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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.

Key words: carbon sequestration, conventional, NECB, soil respiration, standing biomass, sustainable

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 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 2050, 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 III 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 III 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 et al., 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 III 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 (N 40° 23’ E 16° 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 >2mm), 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. 6,500 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 (22.2 C/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 manipulate the compost application, tillage, pruning residues and cover crops mulching, etc. Therefore, according to Clewer and Skarisbrik (2001), under these fairly uniform conditions, the sampling programme employed a completely randomised design (CRD) with single-tree experimental plots with 3-20 independent replicates per treatment.

2.2 Net Ecosystem Carbon Balance (NECB)

The net annual rate of C change (accumulation/loss) in the orchard ecosystem was assessed through the NECB (Chapin III et al., 2006) based on the equation:

$$NECB = NEP + LTC$$

where NEP is the net ecosystem production calculated as the difference between above- and below-ground net primary production (NPP) (assessed through the above- and below-ground annual biome biomass) and the heterotrophic component of soil respiration (R_h); the

LTC represents the lateral transport of carbon related to anthropogenic imports/exports such as fruit harvest, removing of pruning residuals and import of organic fertilisers. The amount of C exported by fruit at harvest was that computed as NPP (see below). Whereas, the amount of lateral transport due to the removal of pruning residuals was determined collecting the pruning material in winter from 15 trees per treatment, and analysing their dry matter (DM) content and C concentration on pruned subsample shoots (see 2.4 paragraph). Carbon imported through compost application was determined based on the amount of compost supplied and its declared C content.

The NECB was calculated on a yearly basis and expressed as g C m^{-2} yr^{-1}, details on NECB components are reported below. Possible fluxes of C due to soil erosion were not considered because soil was flat, fluxes of methane, carbon monoxide, volatile organic carbon, and dissolved organic and inorganic C were also not considered in the present study.

2.2.1 Above-ground NPP: current-year and standing biomass

Newly produced above-ground annual biomass was calculated as dry mass and C content of current-year biomass (shoots, foliage, fruits) from both trees and cover crops and the increment of standing biomass from trees (trunk, branches).

2.2.1.1 Leaf and shoots

Each year in October/November leaves were collected to estimate the NPP from leaves by placing nets on the ground underneath five trees per treatment, and eventually leaf fall was manually completed. The woody material removed by routine annual pruning in winter was collected from 10 trees (×5 per treatment) and partitioned in current-year shoots and branches. The total length of current-year shoots left after pruning on the trees was measured and their DM content estimated through pruned subsample shoots. Each year (mid-July) trees were subjected to summer pruning removing un-fruiting shoots. This summer pruning material was sampled from 5 trees per treatment. Subsamples (×3 per tree) were used for DM determination.

2.2.1.2 Fruit

At harvest (mid-June) fruit yield (fresh weights) were measured yearly on 20 trees per block and results expressed as t $ha^{-1}yr^{-1}$. Fruit DM was estimated through subsamples (× 3 per tree). The NPP of thinned fruit was also measured picking thinned fruit from three $1m^2$ areas per tree (×5 per treatment) in May.

2.2.1.3 Branches and trunk growth

At the end of the last year of the experiment, 3 trees per treatment were sawn at ground level and aerial biomass partitioned in current-year shoots and branches including trunks. Then annual NPP of the standing biomass (branches + trunks) (Δ_{WOOD}) was calculated assuming a mean annual increment of 7 g DM g^{-1} DM (Grossman and DeJong, 1994).

2.2.1.4 Cover crops

At the time of each mowing operation, an 'understory clippings' sample was randomly taken from a typical 1 m^2 area (×3) in the S_{mng} and C_{mng} plots to estimate the amount of C returned to the soil by mowing.

