Sub-chapter 2.3.3

Challenges for mitigating Mediterranean soil erosion under global change

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Introduction

Soil is an essential resource that provides a wide range of ecosystem services (Dominati et al. 2010). Its formation is slow, but its destruction can be rapid. Soil erosion by water is a natural phenomenon that is impacted by human activities and global change. The long history of intense cultivation and a unique combination of relief, parent material and climate conditions makes Mediterranean soils and soil patterns very different from those in other regions in the world. Several studies have shown that, in the Mediterranean basin, current soil loss rates drastically exceed soil formation rates (Kosmas et al. 1997). In addition, an increase in intense precipitation events due to climate change is expected in the 21st century. For these reasons, suitable adaptive managing strategies for Mediterranean soils cannot be simply transposed from experiments conducted in other regions of the world. This paper presents the main lessons to be drawn and challenges involved in preventing soil erosion in the Mediterranean region under global change reported in the literature, plus results obtained in several research projects[1].

Soil erosion in the Mediterranean basin

Mediterranean soils are particularly prone to erosion (García-Ruiz et al. 2013) because of (i) marked relief, 45% of the region has slopes greater than 8%, (ii) the high frequency of intense rainfall events (> 100 mm h^{-1}) in fall and winter, (iii) the presence of poor, shallow and skeletal soils, and (iv) sparse natural vegetation subjected to severe summer droughts. In addition to these natural drivers, intense cultivation even on steep slopes, burning, overgrazing and deforestation can greatly accelerate soil erosion, which, on the other hand, is limited by the many soil and water conservation measures (SWC) such as terracing in hilly areas.

The impacts of soil erosion can be divided into on-site and off-site effects. On-site effects are due to soil loss at field scale which, in certain extreme conditions, can lead to a net loss of cultivated area. This quantitative soil loss impacts agricultural production through the loss of nutrients, soil water reserves, and alterations to soil properties. Soil erosion also has significant off-site effects through the delivery of sediments to rivers, which affects the mobilization of water by siltation of reservoirs, and reduces the quality of water destined for irrigation and drinking.

Higher sediment yields (SY) than in many other regions have been measured in the Mediterranean basin (Woodward, 1995). These were often explained by the high contribution of gully and riverbank erosion processes (Vanmaercke et al. 2012). Gullies and especially badlands have been identified as a major source of sediments involved in siltation of reservoirs in the Mediterranean region (De Vente et al. 2006). The majority of SY occur during a few extreme rainfall events ("time compression", González-Hidalgo et al. 2007). However, these generalities mask huge variability across the basin as a whole. Based on a dataset containing 104 cumulated years of continuous SY measurements in eight small catchments ranging from 0.15 to 1.3 km^2 in size (Figure 1), Smetanova et al. (submitted) show that (i) the annual SY varied between 0 and ~27100 $t{\cdot}km^{-2}{\cdot}yr^{-1}$; (ii) catchments display two main contrasted patterns of SY seasonality; (iii) time compression is highly variable from one catchment to another. Ben Slimane et al. (2015) demonstrated that the predominance of gully and riverbank erosion processes in the Mediterranean basin was site dependent and not as widespread as previously thought.

1. http://www.agence-nationale-recherche.fr/?Projet=ANR-06-VULN-0012, http://www.obs-omere.org/, http://jeai-vecteur.org/, http://www.sicmed.net/#/projets-projects/3778554https://sites.google.com/site/rosmedsicmed/, http://jeai-vecteur.org/

