SOC stocks. Unfortunately, this Program has a very limited government funding (about 0.320 mln.dollars in 2016).
Implementation of the Program is attended by about 300 researchers from 14 academic institutions and 8 universities of Ukraine.
The studies found a negative impact of dehumification on properties and processes in plowed soils: deterioration of chernozems trophic level; aridization of soil profile by strengthening the processes of physical degradation and deterioration of water regime; strengthening preference of downward water flow due to increase cloddiness and fracturing soil; mosaic abiotization of soils due to the increasing density of individual units; deterioration of water resistance of chernozems and increasing of erosion; strengthening of spatial heterogeneity of soil on field; worsening morphological, physiological, soil and productive indicators of plant root systems; weakening the turf soil. All factors lead to lower crop yields.
We studied the ways of reproduction of humus in current Ukrainian crisis conditions and prepared recommendations for the reduction of row crops share in rotations; use of optimal doses and technologies of mineral and organic-mineral fertilizers; application of technologies of minimum and zero tillage; application of both organic fertilizer plant residues and by-products of crops; growing green manure with subsequent plowing; improved utilization of manure and other organic waste as fertilizer source of SOC accumulation in soil.

NSC ISSAR PROPOSALS IN ACTION PLANS TO INCREASE SOC MANAGEMENT CAPACITY ON CHERNOZEMS

International projects and programs:

- Creation of International Network of Centers for chernozems protection with the participation of all interested countries;
- International projects on soil carbon monitoring, dissemination of technologies for SOC improving, on creation and testing of economic incentives for farmers to improve the systems of organic matter in soil;
- Implementation in Ukraine the International Pilot Project for low-cost soil carbon monitoring system on chernozems using spectrometric equipment and technologies of Dutch company SoilCares;

- Organization of international training seminars for studying of SOC monitoring technologies, for example, to study the Ukrainian experience in organizing regular agrochemical survey (certification) of fields;
- Extension of EU project LUCAS on topsoil survey on all European countries, including Ukraine.

National projects with foreign financial and technical support:

- Development of National SOC map in accordance with GSP specifications (carried out with FAO support);
- Creation in Ukraine the National soil-information system; identification of soil information gaps and conducting soil surveys in problem areas;
- Demonstration and dissemination of technologies to improve the humus content in Ukrainian chernozems and reducing of soil degradation;
- SOC loss assessment because of soil sealing in Ukraine;
- Establishment of a all-Ukrainian state system of soil cover monitoring, including SOC indicators;
- Development of theoretical and practical models of economic mechanisms (incentives) to SOC reproduction in agriculture, determine methods of state financial support for SOC reproduction.

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3.1.12 | ALARMING LOSS OF SOIL CARBON STORES DUE TO INTENSIVE FORESTRY MEASURES IN THE BOREAL FOREST ZONE IN FINLAND

Heikki Simola [1,2]

[1] Finnish Association for Nature Conservation (FANC), Helsinki, Finland
[2] Department of Environmental and Biological Sciences, University of Eastern Finland, Joensuu, Finland

ABSTRACT

The effects of modern intensive forestry measures on soil organic carbon (SOC) stores in both mineral soil podsols and peatland histosols have been investigated in Finland with novel methods applying the chronosequence approach (inventories at adjacent natural vs. treated sites, re-investigation of formerly inventoried sampling points).
Regarding peatlands, the results extrapolated to a nationwide figure, indicate an annual loss of 9 Tg C yr^{-1} (33 Tg CO_2 yr^{-1}), which is more than fourfold the magnitude reported for the IPCC for Finland. The new results from mineral soil podsols indicate that soil tilling in connection with clearlogging will persistently diminish the soil SOC stock on average by 10-15 %, with a more profound effect in the middle and northern boreal forest zones. This observation contradicts the figures of steadily increasing mineral soil forest SOC reported for the IPCC from Finland. The 'official' estimate is actually based on a SOC model, which does not take into account the change of original soil C store due to tilling.
The results seriously contradict the alleged climate neutrality of the intensive forestry practices currently conducted in Finland.
Keywords: Podsols, histosols, forest soils, SOC, soil tilling, ditch-draining, Finland

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Timber growth in the Finnish forests has been steadily increasing due to intensive forestry practices, including soil treatments, applied during the past decades throughout the country. Soil treatments has extensively affected both podsols (predominant conifer forest soil type on dry mineral grounds) as well as histosols (peat soils on moist and waterlogged sites). Some 30 % of forest podsols, or 58,000 sq km, have been variously tilled after clearcutting throughout the country since the 1970s. About 60,000 sq km of peatlands have been ditch-drained for forestry; thus, more than 80 % of the original peatlands in the southern and middle parts of the country have been affected.
Regular forest resource inventories were started in Finland already in the 1920s, and the ongoing inventories provide detailed data on the timber stocks and flows, published annually by the Natural Resources Institute, Finland (https://www.luke.fi/en/natural-resources/forest/forest-resources-and-forest-planning/). However, the forest soil organic carbon (SOC) pools are much less precisely accounted for, even though these are considerably larger than those of the tree stock.
I have studied the effect of ditch-draining on the carbon balance of peatlands with my colleagues (Pitkänen *et al*. 2012, 2013, Simola *et al*. 2012), and recently the effects of podsol tilling on mineral soil forests (Simola, submitted manuscript 2017). Our results indicate considerably larger forestry-related SOC losses from both peat and podsol soils than those officially reported for the IPCC for the Finnish LULUCF sector (e.g.:
http://mmm.fi/documents/1410837/1867349/Information_on_LULUCF_actions_FINLAND_final_1.pdf/89fc7c83-ebe9-444a-8deb-ca0c3c08ff8b).

METHODOLOGY

Analyses of ditch draining effects on peat soil SOC
We studied SOC inventory changes on forestry-drained peatlands by re-sampling the peat stratum in 2009 at the precise locations of quantitative peat mass analyses conducted as part of peatland transect surveys during the 1980s. Altogether 37 sites were precisely located by GPS and the entire peat profile of these were cored quantitatively (Simola *et al*. 2012). The

old and new profiles were correlated mainly by their ignition residue stratigraphies; at each site we determined a reference level, identifiable in both profiles, and calculated the cumulative dry mass and C inventories above it.

Using an alternative approach, we analyzed, by similar quantitative methods, adjacent pairwise peat profiles collected from both sides of a ditch demarcating the natural (undrained) and the in the 1970s drained half of an eccentric raised bog in East Finland (Pitkänen *et al*. 2013).

At all the study sites, we also investigated the apparent dynamics of growth and degradation of the surface peat strata by pine seedling root collar analyses (for further details, see Pitkänen *et al* 2012).

Mineral soil (podsol) studies

Effects of forest floor tilling on the soil carbon content were studied at sites where an old natural forest stand is bordered by a younger stand regenerated by clearcutting. Altogether 93 study sites were investigated across the entire Boreal forest zone in Finland (latitude range 59° 57' – 68° 25' N, elevation range 2—390 m a.s.l.). The study sites were selected from aerial photographs so as to represent the various mineral soil treatments customarily applied in Finnish forestry (ploughing, mounding, disc trenching, patch scarification, or no soil preparation). Most of the sites were located at the margins of nature protection areas; in northern Lapland some strip-felling sites were also included. At each site, 20 topsoil cores were taken from both the old forest stand and the adjacent regeneration stand with a 10-cm^2 sampler, down to the uppermost mineral layer, and their organic matter (OM) contents were determined as loss-on-ignition.

RESULTS

Peat profile analyses

Comparison of the re-sampled profiles, with a total of 37 locations, revealed broad variation, from slight increase to marked decrease of SOC; on average the 2009 results indicate a loss of 7.4 (SE ± 2.5) kg m^{-2} dry peat mass when compared with the 1980s values. Expressed on an annual basis, the results indicate an average net loss of 150 g C m−2 year−1 from the soil of drained forestry peatlands in the central parts of Finland. The C balance appeared not to correlate with site fertility (fertility classes according to original vegetation type), nor with post-drainage timber growth. A similar magnitude of C loss was observed for the partially drained mire: on average 131 +/- 28 g C m^{-2} yr^{-1} (mean +/- SE).

Podsol profile SOC investigation

The total material included 93 sites. In order to exclude the short-term OM increase due to logging residue, the main conclusions are drawn from those 75 sites that were aged over ten years since the logging: 48 sites with soil tilling (age range 11—40 years) and 27 non-tilled sites (16—100 years). In nearly 80 % of the tilled sites, the soil OM content had decreased in comparison with the adjacent old forests; non-significant OM increase was observed in a few of the tilled sites due to paludification. As for clearcuts without soil treatment, an average loss of only 300 g OM m^{-2}, or 3.9 %, was observed; the difference between tilling and non-tilling is statistically significant (RMANOVA).

The average OM decrease for all the >10-year tilled sites is 1 260 g OM m^{-2}, corresponding to about 15 % decline from the old-forest level. The effect of tilling on SOC decline is more profound in the northern parts of the country (Middle and Northern Boreal forest zones).

DISCUSSION

Our published carbon inventory studies of forestry-drained peatlands (Simola *et al*. 2012, Pitkänen *et al*. 2013), summarized here, point to a large error in the Finnish GHG accounting. We conclude that the carbon emissions from forestry-drained peatlands in reality would be some 9 Tg C a^{-1} (33 Tg CO_2 a^{-1}), or about 3.5 times higher than the figures currently reported for that land-use category (Ministry on Agriculture and Forestry 2014).

Our root collar study (Pitkänen *et al*. 2012), conducted at the same sites as the present investigation, demonstrates that apparent C accumulation usually takes place at the soil surface, even when the net C balance of the entire peat deposit is negative.

Regarding the podsol forest soils, the big losses from tilled sites as compared with the non-tilled ones points to a fundamental change in soil quality and persistent decline of soil carbon stocks caused by tilling. Based on the current forest floor tilling rate in Finland (1200 km^2 annually), a rough estimate of CO_2 emissions in the order of 2.8 Tg $a^{-1,}$ and a total of some about 130 Tg CO_2 emitted since the 1960s (about 58 000 km^2 of forests tilled so far), can be concluded.

The observed persistent 15% decline of soil carbon stocks, due to the routinely performed soil tilling in connection of clearlogging, clearly contradicts the figures of steadily increasing mineral soil forest SOC reported for the IPCC from

Finland. The 'official' estimate, claiming climate neutrality or even climate benefits for the intensive forestry currently practiced in Finland, is actually based on a SOC model (YASSO07; see Tuomi *et al* 2011), which does not take into account the change of original soil C store due to tilling.

CONCLUSIONS

The results of recent podsol and peat SOC balance change studies, summarized above and presented and discussed in more detail in the referred publications, seriously contradict the alleged climate neutrality of the intensive forestry practices currently conducted in Finland.

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3.1.13 | PEATLAND RESTORATION IN RUSSIA FOR REDUCTION OF CARBON LOSSES AND GREENHOUSE GASES EMISSIONS: THE EXPERIENCE OF LARGE SCALE REWETTING PROJECT

Andrey Sirin[1*], Gennady Suvorov[1], Maria Medvedeva[1], Tatiana Minayeva[1,2], Hans Joosten[3], Irina Kamennova[5], Aleksandr Maslov[1], Anna Vozbrannaya[5], Maxim Chistotin[6], Anastasiya Markina[1], Dmitry Makarov[1], Tamara Glukhova[1], John Couwenberg[3], Marcel Silvius[2], Jozef Bednar[2], Jan Peters[4], Irina Kamennova[5],

[1]ICenter for Peatland Protection and Restoration, Institute of Forest Science Russian Academy of Sciences, sirin@ilan.ras.ru, Russian Federation
[2]Wetlands International, The Netherlands
[3]Greifswald University and Greifswald Mire Centre, Germany
[4]Michael Succow Foundation, Germany
[5]Meschera National Park, Russian Federation
[6]All-Russia Research Institute of Agrochemistry, Russian Federation
[7]Wetlands International Russian Programme, Russian Federation

ABSTRACT

Large areas of peatlands that were drained for agriculture and used for peat extraction in European Part of Russia were left abandoned with CO_2 emissions and high fire risks. Rewetting could return peat soils to their original water-logged state prevent their vulnerability to fires and peat oxidation. The project "Restoring Peatlands in Russia – for fire prevention and climate change mitigation" is aimed to prove effect for climate change mitigation of over 70 thousand hectares of drained abandoned peatlands, rewetted after severe fires of 2010. Different methods based on remote sensing were developed to map peatlands, to assess their conditions, to bind emission factors and carbon data, to evaluate rewetting effectiveness both for fire prevention and GHG assessment. The scientific and practical results of this large-scale project could be expanded to other restoration projects, help further development of methodologies for GHG inventories under UNFCCC and IPCC, and support integration of restoration projects into an economically derived climate change mitigation and adaptation national programs.

Key words: carbon losses, climate change mitigation, greenhouse gases, peatlands, removal, restoration, rewetting

INTRODUCTION

Peatlands occupy more than 8% and, together with paludified shallow-peat lands (peat <0.3 m), occupy even more than 20% of the Russian Federation (Vompersky et al. 2011, etc.). Peatland use has long tradition in Russia: in European part alone the total area of peatlands drained for peat extraction, agriculture, and forestry reached several millions of hectares (Minayeva, Sirin, 2005, Minayeva et al. 2009). Several hundreds of thousands of hectares have been subject to milled peat extraction. Now, such areas are poorly overgrown by vegetation and are subject to water and wind erosion, significant carbon loss and the highest fire danger (Sirin et al. 2011). Vast areas were drained for agricultural purposes, but later largely taken out of service. Milled cut-over peatlands require after-use reclamation. Previously, Soviet standards required reclamation of extracted peatlands for after-extraction utilization (agriculture, forestry, etc.). After the economic changes in the 1990s many half-depleted peatlands were left abandoned without reclamation. They are concentrated mostly in the central part of European Russia (Moscow Region is leading) and are the sites with the largest fire hazard, what became apparent by severe peat fires in 2002 and especially in 2010 (Sirin et al. 2011). Nowadays prevention of peat fires which are a natural phenomenon within the boreal and other zones (Minayeva et al. 2013), but which can occur with increased probability and frequency due to climate change, is nowadays the main driver for peatland restoration in Russia (Sirin et al. 2011). The project "Restoring Peatlands in Russia – for fire prevention and climate change mitigation" (the PeatRus Project) financed under the International Climate Initiative (ICI) by the German Federal Ministry for the Environment, Nature

Conservation, Building and Nuclear Safety (BMUB) is aimed at climate change mitigation and adaptation by restoration of several dozen thousand hectares of drained abandoned peatlands. The project activities are linked to the governmental programme (2010-2013) of rewetting of more than 73,000 ha of fire hazardous abandoned drained peatlands, initiated after severe fires in 2010. The leading project partners are: Wetlands International, Michael Succow Foundation, Greifswald University and the Institute of Forest Science of the Russian Academy of Sciences. The project is supported by the Ministry of Nature Resources and the Environment of the Russian Federation (MNR Russia) and Governments of Moscow, and other provinces.

Inventory of peatlands

Vast, often impassable, peatland areas require reasonable methods to assess and to monitor their conditions and fire hazard status, to support prioritization for restoration, and to test the effectiveness of rewetting and restoration measures for climate change mitigation and for other purposes. Methods for peatland mapping, classification of their land cover, GIS and monitoring system based on Earth Observation (EO) data have been developed and verified. Peatlands, including those transformed by peat extraction, agriculture, forestry, belong to various land categories in Russia, and there is no general system for their inventory and accounting. Remote sensing methodology based on high-resolution (Spot 5) space imagery and supported by various available sectorial (peat geology, forestry, etc.) and cartographic data was introduced and approved for mapping of over 250 thousand hectares of peatlands in the Moscow Province (Sirin et al. 2014), and it can be also used for various scientific and practical tasks, which need development of regional GIS for peatlands. The results of mapping were used to pinpoint peatland fires occurring in 2010 from the archival data, and to evaluate the extent of burned peatland area.

Peatland mapping creates the background for more accurate classification of peatland's vegetation/land cover by cutting off adjacent non-peat areas which could have similar spectral characteristics. The classification approach was developed on the basis of the National park “Meschera” (Vladimir Region) and led to identification of 6 classes: bare peat; sparse willow-herb, reed and birch-reed communities; communities dominated by pine; communities with willow and birch; hydrophilic communities with cat-tail, tall sedges and reed; open/sparsely vegetated water surfaces (Medvedeva et al. 2011). The approach was further tested using different EO data as Spot-5 HRG, Spot-6 HRG, UK-DMC2 MSI and Landsat-7 ETM+ (Landsat-8) satellite images (Medvedeva et al. 2017). The verified methodology was used to monitor and assess status of 73 thousand ha of rewetted peatlands in the Moscow Region.

Assessment of carbon losses and GHGs emissions removal

Significant progress has been made over the last years with respect to estimation of emissions of GHGs from drained peatlands. Combining the latest national inventory reporting to the UNFCCC with the newest IPCC emissions factors (2014) shows that annual greenhouse gas emissions from peat oxidation in drained peatlands worldwide amount to 1.5 Gt of CO_2-eq (excl. emissions from peat fires which may contribute on average another 0.5 Gt). The largest emitters from drained peatlands are Indonesia, the European Union and the Russian Federation; respectively, 27 countries (incl. 14 countries in Europe) being responsible for 95% of all emissions. Long-term studies in the Moscow Region (Russia) show that CO_2 emissions from abandoned peat extraction sites have resulted in carbon losses from 1.6 to 4.7 mg C/ha, depending on the year. This means that the amount of uselessly mineralized peat lost over 10 years would be comparable with annual rate of milled peat production. A lesser limit for C losses due to CO_2 emissions from unused agricultural land (hayfield) was estimated for one year at 0.8 mg C/ha (Suvorov et al. 2015). These estimates do not consider C losses by wind and water erosion, by peat fires. The methodological background for the GHG accounting applied in the project is derived from the recent UNFCCC processes and the updated 2013 (2014) IPCC Wetlands Supplement. The calculations of the reductions of emissions resulting from the rewetting projects in the Moscow Province included three elements: reductions as a consequence of changes in peatland classes' ratio; reduction due to changes in area of ditches; reduction as a consequence of peat fires. As the process to obtain emission factors based on local measurements is not yet complete, more general emission factors had to be used such as those from IPCC guidelines and literature (IPCC 2014, Wilson et al. 2016). Hence, the EFs used in the current study could slightly be altered after studies on local fluxes based on chamber and Eddy Covariance measurements is finalized. Within the project activities the results of national observations will be integrated into the existing vegetation-based Central European GEST model (Couwenberg et al. 2011). The largest carbon losses were found in relation to peat fires (Makarov et al. 2015) and refer to main benefits of rewetting for climate change mitigation.

CONCLUSIONS

The large-scale rewetting demands an integrative approach to planning, implementation, monitoring and adaptive management. The PeatRus Project is the testing ground for development and implementation of the methodology based on the integrative approach. The scientific and practical results obtained could be expanded to other restoration projects, could contribute to further development of methodologies for GHG inventories under UNFCCC and IPCC, and could enhance integration of restoration projects into economically driven climate change mitigation and adaptation national programs.

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3.1.14 | DIMINISHING PEAT OXIDATION OF AGRICULTURAL PEAT SOILS BY INFILTRATION VIA SUBMERGED DRAINS

J.J.H. van den Akker* [1], R.F.A. Hendriks[2]

[1] janjh.vandenakker@wur.nl, Wageningen Environmental Research, Wageningen University & Research
[2] Wageningen Environmental Research, Wageningen University & Research

ABSTRACT

Oxidation of peat soils used in dairy farming in the western peat area of The Netherlands causes subsidence rates up to 13 mm.y^{-1} and emissions of CO_2 to about 27 t.ha^{-1}.y^{-1}. In 2003 experiments started with subsurface irrigation by submerged drains to raise groundwater levels to reduce oxidation and so subsidence and GHG emissions. Subsidence and so CO_2 emissions were reduced with at least 50% and the trafficability improved. The advantages of submerged drains for dairy farmers beside the reduction of subsidence are the improved trafficability, reduced drought risk and reduced loss of grass yield in wet periods by trampling. This makes for dairy farmers the use of submerged drains an acceptable solution in contrary to the often suggested solution to raise ditchwater levels. This acceptance by dairy farmers makes submerged drains a promising tool to preserve the valued cultural historic peat soil landscape.
Keywords: peat soils, subsidence, oxidation, submerged drains, GHG emissions, climate addaptation

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

In the introduction, state the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.]
About 9% of the area of the Netherlands is covered by peat soils (about 290,000 ha), mainly drained and in use for dairy farming (about 223,000 ha). Peat soils in the densely inhabited western part of the Netherlands are valued as an open landscape with a rich cultural history, which should be preserved. About 40 years ago a strong modernization and mechanization of dairy farming started. This required improvement of drainage conditions and bearing capacity of peat soils in agricultural use and therefore in large areas ditchwater levels were lowered several decimeters. The lowering of ditchwater levels caused a strong increase of subsidence of the peat soils. The major part of peat soils in the western part of the Netherlands is in use as permanent pasture with ditchwater levels up to 60 cm minus surface. Organic soils above groundwater level are exposed to the air and decompose. This causes a subsidence of 8 – 12 mm per year and emission of greenhouse gasses, mainly CO_2. Subsidence of one centimeter per year equates to an emission of about 22 tons of CO_2 per hectare per year (Van den Akker et al., 2008). Van den Akker et al. (2008) calculated an emission of 4.25 Mtonne CO_2 per year for the agricultural peat soils in the Netherlands. Per ha this is about 19 tonne CO_2 per year. The total CO_2 emission per year by oxidation of peat soils in agricultural use is about 2.5 % of the national anthropological CO_2 emission of the Netherlands.
In the Netherlands every 10 years ditchwater levels are lowered about 10 cm and so adapted to the subsidence. However, in this way also groundwater levels are lowered about 10 cm. In time the upper part of wooden foundation piles are exposed to oxygen and start to rot. In this way subsidence causes damage to infrastructure and buildings. Because the subsidence is not the same everywhere, water management becomes ever more complex and expensive. Many wetlands become difficult to preserve as “wetland” because subsidence of adjacent drained agricultural land results in ‘islands of peat’ surrounded by lower elevation agricultural lands. The higher wetlands drain towards the lower agricultural land, become too dry and degrade. In a time with raising sea levels, it is also not wise to allow subsidence rates of one cm per year.

The problems caused by subsidence of peat soils together with the increasing interest in GHG emissions and eutrofication of surface waters by degrading peat soil was reason to start in 2003 the EU funded project EUROPEAT (QLK5-CT-2002-01835) with the aim to identify degradation processes of agricultural peat lands and find ways to diminish peat land degradation (Van den Akker et al., 2008, Van den Akker, 2010). Research on infiltration of ditchwater via submerged drains to raise groundwater levels in summer to conserve peat land started end of 2003 in the EUROPEAT project. The aim was to halve subsidence and CO_2 emission in this way.

In this paper we focus on the measurements of subsidence, and so indirect on CO_2 emission and on the expected extra supply of inlet water due to the improved infiltration by submerged drains.

METHODOLOGY

To test whether subsurface irrigation with drainage tubes (see Figure 1) will indeed reduce subsidence and so emission of CO_2 of peat soils, we started in autumn 2003 with installing submerged drains on two parcels (Zegveld 2 and Zegveld 3) on a fen peat soil without a thin clay cover. Distances between the drains were 4, 8 and 12 meter. As a reference in a part of the parcels no drains were installed. On Zegveld 3 we monitor already from 1970 on the surface level of the reference part of the parcel. The long term subsidence of Zegveld 3 is 10.8 mm per year. The ditchwater level is 55 cm below the surface level.

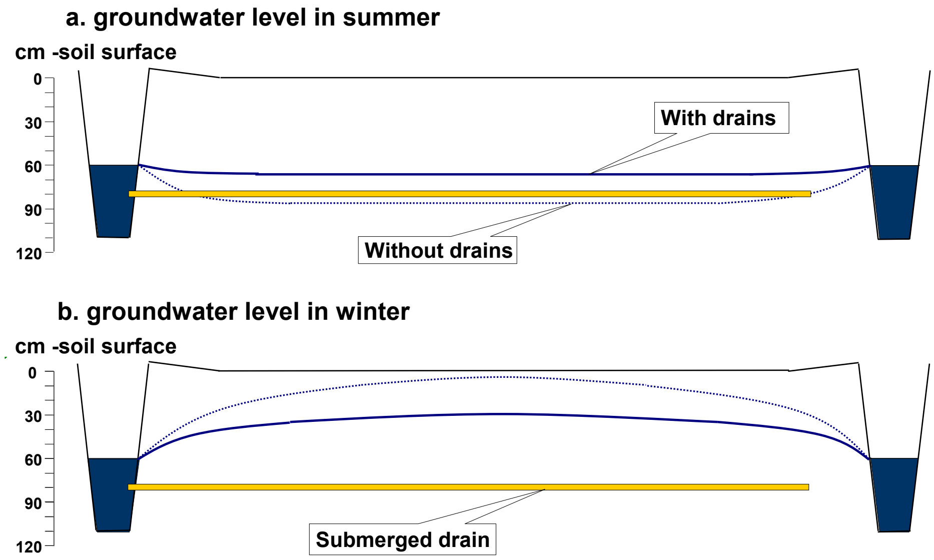

Fig. 1: Reduction of peat oxidation and subsidence and CO_2-emissions by raising groundwater levels with infiltration via submerged drains in summer level. In wet periods the submerged drains will function as drainage.

Starting in early spring 2004 the surface level was measured in three cross sections. In the reference the distance between the cross sections was 10 m. In the plots with submerged drains the cross sections were situated in the middle between two submerged drains. The measurements were performed in early spring, just before the grass starts to grow and to evaporate soil water. At that moment the swell of the peat is at his maximum. In this way we avoid as much as possible that we measure subsidence due to temporally drying shrinkage of the peat, which can be more than 10 cm at the end of a dry summer.

RESULTS

The results of Zegveld 3 are presented in Figure 2. The subsidence in the period 2004 – 2015 is strongly influenced by the fact that 2003 was a very dry year and that the summers in the period 2004 – 2015 were all moderately or very wet. This means that the soil was not completely rewetted and swollen in spring 2004 and had a potential of swelling in the following moderately or very wet years. These specific circumstances resulted in a subsidence rate of the reference of just 5.2 mm per year, while the long term subsidence is 10.8 mm. The effect of the large swelling potential after the dry year 2003 becomes also clear in the situation with drains at a distance of 4 meter: the subsidence rate is just 2.5 mm per year and in spring 2008, after the very wet year 2007, the level of the soil surface is even higher than in spring 2004. It is clear that the subsidence rate of the reference is about twice the subsidence rate of the parcel area with drains at distances of 4 meter.

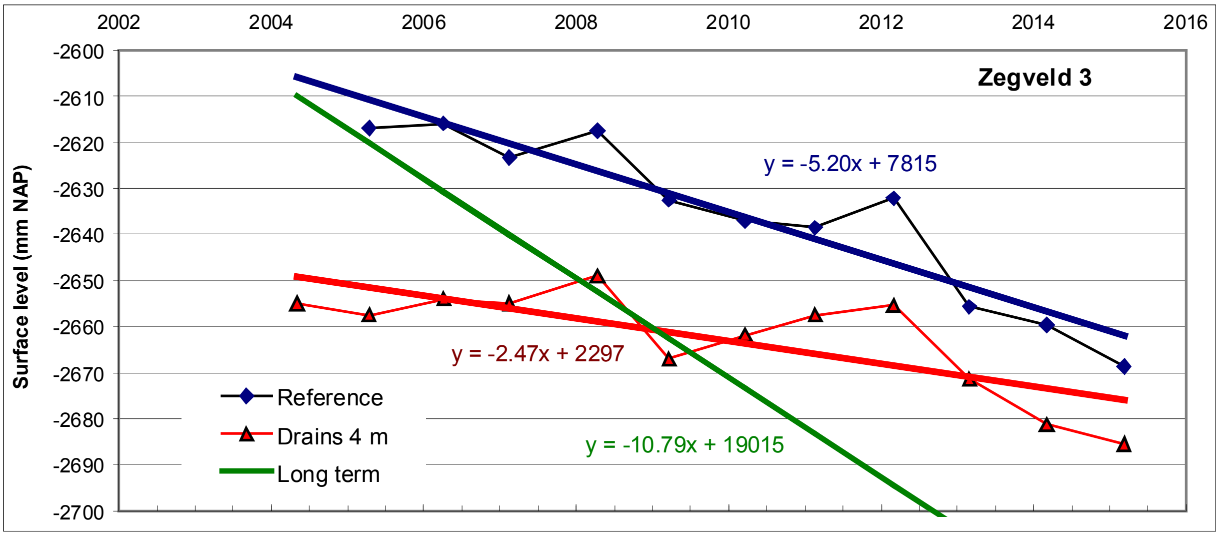

Fig. 2: Subsidence 2004 – 2015 of peat soil without submerged drains (Reference) and with submerged drains at a distance of 4 meters (Drains 4 m). The long term subsidence is 10.8 mm per year. NAP = the Dutch national reference level, which is about the average sea water level.

DISCUSSION

The effect of the very dry year 2003 and the wet summers of 2004 – 2015 on the subsidence rate is pronounced and requires a longer period of monitoring. In fact we would like to include some very dry years because then we expect to benefit most from the infiltration of ditchwater to reduce peat oxidation. Nevertheless the results are convincing and the use of submerged drains to minimize subsidence is promising because even without dry years the subsidence is halved. This makes it rather sure that the aim to halve the subsidence and CO_2 emission can be fulfilled.

The PBL Netherlands Environmental Assessment Agency investigated in a recent report (Van den Born et al., 2017) possible measures to reduce subsidence and CO_2-emissions. The study shows that subsurface irrigation by submerged drains in agricultural areas leads to a halving of subsidence without exerting negative effects on grass yields. The measure preserves agricultural features and improves the outlook for dairy farming on peatland. This measure is at the moment directly suitable for at least 40% of the peatlands and is an economical feasible measure for the dairyfarmers and for the society as a whole. The measure is also appropriate for areas with deeper ditchwater levels if ditch water levels are raised. In that case peat oxidation can be reduced to about a quarter of the original oxidation, while the drainage function of the submerged drains prevent that the peatland becomes too wet.

Farmers are firmly opposing the often suggested raising of ditchwater levels, however, are positive about the use of submerged drains for subsurface irrigation. Raising ditchwater level reduces trafficability and increases the risk of trampling by cows, while the use of submerged drains has the opposite effect. Farmers also appreciate the fact that the use of submerged drains makes farm management easier and reduces the problems in case of long wet periods. Therefore we have good hope that submerged drains will be widely adopted in practice.

CONCLUSIONS

The use of submerged drains can reduce peat oxidation and subsidence and CO_2-emissions of peatlands in agricultural landuse with at least 50%.
The fact that the use of submerged drains is an acceptable solution for dairy farmers and no landuse change is required makes the introduction of the measure relatively easy.

