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Effect of compost application on the dynamics of carbon in a nectarine orchard ecosystem

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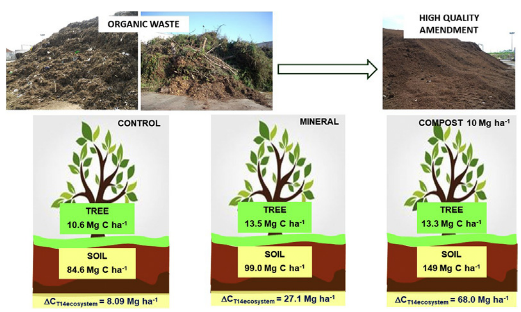
HIGHLIGHTS

- Compost at 5 and 10 t ha^{-1} yr^{-1} were compared with control and mineral fertilization for 14 years in a nectarine orchard
- Compost at 10 t ha^{-1} showed a plant growth and yield, similar to mineral fertilization
- Compost application increased soil organic C, microbial and extractable C
- The rate of compost application of 10 t ha^{-1} showed a C storage in soils 3 times higher than the rate of 5 t ha^{-1}fold

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of the present study was to compare the quantity and the type of carbon (C) stored during the 14-year lifetime of a commercial nectarine orchard ecosystem fertilized with mineral or organic fertilizers.

The study was carried out in the Po valley, Italy, in a nectarine orchard of the variety Stark RedGold, grafted on GF677 hybrid peach × almond. Since orchard planting in August 2001, the following treatments were applied in a randomized complete block design with four replicates per block and compared: 1. unfertilized control; 2. mineral fertilization (including P and K at planting and N applied as NO_3NH_4 yearly at the rate of 70–130 kg ha^{-1}); 3. compost application at a rate of 5 Mg DW ha^{-1} yr^{-1}; 4. compost application at a rate of 10 Mg DW ha^{-1} yr^{-1}. Compost was obtained from domestic organic wastes mixed with pruning material from urban ornamental trees and garden management after a 3-month stabilization period.

Application of compost at the highest rate increased C in the soil; the amount of C sequestered was approximately 60% from amendment source and 40% from the net primary production of trees and grasses with a net increase of C compared to mineral fertilization.

Compost application was found to be a win-win strategy to increase C storage in soil and, at the same time, to promote plant growth and yield to levels similar to those obtained with mineral fertilization. The rate of C application is crucial, indicated by the fact that compost supply at the rate of 10 Mg ha^{-1} yr^{-1} was the only fertilization strategy of the ones tested that resulted in higher C sequestration. This shows that compost amendment may stimulate an increase in the net primary production of plants.

1. Introduction

The rising interest in carbon (C) budgeting is due to the well documented effect of the increased atmospheric carbon dioxide (CO_2) concentration on global warming (Mastrandrea et al., 2015). On one

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hand, forests and, to a smaller extent, grasslands are considered sinks for atmospheric C sequestration, and thus effective systems to reduce temperature increases (Valentini et al., 2000; Luyssaert et al., 2007; Pan et al., 2011; Abdalla et al., 2013). On the other hand, agricultural systems are often considered potential sources of CO_2 (Smith et al., 2005; Ciais et al., 2010; Ceschia et al., 2010; Abdalla et al., 2013). However, since C sequestration implies the transfer of CO_2 from the atmosphere to living pools, orchards could contribute to the storage of C (Wu et al., 2012; Zanotelli et al., 2013), owing to photosynthesis that enables plants to fix C and transform it into carbohydrates. Plant C is stored in perennial organs such as branches, trunk, and roots, as well as ephemeral parts of the plant like leaves and fruits. While fruits are removed from the orchard, leaves, through autumn abscission and pruning wood, are left in the orchard and incorporated into the soil contributing to the soil organic carbon (SOC) increase. High C assimilation rates have been observed in apple trees orchard (Reyes et al., 2006). Also, management techniques that aim to enhance yield, besides increasing farmer's profits, have been shown to consequently improve C sequestration.

In addition, the soil plays a relevant role in the mitigation of climate change since it acts as an important C reservoir. Soils of agroecosystems, especially those degraded by intensive agricultural practices, are severely depleted of their SOC pool; in some soils, the concentration of SOC is below the critical level of 1.5% (Lal et al., 2015). Thus, soils of agroecosystems can have an important C sink capacity. Soil organic C sequestration is defined as: "the process of transferring CO_2 from the atmosphere to the soil through plants, plant residues, and other organic compounds, which are stored and retained in soil as soil organic matter (SOM)" (Lal et al., 2015). Thus, at the recent Paris climate conference (UNFCCC-COP21, December 2015), it was proposed to increase SOC sequestration at the rate of 4‰ per year to balance the continuing anthropogenic emissions of C (Lal et al., 2015). Consequently, the maintenance and improvement of SOC has become one of the milestones of the European Commission for a resource-efficient Europe (EC, 2011). The use of ground cover vegetation in the alleys between tree rows (Marquez et al., 2013) and the use of organic amendments (Neilsen et al., 2014) could help to increase SOC.

