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Soil genetic erosion: New conceptual developments in soil security

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ABSTRACT

In the last decades, in some Mediterranean areas, pedodiversity decreased mainly due to pedotechnique application in large-scale farming that transformed original soils into Anthrosols. Supporting the consideration that soils can be considered as living systems, the original concept of 'soil genetic erosion' is re-proposed. Data, extrapolated and modeled from a Soil Information System in a study case representative of a Mediterranean landscape, predicted that most of the soil types would disappear in few years leading to a decrease of the soil diversity and originating soil genetic erosion. This circumstance is intentionally here told in form of a story where the fairy tale characters are some soils facing extinction in the landscape. Soil genetic erosion could result in a negative impact on the environment because it reduces the soil's security through a drastic reduction of the soil ecosystem services with a decrease of the immaterial benefit for the environment. The conviction that soils, as well as animals and plants, are living bodies, and pedodiversity is equally important as biodiversity in maintaining sustainability and ecosystem services, might truly attract the attention of the public opinion. Besides, focussing more on the soil economic dimension and strengthening the assignation of 'economic value' to the soil ecosystem services, also politicians and administrators could increase their interest in soil security.

1. Introduction

The knowledge of the historical evolution of the agricultural landscapes and the evaluation of the long-term role played by soil erosion in landscape evolution and socio-economic dynamics is one of the main research topics in soil science at worldwide level (Boardman, 2007; Dotterweich, 2013). Recently, in Yangling, Shaanxi, China, from September 12th to 16th 2018, the World Association of Soil and Water Conservation (WASWAC), the Desert Net International (DNI) and the Chinese Society of Soil and Water Conservation, organized a "Global Soil Erosion Research Forum 2018" (GSERF-2018). The main aim of the GSERF-2018 was to "*shed new light on soil erosion and ecological conservation*" in particular agricultural landscapes all over the world. Shedding new light on soil erosion can be seen as a sort of exercise in identifying the new challenges faced by soil science at the beginning of the third millennium. Such exercise can be absolutely rewarding if we consider that the history of soil science highlights that any discipline, and soil science in particular, has tended to leap forward most significantly when a crucial event or important societal pressure drive researchers to focus the attention on a specific challenge (Baveye, 2015; Dazzi, Lo Papa, & Poma, 2013). For instance, the 1930s Dust Bowl Drought on the US Great Plains was an environmental crisis with failure of agricultural systems, landscape denudation and elevated atmospheric dust loads (Bolles, Forman, & Sweeney, 2017; Hu, Torres-Alavez, & Van Den Broeke, 2018). The public concern associated with the Dust Bowl has led to significant research efforts, to the launch of several soil conservation programs and to the creation of the US Soil Conservation Service (Baveye et al., 2011; Sylvester & Rupley, 2012).

In the second half of the nineteenth century, the increase of a general consciousness of soil degradation being a reality in Europe determined an equal increase of the need for the development of a meaningful soil conservation policy in Europe (Panagos et al., 2016). In response to this increased consciousness, on 4 November 1988, 18 experts from 10 European countries (Dazzi et al., 2019a), founded the "European Society for Soil Conservation" (ESSC) in Leuven (Belgium). In the same period, several science academies in most European countries dedicated significant attention to this topic and researchers began to be able to identify key challenges for soil erosion through collective reflection. In the second half of the last century, particularly in Europe, hundreds and hundreds of

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researchers started to develop research programs aiming at increasing the knowledge on soil erosion: from continental scale to the soil aggregate scale, all the aspects concerning soil erosion in its widest meaning were deeply investigated. Thousands and thousands of research papers were published in any kind of scientific and popular journals. This trend continues. A web search of the terms “soil erosion” in Scopus and Web of Science, considering the last 5 years (2014–2018), returns respectively 12,178 and 11,201 results. This means that in the last 5 years, every month on average, more than 203 or more than 186 scientific papers (respectively according to Scopus and Web of Science) have been published on research topics labeled as “soil erosion”, (Table 1).

