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Carbon budget in a Mediterranean peach orchard under different management practices

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ABSTRACT

The soil organic carbon (SOC) content of many Mediterranean soils is low (~1%) and this hinders both economic and ecologic progress. The climate in much of the Mediterranean region (low annual precipitation, cool wet winters, hot dry summers), combined with traditional agricultural practices has a major impact on the carbon (C) cycle. To increase our knowledge of C fluxes in Mediterranean agro-ecosystems, this paper examines the effects on the soil and biome C budgets of a peach (*Prunus persica* L. Batsch) orchard, seven years after adopting sustainable management practices (S_{mng}). The result is compared with the continued use of locally conventional management practices (C_{mng}). Sustainable management involved zero-tillage, weed mowing, retention of above-ground residues and the import of organic amendments, while C_{mng} involved tillage, removal of pruning residues and the application of mineral fertilisers. The annual net ecosystem production (NEP) was determined through field measurements of soil respiration (Li-6400, LI-COR, USA) and above- and below-ground biomass sampling. The mean annual NEP was close to 320 and 475 g C m^{-2} yr^{-1} in the C_{mng} and S_{mng} plots, respectively. As managed ecosystems, anthropogenic C imports/exports and related changes of soil C pool were then accounted for through the net ecosystem C balance (NECB). The NECB approximated 90 g C m^{-2} yr^{-1} for C_{mng} and 730 g C m^{-2} yr^{-1} for S_{mng}. This result highlights the critical role of appropriate management of the variable components on sustaining ecosystem resilience, including the management of pruning residues, the import of organic materials, and the maintenance of a cover crop. Over a 7-year study period, C stock (SOC and litter) increased at a mean rate of ~145 g C m^{-2} yr^{-1} in the S_{mng} plot while it increased at only ~7.5 g C m^{-2} yr^{-1} in the C_{mng} plot. Whole-tree standing biomass was measured by tree excavation revealing that the C sequestered over the 14-year lifetime of the orchard was close to 25 t C ha^{-1}. This study provides information on C stock variation (soil + biome) and on annual net atmospheric C removal (NEP) in a cultivated peach orchard under Mediterranean climate conditions.

1. Introduction

Agriculture is a key socio-economic sector and thus a driving force for sustainable development as it relates to a number of crucial conditions of sustainability and ecosystem services delivery including conservation of natural capital (Costanza et al., 1997; Bithas and Nijkamp, 2006; Bithas, 2008). Agriculture is also pivotal to our response to climate change because it both contributes to greenhouse gas (GHG) sinks through photosynthesis and also to GHG emissions through the microbial processes of organic matter decomposition and through human management/disturbance of agro-ecosystems (Tubiello et al., 2015).

Within the UN Framework Convention on Climate Change (UNFCCC), the European Commission (EC) is already taking actions to reduce GHG emissions in all economic sectors including agriculture as combined in the so-called LULUCF sector (land-use, land-use change and forestry) (see EC, 2013). Although rigorous accounting of the C fluxes in the agricultural sector is of high significance, standard accounting methods fail to approximate the relevant characteristics of certain agricultural activities (EC, 2013). In this regard, aspects of orchard and vineyard

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management relevant to climate change mitigation and adaptation strategy (e.g. carbon removal and storage in the soil and in woody biomass) are rarely reported under UNFCCC accounting protocols (Huffman et al., 2015). This is likely because orchards do not conform to the definition of a 'forest' with the result that orchards are sometimes listed under 'grasslands' so that the carbon (C) stored in orchard tree biomass is not accounted for (Arets et al., 2014). Similarly, variations in the C pools (e.g. soil organic carbon and crop biomass) associated with land use change and with different management (e.g. sustainable, conventional) are often not accounted for in assessments of product life cycle greenhouse gas emissions due to limited information and inadequate accounting procedures (PAS, 2008; Goglio et al., 2015).

The seasonal carbon removal capacity of biome is related to its metabolism, particularly to the balance between photosynthesis and respiration (Sala et al., 2012). Hence, environmental conditions (especially air temperature and soil moisture) are influential both on the photosynthetic capacity and also on the respiratory demand of trees (Grossman and DeJong, 1994). Therefore, climate is pivotal in understanding the balance between C removal, C sequestration and C release. As noted by Panzacchi et al. (2012) only a few reports provide annualised information on orchard C fluxes, especially in relation to the Mediterranean ecoregion, and such information as is available relates predominantly to evergreen species such as olives, oranges (Almagro et al., 2009; Liguori et al., 2009; Nardino et al., 2013; Palese et al., 2013). Because evergreen spp. have a year-round physiological activity (Nardino et al., 2013), they are likely to differ from deciduous ones in terms of their C sequestration capability. Hence, better information on C fluxes in deciduous orchards in Mediterranean climates is highly desirable if GHG accounting is to be improved.

