Role of the Mediterranean forest in soil and water conservation: a challenging balance

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Jean Albergel, Jean Collinet, Patrick Zante, Mohamed Hedi Hamrouni. Role of the Mediterranean forest in soil and water conservation: a challenging balance. Water for Forest and People in the Mediterranean: a Challenging Balance : L'eau pour les forêts et les hommes en région méditerranéenne : un équilibre à trouver, European Forest Institute, 197 p., 2010, What Science can tell us, 978-952-5453-79-9. hal-02819657

What Science
Can Tell Us

Water for Forests and People in the Mediterranean Region

– A Challenging Balance

Yves Birot, Carlos Gracia and Marc Palahí (editors)

What Science Can Tell Us 1
2011

What Science Can Tell Us

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Layout: Kopijyvä Oy / Janne Kuivalainen
Printing: Kopijyvä Oy

Disclaimer: This volume has been developed with the support of the SylvaMED Project "Mediterranean forests for all", with the financial contribution of the European Union through its European Regional Development Fund and the Programme MED. The views expressed are those of the authors and do not necessarily represent those of the European Forest Institute or the European Union.

ISBN: 978-952-5453-79-9 (printed)
ISBN: 978-952-5453-80-5 (pdf)

EUROPEAN FOREST INSTITUTE

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CENTRE FORESTAL / TECNOLÒGIC DE CATALUNYA
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Projet cofinancé par le Fonds Européen de Développement Régional
Project cofinanced by the European Regional Development Fund

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1.5.

Role of the Mediterranean Forest in Soil and Water Conservation

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In the Mediterranean, soils constitute a fragile component of terrestrial ecosystems; they are susceptible to erosion as they are exposed to heavy and intense rainfall, followed by marked runoff phenomena accelerated by the hilly or mountainous topography. The issues of water and soil must therefore be considered together.

As pointed out in section 1.4, rainfall regime in the Mediterranean is characterised by intense meteorological events, with an important fraction of annual precipitation falling in a few days. These features, combined with intensive and destructive land use (forest clearing, overgrazing and fires) over millennia have resulted in marked regressive ecological evolution of the terrestrial ecosystem, in particular due to pronounced erosion phenomena. Soil erosion is still a major phenomenon today as illustrated in Figures 20, 25 and 26.

For example, two vast climatic areas of the Iberian Peninsula and Maghreb are characterised by soil parent material developed on limestone and marl of the Cretaceous and Tertiary periods. The semi-arid region is characterised by rains of 300 to 600 mm, an inter-annual variability of 25% to 50% and 4–7 dry months. The climatic conditions, which were once more humid, have allowed for the differentiation of isohumic* soils, red fersiallitic* soils more or less encrusted on limestone or, in conditions of lower drainage or on marls, vertic* and waterlogged soils. In this area, climax formations are found such as: oleaster bush, forests of Aleppo pines, cedars, junipers and cypress. The sub-humid region receives 600 to 800 mm annually with a variability of 10% to 25% and 3–5 dry months. Continuous moisture has produced a soil darkening. The red soils are formed on carbonated hard rocks. However it is not rare to observe, on hard limestone, soils with brown tints; this soil darkening affected the profile either totality or partially1. The darkening of fersiallitic soil brings an upgrade of the essential physical characteristics, the porosity, the useful reserve and the resistance of the aggregates to erosion. To the previous climatic formations, one can add sclerophyllous oaks: holm (*Q. ilex*), cork (*Q. suber*) and shrub (*Q. coccifera*) oaks.

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[1] The darkening of fersiallitic soils (distinct from the darkening by the organic matter) is possible when the climatic and land cover conditions are intermediate (sub humid climate); however, a category of brown fersiallitic soil saturated in calcium it exists (subgroup of fersiallitic soils).

