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Microbial indicators related to soil carbon in Mediterranean land use systems

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Abstract

Soil C mineralization activity and microbial indices were measured in agricultural, forest and grassland soils, characterized by different managements in two adjacent fields: agricultural (conventional vs. organic), forest (conifer vs. broadleaf), grassland (naturally grazed grass vs. alfalfa ungrazed). The aim of the study was to determine if the land use and the management practices modified C mineralization activity and kinetics, microbial biomass size, microbial and metabolic quotients (C_{mic}/C_{org} ratio and qCO_2).

Land use induced significant changes in microbial biomass content, in most of the microbial indices, and in the cumulative CO_2 production which showed the highest values for agricultural soils (300 μg C–CO_2 g^{-1} 28 d^{-1}) and the lowest for grassland soils (120 μg C–CO_2 g^{-1} 28 d^{-1}). In agricultural soils, a large availability of potentially mineralizable C (C_0) was determined. Forest soils mineralization activity was mainly dependent on environmental factors such as aboveground tree species and soil pH which probably induced changes in microbial community structure and/or functionality. This could also explain the significant differences found on chemical, biochemical and microbiological properties of the two forest soils under the two managements.

Grassland soils were characterized by a high stability of soil organic matter (SOM) and consequently a low mineralization activity. Although total nitrogen and soil C/N ratio varied between the two soils, the management practices did not affect C mineralization activity. In conclusion the results show that microbially mediated processes can be largely affected by land use confirming its role as a significant driver of soil C changes.

Keywords: Land use; C mineralization; Soil management; Microbial indices; Mediterranean environment

1. Introduction

Losses of soil organic carbon (SOC) often occur when converting from natural to agricultural ecosystems. This can be due to reduced inputs of organic matter, reduced physical protection of SOC as a result of tillage (Davidson and Ackerman, 1993), changes in soil moisture and temperature regime accentuating decomposition rates, and/or a lower fraction of non-soluble materials in more readily decomposed crop residues and soil erosion (Tan and Lal, 2005). Hajabbasi et al. (1997) reported that deforestation and subsequent tillage practices resulted in almost a 50% decrease in organic C compared to undisturbed forest soil. Soil tillage involves the physical disturbance of the upper soil layers. It has been demonstrated that conventional tillage decreases soil aggregates and also alters their turnover, thus influencing C stability in the soil (Paustian et al., 2000). Conservation tillage techniques seem to increase total organic C (TOC) in the upper layer, thus increasing the micro-aggregation and

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aggregate stability (Shepherd et al., 2002; Carter, 1992; Pagliai et al., 1981). These practices therefore could promote an enhancement of C *sink* at the global scale of about 4.9 Pg (Lal, 1997). It is widely documented that organic agriculture techniques may increase soil organic matter (SOM) content (Andrews et al., 2002; Goh et al., 2001; Clark et al., 1998; Drinkwater et al., 1995) and/or quality (Marinari et al., 2007; Wander and Traina, 1996). Moreover, crop rotation with leguminous crops, reduced or zero-tillage and field application of manure and sludge, etc. have mitigated CO_2 efflux from soils and can therefore be considered an effective means to promote C storage in the soil (Sanchez et al., 2002).

Indigenous forests and grassland ecosystems are major reservoirs of terrestrial C (Post et al., 1990; Ross et al., 1996). Forest soil C stock may comprise as much as 85% of the terrestrial C stock in boreal forest, 60% in temperate forest and 50% in tropical rainforests (Dixon et al., 1994). The rate of SOC sequestration, and the magnitude and quality of soil C stock depend on the complex interactions between climate, soil, tree species and management, and chemical composition of the litter as determined by the dominant tree species (Lal, 2005). Indeed forest soils support a diverse plant community where groups of species may have their own strategy for using soil resources.

Changes in land use and soil management practices induce variations in soil organic C, and are largely responsible for increases in atmospheric CO_2 from terrestrial ecosystem (Canadell et al., 2000). The use of microbial indices is particularly useful in detecting changes occurring in microbial pool and activity (Dilly, 2005; Moscatelli et al., 2005; Dilly and Munch, 1998) and have also been used in comparing different land uses (Dilly et al., 2003). The ratio of microbial biomass C to total organic C (C_{mic}/C_{org} ratio) has been widely used as an indicator of future changes in organic matter status due to alterations in land use, cropping systems and tillage practices (Sparling, 1997). It also indicates the substrate availability to soil microflora (Anderson and Domsch, 1989). The metabolic quotient (qCO_2, ratio of respired C to biomass C) is a valid indicator of the microbial efficiency in the use of energy and the degree of substrate limitation for soil microbes (Dilly and Munch, 1998). Increased microbial activity per unit of biomass is related to a greater level of available organic C but also to an enhanced use of C energy for maintenance rather than for growth (Islam and Weil, 2000).

In this study we measured soil C mineralization activity and microbial indices in three soils under different land uses: agricultural, forest and grassland. Two management practices were observed and adopted for each land use type in two adjacent fields: agricultural (conventional vs. organic), forest (conifer vs. broadleaf), pasture (naturally grazed grass vs. alfalfa ungrazed).

The aim of the study was to determine whether the land uses and management practices caused significant changes in C mineralization activity and kinetics, microbial biomass size, microbial and metabolic quotients, as C_{mic}/C_{org} ratio and qCO_2.

2. Materials and methods

2.1. Sites description and soil sampling

In November 2004 soil samples were collected in three sites located in the province of Viterbo, Italy: Bomarzo (agricultural soil, *Vertic Xerocherpts*, latitude 42°29′N, longitude 12°16′E, 165 m asl, average annual temperature 14.2 °C, average annual precipitation 830 mm), Civita Castellana (grassland soil, *Mollic Haploxeralfs*, latitude 42°18′N, longitude 12°24′E, 145 m asl, average annual temperature 14.6 °C, average annual precipitation 796 mm) and Monte Rufeno Natural Reserve (forest soil, *Umbric dystrochrept*, latitude 42°49′N, longitude 11°52′E, 420 m asl, average annual temperature 12.9 °C, average annual precipitation 632 mm).

For each land use (agricultural, forest and pasture) we chose two adjacent fields, each managed as follows: conventional (AC) and organic agriculture (AO); conifer (*Pinus strobus* L. and *Pinus pinaster* L.) (FC) and broadleaves (*Quercus cerris* L.) (FB) forest; alfalfa (*Medicago sativa* L.) ungrazed (GU) and naturally grazed (GG) grassland. In the agricultural soil the crop succession of the conventional system was similar to that of the organic system. Since 1993 the organic and conventional fields of the farm have been used to grow durum wheat (*Triticum durum* Desf.) and sunflower (*Helianthus annuus* L.) in rotation. At the time of sampling, agricultural soils had not been cropped and were under fallow. For further information on agricultural management see Marinari et al. (2006). The forest site presents two contiguous plots: one coetaneous stand of eastern white pine (*P. strobus* L.) and maritime pine (*P. pinaster* L.) planted 30 years ago; the other one is an indigenous wood of bitter oak (*Q. cerris* L.), managed previously as coppice and for the past 6 years converted to stand. The grassland site consists of one field of alfalfa (*M. sativa* L.) mowed and ungrazed for 6 years and one contiguous field with a natural multi-year grass grazed for 4 years.