In the scientific literature, thousands of research papers and hundreds of books, have taken into account all the aspects related to soil erosion and its relation with soil features, land use change, climatic factors, anthropic influence (Nearing, Xie, Liu, & Ye, 2017; Uri, 2000), even the influence on the societal behaviour, on migration and on the social conflicts (Bedunah & Angerer, 2012). Thus, in shedding new light on soil erosion and ecological conservation, and in identifying the key challenges faced by soil erosion in specific agricultural landscapes, particularly those characterized by pedotechnique applications to increase the farmer's income, we should stress a somewhat original concept of erosion that can be defined “soil genetic erosion” (Lo Papa, Palermo, & Dazzi, 2013). This concept follows from the consideration that, as well as animals and plants, “*soils are in essence, living organic bodies that lie between, and demonstrate the integration of, the physical and biological realms in the landscape*” (Dingwall, Weighell, & Badman, 2005, p. 44). When in a particular ecosystem the number of the *living organic bodies* (the living beings) decreases, the biodiversity declines and, consequently, may diminish the human wellbeing linked to the services that particular ecosystem can provide for people (MEA, 2005). The decrease of the biological systems is at the base of the great problem of the erosion of the genetic resources (FAO, 2010, pp. 184–185; van de Wouw, Kik, van Hintum, van Treuren, & Visser, 2009). The “genetic erosion” concept was proposed in a conservation/management perspective to indicate the huge loss of useful genes and genotype combinations, often driven by anthropogenic environmental change (Bijlsma & Loeschcke, 2012) and is considered “*a major threat to biodiversity because it can reduce fitness and ultimately contribute to the extinction of populations*” (Leroy et al., 2018). Such concept, applied to the soils considered as individuals (soil types) of a population (soilscape), by extension lead to the concept of soil genetic erosion. This concept was proposed in a conservation/management perspective to indicate the huge loss of useful soil types in the soilscape, often driven by anthropogenic environmental change (Dazzi, 1995), and is considered one of the major threat to pedodiversity because it can reduce soil quality and ultimately contribute to the extinction of soil types (Dazzi & Lo Papa, 2013).

All the living systems - humans, plants, animals - are extremely diverse one another and, during their genesis and evolution obey to the laws of thermodynamic (Addiscott, 1995). As far as concern the soils, the slow transformation of the parent rock (a not living system) into soil (a living system) (FAO, 2015; Jones Sauer, 2016), driven by the laws of thermodynamics, leads to a decrease of the entropy (Smeck, Runge, & MacIntosh, 1983) and consequently, to an increase of the order in the soil system. This allows for a significant diversity of the soils that deeply influences the soil security, defined as the maintenance and improvement of the capacity of the world's soil resources to produce food, fibre and freshwater, contribute to energy and climate sustainability, and maintain the biodiversity and the overall protection of the ecosystem (Koch, McBratney, & Lal, 2012; Koch, McBratney, Adams, Field, & Hill, 2013; McBratney, Field, & Koch, 2014). Soil security, in turn, relies on the soil's ecosystem services, i.e. the benefit that people derive from soils (Dominati, Patterson, & Mackay, 2010; MEA, 2005). Following Lal (2010), we can affirm that whereas there is a decline in the soil quality, a concomitant decline in the ability of the soil to provide ecosystem services and goods appears. Therefore, a secure soil, i.e. a “good” soil (Carter et al., 1997; McBratney et al., 2014), is required for a secure supply of food and fibre, of clean freshwater and for contributing to the overall protection of the ecosystem. When in a particular ecotone several different natural soils are replaced by one anthropogenic soil, this decreases the soil diversity, also soils security and the overall soils ability to provide ecosystem services. In this case, we refer to the “soil genetic erosion”.

Starting from these reflections, that are not completely new, because we proposed this topic years ago (Dazzi, 1995), our main goal is to stimulate a wide scientific audience on a particular soil threat that is not widely known. This topic might be considered as a speculative or a philosophic one. Anyway, it has a strong impact on the overall quality of the soilscape where it happens and undermines the soilscape variability and security.

In details, the aims of this paper are i) to illustrate the concept of “soil genetic erosion” using a particular study case and ii) to stress that it represents an original environmental challenge for soil scientists, as such threat might be even equally dangerous than the well-known soil erosion because decrease the overall quality of a soilscape. To achieve these purposes we have chosen to move some parts of this paper a little bit aside from the “traditional” scientific framework and language, telling the unlucky story of a Mollisol and its fellow-soils, all regarded as they were fairy tales, living associated in a Mediterranean study area (Lo Papa & Dazzi, 2013; Lo Papa, Palermo, & Dazzi, 2011).

2. The unlucky story of a Mollisol and its fellow-soils

Thousands of years ago, in a large island in the middle of the Mediterranean Sea (Fig. 1), kissed by the sun and wetted by winter sporadic rainfalls, a quite dark and loamy Mollisol was born (Fig. 2a).

