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Soil Carbon Storage and Sequestration on Pianosa Island

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Abstract

The soils of Pianosa, substantially homogeneous with regard to their parent material and pedological evolution, have different agronomic histories. However, the effects of agricultural activities on soil and vegetation are still very recognizable, even if there has been no human activity for seven years. Representative areas characterized by different land use were selected to give an overview of the soil of the mains ecosystems. Soil ecosystems were characterized on the basis of their chemical, physical and biological properties. The total organic and inorganic C content of the island soils was calculated and a map of distribution of soil organic carbon was drawn up. This was done in order to obtain a basis for the assessment of the dynamics of organic C as influenced by human activities, and the relationships between ecosystems and C sequestration. Physical and chemical analysis showed the impact of human activity on soil fertility. Modifications of soil structure were observed and a noteworthy reduction of soil organic C and N contents was found both in the abandoned arable areas and in the permanent pasture land compared to the macchia ecosystem, considered as the natural starting condition. However, the microbial properties showed a good biochemical recovery of the soil previously subjected to cultivation, providing interesting information both on CO_2 exchanges and on resilience of the island soil ecosystems.

Introduction

Soil represents the major C pool of terrestrial ecosystem (1500 Pg C). On a global scale, the soil C amount is about three times the C content of the terrestrial biomass (560 Pg C) and about twice that of the atmosphere (720 Pg C). Therefore the pedosphere, through many interactive mechanisms with the atmosphere and biosphere, plays an important role in the global C cycle (Lal *et al*. 1998).

As atmospheric CO_2 concentrations increase, quantifying and predicting the capacity of C sequestration in soils become increasingly important. The Kyoto conference, challenging the industrialized world to reduce greenhouse emissions, provided an impetus to discern ecosystem C source/sink relationships. The goal of terrestrial C sequestration is to develop management practices that favour the formation of stable forms of C. Forest ecosystems represent 60% of the terrestrial carbon budget (Lal *et al*. 1995), which suggests that forest management and forest disturbances may have a strong effect on C cycling (Evans *et al*. 2001). In the Mediterranean environment soils under macchia and woodland can play an important role as a sink of C. The identification of methods to evaluate and monitor the variations of soil C reserves in these ecosystems will be increasingly paramount.

Soil organic matter (SOM) affects all soil functions and it is one of the main factors influencing the C cycle. SOM originates from C fixed by plants and released to the soil in the form of leaf and wood litter, roots, and root exudates. It consists of a heterogeneous mixture of interacting polymers (Sposito 1989), whose turnover rates range from days to millennia (Trumbore 1997; Stevenson & Cole 1999). The rate of soil C turnover depends on the nature of litter inputs (Stump & Binkley 1992) and microbial activity (McGill 1996), but also on the soil physical environment. This in turn is determined by temperature (Rustad & Fernandez, 1998), particle-size and mineralogy (Baldock *et al*. 1992; Feller & Beare 1997), pH and oxygen availability (Bunnell *et al*. 1977), aggregate formation and destruction (Tisdall & Oades 1982; Oades 1984), as well as human activities and in particular by agricultural management.

Pianosa abandonment, after an intensive use of the soil, provides a good opportunity to study the effect of human activities on soil natural ecosystems in the Mediterranean environment and to assess the degree of soil resilience after different land uses.

The aims of this work were i) to characterize soil ecosystems on the basis of their chemical, physical and biological properties, ii) to calculate the total organic C content of the island soils and iii) to draw up a map of soil organic carbon in order to obtain a basis for the assessment of the dynamics of organic C as influenced by human activities and the relationship between ecosystems and C sequestration.

Materials and Methods

The soils of the island, formed on Pliocene limestones and sandstones, are characterized by a strong skeletal component and by a shallow depth. The mean soil depth was less than 30 cm for all the ecosystems. These soils, characterized by a sandy loamy texture (Table 1), can be ascribed to the Leptosols group according to the World Reference Base for Soil Resources (ISSS-ISRIC-FAO 1998).

Table 1. Texture of soil samples collected in the representative areas (± standard deviation).

