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Carbon and nitrogen in soil and vine roots in harrowed and grass-covered vineyards

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ABSTRACT

To examine the effects of vineyard soil management on soil C and N content and quality, we studied harrowed and grass-covered vineyards on a soil developed on plio-pleistocene, marine sediments. A soil naturally covered by grasses adjacent to the vineyards served as control. To reach this goal, we assessed (1) the distribution of C and N and their ^{13}C and ^{15}N signatures in different soil organic matter pools, (2) the amount of C and N as live and dead vine fine roots and their ^{13}C, ^{15}N and ^{14}C signatures, and (3) the stocks of C and N forms accumulated at two soil-depth intervals (0–50 and 50–100 cm).

Independent of the soil management, the vines increased the total organic C and total N content in the deeper soil horizons because of root turnover and rhizodeposition processes. In the upper horizons, a greater organic matter accumulation was fostered by the presence of the grass cover and the absence of tillage. The grass cover favoured the organic C storage mainly in the form of particulate and highly stabilised organic matter (humic acids and humin), and reduced the soil N content by plant uptake, whereas the harrowing produced a greater abundance of fulvic acids, which were mainly ascribed to oxidative processes enhanced by the soil tillage. In both vineyard soils, decaying vine roots represented an important source of organic C and N, especially in the deepest horizons. Indeed, isotope analyses revealed a more intense degradation of the dead vine roots in the deeper soil portion, where they likely constituted the main substrate for soil microorganisms. In the deepest horizons of the grass-covered vineyard, the greater mean residence time of the decaying vine roots and the lower root production were attributed to the easily available energetic substrates supplied by grass root turnover and rhizodeposition, which were preferentially used by microorganisms. This fact fostered a larger C accumulation in the grass-covered than in the harrowed vineyard.

1. Introduction

Soil properties are directly linked up to soil organic matter (SOM) content and quality, which are controlled by climate, vegetation, soil type and management (e.g., Guo and Gifford, 2002; Seddaiu et al., 2013). In agro-ecosystems, practices such as crop choice, tillage and machinery, organic inputs, fertilisers and xenobiotics usage also affect the content and the characteristics of SOM (Campbell et al., 1999; Lal, 2004). The transition from traditional farming to intensive agriculture, coupled with the use of large amounts of chemical fertilizers, has led to a loss of SOM from cultivated soils (Miller et al., 2004). Over the last 150 years, the land use and land-cover changes contributed to about 33% of the total anthropogenic carbon emissions (Houghton, 1999), with a consequent worsening of soil fertility and quality (Lal, 2004) and a significant contribution to global warming (IPCC, 2000; Burney et al., 2010). The growing interest in the sustainable use of soil, environmental quality and long-term productivity of agro-ecosystems (UNFCCC, 2008) has led to increasing use of agricultural practices that favour the conservation or increase of SOM (Paustian et al., 1997; Lal, 2004).

While there are numerous studies dealing with the influence of agricultural practices on the content and dynamics of SOM in annual cropping systems (e.g., Doran, 2002; Tilman et al., 2002), little is known for perennial cropping systems (Carlisle et al., 2006), which can be defined as the cultivations that last for more than two

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growing seasons and whose economic life spans for several years. Perennial woody crops cover large areas worldwide. For example, in the twenty seven-European Union Member States about 23,778 km^2 are occupied by fruit and berry plantations, 41,375 km^2 by olive trees, and 33,103 km^2 by vineyards (Eurostat, 2008). Vineyards also cover large areas outside Europe, with about 33,000 km^2 in the year 2011; of these, 21.9% are in Asia and 20.9% in USA and Southern Hemisphere (OIV, 2012).

Considering the worldwide diffusion of grape cultivation, there is an increasing need for sustainable management practices increasing SOM levels and consequently soil fertility and functioning. In this regards, a great debate exists on which is the best vineyard soil management in order to obtain the finest grape quality and to reduce costs and ecosystem impact of vine cultivation (Ripoche et al., 2010; Guerra and Steenwerth, 2012). Tillage is considered the best way to conserve water and control weeds, although it may favour erosion and stimulate the oxidation of SOM following the disruption of soil aggregates (Balesdent et al., 2000; Steenwerth et al., 2010). In contrast, growing grass in the vineyard alleys reduces erosion in the hilly environments and favours the traffic of farm machinery (Corti et al., 2011), but increases competition for nutrients and water (Goulet et al., 2004). With respect to SOM, Goulet et al. (2004) observed an increase of the organic C in the topsoil of vineyards from Champagne (France) subjected to organic-mulch or bluegrass cover over 9 years. Ruiz-Colmenero et al. (2013), after 4 years, found an increase of soil organic C in a grass-covered vineyard located in the Henares River basin (Spain) and attributed the increase mostly to incorporation of vegetative residues and decomposition of grass roots. Conversely, in vineyard soils from a semi-arid Mediterranean environment (Sardinia, Italy), Seddaiu et al. (2013) found that, after 20 years, tillage and grass-cover have had a similar effect on the organic C content. From these reports one might argue that the influence of soil management on SOM storage in vineyard is site-specific. Further, as SOM is made of a mixture of heterogeneous compounds that have specific stabilisation mechanisms and turnover rates (von Lützow et al., 2007), its fractionation by physical and/or chemical methods into pools and their quantification and characterisation can help to better understand the dynamics of organic C in agro-ecosystems. Following a chemical fractionation of SOM, Seddaiu et al. (2013) assessed that low levels of humic acids and a low stabilisation degree of SOM in tilled vineyard was due to disturbances produced by harrowing and nitrogen fertilisation, while higher content of humin was accumulated in annual cropping systems with grass cover and reduced tillage. Yang et al. (2004) reported an increase of humic acids and humin in the presence of grass cover or rotation with clover or rye grass.

