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Effects of ephemeral gully erosion on soil degradation in a cultivated area in Sicily (Italy)

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ABSTRACT

Water erosion is the main cause of soil degradation on cultivated lands under Mediterranean climate. In these conditions, ephemeral gully erosion (EGE) is a major contributor to loss of soil productivity due to the big amounts of soil removed from the most productive top-layer. However, only a few studies on the effects of EGE and artificial controlling measures on soil degradation are available. The objective of this study was to assess the impact of EGE combined with soil infilling by tillage on several physicochemical soil properties related to soil fertility and productivity through the calculation of a soil quality index (SQI) by means of a statistical approach. It was hypothesized that the sites affected by this process of erosion and infilling of ephemeral gullies (EGs) exhibit considerable changes in the soil properties compared with locations that do not undergo this process. The study site consisted of 5 fields with contrasting soil properties which have been continuously cultivated with winter wheat. The site, located in the internal area of Sicily (Italy), represented a typical Mediterranean arable land and was severely affected by EGE. A set of soil samples were collected to investigate the spatial variation of the SQI across each location: 12 sample points in the EGE area; 4 samples in the deposition zone; 4 reference points in the area unaffected by EGE. The SQI was estimated by closely monitoring a set of main chemical and physical soil variables which influence soil fertility status: particle size (sand, silt and clay content), bulk density, gravimetric moisture, pH, electrical conductivity, carbon content (inorganic, organic and total), nitrogen content (ammonium, nitrate and total) and available phosphorus. The results showed that channelized erosion posed a threat to soil quality status even at a single cultivated field's level; therefore, the soil's ability to sustain crop production is expected to be compromised in the long run. Reductions of the SQI were observed at the EGs system area and at the deposition area in every EGs. Besides that, the lowest values of SQI were obtained inside the EGs channel and in the nearby soil areas, which were generally used to fill those channels. Soil degradation occurred in the areas which were subjected to EGE and infilling process, with key soil properties being clay (CC), sand (SaC), silt (SiC), and total organic carbon (TOC) contents. This approach helps to understand the impacts of EGE and its controlling measures on soil degradation in Mediterranean agricultural fields.

1. Introduction

Soil erosion is considered one of the most important processes of land degradation worldwide, and it represents a serious threat to the provision of food supply and security, protection of human health and natural ecosystems, and economic development of countries. Water erosion processes are classified as sheet or interrill erosion, and linear or channelized erosion (rill and gully erosion) (Boardman, 2006). In temperate regions, almost all cases of erosion involve rilling and/or gullying as the dominant process (Auzet et al., 1993; Boardman, 2006; Chaplot et al., 2005). Different gully types have been described in the literature: permanent or classic, bank, and ephemeral gullies (Poesen et al., 2003). Permanent gullies are landforms created through the incision of alluvial or colluvial deposits by overland or subsurface flows (Rustomji, 2006), which generally result from the erosion caused by the concentration of surface runoff during or immediately following heavy rains. These gullies are deep enough (usually >0.50 m) to

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interfere with, and not to be obliterated by, normal tillage operations (Soil Science Society of America, 2001). On the other side, bank gullies develop whenever concentrated flow crosses an earth bank (Poesen et al., 2003). Finally, ephemeral gullies (EGs) are channel incisions larger than rills, but smaller than classical gullies. They can be removed by conventional tillage, but then recreate at the same location as soon as additional runoff events occur (e.g. Capra and Scicolone, 2002; Capra, 2013; Casalí et al., 1999; Foster, 1986). In agricultural lands, ephemeral gully erosion (EGE) not only determines (sometimes dominant) severe soil loss (Auzet et al., 1993; Poesen et al., 2003; Taguas et al., 2012; Wilson et al., 2008), but also contributes to the gradual degradation of soil quality, which results in a decline in the potential productivity of the soil (Chaplot et al., 2005; Liu et al., 2013). Many research efforts have been carried out for measuring and modelling rill and gully erosion (Casalí et al., 2006; Di Stefano and Ferro, 2011; Di Stefano et al., 2013), also using terrestrial photogrammetry (Carollo et al., 2015) and the three dimensional photo-reconstruction techniques (Gómez-Gutiérrez et al., 2014), while the research of how channelized erosion affect soil quality is still limited (Bone et al., 2014).

Soil degradation by EGs is a serious and progressive process which is controlled by two main events recurring over time. One is an increased surface runoff following heavy rain with sufficient erosive power to remove large amounts of surface soil material (Nachtergaele et al., 2001). The other event is represented by the mechanical operations aimed at filling the eroded surface with soil material taken from adjacent areas. This practice deletes the gully and restores the original swale of the terrain; however, it also exposes deep soil layers to the erosive action of the EG during the next runoff events. In the long term, the cyclical nature of both processes may gradually lead to a thinner soil profile (i.e. loss of fertility) in areas surrounding the EG, and ultimately to a continued increase in the size of the surface degraded by the gully, due to the use of soil material from increasingly remote areas for infilling the channel (Liu et al., 2013; Yan et al., 2010). In addition, the topsoil fertility, where most nutrients concentrate, gradually decreases from distant unaffected areas towards the gully channel. These previous statements confirm the need to provide a quantitative assessment of how the EGE-infilling process affects soil quality so as to develop suitable controlling measures able to protect the soil resource and maintain the sustainability of croplands (Doran and Parkin, 1996). Because soil quality cannot be measured directly, this attribute is usually determined by measuring several soil properties (physical, chemical and/or biological), termed indicators; and by trying to set out thresholds for these indicators (Paz-Ferreiro and Fu, 2013; Xu et al., 2006). The literature has reported several studies that were conducted in order to examine type, number, accuracy and thresholds of different soil quality indicators in a wide range of scenarios affected by soil degradation (e.g. scale, land use, conservation practices, etc.) (e.g. Brunner et al., 2008; Douglas et al., 2003; Jackson et al., 2003; Li et al., 2004; Mandal et al., 2008; Tesfahunegn, 2016). These studies concluded that soil quality degradation on agricultural environments affected by soil erosion can be mainly assessed through physical and chemical indicators (Bone et al., 2014; Pulido Moncada et al., 2015; Paz-Ferreiro and Fu, 2013).