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THEME 3.2 | MANAGING SOC IN GRASSLANDS, AND LIVESTOCK PRODUCTION SYSTEMS

3.2.1 | LAND COVER AND LAND USE CHANGE DRIVEN CHANGE OF REGIONAL SOIL ORGANIC CARBON STORAGE IN CROPLANDS AND GRASSLANDS OF NORTH-EAST SLOVAKIA

Rastislav Skalský[1], Gabriela Barančíková[1*], Štefan Koco[1], Jarmila Makovníková[1], Zuzana Tarasovičová[1], Ján Halas[1], Peter Koleda[1], Monika Gutteková1 & Jozef Takáč[1]

[1] National Agricultural and Food Centre, Soil Science and Conservation Research Institute, Gagarinova 10, 827 13 Bratislava, Slovakia

ABSTRACT

Soil organic carbon (SOC) is mostly accumulated in topsoil and therefore sensitive to change in land cover and land use. This impact can be amplified when SOC storage is quantified across the regions instead of single sites. Effective way how to estimate regional SOC storage is coupling SOC turnover models with spatial data. The RothC model was used in this study together with national-coverage legacy soil data on soil dating back to 1970, land cover, and land use data with the goal to reconstruct current SOC storage in the *Ondavská Vrchovina* region. Estimated initial SOC stock in cropland and grassland was 4.21 Mt in 1970. It increased of 22.6 % between 1970 and 2013 to current value of 5.16 Mt. It was found that the SOC storage development trajectory was affected by both land cover change and the quantity of organic carbon coming to soil; the latter buffering negative impact of grassland to cropland conversions but the same time limiting possible positive impact of cropland to grassland conversions. The approach presented in this study allows for direct up-scaling for national-scale SOC storage estimates.

Keywords: RothC, gridded SOC model, legacy soil data, National soil inventory data

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Soil organic carbon (SOC) is mostly accumulated in top soil layers and therefore sensitive to land cover change and change in management practices. Conversion of grassland to cropland can lead to significant SOC loses in semi-natural ecosystems, whereas in intensively managed agro-ecosystems it is biomass removal, low input of plant residua, insufficient supply of organic fertilizers, and tillage practices leading to possible SOC loss. This could be amplified if impacts of land cover and land use change on SOC storage are summarised across the regions rather than individual sites. Possible way how to detect changes in SOC over larger regions is process-based modelling. The RothC model (Colleman & Jenkinson, 2014) requires only limited number of easy-to-obtain inputs which makes it very applicable for regional studies covering the range from local to global scales. It also was proven well respond to soil management making it good tool for analysing impacts of land use on SOC stock. National agricultural soils inventory in Slovakia was finished in 1970 and produced polygon soil maps and measured soil profile data (Němeček *et al.,* 1967). An attempt was done to estimate current SOC stock in agricultural soils from initial SOC stocks around 1970 with RothC model and historical records on weather and crop management (Barančíková *et al.,* 2010, 2012). Given the spatial resolution of gridded data used to run the model (10k) and ignoring land cover change during the simulation period the outputs gave only very general and rough estimate. Here we focus on the cropland and grassland SOC stock change in the 3129.00 km^2 big highland region in eastern Slovakia (*Ondavská Vrchovina* mts.) between years 1970 and 2013. This region was subject of many land cover and land use changes with cropland to grassland (and vice-versa) conversions and varying intensity of crop management, both responding to socio-economic and political developments in Slovakia. Building upon our earlier work in this region (Koco *et al,*. 2016) in which we introduced a set of theoretical soil management scenarios to mimic real land use change, we make a step forward with combining initial SOC stocks around 1970, historical record on land cover change, and theoretical land use scenarios to come up with estimates of current SOC stock in 1k spatial resolution. We also analyse the impacts of land cover and land use on regional SOC stock.

METHODOLOGY

The Rothc-26.3 model (Coleman & Jenskinson, 2014) is a model of the turnover of organic carbon in non-waterlogged soils accounting for type of soil, weather, plant cover and input of organic carbon to the soil.

All data necessary to run the RothC model were organized within the 1k spatial resolution grid yielding simulation units (SimU) with unique combination of weather, soil, land cover, and land use and their corresponding areas. Monthly annual means for years 1970 – 2013 on temperature, sum of rainfall, and sum of potential evapotranspiration (estimated by Penmann-Moneith method) were allocated to each SimU from three WMO weather stations (WMO 11993, WMO 11976, and WMO 1977). Cropland and grassland areas were taken from national Land Parcel Identification System (LPIS) for 2003 and 2013, or were interpreted from Landsat 5, Landsat 4, and Landsat 7 imagery for years 1994 and 1986. Cropland and grassland areas for starting year 1970 were interpreted from 1:10k scale historical topography maps. The LPIS 2013 borders were kept constant throughout whole modelling time period. Seven unique combinations of soil type and land cover class were identified based on topsoil SOC content from 1308 measured soil profiles and subsequently used to allocate land cover specific topsoil (0 – 30 cm) SOC densities [$t.ha^{-1}$] and clay content to all SimU via polygon data on soil type and land cover class in 1970. The SimU and year specific yearly quantities of organic carbon coming to soil from plant residua and farmyard manure were estimated from variety of input data including regional (NUTS2, NUTS4) statistical data on crop yields, farmyard manure production, and number of animals and LPIS dataset (Table 1). Theoretical scenarios of cropland to grassland and grassland to cropland conversions in respective years 1971, 1980, 1990, and 2000 and organic carbon input quantities associated (Table 1) were taken to mimic real changes of land use during the simulation period (Koco *et al.,* 2016). The RothC model simulations were done for combination of all SimU and scenarios between years 1970 and 2013. Simulated SOC densities [$t.ha^{-1}$] were then used for calculating SimU and land cover specific SOC storage [Mt] in five distinct time intervals based on observed land cover change (1970, 1986, 1994, 2003, and 2013).

Table 1: Land cover specific organic carbon input into the soil [$t.ha^{-1}$] from crop residua and farmyard manure in the period 1970 – 2013 as averaged across all SimU (Explanations: CPR – organic carbon from crop residua, C_FYM – organic carbon from farmyard manure)

	cropland [tC/ha/y]			grassland [tC/ha/y]		
decade	C_PR	C_FYM	C_PR+ C_ FYM	C_PR	C_FYM	C_PR+ C_FYM
1970 - 1980	1,74	0,54	2,28	2,88	1,07	3,95
1981 - 1990	1,64	0,54	2,18	2,88	1,17	4,05
1991 - 2000	1,75	0,53	2,28	2,09	0,66	2,75
2001 - 2013	2,62	0,57	3,19	1,77	1,07	2,84

RESULTS

Total agricultural area in *Ondavská Vrchovina* region between 1970 and 2013 was 1072.5 km^2 with cropland area being 655.8 km^2 and grassland area 416.7 km^2 at the beginning of the simulation period (1970). Due to the land cover conversions it changed to current values in 2013 of 486.4 km^2 and 586.1 km^2 in cropland and grassland respectively. Cropland area initially extended in 1986 to its recorded maximum (709.7 km^2) and then subsided in 1994 and 2003 close to current values, corresponding to maximum extent of grassland 602.5 km^2 recorded in 2003. In the last decade slight increase of cropland area was observed again (Fig. 1). Initial estimated SOC storage in the *Ondavská Vrchovina* region was 4.21 Mt with cropland contributing 2.57 Mt and grassland contributing 1.64 Mt; the quantities mostly reflecting the ratio of cropland and grassland areas (Fig. 1). The SOC storage development over the simulation period had increasing trend before 1994, then kept balanced with only slight decrease in 2003. Current SOC storage estimated for 2013 was 5.16 Mt, with cropland contributing 2.34 Mt and grassland contributing 2.86 Mt (Fig. 1). Net SOC gain of the region between the years 1970 and 2013 was 0.95 Mt which represent 22.6 % of initial SOC storage in 1970. The SOC storage trajectories of cropland and grassland followed in general observed change in cropland and grassland areas; with 8.9 % decrease and 74.4 % increase of initial SOC storage in cropland

and grassland, respectively. Current SOC storage estimated for 2013 in case of the scenario without any land cover change was 5.18 Mt, with cropland contributing 3.12 Mt and grassland contributing 2.06 Mt (Fig. 1).

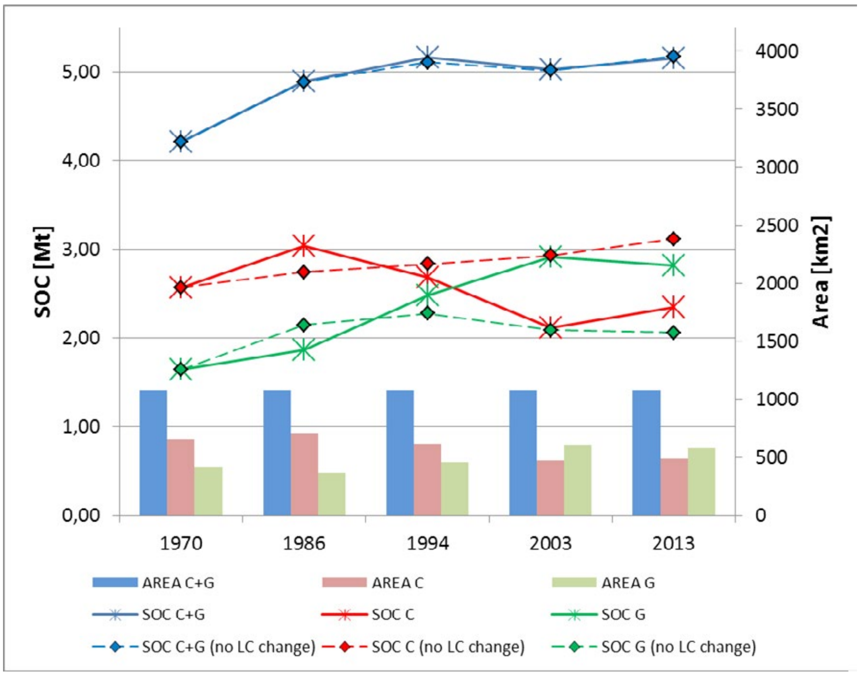

Fig. 1: The SOC storage and corresponding cropland and grassland areas as estimated for the Ondavská Vrchovina region for the years with observed land cover change (Explanations: C – cropland, G - grassland)

DISCUSSION

Increasing trend of SOC storage over the last 54 years which was simulated with RothC model in the *Ondavská Vrchovina* region was also reported by Barančíková *et al.* (2010) in their study about SOC stock development in Slovakia after 1970 using both the RothC modelling and independent set of measured soil profile data covering period of 1970 – 2007. Increase of SOC stock in topsoil during last fifty years was also simulated by Kaczynski *et al.* (2017) with reconstructed land use and theoretical scenarios in southwest Poland. Similarly, slight SOC stock increase in last thirty years was also shown for different climate conditions in northeast of Spain by Alvaro-Fuentes *et al.* (2011). It is obvious, that the quantities of land cover conversions – 25.83 % decrease of cropland area and 40.65 % increase of grassland area in *Ondavská Vrchovina* region do not fully correspond to those of SOC storage (with 8.9 % decrease in cropland and 74.4 % increase in grassland). The amount of organic carbon coming to soil from the management (Table 1) played also an important role. Although it makes only slight difference in total SOC storage values (5.16 Mt compared to 5.18 Mt in 2013), there is an obvious shift in cropland and grassland SOC storage development trajectories with and without land cover change assumed (Fig. 1).The SOC storage trajectories in case of no land cover change responded clearly to organic carbon inputs to the soil, this leading to 21.4 % and 25.5 % increase of initial SOC storage over the modelling period in cropland and grassland, respectively. After 1994 the SOC storage in *Ondavská Vrchovina* region was affected by the land cover and the land use change acting in opposite directions. Although cropland was continuously subsiding in area, its organic carbon inputs kept growing at the end which well buffered potential SOC loss. On the contrary, the adverse effect of decreased amount of organic carbon inputs to grassland after 1994 caused SOC storage loss in existing grassland areas as well as it weakened otherwise very positive impact of cropland to grassland conversion.

CONCLUSIONS

The SOC storage in topsoil of cropland and grassland soils in *Ondavská Vrchovina* region was simulated over the period of 1970 – 2013 with RothC model and national-scale legacy soil data, weather data, and time record of land cover and land use change; all data organized within the 1k spatial resolution grid. Estimated initial SOC stock in croplands and grasslands was 4.21 Mt in 1970 which increased till 2013 of 22.6 % to current estimated value of 5.16 Mt. The SOC storage development between 1970 and 2013 was affected by both the land cover change and the quantity of organic carbon coming to soil under cropland or grassland management. Management intensity also buffered negative impact of grassland to cropland conversions, as well as it limited possible positive impact of cropland to grassland conversions; this mostly after 1994. The approach presented in this study can be up-scaled to national scale for estimating current levels of SOC storage in croplands and grasslands of Slovakia.

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3.2.2 | CARBON SEQUESTRATION POTENTIAL IN THE SAVANNAS ECOSYSTEMS OF VENEZUELAN FLATLANDS

R.M. Hernández-Hernández[1], D. Acevedo[2], L. Sarmiento[2].

[1]Instituto de Estudios Científicos y Tecnológicos IDECYT. Centro de Agroecología Tropical, Laboratorio de Biogeoquímica, Universidad Simón Rodríguez, Miranda, Venezuela. rodama33@yahoo.com.mx
[2]Instituto de Ciencias Ambientales y Ecológicas (ICAE), Universidad de Los Andes, Mérida, Venezuela. dimas@ula.ve y lsarmien@ula.ve

ABSTRACT

The flatlands occupy 28% (25Mha) of Venezuela. They are dominated by ecosystems of savannas with different landscapes, soils, and vegetation adapted to acid soils, low fertility and subjected to frequent fires. Historically, they are predominantly used as extensive cattle ranching. Nevertheless, the agricultural use has been intensified at the expense of many natural savannas. These land use changes may affect the storage and the potential for C sequestration in their soils. Through an extensive review of literature of the soils in the Venezuelan flatlands, we calculated the stocks of soil C for each major landscape, ecosystems and land use type, by using existing data on C content (%), bulk density and extent, down to a depth of 0-30 cm. The C contents increase from the eastern drier flatlands to the more humid and younger western flatlands, and from seasonal to hyperseasonal and semiseasonal savannas. The poorly drained plains, about 20% of the flatlands, store the highest C (323.8 Tg C). In well drained savannas, introduced pastures increased the storage. If all the flatlands were covered with well managed pastures, it would have a potential of sequestration of around 0.54 Pg C.

Key words: sequestration of C; Venezuelan flatlands; savannas; farming systems.

INTRODUCTION

The Neotropical savannas are ecosystems that cover approximately 269 Mha in South America. They constitute one of the most extensive areas with potential to increase different kinds of agricultural production. These savannas are located in Brazil (204 Mha), Venezuela (25 Mha), Colombia (23Mha), Bolivia (13 Mha) and Guyana (4 Mha). They generally are defined by perennial grasses with disperse woody species, where water availability follows a seasonal pattern. The savannas of Brazil and Guyana have evolved from ancient Precambrian shields, while the flatlands of Venezuela, Colombia and Bolivia are formed mostly from younger quaternary sediments from the Andes.

In Venezuela, the savannas occupy around 25 Mha or 28% of its territory. They are dominated by grasses that growth in dystrophic soils. Well drained soils are predominant, but there are also extensive areas with poor drainage during the rainy season, with different adapted pastures. All soils are subjected to a dry season (4 to 6 months) and a wet season for the rest of the year. Other factor important in its formation and functioning is the recurrent anthropic fires during the dry season.

Due to the low quality of the native pastures, the most extended type of land use is extensive grazing. But in the last decades, it is being partly substituted by a more intensive grazing, including introduced pastures and rotations with cereals and other agricultural uses (beans, sunflower, and planted forest like Pinus, Eucaliptus, etc.)

Early studies show that the conversion of native savannas to introduced pastures increase the soil organic matter (SOM) (Fisher et al., 1997), diminish the net flow of greenhouse gases to the atmosphere, and increase the net income of C in the ecosystem (Rondón et al., 2006). López-Hernández et al. (2014) point out an increase in the C content due to the change of tillage in annual crops and the use of different cover crops associated to maize (Hernández-Hernández et al., 2013). The recent development of new an adequate farming systems (Valencia et al., 2004), together to long term evaluations (San José et al., 2003) show that the transformation of native savannas to pastures or to annual crops with an appropriate management could be considered sustainable.

The increase of SOM, with the change of land use from native savannas to pastures or crops is quite complex. This is mostly due to the different landscape positions: alluvial plains, eolic plains, elevated plateaus and rolling-hills (Berroterán, 1988;

Schargel, 2003), also to the different climates; from the drier eastern plains to the more humid in the west, and also to the four types of functional vegetation communities: seasonal, hyperseasonal, semiseasonal and gallery forest (Sarmiento, 2000). The available information on soil C is very fragmented and there is lack of a uniform methodology that limits a proper interpretation and extrapolation of the available data.

Among the major difficulties to know properly the storage and evaluate the potential sequestration of soil C are: i.-Values of C expressed in terms of concentration ii.-lack of soil bulk density values iii.- values determined at shallow depths.

The objectives of this paper, based on an exhaustive review of literature of soils in the flatlands of Venezuela, were: i.- to compile the results published about of C (%) at depths from 0 to 30 cm and its bulk density and ii.- to estimate the storage and potential sequestration of C in the soil, derived from the changes in land use in this ecoregion. These estimates assume homogeneity in the landscape units and the average of C content.

METHODOLOGY

From an extensive search of bibliography we obtained data from: areas of the main types of landscapes and their ecosystems, the area of the main land use types, the soil C content (%), bulk density of the first 30 cm of soil, the distribution of the principal suborders of soils (Berroterán,1988; PINT, 1979; Schargel, 2003; Comerma y Luque, 1971; Hernández-Hernández et al., 2004; López-Hernández et al., 2014; Zinck y Stagno, 1966). For each paper reviewed, we calculated the stock of C for each depth, using the values of C content (%) and the corresponding bulk density; followed by the estimationof Cthat had been stored per hectare in the firsts 30 cm. Later, we calculated the accumulation of C in the soil for the different landscape units, using the average of C stock, the values of extend of the ecosystems and types of land use.

RESULTS

We found Venezuelan flatlands represents around 28% of the country i.e 26.2 Mha. The most extensive landscape unit correspond to the alluvial and eolic plains (14.17 Mha), from them, the poor–drained savannas cover 7.45 Mha and the well-drained 6.42 Mha. The elevated plateaus (Mesas) cover 6.48 Mha and the rolling hills 3.15 Mha. The variety of landscapes shows also a diversity of soils, the alluvial plains have mostly Inceptisols, Mollisols, Alfisols and Vertisols, while the eolic plains have Ultisols and Entisols. In the elevated plateaus, dominate Ultisols and Oxisols, whereas in the gallery forest are mostly Inceptisols. The seasonal savannas occupy 56% of the area, with ranges between 0.8- 3.5% and 1.2-1.8% g.cm3 for C content and the bulk density respectively, being the lowest values under forest and the highest values in the seasonal savannas. The levels of C content show two increasing tendencies: i.- geographical, from the east to the west and ii.-) ecological systems, from seasonal savannas to hyperseasonal , semiseasonal and forest (Table 1).

For the remaining natural systems, the highest capacity to accumulate C in the first 30 cm is found in the alluvial plains, especially the ones occupying the lower positions or with poor drainage. In Table 2 we can observe that in the well-drained plains, introduced pastures increase significantly the C stock, while annual crops under conventional tillage and the forest plantations reduce their storage in the order of 12 and 35%, respectively. Nevertheless, there are no visible changes with minimum or non-tillage.

Table 1. Carbon content and stocks in the top 30 cm of soils from Venezuelan flatlands.

Regions	Landscapes	C stocks ($MgC.ha^{-1}$)	C (%)
	Recent alluvial plains		
West	Deciduous forests	77.0 ± 19.4	5.0 ± 1.3
	Hyperseasonal savannas (lowlands)	45.2 ± 17.3	3.2 ± 1.4
	Semiseasonal savannas (lowlands)	61.5 ± 12.0	5.2 ± 1.1
	Alluvial Plains from the Pleistocene		
West	Hyperseasonal savannas (lowlands)	39.0 ± 8.5	2.6 ± 0.6
	Seasonal savannas	33.5 ± 6.4	2.2 ± 0.5

East	Seasonal savannas	42	0.9
Central	Seasonal savannas	46	2.9
	Eolic Plains		
West	Poorly drained savannas	65 ± 7.1	4.2 ± 0.3
	Well drained savannas	22 ± 4.2	1.4 ± 0.2
	Elevated Plateaus		
West	Seasonal savannas	24 ± 9.9	1.6 ± 0.7
East	Seasonal savannas	17.7 ± 7.5	0.8 ± 0.5
Central	Seasonal savannas	51.3 ± 22.5	3.5 ± 1.6
	Rolling hills		
Central	Seasonal savannas	31	3.3

Original data from: Campos (1999), Colmenares et al. (1974), Comerma and Chirinos (1976), Gómez (2004), Güerere (1992), Hernández-Hernández et al. (2004), Hernández-Hernández and Domínguez (2002), Hernández-Hernández and López-Hernández (2002), Malavé (1981), Pérez-Materán et al. (1980), PINT(1979; 1985; 1990), Schargel (1972; 1978), Westin (1962), Zinck and Stagno (1966). Tomado de Rondón et al. (2006).

DISCUSSION

Historically, the savannas have been used with extensive cattle ranching, including frequent fire in the dry season to renovate the outbreak of the more palatable nayive grasses; crops in more fertile soils in areas along the rivers; and wood extraction in natural forest. Animal husbandry has been intensified with the introduction of improved pastures: Brachiarias, Panicums and Digitarias, among others, with the purpose to increase the double purpose cattle (milk and beef). Besides intensification with crops like maize, sunflower, sorghum, beans, cotton, sugarcane, cassava, bananas, minor fruits, and forest plantations, mainly *Pinus caribaea* and *Eucaliptus sp*. At present we have around 6 Mha of introduced pastures, 2 Mha of annual crops and 0.8 Mha of planted forests. All these uses represent around 29% of the ecoregion, remaining under native grasses about 17 Mha and 1.5 Mha under native forest.

Considering that the expansion of the agricultural frontier in Venezuela is mostly concentrated in the flatlands ("Llanos"), the risk to decrease the C stock in the soils is high (López-Hernández et al., 2014), and moreover, if the gallery forest are cleared. The substitution of native grasses for introduced pastures has augmented the capacity to storage C in the soils (Hernández-Hernández et al., 2013), especially in the alluvial plains. Forest plantations have not promoted an increase of C, especially the ones of *Pinus caribaea* in the eastern plains, where the decomposition rate is low (Campos, 1999).

In summary, for the top 30 cm of the savanna soils, we estimate a C stock of 1.3 Pg C, and if we assume the same storage down to 100 cm depth, it would result in 0.52% of C for the whole ecoregion. These estimates should be looked upon carefully, due that we assume homogeneity of the functional units and the C content was estimated with limited data. Considering that all the ecoregion could be converted into well managed pastures, the C sequestration potential would be 0.54 Pg.

Table 2. Estimated C stocks for the main land use systems in the Venezuelan flatlands.

	Area	Estimated Carbon stocks (0-30 cm depth)
Landscape position/land use	(Mha)	$MgC.ha^{-1}$
Remaining natural systems		
Elevated plateaus	5.04	35.66
Well drained lowlands	4.81	43.16

Poorly drained low plains	5.45	59.41
Rolling hills	1.66	40.00
Gallery and deciduous forest	1.52	75.00
Subtotal	18.48	
Modified systems		
Introduced pastures	5.00	78.00
Annual crops, conventional tillage	0.83	38.10
Annual crops, reduced tillage	0.17	43.20
Tree plantations	0.80	27.00
Urban, water bodies etc.	0.90	
Subtotal	7.70	
Total	26.18	
Published in (Rondon et al. 2006)		

CONCLUSIONS

The Venezuelan savannas have a great potential to sequester C in their soils, but there is a large variation according to the landscape unit and the geographical location. The alluvial and the eolic plains have the largest capacity, due to their extent and to the high C content in the upper 30 cm of their soils. Data indicate that this capacity increases toward the western llanos, probably due to an increase in rainfall as it gets closer to the Andean piedmont. It is necessary to obtain more data on soil C, including information on bulk density and georefercning it to have a precise plotting. All these studies are very necessary due to Neotropical savannas play an important role in the biogeochemical cycles, are a reservoir of biodiversity and provide important ecosystem services.

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3.2.3 | LONG-TERM EFFECT OF DIFFERENT AGRICULTURAL SOIL USE AND MANAGEMENT SYSTEMS ON THE ORGANIC CARBON CONTENT OF URUGUAY PRAIRIE SOILS.

Fernando García-Préchac[6], Oswaldo Ernst[7], Gullermo Siri-Prieto[2], Lucía Salvo[2], Andrés Quincke[8] and José A. Terra[3]

BACKGROUND INFORMATION

Uruguay continental area is 16.99 Mha, located between 30-35˚ S and 53-58˚ W. Annual average precipitation is 1100 mm (± 200 mm); mean annual temperature is 24˚C in summer and 12˚C in winter. The country belongs to the Río de la Plata Grasslands Physiographic Unit (Paruelo *et al.* 2001), that still occupy 65% of the territory. Topography is gently rolled; dominant slopes are 3-6%, with some flat plains and areas with more than 8%; mean altitude over the sea level is 140 m. In Soil Taxonomy, the most important soils are Molisols and Vertisols, but there are significant areas of Alfisols, Ultisols, Inceptisols, Entisols and Histosols.

Durán (1998) calculated the Uruguayan soils organic carbon (SOC) content, using the national general soil map (1:1 million scale, 99 mapping units). Values came from sampling and analyzing 200 profiles, mostly undisturbed soils. Therefore, his information represents the country potential SOC content. Durán results indicate that down to 1 m depth, soils of the country continental area can hold 2.3 Pg of SOC, with a mean value of 13.4 $kg.m^{-2}.m^{-1}$. This is 17% above the world average of 11.5 $kg.m^{-2}.m^{-1}$ (Eswaran *et al.*, 1993 and 1995, cit. by Durán, 1998). It should be pointed out that the area occupied by the mapping units dominated by Molisols and Vertisols, representing 30.6% of the country, have SOC content from 15 $kg.m^{-2}.m^{-1}$ to 20 $kg.m^{-2}.m^{-1}$ and more. Also, 40-45% of these soils SOC is in the upper 20 cm of the profile.

Until mid XX Century agricultural use was continuous crops (CC) with conventional tillage (CT), being wheat the main crop, with several tillage operations and low crop residues return. This generated important erosion rates and soil degradation, affecting around 30% of the country surface by mid 60s, in the most productive soils areas (Cayssials *et al.*, 1978, cit. by Durán and García Préchac, 2007). An actualization at the end of the XX Century (Sganga *et al.*, 2005, cit. by Durán and García Préchac, 2007), showed the same proportion of affected territory (30.1%), separating the following categories: Slight 18.3%, Moderate 9.9%, Severe 1.3% and Very Severe 0.6%.

By mid 60s, there was a general adoption of crop-pasture rotations (CPR), cropping 3-4 years followed by other 3-4 years of seeded grass and legumes pastures for direct grazing. This change, even with CT, resulted in important erosion rate reduction and SOC content recovery during the pasture CPRs periods (Garcia Préchac *et al.*, 2004). During the 90s no-till (NT) substituted CT; this, together with the CPRs, improved even more soil conservation (García Préchac *et al.*, 2004).

Beginning the XXI century a new cropping intensification started, resulting in less pasture duration in the CPRs or even its elimination, generating a great increment of CC area. This dramatic change was due to new agricultural enterprises of great scale, generating structural changes in land size, tenure, and operational management (Arbeletche *et al.*, 2010). Soybean became the new leading crop, growing its area from almost nothing (around 10 kha by 1999) to 1.4 Mha in 2014. This took Uruguay without experimental data of it consequences on soils, because soybean was not previously important. Thus, models (USLE/RUSLE to estimate erosion, and CENTURY to estimate SOC) were used (Clérici *et al.*, 2004, cit. by García Préchac *et al.*, 2004; Morón, 2009). Their predictions indicated that CC with NT soybean monoculture is not sustainable due to its erosion rate and loss of SOC. Including winter cover crops or double annual cropping of soybeans and wheat could reduce erosion close to Tolerance (Typically 7 $Mg.ha^{-1}.year^{-1}$), but not totally the loss of SOC. Sustainability could be achieved with CPR-NT systems, producing erosion rates similar to the ones under natural grasses and keeping or modestly increasing SOC content.

6 Faculty of Agronomy-University of Uruguay, ITPS Member.
7 Faculty of Agronomy-University of Uruguay.
8 National Institute of Agricultural Research, Uruguay

EXPERIMENTAL RESULTS

There are three long-term experiments in Uruguayan Argiudols, comparing soil use and management alternatives. The oldest started in 1962 in the Experimental Station INIA-La Estanzuela (34˚20'12.31" S and 57˚41'08.14" W). Soil is a Typic Argiudol, Silty Clay Loam, 2.2 % SOC original content in 0-20 cm depth; site slope is 3.5%. Results during the period of CT soil management were reviewed by García Préchac *et al.* (2004). Figure 1 presents all SOC data, including the period after switching to NT management in 2007.

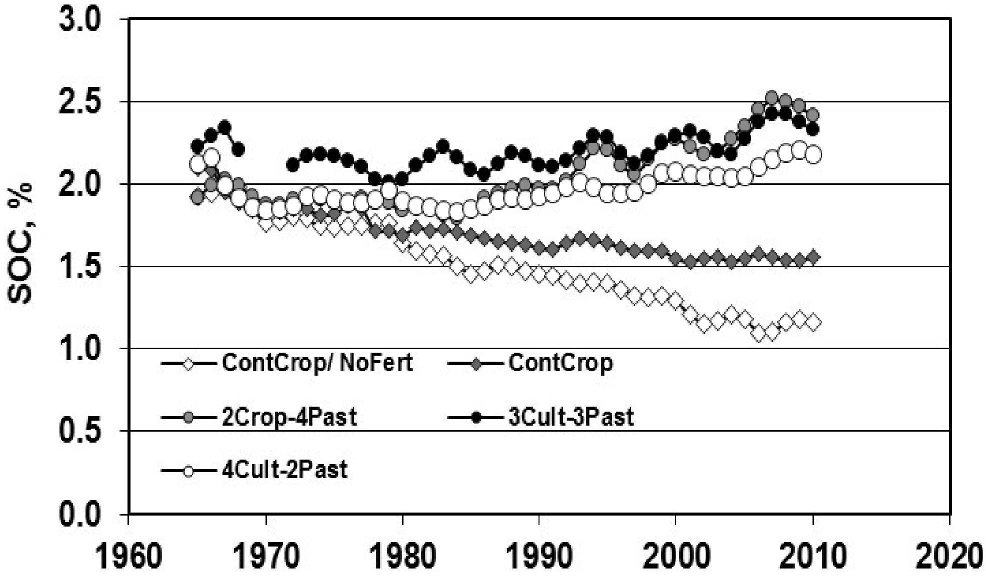

Figure 1. Percent gravimetric SOC content at 0-15 cm depth of the Typic Argiudol in the long-term rotation experiment in INIA-La Estanzuela (Quincke et al., 2012).

SOC decrease in CC with no N and P fertilization was continuous over time, being it last value 45% of the original. But in CC with N and P fertilization the evolution reached a steady state around 72% of the original. SOC content was always higher in the CPRs, and more with longer time under pasture and less under crops. The most important result is that with CT during 47 years, or with NT from 2007, SOC content in the CPRs did not differ of the original one.

