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Soil organic matter characteristics, biochemical activity and antioxidant capacity in Mediterranean land use systems

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A B S T R A C T

The characteristics of soil quality were measured in adjacent agricultural (horticultural cropping sequence, HC), native grassland (naturally grazed, NG) and forest (indigenous wood of holm-oak, F) soils. The objective of the research was to assess the influence of different land uses on soil organic matter characteristics, biochemical activity and antioxidant capacity in selected fields of the Mediterranean environment in central Italy under a specific climatic regime.

Land use induced significant changes in the content and quality of soil organic matter, biochemical activity and antioxidant capacity, with more pronounced differences between soils under HC and F than soils under HC and NG. The HC soil showed the lowest amounts of total organic carbon (TOC), microbial biomass C (MB-C), water-soluble organic C (WSOC), water- and alkali-soluble phenols. The organic matter of HC was characterized by the lowest percentage of MB-C and of light fraction carbon (LF-C). The dehydrogenase activity (DH-ase), metabolic potential (MP), hydrolyzing coefficient (HyC), potentially mineralizable C (C_0) and C mineralized (C_m) were clearly lower in HC. The specific respiration activity of biomass (qCO_2) was the highest in HC soil (1.3 μg CO_2–C μg biomass C^{-1}) and lowest in F soil (0.5 μg CO_2–C μg biomass C^{-1}) and was inversely related with pH, TOC and MB-C contents. The antioxidant capacity of soils (TEAC) was the highest in NG and related to the amount of alkali-soluble phenols. The rate constant of organic matter mineralization (k) appeared to depend on TEAC rather than the relative amounts of the labile C pools. These results seem to explain the role of phenols as controller of the mineralization rate of organic matter.

1. Introduction

Agronomic practices designed to optimize production in agriculture, including the interconversion of forest and agricultural land, strongly affect soil quality. Long term researches (Haynes and Tregurtha, 1999; Moscatelli et al., 2007; Saviozzi et al., 1994; Tan and Lal, 2005) have shown that cultivation of native soil, in addition to climatic and pedogenic factors (Parton et al., 1987), decreases the soil organic matter content. Hajabbasi et al. (1997) reported that deforestation and subsequent tillage practices resulted in almost a 50% decrease in organic matter. Maintaining the organic matter content requires a balance between addition and decomposition rates. As changes in land use can markedly affect both the pool size and turnover rate of organic C, it is important to analyze their nature and impacts. Merino et al. (2004) showed that transformation of the cropland to pasture slightly increased the organic and microbial biomass C contents, whereas afforestation significantly increased these variables.

Changes in land use and soil management practices decreasing the organic matter content are largely responsible for increases in atmospheric CO_2 from terrestrial ecosystem (Canadell et al., 2000). Consequently, efficient utilization of soil as a C sink will require identification of soil systems with high potential for sequestration and improved methods of monitoring soil C. Recently, land protection from deforestation to minimize future emissions of CO_2 has gained wide international support (Gullison et al., 2007; Turner et al., 2009). The Copenhagen Accord (2009) features land protection as a mechanism to provide diminished CO_2 emissions, although some scientists question whether reduced deforestation can appreciably decrease atmospheric CO_2 (van der Werf et al., 2009).

Recently, it was hypothesized by Rimmer (2006) that the protection of the organic matter from oxidation is linked to the soil antioxidant capacity (TEAC). The mechanism explaining this effect is probably the antioxidant activity of the phenol compounds in soil organic matter and in associated plant materials, able to slow the rate of oxidation so controlling the rate of breakdown in more labile and easily degradable fractions. As reported by Zibilske and Bradford (2007), the accumulation of soil organic matter could be stimulated by using cover crops with higher phenol content, which

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could slow C mineralization. Rimmer and Smith (2009) and Rimmer and Abbott (2011) demonstrated that the amounts of antioxidants vary from soil to soil, reflecting soil water-soluble organic (WSOC) and total (TOC) C contents. Since for a given soil within a given climate, land use and soil management determine the amount and quality of soil organic matter, the measure of the TEAC could be a useful tool to highlight any difference and especially provide mechanisms for understanding these differences.

The relationship between land use and properties of soil organic matter is not completely understood because a large proportion of the organic fraction is very stable with a turnover time that may be as long as several thousand years (Stevenson, 1982). Changes in organic matter content occur slowly and do not always provide adequate information of changes in soil quality that may occur. The labile organic matter pools can be considered as fine indicators of soil quality because they are highly dynamic, readily available to soil organisms and much more sensitive than total organic matter to changes in soil land use (Haynes, 2004). Within the labile pools, the light organic matter fraction consists of partially decomposed plant litter, and it acts as a substrate for soil microbial activity (Greenland and Ford, 1964). Water soluble organic matter consists of organic compounds present in soil solution, and is a primary source of mineralizable substrate for microbial biomass (Cook and Allan, 1992). Measurement of potentially mineralizable C has also been suggested to be important because it represents a bioassay of labile organic matter using the microorganisms to release labile organic fractions of C (Gregorich et al., 1994; Riffaldi et al., 2003).

