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The "genetic erosion" of the soil ecosystem

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Abstract

This paper takes into consideration the influence of human activities on the loss of pedodiversity in a Mediterranean area due to large scale farming. In particular it examines the quantitative and qualitative soil changes in a period of 53 years (from 1955 to 2008) evaluating the loss of soil diversity at soil subgroups level of the USDA Soil Taxonomy system. The following indices were used: richness; Shannon's diversity index; Simpson diversity index; Shannon's evenness index; Simpson's evenness index. In this case study, considering what we observed in time, the human intervention in soil transformation could increase the diversity in the landscape in an initial phase, but forwarding by large scale farming the result is a huge loss of pedodiversity in time, as diversity indices remarkably have shown. This analysis enabled identification of disappeared soil types, with their unique history of formation. In our opinion this strongly reflects a sort of "genetic erosion" of the soil types, resulting in a substantial weakening of the whole pedo-ecosystem.

Key Words: Pedodiversity, Anthropogenic soil, Soil genetic erosion

1 Introduction

The awareness that soils are very important dynamic components of terrestrial ecosystems has risen slowly mainly because they have historically viewed as economic resources by governments and private interests and investors (Binkley, 2006).

The soil state-forming equation, firstly enunciated by Shaw in 1932 and subsequently developed by Jenny in 1941 (Schaetzl and Anderson, 2007), suggests that a soil body is a product of the integrated effects of climate, organisms, relief, and parent material all operating over time. Jenny's equation in terms of ecosystems, becomes: $l, s, v, a = f(L_o \cdot P_x, t)$: i. e. the property of the ecosystem "l", soil "s", vegetation "v", and animals "a", are function of the system early state "L_0", of the flux potentials "P_x" and the past time "t" (Amundson and Jenny, 1991). This means that the unique different soils occurring in different areas reflect a unique combination of soil forming factors. Bockheim (2005) reinforced such theory and illustrated also the parallelism of the basic concepts between bioecological and pedological systems: pedological equivalents include soil geography (biogeography), intergrades at the subgroup level in Soil Taxonomy (convergence), soil associations (metapopulations), endangered soil taxa (endangered species), and pedodiversity (biodiversity). Pedodiversity has received considerable recent interest, especially as peculiar aspect of biodiversity and has been assessed by several authors by applying diversity indices used in ecology (Guo et al., 2003; Ibáñez et al., 1995; Ibáñez et al., 1998; Phillips, 2001; Dazzi, 2002; Saldana and Ibáñez, 2004; McBratney and Minasny, 2007).

During the 1990's the concept of pedodiversity started to be diffused in the scientific literature (Ibañez et al., 1990) and the decrement of the soil diversity in space and time has been seen as a sort of "*genetic erosion*" affecting soil ecosystems (Dazzi, 1995) meaning that different soil types face gradual or drastic reduction or complete loss of their unique "*genetic features*", particularly due to human activity. In biology the anthropic activities are often a cause of genetic erosion that leads animal and plant species to extinction; in the same way, in pedology anthropic activities may lead different soil types to extinction. Many times are the best soils that are lost forever (Dazzi and

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Lo Papa, 2013).

The most productive soils in agriculture are often very suitable for residential and industrial building and their favorable characteristics attract intensive development and investments (Lopez et al., 2001; Elvidge et al., 2004). Amundson et al., (2003) reported that 4.5% of the soils in the USA are threatened by substantial loss or complete extinction due to agriculture overexploitation and urbanization. Same situation occurs in China, where it was shown that residential, commercial and industrial development, known as "urban sprawl," is consuming soil resources, threatening mainly the best agricultural soils (Zhang et al., 2007).

In many areas of the world, several soil types are probably on the verge of being completely sealed by urban sprawl. There are also examples which are less striking but just as dangerous for maintaining the soilscape pedodiversity, such as the case of anthropogenic soils created using specific pedotechniques for some land uses in large scale farming (Dazzi et al., 2008; Lo Papa et al., 2011). As a rule, the anthropogenic soil-forming processes relating to agricultural use, influence soil properties over hundreds of years. In the case of soils affected by incisive pedotecniques in large scale farming, the anthropogenic processes can be extremely fast-acting (Bryant and Galbraith, 2003; Dazzi and Monteleone, 2007). Over the last few years, such anthropogenic processes have transformed many soils in traditional vine-growing areas of Mediterranean Europe, where the capital earned from vineyard cultivation is substantial (Dazzi et al., 2004; Pla Sentis et al., 2004; Coulouma et al., 2006; Costantini and Barbetti 2008). Besides, this phenomenon is also concerning new vine-growing areas outside Europe (Fairbanks et al., 2004). Transformations of different natural soils in anthropogenic ones in large scale farming by incisive pedotechniques and the consequent decrease of the soil diversity can be considered as a sort of "genetic erosion" of the soil system. In fact, each soil loses its own natural genetic configuration that allows to distinguish soils as well as it happens for the living systems: plants and animals.