Its parents, particularly the rock, a marly limestone from Pleistocene, and the vegetation, several types of steppe grasses, were very proud of him. During the centuries slowly and continuously the Mollisol developed, wetted by the rain, dried by the sun and fed by the decayed roots and by the organic residues of the herbaceous plants gently swung by the wind. The Mollisol was grown big and strong and was very proud to show a nice mollic epipédon underlain by a cambic endopédon. It shared the same soilscape mainly with an Alfisol (Fig. 2b) and an Inceptisol (Fig. 2c). The Alfisol as well was very proud to show a wonderful argillic endopédon and the same did the Inceptisol with its cambic horizon. In this soilscape, also a Vertisol and an Entisol occupied smaller areas. All together, and in a different way, these soils contributed in the overall protection and quality of the environment where they lived, producing food, fibre and contributing in regulating the water cycle

Table 1
Number of scientific publications returned by searching ‘soil’ AND ‘erosion’ in ‘Article Title’, ‘Abstract’ and ‘Keywords’ in Scopus and Web of Science (verified on May 13th, 2019).

Year	Scopus	Web of Science
2014	2175	1728
2015	2259	2186
2016	2418	2307
2017	2616	2364
2018	2710	2616
TOTAL	**12,178**	**11,201**

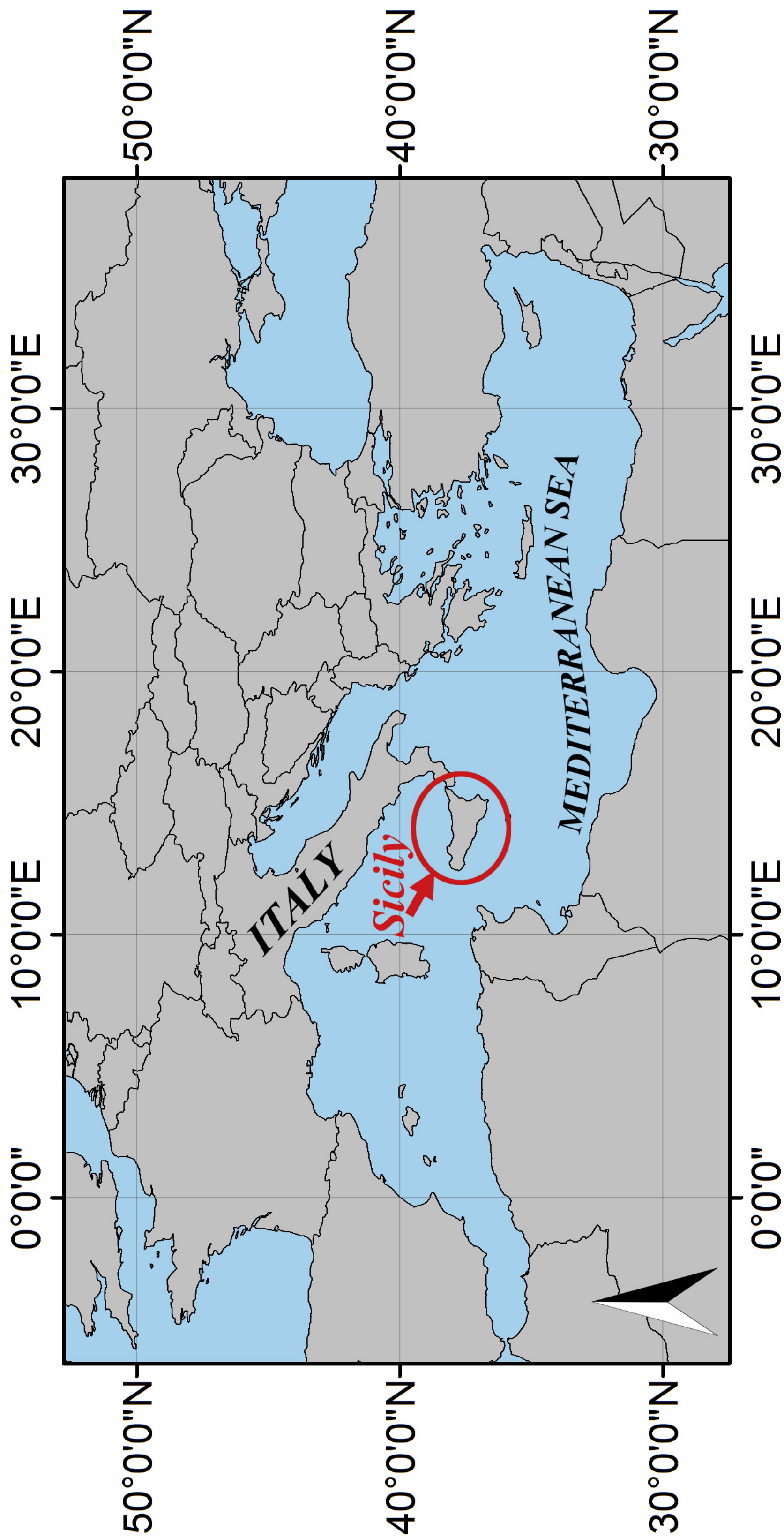

Fig. 1. Location of the area.