2.2.2 Below-ground NPP: current-year and coarse root biomass

The 3 trees per treatment used for the above-ground biomass determination were excavated to measure the root biomass. A backhoe was used to excavate trenches 2.5 m from each tree to a depth of ~ 1.5 m. Then soil blocks (approx. 30 × 30 × 50 cm) were removed from a 5 × 4 m area around each tree, blocks were manually sifted and all roots were collected. According to Abrisqueta et al. (2008) roots were partitioned in two classes: current-year roots (<2 mm diameter) and coarse roots (>2 mm). Annual biomass increment of coarse roots (Δ_{ROOT}) were calculated as for the above-ground biomass (Grossman and DeJong, 1994). Root biomass of the cover crops was estimated as 15% of the above-ground one (De Baets, 2011).

2.3 Carbon sequestration in soil and in tree biomass

2.3.1 SOC

At the beginning of this study (winter 2003-2004), an initial composite soil sample was taken for SOC analysis. Nine soil cores at three depths (0-10, 10-20 and 20-40 cm) were collected at random from each S_{mng} and C_{mng} block with a soil probe in the row and the inter-row (visible crop residues were previously removed from the soil surface). Soil cores from the same depths were combined in 3 subsamples and passed through a 2-mm sieve while still moist and then air dried. Soil coarse fraction (>2 mm) was similarly 15%ww in all layers. At the end of the study (late December 2010), the collecting of soil samples was repeated using the same procedures to quantify any changes in SOC. Determination of SOC was obtained by using the potassium-dichromate oxidation procedure. Soil bulk density was determined through the soil core method (Blake and Hartge, 1986) in soil samples collected in parallel with those collected for SOC determination. For calculation of aerial and C stock the bulk density was corrected for the coarse soil fraction assuming an average density of that fraction to be 2.65 Mg m^{-3} (Page-Dumroese et al., 1999). Changes of soil C concentration (%) and stock (t C ha^{-1}) were than calculated for each layer as the difference between initial and final values. After that, the mean annual carbon accumulation rate (g C m^{-2} yr^{-1}) was calculated considering the 7-year duration of the experiment.

2.3.2 Litter

At the end of the experimental period (winter 2010), three randomly chosen 1×1 m areas were used in both S_{mng} and C_{mng} blocks to determine the litter carbon storage lying on the surface of the mineral topsoil. All leaf and weed residues, twigs and 1-3 cm diameter branches, fruits and bark were considered litter in line with IPCC (2006) guidance on C pools. All organic matter within each area was collected and washed through a series of sieves to remove all adhering soil particles before being dried for C determination. The change of litter C stock was calculated as the difference between the initial and final values, annual mean litter biomass accumulation rate was then calculated dividing collected biomass by the duration (7 years) of the experiment assuming no litter at the beginning of the experiment.

2.3.3 Total standing biomass accumulated during the orchard lifetime

The amount of C stored in tree above- and below-ground standing biomass throughout the orchard lifetime (14 years) was calculated as the difference between the initial tree standing biomass of a 1-year old peach seedling reported in Xiloyannis et al., (2007) and the tree biomass determined in this study through complete excavations of trees (see above the Δ_{WOOD} and Δ_{ROOT} determinations).

2.4. Dry matter and C determination

After recording the fresh weights for each organ category and treatment, subsamples were weighed and dried to a constant weight at 105°C in a ventilated oven and reweighed for dry matter (DM) determination. The length of current-year shoots subsamples was also measured to determine the amount of DM per unit length used for dry weight estimates of unpruned current-year shoots. The dried samples were then weighed and ground in a mixer ball mill to a fine powder which was used for carbon determination (dry combustion method, LECO-SC). Carbon content was calculated for each organic component by multiplying the carbon fraction by the biomass (dry weight) produced per component and expressed as g C m^{-2} yr^{-1}.

2.5. Soil C input

Amounts of annual C input were determined by the summation of C derived from compost and pruning residuals (S_{mng}) and NPP values of those organs falling to the ground such as leaves, thinned fruits, summer pruning, cover crops and 95% of the current-year root biomass of trees (Zanotelli et al., 2014).