Following such considerations and taking into account a case study, in this paper we wish to highlight *i*) the human influence in modifying the variability of soil types due to the application of pedotechniques in large scale farming and *ii*) how anthropogenic activities on several different soils can be effectively considered as "genetic erosion" of the soil resource.

2 Materials and methods

To fit our aims, we took into consideration the soilscape evolution of Mazzarrone area from 1955 to 2008. Mazzarrone is a small town in South-East of Sicily, Italy (37.0849°N, 14.5590°E), with a typical Mediterranean climate (average annual rainfall: 452 mm; average annual temperature: 18℃). Its administrative territory covers an area of 3,457 hectares ranging from 115 m to 335 m a.s.l. From a litho-morphological point of view, it is characterized by a fairly flat morphology and by rock outcrops that, dating back to the Pleistocene and Holocene, are made by clay and sandy-clays, fossiliferous yellowish sandstones, fine quartzitic sands, weakly cemented sands, lacustrin and fluvial deposits and marly limestones.

These environmental features have driven the development of soils with a quite different level of evolution (Entisols, Inceptisols, Vertisols, Alfisols and Mollisols). At present, the majority of soil types shows very strong anthropogenic features due to the pedotechniques used to generate soils suitable for vineyards (Dazzi and Monteleone, 2007). In Mazzarrone area the most of farms are vine growing (Palermo et al., 2009), favoured also by the Mediterranean features of the climate.

To explore the human influence on soil diversity loss, we started from the findings of a sociological and ethnological essay (Lo Verde, 1995) coupled with soil data from unpublished soil surveys carried out from 1964 to 2008. These last were supported by aerial photo interpretation and land use maps in the years 1955, 1966, 1987, 1997, 2000, 2008 and were validated in field. The legend of every soil map shows the spatial distribution of the soils classified at subgroup level according to Soil Taxonomy (Soil Survey Staff, 2010). A Geographic Information System (GIS) technology was used to manage and analyse land use and soil maps and their relationship and evolution in time.

The pedodiversity in the study area was assessed in different years using the soil map showing the original soilscape before any human intervention (1955), and soil maps in 1966, 1987, 1997, 2000 and 2008. To estimate the changes of pedodiversity we used the following indices:

i) Richness (s), is the number of different soil types, corresponding to the number of soil to a specific taxonomic system (i.e., soil subgroups of Soil Taxonomy).

ii) Shannon's Diversity Index,

$$*SHDI = -\sum_{i=1}^{n} S_i \ln S_i$$

is a popular measure of diversity in community ecology, applied here to soilscapes. *SHDI* ranges > 0 with no limits and equals to 0 when the soilscape contains only one class (i. e., no diversity).

iii) Simpson Diversity Index,

$$*SIDI = 1 - \sum_{i=1}^{n} S_i^2$$

is another diversity measure in community ecology. It is less sensitive to the presence of rare classes and has an interpretation that is much more intuitive than Shannon's index. It ranges from 0 to 1 (0 when the soilscape contains only one class, i. e., no diversity).

iv) Shannon's Evenness Index,

$$*SHEI \frac{-\sum_{i=1}^{n} S_i \times \ln S_i}{\ln n}$$

it expresses conceptually the complement of dominance. An even distribution of area among class types results in maximum evenness. *SHEI* ranges between 0 and 1: it is 0 when the soilscape contains only one class (i. e., no diversity) and approaches 0 when the distribution of area among the different classes becomes uneven (i. e., dominated only by one class type). *SHEI* equals 1 when distribution of area among classes is perfectly even (i. e., proportional abundances are the same).

v) Simpson's Evenness Index,

$$*SIEI = \frac{1 - \sum_{i=1}^{n} S_i^2}{1 - \frac{1}{n}}$$

it expresses conceptually the complement of dominance. An even distribution of area among class types results in maximum evenness. *SIEI* ranges between 0 and 1 and, like Shannon's Evenness Index, it is 0 when the soilscape contains only one class (i. e., no diversity) and assumes value 1 when distribution of area among classes is perfectly even (i. e., proportional abundances are the same).