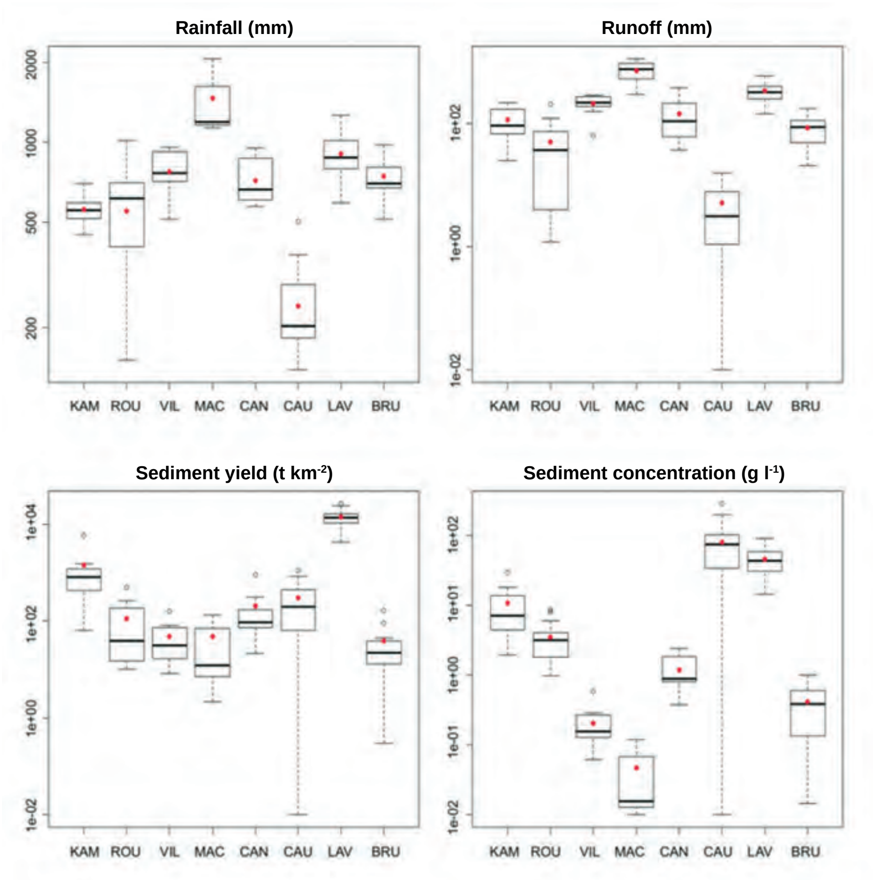

Figure 1
Range of intensity of erosion processes in the Mediterranean basin illustrated through inter-annual variability of rainfall (mm), runoff (mm), sediment yield (SY) ($t{\cdot}km^{-2}$) and sediment concentration ($g{\cdot}l^{-1}$) observed in 8 catchments of the R_Osmed network: KAM (Kamech, Tunisia), ROU (Roujan, France), VIL (Can Vila, Spain), MAC (Macieira de Alcôba, Portugal), CAN (Cannata, Italy), CAU (El Cautivo, Spain), LAV (Laval, France), BRU (Brusquet, Spain). Inter-annual means are plotted as red circles.

Expected future changes in Mediterranean soil resources under global change

Climate change will have both direct and indirect effects on soil erosion. Direct effects are due to changes in the amount, erosive power and spatio-temporal pattern of rainfall. Global change model projections indicate that longer droughts and more frequent extreme precipitation events are likely to occur.

Because of the high degree of SY time compression, the increased frequency and intensity of the largest events will increase soil erosion. The soil system reacts non-linearly to such changes, so even small increases in rainfall amount or intensity can dramatically increase soil loss rates. Climate change could also lead to a temporal shift in both the vegetation cover and the rainfall pattern that could positively or negatively indirectly affect erosion rates: the decline in surface runoff (which triggers erosion) could be partly counterbalanced by reduced biomass growth. Soil erosion could also be strongly affected by changes in land use and management due to human drivers (e.g., technological changes, demographic and socioeconomic trends and governance structures). Indeed, land use and management controls both soil characteristics and the distribution of overland flows. Some widespread crops, including vineyards and olive groves, and practices such as extensive overgrazing in mountain areas are known to encourage erosion. An increase in land abandonment and forest fires because of global change could also increase erosion in young fallows and post-fire conditions.

In the MESOEROS21[2] project, the impact of changes in rainfall characteristics and land cover on the risk of soil erosion in the Mediterranean basin was evaluated using a set of erosion models on (i) small and medium size gauged watersheds in France, Tunisia and Morocco, and (ii) the Mediterranean basin as a whole. The models were parameterized using measurements from highly gauged catchments and applied to the largest basins to calculate present and future conditions. Climate changes were estimated from global general circulation simulations and adapted to local conditions. Several land use change scenarios were built, including an «Accentuation » scenario in which both cultivated and natural vegetation are degraded, and a « Protection » scenario in which natural vegetation and good practices in cultivated area are favored. Two main results of the project (Paroissien et al. 2015; Simonneaux et al. 2015, Cerdan et al. 2011) were:

1) Simulating soil erosion rates is difficult because of the marked spatial and temporal variability of the processes involved and the uncertainty associated with the input parameters;

2) Land use is the main driver of changes in erosion risk and soil vulnerability in the Mediterranean basin.

2. Mediterranean Soils EROsion and vulnerability to global change during the 21st century

Main challenges for the future of Mediterranean soil resources

Toward a better knowledge of the factors and processes involved in soil erosion

Despite the increased availability of spatially distributed data, model application is still hampered by the low quality of input data. We therefore need to make better use of recent techniques to complete the too sparse legacy soil data to capture short scale soil variations in the Mediterranean basin and to improve our knowledge of future conditions to design efficient adaptation techniques. Long-term catchment erosion monitoring systems and Mediterranean networking initiatives are ideal ways to obtain a good picture of the variability of erosion processes and to explore the specific role of major/extreme events or sedimentological connectivity involved in sediment yield (SY) variability.

Toward the evaluation of soil risk

There is a need for a scientifically sound yet simple index of the risk of soil erosion that combines erosion rates and vulnerability and can be readily understood by decision makers. When assessing soil erosion vulnerability, it is important to consider the soil as a patrimonial resource that combines several basic soil functions (e.g., soil fertility and carbon storage) but also cultural and civilizational values related to religion, livelihood and health (Minami, 2009). The choice and valuation of criteria to be used for SE vulnerability are however complex issues, especially in the Mediterranean basin where for example, vineyards or olive trees can grow in soils that would be considered as very degraded using standard criteria. Even when the focus is on a very simple criterion such as soil depth as in Paroissien et al. (2015), soil vulnerability to erosion is difficult to estimate because soil depth is neither a standard, nor an easy, measurement.