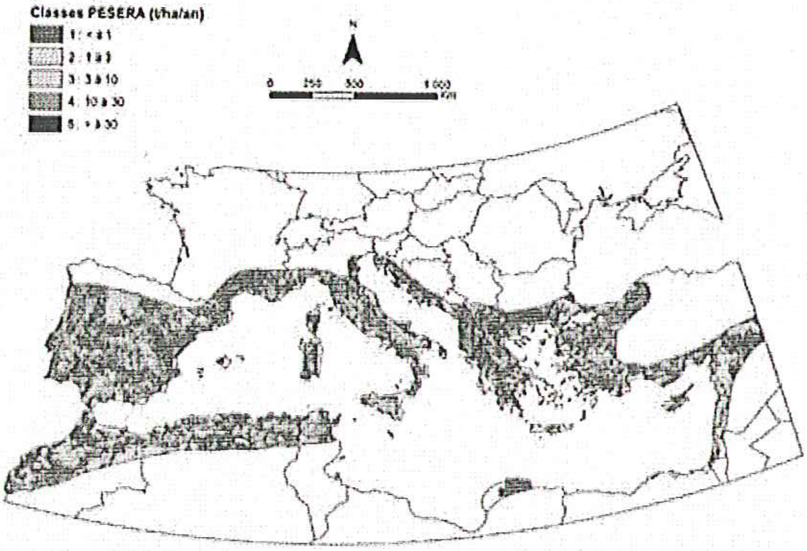


Figure 20. Map of soil erosion for the Mediterranean Basin for current conditions (PESERA Simulation). Source: Y. Le Bissonnais et al. 2010.

The original soil covers have more or less disappeared due to drier climate and concurrent geological cycles of erosion. The export of wood since the Phoenician era (1000 BC) and the increase of agriculture since the Roman era (200 BC) intensified anthropogenic erosion by leaving a landscape where rocks, regolith and continuous or fragmented calcareous encrusting are exposed. In these landscapes, the climatic vegetation has deteriorated into *maquis* (acidic soils), and *garrigues* (calcareous soils); however, some forests, usually found upstream of catchment areas of more than 50 km² where cattle breeding (sheep) is dominant, have been saved.

The balance models typically take into account various fluxes between the forest cover and the atmosphere: atmospheric carbon is fixed in vegetation by photosynthesis; it is stored in the leaves, wood, roots and the soil receiving the debris and accommodating a more or less strong biological activity. This carbon is re-emitted during plant respiration or the decomposition of organic matter. Trees, on the other hand, re-evaporate rainwater intercepted by the leaves or water taken up from the soil through transpiration. Finally, forests and soils reflect part of the solar infrared radiation. These different fluxes are mainly quantified in continuous forest cover situation and thus in more humid areas than in the Mediterranean. With smaller biomass, growth dynamics and flux intensities that are different from those of temperate and even more humid forests, Mediterranean forests should continue to play an important role in a context of the precarious subsistence of neighboring societies, and the difficult management and conservation of water and soil – although from north to south and from east to west of the "olive tree range" the situations differ. Indicators of stocks and fluxes of hydrous, organic and mineral compounds allow, within certain limits, to assess the fragility and resilience of the binomial soil and vegetation.

Raindrop energy impacting the soil can be controlled by vegetation, above a ground cover rate of 20% to 30%, with small differences between plants, shrubs and trees.

Water related soil erosion processes consist of the:

a) impact of the kinetic energy of falling rain drops resulting in the fragmentation of soil aggregates into finer particles (rain splash erosion);
b) role of runoff which acts as carrier of these particles; and
c) role of runoff as active erosion agent (sheet and/or gully erosion).

These mechanisms are, in turn, related to the characteristics of the vegetation cover since foliage intercepts part of the rain, reducing the splash effect and contributing to the re-emission of water to the atmosphere through evaporation (see section 1.4), and as the root systems limit the mobility of soil particles. Of course, erosion and runoff are also related to soil features; in particular, structural stability and hydro-dynamic characteristics.