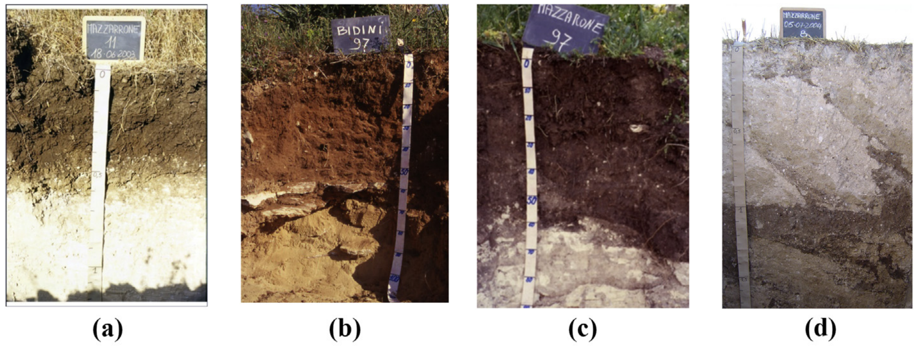

Fig. 2. The Mollisol (a) and its fellow-soils Alfisol (b); Inceptisol (c); the Anthrosol (d) showing oblique horizons and heterogeneous material generated by pedotechnique.

and in maintaining the quality of the water, the climate stability and the biodiversity. In a few words, they exhibit good security sustained by strong ability in producing ecosystem services.

The happy life of the Mollisol of its fellow-soils unexpectedly changed during the 1960s, when a farmer living in a village at a stone's throw from it, decided to grow table grapes. When the roots of the grape started to spread inside the marly limestone below the mollic horizon, the plant surprisingly, increased the quantity and quality of the yield. The farmer was very happy to sell the surplus of the production and to get a good income. The awareness perceived by the farmer that it was possible to increase his income and consequently the lifestyle of his family, was the beginning of an unlucky fate for the Mollisol and for its fellow-soils.

When the farmer realized that the calcium carbonate in the marly limestone of the subsoil has had a positive effect on the quality of the grapes because of calcium increase the crunchiness of the fruits, they started to plough the Mollisol up to a depth of 100 cm with a mouldboard one-furrow plough. The aim was to increase the amount of calcium carbonate in the whole profile. When the hard iron-spade of a plough penetrate deeply in it, the Mollisol feels its essence completely devastated. Some of its parts, in particular peds belonging to the mollic horizon, survived inside such devastated soil, continuing to function inside a new soil shape. Soon, however, the farmer realized also that the lighter soil colour on the surface, increasing the soil albedo, determined a positive effect on the content of sugars in the fruits.

This awareness was a sort of death sentence for the Mollisol. It was covered with a thick layer of human transported marly limestone material (HTM) that, with a mouldboard one-furrow plough was completely and deeply mixing to the whole soil. In this way, the Mollisol was completely destroyed and transformed into an anthropogenic soil (Fig. 2d) (Dazzi & Lo Papa, 2016; Lo Papa, Vittori Antisari, Vianello, & Dazzi, 2018). The same did the farmers in the surrounding areas when they, observing their neighbour, realized that it was possible to increase the income by cultivating table grapes on anthropogenic soils (Lo Verde, 1995).

All around the village and even beyond the village-limits, all the farmers year after year, started to plant table grapes. The widespread expansion of the vineyards was achieved through very deep ploughing, excavation, land leveling and trenching. Trucks were used to spread large amounts of calcareous materials over the soilscape to reshape the morphology and improve the quality of the grapes.

In origin (Lo Papa et al., 2011) and following the Soil Taxonomy system (ST), the soilscape inside the administrative limits of the village (in total 3457 ha), was characterized by five soil Orders (Soil Survey Staff, 2014): Mollisols, Alfisols and Inceptisols were prevalent; Entisols and Vertisols were less diffused. These soil Orders, subdivided into 15 ST subgroups (Fig. 3) testify the great pedodiversity of the soilscape.