Other experiment started in 1994 in the Experimental Station EEMAC, Faculty of Agronomy-Univ. of Uruguay (32˚ 23´40.13¨S and, 58˚ 03´ 26.48¨ W). Soil is a Typic Argiudol, Clay Loam, with 3% gravimetric SOC original content. The site differs from La Estanzuela in its slope that is less than 1%. Treatments are CC or CPR (3 yrs. crops-3 yrs. pasture), combined with CT or NT. SOC content was determined at 0-15 cm depth after one rotation cycle of the CPR and discussed in a review (García Préchac *et al.*, 2004). Results indicated that the lowest SOC content was under CC with CT, but there were no significant differences between the other treatments (CC-NT, CPR-NT and CPR-CT). These results were confirmed in later measurements, after two cycles of rotation (Ernst and Siri-Prieto, 2009; Salvo *et al.*, 2010). This last work evaluated a variant introduced in 2000, consisting in splitting the plots during the cropping cycle to contrast planting soybean or sunflowers versus sorghum or corn in summer. The difference between the quantity and quality of the C3 vs. C4 crops residues was significant, with more SOC under the second ones. Lack of erosion in this experiment, due to low slope grade, is the explanation given for no significant difference between the treatments with NT, in particular, between CC-NT, CPR-NT, and even CPR-CT. SOC physical fractionation and ^{13}C studies at different depths (Salvo *et al.*, 2014) found that SOC dynamics during the experimental time was mainly in the particulate fraction (POM-C), in which occurred 63% of the losses, meanwhile there were no significant differences in the mineral associated organic C (MAOM-C). After 9.5 years, only 14.5% of the SOC in the 0-18 cm layer was young C, being the largest proportion incorporated no deeper than 6 cm. Only 17% of the plant residues were incorporated in the topsoil. Estimated half life of C in the 0-18 cm depth was 28 years, but it varied from less than 5 years for POM-C to 400 years for MAOM-C.

The third experiment is in the Experimental Unit INIA-Palo a Pique (33˚20'12.31" S and 54˚29'34.43" W), in an Abruptic Argiudol, Silty Loam, with 1.7 % SOC original content in 1995. Experimental area is 72 ha, with 6 ha experimental units (Terra and García Préchac, 2001). All soil management is NT. Soil uses contrasted are: CC: annual winter oats and ryegrass directly grazed, and Sorghum or Moha in summer for silage or hay; SR (short rotation): two years idem CC and two years pasture; LR (long rotation): two years idem CC and 4 years pasture; PP (permanent pasture): regenerated natural pasture over seeded with perennial legumes. After 8 years, SOC and particulate organic carbon (C-POM, 53-2000 µm) were determined at 0-15 cm depth (Terra *et al.*, 2006). LR increased SOC by 19% compared to CC (31.8 $Mg.ha^{-1}$); no SOC differences were found between LR, SR and PP. Plots under pastures had 14% higher SOC than plots under crops (33.7 $Mg.ha^{-1}$). Crops rotated with pastures in LR and SR, had 5% more SOC than crops in CC (31.8 $Mg.ha^{-1}$). Pastures of 3-4 years had 33% more SOC than 1-2 years pastures (34.4 $Mg.ha^{-1}$). The lowest and greatest C-POM were in CC and in 3-4 years pastures of LR (8.2 and 12.6 Mg $C.ha^{-1}$, respectively). The paper concludes that CPR-NT systems including long-term seeded pastures of grasses and legumes preserved SOC content, even in high biomass extractive systems.

CONCLUSIONS

Long-term experimental results confirmed the majority of models predictions, except the possible long-term increase of SOC in CPR-NT. The majority of the results showed no significant changes of this use and management compared with the experimental original SOC contents.

Results showed that CC-NT with predominance of grasses instead of soybean or sunflower in the cropping sequence could arrive not only to control erosion but also to keep SOC content close to the original.

Changes in SOC content under the different NT systems were detected close to soil surface. This could be due to the predominant over-ground origin of the residues. SOC changes were detected in the particulate fraction with low time of residence.

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3.2.4 | C SEQUESTRATION OF A GRAZED PERMANENT GRASSLANDS: USES OF COMPLEMENTARY METHODS FOR DATA ANALYSES AND INTERPRETATION

K Klumpp[1*], JMG Bloor [1], R Nemoto[1], D Herfurth[1], D Darsonville[1]

[1][INRA, Grassland Ecosystem Research Unite, Clermont Ferrand France , katja.klumpp@inra.fr]

Keywords: soil organic matter pools, eddy covariance, soil inventory, grazing, grasslands

Temperate grasslands have been recognized for their great potential to sequester an important amount of carbon, contributing to slow down the current rise in "greenhouse" gases and associated effect. However, the quantification of this C sink activity has been greatly questioned, due to the uncertainty associated to those values being as important as the sink itself. So far, soil inventories are the most direct approach to investigate C sequestration via changes SOC, while an alternative to the direct measurement of C stock changes in grasslands is to measure the net balance of C fluxes exchanged at the system boundaries. This approach provides a high temporal resolution and changes in C stock can be detected within one year. Here we measured net C sequestration over 12 years using both methods (i.e. three soil inventories and eddy covariance technique) on two upland semi-natural pasture grazed by heifers at two contrasted stocking rate (high vs low). Moreover, to assess the becoming of sequestrated C, soils were analysed in details i) for their soil organic matter pools (i.e. labile, passive, inert; Zimmermann et al method) and ii) spatial distribution of soil C stock changes at field scale over time.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

In the introduction, state the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.]

Temperate grasslands have been recognized to significantly contribute to the terrestrial C sink by sequestering C in soil organic matter. Grasslands have thus a great potential to sequester an important amount of carbon, contributing to slow down the current rise in "greenhouse" gases and associated effect. However, the quantification of this C sink activity has been greatly questioned, due to the uncertainty associated to those values being as important as the sink itself. Average values of 0.7±0.1 t C ha^{-1} yr-1 has been cited by different studies (Soussana *et al.* 2010, Ciais *et al.* 2010) (eddy covariance-technique, EC) while soil inventory measurements reported only 0.05±0.3 t C ha1 yr-1. Accordingly, the quantification of this "sink-strengh" has been greatly questioned, due to the uncertainty associated to those values being as important as the sink itself. More recent studies have shown that high uncertainties linked to EC-technique can be attributed to management practices, climate and grassland type (natural, sown, tall grass, etc) affecting soil carbon sequestration rates (Klumpp *et al.* 2011). So far, soil inventories are the most direct approach to investigate C sequestration via changes SOC. Despite the fact that this method require a large number of soil profiles, sampled at time scales longer than 5 years, it may take into account stock changes until deep soil layers (Weismeier *et al.* 2012). However, past studies, often report SOC changes of top and medium soil layer (0 - 30cm) leading to the conclusion that grasslands are in equilibrium (Smith *et al.* 2014). In spite of this, management-related change often happen in deeper (>30cm) soil layers C (Weismeier *et al.* 2012).

An alternative to the direct measurement of C stock changes in grasslands is to measure the net ecosystem exchange of C (NEE) at the system boundaries. Net carbon storage (NCS) can be estimated by uses of NEE and by taking to account other carbon imports (i.e. organic fertilisation) and exports (i.e. losses via C leaching, harvest, animal body mass increase) in the field. This approach provides a high temporal (i.e 10-20Hz) and spatial resolution (i.e. fetch corresponds to ~ 100 times the measure height) and changes in C stock can be detected within one year. Only few studies have compared EC measurements and soil inventories in grassland ecosystems, concluding that the caution needs to be taken with regard to C budget closure. Here we like to assess the ability to capture net carbon sequestration of grassland ecosystems over 12 years using both methods (i.e. soil inventories and eddy covariance technique) on two upland semi-natural pasture grazed by heifers at two contrasted stocking rate (high vs low). Moreover, to assess where sequestrated C goes, soils were analysed in details i)for their soil organic matter pools with respect to soil layers (i.e. labile, passive, inert; Zimmermann et al method) and ii) spatial distribution of soil C stock changes over time at field scale.

METHODOLOGY

The study is located on an upland semi-natural permanent grassland (SOERE-ACBB Laqueuille, France 45°38'N, 2°44'E, 1040m asl.) The experimental field comprises two adjacent paddocks (2.8 and 3.4ha), continuously grazed by heifers from May to October with a high and low animal stocking rate (1.1 and 0.6 LSU/ ha.yr) and fertilization (210 and zero kg/ha.yr), respectively. Both paddocks are equipped with an eddy covariance flux measurement system (EC) and measure actively since 2003. H2O and CO_2 flux (i.e. net ecosystem exchange, NEE) calculation and correction are done following European Fluxdata guidelines. Annual NCS calculation were carried out for each paddock using EC data and measured C imports (non) and C exports (i.e. CH_4, animal weight gain, leaching).
Since setup of the field site, soil inventories were carried out in 2004 (t0, initial C stocks), 2008 (t1) and 2012 (t2). Inventories comprised a spatial sampling design and sampling were done down to bedrock on 60 cm depth (0-10cm, 10-20cm 20-40cm and 40-60cm) in order to account for changes in deeper layers. To asses changes in soil C stock, soil organic matter fraction were analyzed according to the soil fractionation method described by [Zimmermann *et al.*, 2007] for the 2008 and 2012 campaign.

Results

According to soil inventories and EC technique, both paddocks are a net sink of C with a mean C sequestration rate of 2 t C/ ha.yr. Concerning management, both methods showed a slightly higher C sequestration under high animal stocking rate and fertilization than under low stocking rate. However, no significant differences could be highlighted between managements. Soil inventories provided evidence that C was mostly stored in deeper soil layers (10-60 cm) whereas top soil C stocks decreased over time in both fields. Soil fractionation results revealed changes in the size of soil C pools over time and between soil layers. For Example, between 2008 and 2012, the humidified C pool in the 10-20cm layer seems to move to the inert (stable) soil C pool of the 20-40cm soil layer. Spatial analyses of soil C stocks, revealed the grazing intensities have a significant effect on the spatial distribution of carbon stocks (fig 1).

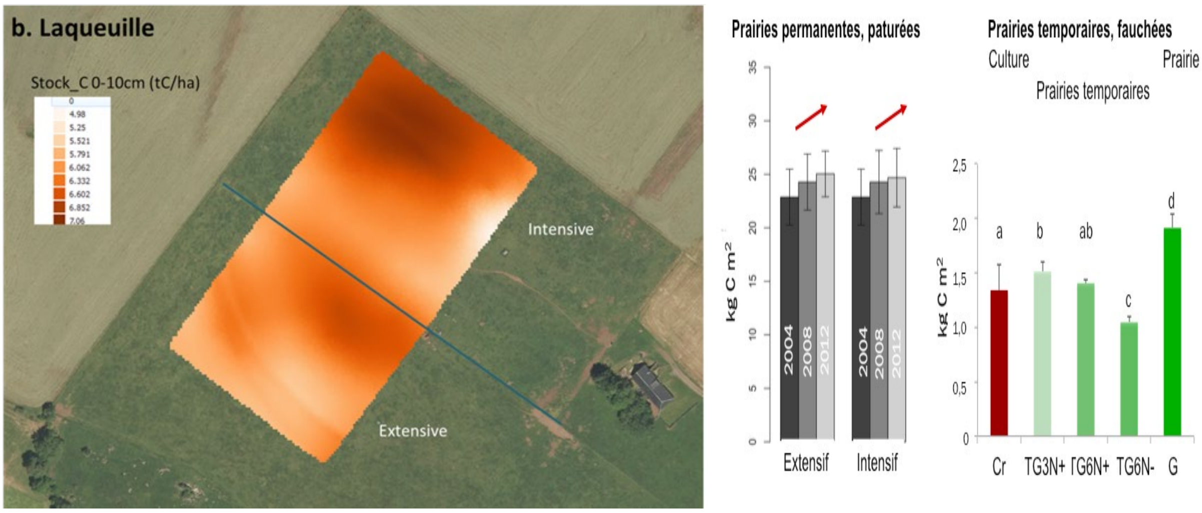

Fig. 1: Soil C stocks distribution in the 0-10cm layer (map) and stock changes over time (0-60cm) under high (intensive) and low (extensive) stocking density grazed paddock.

DISCUSSION

Both methods confirm (NCS and soil inventories) that Laqueuille permanent grasslands acts as a "sinks" of C from the atmosphere, and the comparison of methods, the volumetric approach was in good agreement with the NCS estimation. Nonetheless, the ability of the two methods to detect significant changes in soil C stocks were limited by their total uncertainty resulting from spatial and temporal variation of C stock changes (i.e. soil) and C sequestration (EC-Technique). Accordingly, long term experiments are needed to compare methods over longer time periods. Detailed analyses of stock changes per soil layer and soil organic fraction allowed to follow C sequestration overtime and space; C is stored and transferred to deeper layers.

CONCLUSIONS

Both methods measured comparable net C sequestration, while each methods and analyses exhibits complementary results which may help to i) understand the impact of environmental (climate), management (stocking rate) on C sequestration when using EC -technique, ii) soil stock change over a soil profile when using soil inventories, iii) mechanisms and processes and using soil fractionation methods and iv)spatial variabilities when using a spatial sampling design for soil inventory measurements .

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3.2.5. | SUB-SURFACE SOIL ORGANIC CARBON STOCK AFFECTED BY TREE LINES IN AN OXISOL UNDER INTEGRATED CROP-LIVESTOCK-FORESTRY IN THE SOUTHERN AMAZON[A]

Madari, B.E.[1*], Oliveira, J.M.[1,2], Carvalho, M.T.M.[1], Wruck, F.J.[1], Machado, P.L.O.A.[1]

1 beata.madari@embrapa.br, Brazilian Agricultural Research Corporation (Embrapa Arroz e Feijão), Brazil

2 Federal University of Goiás,Goiânia-GO, Brazil

ABSTRACT

The carbon (C) removed from the atmosphere through photosynthesis may be finally transferred into the soil. Soil organic C storage (SOC), therefore, is an important indicator of the capacity of a production system to sequester SOC. Integrated agriculture production systems (IS) are one of the main strategies of the Brazilian government to reduce or compensate for C emissions from agriculture. Besides, IS are also important means of intensifying and diversifying production and at the same time propitiate benefits to the environment. Our goal was to see whether IS in the form of crop-livestock-forestry (ICLF) could stock more SOC than continuous Pasture without soil management and to contribute to the elucidation of the role of trees in SOC accumulation. The study was carried out in the north of Mato Grosso State, Brazil. Intensive land use was represented by two sites recently under ICLF implemented 3 years before the study. Carbon stocks were analyzed for the 0.0-0.3 and 0.0-1.0 m layers. Around 50% of all C was stored below the 0.3 m. The high C storage places in ICLF were identified in the tree lines at 0.3-1.0 m where N deficiency was not present.

Keywords: Integrated systems (IS); Total soil C; Total soil N; $\delta^{13}C$; Pasture; Eucalyptus spp

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Lower emission of greenhouse gases (GHG) and atmospheric carbon (C) sequestration are among the environmental services that can be provided by farming. Integrated farming systems (IS), became a widely cited concept, as they seek to achieve enhanced production with reduced impacts on the environment. Integrated systems is a production strategy that combines crop, livestock and forestry activities in the same area (Gil *et al.* 2015).

A great diversity of IS exists worldwide, evidencing the need for and adaptability of the concept to various ecoregions and production purposes (Sulc and Franzluebbers 2014; Peyraud *et al.* 2014). These are common in being able to capture ecological interactions between different land use systems, providing opportunities for more efficient agriculture ecosystems in the cycling of nutrients, preserving the natural and environmental resources, improving soil quality and increasing biodiversity (Lemaire *et al.* 2014).

Large C accumulation capacity is associated to integrated crop-livestock-forestry (ICLF) due to the assimilation of additional atmospheric C in the biomass compared to conventional agriculture, some forestry (monocultures) systems and to other IS without trees. To achieve C sequestration in the soil, besides the biomass, is relevant, since part of the soil C may actually be immobilized and stored in the soil from days to decades or even hundreds of years, depending on the mechanism of immobilization and the processes of soil organic matter transformation.

The aim of this study was to assess soil C stocks under two intensively used agriculture areas, under ICLF, in comparison to a continuous pasture without soil management, in the southern part of the Amazon ecosystem, in real farm conditions. Besides, we hope to contribute to the elucidation of the role of the trees to the accumulation of C in the soil.

[a] Based on Oliveira *et al.* Integrated farming systems for improving soil carbon balance in the southern Amazon of Brazil - a case study. Regional Environmental Change (in press)

METHODOLOGY

Data were collected at a private property near Nova Canaã do Norte in Mato Grosso State of Brazil (10°38'13" S, 55°42'32" W). The farm was originally covered by Rain Forest which was partly preserved. The soil was kaolinitic Oxisol, throughout the farm, in a slightly rolling topography. The climate was tropical with dry winter (May-August), the average annual rainfall being around 1,954 mm of which about 95% was concentrated between September and April. The mean annual temperature was 26°C.

A continuously grazed pasture (Pasture), and two ICLFs were studied. The ICLF sites had *E. urograndis* as the tree component. *E. urograndis* is one of the most cultivated species in forestry in Brazil due to its high productivity, ecological adaptability and merchantability. In the ICLFs the trees were arranged in lines within the sites. In one of the sites, each tree line was composed of one tree row (ICLF1), in the other, of three tree rows (ICLF3). The Pasture (*Urochloa brizantha*), around 5 ha, was considered degraded because of the low forage production, presence of patches not covered by grass and its soil physical properties. The Pasture as well as the site where the ICLFs were installed had been under native forest which was removed from the area in 1998. The Pasture remained under continuous grazing after 1998, and since then, the area had no soil management and received no fertilizer or lime. The deforested area where the ICLFs were implemented was used and managed similarly between 1998 and 2009, alternating grazing and annual crops. January 2009, ICLF1 and ICLF3 were implemented in 4.7 ha each, within a larger, 42,7 ha area. For comparison between the ICLFs and Pasture the period of 2000-2012 was considered. We evaluated how much more SOC was present in the soil where more and more intensive land use was introduced on the deforested area, first by alternating and then combining different land uses and agriculture activities in ICLF, instead of continuous low-intensity Pasture. We called it SOC stock diferentiation.The Pasture was taken as reference for the SOC accumulation study in the ICLFs.

Soil samples were taken in February 2012, collecting 5 replicates for each measurement. Horizontally, soil and plant sampling was done in a manner to respect the structure of the sites in terms of the disposition of the tree lines to be able to infer on tree line effects. Vertically, the soil was sampled to 1 m depth, devided in 8 sampling layers to be able to study the vertical stratification of soil properties.

Total soil and plant C, N and isotope ratio (δ ‰) was analyzed by dry combustion (950 °C) using Vario Isotope Cube coupled in series with a mass spectrometer (Isoprime, Elementar Inc. Hanau, Germany) (Elementar Inc., Hanau, Germany). Total SOC and N stocks were calculated for equivalent soil mass per soil sampling layer, for each sampling position in each ICLF site, using Pasture as reference. SOC and N stocks were analyzed for the 0.0-0.3, 0.3-1.0 and 0.0-1.0 m layers. The sampling positions in the ICLFs were compared individually to the Pasture to evaluate the role of each ICLF position in the C dynamics of the site. Then, the average SOC and N stocks of each ICLF were calculated, obtained as the weighted average of all sampling positions within. In this calculus each sampling position was represented in the proportion in which it covered the sampled area.

To analyse the data we used linear mixed models that allowed us to account for potential spatial correlation among sets of sampling positions (soil profiles). Dunnett tests indicated if there were significant effects for the ICLF treatments compared to the Pasture. Analyses were performed using the linear mixed model procedure (Proc MIXED) of the statistical software SAS/STAT® (SAS Institute Inc. 2008).

RESULTS

Soil organic carbon (SOC) stocks

Considering a 1 m deep soil layer, the top 0.3 m stored about 49% of SOC and, correspondingly, the underlying 0.7 m contained 51%. In the top 0.3 m soil layer soil C stocks varied between 55.05 (Pasture) and 66.74 (ICLF1-5) Mg ha^{-1} and no significant differences were observed among the ICLFs and the Pasture (Fig. 1).

Higher SOC stocks than in Pasture (55.61 Mg C ha^{-1}) were observed, however, at 0.3-0-1.0 m, for the central and external tree rows of ICLF3 (71.66 and 72.92 Mg C ha^{-1}, respectively). At ICLF3-CR there was 16.05 and at ICLF3-ER 17.31 Mg ha^{-1} more SOC than under the Pasture that corresponds to 1.33 and 1.44 Mg ha^{-1} annual positive differentiation, respectively, in SOC stock beneath the top 0.3 m soil layer under the tree lines, considering 12 years of soil management. No significant SOC accumulation was observed in the other sampling positions. Considering the 0.0-1.0 m soil layer, the SOC stock differentiation rate under the tree line in ICLF3 (ICLF3-CR and ICLF3-ER), was an annual 1.91 Mg ha^{-1}.

To evaluate the overall potential of the ICLFs to accumulate or preserve SOC, we calculated the average weighted SOC and N stocks. The ICLF3 had a positive overall SOC balance (128.34 Mg C ha^{-1}), compared to the continuous pasture (110.66 Mg C ha^{-1}), while the ICLF1 (110.21 Mg C ha^{-1}) did not differ from that. The additional 17.68 Mg SOC ha^{-1} in the ICLF3 means an annual 1.47 Mg SOC ha^{-1} differentiation rate between the Pasture and the ICLF system.

The isotopic signature ($\delta^{13}C$) of the soil

The soil under Pasture had greater abundance of ^{13}C than the areas under ICLF down to 0.4 m, except ICLF3-9 (-23,32) that was similar to the Pasture at 0.3-0.4 m. The stronger C3 signal in the ICLFs at 0.0 to 0.4 m can be attributed to the C3 annual crops, which dominated the first two years (2008-2010) of ICLF, such as rice and soybean, and to eucalyptus. In the 0.4-0.6 m layer only the ICLF1 was different from the Pasture (-22.02). In the 0.6-1.0 m soil layer the effect of agriculture management systems was not detected with the stable carbon isotope technique (Fig. 1). Below 0.6 m the isotope signature of the soils (-20.32-21.99) of the evaluated areas was comparable to the native Forest soil and indicated a mixture of C3 and C4 plants, representing earlier geological times (Pessenda *et al.* 1998).

DISCUSSION

While in ICLF3 our results indicated that the system affected SOC stocks in the subsurface layer under the tree line, the same was not observed for the ICLF1. The annual SOC differentiation rates between the Pasture and the ICLFs were, however, positive at all sampling positions and at all soil layers (Table 1). In ICLF3 in the 0.3-1.0 and 0.0-1.0 m layers a decline in the SOC differentiation rate from the central tree row (ICLF3-CR) to the middle of the ally pasture (ICLF3-9) could be observed. Similar trend did not exist neither in the 0.0-0.3 m soil layer in the same area (ICLF3) nor in the ICLF1. In the area under ICLF3, therefore, we found strong indication that the trees had important role in subsurface C accumulation or preservation.

We suspect that the different behavior of the two areas in C dynamics could lay in the great heterogeneity of the studied area that extended, considering the Pasture and the ICLFs, over 42.7 ha. It is known that the nutrient balance influences C accumulation in tropical and subtropical agricultural and grassland soils and that N has an important role in it (Kirkby *et al.* 2014). We measured that the ICLF1 had generally lower N content than the area under continuous Pasture, especially at the ICLF1-2.5, 5 and 10 sampling positions, where it was significantly lower. Under the ICLF3 two sampling positions (ICLF3-ER at 0.3-1.0 m and ICLF3-CR at 0.0-1.0 m) had more N than the Pasture (data not shown).

The interdependence between N and SOC in the soil could also be observed by the correlation between their concentrations in the ICLFs (R^2=0.96 at 0.0-0.3 m and R^2=0.97 at 0.0-1.0 m), supporting the idea that N deficit in the soil may be limiting to the accumulation of SOC. It was therefore clear that the sites under ICLF1 and ICLF3, had different conditions for SOC accumulation in the soil.

CONCLUSIONS

The variation in the isotopic composition ($\delta^{13}C$) of the soil was strongly affected by the change in land use, showing evidence that vegetation change affected soil organic matter in short term down to 0.6 meters in the soil profile. In quantitative terms, however, evaluating only the top 0.3 m, the effect of the agricultural management systems on SOC stocks was not detectable. Difference in the SOC stocks was identified, however, below 0.3 m, in the tree lines of the ICLF site with three tree rows in the tree lines (ICLF3). This ICLF resulted in overall higher SOC stock, considering a one-meter deep soil layer, when compared to a site under continuous pasture. SOC dynamics was closely related to soil N. While the ICLF3 site had more SOC, another, ICLF1, which had been implemented on a site that showed N deficiency, did not accumulate SOC compared to the pasture site. Adopted sampling pattern to the functional heterogeneity of the ICLF was necessary to evaluate its effect on SOC stocks. Our results indicated that, in the edaphic-climatic conditions of the study site, agriculture systems that include forest component can represent viable solutions for SOC accumulation even in the short term if soil fertility constraints are not present. As land use and management can directly influence soil conditions, including the nutritional status of soils, it is important that adequate and, if necessary, corrective soil management be coupled to the implementation of ICLF, or any IS, to bring out or enhance their potential. Nevertheless, more investigation is necessary on the driving forces and impediments of SOC accumulation in IS, including detailed research on soil organic matter stability.

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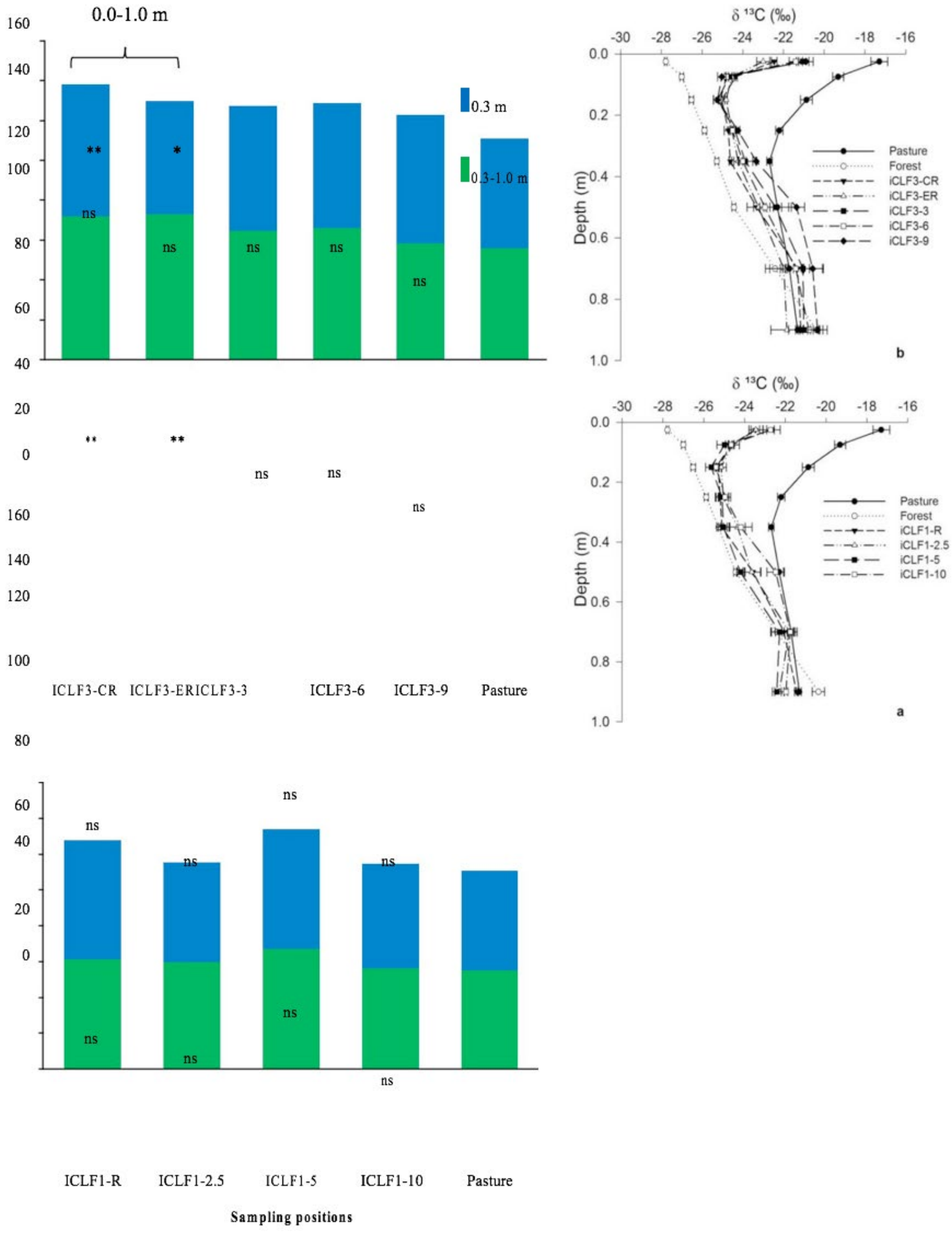

Fig. 1: Soil organic carbon (SOC) stocks (Mg C ha^{-1}) in the 0.0-0.3 and 0.3-1.0 m soil layers and isotope ratio (· ^{13}C, ‰) in the clay oxisol, under integrated crop-livestock-forestry systems (ICLF1 and ICLF3) compared to continuous Pasture, in Nova Canaã do Norte, Mato Grosso State, Brazil.
Pasture: site continuously used as pasture;

ICLF1-R: sampling position on the tree line in the integrated crop-livestock-forestry system with one row of eucalyptus trees by tree line (ICLF1);

ICLF1-2.5, ICLF1-5 and ICLF1-10: sampling positions in ICLF1, 2.5, 5 and 10 meters away from the tree line in the direction of the middle of the ally pasture;

ICLF3-CR: sampling position on the central tree line in the integrated crop-livestock-forestry system with three rows of eucalyptus trees by tree line (ICLF3);

ICLF3-ER: sampling position on the external tree line in the integrated crop-livestock-forestry system with three rows of eucalyptus trees by tree line (ICLF3);

ICLF3-3, ICLF3-6 and ICLF3-9: sampling positions in ICLF3, 3, 6 and 9 meters away from the external row of trees; Forest: native forest.

*The means of each sampling position of ICLFs were compared to the Pasture using the Dunnett test. The stars indicate difference from the Pasture at ** p≤0.05; * p≤0.1; ns not significant at p≤0.1.*

Table 1: Annual soil organic carbon (SOC, Mg C ha⁻¹) differentiation rates in the 0.0-0.3, 0.3-1.0 and 0.0-1.0 m soil layers in the clay oxisol, under integrated crop-livestock-forestry systems (ICLF1 and ICLF3), compared to continuous Pasture, in Nova Canaã do Norte, Mato Grosso State, Brazil.