	Clay	Loam	Sand
	g kg^{-1}		
Macchia	**133** ± 46	**241** ± 58	**626** ± 88
Permanent pasture	**161** ± 39	**247** ± 51	**592** ± 62
Arable fields	**162** ± 57	**236** ± 49	**602** ± 109

Different ecosystems were found on the island, mostly related to differing land uses, and for the purpose of this study three main ecosystem types were selected. These corresponded to the following representative vegetation systems: natural Mediterranean macchia, abandoned arable fields (in rotation with pasture and fallow), and permanent pasture land. In fact, two different types of grazing were found on the island: pastures in rotation with other crops and standing pastures not tilled in the last fifty years. The latter, identified also by the analysis of maps of the past crop rotations and the memories of previous island inhabitants, was prevalent in the western part of the island, the less intensively cultivated area, probably because far from the village. The vegetation of these areas was approximately similar to those of pastures in rotation, but the soil showed significant differences from the tilled ones. In the present work all macchia areas (with more or less evolved vegetation) were grouped together, because of the similarity of their soils.

114 soil samples were collected following a regular net (300x300m) covering the entire island. Each sampling site was georeferenced and individualized in the field by a GPS. In the more representative sites other samples (20 in total) were collected as further controls.

Since the soils were very shallow and with not well defined horizons, the samples were taken by using a Holland auger, sampling the entire soil profile from the surface to the parent material. The samples were successively thoroughly mixed and a subsample was used for the analysis. Each sampling site was ascribed to one of the three ecosystems on the basis of its vegetation and agronomic history.

Soil density was determined in the field by excavating a large hole and determining its volume by lining the hole with a thin plastic sheet and measuring the quantity of water required to fill the hole.

The material obtained from the excavation was used in the laboratory to determine the water content, the volume and the weight of the soil skeleton (>2 mm) and the wet and dry densities of the <2 mm soil fraction.

Laboratory analyses were performed in order to characterize the physical, chemical and biochemical properties of the soil samples.

Chemical and physical analyses

Chemical analyses were performed on 0-2 mm air dried soil fractions.

Texture, pH and cation exchange capacity (CEC) were determined by standard methods (S.I.S.S. 1985).

Carbon and nitrogen content was determined using a CHNS Analyzer Carlo Erba NA 1500. Because of the calcareous nature of the soils, the procedure reported by Santi *et al*. (2005) was used to distinguish the organic from the inorganic C. Two aliquots of each sample, in two replicates, were analysed by dry combustion i) the first without treatment, to assess the total C and N content, ii) the other after treatment with excess of HCl, for carbonate removal, to assess only the organic C content.

Total content of Zn, Cu, Pb and Ni was measured after nitric-perchloric digestion using an atomic absorption spectrometer (Perkin-Elmer 3030, equipped with a background corrector).

Total porosity and pore size distribution (PSD) were determined by the Hg intrusion method on undisturbed soil aggregates (1-2 cm in size) (Guidi *et al*. 1985) to evaluate the structural soil properties and their interaction with organic matter.

Soil organic C map and total C content

A georeferenced map of soil organic C distribution in the ecosystems was produced on the basis of the data obtained by C analysis (Fig. 4).

The analysis of airborne photos of the island (source Regione Toscana Government, Italy) and further field examina-

Table 2. Some chemical properties of soil samples collected in the representative areas (± standard deviation).

	Organic N	Organic C	C/N	pH	CEC
	g kg^{-1}	g kg^{-1}		(H_2O)	cmol (+) kg^{-1}
Macchia	**4,46** ± 0,10	**58,4** ± 0,4	**13,1**	**7,5** ± 0,3	**26,8** ± 5,0
Permanent pasture	**3,13** ± 0,18	**35,8** ± 0,5	**11,4**	**7,8** ± 0,2	**26,2** ± 3,3
Arable fields	**2,01** ± 0,12	**22,5** ± 0,3	**11,2**	**7,9** ± 0,2	**21,6** ± 5,3

Table 3. Heavy metal content of soil samples collected in the representative areas (± standard deviation).

	Zn	Cu	Ni	Pb	Cd
	mg kg^{-1}				
Macchia	**65,0** ± 8,7	**19,4** ± 1,3	**49,4** ± 5,6	**35,2** ± 5,2	**0,08** ± 0,01
Permanent pasture	**41,9** ± 4,3	**16,9** ± 3,1	**45,0** ± 5,4	**30,8** ± 2,4	**0,09** ± 0,01
Arable fields	**34,4** ± 3,8	**17,5** ± 2,4	**44,4** ± 2,4	**47,5** ± 3,5	**0,08** ± 0,01

Table 4. Microbial biomass and respiration of soil samples collected in the representative areas (± standard deviation).