The transformation of the soilscape and the land use change due to the spread of the table grape cultivation started in the 1970s. Land use change led to a considerable increase in the per-capita income of the local farmers that, in comparison with the traditional crops that were grown on the original soils (mainly durum wheat, almond and olive trees), in the 1990s reached even 400% (Dazzi & Monteleone, 2007; Lo Verde, 1995) and, nowadays, more than 7000% (Dazzi, Galati, Crescimanno, & Lo Papa, 2019b).

3. Evolution of the soilscape over time

The soilscape changes in the period 1955–2010, has been previously monitored mapping soils of the study area in the years 1955, 1966, 1987, 1997, 2000, 2010 by Lo Papa et al., 2011; 2013. Besides, a stochastic simulation was been used to predict the evolution of the soilscape in 2050 (Lo Papa et al., 2011). Data of the soil pattern changes over time and the projections in 2050 (predicted) suggests that almost certainly the Calcic Haploxerolls, the Typic Haploxerolls and the Pachic Haploxerolls will disappear because they will be entirely transformed in anthropogenic soils. The Typic Calcixerepts, the Vertic Haploxerepts, the Typic Haploxeralfs and the Inceptic Haploxeralfs surely will be reduced to a few hectares for the same reason (Fig. 4).

Vertisols, as well as Entisols (Lithic and Vertic), due to their intrinsic features will remain untouched, while Anthrosols (the human-made soils) will monopolize the soilscape almost completely. Therefore, as far as happens for the biological systems (animal and plant populations) where anthropic actions decrease the presence of individuals originating "genetic erosion", in our case of soilscape evolution, there is a decrease in soil types or diversity, i.e. "soil genetic erosion".

4. Consequences of the soil genetic erosion

4.1. *Influence of the soil genetic erosion on other soil threats*

In the study area, the enormous anthropic pressure to generate anthropogenic soils suitable for table grape cultivation has led to some other soil threats. Soils, so drastically ploughed and transformed, remain defenseless to erosion as well as it happens in many other vine-growing areas of the Mediterranean regions (Corti et al., 2011; Prosdocimi, Cerdà, & Tarolli, 2016). Next to these aspects are those linked to the massive use of pesticides and of plastic films that determine, directly or indirectly, soil pollution (Lo Papa & Dazzi, 2013). Plastic films are used to cover vineyards with the purpose to postpone in December the harvest-time and getting a