Treatment		Soil layer (m)	
	0.0-0.3	0.3-1.0	0.0-1.0
ICLF1-R[a]	0.95	0.46	1.41
ICLF1-2.5[b]	0.08	0.33	0.40
ICLF1-5[c]	0.97	0.95	1.92
ICLF1-10[d]	0.27	0.05	0.32
	$y = -0.1156x + 0.8567$	$y = -0.0595x + 0.595$	$y = -0.1754x + 1.4521$
	$R^2 = 0.1034$	$R^2 = 0.0423$	$R^2 = 0.0839$
ICLF3-CR[e]	0.92	1.34	2.26
ICLF3-ER[f]	0.13	1.44	1.57
ICLF3-3[g]	0.65	0.72	1.36
ICLF3-6[h]	0.65	0.85	1.50
ICLF3-9[i]	0.77	0.21	0.99
	$y = 0.0225x + 0.5555$	$y = -0.2837x + 1.7638$	$y = -0.2613x + 2.3193$
	$R^2 = 0.0144$	$R^2 = 0.8121$	$R^2 = 0.8016$

ICLF1-R: sampling position on the tree line in the integrated crop-livestock-forestry system with one row of eucalyptus trees by tree line (ICLF1),

ICLF1-2.5, ICLF1-5 and ICLF1-10: sampling positions in ICLF1, 2.5, 5 and 10 meters away from the tree line in the direction of the middle of the ally pasture,

ICLF3-CR: sampling position on the central tree line in the integrated crop-livestock-forestry system with three rows of eucalyptus trees by tree line (ICLF3),

ICLF3-ER: sampling position on the external tree line in the integrated crop-livestock-forestry system with three rows of eucalyptus trees by tree line (ICLF3),

ICLF3-3, ICLF3-6 and ICLF3-9: sampling positions in ICLF3, 3, 6 and 9 meters away from the external row of trees.

Source: Oliveira *et al.* Integrated farming systems for improving soil carbon balance in the southern Amazon of Brazil - a case study. Regional Environmental Change (in press)

3.2.6. | IMPACT OF LAND USE AND SOIL DEPTH ON SOIL ORGANIC CARBON ACCUMULATION AND OTHER SOIL PROPERTIES IN MINNA, SOUTHERN GUINEA SAVANNA OF NIGERIA.

Uzoma, O.A, SAAD, F, Ugboko, F.A, Ighravwe, G.A, Abdullah, A and Bala, A

Department of Soil Science and Land Management, Federal University of Technology, Minna.
Corresponding e-mail: uzo_ozo@yahoo.com

ABSTRACT

Changes in soil organic carbon can be monitored by measuring changes in microbial population, microbial Carbon and Phosphorus (C: P)ratios and urease activities of marginal soils in the sub-Saharan Africa. This marginal soils are utilized for arable crop production or reserved for agroforestry or afforestation. A research was carried out at the afforestation site of the Federal University of Technology, Minna in February, 2016. The afforestation site falls under the Southern Guinea Savanna agro-ecological zone of Nigeria with a GPs location of Lat 09^{o} 31^{1} 214^{11} N , Long 06^{o} 27^{1} 604^{11} E and an elevation of 233 m. Minna has an average annual relative humidity of 48.9% and average annual temperature of 27^{0}C. The forest was eleven years old at the time of the experiment and has 3 different tree vegetations comprising of Gmelina, Cashew and Teak. Each vegetation covered 4.5 km and had inter and intra row spacing of 5m. Adjacent the tree vegetations are arable lands cultivated by local farmers. The experiment was a 4 x 3 factorial experiment fitted to a Completely Randomized Design (CRD) replicated 3 times. Therefore the set of treatments are four land use types as follows: Arable land, Lands used for Cashew, Gmelina and Teak afforestation respectively. The 2^{nd} set of treatments are 3 soil depths as follows: 0-5cm, 5-10cm, and 10-15cm. The aim of the experiment was to investigate the effect of these land uses on soil chemical and microbial properties and measure the variance of these soil properties with soil depth. The experiment would also reveal the land use that best conserves carbon and enhance soil health. The experiment was initiated by sampling soils under these vegetations at different soil depths. Prior to sampling across treatments, soil auger was sterilized with methylated spirit and flamed to prevent cross contamination. After sampling, soils were bulked according to treatments and taken to the laboratory for chemical and microbiological studies according to standard methods Results obtained revealed that Organic carbon (OC) was averagely highest under arable land than under tree vegetation especially at 0-5cm soil depth. Although Gmelina trees accumulated the highest OC of 11.9 g Kg-1 at 0 -5cm depth, Teak vegetation averagely recorded the highest OC followed by Gmelina and Cashew in that sequence. Soil available P followed the same pattern except that soils under Gmelina vegetation recorded the lowest available P. Soils under tree vegetation recorded the highest fungi population compared to soils under arable crop production probably as a result of higher lignin content found in the trees. Amongst the trees, Teak averagely recorded fungi populations values that were lower than the values recorded under the other trees even though these values were not statistically different. Conversely, soils under Arable land recorded the highest bacteria count while those under Gmelina recorded the lowest counts as a result of the presence of easily decomposable plant species and more biodiversity in the arable land. Microbial C: P ratio were narrowest under Cashew vegetation and widest under Gmelina vegetation suggesting that soils under Cashew were more mineralized than those under Gmelina. This may be difficult to understand considering the fact that litter falls from cashew are more difficult to decompose than litter falls from Gmelina. The potential of Cashew trees to improve P mineralization may come from the solubilization of P by their root exudates. Arable land recorded the lowest urease activity suggesting lowest ammonia loss through volatilization. This Arable land that was adjacent the Forest most likely enjoyed inputs from litter falls than organic inputs from grazing animals and that probably explained why ammonia loss through volatilization was minimal. The most likely reason why the Afforestation sites recorded the highest ammonia loss through volatilization may be linked to activity of Fulani herds men who graze their cattle in the forest reserve. The cow dung and urine from their cattle is high in ammonia. Another reason why the forest reserve recorded highest ammonia loss may come from the alkalinity of their soils which is a function of the quality of litter falls. Result obtained in this research has demonstrated that Land cultivated to arable crops in sub-Saharan Africa accumulated more organic carbon which inturn increased microbial life especially heterotrophic microbes. This microbes synthesize enzymes like urease when nitrogen is limiting and because nitrogen was not limiting under arable cropping system, urease activity was low and consequently, the microbial C:P ratio was the second narrowest.

Key words: Land use, soil depth, soil organic carbon, urease activity, microbial population, counts, C: P ratio, Arable land, Gmelina, Cashew, Teak

3.2.7. | IS IT POSSIBLE TO MITIGATE GREENHOUSE GAS EMISSIONS FROM AGRICULTURAL SOIL BY INTRODUCTION OF TEMPORARY GRASSLAND INTO CROPPING CYCLES?

Rumpel, C.[1,*], Massad, R.S.[2], Crème, A.[1], Carozzi, M.[2], Chabbi, A.[3], Klump, K.[4], Leroux, X.[5], Martin, R.[4], Vuichard, N.[6]

[1][IEES, UMR 7618, CNRS-INRA-ENS-Paris 6, bât EGER, 78850 Thiverval-Grignon, FR, (cornelia.rumpel@inra.fr)]

[2][INRA, UMR ECOSYS, INRA, AgroParisTech, Université Paris-Saclay, 78850, Thiverval-Grignon, FR

[3] INRA, Unité de Recherches Pluridisciplinaires sur la Prairie et les Plantes Fourragères, F-86600 Lusignan, FR

[4][INRA, UMR 0874 UREP Unité de Recherche sur l'Ecosystème Prairial, 63000 Clermont-Ferrand, FR]

[5][Université de Lyon, Microbial Ecology Centre (UMR 5557 CNRS, USC 1364 INRA), Villeurbanne, FR]

[6][Laboratoire des Sciences du Climat et de l'Environnement, UMR8212, CEA-CNRS-UVSQ, 91191 Gif-sur-Yvette, FR]

ABSTRACT

Agriculture contributes strongly to greenhouse gas emissions, in particular through the emission of N_2O. In this study, we investigated the intensity of such emissions from French grassland soils under contrasting management by combining an experimental and a modelling approach. The objectives of this study were to measure and estimate N_2O emissions and C storage at field scale and to assess the effects of grassland management on the processes determining soil organic C-storage and greenhouse gas emissions. Our conceptual approach included modelling of N_2O emissions from grasslands and the investigation of the controls of N_2O emissions by means of the characterisation of soil organic matter (SOM) composition as well as microbial communities. We continuously measured greenhouse gas emissions at long term grassland experiments in France. Moreover, we investigated the nature of SOM and the abundance and the activities of microbial communities in the soils from the different grassland managements.

Our data indicated that grassland management practices, such as grazing, mowing, animal density, fertilisation and length of grassland periods, influenced soil C-storage, SOM composition and microbial abundance and activity. Such effects may be observed as legacy effects even after several years of cropping. Greenhouse gas emissions, in particular those of N_2O, are strongly influenced by the management practices and their effects on SOM and soil microbial parameters. As they are contrasting, a compromise has to be found in order to ensure optimal ecosystem services of grassland systems.

Keywords: temporary grassland, soil organic matter composition, microbiology, greenhouse gaz emissions

EXTENDED ABSTRACT

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Grassland systems are important in terms of carbon storage and mitigation of greenhouse gas emissions, in particular those of CO_2 and N_2O. Their introductions into cropping cycles could be a solution to maintain and increase the carbon storage potential of agroecosystems (Lemaire et al., 2015). However, there are two important knowledge gaps: (1) a big uncertainty concerning the quantification of C and N fluxes in grassland systems under contrasting management and (2) a lack of evaluation of practices to mitigate greenhouse gas emissions from these soils. This calls for integrated modelling of greenhouse gas emissions and carbon storage, while taking into consideration soil parameters and ecosystem services provided by these systems. For this study, we proposed to reduce uncertainties concerning the prediction of greenhouse gas emissions and soil C and N storage using a long term experimental site with grasslands under contrasting management. Temporary grassland management included mowing, presence or absence of N fertilisation and different duration of grassland phase. The legacy effect of grassland management on SOM and microbial parameters was investigated at the same sites during field campaign aiming to couple N_2O emission measurements with soil organic matter characteristics and microbial parameters. The aims of the study were (1) to determine linkages between microbial characteristics, soil organic matter status and greenhouse gas fluxes and (2) to assess the effect of grassland management practices on C storage, SOM, microbial parameters and N_2O emissions of agricultural soils.

METHODOLOGY

For the modelling exercise we used two models, CERES-EGC and PaSim, and continuous data from a long term observatory for environmental research including pasture,mowed grasslands and croplands. First, we ran the crop model CERES-EGC and the grassland model PaSim in their spatialized versions to obtain European wide greenhouse gas emission maps for agricultural soils at a resolution of 770 km^2. To simulate greenhouse gas emissions from soils in rotation with crop and temperate grasslands we finalise the development of the FarmSim model resulting from the coupling of the above mentioned models. This model was used to validate and investigate the processes leading to greenhouse gas emissions under different management; at this aim we used the data from the forage and grasslands observatory, from 2005 to 2011 and reproduced continuous soil measured data as water, N and C with the new model. In addition, at this site we carried out a field experiment and investigated simultaneously greenhouse gas emissions, soil organic matter stocks, composition as well as activity and abundance of microbial communities. The treatments included in the experiment were (i) 9-year permanent grassland and (ii) permanent cropland, (iii) 3-year fertilised temporary grassland, (iv) 6-year fertilised and (v) unfertilised temporary grassland. When temporary grassland soils had experienced a 3-year crop cycle, the first 10 cm of soils were sampled in order to investigate the legacy effects of grassland duration (3 or 6 years) and fertilisation (with or without N). Soil organic matter stocks were determined and SOM composition was analysed for lignin as well as carbohydrate content and composition, and microbial communities were characterised with a genetic approach, investigating the genes involved in N_2O emissions.

RESULTS

Our data indicated that the uncertainties concerning the evolution of N_2O emissions through all models are high, due to the poor reproduction of measured N_2O data. In fact, by using the coupled model FarmSim, the simulation of a 6-year fertilised temporary grassland followed by 3 years of crops, resulted with RMSE in the order of 3.9 g N_2O ha^{-1} d^{-1} and a modelling efficiency (EF) of -0.89; the simulation of a 9-year permanent grassland resulted with RMSE and EF of 16.5 N_2O ha^{-1} d^{-1} and 0.01, respectively. Our study intended to address these shortcomings in models by the detailed investigation of soil parameters driving N_2O emissions and the identification of new processes to be incorporated in the models. Our experimental data about soil organic matter sampled in the different treatments, showed contrasting carbon stocks. Permanent grassland presented after 9 years significantly higher C stocks than permanent cropland but also showed much higher N_2O emissions. Temporary grassland management induced legacy effects, which persisted after the 3-year cropland phase. Accordingly, carbon stocks and N_2O emissions were observed to decrease without N fertilisation during a 6-year temporary grassland as compared to continuous cropland (Fig. 1). Temporary grassland duration was less important with regards to legacy effects concerning C storage and N_2O emissions.

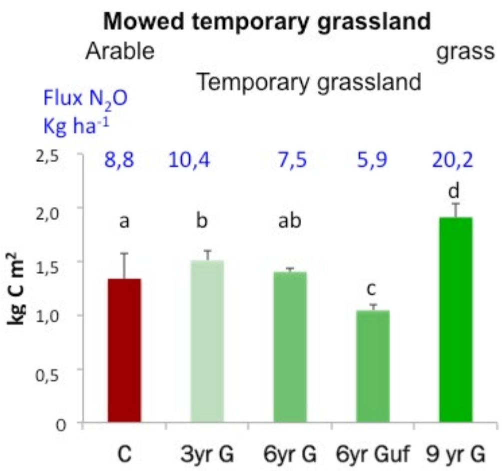

Fig. 1: Carbon storage in soils from the study site, including 9 years continuous crop (C), 9 years continuous grassland (9yrG), and temporary grasslands after 3 years of crop, which include 3 years fertilized grassland (3yrG), 6 years fertilized grassland (6yrG) and 6 years of unfertilized grassland (6yrGuf)

The legacy effect of grasslands on SOM composition was characterised by higher concentrations of fresh plant-derived compounds as compared to cropland SOM. Microbial communities of grassland soils involved in N_2O emissions were in turn less dependent on labile C input as compared to those of cropland soils. These parameters showed a linear correlation with grassland duration. Principal component analyses of parameters characterising soil microbial communities and soil organic matter composition showed separation of permanent grassland and cropland. Fertilised temporary grasslands were in between both controls if its duration was of 6 years, while 3 years fertilised grassland was not different from cropland. Unfertilised temporary grasslands were separated from all others.

DISCUSSION

According to our data, it seems that while grasslands are beneficial for increasing C storage, at the same time they increase N_2O emissions, which is an adverse effect with regards to climate change mitigation. The soil inherent mechanisms leading to such emissions may be related to the high input of fresh plant-derived SOM, which stimulates the activity of microorganisms involved in denitrification. Indeed, permanent soil cover and high root litter input may lead to the accumulation of high amounts of particulate organic matter (Rumpel et al., 2015). In addition to absence of dependence on labile C, N_2O emissions may also be due to the N fertilisers used needed to maintain grassland productivity. This practice is necessary, as unfertilised grasslands are unproductive and also store less soil carbon.

CONCLUSIONS

We investigated the legacy effect of temporary grassland management on N_2O emissions, composition and activity of microbial communities and soil organic matter characteristics. Our data showed that modelling of such emissions in temporary grassland soils need to be improved, as the existing models even after their coupling did not correctly reproduce the measured emissions. Our field experiment indicated that there is a close relationship between SOM parameters and N_2O emissions, which is influenced by grassland management and leads to legacy effects, which persist after 3 years of continuous crop. It seems that a compromise has to be found concerning grassland management in order to optimise ecosystem services.

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3.2.8. | DIGGING DEEPER: STORING STABLE CARBON FOR CLIMATE SMART LAND MANAGEMENT

Rachel E. Creamer[1], Gemma Torres-Sallan[2,3], Lilian O'Sullivan[2], Gary Lanigan[2], Iolanda Simo[2], Ken Byrne[4], and Rogier P. O. Schulte[1*]

[1]Wagenigen University and Research, The Netherlands, rachel.creamer@wur.nl

[2]Teagasc, Ireland

[3]University of Limerick, Limerick, Ireland

Soils play a key role in the global carbon cycle, and their potential to offset some of the anthropogenic greenhouse gas emissions has recently been recognised by international policy initiatives such as the 4per1000 (UNFCCC) and the European Commission proposals for 'flexibility' in using the LULUFC sector for meeting the 2030 climate. Whilst the literature lists numerous options for increasing Soil Organic Carbon (SOC) contents of soils where SOC has been depleted (typically under arable land use), options to augment carbon sequestration rates in temperate grasslands have remained elusive. Whilst grasslands typically store large quantities of SOC, not all forms of SOC are equally valuable as long-term stable stores of carbon: the majority is available for mineralisation and potentially re-emitted to the atmosphere. In this study, we identify the main aggregate fractions associated with the long-term stable SOC down to 1 m depth and finds that soils enriched with silt and clay in the lower soil horizons provide the greatest potential for long term SOC. We derive a framework for climate-smart land management for temperate grasslands, and conclude that a soil type specific approach to land management will be more effective than blanket policies.

Keywords: Aggregate size, argic horizon, climate, grassland, illuviation, Ireland

INTRODUCTION

Soils store an estimated 1500-2000 Pg of Soil Organic Carbon (SOC) in the top 1 metre (Janzen, 2005): thrice the amount of carbon located in the atmosphere, and four times more carbon than the above-ground vegetation (Lal, 2008). Soils can be a source or sink of greenhouse gas (GHG) emissions; at global level these amount to fluxes of *c*. 5 Gt and -2 Gt CO_2e, respectively, equating to 10% and -4% of global anthropogenic GHG emissions, respectively (FAO, 2014). Reducing soil emissions and augmenting sinks provides a promising approach to partial offsetting of agricultural GHG emissions (Smith et al., 2008). This has received further prominence by the 4 per 1000 initiative (http://4p1000.org/understand), which played a central role at the adoption of the Paris Agreement at the UNFCCC Conference of Parties (COP) 21 in December 2015.
Whilst individual European Union (EU) Member States are currently not permitted to use the LULUCF sector to offset emissions from other sectors to meet their 2020 GHG reduction targets under the EU Climate and Energy Package 2020 (http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm), this policy is now due to be revised with the recent proposals by the European Commission for flexibility in allowing use of the land use sector to offset national emissions (http://europa.eu/rapid/press-release_IP-16-2545_en.htm) for the period 2020-2030. This policy shift will now allow for the pro-active management of SOC as an additional mitigation option to reduce national GHG emissions.
The scientific literature lists numerous land management practices that may be applied to restore SOC stocks on depleted soils, for example through improved tillage practices and recycling and incorporation of organic materials. In addition, options for reducing carbon dioxide emissions from drained organic soils are increasingly the focus of attention (e.g. Schulte *et al*, 2016). However, we found few studies that investigated options to increase carbon sequestration in soils in which SOC concentrations have not been depleted and are not limiting agricultural production *per se*, specifically grassland soils.
The IPCC provides good practice guidance on the methodology to account for the impact of land use management and land use change on organic carbon stocks in soils 1. For Tier 1 (default) or Tier 2 (national-specific) approaches, a stock change is calculated by assessing the reference SOC level down to 30 cm and measuring again after a period of at least 3 to 5 years. However, this approach neither accounts for different turnover rates of different fractions of SOC, nor recognises the substantial pools of recalcitrant SOC that exist below 30 cm and may be affected by land management.
In this study, we assess the potential to augment sequestration of stable carbon in soils and subsoils in temperate grasslands, with a view to developing a coherent framework for the climate-smart land management of land for one of these regions, namely the Atlantic climate zone of Europe, using Ireland as a national case study.

METHODOLOGY

Soil selection and sampling

Forty grassland sites were sampled, representing six different soil types with a range of SOC and textural characteristics typical of grasslands in Ireland. At each site, a profile pit was dug to a depth of 1 mm, described according to the FAO field handbook *Guidelines for soil description* (REF) and classified using the Irish Soil Information System (Creamer *et al*., 2014). Soil samples (300 g) were taken and sieved at 8 mm and dried at 40ºC for 7 days. Samples for soil bulk density measurement were taken in triplicate using (5 x 5 cm) cores from each horizon. Additional physical and chemical measures were carried out according to Massey *et al*. (2014).

Aggregate separation

An adaptation of the wet sieving method was followed to separate each sample into four aggregate sizes: large macroaggregates (2-8 mm), small macroaggregates(250 µm-2 mm), microaggregates (53-250 µm) and silt plus clay (<53 µm) (SI 3). For each sample, the proportion of stones (>2 mm), coarse sand (250-2000 µm) and fine sand (53-250 µm) was analysed with a modification of the ISO 11277: 1998 for particle size analysis. The percentage of each aggregate size was calculated by subtracting same-sized sand content from the total fraction weight of each fraction.

Soil Organic Carbon analysis

For each aggregate fraction carbonates were removed by acid fumigation, following Harris *et al*., 2001. SOC of each fraction was analysed with a LECO Truspec CN analyser following ISO 10694:1195, and expressed on a sand-free basis [20]. To calculate the bulk soil SOC proportions throughout the profile, total SOC content of each horizon was multiplied by the bulk density of that horizon, thus obtaining g SOC cm^{-3}. Since the data was collected on a per horizon basis, the weighted average of the SOC content of the different horizons was used to calculate the proportion of SOC in the first 30 cm.

Statistical Analysis

The physical fractionation process resulted in four relative aggregate size proportions for each horizon and four associated SOC contents. In order to synthesise the data, we summarised the distribution of SOC across the aggregate sizes by applying a normal distribution to each sample against the log-transformed aggregate size, and deriving the *m*-statistic, which is the mean of the distribution, and thus the natural logarithm of the aggregate size that cumulatively contains 50% of the SOC in the sample, starting from the silt plus clay fraction and progressively including the SOC located in the bigger size fractions.

Results

Figure 1 shows the distribution of SOC across the four different aggregate size classes in all six soil types.
This figure is divided in four quadrants: A and B (top) indicate the top 30 cm of all soil profiles, while quadrants C and D, (bottom) indicate the subsoil. Quadrants A and C (left) correspond to the samples where more than 50% of SOC is located in silt plus clay and microaggregate fractions – indicating stability as C associated with smaller aggregates is more protected against mineralisation. Quadrants B and D (right) show the samples where more than 50% of SOC is associated with macroaggregates or large macroaggregates. This figure reveals three patterns:

1. The total amount of SOC declines with depth in all soils: 68.9% of the SOC was found within the top 30 cm of the soil profiles, and a significant proportion (84%) was located within large and small macroaggregates (quadrant B) for all soil types.
2. The proportion of SOC associated with large and small macroaggregates declines with depth in all soils;
3. Only below 30 cm, did differences between soil types emerge: quadrant C shows that in the subsoils affected by clay illuviation (namely: Typical Luvisol, Stagnic Luvisol and Typical Surface-Water Gley), more than 50% of the SOC is associated with microaggregates and silt plus clay fractions. While SOC found in Brown Earths below 30 cm, much still remains associated with large and small macroaggregates, even at depth (quadrant D).

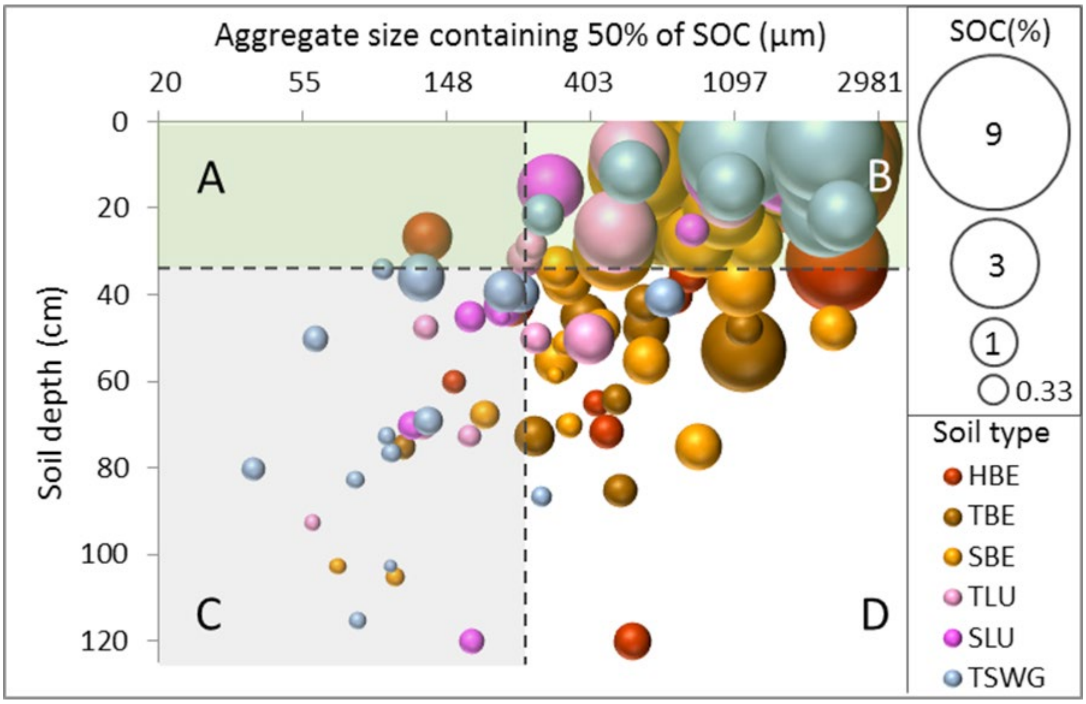

Figure 1. Relative distribution of SOC within aggregates by depth. Bubble size represents total SOC of the bulk sample at that depth. Colours indicate individual soil subgroups: HBE = Humic Brown Earth; TBC = Typical Brown Earth; SBE = Stagnic Brown Earth; TLU = Typical Luvisol; SLU = Stagnic Luvisol; TSWG = Typical Surface-water Gley.

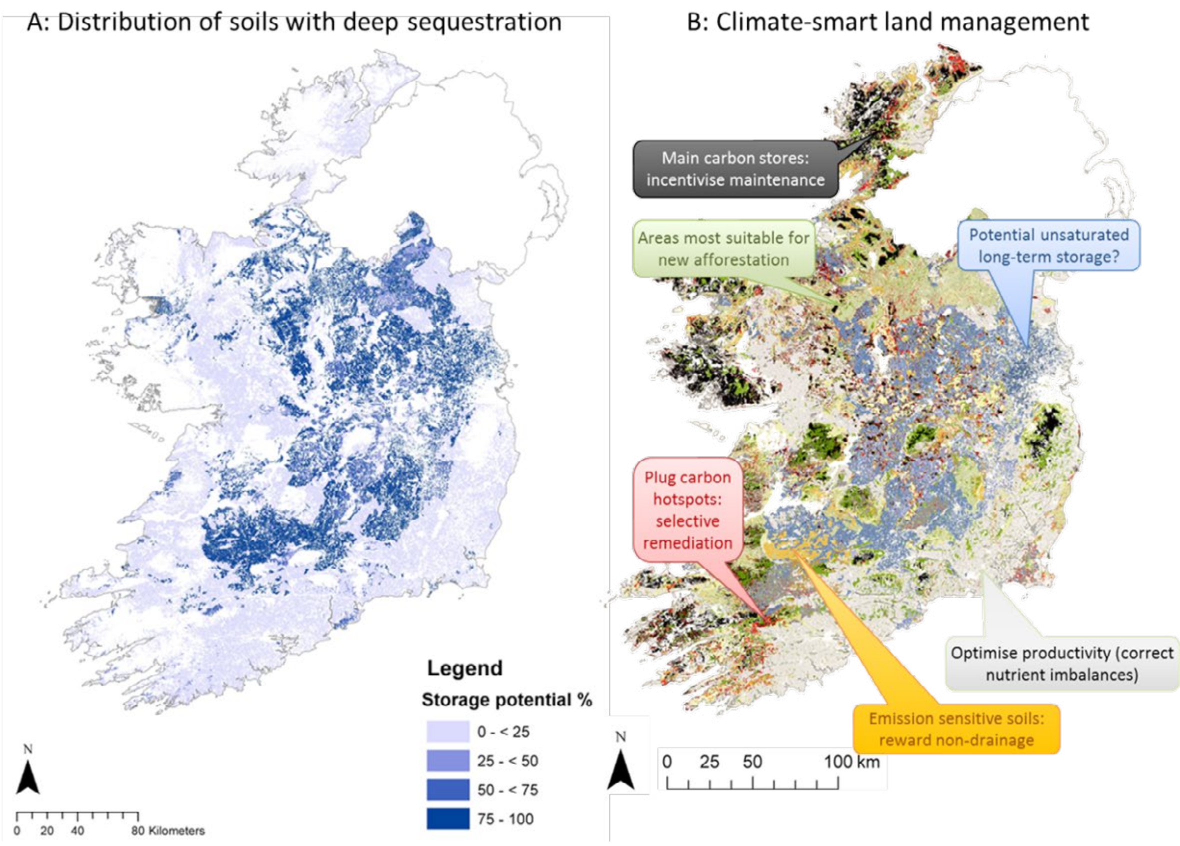

Figure 2. Indicative maps showing: A) the geographical distribution of soils that to store stable carbon at depth. Storage potential is calculated based on the percentage of area within the soil association covered by soils with argic properties. B): a framework for climate-smart land management. Source: Schulte et al. (2016)

DISCUSSION

We combined the results from this study with the outcomes of four previous studies, that relate to management options for different parts of the carbon cycle, resulting in the combined map (Figure 2b) that shows a mosaic of management options for climate-smart land management:
Maintenance of existing SOC stocks (black areas): Most (53-75%) of the current SOC stock in Ireland is contained in peat soils, which occupy 21-25% of the land area, and store an estimated 1,100 - 1,600 Mt carbon (Gutzler *et al*., under review), which is equivalent to two or three centuries of national agricultural GHG emissions.
Reduction of existing SOC emissions (red areas): following the revision of the emission coefficients in the IPCC Wetlands supplement (IPCC, 2014), artificially drained wet soils now represent the single largest source of SOC losses from land in Ireland. Gutzler *et al*. (under review) found that 'emission hotspots' associated with intensively managed (cropland and grassland) histic soils that were drained in the past cover a mere 6% of the total agricultural area, yet are responsible for 59% of total annual emissions arising from land drainage.
Prevention of new SOC emissions (yellow areas): The installation of drainage systems extends the grass growing and grazing season, but is associated with losses of SOC as a result of oxidation. O'Sullivan *et al*. (2015) assessed the cost-benefit ratio between productivity and carbon losses, using carbon pricing, for contrasting grassland soils. Using the 2030 carbon price projections adopted by the European Commission, we found that on some soils, the financial benefits from increased productivity were outweighed by financial 'penalties' arising from the associated increase in GHG emissions. We labelled these as 'emission sensitive soils' that are at risk of becoming new 'emission hotspots'.
Enhancing sequestration through land use change (afforestation) (green areas): at 11%, Ireland has the lowest forestry cover amongst EU Member States. Therefore, conversion of farmland to forestry is considered one of the most viable land management options within the current LULUCF accounting framework. However, not all soils or regions are equally suitable for new afforestation. identified 1.3 million hectares of marginal agricultural land outside priority areas for habitat conservation, where competition from other demands on land use is low.
Some areas of the map remain 'blank', suggesting that none of the aforementioned management strategies are particularly relevant for these soils, which coincide with the most productive regions of Ireland that are characterised by cambisols. International evidence suggests that SOC stocks on these soils may be augmented by optimising productivity through sustainable intensification, e.g. by rectifying soil nutrient imbalances (Smith et al., 2008), with co-benefits for the aquatic environment.

CONCLUSIONS

In this study we have demonstrated that not only the quantity of SOC, but also its 'quality', in terms of residence time, shows significant differences between soils. Our assessment suggests that SOC may be managed most efficiently if management practices are targeted towards the appropriate flux or store of the SOC cycle, which may differ between soil types and regions. This suggests that 'blanket' national policies, for example untargeted incentivisation schemes for afforestation or the maintenance of undrained soils, may represent poor value for money and lead to unwarranted competition between land use categories.