The effects of a forest begin with the interception of rainwater before it reaches the ground. Depending on the local ecological conditions, we find different types of plant and structural organisations that strongly interfere with the rain splash effect and the genesis of runoff, and thus with the mobilisation of erodible land. The share of inter-

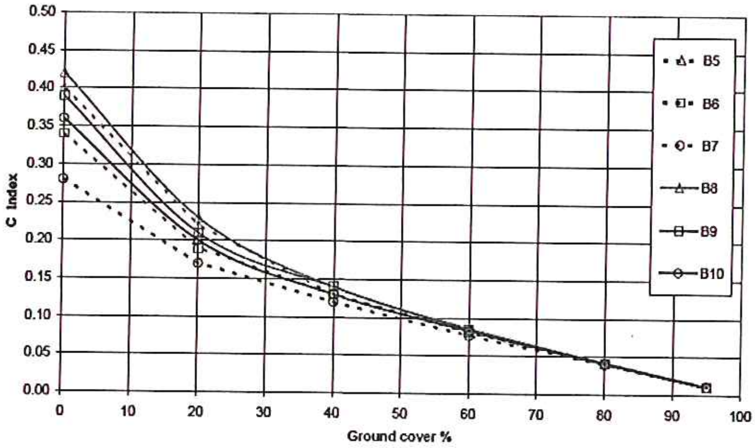


Figure 21. Role of plant cover in limiting raindrop energy: C Index for various ground cover types canopies (C = 1 in the total absence of interception on a clean tilled continuous fallow: a situation presenting maximum vulnerability)

- B5: 25% shrubby stratum with raindrop falling from 2m + herbaceous ground cover with broad leaves
- B6 : 50% shrubby stratum with raindrop falling from 2m + herbaceous ground cover with broad leaves
- B7 : 75% shrubby stratum with raindrop falling from 2m + herbaceous ground cover with broad leaves
- B8 : 25% of forested stratum with raindrop falling from 4m + herbaceous ground cover with broad leaves
- B9 : 50% of forested stratum with raindrop falling from 4m + herbaceous ground cover with broad leaves
- B10 : 75% of forested stratum with raindrop falling from 4m + herbaceous ground cover with broad leaves

ception in the water balance equation has been documented in section 1.4. Hereafter, the emphasis will be put on the structure of vegetation layers and its role for controlling raindrop energy. The importance of this factor has been taken into account in the development of new models for predicting water erosion, through the quantification of the interception of rainfall energy through various plant structures from the trees to the herbaceous layer. Figure 21 illustrates the values of the ground cover and management index C as related to various plant cover types, corresponding to different combinations of heights and densities of canopy and ground coverage. One can conclude that differences between plant cover types are limited above a threshold of ground cover above 20% to 30%; in other words, shrubby vegetation can be as efficient (and even better) as a forest regarding the control of splash effect. In terms of water budget, shrubby vegetation is in general less water consuming than forest.

Forest soils have a comparative advantage vis-à-vis other soil types regarding porosity and hydraulic conductivity, and reduced susceptibility to rain splash effects.

When water from stemflow, throughfall and raindrops reach the ground, several processes can take place. The water recharge of soil layers will start, followed by seepage in more or less deep levels, usually before the occurrence of runoff. Soil characteristics play an important part in the relative share and intensity of these processes. To a large extent, they are related to the ecosystem type which influences the physical and biochemical transformations of upper layers, facilitating soil water recharge and deep drainage by seepage.

In the case of forests, various studies have shown that

- In hardwood forests, structural changes of surface horizons related to polymerize humic compounds stabilising the structures of the initial horizons are to be observed. However, this action is limited in pine and teak forests and almost invalidated in eucalyptus forests, whose litter secrete antibiotic substances that limit the mineralisation and humification of litter.
- Animal and microbial biological activity promotes porosity. Worms emit 3 t/ha of castings in forests vs. 0.5 t/ha for less biologically active soil types. This activity counteracts the development of surface crusts and heavily favours the surface hydraulic conductivity as well as, unfortunately, the mobilisation and erosion of thin mountain soil.
- Increased protection of the soil top layers by litter or a herbaceous layer acts as mulch, dispersing the incoming energy in the proportions as shown in Figure 21.
- A deep porosity is favoured by the development of roots; however, this will depend on the structure of the root system, size of the roots (hairy surface, pivotal system, etc) and its health status.