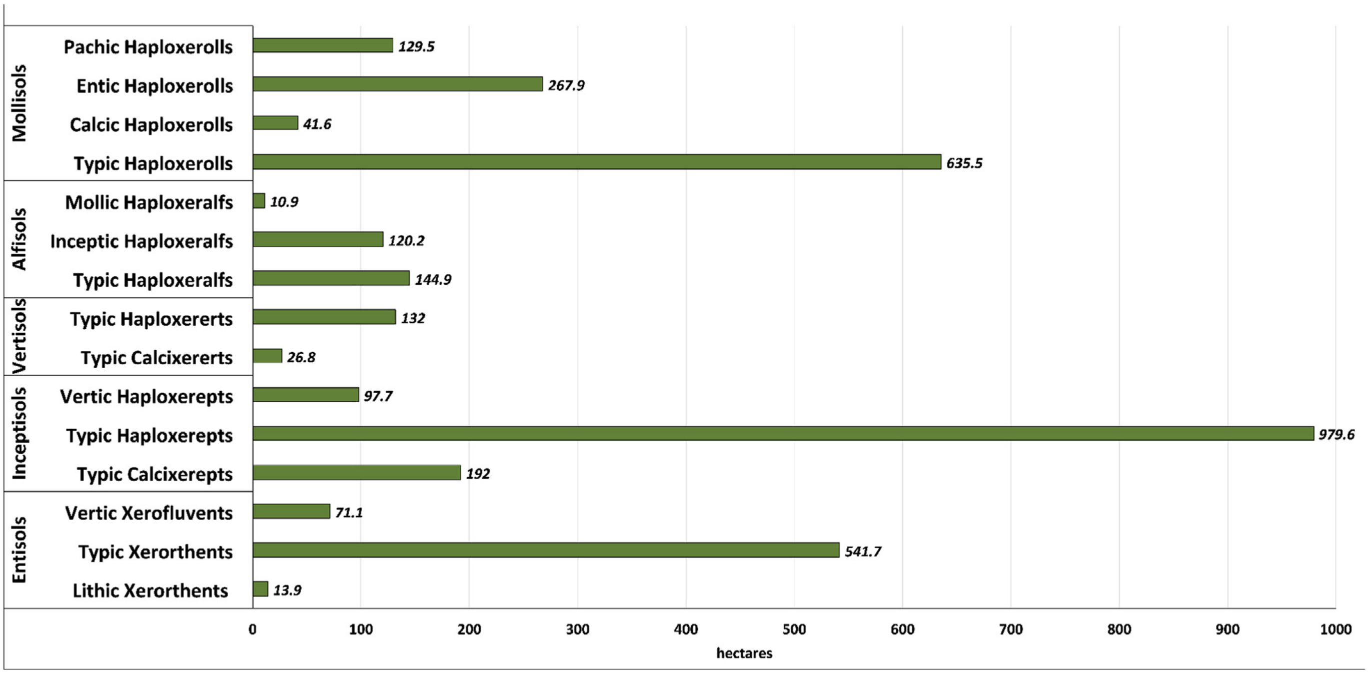

Fig. 3. Diffusion of the original soils that characterized the soilscape before the 1960s. They were classified at subgroup level according to the ST (Soil Survey Staff, 2014).

higher selling price. These plastic films are used only for two years and even if the law imposes the recycling of the plastic, this is often abandoned in the environment, burned together with the stocks and releases toxic compounds. Moreover, to maintain grapes on the plants until December, farmers use massive quantities of pesticides (xenobiotic agents and heavy metals) which could determine soil pollution.

4.2. Soil genetic erosion and soil security

Lal (2010) affirms that if soil quality declines, also the ability of the soil to provide ecosystem services and goods declines. Therefore, for a secure supply of food and fibre, of clean freshwater and for contributing to the overall protection of the ecosystem, in short, to guarantee soil security, we need a secure soil i.e. a “good quality” soil (Carter et al., 1997; McBratney et al., 2014).

To determine if the soils of our study area have to be considered “good/secure” or “bad/insecure”, we have analysed the dimension of capability, condition, capital, connectivity and codification as defined by McBratney et al. (2014) and recently by Field (2017). In doing this, we have referred these dimensions to the benchmark soil of each soil order using soil data from previous papers (Table 2).

Capability is a term originally used to define the ability of a soil to produce without deteriorating over a long period of time (Klingebiel & Montgomery, 1961) and recently (Bouma et al., 2017), the intrinsic capacity of a soil to contribute to ecosystem services. The application of the Land Capability Classification System highlights the land classes, subclasses and units assigned. From a capability point of view, the best soils are Mollisols, while the worst are Anthrosols.

Soil condition can be deduced by considering the main soil quality properties i.e. a set of indicators (generally a group of physical and chemical soil parameters) that are linked to a soil function and that all-in-all allow to define a soil as a “good/secure” or a “bad/insecure” soil (Doran & Zeiss, 2000). Soil condition can be defined using the Soil Potential Index ((SPI – a parametric system based on the Storie Index modified by Mancini and Ronchetti (1968) for the Italian soilscape)) that is based on the evaluation of a set of physical and chemical soil parameters. Mollisols got the highest score (85), while Anthrosols the lowest (28).

The “natural” capital of the soil is determined by the compositional state of the soil system, i. e. the stocks of material contained in a soil (Robinson, Lebron, & Vereecken, 2009). These stocks embrace a number of indicators (Robinson et al., 2009) that, all told, are the same that underpin the concept of soil fertility and that allow for the evaluation of the soil natural capital (Costanza et al., 1997). It is excellent for Mollisols, decreases for the other soils and is poor for Anthrosols.

Connectivity concerns the awareness developed by society on the soil's role in the environmental equilibrium and brings the people in a social dimension (McBratney et al., 2014). The numerous farmers that have transformed so heavily the soilscape of our study area are driven only by the willingness of increasing their income and not by the social imperative of protecting the environment. Thousands and thousands of hectares with good or fairly good natural soils were covered with a deep HTM made by marly limestone and thousands of hectares of Anthropogenic soils were tailored to grow table grapes under tunnel-shaped greenhouses (Dazzi & Lo Papa, 2016). From the farmers' point of view, the Anthrosol is considered the “good/secure” soil, while the natural soils are the “bad/insecure” ones. Anyway, from a pedo-Logic point of view (i.e. applying a rational and scientific knowledge coupled with a logic pedo-thought), things are the *vice versa*.