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3.2.9. | SOIL ORGANIC CARBON STOCK CHANGES UNDER GRAZED GRASSLANDS IN NEW ZEALAND

Louis A Schipper[1,2], Paul L Mudge[3,2], Miko U F Kirschbaum[4,2], Carolyn B Hedley[4,2], Nancy E Golubiewski[4,5], Simeon J Smaill[6], Francis M Kelliher[7,8,2], David Whitehead[8,2 *]

[1]University of Waikato, Hamilton, New Zealand, louis.schipper@waikato.ac.nz
[2] New Zealand Agricultural Greenhouse Gas Research Centre
[3]Landcare Research, Hamilton, New Zealand
[4]Landcare Research, Palmerston North, New Zealand,
[5]Auckland Council, Auckland, New Zealand
[6]Scion, Christchurch, New Zealand
[7]AgResearch, Lincoln, New Zealand
[8]Lincoln University, Lincoln, New Zealand
[9]Landcare Research, Lincoln, New Zealand, whiteheadd@landcareresearch.co.nz

ABSTRACT

We reviewed New Zealand studies of changes in soil carbon following conversion from woody vegetation to grassland, and under long-term grazed grasslands. Soil carbon increased by 13.7 MgC ha^{-1} following initial conversion from forests to grassland. In the last 3-4 decades, resampling of soils under grassland on flat land showed that soil carbon had declined for Allophanic, Gley and Organic soils by 0.54, 0.32 and 2.9 MgC ha^{-1} y^{-1}, respectively. For the same period, soil carbon had increased in grassland soils on stable mid-slope hill country by 0.6 MgC ha^{-1} y^{-1}. We do not know if these changes are ongoing, except for the Organic soils where losses will continue if they remain drained. Addition of phosphorus fertiliser did not result in changes in carbon stocks. Irrigation resulted in decreasing soil carbon by 7 MgC ha^{-1}. Carbon losses during grassland renewal ranged between 0.8-4.1 MgC ha^{-1}. Soil carbon increased in tussock grasslands with addition of fertiliser when not overgrazed. Estimates at the national scale suggest show no change or a gain in soil carbon but uncertainties are large. We advocate for improved sampling and investigation of the causes for changes in soil carbon.
Keywords: carbon inventory, carbon stocks, grassland, land use change, land management

EXTENDED ABSTRACT

INTRODUCTION

Globally, there is twice as much carbon in the soil than that in terrestrial vegetation and the atmosphere combined, and retaining or increasing soil carbon is important for both climate stability and for maintaining and improving soil services. To a large degree, the opportunity to increase soil carbon depends on land use and management of productive land. In New Zealand, the predominant productive land use is grassland grazed by dairy cows and drystock such as sheep and beef animals. In 2012, there were about 5.8 Mha of high producing grassland (22% of New Zealand's total land area), 7.5 Mha of low producing grassland (28%) and 1.4 Mha of grassland with woody biomass (5%). Originally, New Zealand was largely covered by forest that was converted to grassland following human arrival. Following this conversion to grasslands for grazing, production increased over time due to a number of management strategies such as applications of fertiliser and lime together with the optimisation of grazing regimes.

Although land use has been intensifying in New Zealand grazing systems for decades (MacLeod & Moller 2006), few data exist to understand its consequences for soil quality, including changes in soil carbon. Changes in soil carbon stocks are the net effect of plant inputs originating from plant photosynthesis and heterotrophic respiration. Knowing whether different management strategies increase or decrease carbon stocks is problematic because many of the factors that are manipulated alter rates of both carbon inputs and losses.

Changes in soil organic carbon are determined by the complex interplay between (1) changes in net primary production; (2) the carbon fraction taken off-site through grazing; (3) carbon allocation within the system between labile and stabilised soil carbon and (4) changes in soil carbon decomposition rates. There is a particularly important trade-off between carbon removed by grazing or remaining on site and available for soil carbon formation (Kirschbaum *et al.* 2017). Changes in soil carbon cannot be understood fully unless all four factors are considered together in an overall assessment.

OBJECTIVE

To improve our understanding of soil carbon dynamic in New Zealand, we reviewed all available published information on the influence of land use and management on soil carbon in New Zealand's grazed grassland systems. We synthesised values as reported in the various studies, assuming the authors used the best approach to estimate annual soil carbon stock changes to a specified depth.

LAND USE CHANGE TO AND FROM GRASSLAND

The effects of land use change were modelled by McNeill *et al.* (2014) including the conversions between native forest, low producing grassland, tussock grassland, exotic forest and high producing grasslands (Table 1). In general, soil carbon was higher in the mineral soils for high producing grasslands compared with those for other land uses. Soil carbon stocks were lower in forests but this estimate did not include above-ground biomass which would have been higher in forests. While this conclusion was derived using a statistical model, we also found that the difference between forest and grassland soils was well supported by comparative stock measurements made on adjacent grassland and forest sites.

CHANGES WITHIN GRASSLANDS FOR DIFFERENT SOIL ORDERS

While much of New Zealand has been under grassland for many decades, over the last few decades, several studies have identified additional changes in soil carbon within the category of high producing grasslands. Schipper *et al.* (2014) demonstrated that, for flat land, Allophanic and Gley soils had lost soil carbon at an average statistically significant rate of 0.54 and 0.32 MgC ha^{-1} y^{-1} respectively, with no other detectable significant changes for other soil orders except Organic soils. In contrast, Parfitt et al (2014) reported no statistically significant changes in soil carbon under drystock and dairy farming. As these studies were undertaken over different periods of time and samples taken from different depths, the discrepancies warrant further investigation. Both these studies showed that soil carbon on the stable mid-slopes of hill country increased significantly. Whether these changes are ongoing remains an important question to address.

In agreement with international studies, drainage of Organic soils resulted in large losses of carbon. These losses are expected to continue as long as the peat is drained (Campbell *et al.* 2015, Pronger et al 2014, Schipper & McLeod 2002). For their small area in New Zealand, these carbon losses represent a disproportionate contribution to changes in the national soil carbon inventory. Further, in New Zealand currently we do not have land management solutions targeted at reducing these losses.

Table 1: Soil organic carbon (SOC) changes attributable to land use change. Land use effects are expressed relative to the value of SOC for low producing grassland taken from the intercept in the model described by McNeill et al. (2014).

Model intercept	SOC (MgC ha^{-1})	Standard error
Low producing grassland	106.0	3.9
Land use category	Change in SOC from land use effect (MgC ha^{-1})	Standard error
Pre-1990 natural forests	-13.7	3.7
Pre-1990 planted forests	-13.5	5.8
Post-1989 planted forests	-14.1	4.9

Grassland with woody biomass	-7.8	3.7
High-producing grassland	-0.6	3.1
Perennial cropland	-17.5	6.4
Annual cropland	-16.2	4.5
Vegetated wetland	30.1	8.5

EFFECTS OF GRASSLAND MANAGEMENT ON SOIL CARBON STOCKS

In New Zealand, various management practices aim to increase grassland productivity, including addition of fertiliser with phosphorus, nitrogen and other nutrients, irrigation, and grassland renewal. From the few studies where changes in soil carbon have been measured under different management practices our findings are:

Drawing from four long-term trials on both flat land and hill country, there was no evidence that phosphorus fertiliser application influenced soil carbon stocks despite, in some cases, a doubling of grassland productivity.

Building on findings from on a long-term flood irrigation trial (Schipper *et al.* 2013), Mudge *et al.* (2017) added a national scale sampling at 24 adjacent sprinkler-irrigated and non-irrigated sites and showed that soil carbon stocks (0-0.3 m depth) were about 7 Mg ha^{-1} lower at irrigated sites compared with those at dryland sites, despite much higher productivity.

Occasional grassland renewal and the associated cultivation led to carbon losses of about 0.8 to 4 MgC ha^{-1} during the renewal process but these are unlikely to greatly affect long-term soil carbon stocks if renewal is infrequent (Rutledge *et al.* 2017). This contrasts with general losses of soil carbon due to frequent and repeated cultivation.

The effect of different animal stock types or numbers of grazing animals on soil carbon stocks is poorly understood (Barnett *et al.* 2014).

There is some evidence that fertiliser inputs to tussock grasslands result in increased soil carbon stocks (McIntosh *et al.* 1994) particularly when grazing is also well managed.

Overall data coverage in New Zealand is still weak or absent for some management practices. For example, there have been no long-term studies of the effect of nitrogen fertiliser application on soil carbon stocks. Multi-factor studies are needed to understand the complex and variable responses of soil carbon, which are affected not only by land use and management, but also soil type, topography, climate, and land cover/ land use history.

Extrapolating data from soils sampled repeatedly beneath grazed grassland to a depth of 0.3 m at the national scale resulted in estimated carbon stock changes of –1.6 to 1.1 MtC y^{-1} (95% confidence limits) according to the Schipper *et al.* (2014) compilation, and 0.8 to 5.1 MtC y^{-1} according to the Parfitt *et al.* (2014) compilation. Limitations of the available data warrant further consideration. For example, there have been no systematic measurements of changes in soil carbon following land use conversion to grazed grassland, or for different management practices. Instead, the estimates available to date have relied on a compilation of soil carbon data from field trials that were established for different purposes. A major constraint of this approach is that these trials are not likely to be representative spatially or temporally. This can affect the estimates and their uncertainty, and a better understanding of their representativeness is needed.

Conclusions

Our analysis revealed large and important gaps in our understanding of both the magnitude and the associated uncertainties of change in soil carbon for New Zealand grasslands. The representativeness of existing soil sampling data is also uncertain. These gaps may best be addressed by establishing a national framework and methodology for sampling soils through time along with site-specific leveraging on previous studies. Establishment of a national measurement system would reduce uncertainty in changes in carbon stock while resampling of existing sample sites or additional sampling at paired land use sites would allow more rapid, but spatially constrained, estimates of changes in soil carbon stocks.

This abstract is based on the recent paper by Schipper *et al.* (2017). A review of soil carbon change in grazed New Zealand pastures. New Zealand Journal of Agricultural Research (in press). http://dx.doi.org/10.1080/00288233.2017.1284134

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THEME 3.3 | MANAGING SOC IN DRYLAND SOILS

3.3.1 | EFFECT OF DEFORESTATION AND MANAGEMENT ON SOIL CARBON STOCKS IN THE SOUTH AMERICAN CHACO

Osinaga, N.[1,3*; 1]; Álvarez, C.R.[*1]; Taboada, M.A.[1,2,3]

[1]Universidad de Buenos Aires, Facultad de Agronomía, Cátedra de Fertilidad y Fertilizantes
[2]Instituto de Suelos INTA Castelar
[3]CONICET

ABSTRACT

In the Argentine sub-humid Chaco since the end of the '70 there has been an advance of the agricultural frontier over the native forest. Loss of forest reduces carbon stocks in vegetation and causes significant losses of soil organic carbon. The objective of this study was to determine the organic carbon (OC) stock up to 1-meter deep and to determine its fractions in the surface soil layers under different land uses: agricultural (less than 10 years and more than 20 years under agriculture), pasture and forest in the Chaco region. The OC contents up to 1 m deep expressed in equivalent mass were as follows: forest (119.3 Mg ha^{-1})> pasture (87.9 Mg ha^{-1})> agricultural (71.9 and 77.3 Mg ha^{-1}). The most sensitive OC fraction was the coarse fraction (2000 µm -212 µm) in the two depths studied (0-5 cm, 5-20 cm). Resistant carbon (<53 µm) was the main fraction of organic matter for all the studied situations except for the forest. The stock of OC, its quality and its distribution in the profile were sensitive to the change of land use in the studied region. The conversion of the Chaco forests to crops was associated with reductions of OC up to the meter deep and with the decrease of the labile fractions. The loss of such important ecosystem service that helps mitigate global warming could be reduced by appropriate management practices, one of which may be the incorporation of pastures of warm-season grasses.

Keywords: Carbon sequestration, particulate carbon, land use change

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Since the end of the 1970s, the Argentine agricultural frontier has been advancing over natural ecosystems (Gasparri et al., 2009; Viglizzo & Jobbagy, 2010). The sub-humid and semi-arid Chaco has one of the largest areas of native forests and since 1997 there has been a notable increase in the deforested area (Albanesi et al., 2003; Volante et al., 2009).

Loss of forests not only reduces carbon stocks in vegetation but also causes significant losses of soil OC (Neill et al., 1998; Post & Kwon, 2000; Desjardins et al., 2004). Chaco forest has 60% of the carbon accumulated in the aerial biomass and 40% in organic matter in the first meter of soil, and because of the large surface area that occupies in Argentina constitutes a large reservoir of carbon (Gasparri et al., 2008). Due to the introduction of agriculture, up to 50% of soil organic matter can be lost after 20 to 30 years in the forests of tropical America, until reaching a new equilibrium (Eswaran et al., 1993). In the eastern sub-humid Chaco, reductions in the levels of organic matter have been detected in the first centimeters, especially of their labile fraction (Álvarez & Lavado, 1998; Roldán et al., 2000; Albanesi et al., 2003; Sánchez (2006). Agricultural practices not only affect the total amount of OC, but also change the relative proportion of OC fractions (Barbero et al., 2006; Conteh et al., 1998). The main reasons for this decline were deforestation plus soybean and cotton monoculture, increased years of agriculture and inadequate management.
In the mid-1990s the adoption of no-till occurred. This technique was adopted in Argentina due to the low production costs,

the possibility to devote less productive areas to agriculture (Satorre, 2005; Derpsch et al., 2010), the save of operation time and to the minimal soil distribution that allows reduce the erosion, recover the stability of the aggregates, conserve water and increase carbon sequestration (Panigatti et al., 2001, Díaz Zorita et al., 2002, Viglizzo et al., In Viglizzo & Jabbagy, 2010).

In the western part of the region, livestock production become important, and in some cases the native forest is replaced by warm-season grasses pastures. This activity produces a lower reduction of the OC contribution to the soil and is expected lower losses of OC than under continuous agriculture (Caruso et al., 2012).

The objective of this study was to determine the organic carbon (OC) stock up to one meter deep and to determine its fractions in the surface soil layers under different land uses: agricultural (less than 10 years and more than 20 years under agriculture), pasture and forest in the Chaco region.

METHODOLOGY

Soil sampling was carried out in production fields of Santiago del Estero province (central area of Argentina). This area is located in the subhumid Chaco natural region (Vargas Gil, 1988). Annual rainfall ranges from 700 mm to 1000 mm. The average annual temperature is 21 ° C. The most representative soils are Haplustolls, Argiustolls and Ustifluvents (Vargas Gil, 1988).
Sixteen cropped fields were selected, eight with less than 10 years and eight with more than 20 years under agriculture. The agricultural management consisted in one summer crop per year (alternating between soybean, maize and cotton) under continuous no-till. Additionally eight situations of native forest (forest curtains) and eight situations of warm-season grasses pastures (Panicum maximun cv. Gatton Panic) were selected. In each situation soil was sampled up to one meter deep: 0 to 5 cm, 5 to 20 cm and then every 20 cm. Four subsamples were taken from each soil interval.
The OC was determined by wet combustion using the Walkley-Black method (Nelson & Sommers, 1996) and in the 0-5 and 5-20 cm intervals particulate OC was also measured (Cambardela and Elliot , 1992). Soil carbon contents are expressed at a fixed depth and as constant soil mass (Neill et al., 1997) to isolate the effect of differences in soil bulk density. In the each situation, soil bulk density was determined by the cylinder method,
The analysis of the variance (ANOVA) was performed and the LSD test ($p \leq 0.05$) was used for the comparison of means. The normality of the data was checked by the modified Shapiro Wilks test.

RESULTS AND DISCUSSION

Soil use influenced soil OC up one meter deep unless in the 20 to 40 cm interval where all situations had the same amount (19.5 Mg ha^{-1}, Figure 1). There was a significant reduction in the OC in agricultural sites relative to the pristine situation (native forest) in the first 20 cm and from 40 to 80 cm depth. The pastures only presented this reduction in the surface layers. Between 34% and 48% of the total OC was found in the first 20 cm of soil, in the forests the carbon was more stratified (Jobbágy & Jackson, 2000). For 0 to 20 cm the decrease in OC was 45%. The vertical distribution of OC tends to follow the design of the root system (Jobbágy & Jackson, 2000).

The OC contents up to one meter deep expressed in equivalent mass (9885 Mg ha^{-1} of soil) followed this trend: forest (19.3 Mg ha^{-1}) > pasture (87.9 Mg ha^{-1}) > agricultural situations (71.9 and 77.3 Mg ha^{-1}). Organic carbon stock in agricultural sites did not differ between years under agricultural so the losses of soil organic carbon occur in the first years of the conversion to agriculture. The soil OC content is related to the carbon input from the vegetation. Net primary production varies between biomes, being higher in forest, intermediate in pastures and lesser in crops (Aber & Melillo, 2001; Follet et al., 2009). In the Pampas region Sainz Rozas et al. (2011) observed that the reduction of OC under agriculture ranges from 36 to 53% relative to the pristine soils. This places our values in the middle of this range of variation. This lost of OC is explained by the lower contribution of crops to the soil (Álvarez, 2006), greater mineralization rate and a greater susceptibility to erosion (Andriulo & Cardone, 1998) in agricultural situations.
Land use has a significant influence on carbon fractions. The most sensitive fraction was the coarse fraction (2000 µm -212 µm) in both studied depths (Figure 2). Resistant carbon (<53 µm) was the main fraction of organic matter for all the studied situations except for the forest, where the more labile and more readily available fractions represented the 65% of the total OC in the surface horizon and 55% in the 5 -20 cm layer (Franzluebbers et al., 1996).

The resistant carbon (<53 µm) content in agricultural sites totalized the 78% of the total OC so there is a redistribution of OC from more labile fractions to more resistant ones, which have a lower nutrient mineralization rate.

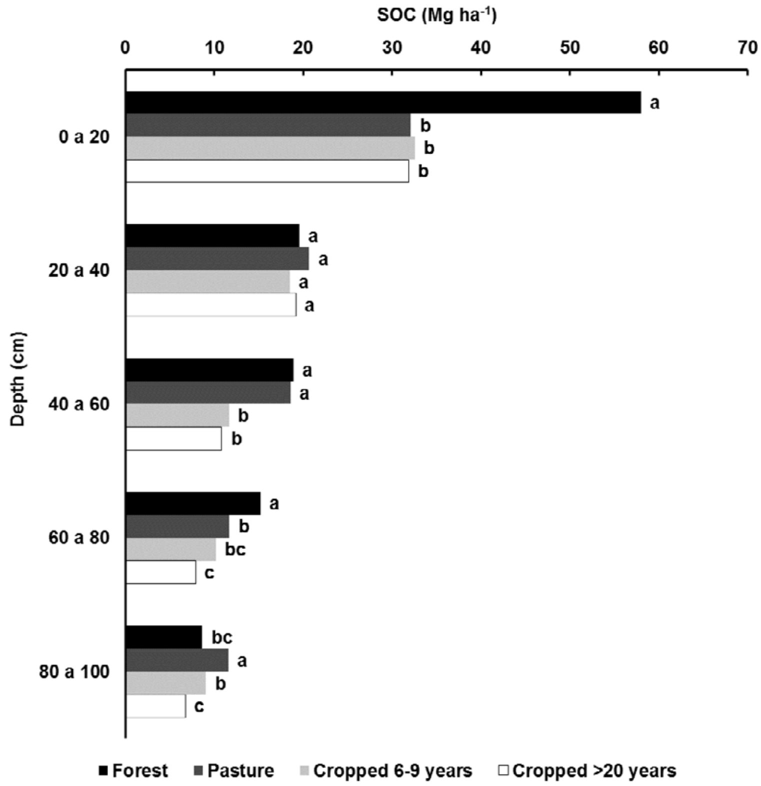

Figura 1. Soil organic carbon (SOC) distribution in depth under different land uses. Different letters indicate significant differences between land uses for a same depth.

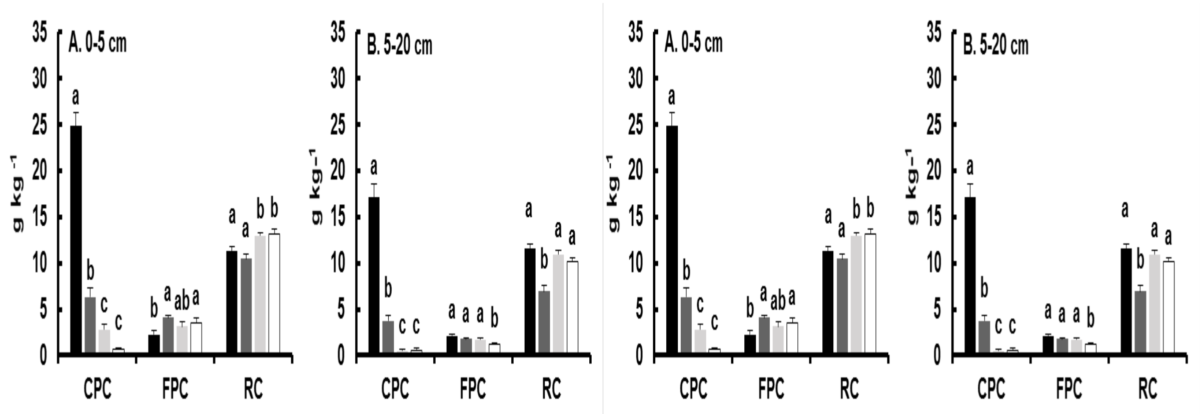

Figure 2: Coarse particulate carbon 2000 µm - 212µm (CPC), fine particulate carbon 212µm - 53µm (FPC) and resistant carbon <53µm (RC) variations associated with land use .A: Depth 0-5 cm. B: Depth 5-20 cm. Different letters indicate significant differences between landñ uses for a same depth interval.

CONCLUSIONS

The OC stock, its quality and its distribution in the profile is sensitive to the change of land use occurred in the studied region. The conversion of the Chaco forest to agriculture produced substantial reductions of OC up to the meter deep and a decrease of the labile fractions in surface layers. The loss of such important ecosystem service that helps mitigate global warming could be mitigated by appropriate management practices, one of which may be the incorporation of pastures.

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3.3.2 | INTEGRATED USE OF ORGANIC CARBON, PLANT NUTRIENTS AND BIO-FERTILIZERS IS KEY TO IMPROVE FIELD CROPS PRODUCTIVITY UNDER ARID AND SEMIARID CLIMATES

Amanullah (ITPS, Pakistan)

Associate Professor of Agronomy, Faculty of Crop Production Science, The University of Agriculture, Peshawar- 25130

*Email: amanullah@aup.edu.pk

ABSTRACT

The 4‰-initiative aims to improve the soil organic carbon through better agricultural practices which are economically and environmentally friendly. Incorporation of soil organic carbon in the soils increases: (1) resistance of soils to erosion, (2) soil water retention, (3) soil fertility and (4) soil biodiversity. Stable and productive soils must have sufficient amount of soil organic carbon to cope with the negative effects of climate change. Under arid and semiarid areas in Northwest Pakistan the low crop productivity is the major cause food insecurity. Low crop productivity in the arid and semiarid regions is attributed to (1) low soil organic carbon, and (2) low soil fertility. Our long term field experiments (2005-2016) indicated that integrated use of organic carbon incorporation in the soil + chemical + bio-fertilizers application increases productivity of field crops [cereals crops (wheat, maize & rice), oilseed crops (sunflower, soybean & canola) and pulses (mungbean, mashbean and chickpea) and smallholder's income. We investigated the new sources of organic carbon [plant materials (onion, garlic, canola, fababean, peach residues etc. which are never tried before) an animal manures (sheep manure, poultry manure and cattle manure)] along with various combination of chemical fertilizers (nitrogen, phosphorus and potassium) with (+) and without (-) bio-fertilizers (beneficial microbes), and found that the yield of field crops (cereal, oilseed and pulses) and growers income increased significantly over control. The results further confirmed that incorporation of organic carbon in the soil not only increase the yield of the current crops but its residual effect also had positive impact on soil health and yield of the succeeding crops especially under cereal-cereal based cropping systems in the arid and semiarid climates in northwest Pakistan. Moreover, the integrated nutrients management practices not only improved crop yield, seed quality and grower's income but also had positive effect on soil health and environment.

Keywords: soil organic carbon, chemical fertilizers, biofertilizers, field crops, cereal crops, oilseed crops, pulse crops, yield, net returns, arid and semiarid climate,

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3.3.3 | SOIL INORGANIC CARBON AND CLIMATE CHANGE IN DRYLANDS? AN EMERGING ISSUE?

Chevallier T[1*], Cournac L[1], Bernoux M[1,4], Cardinael R[2], Cozzi T[3], Girardin, C[3], Chenu, C[3]

[1]IRD, UMR Eco&Sols, Montpellier FRANCE, tiphaine.chevallier@ird.fr
[2]CIRAD, AIDA, Montpellier, FRANCE
[3]AgroParisTech, UMR Ecosys, Grignon FRANCE
[4]FAO, Climate and Environment Division, Rome, ITALY

INTRODUCTION

Terrestrial ecosystems play a major role in regulating the concentration of CO_2 in the atmosphere. A comprehensive understanding of sinks and sources of carbon (C) and their dependence on changing climate is a highly studied research topic to produce accurate estimates of future atmospheric CO_2 concentrations. Soils are considered as one of the largest C pools on Earth. The soil C pool comprises two distinct components: soil organic carbon (SOC) and soil inorganic carbon (SIC), which roughly contribute ⅔ and ⅓, respectively. In general, more attention had been paid to the storage and dynamic of SOC pool, which is considered as a key component of soil functioning and more dynamic than SIC. Because some methodological issues persist in measuring the contribution of SOC and SIC in total soil C or CO_2 fluxes from soils, calcareous soils are poorly studied for the global C cycle. Yet, calcareous soils cover over 30% of the earth's land surface mainly in arid and semi-arid areas where an understanding of SOC dynamics is particularly critical for ensuring food security. In these regions, SOC stocks, a major determinant of soil fertility, are low and agricultural productivity is already limited by climatic conditions. Methods to separate easily SOC and SIC dynamics in soil are thus needed. A study in a large set of French soils showed the potential of mid-infrared reflectance spectroscopy (MIRS) to predict SOC and SIC contents in calcareous soils (Grinand *et al*. 2012). However, SIC is no more seen just as a static C pool in soils and dynamics should be studied. There is increasing evidence that equilibrium in the SIC system may be shifted in one way or another by external factors such as management practices and human-led environmental changes. The three main factors controlling dissolution and precipitation of $CaCO_3$ as listed by Gocke *et al*. (2011) are: (1) CO_2 partial pressure in pore space, (2) pH of soil solution, and (3) mass flow of dissolved carbon species (H_2CO_3, HCO_3^-). Biological activities and climate change can impact all of these three factors and thus may mobilize SIC to emit CO_2 or promote $CaCO_3$ precipitation by modifying the equilibrium between the different dissolved (aq.), gaseous (g) and solid (s) inorganic carbon species.
This equilibrium is formalized by the equations:

$$CaCO_3\,(s) + H^+ \longleftrightarrow Ca^{2+}\,(aq) + HCO_3^-\,(aq.) \qquad \text{Eq. (1)}$$

$$HCO_3^-\,(aq.) + H^+ \longleftrightarrow H_2CO_3\,(aq.) \longleftrightarrow H_2O + CO_2\,(g) \qquad \text{Eq. (2)}$$

Liming practices, which are aimed to increase soil pH, may stimulate CO_2 emission by carbonate dissolution (Bernoux *et al*. 2003). Adding plant residues or organic amendments enhances biological activities, i.e. root and microorganism respiration, resulting in an increase in CO_2 partial pressure, which may either lead to an enhanced trapping of CO_2 through carbonate precipitation, or to a decrease in soil pH resulting in the dissolution of carbonates (Gocke *et al*., 2011). Climate change is also likely to affect the SIC system, as the increasing atmospheric concentration of CO_2, climate warming, and variations in the amount and frequency of rainfall events could modify biological activities and thus equilibrium interactions between soil carbonates and bicarbonates (Emmerich 2003; Chevallier *et al*. 2016). Natural isotopic ^{13}C tracing has been performed using the difference in ^{13}C signatures between SOC and SIC to trace the source of the CO_2 emitted from soils (Stevenon and Verburg, 2006). Here are presented two original studies: the first one in South of France to show SIC can contribute to CO_2 emissions from soil incubation in topsoils and in subsoils, the second one in Tunisia to test how temperature could affect the contributions of SOC and SIC to the CO_2 emitted from a calcareous soil.

MATERIAL AND METHODS

French soils: Two cultivated Fluvisol with two contrasted SOC contents in topsoils, 19 and 9 g SOC kg^{-1} soil, but similar SIC content, about 64 g SIC kg^{-1} soil, were incubated for 28 days at 20°C. In subsoils (10-30, 70-100 and 160-180 cm) the SOC contents were not different between the two soils. The CO_2 and $^{13}CO_2$ emitted from soil samples were directly measured on the gas inside the incubation jars with a micro chromatographer coupled with a mass spectrometer.

Tunisian soils: A cultivated Calcari-Leptic Cambisol Tunisian topsoil (0-10 cm) which contains 66 g C kg^{-1} soil with 44 g SIC kg^{-1} soil was incubated at 4 temperatures (20, 30, 40 and 50°C) for 28 days. In order to determine its ^{13}C natural isotopic abundance, the CO_2 emitted from soil samples and trapped in NaOH was precipitated as $BaCO_3$ by adding $BaCl_2$ (20 mL, 0.5 M). The $BaCO_3$ precipitates were analysed for their carbon isotope abundance.

The contribution of SIC and of SOC to the total amount of CO_2 emitted can be calculated using the standard isotope dilution equation in a first approximation

$$^{13}C_{CO2(t)} = f \,.\, ^{13}C_{CO2\text{-}SIC} + (1 - f) \,.\, ^{13}C_{CO2^{-}SOC}$$

This isotopic method has often been applied by implicitly assuming that the ^{13}C of SIC-derived CO_2 ($^{13}C_{CO2\text{-}SIC}$) is equal to the ^{13}C of SIC ($^{13}C_{SIC}$) and that of SOC-derived CO_2 ($^{13}C_{CO2^{-}SOC}$) is equal to the ^{13}C of SOC ($^{13}C_{SOC}$). CO_2 emission from SIC or SOC is prone to induce isotopic fractionation at various steps but we assumed that this phenomenon is limited in our case (Chevallier *et al*. 2016).

RESULTS AND DISCUSSION

Whatever the soils and the measurement method, alkali traps or gas analysis, the ^{13}C signature of CO_2 emitted from soils differed significantly from that of the SOC. In French soils, the CO_2 emissions were ^{13}C-enriched by around 5‰ to 13‰ compared to the SOC and were therefore shifted towards the ^{13}C signatures of SIC, especially at high soil depth (Fig. 1). The range of ^{13}C signatures of gas samples did not evolve with time more than 2‰. In Tunisian soils, there are also CO_2 emissions ^{13}C-enriched compared to SOC, especially at 40 and 50°C, but this enrichment decreased dramatically with time. This high enrichment by 5 to 13‰ in ^{13}C of the total CO_2 emissions compared to the SOC was opposite to the isotopic fractionation factors predicted between SOC and CO_2 derived from SOC (e.g. Schweizer *et al*. 1999). Such an increase in ^{13}C of the CO_2 emissions cannot be explained without the contribution of an external C pool with high ^{13}C. It likely signed a contribution of SIC, with $^{13}C_{SIC}$ higher than $^{13}C_{SOC}$, to the CO_2 emitted from soils (e.g. Stevenson and Verburg, 2006). Literature data ranged the contribution of SIC to total CO_2 emissions from 0.1 to 0.4 in dry conditions (Inglima *et al*., 2009). Our data showed high values from 0.15 to 0.7 especially at 40 and 50°C and in soil sampled at higher depth than 70 cm.