The genesis of runoff depends on soil surface status, initial soil water content and, of course, on rainfall intensity. The forest cover influences runoff, only by delaying its onset and slowing the establishment of a strong runoff regime.

Box 4. Rainfall, infiltration and runoff

Under rainfall simulation, it was found that the intensity of minimum infiltration Fn (mm / h), or that the maximum intensity of runoff Rx (mm / h), varies with rainfall intensity (I mm / h). This relationship, which may seem surprising, results from the lateral variability of saturated hydraulic conductivity Ksat (mm / h) which, under constant rainfall intensity, corresponds to Fn (mm / h). This fundamental property is explained in Figure 22.

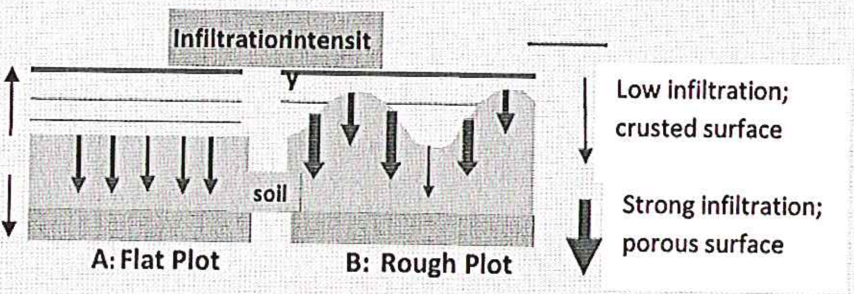


Figure 22. Relationship between soil roughness and saturated hydraulic conductivity, Ksat (mm / h).
Situation A, Flat land: On flat land, the soil is covered with a homogeneous crust; Ksat has the same value everywhere. As soon as the rain intensity (I) exceeds Ksat, runoff appears. The flow only depends on rain intensity and soil slope.

Situation B, Rough land: loamy crusts are more important in the lowest part of the plot; they are affected on the sides of the clods, which are more permeable and are more or less permeable on the summits of hillocks. Ksat varies from one point to another, the number of sites where I > Ksat increases with the height of the flowing water. This is the case of irregular land surfaces, cultivated land, land with high biological activities and with dense vegetation cover - all rough surfaces - and, as a result, irregularly submerged under a depth of run-off for increasing rainfall intensities. An illustration of these behaviors is shown in Figure 23 showing the relationship between a steady regime surfaces run off (Rx) and rainfall intensities (I).

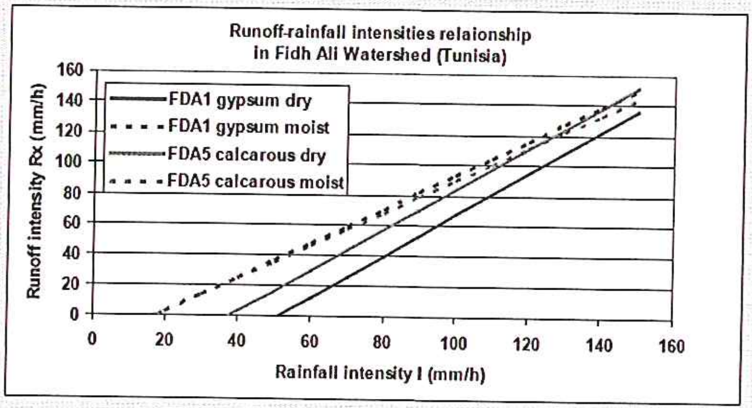


Figure 23. Relationships between runoff maximum intensity Rx and rainfall intensity (I) for gypsum (FDA 1) and limestone (FDA 5) soils with two initial soil moisture contents.
Note that the intersection of regression lines with the abscissa determines the highest intensity of rain (Ilim. mm/h) causing the initial flow. This value can be obtained experimentally by gradually reducing the intensity of simulated rain. FDA 1 is a soil derived from loam gypsum, the surfaces are rough with well-formed but unstable aggregates. With accumulated rainfall, they disperse into a silty clay material. FDA 5 is derived from limestone. The surfaces are quickly smoothed into a fine silty and sandy lining with low infiltration. On initially dry soil, behaviors are parallel but with different rainfall intensity limits: 51mm/h for FDA 1 and 37 mm/h for FDA 5. On initially humid soil, the behaviors converge on surfaces that are smoothed and clogged identically (Ilim '18.5mm/h).

