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Soil management affects carbon dynamics and yield in a Mediterranean peach orchard

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ABSTRACT

A field trial was conducted over a seven-year period, in Mediterranean peach orchard. The aims were (i) to explore the effects of alternative soil-management practices (A_{mng}) on soil and litter carbon (C) reserves, (ii) to monitor the seasonal and (iii) spatial variations of soil CO_2 flushes. The alternative management included no tillage, retention of all aboveground biomass and application of imported organic amendments (15 t ha^{-1} y^{-1} fresh weigh). Locally conventional management (L_{mng}) served as the control: *i.e.* tillage, mineral fertilisation, removal of prunings. The mean total annual C inputs were 4.2 and 2.4 t ha^{-1} in A_{mng} and L_{mng}, respectively. Spatial and temporal variations in CO_2 soil emissions over a 20 m^2 plot (×2) were assessed (Li-6400, LI-COR, USA) on the assumption that root topography and microbial activity declined systematically with distance from the row line. Under A_{mng} practices soil C significantly increased up to 1.78% against 1.38% at L_{mng} block. The C stored as litter and dead wood in A_{mng}, was 16-times that in L_{mng}. On a whole-season basis, CO_2 losses were 20% higher in A_{mng} than in L_{mng}. Soil CO_2 emissions were mostly from the in-row, with the inter-row emissions being lower, especially due to reduced soil-water content during the drier months. It is concluded that despite a higher CO_2 soil emissions, alternative management techniques will partially offset atmospheric CO_2 rise through increased soil C reserves, and that spatial variability of emissions must be taken into account if the accuracy of estimates of large-scale emissions are to be improved.

1. Introduction

During the last century, carbon (C) loss from cultivated soils has in part been to blame for the observed trend for global warming (IPCC, 2007). The agricultural sector currently aims to restore the soil C reservoir through more appropriate soil management practices designed to increase CO_2 sequestration and/or reduce CO_2 emissions. Sequestration of CO_2 in the plant biomass, soil and in its dead organic content (*i.e.* litter and dead wood) has an important environmental impact because of the role of CO_2 in global climate change (IPCC, 2006). European tree crops (including peaches, nectarines, apples, pears, apricots, cherries and oranges) have a significant socio-economic function to the extent that they are grown on approximately 1,422,130 ha, in 20 nations and have an estimated gross annual value of 9.8 billion € (FAO, 2012). Nowadays, agriculture ecosystems have the opportunity to develop new, more economically- and environmentally-friendly policies for mitigating CO_2 emissions which will strengthen the social and environmental roles of orchard systems (Nair et al., 2009). Understanding of the dynamics of C sequestration and release is a prerequisite for developing effective policies for orchard systems. However, at the level of fruit tree production such information is rather limited.

The greenhouse-gas emissions and CO_2-fixing capacity vary widely with tree and orchard age, with planting density, climate, irrigation system, nitrogen supply, tillage and with a host of other management practices (Murthy et al., 1996; Al-Kaisi and Yin, 2005; Sainju et al., 2008; Liguori et al., 2009). Increased C inputs boost soil fertility by raising soil organic C content which, in turn, enhances a number of soil nutrition and soil hydrological proprieties (*e.g.* soil porosity, soil water infiltration rate and retention, soil structural stability) (Bhogal et al., 2009). However, application of C to the soil is expected to raise CO_2 emissions as predicted by the positive relationships found between soil C content and soil CO_2 effluxes (Franzluebbers et al., 2002; Wang et al., 2003). Additionally, oxidation of C substrates by microorganisms (and related CO_2 emissions) will be accelerated by irrigation in semi-arid climates due to their higher soil temperatures (Fang and Moncrieff, 2001).

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Variations in soil C reserves should indicate the suitability of particular soil management practices in terms of C storage. Both time and climate (mostly air temperature and rainfall) are likely to influence the rates of soil organic C (SOC) change in response to the establishment of any new soil managements (Monreal and Janzen, 1993). Hence, especially in semi-arid regions, there is uncertainty about the appropriateness and sustainability of soil managements which increase C supply. This situation is hampering the development of more environmentally-friendly policies.

Although soil CO_2 fluxes as affected by orchard management can be estimated by modelling key soil properties (*e.g.* particle size) and climate parameters (Nieto et al., 2010), *in situ* measurements of these fluxes are highly desirable to reduce uncertainties in estimates of field C dynamics. Spatial gradients in factors affecting soil respiration (*e.g.* moisture, temperature, presence/absence of roots) render CO_2 efflux from a soil very variable spatially to the extent that its coefficient of variation can reach 100% (Baldocchi, 2003).

Variations in root density and C availability represent key sources of spatial variation in soil CO_2 emission both because of root metabolism and also microbial decomposition of dead organic matter (Reth et al., 2005; Sainju et al., 2008). Soil moisture conditions also significantly affect the organic matter mineralisation rate and the ensuing availability of nutrients. For example, under fluctuating soil moistures, amounts of compost-derived N may be only 30–40% of those evolved under more constant conditions (Kruse et al., 2004). The inter-row of a drip-irrigated orchard is exclusively rain fed, implying that in a Mediterranean-type climate, the inter-row soil will be much drier than that within the row (the in-row) for most of the growing season (Ruiz-Sánchez et al., 2005). Hence, to maximise plant nutritional benefits in these climates, organic amendment is best applied using a localised placement technique (Parr, 1989).