As expected, CO_2 emissions from soil increased with increasing temperature and are higher in topsoils than in subsoils (Fig. 2). This increase was generally attributed to a stimulation of SOC decomposition with temperature (Hamdi *et al*. 2013) and to a potential SOC mineralization decrease with depth as SOC contents and microbial biomass also decrease with depth (Fang and Moncrieff, 2005). There is a negative correlation between the amount of CO_2 emitted and ^{13}C values, except at high temperature. At incubation temperature under 30°C, the SOC seems to be the main contributor to the increasing amount of evolved CO_2, even if the calculated amounts of SIC-derived CO_2 could be high in topsoils (Fig. 2). In the other hand, the low ^{13}C values of emitted CO_2 in subsoils signed a high contribution of SIC to CO_2 (0.7) but did not represent high amounts of total emitted CO_2 from SIC (Fig. 2). The CO_2 emissions from SIC seemed to be stimulated by SOC decomposition (Fig.3). The isotope exchanges between SIC- and SOC-derived CO_2 could explain that ^{13}C signatures of CO_2 emissions were not the equaled to the ^{13}C signatures of the SOC. The dynamics of SOC and SIC can be closely linked according to the equation:

$$H_2O + CO_2 + CaCO_3\,(s) \longleftrightarrow Ca^{2+}\,(aq) + 2HCO_3^-\,(aq.) \qquad \text{Eq. (3)}$$

This equation illustrates the possible exchange pathways of C between SOC-derived CO_2 and SIC-derived bicarbonate. In such a scheme, going back and forth, CO_2 emitted by SOC can replace and displace SIC carbonate, which would generate “SIC-labelled” CO_2. The SOC-derived CO_2 is likely to be the essential factor in the dissolution of SIC in the absence of additional H^+ sources. The CO_2 emissions would also be labeled SIC even though they were entirely dependent on SOC mineralization. In other words, an increase in the SIC signature of emitted CO_2 does not directly imply an additional contribution of SIC as a source of CO_2.

At high temperatures, other equilibrium seems to occur. The CO_2 emissions from SIC seemed to be stimulated by additional mechanism than solely SOC decomposition (Fig.3). The increase in CO_2 emissions came along with an increase of the ^{13}C signature of the emitted CO_2. The CO_2 emissions from SIC seemed to be stimulated by temperature. A higher dissolution of SIC is not the explanation as solubility of CO_2 in water decreases with increasing temperature. Isotopic fractionation factors between SIC and SIC-derived CO_2 are temperature dependent, being greatest at low temperatures (Bottinga, 1969). This could explain a part of the increase in ^{13}C emitted CO_2 without the need for invoking a higher amount of CO_2 from SIC with temperature.

Although the qualitative SIC contribution to emitted CO_2 from soils incubated in lab suffers low doubt, this study confirms that quantitative appraisal and assignment are far from being straight forward. Increasing soil temperatures seem to modify dramatically the apparent SIC dynamics. Due to the complexity and diversity of involved phenomena additional information is needed to unravel the mechanisms underlying the effects of temperature on quantity and signature of emitted CO_2.

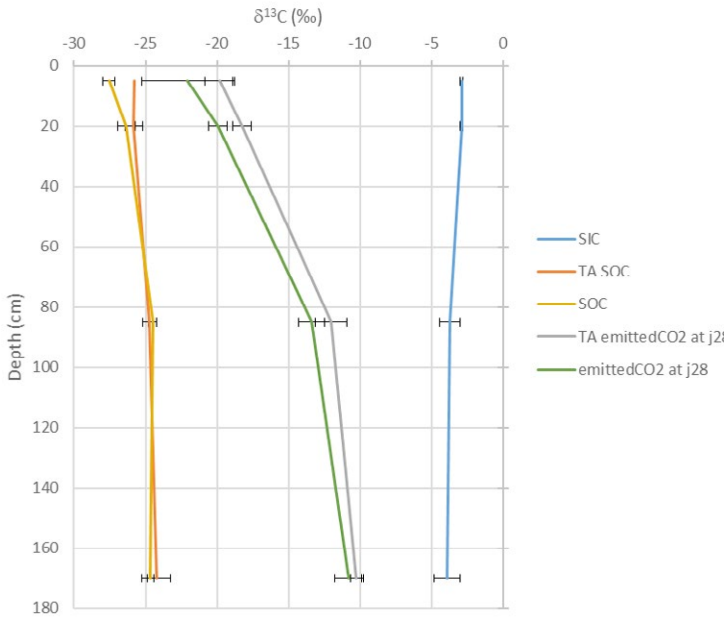

Fig. 1 13C (‰) profil of SOC and SIC and the CO_2 emitted from 2 soils with similar SIC contents but different SOC contents after 28 days (21-28 days).

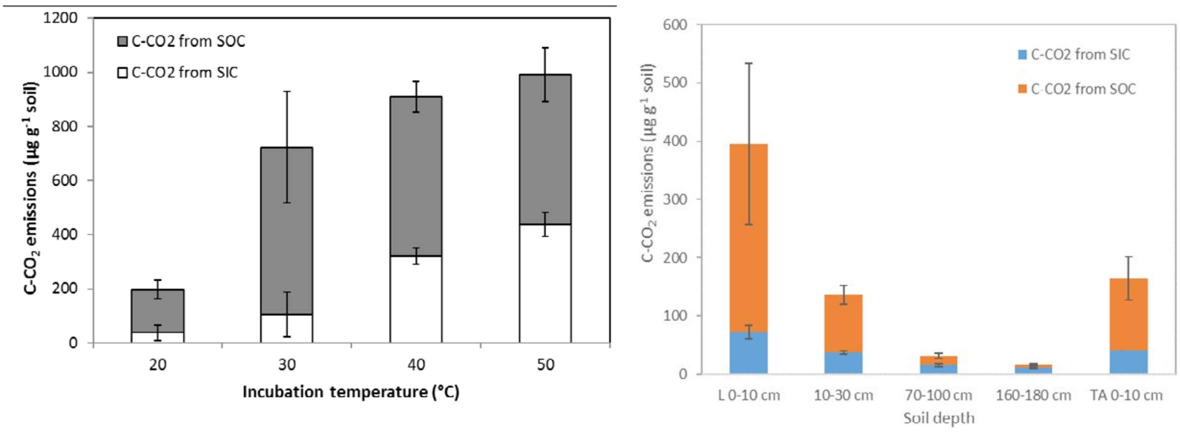

Fig. 2 Cumulative C-CO_2 emissions from soil organic carbon (SOC) and from soil inorganic carbon (SIC) during 28 days of incubations at different temperatures and soil depth. L 0-10 cm and TA 0-10 cm are two top soils with similar SIC contents but different SOC contents.

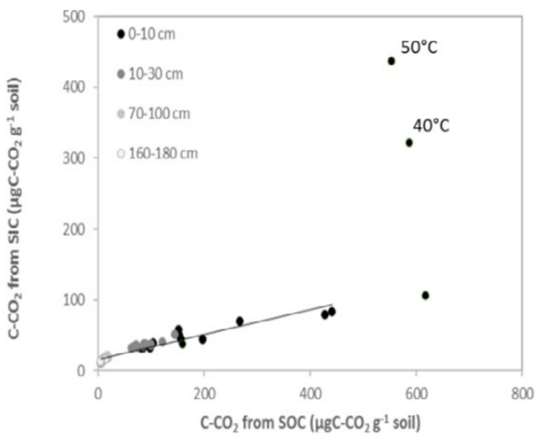

Fig. 3 Relationship between cumulated CO_2 from SIC and SOC of all the soils sampled after 28 days of incubation.

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3.3.4 | MAPPING OF SOIL ORGANIC CARBON STOCK IN THE ARAB COUNTRIES

Darwish*, T. and Fadel[1], A.

[1]National Council for Scientific Research, Beirut. Lebanon P.O. Box: 8281
*Corresponding author: tlldarwish@gmail.com

ABSTRACT

Soil organic matter is a key soil component and plays a critical role in ecosystem functions including soil productivity and resilience to erosion and drought. Most Arab countries are located in semi-arid and arid areas with dominance of drylands soils with poor organic matter content and soil quality. Soil organic carbon (OC) stock in the Arab countries was assessed and mapped using the FAO-UNESCO Digital Soil Map of the World (DSMW). Results were compared with one national large scale OC mapping. They showed low OC stock in the topsoil of more than 69% of the cultivated soils with dominance of Xerosols, Arenosols and Lithosols. The average soil OC stock in the Arab countries is 37±36 ton/ha in the topsoil and 78±69 ton/ha in the standard soil depth. The total OC stock in the arable lands of the Arab countries was estimated at 50 Billion tons with Sudan, Saudi Arabia and Algeria placed on top. The average total OC stock per one Arab country is 0.8 ±1.7 million tons. With increased pressure on limited soil resources, policies must address C sequestration to support soil productivity and improve food production.

Keywords: C sequestration, landuse impact, climate change, drought tolerance.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Soils are at the core of the terrestrial ecosystem. Long time interaction and carbon sequestration lead to soil organic carbon (OC) stocks nearly three times larger than stocks in the vegetation ecosystems (Post *et al*., 1990) and twice larger than stocks in the atmosphere (Eswaran *et al*., 1993). Accurately quantifying SOC stores in soils and monitoring their changes are considered essential to global climate change modeling (Janzen, 2004) and to assessing the state of land degradation.
The Arab countries are spread around the east and north Mediterranean Sea and Arabic peninsula thus they receive the direct impact of arid climate dominating in the surrounding Sahara. Mismanagement disrupts the equilibrium of inherited characteristics of a given soil type, cumulatively built under prevailing land cover and climate (Bhogal *et al*. 2008). Ploughing and landuse change cause a rapid loss of SOC (Guo and Gifford, 2002). Appropriate soil management and even land abandonment may enhance the soil carbon pool (Atallah *et al*., 2015; Boukhoudoud *et al*., 2016). Mapping and quantifying SOC contents and distributions in the Arab countries using available soil data is crucial to assess the nature and potential of available soil resources. Thus, the purpose of this work was to assess and map the soil OC stock at the Arab and national levels to enhance C sequestration.

MATERIAL AND METHODS

Soil OC density was linked to each soil unit and corresponding map to produce soil OC stock and distribution maps in twenty two Arabic States using the digital soil map of the world (DSMW) and its attribute database at 1:5 Million scale (FAO, 2003). Arc Map 10.1 was used for the mapping. The calculation of OC stock in the upper topsoil (0.3m) and subsoil (0.3-1.0m) was done using the following equation:

OC Stock (ton) = [Soil Area (m^2)*Soil Depth (m)*Bulk Density*OC $_{content}$ (%)]/100 equation 1

The OC Content ton ha^{-1} was calculated following the equation:

OC Content ton ha^{-1} = OC Stock/Soil Area (ha) equation 2

RESULTS

A total of 17 major soil groups and 66 soil units were identified for the Arab countries. The identified major soil groups are Yermosols, Lithosols, Regosols, Arenosols, Xerosols, Cambisols, Fluvisols, Luvisols, Solonchaks, Solonets, Andosols, Vertisols, Ferralsols, Gleysols, Kastanazems and Anthrosols. The total area of the arable soils in the Arab region is 11.6 Million SQM (Table 1). The most abundant major soil group is Yermosols with an area of 5.1 million SQM. The second most abundant major soil group in the Arab countries is Lithosols followed by Regosols having 2.3 and 1.05 million SQM respectively. Arenosols and Xerosols have almost equal area of 0.7 million SQM. Ferralsols, Andosols, Kastanozems and Gelysols are the most enriched with OC stock varying from 69 to 232 ton ha^{-1} (Figure 1, Table 1).

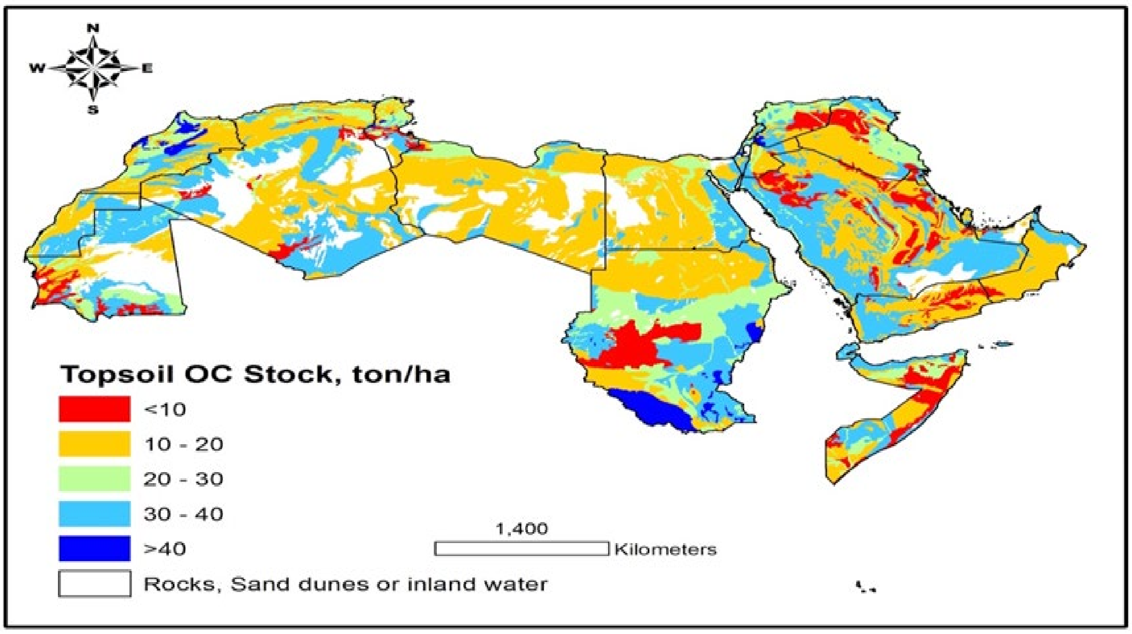

Figure 1. Spatial distribution of OC stock in topsoil (0.3 m) of the Arab countries calculated from the soil information from the DSMW, FAO, 2003

C enrichment of major soil groups is preconditioned by climate and geographic conditions favoring denser and richer vegetation cover and native fertility. Fluvisols, Cambisols, Phaezems, occupy intermediate place in OC stock ranging between 43-95 ton ha^{-1} and 56-114 ton ha^{-1} for the topsoil and entire soil respectively. These soils are affected by their nature, origin of sediments and agricultural practices. The spatial distribution of soil OC in the Arab countries shows relatively high values in topsoil for the soils developed from Mollic type accumulation of soil material, which is positively affected by the geographic, vegetation and climatic conditions, notably Gleysols, Kastanazems and Phaeozems (Figure 1).

The assessment of the total soil OC stock in the entire soil profile to a depth of 1m in the Arab countries revealed the dominance of soils with poor and moderate OC enrichment with more than 83% of the of cultivated soil area containing less than 60 ton ha^{-1} of total OC stock. These soils are in general Lithosols, Arenosols, Regosols, Solanchcks, saline, sodic and gypsic soil units as well as rocky and stony versions of Yermasols and Xerosols with few representatives of Luvisols, Cambisols and Fluvisols. At the national level, the lowest OC stock was observed in the Gulf countries, i.e., Kuwait, UAE, Oman, Bahrain, Saudi Arabia, Yemen and Somalia with a content varying between 11 tons ha^{-1} and 57 tons ha^{-1} in the topsoil and entire soil profile respectively.

Four Arab countries are placed on top concerning C sequestration and build up in the soil. These are Lebanon, Morocco, Sudan and Comoros Islands with a soil OC stock varying between 30 ton ha^{-1} and 92 ton ha^{-1} in the topsoil and entire soil respectively. The geographic location and pedoclimatic conditions favor higher C sequestration in these countries despite the observed risk of soil water erosion.

Table 1. Organic carbon stock in the soils of the Arab countries

Country	Area of Arable lands, SQM	OC stock topsoil tons	OC stock subsoil tons	Total OC Stock tons	OC content topsoil, ton ha^{-1}	OC content subsoil , ton ha^{-1}	OC content 1m, ton ha^{-1}
Algeria	1741562	4,257,645,624	6,319,312,381	10,576,958,005	22.06	30.46	52.52
Bahrain	571	668,070	1,119,160	1,787,230	11.70	19.60	31.30
Comoros	1618	7,460,439	9,011,653	16,472,092	44.55	47.73	92.28
Djibouti	21851	77,058,474	115,526,859	192,585,333	27.92	37.11	65.03
Egypt	842087	1,625,889,954	2,423,066,569	4,048,956,523	23.58	32.20	55.78
Gaza	324	1,108,080	1,394,820	2,502,900	34.2	43.05	77.25
Iraq	431447	761,792,829	1,118,616,632	1,880,409,461	23.01	31.98	54.99
Jordan	89357	170,855,847	263,266,045	434,121,892	22.89	34.58	57.47
Kuwait	17410	28,569,330	31,361,050	59,930,380	18.05	25.77	43.82
Lebanon	10302	29,840,676	42,845,404	72,686,080	30.91	44.78	75.70
Lybia	1246767	2,050,368,240	3,130,508,465	5,180,876,705	24.27	34.50	58.77
mauritania	725140	1,845,098,922	2,846,361,539	4,691,460,461	26.55	38.56	65.10
Morocco	406472.5	1,131,025,853	1,584,351,976	2,715,377,828	29.55	40.17	69.72
Oman	302370	471,041,643	761,251,477	1,232,293,120	16.33	25.13	41.46
Qatar	11384	21,423,936	31,977,575	53,401,511	28.19	40.36	68.55
Saudi Arabia	1852910	4,246,786,230	6,141,018,261	10,387,804,491	20.41	30.09	50.50
Somalia	635989.5	1,251,717,333	1,919,830,644	3,171,547,977	23.19	33.65	56.84
Sudan	2456235.5	6,363,846,111	7,431,089,785	13,794,935,896	35.13	43.45	78.58
Syria	187462	427,844,685	630,335,048	1,058,179,733	27.58	39.77	67.34
Tunisia	137483.5	315,546,645	436,483,614	752,030,259	23.50	31.43	54.92
UAE	50690	125,579,628	170,510,830	296,090,458	19.96	30.07	50.03
Yemen	414580	814,658,622	1,273,523,083	2,088,181,705	20.26	29.35	49.61
Total/average*	11584013	26,025,827,171	36,682,762,869	62,708,590,039	25.17	34.72	59.89

Sudan, Alegria and Saudi Arabia represent the Arab countries with the richest stock in total soil OC among the twenty two Arab countries with a total stock varying between 14 billion tons and 10 billion tons respectively. Lybia, Mauritania, Egypt, Somalia and Morocco represent the intermediate group among Arab countries with a total OC stock ranging in decreasing order between 5 billion tons and 2.7 billion tons respectively. Gulf countries represent the lowest total OC stock reaching as low as 53 thousand tons in Qatar.

DISCUSSION

Yermosols, Arenosols, Lithosols and. Xerosols soil groups contain the lower C stock varying between 12-30 ton ha^{-1} and 19-40 ton ha^{-1} respectively. Long history of water and wind erosion affect the productivity of these soil groups, thus they require anti-erosion measures. The dominant part of the Arab countries represent semi-arid to arid climate with rare wetlands and Ustic or Udic soil moisture regime. That is why 69% of the area of the cultivated soils has low OC stock below 30 ton ha^{-1}, considered by Batjes and Sombroek (1997) as threshold for poor soil OC content. These soils belong to the arid soils groups like Arenosols, Xerosols, Yermosols, Solanchaks and Solonetz. This is in agreement with the findings of Minasny *et al*., (2017). Poor soil quality and the need to produce more food for increased population justifies good soil management and conservation notably crop rotation, application of manure and compost to improve C sequestration and hasten background soil productivity and resilience to drought. Similar good practices resulted in the improvement of C content in the soil after the sowing of legumes between the fruit trees (Darwish *et al*., 2012) and following the application of composted material including treated sludge (Atallah *et al*., 2012). Due to their large geographic distribution, Yermosols, Lithosols and Regosols represent the major soil groups with the highest total OC stock reaching 19 billion tons, 9 billion tons and 7 billion tons respectively. Despite the high OC content in the soil, Gelysols, Fluvisols and Cambisols represent low total OC stock due to their restricted area. Despite their frequent occurrence, Arenosols and Xerosols represent the lowest OC storage.

To test the precision of the used soil database, a comparison between the identified major soil groups in large scale soil information at 1:50,000 scale (Darwish *et al*., 2009) and in small scale soil information derived from the DSMW (1:5 Million) was made. A significantly different number of identified major soil groups of 13 and 5 was found in the first and second soil classification respectively. Topsoil OC stock in Lebanon was 38,047.122 tons, in the first study, compared to 42,845,404 tons representing 11% overestimation in the FAO soil database. The fact that the average values of OC accumulation in the topsoil of the Arab countries shows large standard deviation (100-300) points to the human effect on soil quality through different management systems, practices and land use in the most cultivated lands (Luvisols, Cambisols and Fluvisols).

CONCLUSIONS

Estimation of soil OC stock in the Arab countries using the small scale soil database of the DSMW showed acceptable results for the regional assessment. Alarming figures regarding the low OC stock were found in more than 80% of the area of the studied soil groups. Poor soil quality can affect soil productivity and resilience to drought and erosion. Enormous standard variation values of soil OC stock within the major soil groups were found in intensively managed arable soils indicating human pressure and impact on CO_2 emission. In the frame of week awareness on the role of OC in soil and ecosystem functions, attention must be paid to awareness rising to improve policies and practices oriented to increase C sequestration and meet the sustainable development goals.

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3.3.5 | NATIONAL LAND DEGRADATION NEUTRALITY TARGETS FOSTER SOC SEQUESTRATION IN TURKEY

Hamza Keskin[1*], Günay Erpul[2]

[1][hkeskin@ormansu.gov.tr, Republic of Turkey Ministry of Forestry and Water Affairs, General Directorate of Combating Desertification and Erosion, Ankara, Turkey]
[2][GSP/ITPS Member, Ankara University Faculty of Agriculture Department of Soil Science Ankara, Turkey]

ABSTRACT

Turkey hosted the 12th Conference of Parties (COP12) to the United Nations Convention to Combat Desertification in October 2015, Ankara. During COP12, Turkey has proposed the Ankara Initiative, covering the years 2016-2019, to facilitate attaining the Land Degradation Neutrality (LDN) target for the world. Turkey also prepared a national LDN report in which voluntary LDN targets have been identified with an implementation plan by 2030. It reports activities and strategies to determine, monitor and increase SOC stocks in different land use types. Preliminary assessment of SOC stocks that report used was relied on the map produced by FAO-SEC under FAO/TURKEY Partnership Programme, and map-based predicted SOC values were about 29.8, 45.1 and 37.1 t ha^{-1} for agricultural land, forest land and pastureland, respectively. Another potential dataset is available from the study of SOC stocks mapping based on the World Reference Base (WRB) soil classes at the country scale in Turkey. In addition, a project has been already initiated to better assess SOC stocks by the General Directorate of Combating Desertification and Erosion. Three year-long project aims to estimate national scale SOC stocks in different land use types through upscaling soil samples, to be first implemented in the forest ecosystems to fill the gaps of the previous projects, along with analyzing and compiling existing datasets. This new SOC stocks map will be used for monitoring trends of LDN within Sustainable Development Goals Framework.

Keywords: Soil Organic Carbon, Ankara Initiative, LDN voluntary targets, COP12

3.3.6 | SOIL ORGANIC CARBON: A KEY FACTOR OF SUSTAINABLE AGRICULTURE IN IRAN

Farhad Moshiri[1*], Saeed Samavat[2] and Mohammad Reza Balali[3]

[1]Assistant Prof. and Deputy of Soil fertility and plant nutrition Dep. The leader of soil organic carbon research strategic program, Soil and Water Research Institute (SWRI), Agricultural Research, Education and Extension Organization, Karaj, Iran. Email:fa.moshiri@swri.ir
[2]Assistant Prof. Soil fertility and plant nutrition Dep. Soil and Water Research Institute (SWRI), Agricultural Research, Education and Extension Organization, Karaj, Iran.
[3]Assistant Prof. and Head of Soil fertility and plant nutrition Dep. Soil and Water Research Institute (SWRI), Agricultural Research, Education and Extension Organization, Karaj, Iran.

ABSTRACT

This paper outlines general pictures of soil organic carbon (SOC) in Iran as a heart of sustainable soil fertility. Regarding this, SOC content in 61.6 percent of the agricultural soils of Iran are less than one percent. Declining trend of SOC has been shown in two regions with different climate. Causes which influence reducing SOC in Iran have been mentioned. Some positive signs towards soil organic carbon management including policy making and research results have been described. Finally, future research priorities in understanding the status and management of SOC have been proposed.

Keywords: SOC, Sustainability, Management, Research priority

INTRODUCTION

Soil organic carbon is a key factor in the sustainability of soil fertility and soil ecological services (Lal. 2013). SOC, as one of the major environmental issues and challenges on a global scale is also included in the United Nations Environment Program (Victoria *et al*. 2012). It is known that soil organic matter is effective on food production, nutrient and energy cycling, soil water storage, improving soil physical condition and erosion control, climate regulation, and soil biodiversity (Banwart, *et al*. 2015). Iran is located in the arid and semi-arid region of world with low organic carbon in soils. That's why management of organic carbon in soil is a key factor towards sustainable agriculture in the country. In this paper, we present a general picture of the situation and dynamics of SOC in Iran. The most important and effective methods for SOC management have been introduced and finally some research priorities listed.

METHODOLOGY

The situation of SOC was assessed in 23700 soil samples taken from agricultural lands of Iran during last three decades. The relation between climate condition and the amount of SOC in different agroechological zones of the country also has been analyzed. Moreover, it has been tried to examine the changes of SOC by comparing the data from different time periods. By Referring to research, the effects of different crop management on SOC content were shown. Finally, future research priorities in understanding the status and management of SOC were proposed.

RESULTS

Organic carbon content in soils of Iran

Organic carbon content in 61.6 percent of the agricultural soils of Iran is less than one percent which suggests unsustainability of soil fertility (Balali, *et al*. 2014). SOC content in 21.6 percent of soil samples was less than 0.5 percent, in 40.0 percent of soils between 0.5 to 1%, in 24.04 percent of the soils between 1 and 1.5% and in 14.0 percent of soil samples was more than 1.5 percent which is defined as optimum range (Figure 1).

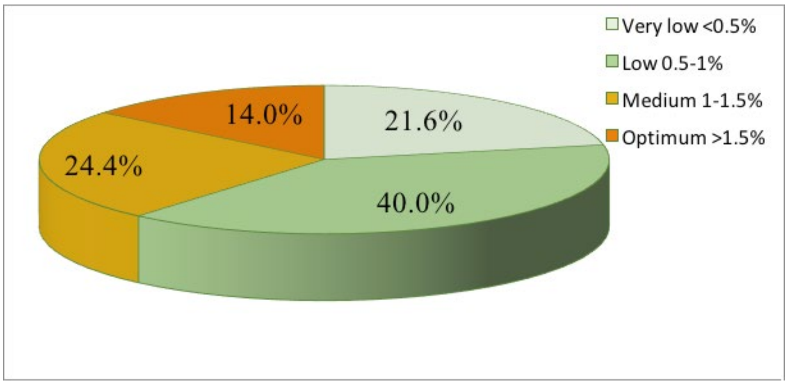

Figure 1. Range of organic carbon content in agricultural soils of Iran

Independent study conducted for monitoring soil quality with 3000 soil benchmarks (one sample for every 600 hectares) confirms these results. The results of this study showed that organic carbon in 68.7 percent of soil samples are less than one percent (sadat and Rezaei, 2014). Assessment of changes in SOC in different time series in Dezful region (semi-dry), south of Iran, represents the declining trend (table 1). This trend also observed in North of Iran (moist-subhumid to humid) which in 1960's average amount of SOC was 3.2 percent (Dewan and Famouri, 1964) which is reduced to 1.7 percent.

Table 1. Changes in SOC in Dezful, South of Iran.

The relative amounts of soil samples contained less than one percent of SOC (%)	Number of soil samples	Time period
79.5	150	1960's
68.3	100	1990's
88.0	200	2000's
100.0	120	2010-2014

Three sets of reasons influence reducing SOC in Iran. 1- Climatic condition. Organic carbon distribution in different agroecological zones of Iran and its compliance with the distribution of rainfall in these areas clearly prove the effects of climatic condition on the amount of organic carbon in soil (figure 2). With the exception of northern and some western regions of the country, there is not enough capacity to the accumulation of organic carbon in soil because of the dry and semi-dry condition. 2- Undeveloped soils (entisol, Inceptisol and Aridisol) and unsuitability of soil quality (shallow depth, salinity and alkalinity, water logging, low fertility of soils) affects the growth and development of plants and afterwards the low amount of SOC storage, 3-Improper soil management which will be explained in the next section (samavat, 2015).

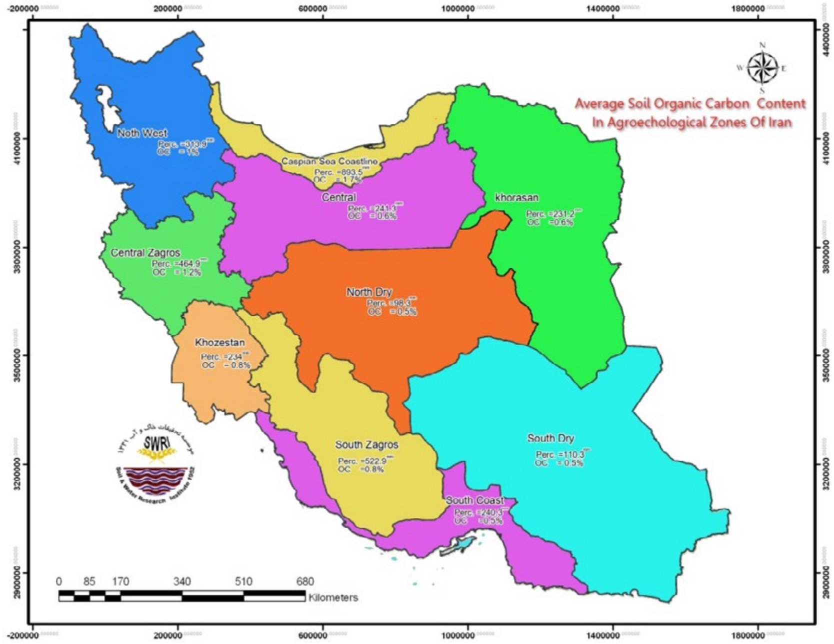

Figure 2. Average SOC in agroegological zones of Iran in relation to annual precipitation.

Management of SOC in Iran

Since land reforms of 1960's and change of agricultural system towards modernization in spite of increase of production, the downward trend of SOC has been started. Much of this decline in SOC associated with the use of chemical fertilizers and without any application of organic fertilizers in crop production, burning crop residue and inappropriate crop rotation and cropping system (e.g. monoculture). On the other hand, in the arid climate of Iran, increasing soil tillage acts as a reducing agent for SOC. Land use change from forest or pasture to agriculture have been also reduced OC storage in soils. Change of rangeland to dry farming in the western regions of Iran led to 23 to 58 percent drop in SOC content (Joneidi, *et al*. 2014).