However, the scarcity of research on in-situ effects of EGE on soil quality has revealed that there is not a consensus on whether the annual infilling of EGs exacerbates or mitigates soil degradation in the long term, nor on what soil physicochemical properties are more negatively affected and, in consequence, appear as key factors in understanding this degradation process (Xu et al., 2016). For example, Liu et al. (2013) showed that, in the Black Soil Region in China, infilling EGs with soil from surrounding areas resulted in a 2% reduction of crop productivity for every 1 cm of soil removed in these areas. Tang et al. (2013), in the same area of study, concluded that the cyclical process of erosion and infilling of (ephemeral) gullies caused soil degradation through a reduction in the nutrient contents (e.g. organic matter, total and available nitrogen, etc.). Conversely, Xu et al. (2016) showed the primary role of EGE as a main driver of soil physical degradation (e.g. silt, aggregate stability, etc.) by comparing soil samples from different EGs depth profiles with samples from unaffected areas in the central region of the Loess Plateau in China.

In general, there is currently no standard or convention for the assessment of soil quality (Bone et al., 2014) and, in particular, there is no clear information on what main soil indicators should be monitored over time to effectively assess the effects of both EGE and refilling tillage practice on soil degradation (i.e. studied soil function). Selecting soil properties which may serve as suitable indicators of changes in soil quality in erosion-affected ecosystems may help assess the impact of the EGE-elimination process on land degradation in quantitative terms. As far as they are responsive, reliable, representative, and easy to measure and interpret, and related to specific soil functions soil attributes are widely used in soil survey programs as well as in studies monitoring changes in the soil fertility/quality status (Burns et al., 2006; Doran and Parkin, 1996; Erkossa et al., 2007). The information provided by indicators can be integrated into a soil quality index (SQI) through a flexible model (Mandal et al., 2008), capable of explaining the status of soil degradation in a specific region and for a determined management goal; according to a minimum data set (MDS) of indicators using different soil measurements (Diack and Stott, 2001; Mukherjee and Lal, 2014). Therefore, the SQI is a value which scores the fitness of the selected indicators from a MDS to assess one (or more) studied soil functions: a high fitness result in a great SQI value (Armenise et al., 2013). In addition, SQI is a sensitive indicator for perceiving the evolution of soil health and quality as conditioned by external agents such as soil (ephemeral) erosion or tillage practice (Xu et al., 2006). Furthermore, spatial variability of these indicators – and therefore the values of SQI – in nearby areas to the gully channel can show the real extent of the negative effect of the above-mentioned erosion-removal process when compared with undisturbed areas (i.e. areas not subjected to erosion and infilling process) in the same fields.

From the authors' knowledge, the effects of erosion and infilling of EGs on the physicochemical soil quality and its spatial variation in relation to the area of influence of the erosive channel, or to the areas commonly used to fill it, have not been evaluated in Mediterranean agricultural environments. The importance of Sicily in southern Italy as one of the most important grain areas under Mediterranean climatic conditions has been reported in a large number of works (e.g. Amato et al., 2013; Ruisi et al., 2014). More specifically, in the central part of Sicily, the process of EGE and subsequent removal by conventional tillage are frequent to occur in agricultural landscapes with steep slopes during the rainy season (e.g. Capra et al., 2012; Capra and La Spada, 2015). The process may constitute a severe threat to the maintenance of the soil fertility status and the protection of soil as a finite environmental resource. Needless to say, in these highly vulnerable croplands a comprehensive set of physical and chemical soil variables can help assess the soil fertility status and, in a dynamic perspective, provide an estimate of changes in soil quality in response to EGE. Since many of these soil physical (e.g. texture, bulk density) and chemical (pH, electrical conductivity, total organic C, total N, inorganic N-forms, available-P, carbonate content) properties have recently been used to monitor the soil degradation process in large EG-prone areas (Tang et al., 2013; Xu et al., 2016), we focused on these so as to propose a soil quality index for quantitative assessments in 5 catchments representative of Mediterranean arable lands located in Southern Italy and affected by the combined processes of EGE and lateral infilling practice. Specific aims of this study were therefore: (1) to identify what physical and chemical properties primarily linked to nutrient dynamics could be efficiently used as basic attributes in the framework for evaluating site-specific changes in soil quality; (2) to increase the understanding of the impact of EGE combined with lateral infilling practice in soil productivity; and (3) to provide recommendations on more appropriate practices to adopt for EG restoration.