Studies of the genesis of water flow erosion – runoff and land mobilisation – have experienced major and successful developments based on the use of **rainfall simulation techniques** in the Maghreb on soil materials of various thicknesses, as well as in dry and wet areas in sub-Saharan Africa. More than the "more or less" profound differentiation in these soils' characteristics is their **surface status** (SS), which controls much of their surface water properties. Runoff appears when rain intensity exceeds saturated hydraulic conductivity as explained in Box 4. The infiltration process also relates to soil porosity and the soil surface roughness.

Soil losses as sediment loads in the running-off water and their dynamics during rainy episodes also depend on soil surface status. Under the forest cover, compared to other plant cover types, the limitation of erosion is linked to the delay of runoff onset and to the slow establishment of a strong runoff regime as above mentioned.

Rainfall simulation techniques are also powerful for assessing the evolution of sediment loads related to the increasing intensities of runoff for different SS. Box 5 summarises the genesis of erosion and the sediment load dynamics in relation to flow and soil surface parameters.

The implication of the Mediterranean forest cover on water and soil conservation is quite different from the clichés too often suggested and accepted, considering that forests are full protection against erosion processes.

There are only few experimental forested watersheds that permit the joint study of hydrology and soil erosion in the Mediterranean area; furthermore, only few rainfall simulation studies have been undertaken under forest conditions. However, the findings of these studies can be complemented with reasonable assumptions derived from intensive study sites under agricultural conditions, selected to reflect the conditions of forest soils. As an example, data based on rainfall simulation studies in Tunisia in crop field situations comparable to the SS of forest soils, have been grouped together: low vegetative cover on aggregate and structural lining; bare land with lining; bare rough land with clods and structural lining; and land sprayed with coarse elements (see Table 3).

In the limestone areas of the Mediterranean, the localisation and extension of forests, and the depth of soils supporting them often depend on the size of the catchment area.

In small catchment areas that are strictly calcareous (<10 km^2), upstream forest soils are eroded up to the regolith as well as the rest of the basin, except at the foot of the slope where thicker soils can be differentiated on colluviums. Upstream, the forests are found on rocks or limestone crusts where the useful water reserves, deflected towards the low humidity, depend on the cracking of these materials for their existence. On the ground, this implies a succession of surface states depending on the period:

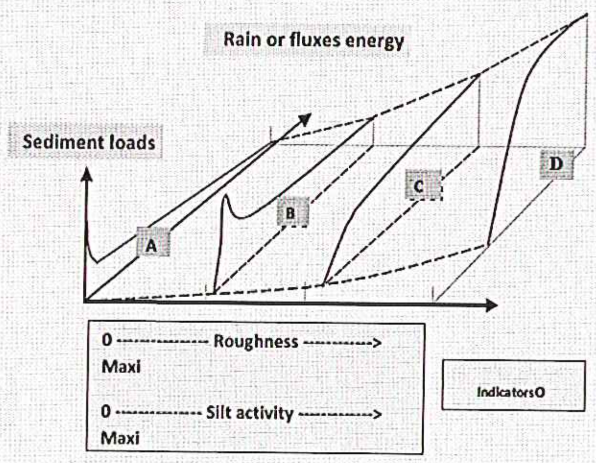
The resumption of the September-October rains on soils with bare gravel, no sprouts and some stubble, as reflected in table 1 by SMA1 result in runoff occurring quickly but lightly during rainfall with higher intensities.