However, there are some positive signs towards soil organic carbon management in a recent decade. Establishment of "High council for development of biological materials and balanced fertilization and pesticide application" in 1995 helped the development of research on soil organic carbon. On average, 286 kg increase in wheat grain yield per hectare has been reported for 1 gr increase of carbon per kilogram of soil (keshavarz, 2013). Samavat (2016) showed that integrated use of chemical and organic fertilizers significantly impact the performance of crops in wheat-corn rotation, the stability of soil aggregates in water, the amount of available water, the efficiency of nutrient uptake and the activity of soil microorganism. These show the importance of soil organic carbon management in sustainability of crop production. Research results have shown of SOC in agricultural lands of Iran.

Organic fertilizers application is one of the most important activities in increasing SOC. Moshiri (2016) showed that the positive effects of animal manure and urban waste compost application in increase the SOC observed up to 2 years in wheat-corn production system. Nevertheless, due to the limits of available organic fertilizers in Iran (almost 9 Mt) and extend of agricultural lands (16000000 ha), it is not possible to increase SOC in a large-scale only with organic fertilizer application. Hence, by using appropriate agricultural practices such as crop rotation, residue retention on soil surface instead of burning, development of conservation tillage there is a hope to maintain and or increase the SOC in Iran. Mirzavand (2015) by establishment of conservation agriculture practice in a long term experiment showed that after 4 years, organic carbon content in soil surface (0-20 cm) was increased by 15 percent using no-tile management in comparison to minimum and conventional tillage.

Research priorities

The significant increase or maintaining optimum level of organic carbon in soils of Iran is not simple. It requires sustained effort that includes two general approaches adding organic matter to the soil and reduces the carbon loss. Due to the soil condition and climate change, it seems the first step must focus on those operations that lead to reduced loss of organic carbon from soils and pay attention to increase the SOC. Thus, future studies should be designed and implemented in response to the following questions

- What is the amount of SOC in the soil profile under different land uses and climatic conditions?
- How is the trend of SOC changes in different regions and climatic conditions?
- What is the carbon storage capacity of soils in Iran?
- To achieve the sustainable soil fertility and good soil ecological services, what is the optimum and desirable amount of organic carbon in the soil?
- What is the effect of soil properties (physical, chemical and biological) on SOC storage capacity?
- What is the impact of different crop management on SOC storage and sequestration?
- What is the effect of organic fertilizer and organic soil conditioner on SOC storage and carbon sequestration?

CONCLUSIONS

Dry and semi-dry climatic condition, existence of several limitations in soils for plant growth, changes in land use, improper soil and crop management practices, the lack of widespread use of organic fertilizers caused the low content of organic carbon in soils of Iran. Research studies have shown that the amount of organic carbon in soils of Iran is declining. In order to maintain or increase SOC, at first, the soil carbon reducing agents must be controlled (reduced tillage) and then use of organic fertilizers (integrated management of soil fertility) and correcting agricultural operation (development of conservation agriculture) must be considered.

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3.3.7 | CARBON MANAGEMENT AND SEQUESTRATION IN DRYLAND SOILS OF MOROCCO: NEXUS APPROACH

Rachid Moussadek[1*] & Rachid Mrabet[1]

1 : National Institute of Agricultural Research, P.O. Box 415 Rabat, 10000 Morocco

(*) Corresponding author

ABSTRACT

The latest report on the State of soils resources in the world points out that, although the stock of carbon is more important in soils than in the atmosphere, a large part (33%) of the soils of the planet are degraded and their organic matter is lost. The reversal of the soils degradation, through the accumulation of their organic matter and the sustainable soil organic management offers a great potential to contribute to the climate change mitigation through soil carbon sequestration.
Over the past decades, there have been concerted efforts to promote such strategy through application of conservation agriculture (CA). CA is a set of soil management practices that minimize the disruption of the soil's structure, composition and natural biodiversity. While research in drylands of Morocco, proves that conservation agriculture increases and improves crop production. However, after nearly two decades of demonstration and advocacy, adoption is still limited. To enhance the CA adoption, as recommended management practices for C sequestration by farmers and land managers may necessitate the use of new approach: nexus approach. This paper investigates discussed the possible pathways of adoption of CA for increasing SOC via a Nexus approach in dry land of Morocco

Keywords: [Soil, Carbon management, Conservation Agriculture, Adoption, Nexus, Drylands, Morocco]

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Carbon management in arable lands has become increasingly important mainly in dry areas in order to increase food security, to combat land degradation and desertification (Lal, 2006) and to reduce climate change impact (Lal, 2004). In fact, restoring degraded agricultural lands by increasing the soil carbon rate through sustainable soil management thereby ensuring sustainable development in dry land which occupies more than 40 percent of the surface of the earth.

In those lands, the main characteristic is lack of water. This constrains crop productivity severely and therefore affects the accumulation of carbon in soils. Therefore, good management of the soil carbon is essential. In addition, the soil organic carbon SOC pool tends to decrease exponentially with temperature (Lal, 2006). The ability of agriculture soil to store or sequester carbon depends on management practices. By employing farming practices that involve minimal disturbance of the soil and encourage carbon sequestration, farmers may be able to slow or even reverse the loss of carbon from their fields. In Moroccan drylands, as example, previous investigations have shown that SOC content in most soils is low and the decade average (from 1987 to 1997) loss of the SOC is about 30% (Soudi *et al.*2003), due to intensive land use. This decline of SOC in cultivated soil of Morocco decreased soil quality and increased the risk of soil degradation (Mrabet *et al.*, 2001). FAO estimated that 71% of Moroccan agricultural soils are degraded and require conservation measures (Bot and Benites, 2005).

To deal with this situation, conservation agriculture has been recommended as an alternative strategy to improve SOC level and ensure carbon accumulation and sequestration (Kassam *et al.*, 2012).
While research in drylands of Morocco, proves that conservation agriculture increases and improves crop production. However, after nearly two decades of demonstration and advocacy, adoption is still limited (Bonzanigo *et al.*, 2016).

To enhance the CA adoption, as recommended management practices for C sequestration by farmers and land managers may necessitate the use of new approach: nexus approach or (Water Energy and Food: WEF approach) (Lal..2016).

The term nexus was proposed to emphasize creating more goods and services while using fewer resources and inducing less wastes and pollution. In other terms, this is a strategy by which to produce more food without using more land, water and energy-based input (Howells *et al*. 2013). This is achievable when soils have the capacity to restore their physical, chemical and biological quality through enhancing ecological and biological processes.
This paper investigates discussed the possible pathways of adoption of CA for increasing SOC via a Nexus approach in dry land of Morocco.

SOC MANAGEMENT IN CENTRAL MOROCCO: NEXUS APPRAOCH

The region of Central Morocco is the most important production area for cereals in Morocco, both in terms of share in agricultural surface and production (Mrabet *et al*., 2012). Soil types vary. About fifty percent of the region has deep clay soils (mainly Vertisol, Cambisol, and Calcisol).
Crops grow under rainfed conditions in 96.5% of the cases. At present, the predominant crop rotation in the region is cereal/cereal. Only 15% of farmers apply cereal/legumes or fallow rotation (cereals one year, fallow the second year), and these numbers keep decreasing. According to farmers, the decrease in using this rotation is essentially due market prices, which are more stable for cereals, and the higher labour and herbicide requirements of legumes (Boughlala and Dahan, 2011).

RESULTS AND DISCUSSION

To deal with this situation, conservation agriculture has been recommended as an alternative strategy to invert the soil degradation spiral in many parts of the world. CA systems, which consist of eliminating soil tillage and inversion, maintaining crop residue cover, and ensuring proper crop sequences, have been reported to improve SOC level and ensure carbon accumulation and sequestration in diverse soils from contrasted climate regimes and especially in dryland areas.

- Soil quality under CA: The concentrations of organic matter in top soils in dry land regions routinely increase under CA systems, due to a favorable shift in the balance of accumulation and decomposition. As shown by Moussadek *et al*. (2014), the soil organic carbon (SOC) pool to 30 cm depth of a Vertisol in Central Morocco (Zaer region) increased from 28.79 Mg ha^{-1} in conventional tillage (CT) to 31.89 Mg ha^{-1} in conservation agriculture system with average SOC sequestration rate of 0.44 Mg ha^{-1} yr^{-1} for the 7-yr period. The same positive trend of SOC sequestration was found by Mrabet *et al*. (2001) after 11 year period under CA in Chaouia region.

- Water under CA: Various research studies in dry lands reported enhanced water use efficiency (until 60%) under CA treatments (Mrabet *et al*., 2009), with subsequent seasons, which is due to water harvesting and reducing runoff under these practices. In fact, using rainfall simulation technique, Moussadek *et al*. (2011) concluded that CA maximize the green water component of the hydrological cycle and minimize losses by runoff and evaporation in semiarid areas of Morocco (Figure 1).

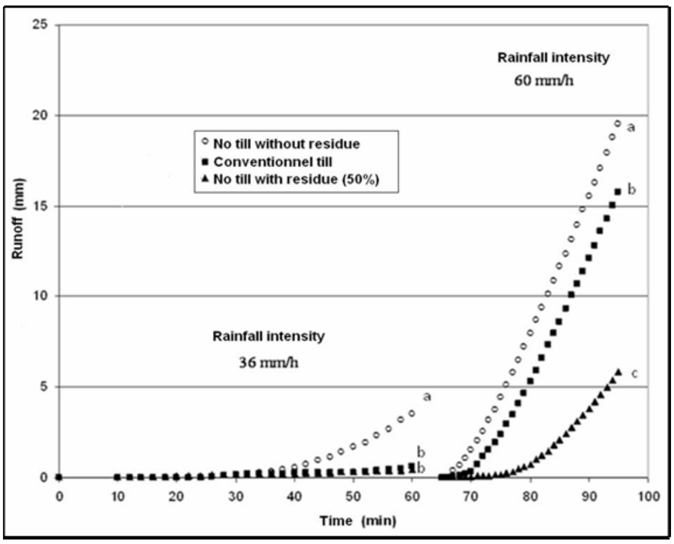

Figure 1. Runoff loss as affected by tillage and NT residue removal under two rainfall intensities in Zaers region (Moussadek et al., 2011).

- Energy under CA: Concerning the fossil energy, Elgharass *et al*. (2009) showed that 40 L ha^{-1} of fuel consumption is reduced under CA.

- Food under CA: Crops under CA system showed the highest yield compared to conventional system in different arid zones (Table 1). Higher yields result in a greater amount of crop residues left in the field, which consequently contribute to the SOC pool. It is then worth saying that CA helps adapt agricultural production to dry land climate change (Mrabet *et al*., 2011).

Table 1: Regional assessment of wheat yield (Mg ha^{-1}) under no-tillage (NT) and conventional tillage (CT) systems in Morocco. (Mrabet et al., 2011)

region	Soil type	Rotation	NT	CT	Years
Abda	Vertisol	Wheat-Fallow	3.10	2.40	19
(270 mm)	Vertisol	Continuous Wheat	1.60	1.60	19
Chaouia	Mollisol	Continuous Wheat	2.47	2.36	4
(358 mm)	Vertisol	Wheat-Fallow	3.70	2.60	10
	Vertisol	Continuous Wheat	1.90	1.40	10
	Mollisol	Different rotations	2.21	1.90	9
	Vertisol	Wheat-Chickpea	1.87	0.76	3
	Rendzina	Wheat-Chickpea	2.53	1.47	9
Zaers (410 mm)	Vertisol	Wheat-Lentils	1.97	1.41	4
	Entisol	Wheat-Lentils	2.99	2.72	4
	Alfisol	Wheat-Lentils	2.71	2.49	4
Sais	Vertisol	Different rotations	2.55	2.49	4
(438 mm)	Alfisol	Different rotations	2.72	2.74	4
Gharb (570 mm)	Vertisol	Continuous Wheat	2.80	2.26	3

CONCLUSIONS

Issues like CA, as best practices to increase soil carbon management simply cannot be overlooked by smallholder farmers in dryland. In fact, increased income is a key motivation for those farmers to adopt CA as an innovation. The nexus approach may include an identification of market opportunities.
Hence, the governance dimension, accompanying this innovation to be implemented, becomes essential in providing an enabling framework and institutional environment for smallholder farmers. This approach should be used to highlight the need of capacity building to make this SOC farming technologies more adoptable.

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3.3.8 | CHALLENGES OF SOIL ORGANIC CARBON SEQUESTRATION IN DRYLANDS

Rachid Mrabet[1], Mohamed Badraoui[1,2], Rachid Moussadek[1], and Brahim Soudi[2]

[1] : National Institute of Agricultural Research, P.O. Box 415 Rabat, 10000 Morocco
[2] : Hassan II Agronomic and Veterinary Sciences Institute, P.O. Box 6202 Madinat Al Irfane Rabat, Morocco
* : Presenting author : rachidmrabet@gmail.com

ABSTRACT

Drylands span over 40% of the Earth's continental area and are expanding due climate change. They are home of one-third of global population with increasing demands for food and resources. Weather variability, drought and depleting vegetation are dominant concerns in declining soil organic matter (SOM) pool and agricultural sustainability. Land degradation and soil erosion, engaged by destructive land management practices, are impacting soil functions and compromising their productive capacity. Thus, most drylands contain ~ 1 % of SOM, and frequently less than 0.5 %. Increasing SOM levels is critical and challenging. This paper outlines challenges and barriers for devising organic carbon sequestration in dryland's impoverished and depleted soils. It also highlights several questions which scientists should resolve related to how potential carbon sequestration may be best quantified and how practical methods to implement sequestration measures may best be adopted and adapted to dryland soils. Yet, it is strategic and beneficial for world community to invest in carbon sequestration and management of drylands.

Keywords: Drylands, Carbon sequestration, Climate change, Soil organic matter, Carbon management

Introduction, scope and main objectives

Drylands are defined as regions where precipitation is counter balanced by evaporation from surfaces and transpiration by plants (evapotranspiration). The aridity of a region is generally measured by the aridity index (AI), which is the ratio of total annual precipitation to potential evapotranspiration. Drylands are defined as regions with AI < 0.65 and four dryland systems were defined hyper-arid (AI < 0.05), arid ($0.05 <$ AI < 0.2), semiarid ($0.2 <$ AI < 0.5) and dry sub-humid ($0.5 <$ AI < 0.65).

Drylands are the largest biome on earth with no clear boundaries. They concern 41.3% of the Earth's continental area and are expending (Figure 1). Of this, 3.5 to 4.0 Billion ha (57- 65%) are either desertified or prone to desertification (Lal, 2003).

38% of the world's population are living in dry areas. Predictions by Huang *et al*. (2015) include a growth in the land mass of dryland ecosystems by 11 to 23 % before the year 2100. In drylands, droughts, desertification and land mis-management are threatening the livelihoods and well being of more than 1.2 billion inhabitants in 110 countries. In addition, scarcity of water and aridity reduce photosynthetic capacity of vegetation and carbon uptake. In fact, water availability is tied to Net Primary Production (NPP). Supporting half of the world's livestock, rangelands, vast natural landscapes, are habitats for wildlife. Due to climate change, the area covered by rangelands will grow.

The scope of this paper is to develop the dryland characteristic that unfavor carbon sequestration in dryland soils. It was estimated that organic carbon stored in world soils is 2000-25000 Gt of which 27-36% are in drylands areas. In terms of inorganic carbon, dry areas store 97% of world soils (950 Gt). Drylands face a myriad of problems that affect carbon sequestration and NPP.

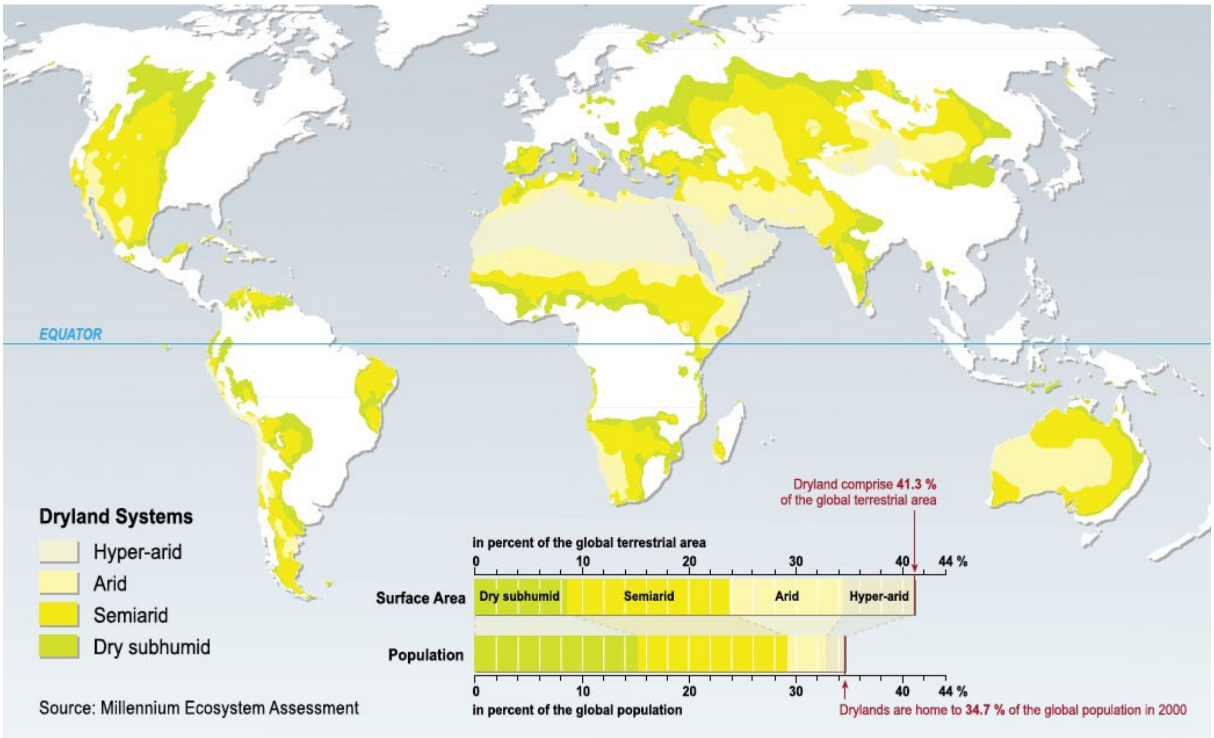

Figure 1: Global Map of Drylands (Millennium Ecosystem Assessment)

CHALLENGES AND BARRIERS FOR CARBON SEQUESTRATION

Globally, ten to twenty per cent of drylands are degraded. Due to poor management dryland ecosystems contribute 0.23 – 0.29 Gt of carbon a year to the atmosphere. Climate significantly influences large scale patterns of NPP and soil carbon sequestration through:

- Lack of water (low water availability)
- Low and erratic rainfall (chronic shortage of soil moisture)
- Brief periods or pulses of water sufficiency
- High temperatures (amplitudes) and soil respiration (mean annual temperature greater than 30°C)
- Cold temperatures (mean annual temperature less than 20°C).

Ingram and Fernandes (2001) have summarized major factors affecting soil carbon sequestration in figure 2. Climate determines the attainable storage of organic carbon in soil by regulating plant production. Inherent soil properties (texture, mineralogy), climate, gross productivity and carbon allocation, soil biota and their carbon use efficiency and land management control soil carbon accumulation and storage. The vegetation cover in dryland ecosystems is highly variable and bare soils are dominant. This result in low soil organic carbon.

In the other side, the soil carbon stabilization efficacy is negatively affected by:

- Low soil organic matter (0.5-1 %) ;
- Low microbial diversity ;
- Low soil fertility (nutrient content particularly N, P and S) ;
- Widespread loss of soil functions (Poor land management);
- Erosion by water and wind;
- Overgrazing and excessive biomass removal.

Despite low precipitation and microbial activity, photo degradation of above-ground biomass induces significant soil carbon loss (Austin & Vivanco, 2006). While, van Asperen *et al*. (2015) encouraged to study thermal degradation of litter as an abiotic decomposition process.

According to Maestre *et al*. (2015), due to decreased soil organic carbon, there is a shift in microbial composition due aridity and loss of soil organic matter as shown in figure 3. According to Glenn *et al*. (1993), drier soils *per se* are less likely to lose carbon owing to conclude that residence time of C is long, sometimes even longer than in forest soils.

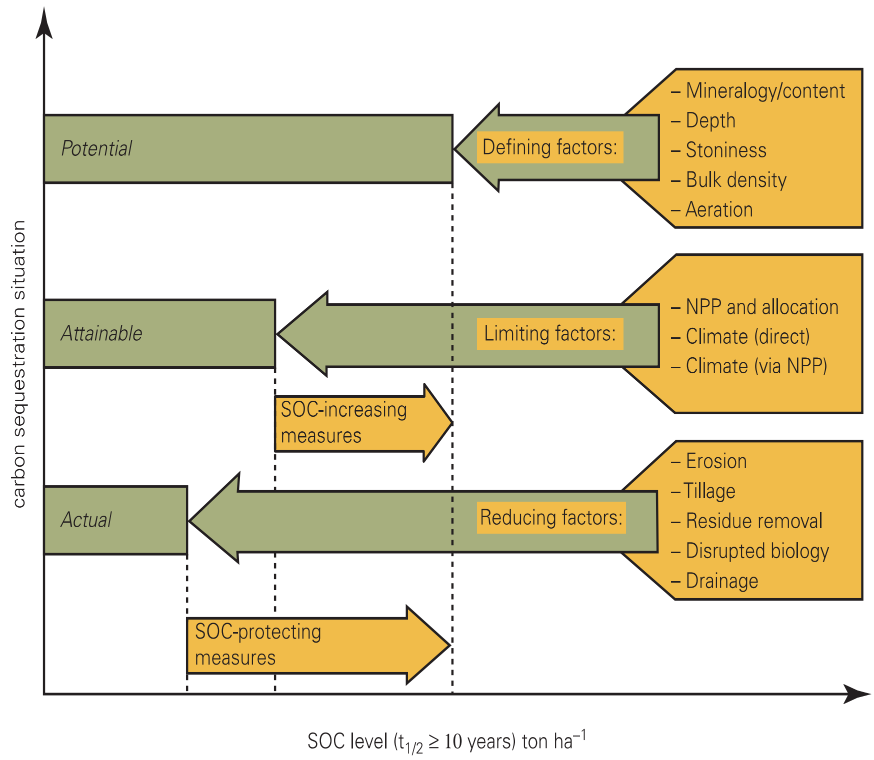

Figure 2: Soil, Climatic and Management Factors affecting carbon sequestration (Ingram and Fernandes, 2001).

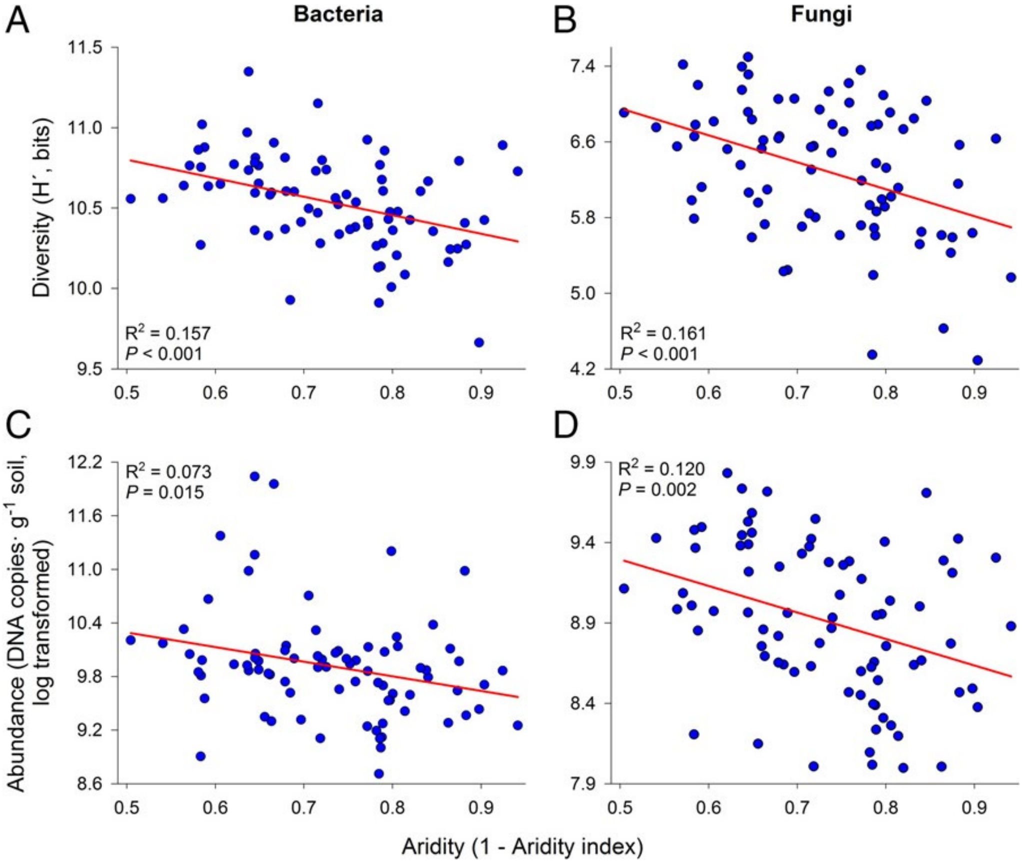

Figure 3: Aridity and diversity and abundance of soil bacteria and fungi (Maestre et al., 2015).

CARBON SEQUESTRATION STRATEGIES

Global potential of C sequestration in dryland eco- systems is large and has been estimated by Lal (2001) as 0.4–0.6 Gt of carbon a year. Soil carbon is in a constant state of flux. Carbon sequestration is subject to reversibility and impermanence. Most of the potential soil carbon sequestration takes place within the first 20 to 30 years of adopting improved land management practices. In other words, While the capacity of soil carbon sequestration is potentially immense, soils can reach a carbon saturation limit.

In fact, various barriers are preventing adoption of carbon sequestration strategies by dryland farmers. Among these barriers, the most important are:

- Time barriers: Breaking down centuries of poor practices;
- Financial barriers (lack of incentives and subsidies);
- Knowledge barriers (weak knowledge management systems);
- Resource weaknesses (tailored insurance products);
- Technical and logistical difficulties;
- Institutional fragilities;
- Socio-cultural obstacles.

According to Lal (2003), assuming that two-thirds of the historic loss can be re-sequestered, the total potential of SOC sequestration is 12 to 20 Pg C over a 50-year period. With development in sciences and technologies relevant to drylands, drawdown strategies for carbon sequestration in soils can be possible using climate-smart land use and management practices (i.e. afforestation with appropriate species, soil management on croplands, pasture management on grazing lands), and restoration of degraded soils and ecosystems. Several agricultural management systems have emerged as having the potential to increase soil carbon. Conservation agriculture practices; including no- tillage, plant residue management, and crop rotations; affect the carbon cycle in agricultural systems, thereby increasing soil carbon content and it storage (Mrabet, 2011).

CONCLUSIONS

Soil carbon sequestration is a shared responsibility and should be seen as a win-win policy permitting sustainability and climate change mitigation. However, huge efforts are needed to change trends. It is essential for taking early actions to prevent the aggravation of further degradation of drylands through strategic restoration of soils and carbon sequestration options. In fact, Reynolds *et al*. (2007) suggested a need to shift from a negative image of dryland desertification to a more forwarding-perspective of dryland development. This will help merging research and policy visions towards re-sequestering carbon in soils of this biome. Hence, considerable debates over the potential of soil carbon sequestration in drylands will continue to remain in the near future. But, the full understanding of carbon sequestration factors, processes and mechanisms should not delay implementing actions and strategies. The sequestration of organic carbon on dryland soils is also a way of optimizing the nexus of essential services – provisioning food, water and energy, maintaining biodiversity and regulating climate.

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3.3.9 | REHABILITATING DEGRADED CROPLANDS FOR IMPROVED CROP PRODUCTIVITY AND SOIL CARBON SEQUESTRATION ON SMALLHOLDER FARMS IN ZIMBABWE

[1]Nezomba, H*, [1]Mtambanengwe, [1]F, Mapfumo, P and [2]Tittonell, P

[1]Soil Fertility Consortium for Southern Africa (SOFECSA), Department of Soil Science and Agricultural Engineering, University of Zimbabwe, P.O. Box MP167, Mount Pleasant, Harare, Zimbabwe. Corresponding author: hatinezomba@gmail.com

[2]Farming Systems Ecology, Wageningen University, P.O. Box 430, 6700AK, Wageningen, The Netherlands

INTRODUCTION, SCOPE AND OBJECTIVES

Most croplands in smallholder farming systems in Southern Africa are degraded, as evidenced by severe nutrient deficiencies, critically low SOM levels and a general low response of the soils to mineral fertilizer addition (Mapfumo *et al*., 2005; Nezomba *et al*., 2010). Against this background, the region is facing increased demands for food due to population rise (FAO, IFAD and WFP, 2014), and unfavourable changes in climatic patterns (IPCC, 2013). Rehabilitating the degraded croplands is therefore key not only to increasing farm-level crop production, but also for sequestering soil carbon to reduce greenhouse gas emissions. Nitrogen (N)-fixing indigenous herbaceous legumes, commonly referred to as weeds by farmers, were found to establish well on degraded sandy soils on smallholder farms in Zimbabwe when sown at high seed rates (Mapfumo *et al*., 2005; Nezomba *et al*., 2010). Because of their ability to fix N, we envisaged that the establishment of these legumes on degraded soils could enable crops to respond better to subsequent applications of the small amounts of organic and inorganic nutrient resources commonly available to farmers. The inclusion of legumes in cropping sequences as well as combined application of organic and inorganic fertilizers form the core of integrated soil fertility management (ISFM); an approach designed to increase soil productivity in resource-limited environments (Vanlauwe *et al*., 2010). Conducted on degraded sandy soils on smallholder farms in eastern Zimbabwe, the specific objectives of this study were therefore to (i) assess the effect of indigenous herbaceous legume fallows (indifallows) on above-ground C and N productivity on degraded soils, (ii) determine maize grain yield responses to mineral N fertilizer under indigenous legume-based ISFM sequences and (iii) determine the influence of indigenous legume-based ISFM sequences on soil carbon dynamics.

METHODOLOGY

This paper reports findings of a 3-year study conducted on degraded sandy soils (< 10% clay, < 0.3% organic carbon, < 4 ppm available P) on smallholder farms in Zimbabwe. First, non-cultivated N_2-fixing indigenous legumes, mostly of the genera *Crotalaria*, *Indigofera* and *Tephrosia*, were planted at 120 seeds m^{-2} $species^{-1}$ on ploughed fields. In the second year, the legumes biomass was incorporated into soil together with an equivalent of 7 t ha^{-1} of cattle manure. A maize crop was then planted. In the third year, a second maize test crop was planted. Natural fallow and continuous maize were used as controls. The experimental treatments are described in detail in Table 1. Data were collected on legume biomass productivity (Year 1), changes in soil microbial biomass (Year 3), changes in total carbon and maize grain yield responses (Year 3).