Codification is related to all those initiatives and policies that underpin accurate land management and correct soil conservation. The Seventh Environment Action Programme (EU, 2014) aims to ensure that, in the coming years, the land is managed sustainably in the European Union, the soil is adequately protected and the remediation of contaminated sites is well underway. It also commits the EU and its Member States to increase efforts to reduce soil erosion, increase soil organic matter contents and remediate contaminated sites. We believe this is not enough as such commitments must be followed by effective and positive actions to preserve the multi-functionality of soil and its role in

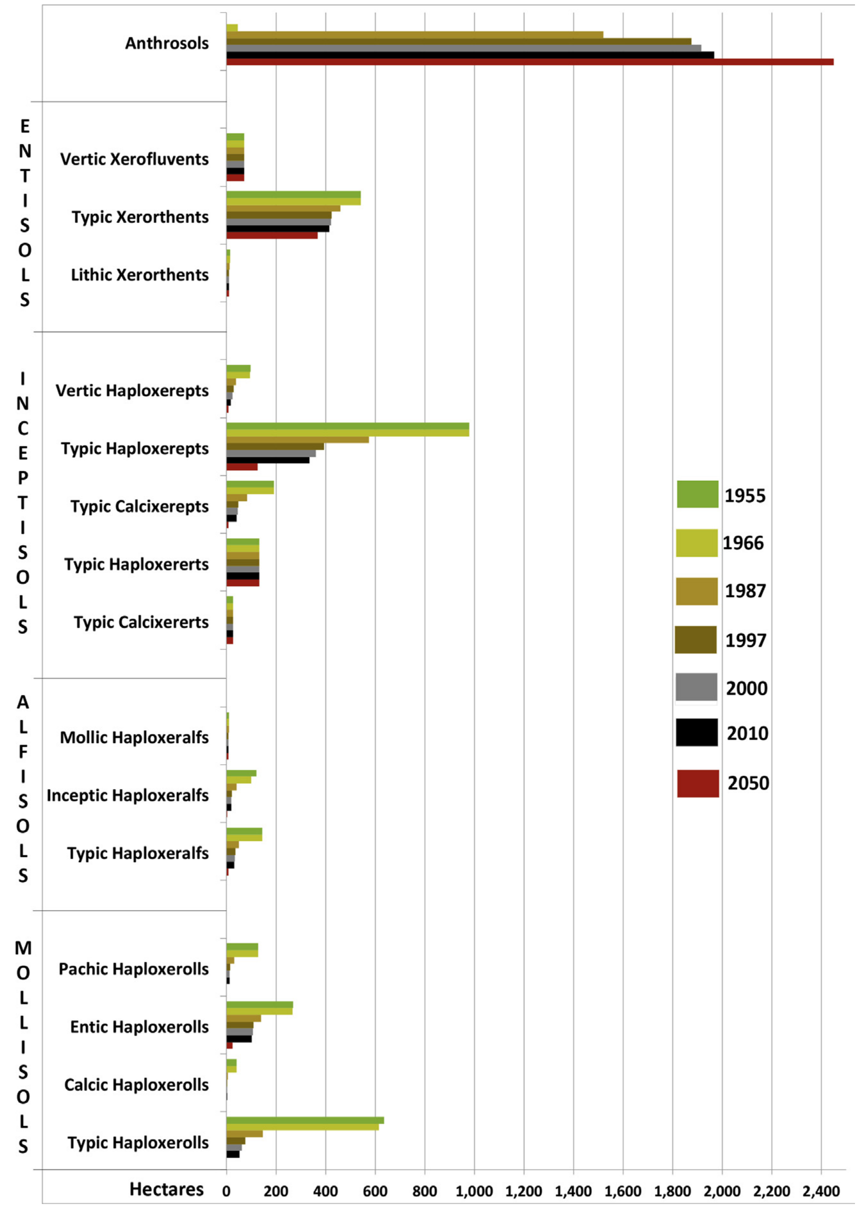

Fig. 4. Soil pattern change in the landscape from 1955 to 2050. Particularly evident is: the decrease of Mollisols and of its fellow-soils and the tremendous increase of the Anthrosols.

Table 2
Evaluation of the soil security dimensions for each soil order of the study area.

Dimension	Mollisols	Vertisols	Alfisols	Inceptisols	Entisols	Anthrosols
Capability	I	II s $_4$	II s $_3$	II s $_{1-3}$	III s $_{1-2}$	IV s $_4$
Condition	Score 85	Score 68	Score 47	Score 44	Score 31	Score 28
Capital	Excellent	Good	Sufficient	Sufficient	Fair	Poor
Connectivity	Bad	Bad	Bad	Bad	Bad	Good
Codification	Poor	Poor	Poor	Poor	Poor	Poor

environmental equilibria, and in human health and welfare. As stressed by Bouma, van Altvorst, Eweg, Smeets, and van Latesteijn (2011) the problem is not to decide what is right or wrong but what is better or worse for the whole society. At the moment soil codification can be considered poor.