Beside C sequestration, the enhancement of SOM increases the storage of water and nutrients, stimulates soil biological activity, and it is associated with improved orchard soil quality (Neilsen et al., 2003; Canali et al., 2009) and tree performance (Cline et al., 2011). SOC sequestration is achieved in those management systems that add high amounts of biomass to the soil and, at the same time, cause minimal soil disturbance (Lal, 2004; Cattaneo et al., 2014).

The application of organic amendments is an effective strategy to enhance SOC sequestration; however, contrasting conclusions have been reported on the relationship between the application of organic amendments and C retention in soils. Fontaine et al. (2004) concluded that the application of fresh C stimulates the decomposition of soil C and leads to a negative C balance. On the other hand, other studies (Adani et al., 2009; Ryals and Silver, 2013) showed that a higher organic amendment application rate leads to an increase in the amount of C sequestered into the soil. Very less is known about the long-term effect of compost application on soil C sequestration in orchard systems (Mays et al., 2014; Pardo et al., 2017; Vicente-Vicente et al., 2016); although many studies have demonstrated that compost application increases C sequestration in soil (Bhattacharya et al., 2016; Christensen et al., 2009; Diacono and Montemurro, 2010; Martínez-Blanco et al., 2013; Thangarjan et al., 2013).

Orchards, in comparison to annual crops (Smaje, 2015), have structural characteristics that allow them to sequester significant quantities of atmospheric C. This is because of: i) the long orchard life cycle, which allows the accumulation of C in perennial organs such as trunk, branches, and roots and in the soil through rhizodeposition; ii) reduced soil tillage, which preserves SOM from mineralization; iii) grassing of the alleys, which contributes to the buildup of SOM. In addition, the supply of compost or other organic amendments as supplements to mineral fertilization largely contributes to increase SOC and consequently C sequestration. Besides representing a source of high quality organic matter, compost is a suitable approach to recycle municipal solid and food industry related wastes.

The aim of the present experiment was to compare the quantity and the quality of C stored in a 14-year-old, commercial nectarine-orchard ecosystem, fertilized with mineral or organic fertilizers since its planting.

2. Materials and methods

2.1. Plant materials and treatments

The trial was conducted from 2001 to 2014 at the experimental farm "M. Marani" near Ravenna, Italy (44°27′ N; 12°13′ E), in a temperate area characterized by an annual precipitation level (average 1991–2015) of 696 mm and average annual temperature of 14.1 °C (ARPA, 2017), with increases of 51 mm and 1.2 °C, respectively, compared to the previous 30-year period (1961–1990). The soil is classified as a Calcaric Cambisol (WRB IWG, 2014) and the main characteristics at the beginning of the experiment are summarized in Table 1. The experiment was conducted in a nectarine [*Prunus persica* (L.) Batsch var. *nucipersica* (Sucow) C.K. Schneid.] orchard of the variety Stark RedGold, grafted on hybrid GF677 (*Prunus persica* × *Prunus amygdalus*), established in August 2001, with a distance between plants in the row of 3.8 m and between rows of 5 m. Trees were trained in a "delayed-vasette" system, and irrigated with a drip system during summer (June–September) to match daily evapotranspiration. The soil was tilled to a depth of 0.25 m in 2-m wide tree rows, while alleys were covered with resident vegetation, mowed 3 times a year. According to a complete randomized block design, with 4 plants used as replicates, four fertilization treatments were compared since 2001: 1. unfertilized control; 2. mineral fertilization, including phosphorous (P; 100 kg ha^{-1}) and potassium (K; 200 kg ha^{-1}) applied at planting only and nitrogen (N; 70 kg ha^{-1}) applied yearly, split between May (60%) and September (40%). In 2004, N application rate was increased to 120 kg ha^{-1} yr^{-1} and then, from 2006 to 130 kg ha^{-1} yr^{-1}; 3. compost application at 5 Mg dry weight (DW) ha^{-1} yr^{-1}; 4. compost application at 10 Mg DW ha^{-1} yr^{-1}. Compost was applied in the 2-m wide tree row, tilled into the soil to a depth of 0.25 m and split as in mineral fertilization. The compost used in this experiment (Table 2), classified as municipal solid waste, was prepared by a local composting plant, using domestic organic wastes (50%) mixed with pruning material from urban ornamental trees and garden management (50%). In detail, the domestic organic waste and the pruning material were carefully mixed together. These were decomposed in an aerobic process under controlled humidity and temperature conditions for at least 3 months to obtain a biologically stable product. During the whole period of the experiment, pruned wood was left on the ground and chopped according to the common practices of the area.

Table 1
Physical and chemical characteristics of the soil at the beginning of the trial (average of 4 replicates ± standard deviation).

Soil characteristics	
Sand (%)	6.7 (±1.5)
Silt (%)	67 (±1.41)
Clay (%)	26.2 (±1.71)
pH	7.8 (±0.05)
Total N (‰)	0.95 (±0.13)
Total carbonate (% $CaCO_3$)	30.5 (±1.29)
Active carbonate (% $CaCO_3$)	12.5 (±1.29)
Organic matter (%)	1.68 (±0.13)
K extractable (mg kg^{-1})	183 (±28)
P Olsen (mg kg^{-1})	18.7 (±1.0)
Cation exchange capacity ($cmol_+$ kg^{-1})	10.1 (±1.95)
Electrical conductivity (μS cm^{-1})	200 (±8)