All the pedodiversity indices were compute in GIS environment using the Fragstats tool (Mc Garigal et al., 2002).

3 Results and discussion

Many times, in ageless agricultural systems, human activity as a soil forming factor can be traced back to agricultural land management. In our case, the farmers' empirical observation that on calcaric soils vineyard found a very suitable environment, was the motivating factor of a large land use change and soilscape modification that involved almost all the Mazzarrone area.

Such large landscape transformation was determined by the expansion of the vineyards and was achieved by means of pedotechniques consisting in very deep ploughing, earth movement and land levelling. Human action was so intense (and still today is) that most of the soils, constituting originally the soilscape of Mazzarrone, have totally disappeared and have been replaced by soils that have to be considered anthropic. These soils were classified as Miscic Geofragmexerants, (Dazzi and Monteleone 2007) or Geomiscic Anthrosols (Dazzi et al., 2009), proposals following the Soil Taxonomy (Soil Survey Staff, 2010) and the WRB (IUSS Working Group WRB, 2006) respectively.

Spatial statistics and aerial photos show that in the 1960's, most of the study area, once covered by oak and maquis, was mostly used for arable farming, olive groves and almond groves (Gentile, 1968) grown on the soils that originally formed the Mazzarrone soilscape. Such soils were represented by 5 soil orders: Entisols, Inceptisols, Vertisols, Alfisols and Mollisols, subdivided in 6 suborders, 8 great groups and 15 subgroups (Table 1). In particular,

* Where S is the portion of soilscape occupied by a soil class i, and n is the total number of soil classes forming the soilscape.

Soils in the more stable morphology (flat or very gentle slope), were Inceptic, Mollic and Typic Haploxeralfs i. e. moderately deep soils, with a rather shallow and not very thick argillic horizon that, depending on the morphology and mainly on the plant cover, might be overlaid by a mollic epipedon. The less stable morphologies (gentle or moderately steep slopes), showed Vertic and Typic Haploxerepts, Typic Calcixerepts and Calcic, Entic, Pachic and Typic Haploxerolls, i. e. soils in general moderately deep with a cambic or a calcic horizon overlaid, in several cases, by a mollic epipedon. The steeper morphologies and the slope side of the stream valleys were, and in some cases still are, characterized by Lithic and Typic Xerorthents, more or less shallow soils exposed to erosion. The bottom valleys till today are characterized by Vertic Xerofluvents (deep soils strongly influenced by the features of the parent material) and by Typic Haploxererts and Typic Calcixererts (very deep and clayey soils).

Table 1 Transformation (in hectares and %) of pre-existent soils into anthropogenic soils till to 2008

Original soils[1]	Miscic Geofragmexerants[2]	%	Urban Sealing[3]	%	Reservoir Sealing[4]	%	Total	%
Entisols								
Lithic Xerorthents	3	21.4	0	0.0	0	0.0	3	21.4
Typic Xerorthents	118	21.8	4	0.7	5	0.9	127	23.4
Vertic Xerofluvents	0	0.0	0	0.0	0	0.0	0	0.0
Inceptisols								
Typic Calcixerepts	145	75.5	4	2.1	2	1.0	151	78.6
Typic Haploxerepts	565	57.7	43	4.4	36	3.7	644	65.7
Vertic Haploxerepts	76	77.6	0	0.0	4	4.1	80	81.6
Vertisols								
Typic Calcixererts	0	0.0	0	0.0	0	0.0	0	0.0
Typic Haploxererts	0	0.0	0	0.0	0	0.0	0	0.0
Alfisols								
Inceptic Haploxeralfs	99	82.5	0	0.0	3	2.5	102	85.0
Mollic Haploxeralfs	2	18.2	0	0.0	0	0.0	2	18.2
Typic Haploxeralfs	106	73.1	1	0.7	7	4.8	114	78.6
Mollisols								
Calcic Haploxerolls	37	88.1	1	2.4	1	2.4	39	92.9
Entic Haploxerolls	150	56.0	9	3.4	7	2.6	166	61.9
Pachic Haploxerolls	109	84.5	1	0.8	7	5.4	117	90.7
Typic Haploxerolls	557	87.7	7	1.1	19	3.0	583	91.8
Total	1967		70		91		2128	

1 Before large scale farming.
2 Anthropogenic soils originated by large scale farming as classified by Dazzi and Monteleone (2007).
3 Soil sealing by housing and roads construction.
4 Soil sealing by water reservoirs construction.