	C biomass	CO_2
	(mg C kg^{-1} dry soil)	(mg CO_2 kg^{-1} dry soil)
Macchia	**119,5** ± 22,0	**243** ± 33
Permanent pasture	**58,2** ± 12,4	**180** ± 23
Arable fields	**65,0** ± 9,1	**171** ± 32

tions allowed to redefine in detail the ecosystem boundaries, which were then reported on a topographic map.

Total soil organic and inorganic C content of the entire island was calculated on the basis of soil depths, bulk densities, surface areas graphically calculated on the map, and the mean of soil C content values calculated for each ecosystem (Tab. 5).

Biological analysis

Soil samples used for respiration and biomass carbon determination were pre-incubated. The 0-2 mm soil fraction was wetted up to reach 60% of the water-holding capacity (WHC) and stored under controlled conditions. Soil respiration was determined according to Isermeyer (1952), estimating the CO_2 evolved during soil incubation in a closed system. Four replicates of each soil sample (25 g of each, oven dry-weight equivalent) were rewetted to their 33 kPa water tension and incubated at 30°C. CO_2 evolution was measured after 7 days incubation. Average values are given in mg CO_2-C/kg of soil oven dry-weight equivalent, and were used as basal respiration values, for each soil. Microbial biomass was determined according to the fumigation extraction method described by Vance *et al*. (1987).

Results and Discussion

Figures 1, 2 and 3 show the PSD relative to the three main ecosystems.

In terms of total porosity, macchia ecosystems presented the highest value of pore volume, 322 mm^3 g^{-1}, whereas soils under permanent pasture and under cultivation showed a lower presence of pores of a diameter greater than 30 μm (20% less than the soils under macchia). These pores are important both for water movement and biological activities, and their reduction is a typical consequence of the trampling and of the losses of organic C as a consequence of human management.

Soil organic C content resulted notably affected by human activity, as shown by Table 2. Considering the macchia as the natural starting condition, the extensive cultivation reduced the C content by more than 60% and the N content by around 55%, while the pasture induced a reduction of around 40% for the C and 30% for the N.

With regard to the total content of heavy metals such as Zn, Cu, Ni, Pb and Cd, no significant differences were detected among the three different soil ecosystems (Tab. 3), indicating a low effect of human activity on these elements. Only the Zn concentration resulted higher in the macchia, mainly due to its higher organic matter content and to the higher CEC of this soil ecosystem (Tab. 2). The values, however, fall within the range of the typical concentrations of Tuscan soils.

Soil biomass and microbial respiration analysis showed the highest concentration of the C microbial biomass in the macchia, characterized by a high organic matter content, while in the pasture land and in the cultivated areas the values were around half (49% and 55% respectively).

The higher accumulation of organic matter in the topsoil of the macchia probably maintains better conditions of structure (see Hg intrusion data), humidity and temperature, favouring the development of microbial biomass.

Soil samples collected in the permanent pasture and in the arable fields showed statistically comparable concentrations of C microbial biomass, in spite of the different organic matter content (Tab. 4). In the macchia a large emission of CO_2 agreed with the greatest presence of microbial biomass in the soil and it was meaningfully higher (of around 40%) than the pasture lands and the cultivated areas.

The substantial comparability of the results related to the presence and the activity of the microbial biomass in the

Table 5. Total soil organic and inorganic C in the three ecosystems and in the entire island.

	Surface areas	Soil depth	Organic C	Inorganic C	Total organic C in the Ecosystem	Total inorganic C in the Ecosystem
	ha	cm*	T ha^{-1}	T ha^{-1}	t	t
Macchia (46)	**394,8**	**16,5**	**67,0**	**20,9**	**26.451,6**	**8.251,3**
Permanent pasture (12)	**96,7**	**15,0**	**25,6**	**20,3**	**2.457,5**	**1.963,0**
Arable fields (53)	**439,7**	**15,4**	**42,3**	**79,5**	**18.599,3**	**34.956,2**
Rocks & buildings (3)	**93,0**	**-**	**-**	**-**	**-**	**-**
Totals	**1.024,2**				**47.526,4**	**45.170,2**

Figure 1. PSD of soil aggregates from macchia ecosystem.