Table 1. Sequencing framework of ISFM options on degraded sandy soils on smallholder farms in Zimbabwe. Adapted from Nezomba et al. (2015)

Sequencing option	Year 1	Year 2	Year 3
'Indifallow-start '			

	Indifallow + P	Maize + cattle manure + mineral fertilizer N and P	Maize + mineral fertilizer N and P
'Sunnhemp-start'	Sunnhemp fallow + P	Maize + cattle manure + mineral fertilizer N and P	Maize + mineral fertilizer N and P
'Natural fallow-start'			
	Natural fallow + P	Maize + cattle manure + mineral fertilizer N and P	Maize + mineral fertilizer N and P
Fertilized maize	Fertilized maize	Fertilized maize	Fertilized maize
Unfertilized maize	Unfertilized maize	Unfertilized maize	Unfertilized maize

RESULTS

Initial biomass productivity on degraded soils: Above-ground biomass carbon (C) and nitrogen (N) accumulation were 3038 kg ha^{-1} and 203 kg ha^{-1}, respectively, under 1-year indigenous legume fallow (indifallow) against 518 kg C ha^{-1} and 14 kg N ha^{-1} under 1-year natural fallow. Indigenous legumes contributed > 80% of the biomass produced under indifallows.

Maize yield response under herbaceous legume-based ISFM sequences: When all the treatments were planted with a maize test crop in the third year, herbaceous legume-based sequences showed the highest response to mineral fertilizer N compared with natural fallow-based sequences and continuous fertilized maize. Maize grain yields averaged 2.5 t ha^{-1} under herbaceous legume-based ISFM sequences compared with a maximum of 1.1 t ha^{-1} under mineral fertilizer alone and < 0.4 t ha^{-1} with no fertilizer (Figure 1).

Effects of ISFM sequences on soil C sequestration: Herbaceous legume-based ISFM sequences gave the highest microbial biomass C (MBC) of 243 mg kg^{-1} soil compared with 187 mg kg^{-1} soil under continuous maize. Also, MBC to organic C ratio averaged 7; about 1.5 times more than under the natural fallow-based sequence. Continuous maize treatments gave higher metabolic quotients (qCO_2) than legume-based sequences indicating a lower microbial efficiency under the former. Soil organic C (0-20 cm depth) was not significantly different between natural fallow- and herbaceous legume-based ISFM sequences (4.0 t C ha^{-1} under natural fallow-based ISFM sequence, and 3.5 t C ha^{-1} under herbaceous legume-based ISFM sequences).

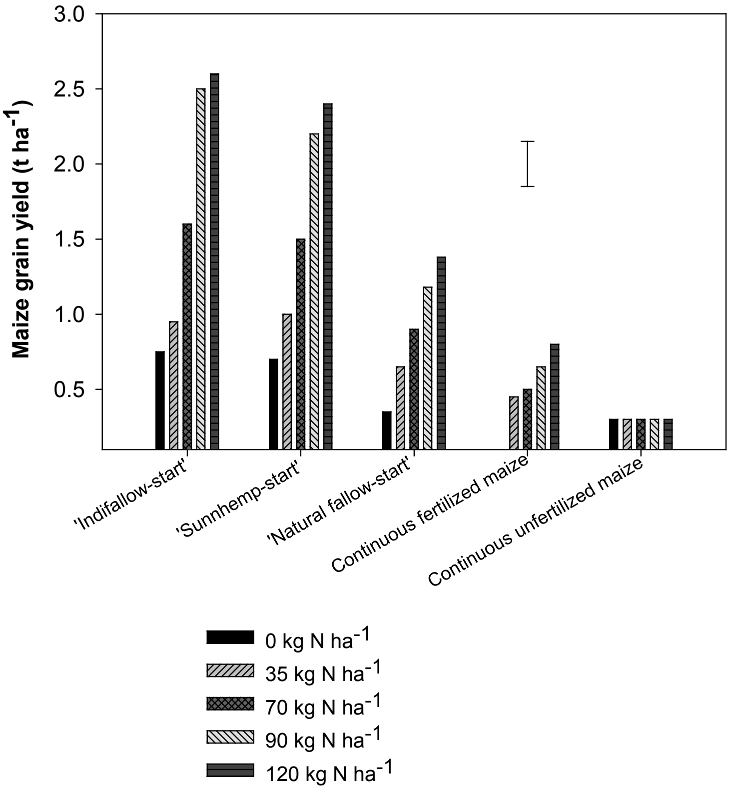

Figure 1. Maize grain yields (t ha-1) and responses to mineral N fertilizer different ISFM sequences on degraded soils in Hwedza farming communities in Zimbabwe. Vertical bars represent standard error of the difference of means (SEDs)

DISCUSSION

Degraded soils are typified by low net primary productivity, which leads to low soil organic matter content and physico-chemical fertility. However, in this study, 1-year indifallow yielded > 3 t C ha^{-1} of above-ground biomass on nutrient-depleted soils, while 1-year natural fallow accumulated < 1 t C ha^{-1}. The high amounts of C and N measured under 1-year indifallow and 1-year sunnhemp fallow was due to the biomass contributed by legume species. Herbaceous N_2-fixing legumes, such as naturally-adapted indigenous legumes, therefore offer prospects for generating high initial biomass on sandy degraded soils. Microbial biomass was highest under herbaceous legume-based ISFM sequences suggesting that the legumes biomass generated in the first year and cattle manure applied in the second year provided labile C and N to stimulate soil microbial activity. Inclusion of legumes in cereal-based cropping systems has been shown to increase microbial biomass (Silva *et al*., 2010). The ratio of microbial biomass carbon to total soil organic C was highest under herbaceous legume-based ISFM sequences indicating greater biological activity that would suggest a faster soil rehabilitation potential as compared to the other treatments. The higher maize response to mineral N fertilizer under the legume-based ISFM sequences could be explained by increased soil N availability through addition of legume biomass and cattle manure.

CONCLUSIONS

Seeding of indigenous legumes on degraded sandy soils led to more biomass C and N production than leaving the fields to natural fallow. The predominantly legume biomass produced under indifallow in combination with cattle manure increased soil biological activity (microbial biomass) and the responsiveness of the degraded soils to mineral N fertilizer. On the other hand, building soil organic carbon is a major challenge on cultivated sandy soils in tropical environments.

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3.3.10 | PROTECTION OF SOIL FROM THE LOSS OF ORGANIC CARBON BY TAKING INTO ACCOUNT EROSION AND MANAGING LAND USE AT VARYING SOIL TYPE: INDICATION FROM A MODEL SEMIARID AREA

Sergio Saia[1*], Calogero Schillaci [2,3], Aldo Lipani[4], Maria Fantappiè[5], Michael Märker[3,6], Luigi Lombardo[7], Maria G. Matranga[8], Vito Ferraro[8], Fabio Guaitoli[9], Marco Acutis[2]

1 [Italy Council for Agricultural Research and Economics (CREA), Cereal Research Center (CREA-CER), Foggia, Italy, sergio.saia@crea.gov.it, *corresponding author]
2 [Department of Agricultural and Environmental Science (DISAA), University of Milan Via Celoria 2, 20133 Milan, calogero.schillaci@unimi.it]
3 [Department of Geosciences, Tübingen University, Germany Rümelinstr 19-23 Tübingen, Germany]
4 [Institute of Software Technology and Interactive Systems, TU Wien, aldo.lipani@gmail.com]
5 [Council for Agricultural Research and Economics (CREA), Centre for Agrobiology and Pedology (CRA-ABP), Florence, Italy, maria.fantappie@crea.gov.it]
6 [Department of Earth and Environmental Sciences, University of Pavia, Italy. Michael.maerker@unipv.it]
7 [Physical Sciences and Engineering Division, King Abdullah University of Science and Technology, Tuwal, Jeddah. luigi.lombardo83@gmail.com]
8 [Regional Bureau for Agriculture, Rural Development and Mediterranean Fishery, the Department of Agriculture, Service 7 UOS7.03 Geographical Information Systems, Cartography and Broadband Connection in Agriculture, Palermo, mariagabriella.matranga@regione.sicilia.it, vito.ferraro@regione.sicilia.it]
9 [Regional Bureau for Agriculture, Rural Development and Mediterranean Fishery, the Department of Agriculture, Service 5 UOS5.05 - Valutazione territoriale e gestione del rischio in agricoltura, , fabio.guiaitoli@regione.sicilia.it]

ABSTRACT

Drylands cover nearly of the half of the world and are inhabited by ca. 40 % of the world's population. Such lands harbour a variety of soils whose net primary and agricultural production is limited by water scarcity and high temperatures in the area, and other soil-specific traits, including actual and potential soil erosion. In such conditions, preservation of the soil organic carbon (SOC) pool has a striking potential to mitigate the loss of fertility and thus yield potential and variability among years. Here we used a reference semiarid area (Sicily, Italy) for the estimate of the importance of land use and soil erosion potential on SOC variation in space and time. The most important predictors of SOC concentration were soil texture, land use, valley depth, rainfall, channel network base level. SOC variation in the area strongly depended on the subarea and did not match the SOC at the baseline. The present results can imply both agronomic and policy consequences at the district level and call for an intervention on soil fertility to maintain agriculture productivity. These results can help in calibrating models of SOC dynamic under various management or climate change scenarios.

Keywords: Soil Organic Carbon, Drylands, Worldclim, Soil erosion, Boosted regression trees, geographic information systems, remote sensing.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

Drylands cover nearly half of the world and are inhabited by ca. 40 % of the world's population. Such lands, mostly occurring in undeveloped and developing countries, harbour a variety of soils whose net primary and agricultural production is limited by water scarcity and high temperatures in the area, low water holding capacity (WHC) and fertility of the soil and other soil-specific traits, including potential and actual soil erosion. In such conditions, the preservation of the soil organic carbon (SOC) pool, especially in the topsoil, has a striking potential to mitigate the loss of WHC and fertility and thus yield potential and variability among years, and also increase the CO_2 sequestration ability of the soil. These are further needed at the light of the current climate change, which is mostly harming the fragile (agro-)ecosystems of drylands. It is well known that cultivation have frequently negative effects on SOC accumulation and soil resilience to erosion, desertification and climate change (Kämpf *et al.*, 2016; Novara *et al.*, 2013; Schillaci *et al.*, 2017). This implies that SOC management plays a direct and crucial role in the world economy and is strategic to combat hunger and poverty. A number of agronomical management measures can be adopted to mitigate loss of carbon and carbon-rich soil aggregates and preserve soil ecosystem services. The most important of which include land use, land cover, the choice of crop species and genotypes, and soil management techniques, especially tillage. However, the role of each of these techniques and their interaction on SOC concentration, stock and change in space and time appear far to be clarified since it varies with the environmental traits of the site under study (Alcántara *et al.*, 2016; Álvaro-Fuentes *et al.*, 2014; Haddaway *et al.*, 2016) and likely with the gross income of the population in the area and nation. In addition, the lack of data from many areas strongly impairs the ability to produce reliable indications on the site-specific management able to preserve SOC and produce stimuli to actual agricultural yield and potential income. In the present experiment, we used a reference semiarid area (Sicily, Italy) for the estimate of the importance of land use and soil erosion potential on SOC variation in time (both as % and absolute compared to the initial) at varying soil type and aridity of the environment. Sicily has great potential as an open laboratory for studies about ecological issues and anthropic pressure on the agro-ecosystems thanks to the variability of its traits and deep knowledge of its soils. Indeed, a total of about 7000 soil samples corresponding to ca. 2700 georeferenced points (more than 1 point each 10 km^2, Fig. 1A) are available, with information on SOC concentration, bulk density and soil texture. In addition, Sicily has variable, but on average high, demographic density and % area cropped in its territory, an ancient environmental and sociological history, a high climatic variability, several land uses and dominations from different populations, which introduced various plant species and management techniques and environmental heritages. The sum of such conditions makes Sicily an open and well suited laboratory to study the impact of anthropic pressure and of environmental variation at large scale (ecosystem level) and micro scale (few squared km), and of land cultivation and management on other environmental traits, including SOC distribution and dynamics.

In particular, we defined and account topsoil SOC changes in the recent time (a 15-years timespan) with the implementation of the digital soil mapping (DSM) algorithm to a legacy dataset.

This will allow to suggest, also on the base of the latest erosion maps, possible interventions such as the application of conservation management techniques or provision of benefits to certain land uses including permanent cropping or reforestation to insure the maintenance of productivity of soils for the next generation.

METHODOLOGY

Sicily (Italy) is a semiarid area in the very middle of the Mediterranean Sea. It's extended 25,286 km^2, 60% of which is cultivated. It has a mean annual temperatures of 1.8 °C to 15.0 °C and mean annual rainfall from 350 to 1300 mm. Main annual crops are winter cereals, legumes and a wide range of horticultural crops; the main perennial crops are olive groves, vineyards and fruit trees such as citrus, almonds, stone fruits. Woodlands are mostly anthropic. Adoption of conservative soil management techniques is almost absent. Dominant soils (World Reference Base) are Calcaric Regosols, Haplic Calcisols, Calcic Vertisols, Vitric or Silandic Andosols, Calcaric and/or Mollic Leptosols, Calcaric Phaeozems, and Fluvic Cambisols. Hence it can be considered quite representative of many countries. The Regional Bureau for Agriculture, Rural Development and Mediterranean Fishery, the Department of Agriculture, and Service 7 UOS7.03 provided the dataset used in this study, which included soil texture (by sedimentation method) and organic C concentration in the topsoil (0-40 cm). Meteorological data were drawn from Worldclim (Hijmans *et al.*, 2005), land covers from CORINE of the years 1990 and 2006 at 100-m spatial resolution for the models built for the year 1993 and 2008, respectively (http://land.copernicus.eu/pan-european/corine-land-cover). The analysis of SOC change was carried out according to arable land (ARA), vineyards, fruit trees and berry plantations, and olive groves (grouped in VFO), annual crops associated with permanent crops, complex cultivation patterns, land principally occupied by agriculture, with significant areas of natural vegetation (grouped in CCP). Remote sensing-derived predictors consisted of the LANDSAT 5 spectral bands and the Normalized Difference Vegetation Index (NDVI) was derived and included as explanatory variable of SOC. Shuttle Radar Topography Mission (SRTM-C) digital elevation model (DEM, September 2014, 1-arcsec spatial resolution) was used for the calculation of the morphometric spatial predictors by means of SAGA GIS. Eleven terrain attributes were calculated: 1) slope, 2) catchment area, 3) aspect, 4) plan curvature, 5) profile curvature, 6) length-slope factor, 7) channel network base level, 8) convergence index, 9) valley depth, 10) topographic wetness index, 11) landform classification. Boosted Regression Trees (BRT, Elith et al., 2008) was used to identify the relationships between SOC and its predictors and to regionalize the SOC (as variation of its concentration and mean amount per soil pixel). Relationships between variables are explained through response curves. We used the R software and the 'dismo' package developed by Elith et al. (2008). Finally, the soil erosion risk map by Fantappiè et al. (2015) was compared to the variation of SOC in a 15 years (1993 to 2008) timespan.

RESULTS

We predicted SOC concentration and its variation in time (Fig. 1B) and SOC stock (Fig. 1C) across Sicily, and also estimated the SOC stock and the variation of the SOC concentration for different land covers (Fig. 1D). Annual rainfall, soil texture, land cover (CORINE), and mean annual temperature were the most important predictors of SOC stock. Our prediction of SOC stock ($R^2 = 0.470$) better fitted to the entry data than other wide scale predictions (Global Soil Organic Carbon Estimates, $R^2 = 0.034$; and International Soil Reference and Information Centre Soil Grids, $R^2 = 0.127$). Prediction of SOC concentration showed high accuracy, with pseudo-R^2 higher than 0.693 for the 1993 and 0.634 for 2008 data. The most important predictors of SOC concentration were soil texture; land use; valley depth; rainfall; channel network base level, a measure correlated with the height above the see level [a.s.l.] of the basin upon each pixel and thus to the chance of receiving SOC by erosion; and length-slope (LS) factor, which is correlated to erosion potential of the area. The variation of the SOC strongly depended on the subarea within the region and did not match the SOC map at the baseline (1993). Such variation was partly explained by the potential erosion and deposition of soil after erosion.

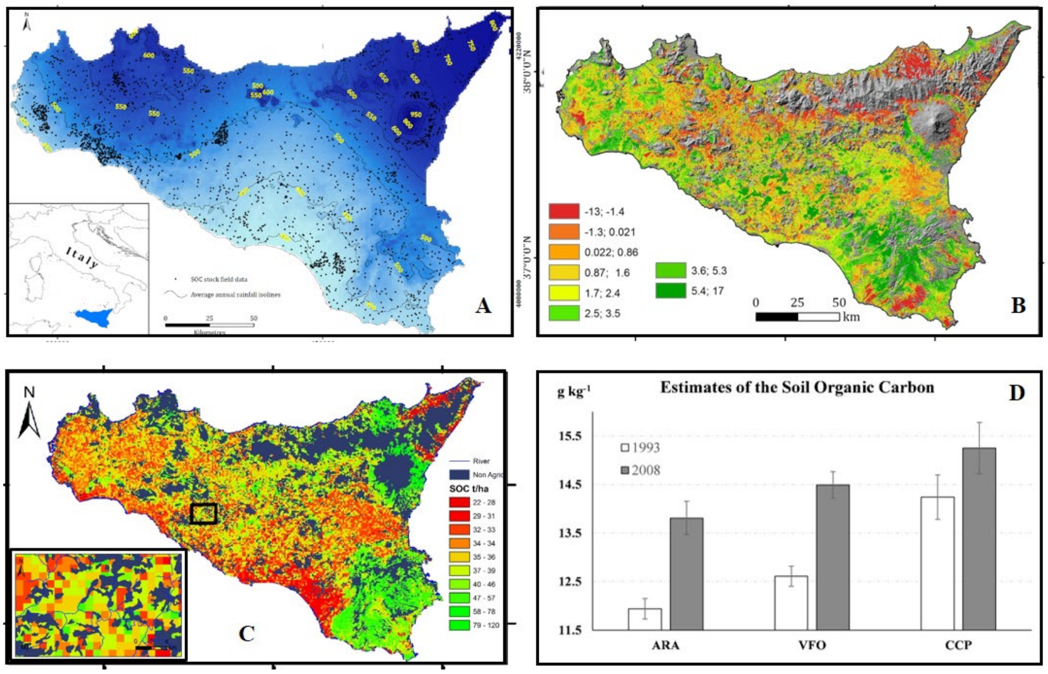

Fig. 1: [A: Locations of the sampling sites in the area under study (Sicily). The mean annual rainfall is shown in mm/year (published in Schillaci et al., 2017). B: 100-meters resolution map of the difference in the SOC (expressed in g C kg^{-1}) during the study period. Reddish pixels indicates a loss and greenish pixels a gain in the SOC during time. Grey for non agricultural areas. C: 1-km resolution of the SOC stock (expressed in t C ha^{-1}). Reddish pixels indicates low stock and greenish pixels high stock. Grey for non agricultural areas. D: SOC concentration (g C kg^{-1}±S.E.) in each of the land use groups used in 1993 and 2008. ARA for arable land; VFO for vineyards, fruit trees and berry plantations, and olive groves; CCP for annual crops associated with permanent crops, complex cultivation patterns, land principally occupied by agriculture with significant areas of natural vegetation.]

DISCUSSION

The mean prediction of the SOC stock of the year 2000 (Schillaci *et al.*, 2017) amounted to 37.44 t ha^{-1} and its range predicted at a R^2=0.47. Similar or lower fit statistics were found when other similar algorithms were applied in many other countries including humid, tropical, monsoon, and drylands (France, Indiana, Western Ghats – India, Nigeria) (Akpa *et al.*, 2016; Martin *et al.*, 2014; Mishra *et al.*, 2009; Seen *et al.*, 2010). The estimation procedure individuated annual average rainfall and temperature as fundamental factors of SOC accumulation and depletion, respectively. The importance of temperature on increasing SOC stock was found to be high only when soil water availability is adequate to sustain the microbial activity (Ma *et al.*, 2014). In general, the higher was the clay content of soil, the higher its SOC stock. This results agrees with studies showing the strong SOC protection ability of clays (e.g. Six and Paustian, 2014) and others also found clay content an important feature on SOC stock estimate (Martin *et al.*, 2014). This suggest that measure to mitigate soil C loss (through reduced erosion rates and augmented C input) strongly need to deal with the texture information. This can also give important information to estimate the rate of SOC variation in time, especially when climate change scenarios are hypothesized. However, the trade-off of the role of SOC on climate change and effects of climate change on SOC at a given location, ecosystem or area depends on various management and environmental variables (e.g. soil texture or tillage, Stockmann et al., 2013). In this framework, the study period in this study, despite selected according to the highest availability of data per year, allowed us to depict a short-term variation of SOC within a well-characterized period: its beginning (1993) luckily fell soon before a number of European and worldwide policy measures which profoundly impacted agriculture, including the Regulation EEC 1272/88 on set-aside; the United Nations Framework Convention on Climate Change of 1993; and the World Trade Organization Marrakesh Agreement. Its end (2008) fell soon after the abolishment of the compulsory set aside in the EU and the decoupled CAP EU payments to agriculture in 2005. This makes it a period of low agricultural dynamic in term of land use change and management techniques, the latter of which were dominated by deep ploughing. In particular, we found that only the area covered by CCP increased by 55%, which was likely due to the temporarily conversion of grassland to pastures or land abandonment. As expected, we found that the SOC of ARA was lower than the SOC of VFO and that of VFO lower than CCP. In general, we found that SOC increased from 1993 to 2008 in the island. We mostly attribute it to the application of Good Agricultural and Environmental Conditions and recourse to the set aside, and ease of increase SOC in low-SOC soils (Borrelli *et al.*, 2016; Kämpf *et al.*, 2016), such as those in the present study. In the northern, rainy, part of Sicily, in spite of conditions conducive to SOC accumulation, we found a reduction of SOC and this was strongly related to soil erosion potential. Similarly, a fifth of the increase of SOC in the ARA and VFO areas was explained by catchment area, landforms, valley depth and channel network base level, which are related to soil deposition

CONCLUSIONS

Space-time mapping of SOC can be a valuable tool to aid in the study of the global carbon cycles at wide scale and guide decision-making processes. Here we showed that such processes also relies on existence or accessibility of data, including SOC at representative locations, bulk density, land use, soil texture, rainfall, temperature and RS data. The results of the present experiment also yield valuable information for assessing the effect of a climate change scenario on SOC stocks and their spatial distribution in semiarid areas, where low rainfall and high temperatures limit SOC accumulation patterns. The present results can imply both agronomic and policy consequences at the district level and call for an intervention on soil fertility to maintain agriculture productivity (Acutis *et al.*, 2014; Dono *et al.*, 2016). These results can help in calibrating models of SOC dynamic under various management or climate change scenarios.

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3.3.11 | SEQUESTERING SOIL CARBON IN THE LOW INPUT FARMING SYSTEMS OF THE SEMI-ARID TROPICS – DOES LITTER QUALITY MATTER?

Anthony M. Whitbread[1*], Rod Lefroy[2], Graeme Blair[3]

[1]International Crops Research Institute for the Semi-Arid Tropics, Patancheru India. a.whitbread@cgiar.org
[2] Agricultural Consultant, rod.lefroy@bluewin.ch
[3] Department of Soil Science and Agronomy, University of New England, Armidale Australia. ourfing@bigpond.com

ABSTRACT

Maintaining soil organic matter (SOM) in low input smallholder rice cropping systems worldwide is of paramount importance to maintaining livelihoods and food security. A long term rainfed lowland rice experiment tested the hypothesis that applying small (1.5 t/ha dry matter) annual additions of slowly decomposable plant materials which were grown offsite and applied prior to land preparation, could result in increased soil organic carbon, crop yield and improve the recovery of nutrients compared with plant materials of higher quality or straw retention alone. Annual leaf litter applications over 9 seasons resulted in significant increases in SOC of 39% (from 3.5 to 4.9 mg/g) in the leaf litter treatments compared to only 13 % in the no-leaf litter control. In terms of rice grain production and nutrient use efficiency, leaf litter quality was an important driver. Apparent nutrient recovery of nitrogen and sulfur reflected the decomposition rate of the added residues. Sustainable farming systems will require that crop yields are stable through the maintenance of soil fertility and the balanced use of nutrients in the system. The results of this study are therefore highly significant and provide evidence that low rate, long term residue management can have profound effects.

Keywords: Soil carbon, labile carbon, residue management, rice cropping systems, soil organic matter, apparent nutrient recovery, long-term trial.

INTRODUCTION, SCOPE AND MAIN OBJECTIVES

The SOM content of agricultural soils plays an important role in many aspects of chemical, biological and structural fertility. In annual-based rainfed cropping systems of the semi-arid tropics, there have been few studies providing evidence that soil SOM can be increased without substantial off-site additions of organic residues, or long periods under pasture or forestry. So one can conclude that under most rainfed arable systems, with crop residue retention, the best that can be achieved is the maintenance of soil organic carbon (SOC), and under some management such as conservation agriculture, small increases in SOC in the topsoil layer. But focusing only on SOC content misses an important part of the story. In low input systems, productivity is closely connected to soil organic matter status, which can be very low in subtropical climates (<1% in many soils). Organic inputs such as leaf litters, crop residues or farm yard manure, in such systems provide both a short-term supply of nutrients through decomposition and substrate for the synthesis of SOM. An understanding of the litter decomposition processes is therefore central to developing improved management practices for plant residues which may maintain long-term soil organic carbon content and soil nutrient supply rate.

METHODOLOGY

A long term (12 year) rainfed lowland rice experiment tested the hypothesis that applying small (1.5 t/ha dry matter) annual additions of slowly decomposable plant materials which were grown offsite and applied prior to land preparation, could result in increased soil organic carbon, crop yield and improve the recovery of nutrients compared with plant materials of higher quality or straw retention alone. This experiment was commenced in 1992 at the Ubon Rice Research Center (15o12`N; 104o41`E, 123 masl) on an infertile acid sandy soil (Aeric Paleaquult). The site of the experiment had been cleared in 1971 and farmed to rice for at least 20 years prior to the experiment. Pre-trial soil samples showed high bulk density (mean=1.47 g/cm3), low water holding capacity, low cation exchange capacity (sum of Ca2+, Mg2+, Na2+, K+) = 5.9 cmol/kg, low concentration of total organic C of 3.5 mg/g, moderate available P (Bray II) of 19 mg/kg; low exchangeable K of 0.04 cmol kg-1.

The experiment consisted of a complete factorial design with five leaf litter treatments (No leaf litter, *Cajanus cajan, Acacia auriculiformis, Samanea saman* and *Phyllanthus taxodifolius* applied at 1500 kg dry weight/ha and incorporated 1 week before transplanting, two inorganic fertiliser rates (Low 25:7:7 and High 50:14:14 kg/ha of N, P and K, respectively) and two after-harvest rice stubble treatments (stubble removed and returned), with 3 replications. Plot size was 3 x 5 m. The experiment was repeated over 12 years (first rice crop in 1992 and final crop in 2003) in the same plots and using the same management in all years. Details of field management and analytics can be found in Blair *et al*. 1996, Naklang *et al*. (1999) and Whitbread *et al*. (1999).

RESULTS

This experiment, first reported by Naklang *et al*. (1999) and Whitbread *et al*. (1999), showed that annual leaf litter applications over 9 seasons resulted in significant increases in SOC of 39% (from 3.5 to 4.9 mg/g) in the leaf litter treatments compared to only 13 % in the no-leaf litter control. While decomposition rate of the 5 leaf litters varied widely, there was no significant difference in their effect on SOC sequestration. There was also no significant increase observed in soil C as a result of the return of straw to the system.

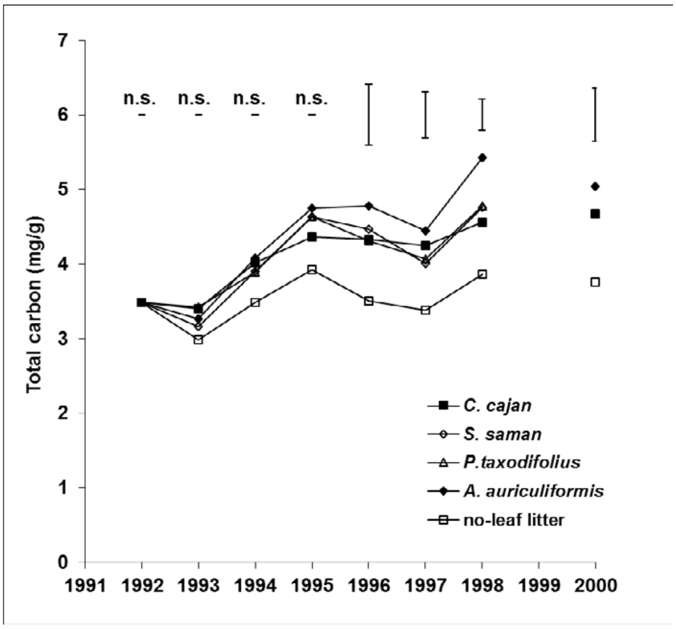

Fig. 1: Total carbon (mg/g) of the leaf litter and the no leaf litter control treatments in 1992-1998 and 2000 (Note. Data presented in averaged across fertiliser + after harvest stubble treatments).

In terms of rice grain production and nutrient use efficiency, leaf litter quality was an important driver. In the initial years of the trial, grain yield was increased in the range of 364 - 670 kg/ha relative to the no leaf litter control in treatments with higher quality leaf litters however this effect decreased with each successive season until the 6th season where all leaf litter treatments yielded similarly and significantly more than the no leaf litter control. Apparent recovery of plant available nitrogen and sulfur, both highly mobile nutrients, increased in each season in all leaf litter treatments with highest apparent recoveries associated with the applications of the lowest quality leaf litter. The benefits of organic resources in improving the efficiency with which mineral fertilisers are utilized may be small in the short-term but higher in the longer-term because of this link to maintenance of SOM content.

DISCUSSION

The generally poor soil fertility status in northeast Thailand, resulting from low inherent nutrient content, low fertiliser use and the dominance of sandy soils, has been reported frequently (Haefele *et al*. 2006; Boling *et al*. 2008). In these fine-textured soils, nutrients and soluble carbon compounds may move down the profile, thus resulting in little, or no, long term increase in soil fertility when residues are added.

The relatively small increases in SOC (1.2 - 1.6 mg/g) associated with this residue management system demonstrate how difficult it is to increase soil organic matter content in such annual cropping systems in the semi-arid tropics. Many studies have shown that the quality of plant residues has a profound effect on decomposition pattern and in effect on the mineralisation-immobilisation dynamics of soil nutrients (Vanlauwe *et al*. 2004). In most cases, the availability of soil inorganic N will, at least in the short term, control the kinetics of C decomposition (Corbeels *et al*. 2000). While C:N ratio of plant material is normally closely correlated to potential decomposition rate, some residues, for example *Mucuna pruriens* or *Flemingia macrophyla* both tropical legumes, display decomposition patterns that are modified by high polyphenol content despite high leaf N concentration and a low C:N ratio (Vanlawue *et al*. 1996). Although the decomposition process results in the transformation of organic matter into more stable forms (Jenkinson 1981), whether more slowly decomposable organic materials can be used in agricultural systems to raise SOM content is still not clear (Palm *et al*. 2001).

CONCLUSIONS

Studies that report on the positive effects of organic residues or FYM application on crop yield, nutrient uptake or increased SOC are not new, but in most cases use unrealistically high application rates from off-site sources. This study is unique in its long term application of leaf litters with varying qualities to a rice system. While the effect of residue application on increasing SOC are modest, the impacts on rice grain yield and the efficiency of nutrient recovery are significant and provide the basis for a sustainable rice system.

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