In the Mazzarrone area, land use change and the soilscape reshaping started in a very visible way during the 1970's. The economic explosion was during the 1980's, when cultivation started to be converted everywhere producing not only a large land use change and a huge modification of the landscape but also a conspicuous increase in the per-capita income that, according to the findings of a sociological survey (Lo Verde, 1995), reached even 400%. In that period, vineyards replaced arable land, almond-yards, olive groves and natural grazing with a consistent and evident transformation of the landscape through the application of pedotechniques consisting mainly in covering deeply ploughed soils with a 50 – 70 cm deep marly limestone stratum that was incorporated to the soils with another one deep ploughing. As previously highlighted, vineyards are almost the only land use in Mazzarrone (Fig. 1).

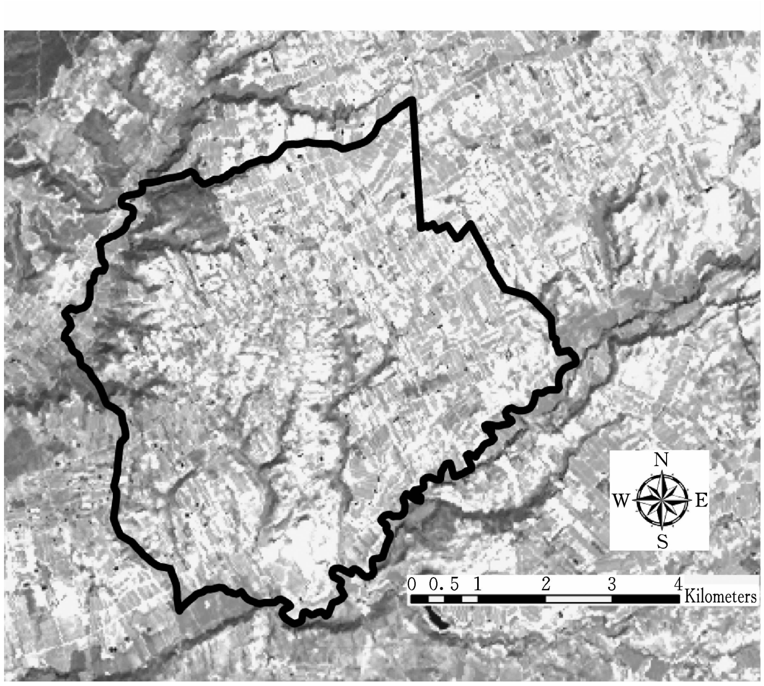

Fig. 1 The Mazzarrone landscape in 1999(All the areas in cyan are anthropogenic soils.)
(Landsat 7 ETM + -29/09/1999 - band composition 7 - 4 - 2)

The analysis of the transformation of the original soils in anthropic ones as well as the soil consumption and sealing due to urban expansion and construction of reservoirs(Table 1) highlights that the most transformed soils belong to the Mollisols followed by Inceptisols and Alfisols and that most of Mollisols, Inceptisols and Alfisols subgroups almost completely disappeared due to the transformation in anthropogenic soils or by sealing.

Fig. 2 shows the changes in soil patterns from 1955 to 2008. The dataset was used to calculate pedodiversity indices. Fig. 3 shows the pedodiversity indices measured at subgroup level in the Mazzarrone area during the observed period of time. As well as concerns the soil subgroup, Mazzarrone area showed a richness value(s) equal to 15 in 1955 and 1966 and to 16 in the following years. All the adopted diversity indices with spatial dimension, Shannon and Simpson, show a slight increment of pedodiversity from 1955 to 1966 and a rapid decreasing trend till to 2008. Evenness indices show the same decreasing trend in time.