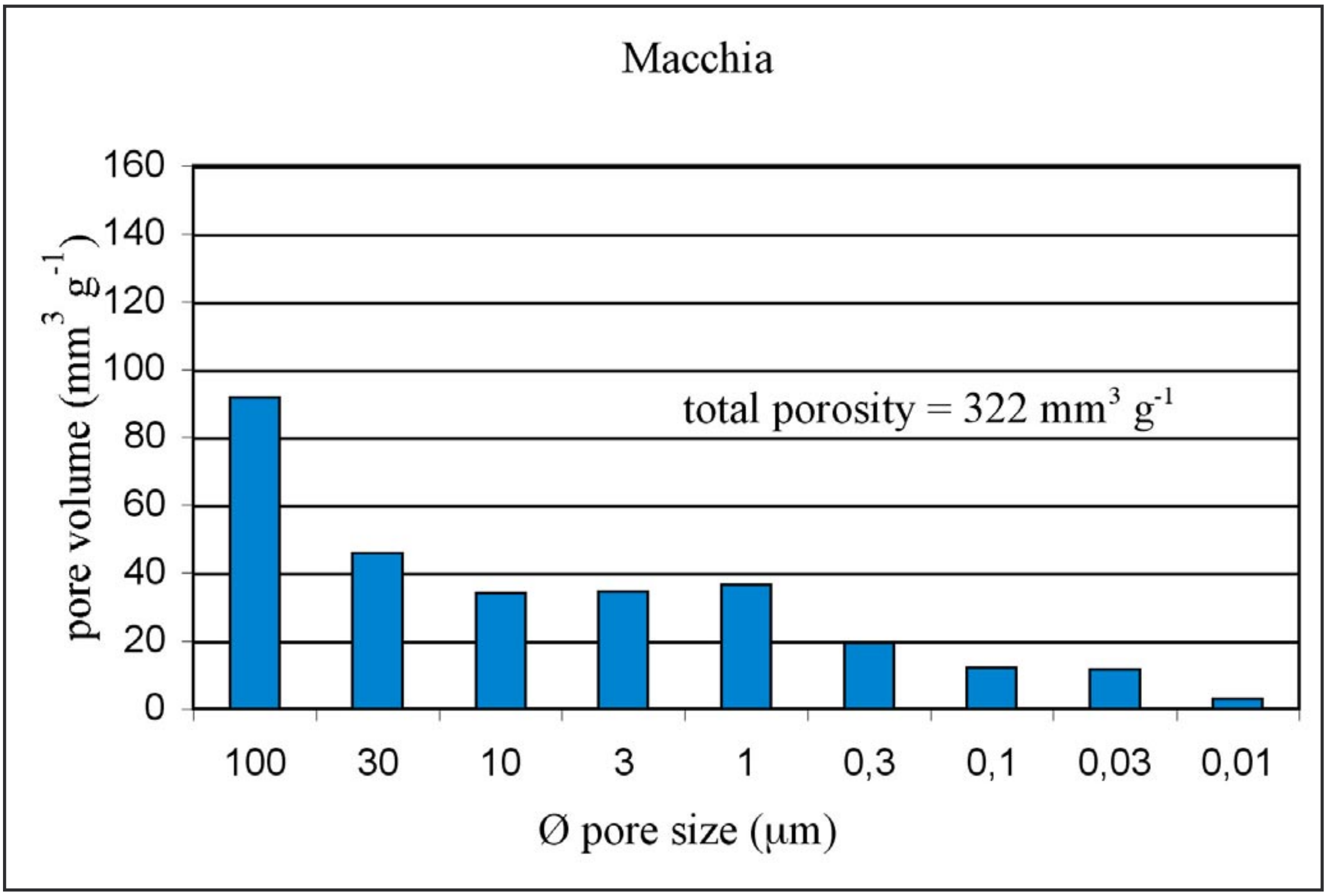


Figure 2. PSD of soil aggregates from permanent pasture ecosystem.