Most ecologists describe imbalances in C uptake and loss by ecosystem respiration as net ecosystem production (NEP), where this reflects ecosystem metabolism and its interaction with the environment (e.g. weather, soil water) (Chapin et al., 2006). However, cultivated land is a managed ecosystem, hence analysis of its C fluxes should account for the net of all C imports/exports to/from the orchard, including those generated by anthropogenic activity. In cropland, organic C can enter the ecosystem through the additions of organic fertiliser (manure, compost, biochar etc.). Meanwhile, C can leave through a range of possible non-respiratory C losses (harvest removal, fire, erosion, leaching etc.). An assessment of these fluxes is necessary for proper identification of feasible GHG mitigation options at local, regional and national scales (Nayak et al., 2015). At the orchard scale, some management options (tillage, cover crops, burning or mulching of pruning residues, use of organic or inorganic fertilisers etc.) will have significant impacts on C fluxes (West and Marland, 2002), however the impacts of these practices on the overall C fluxes in a Mediterranean deciduous orchard have not been adequately explored. The overall C balance from all physical, biological and anthropogenic C imports/exports has been conceptualised within the framework of the Net Ecosystem Carbon Balance (NECB) (Chapin et al., 2006) which identifies an orchard as a net sink, where NECB > 0, or as a net source, where NECB < 0.

Despite some criticism of the significance of cultivated soil at the scale of global C cycles due to the issue of permanence of SOC stocks (Schlesinger, 1990; Smith et al., 2007), there is general consensus on the function of soil to potentially serve as a stable reservoir for atmospheric CO_2. Thus, at the recent Paris climate conference (UNFCCC-COP21, December 2015) it was proposed that SOC sequestration be increased at the rate of 4‰ per year to offset continuing global anthropogenic emissions (Lal, 2015). Sustainable agricultural ecosystems (including orchards) have the potential to sequester C at rates similar to those of forests (Wu et al., 2012; Zanotelli et al., 2013), however their role in delivering climate change mitigation remains controversial (Powlson et al., 2016 and references therein). The contribution of agricultural ecosystems (soil + biome) to the overall C fluxes of the LULUCF sector is still debated, as can be inferred from the public consultation launched by EC on the integration of agriculture, forestry and land use into the EU's climate and energy policy for 2030 (see http://ec.europa.eu/clima/consultations/articles/0026_en.htm).

With this as background, the first objective of this study was to test the hypothesis that in a sustainable Mediterranean peach orchard (*Prunus persica* L. Batsch), the absolute annual C change as affected by plant metabolism (NEP), as well as by the removal of harvested fruit, pruning residues etc., and by the import of organic fertilisers and cover crops, is net positive (i.e. NECB > 0). This would allow it to be considered a C sink (*sensu* Chapin et al., 2006). The second objective, was to examine whether a switch from conventional to sustainable cultivation over a medium temporal horizon in a Mediterranean peach orchard would significantly contribute to GHG mitigation through the growth of the soil C pools (SOC and litter). The third objective, was to quantify C sequestration in standing above- and below-ground biomass of fruit trees growing in a Mediterranean peach orchard throughout their commercial lifetime.

2. Materials and methods

2.1. Study site and treatment application

The study was conducted in southern Italy (N40°23′ E16°42′) under Mediterranean climatic conditions where long-term average annual rainfall is 550 mm and is highly seasonal, usually falling between October and May, with insignificant amounts between June and September. The mean annual maximum air temperature is 21.4 °C, with mean peaks at 35.5 °C in July (SAL Service, ALSIA Basilicata Region). Trials were carried out in a peach (*Prunus persica* (L.) Batsch Nectarine) orchard cv. Super Crimson grafted on GF677 planted at the beginning of 1997 on a *Typic Xerofluvents*, WRB, sandy-loam soil (68.8% sand, 16% silt and 15.3% clay, 15%ww of soil coarse fraction >2 mm), 23 m a.s.l. Trees were trained to delayed-vase and spaced 5 m between rows and 4 m along the row. The orchard was managed according to locally conventional practice (C_{mng}); drip irrigation (approx. 6500 m^3 ha^{-1} per year) and fertilization were localised along the row (a 1.0 m wide band), on average the orchard received 140 (N), 70 (P) and 100 (K) kg ha^{-1} each year. Soil was evenly tilled 4–5 times during the growing season (February–August) using an 18-disc harrow (10 cm depth) and pruning was done in winter and all residues were removed and burned.

A 1 ha block was subjected to sustainable management (S_{mng}) for a 7-year period starting from 2004. Soil was untilled and the spontaneous understorey 'grass' was mowed three times (usually in March, May and June to 3–4 cm). Fertilisation was based on tree demand and on the availability of essential nutrients in the soil (soil analyses) (Xiloyannis et al., 2006; Montanaro et al., 2010). In the S_{mng} block, only N was supplied as mineral fertiliser (50–60 kg ha^{-1} per year). Organic amendment (compost) was supplied in winter at a rate of 15 t ha^{-1} per year (fresh weight, 25% moisture content). The compost was localised in a ~1 m wide band along the row. The compost (22.2C/N; Eco-Pol SpA – Italy) on average contained on a dry matter basis 35% C, 2.02% total N, 1.8% organic N, 1.86% K_2O, and 0.9% P_2O_5. Pruning was done each year in December and January and the pruning biomass was chipped and evenly distributed in the alley.

Based on preliminary observations carried out at the beginning of the experiment, within each block there was no heterogeneity in SOC, in trees shape/size, in supply of nutrients and irrigation; application of treatments was uniform because it was easy to