Toward site specific conservation strategies

Mediterranean civilizations have successively developed or improved a wide range of techniques to improve water conservation and management, increase agricultural production, and reduce soil erosion. These techniques mainly concern correcting the slope/ reducing water velocity (e.g. through terraces), increasing ground cover (e.g. through the use of cover crops), restoring rangelands, and/or improving soil quality (e.g. through amendments). Recently SWC techniques have extended to sustainable land management or conservation agriculture that favor less soil disturbance, using crop residues as mulch, continuous ground cover, and crop rotations or associations. The efficiency of no-till conservation agriculture in increasing topsoil soil organic content and improve the soil water storage is widely recognised in the Mediterranean basin (Mrabet, 2011). However, these techniques

Box 1
Challenging issues for mitigating Mediterranean soil erosion under global change

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Raindrops control detachment directly through their impact on the soil matrix and indirectly through runoff, which is generally related to the decrease in infiltrability as a direct consequence of the degradation of the superficial structure under the action of rain (Moore and Singer, 1990). Rain also plays a role in particle transport: either in transport caused by the impact of drops, or in transport flow caused by raindrops (Kinnel, 2005). Looking at detachment by raindrops in more detail, it turns out that the rain actually controls two distinct successive processes: 1) the disintegration of particles at the surface and 2) the motion of the fragments produced by disaggregation by splash effect. Rain therefore plays an important role both in the total mass of eroded soil and in the size of the particles set in motion (Legout et al., 2005). Rainfall is usually directly measured by rain gauges but these only provide local and partial information for the scientific issues we want to address.

The first issue concerns the appropriate descriptors for rain (the diameter and number of drops, rain intensity and kinetic energy, and so on) that influence the erosion processes: they are not yet well defined and no consensus has yet been reached in the scientific community. It is consequently necessary to diversify measurements of rain to identify which factors concern erosion. A disdrometer is an instrument used to measure droplet size distributions and the values of other descriptors of rain. This instrument was used during laboratory experiments of detachment with rainfall simulators generating different intensities and energies. These experiments confirmed that the strongest kinetic energies were associated with the largest detached masses. It was also demonstrated that the strongest energies detached the largest proportions of fine particles (that are more easily mobilized by runoff). These observations were confirmed on 120 m² erosion plots under natural rainfall.

The second issue concerns the spatio-temporal structures of rainfall that lead to significant hydro-sedimentary responses. To address this issue, access to spatialized information with high temporal frequency is required. Although weather radar provides indirect measurements, it fulfils this requirement. It is a complementary observation tool that is all the more useful as Mediterranean rainfall can be very localized and last only a very short time (often a few minutes).

Several observation systems are available to deal with these issues including "ORE Draix" in the Southern Alps, "SNO OHMCV" in the Cevennes and "ORE OMERE" for Kamech watersheds in north eastern Tunisia. These observatories have hydro-sedimentary devices for the measurement of suspended sediments, sometimes sediment traps, and precipitation devices (rain gauges, disdrometers, sometimes radar) in various hydro-climatic and soil-use contexts.

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have varying degree of success depending on the environmental and societal contexts (García-Ruiz, 2013). Maintaining a continuous land cover may for instance have positive impacts on soil protection but negatives ones on production because of competition for water in semi-arid areas (Marques et al. 2010). In the end, the benefit of each technique needs to be checked in site-specific conditions, especially in Mediterranean areas where the complexity of the landscape results in significantly diverse contexts. Lessons from past changes in the Mediterranean environment through a review of adaptation techniques already experimented and a site by site evaluation of their soil protection efficiency and acceptability by local farmers will be helpful. Many mitigation strategies cited above are based on profound changes in agricultural practices. The massive introduction of such strategies in existing Mediterranean agrosystems is a challenge, and will have to take the specificities of each agrosystem into account, along with its socio-economic and environmental dimensions, and be supported by local or national policies.

Conclusions

Mediterranean soil resources are crucial for the social and economic development of the region but their sustainability is threatened by intense erosion processes, which have severe on-site and off-site effects. However, the nature and intensity of active erosion processes are as varied as the mosaic of Mediterranean landscapes. Realistic maps of soil erosion risk, vulnerability and sustainability cannot be produced without knowledge of erosion factors and processes acquired in awareness of this diversity.

When we modeled future soil degradation and catchment sediment delivery, the direct impacts of climate change alone were found to be lower than the impacts of changes in land use or in land management. The first challenge is thus to better forecast future changes in land use/management changes, whether or not driven by climate. The second challenge is to propose a strategy to anticipate projected changes and to mitigate their impacts. A wide range of adaptation or mitigation techniques exists and many have already been tested in the Mediterranean basin. It is now important to evaluate their efficiency and acceptability in the wide range of site-specific conditions. This will require new integrated approaches able to combine (i) quantitative and qualitative impacts of soil erosion; and (ii) natural and anthropogenic factors and processes.

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The Mediterranean Region under Climate Change

A Scientific Update

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