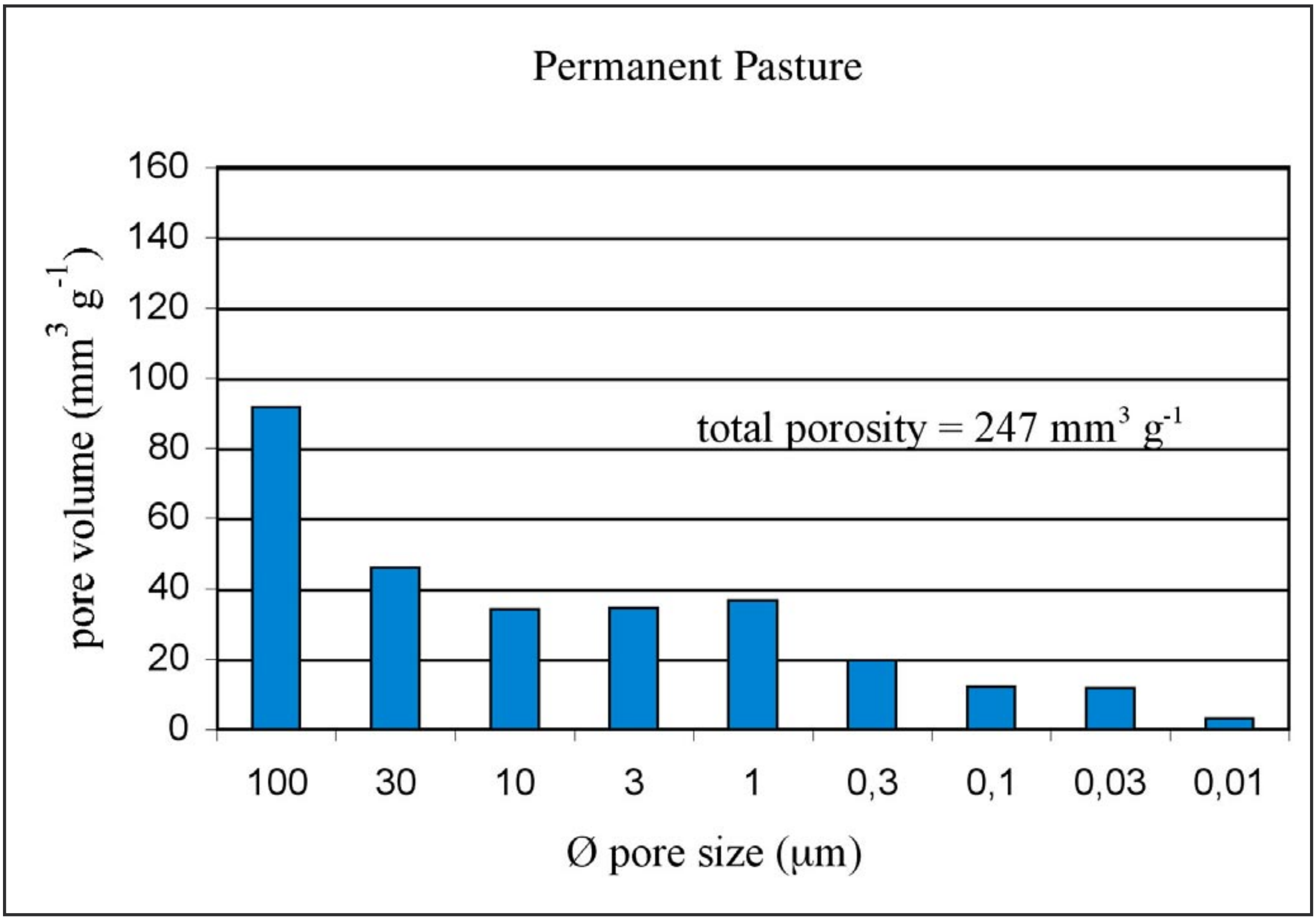