Box 5. Genesis of erosion and sediment load dynamics in relation to flow and soil surface parameters

Figure 24 illustrates the behavior of four contrasted soil types regarding sediment load in relation to rain and flow energy. Curve A reflects the behavior of soil with very low structural stability. The collapse of aggregates by dissipation of rain energy smoothes the surface and forms a lining with low infiltration. The thickness of the water flow intercepts the energy streaming across the surface. The flow remains laminar and thus less abrasive; we then observe a gradual depletion of exportable soil particles. The increase of sediment load is mainly linked to a strong increase of runoff. Curve D reflects the behaviour of land with higher structural stability. The collapse of aggregates by dissipation of rain energy is much more gradual. The delay in the onset of the runoff is also explained by open pores at the surface of the soil. There is no formation of a lining apart from a fragile and porous structural lining. There is no smoothing of the surface except for a major rainfall. As the thickness of the water flow is low, the runoff does not affect the entire surface. There is little interception of energy on the surface, so the splash effect remains stable. Because the surface is rough, the flow becomes turbulent and thus abrasive. As a result, there is a rapid increase in erosion, which may seem contradictory since it is the structural stability which is at the origin of this process. Here, the limitations of erosion will only be linked to the delay of the onset of runoff and to the slow establishment of strong runoff regimes - the first thing that farmland "conservationists" or foresters must consider.

Figure 24. Sediment loads in relation to flows and surface status parameters.

Considering the above, intermediate situations illustrated by curves B and C are easy to interpret. The changes in sediment loads are also associated with different conditions of roughness, mineralogical clay activity (swelling-shrinkage), structuring or disintegrating salt load, crusts and the spreading of coarse elements which act as excellent behavioral indicators.



The start of the rainy season with a more or less significant decrease until April and the rainstorms in May; growth of a grass cover at SMA3 with lightly loaded runoff which becomes more delayed as the grass cover becomes dense and continuous.

In larger catchment areas (> 50 km²) it is not uncommon to find relics of deep red fersiallitic soil in limestone nodules upstream of these areas, unaffected by erosion cycles but can be next to rock outcrops. Forests on structured materials were maintained in these areas thanks to iron oxides and polymerized humic compounds. As these soils have good water reserves and areas with high conductivity, vegetation grows rapidly from October to May. We are getting to the following successive situations: SM1 to SM2 to SM3 with lightly loaded runoff and gradually decreasing rain intensity limits thereby replenishing the usable water reserves.

In these basins, marls are sometimes squeezed into the limestone beds and they give the landscape badlands. Areolar erosion on limestone (<5t/ha/year) becomes linear with peaks of about 50t/ha/year. There is no forest but low shrub vegetation with

Figure 25. The formation of badlands on marl-limestone parent material resulting from the removal of the matorral. Tleta watershed, Ibn Batouta dam, Western Rif, Morroco. Photo by P. Zante.

Figure 26. Gully erosion on calcareous loams (south of Fahs bridge, Tunisia). Photo by P. Zante.

little grass or bare surfaces as their reserves are diverted to high humidity; continuous abrasion prevents germination. The behaviours are similar to those of SML2 then SML1 sites where the collapse of structures supplies heavy loads for runoff that was first delayed but is rapidly increasing afterward.

Further research is needed to develop a body of knowledge on water and soil conservation under forest conditions in the Mediterranean. A concerted research programme around the Mediterranean Basin could offer interesting perspectives.

Examples of in-depth studies that analyse the factors affecting the behaviour of the forest-soil pair are rare. Experimental approaches must precede modelling; they are needed to improve the models' calibration and allowing their validation pro parte. An example of a fast and easy field experiment to be implemented can be the rainfall simulation

Table 3. Rainfall simulation studies in the Siliana region, Tunisia. Average rainfall (30 years) = 430mm; rainfall erosivity: 57-130 megajoules.mm / ha.h by year
Runoff and erosion results in relation to Soil Surface status (SS) of plots whose behavior is assumed to be comparable with those of Mediterranean forest soils.