Going back to soil security issues, many authors stressed that they rely on the soil's ecosystem services (Dominati et al., 2010; MEA, 2005). Trying to compare the soil security and, by extension, the ecosystem services provided by the soilscape before the anthropic influence (mainly Mollisols, Alfisols and Inceptisols), with the ecosystem services provided by the anthropogenic soils, we might conclude that, reasonably, all the ecosystem services provided by the natural soils could be positively evaluated. On the contrary, the majority of the ecosystem services provided by the anthropogenic soils should be negatively evaluated (probably except those concerning "new soil formation and evolution" and "biomass production", MEA, 2005). Consequently, the "soil genetic erosion" could result in a negative impact on the environment, because it reduces the overall soil security through the reduction of the soil ecosystem services. Moreover, it could increase some traditional soil threats such as erosion and pollution.

Soil scientists have long been talking about the importance of soil in meeting our growing demands for food, water and energy, as well as in providing ecosystem services that affect climate change, human health and biodiversity.

The inter-relationships between soils and social issues – such as food safety, sustainability, climate change, carbon sequestration, greenhouse gas emissions, degradation by erosion, loss of organic matter and nutrients – are fundamental elements of the soil security concept (Bouma & McBratney, 2013; McBratney et al., 2014) that relies on the soil's ecosystem services. In order to ensure that soil security and ecosystem services are not merely abstractions, we believe mandatory to consider soils not only as natural resources but also as media producing economy (Dominati et al., 2010; Jónsson & Davíðsdóttir, 2016). Such a concept should be aligned with the need for policy to help to ensure soil security by encouraging sound and sustainable soil management practices. With the beginning of the Anthropocene, we started to live in a global village where "*money makes the world go round*" (Derviş, 2012; Kander & Ebb, 1972) and economic production and dissemination of knowledge play key roles in the creation of wealth. Such reflexions lead to consider soils onto a broader and more appropriate scale, one that better reflects its economic importance. The same devoted to the soil in China 4000 years BP, in Egypt 3000 years BP, in Mexico 500 BP and in Germany about 100 years ago (Bednarski, 2012; Fackler, 1924; Jones et al., 2013; Landon, 1991; Williams, 2006) where soils through their qualities, were used as a base for taxation purposes.

Thus, to contrast soil genetic erosion, to ensure soil security and to preserve soil ecosystem services in an era characterized by the ever-prevalent influence of humans on soil and a continuous lack of consideration from politicians and administrators concerning the importance of soils in the environmental equilibria, we need a new vision of the soil aimed at stressing the "economic value" of the services offered by the soils (Dominati et al., 2010; Jónsson & Davíðsdóttir, 2016). This would require an up-to-date and effective motto for soil: "*Soil is a natural resource that must be preserved to drive positively the ecosystem services and the economy of the social systems*". Such catchphrase focussing the attention also on the soil monetary dimension might truly attract the attention of politicians and administrators.

5. Conclusions

The original concept of 'soil genetic erosion' is here re-proposed and stressed to stimulate the interest of the scientific community on an ever-increasing soil threat affecting especially the Mediterranean areas. Such degradation process, as equally dangerous as soil erosion and other soil threats, causes a loss in pedodiversity, provokes disequilibrium in soil ecosystem services and affects seriously the soil security.

Considering soils as living organisms, elevated to the dignity of individuals (soil types) of populations (soilscapes), a study case, where soils have been transformed over time by large-scale farming, is here shown in a thought–provoking way, trying to provide arguments and concepts in a less orthodox scientific language, in order to raise a greater appeal to the general public and to shake the people opinion.

Intensive large-scale farming, that requires the application of pedotechniques for soil transformation, was the driving force leading to soil genetic erosion. Behind this farming lays the opportunity of generating huge profits in agriculture and the highest food production. The unbalanced perception of soils as a means of production for the generation of capitals undermines the soil security.

The concept of soil security already embraces the 'economic dimension'. Probably stressing the "monetary value" of all ecosystem services provided by the soils could truly attract the attention of politicians and administrators.

The vision of soils as living bodies and the awareness of the soil genetic erosion as severe threat could attract the general public.

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