Hence, assuming (i) that localised irrigation concentrates root biomass within the row where soil water content is also highest (Ruiz-Sánchez et al., 2005) and (ii) that localised (in-row) placement of organic amendments increases C availability (in-row compared with inter-row), it is hypothesised that CO_2 emissions will be higher in-row than inter-row.

Based on this background, we examine whether increased C inputs in a peach orchard in a Mediterranean climate are sufficient to significantly increase SOC after a temporal horizon of seven years. Our study's secondary aim was to study the seasonal CO_2 soil emissions from a peach orchard under locally conventional (L_{mng}) (continual tillage, burning of crop residues, mineral fertilisation) and alternative management practices (A_{mng}) (no tillage, cover crop, organic fertilisation, mulching of crop residues). As our third objective, we test the hypothesis that for a Mediterranean peach orchard, under drip irrigation and with in-row compost placement CO_2 emissions are higher in-row than inter-row.

2. Materials and methods

2.1. Site and plant material description

The study was conducted in southern Italy on a private farm (N 40° 23′ E 16° 42′). Long-term average annual rainfall in the region is 550 mm and is highly seasonal, usually falling between October and May, with insignificant amounts between June and September. The average maximum annual temperature is 36 °C (SAL Service, ALSIA Basilicata Region). Trials were carried out in a peach (*Prunus persica* (L.) Batsch *Nectarine*; cv. Super Crimson grafted on GF677) orchard planted in 1997 on a *Typic Xerofluvents*, WRB, sandy-loam soil (68.8% sand, 16% silt and 15.3% clay), 23 m a.s.l. Trees were trained to delayed-vase and spaced 5 m between rows and 4 m along the row.

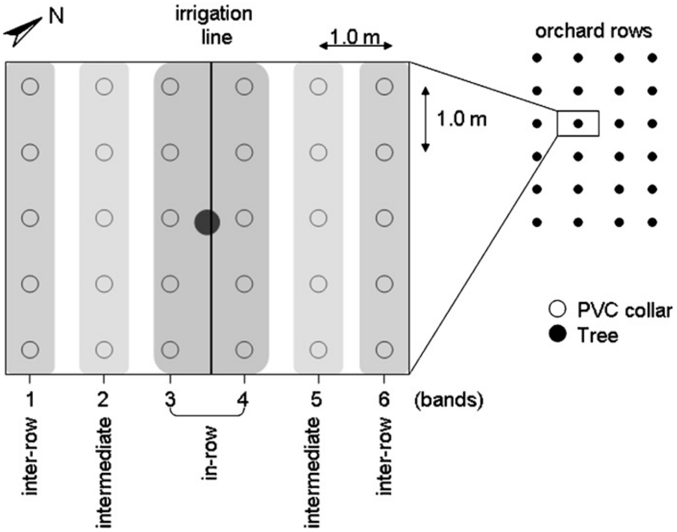

Fig. 1. Location of the six soil bands and of the 30 sampling positions for CO_2 (PVC collars) and for soil within each plot.

Since establishment, the orchard was managed according to local practice (L_{mng}). Irrigation was through drippers (two per tree) each with a discharge rate of $8\,L\,h^{-1}$ and wetting a ~1.0 m wide strip along the in-row. The orchard was irrigated weekly during the growing season (April to September) but twice weekly during summer (June to August). Mineral fertilisers were applied by fertigation at an annual rate of 137.5 (N), 31 (P), 41.5 (K) and 2.3 (Ca) $kg\,ha^{-1}$. Soil was tilled 4–5 times during the growing season using an 18-disc harrow (~10 cm depth). Tillage included both the in-row and the inter-row. Pruning was done in winter and all residues were removed.

From 2004 to 2010, a 1 ha block was subjected to alternative management (A_{mng}) in which all soil was untilled and the understorey 'grass' was mowed three times (usually in March, May and June) to 3–4 cm. Fertilisation was based on tree demand and on availability of essential nutrients in the soil analyses (Xiloyannis et al., 2006; Montanaro et al., 2010). In the A_{mng} block, minerals were supplied via fertigation at a mean annual rate of 55 (N), 4.5 (P) and 2.3 (Ca) $kg\,ha^{-1}$. Each year in January, $15\,t\,ha^{-1}$ (fresh weight, ~25% moisture content) of organic amendment (compost) was distributed in a ~1 m wide band along the in-row of soil surface, it was not incorporated in the soil. The compost (~22.2 C/N; Eco-Pol SpA – Italy) contained on dry matter basis, 2.02% (±0.31 SE) total N, 1.8% (±0.26) organic N, 1.86% (±0.3) K_2O, and 0.9% (±0.18) P_2O_5 supplying each year approximately a further 230 kg N, 170 kg K and 40 kg P ha^{-1}. The percentages of nutrients into compost are the mean of five analysis carried out in five different years of the experiment. Pruning was done each year in December and January and the pruning biomass was chipped and evenly distributed in the alley.

2.2. Soil CO_2 efflux measurements

On each soil CO_2 sampling time, emissions were measured *in situ* over the year 2010 at 30 locations per treatment, distributed at 1 m centres around a tree (see Fig. 1). Locations were always the same throughout the experiment. A non-dispersive infrared gas analyser (Li-6400, LI-COR, Lincoln, NE, USA) equipped with a soil respiration chamber (Model Li-6400-09) was used to measure CO_2 efflux by fitting the chamber to a collar (a 6 cm long section of 10 cm ID PVC pipe). In all, 60 PVC collars were pressed into the soil to a depth of 4 cm, one collar in each location. Collars were installed at the beginning of the experiment (8 January 2010) and