Soil and loose depth	Sites	Topo	Slope	C + S	landuse	SSF				Runoff		Erosion
1	2	3	4	5	6	7 Slaking crust	8 Struct. crust	9 Cracks	10 Gravels	11 Rx (I) r^2	12 I lim	13 Load (R) r^2
Brown limestone on marl limestone (30cm)	SM1	upstream	19	52	unploughed	45	45	4	0	1.06I-10.1 0.98	9.5	$0.008R^2 - 0.086R + 11.97$ 0.98
	SM2	middle	12	50	fallow	78	18	0	1	1.03I-11.9 0.97	11.6	$0.006R^2 - 0.033R + 13.26$ 0.92
	SM3	downstream	10	45	wheat + weeds	59	23	0.5	0	1.05I-24.4 0.93	23.3	$0.275R+3.63$ 0.95
Brown calcium, concretioned on colluvium (70cm)	SML3	upstream	8	54	wheat seedlings	54	24	4	2	0.95I-15.6 0.98	15.7	$0.004R^2 - 0.352R + 25.44$ 0.79
	SML2	middle	10	50	fresh ploughing	16	54	6	0	Rx not met	> 42	C.max.4.4g/l to I = 120mm/h
	SML1	downstream	13	48	bare fallow	72	16	5	5	1.00I-6.4 0.97	6.4	$-0.004R^2 + 1.392R - 2.7$ 0.87
Scattered outcrops of fragmented calcareous crusts (0cm)	SMA1	middle	12	49	bare fallow	44	20	0	34	0.95I-2.1 0.96	2.2	$0.002R^2 - 0.125R+9.99$ 0.70
	SMA3	middle	9	62	Fallow + culm	28	9	0	12	1.09I-23.3 0.97	21.2	$0.016R + 0.82$ 0.82
	SMA4	middle	15	63	recent ploughing	33	12	1	7	0.91I.10.0.89	12.1	$0.001R^2 + 0.015R + 2.35$ 0.69

Legend:
1 Soil classification (CPCS), parent material and depth of soft soil (<50EG).
2 Sites of rainfall simulation plots with different toposequence in the Siliana region (Tunisia).
3, 4 Topographic position on slopes from 300 to 1,000m in length and slope in %.
5 Texture of soil: clay (<2m) + fine silt (2-20) + coarse silt (20-50) in % of soil without gravels.
6 Agricultural land-use during the tests.
7, 8, 9, 10 Soil Surface Features: slaking crust, structural crust (more or less collapsed clods or aggregates surrounded by dispersion material of these structures), partially
smectic desiccation cracks in clay soils; rate of gravel (2 to 20mm) and pebbles (>20 mm) laid on the ground.
11, 12 Relationship between runoff intensity at constant speed and intensity of rainfall; minimal intensity limit I.
13 Relationship between sediment load contained in the runoff and runoff intensity R, detection of areolar or linear erosions.

on plots representative of soils, cover and soil surface features, and whose data can be easily coupled with natural rainfall occurrences. Such approaches entail respecting the phenological stages of the forest (upper and understorey) and taking into account the energy changes related to rainfall interception.

Recommended reading

- Bellot, J. and Escarre, A. 1991. Chemical characteristics and temporal variations of nutrients in throughfall and stemflow of three species in Mediterranean holm oak forest. Forest.Ecology and Management 41: 125–135.
- Casalı, J., Lopez, J. and Giraldez, J.V. 1999. Ephemeral gully erosion in Southern Navarra (Spain). Catena 36: 65–84.
- Poesen, J., Nachtergaele, J., Verstraeten, G. and Valentin, C., 2003. Gully erosion and environmental change: importance and research needs. Catena 50: 91–133.
- Roose, E.J., Lal, R., Feller, C., Barthes. B. and Stewart, B.A. (eds.) 2005. Soil Erosion and Carbon Dynamics. CRC Press, Boca Raton, FL. 376 p.
- Roose, E., Albergel, J., De Noni, G., Laouina, A. and Sabir M. 2008. Efficacité de la gestion de l'eau et de la fertilité des sols en milieux semi-arides. Actes de la session VII organisée par le Réseau E-GCES de l'AUF au sein de la conference ISCO de Marrakech (Maroc). AUF - IRD - ENFI. Editions des archives contemporaines. 402 p.