Soil biochemical parameters have also been seen to provide a reliable tool with which to estimate early changes in the dynamics and distribution of soil microbial processes in different land use systems (Bending et al., 2004). Among them, soil enzymes can be considered as good markers of soil biological fertility because of their essential role in soil biology, ease of measurement, and rapid response to changes in soil management such as use of fertilizers, amendments, vegetation cover and pesticides (Gianfreda and Bollag, 1996). Microbial biomass, respiration rate, specific respiration of biomass (qCO_2, ratio of respired C to biomass C), ratio of microbial biomass C to total organic C, are other valid biological measurements that have been suggested as indicators for assessing long-term soil management effects on soil quality (Cardelli et al., 2004; Dilly et al., 2003; Levi-Minzi et al., 2002; Riffaldi et al., 2002; Saviozzi et al., 2007). In particular, such parameters are sensitive to changes in soil C availability, caused by alterations in soil management practice, and can change markedly before any changes in organic matter content are detected (Haynes and Beare, 1996).

Saviozzi et al. (2001), studying several soil enzyme activities in adjacent differently managed soils, reported that generally all the biological properties had maximal activity levels in native grassland soil, followed by forest and then by cultivated soil. Much of the literature agrees with these general trends but data for individual sites show great variability because soils differ considerably in their rates of organic matter loss (Riffaldi et al., 1996), as a result of their chemical and physical properties influencing the magnitude of biological processes and the imposition of different soil management systems. In the Mediterranean area, specifically in central Italy regions where many soils are subjected to loss of organic matter and progressive degradation, researches were carried out on the effect of land uses and management practices on the soil characteristics (Marinari et al., 2007; Moscatelli et al., 2007; Saviozzi et al., 1994, 2001).

Since the management systems react differently in different climatic regimes with respect to soil quality, this research aims to assess the influence of different land uses on soil quality of selected fields in Mediterranean environment of the central Italy under a specific climatic regime.

2. Materials and methods

Three experimental plots were located at Lucignana, near Lucca (Italy), Lat 44°03′00″N Lon 10°32′12″E, on a hilly uniform area about 500 m from sea level. The location has a long-term precipitation average of 1590 mm year^{-1} and a mean annual temperature of 12.4 °C. The soil was sandy clay loam (USDA).

The three plots, located in adjacent sites, consisted of: (1) indigenous wood of holm-oak (Quercus Ilex L.) (F); (2) undisturbed native grassland (NG); (3) horticultural cropping sequence (HC). The F site was a natural age-old wood extended an area of about 1 ha. NG site was a naturally grazed grassland (about 4000 m^2). HC site (about 2500 m^2), consisting mainly and alternatively of legumes and potatoes, was cultivated conventionally from about seventy years, according to local usage for what concerns annual tillage (depth ploughing 25 cm), fertilization, irrigation, and pest control. In the last years, N, P, and K were applied in the form of compound fertilizer (12–12–12). Copper oxychloride was used as fungicide and imidacloprid as insecticide for pest control.

The soil samples, collected in May 2010 and consisting of 20 cores measuring 5 cm dia × 15 cm depth, were air-dried and passed through a 2 mm sieve. Any large root fragments found after sieving were discarded, along with all soil particles larger than 2 mm. pH, cation exchange capacity (CEC), total N (TN), available P and exchangeable K were determined by standard methods (SISS, 1985).

Part of each sample was air dried and stored at 4 °C, before the following analyses were carried out:

- total organic carbon (TOC) by dry combustion (induction furnace 900 CS, Eltra), after removing carbonate C;
- water soluble organic carbon (WSOC) by stirring samples of soil with distilled water (soil/H_2O 1:20) for 24 h at room temperature, centrifuging the suspension at 10,000 rpm for 10 min and, after filtration through a 0.4 μm glass fibre, determining the carbon by dichromate oxidation titration (Ciavatta et al., 1991);
- light fraction (LF) of organic matter was separated from soil samples by the method of Strickland and Sollins (1987) and weighed;
- light fraction carbon (LF-C) by dry combustion (induction furnace 900 CS, Eltra);
- a short term (28 days) aerobic incubation was used to determine the potential of the samples to mineralize organic C. The CO_2 evolution was monitored daily between 1 and 28 days: 50 g of soil were placed in 250-ml glass containers closed with rubber stoppers, moistened at 50% of the maximum water holding capacity and incubated at 25 ± 1 °C; the CO_2 evolved was trapped in NaOH solution and the alkali excess was titrated with HCl (Levi-Minzi et al., 1990); sodium hydroxide reacted with carbon dioxide according to the reaction:

$$CO_2 + H_2O + 2NaOH \rightarrow 2H_2O + Na_2CO_3$$

The CO_2 produced, and then the C mineralized were calculated using the equation:

$$\frac{\text{mg mineralized C}}{100\,\text{g soil}} = \frac{(\text{ml NaOH}_{\text{blank}} - \text{ml NaOH}_{\text{sam}}) \cdot 0.5 \cdot 2 \cdot 12}{2}$$

The results, normalized with respect to time, were expressed as mg of C mineralized/100 g of dry soil.

- microbial biomass C (MB-C) content was determined according to Vance et al. (1987) with extraction from fumigated and unfumigated soils by 0.5 M K_2SO_4, measuring the organic C as described by Jenkinson and Powlson (1976). An extraction