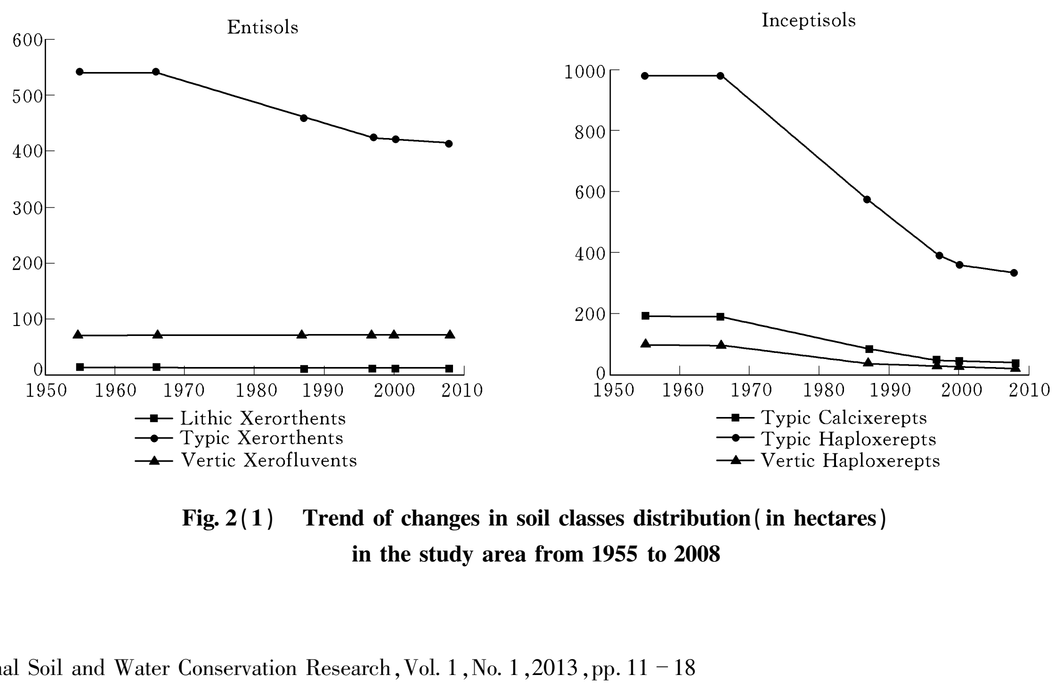

Fig. 2(1) Trend of changes in soil classes distribution(in hectares)
in the study area from 1955 to 2008