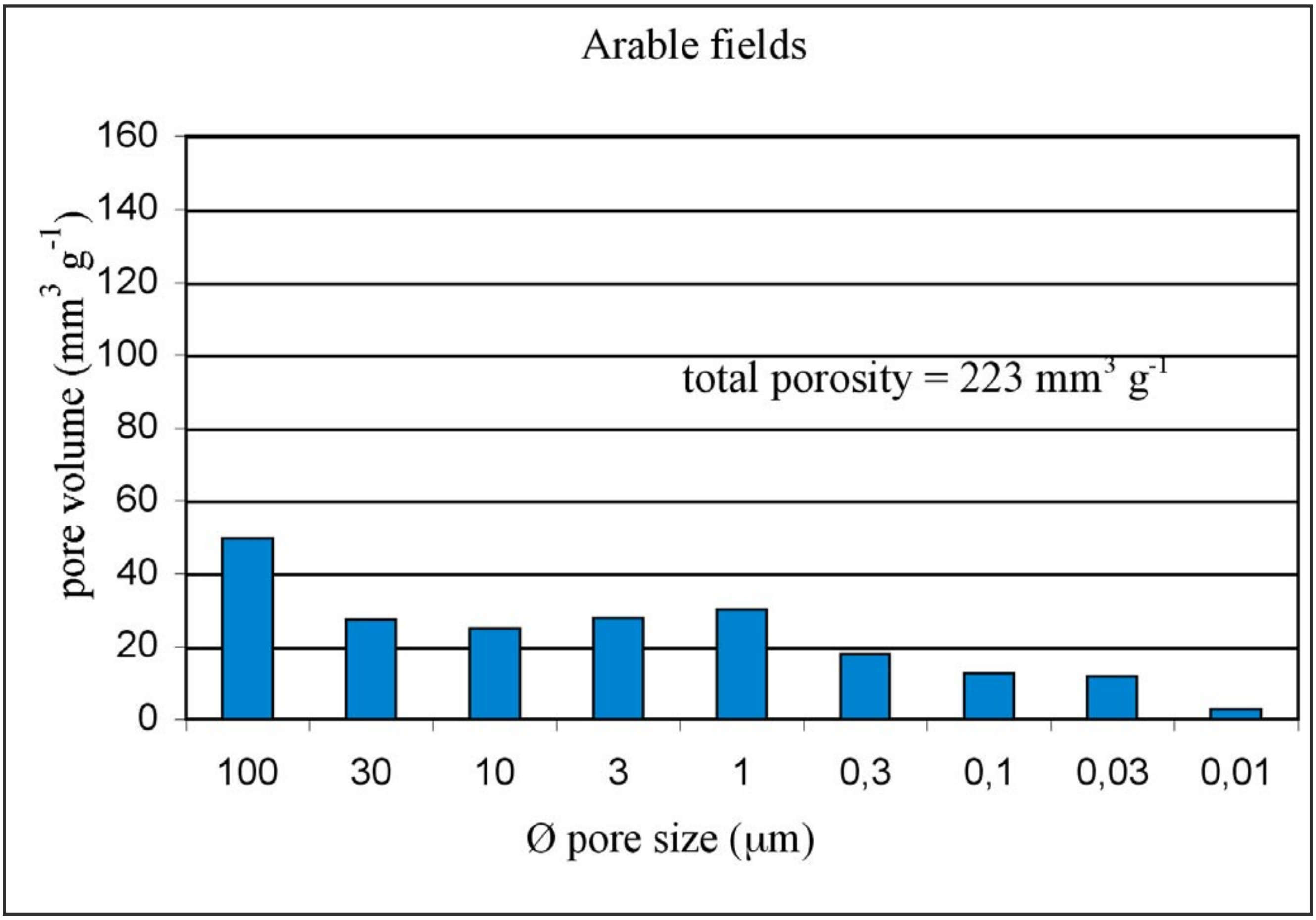