The aim of the study was to examine how soil management (harrowed or grass-covered) affected the different SOM pools in a vineyard soil derived from fine-textured plio-pleistocene marine sediments under Mediterranean climate (central Italy). Specifically, we tested the hypotheses that, with respect to harrowing, grass-cover (1) favours the accumulation of stabilised forms of SOM; (2) reduces vine root production; (3) enhances soil C and N storage. The above hypotheses were tested through the assessment of the distribution of C and N in different SOM pools (water extractable organic matter, humic and fulvic acids, humin) and their ^{13}C and ^{15}N isotopic signatures, the distribution of C and N as live and dead vine roots with their ^{13}C, ^{15}N and ^{14}C isotopic signatures, and the stock of organic C and N accumulated in two soil-depth intervals.

2. Materials and methods

2.1. Study site, soil morphology and soil sampling

The study was conducted in a vineyard of the experimental farm of the Polytechnic University of Marche located in Agugliano (Ancona, Italy) (Fig. 1). The mean annual precipitation of the area is 780 mm, concentrated during autumn and winter and with a summer drought; the mean annual air temperature is 13.3 °C, with July and August as the warmest months and January as the coldest one. The soil, developed from plio-pleistocene marine sediments, is subalkaline to alkaline (pH values range from 7.5 to 8.6) and is classified as fine-loamy, mixed, mesic, Vertic Haplustept (Soil Survey Staff, 2010).

The vineyard occupies an area of about 1 ha with South-Southeast exposure on a 5–6% slope. The soil was cropped with cereals for 60–70 years prior to the vineyard establishment. The vineyard was planted in 1993 with vines (*Vitis vinifera* L.) of the *cv* Montepulciano on a Kober 5BB rootstock after a breaking up (about 70 cm) of the soil. The distance between rows was established at 2.8 m. The vineyard was experimentally designed as differently managed randomised blocks, with the inter-rows harrowed or grass-covered. All plots received a fertilisation of about 30 kg ha^{-1} year^{-1} of N in form of ammonium nitrate or urea only for the first 3 years after the vine planting. Later on, no fertilisation had been done. The harrowed plots were ploughed to 25–30 cm of depth for the first 3 years after the planting, but thereafter only superficial tillage (5–8 cm) was performed using disc, teeth harrow or small ploughs. The grass-covered plots were ploughed 25–30 cm depth for the first 3 years and then left to spontaneous colonisation of herbaceous species; the grass-covered alleys were mown twice per year and the herbage left in place. In both tilled and grass-covered alleys, a strip of soil of about 60 cm wide under the vine trunks was kept free of vegetation by 1–2 herbicide treatments per year with Glyphosate®.

As a control, we selected a site adjacent the vineyard (10 m from the border), naturally covered by grasses and that was part of the field cropped with cereals prior to vine planting. The control was mown twice per year and the herbage left in place.

Soil samples were collected during the early spring of 2003, when the vines were at the beginning of the bud break phase, namely when significant photosynthetic activity and rhizodeposition were limited. For each soil management (harrowed and grass-covered) two plots were considered and, in each plot, one soil trench was opened from row to row. These four trenches were at least 10 m apart. Two trenches were also opened in the control soil at about 18 m apart. The soil profiles were described (see Appendix I) according to Schoeneberger et al. (2002), and sampled by horizons in duplicate. Once in the laboratory, the soil samples were air-dried, sieved at 2 mm, and fine roots removed with the help of a magnifying lens.

2.2. Determination of C and N, and organic matter fractionation

The total organic C (TOC) content was estimated by the Springer and Klee method, and total N content was determined by a Carlo Erba EA1110 dry combustion analyzer.

The organic matter pools were extracted from the samples by sequential fractionation. Briefly, 100 g of sample was placed into a plastic container with water (solid:liquid ratio 1:10) and shaken overnight at room temperature. This allowed recovery of the free particulate organic matter (POM) and water extractable organic matter (WEOM) with minimum disturbance to the remaining organic pools (Jandl and Sollins, 1997; Ghani et al., 2003). The suspension was allowed to stand for 24 h, then the supernatant was collected by sieving at 53 μm. The coarser than 53 μm fraction was washed with water over the sieve, then washed with 0.5 M HCl to eliminate carbonates, washed again with water and then dried at 40 °C; this fraction represented the POM and consisted of large, undecomposed and partly decomposed root and plant fragments (Golchin et al., 1994). The solution used to wash the POM was added to the suspension passed through the 53 μm sieve. After