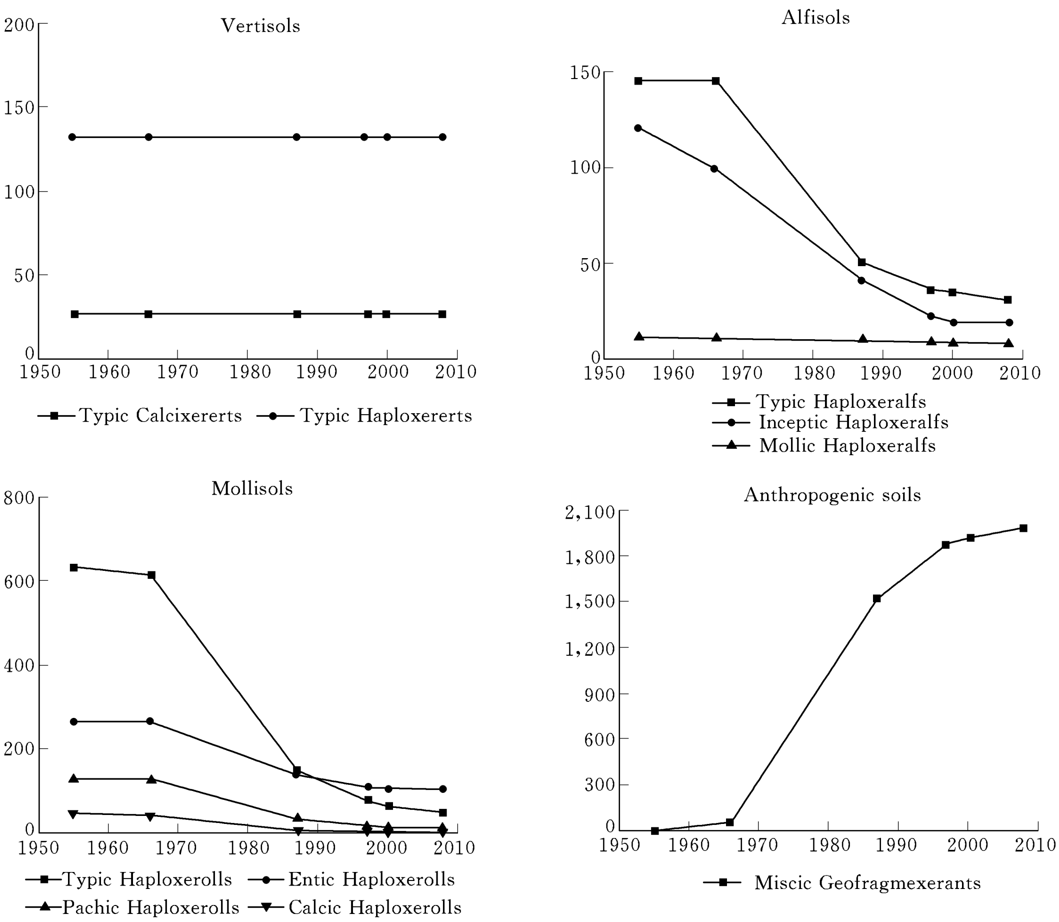

Fig. 2(2) Trend of changes in soil classes distribution(in hectares) in the study area from 1955 to 2008

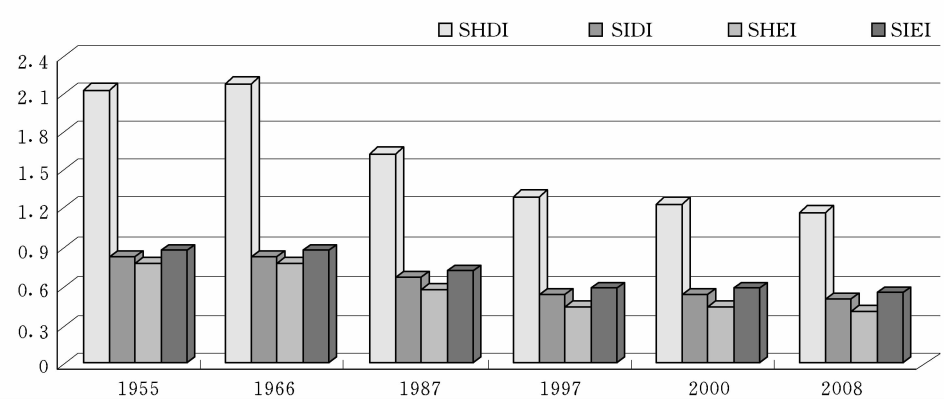

Fig. 3 Pedodiversity measures at soil subgroup level in the Mazzarrone area in time

SHDI = Shannon's Diversity, SIDI = Simpson's Diversity, SHEI = Shannon's Evenness, SIEI = Simpson's Evenness.

We note, particularly looking at the Simpson index, a relatively high value of evenness(0.9) indicating a very high distribution of area among classes: therefore there is an even proportional contribution of each soil class in the system and there is not a dominance of any soil into the soilscape. Interpreting the diversity in the light of the evenness trend, we can affirm that the Mazzarrone soilscape was in past a well-balanced system, where soil classes are divided almost equitably. Soil transformation by large scale farming breaks the equilibrium of Mazzarrone creating in time a dominant soil class which makes uniform the soilscape and undermines, from a taxonomic point of view, the soil diversity.

Considering what we observed in time, we can surely affirm that the human intervention in soil transformation could lead the diversity in the landscape in an initial phase, but forwarding by large scale farming, the evident result is a huge loss of diversity in time, as our indices remarkably have shown.

4 Conclusions

Soils are described as the foundation of life and the unique structures and characteristics of various soils make them key support systems to the diversity of life on earth (Gibbons, 1984; Huston, 1993; Singer and Warkentin, 1996). The potential negative effect of various human activities on soils has been an important topic of concern for soil science in these last decades. As far as concerns the case study we considered, all the morphologies that didn't limit the use of mechanical means to set new vineyards, including also areas steeper, have been involved in an intense "entisolization" process (Fanning and Fanning, 1989), that caused a remarkable reduction of pedodiversity.

Most of the land in Mazzarrone was exposed to excessive anthropic pressure which, in few years, has led to a considerable improvement in the economic conditions of the local population as well as to the disappearance of unemployment. But, these social and economic benefits were obtained at the expenses of the soils and pedodiversity. Farmers, in most cases of large farming, aim mainly at increasing economic profits and higher incomes overexploiting natural resources and particularly the soil, ignoring that each soil has his own evolutive configuration and his own activity that contributes to the natural functioning of the environment. In such situations the soil resilience, namely the soil ability to counteract stress and alterations (Szabolcs, 1994) is very low and in some cases cancelled, because soil exogenous energy fluxes, after human actions, overcome largely all the critical thresholds. In our opinion, what happened in Mazzarrone is a sort of soil "genetic erosion", as it happens in biology when plant and animal species are lost, resulting in a substantial weakening of the whole ecosystem.

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