Figure 3. PSD of soil aggregates from arable fields ecosystem.



permanent pasture and in the arable soils might suggest that after the abandonment of these soils a process of biochemical recovery started. In fact this process might have lead to a similarity in the biological activity of the two soils, despite their different use and C content.

The map in Figure 4 shows the distribution of the soil C content in the island. The areas with the lower C content correspond to the extensively cultivated areas, whereas the highest values of the C content are in the macchia areas. Intermediate values of soil C content were generally measured in the permanent pasture lands (Table 5).

Conclusions

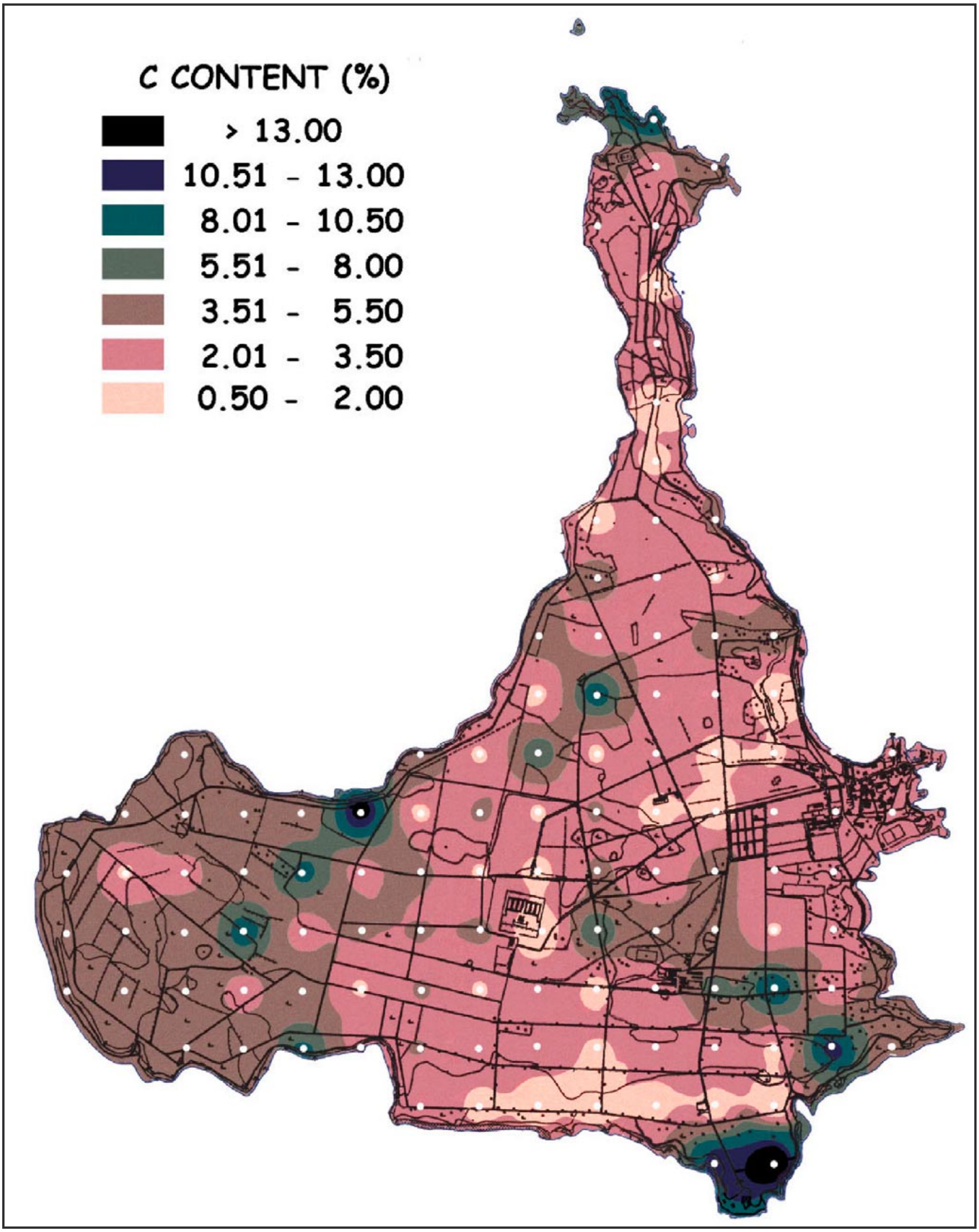
The different soil uses of the island, in the long term, lead to a differentiation of their physical and chemical characteristics. This indicates how the intensity of the human activities affect the ecosystem properties and the C distribution in the soil and, as a consequence, the C sequestration.

After a few years from the abandonment of agricultural activity, the soils previously subjected to pasture and extensive cultivation have reached a significative similarity in terms of microbial biomass and respiration. In spite of this, they maintain substantial differences in comparison with the macchia. This situation seems to indicate that a process of re-naturalization of the island is in progress.

These results, which need to be confirmed and studied in depth, could be used as indicators of the quality of the soil and the impact of agricultural activities.

The production of a map of the C and the characterization of the island soil ecosystems can assume a fundamental importance in evaluating the C dynamics, which are strongly influenced by human management and the protective ability of the soil on the OM. Such dynamics play an important role in the regulation of the C exchange between soil and atmosphere, and have important implications in “global climatic changes.”

Figure 4. Map of the C.



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