2.6. Soil CO_2 emissions

At each plot, soil CO_2 emission (R_s) was measured *in situ* through a non-dispersive infrared gas analyser (Li-6400, LI-COR, Lincoln, NE, USA) equipped with a soil respiration chamber (Model Li-6400-09) fitting to a PVC collar (a 10 cm long section of 10 cm OD PVC pipe). 30 collars per treatment were installed into the soil (4 cm depth) at the beginning of the experiment (January) and remained in place until the end of December 2010. Only for the C_{mng} plots, collars were temporarily removed for approx. 20 min to allow tillage operations and were replaced in the same locations at the end of tillage. Soil CO_2 efflux measurements were made every two or three weeks from January to December during the central part of the day (11 am - 1 pm), all data from the 30 locations per treatment were then averaged. The CO_2 gas analyser operated between a maximum and minimum CO_2 levels which were equal to that measured close to the soil surface just before the measurements ±10 ppm CO_2. The soil temperature (from 0 to 15 cm depth) was measured a few centimetres away using the 6000-09TC Li-COR temperature probe. Daily estimates of the CO_2 soil emissions were derived multiplying by 24 the mean measurements made at each plot considering a 1.15 coefficient as recommended by Savage and Davidson (2003). Then integration of all daily fluxes of each treatment across the studied period was employed to calculate the annual R_s. Values of R_s were partitioned in their heterotrophic respiration (R_h) component assuming R_h equal to 75% of R_s (Matteucci et al., 2015).

2.7. Data analyses

The analysis was performed using OriginPro 9.3 (OriginLab Corporation, USA), data were reported as mean and standard error of the mean (±SE). The comparisons of mean values between S_{mng} and C_{mng} treatments were made by using the Student's *t*-test.

After testing for normality (Kolmogorov–Smirnov test) and homogeneity of variance (Levene test), one-way ANOVA were used to separately examine (i) the differences between soil depths within each “initial” or “final” group, and (ii) the differences between treatments (C_{mng} and S_{mng}) at each depth. A two-way ANOVA (main effects and interactions) for bulk density, SOC and C stock involved the management (C_{mng}, S_{mng}) (factor 1) and the depth (0-10, 10-20 and 20-40 cm) (factor 2). In both one- and two-way ANOVA, the differences among means were identified by post hoc Tukey tests. For the Student's *t*-test and ANOVA *p*-values <0.05 were considered significant. All the parameters used to track the effect of soil managements (bulk density, SOC concentration and C stock) were separately analysed.

3. Results and discussion

3.1 Above- and below-ground NPP

Annual NPP of peach trees was ~655 (S_{mng}) and ~615 (C_{mng}) g C m^{-2} yr^{-1} (Table 1). The reason for the ~6% higher NPP at the S_{mng} plot was almost entirely due to the increased yield (see below) which is expected under increased C input (Wilhelm et al., 1986; Gebrekidan et al., 1999; Mesfine et al., 2005). Results on NPP are in line with mean annual NPP (700 g C m^{-2} yr^{-1}) estimated over a 20-year period at a plum and peach orchard grown in California under Mediterranean type climate conditions (Kroodsma and Field, 2006). Partitioning of annual NPP of trees reveals an ~82% allocation of newly synthesised C to above-ground biomass (including increment of trunks and branches) in both S_{mng} and C_{mng} treatments (Fig. 1) similarly to what was reported for a mid-August maturing peach cultivar (Grossman and DeJong, 1994). However, relative NPP of fruit was higher (and that of leaves lower) in S_{mng} plot than the C_{mng} one which could be interpreted as a better productive/vegetative ratio (Fig. 1). As expected, results on NPP allocation differed from that observed in olive groves that showed a preferential C allocation to roots (60-70% of total NPP) likely because of some specific adaptive mechanisms of olive species to dry conditions (Dichio et al., 2002; Almagro et al., 2010). Atmospheric C fixed by cover crops (above- and below-ground biomass) was approx. 155 and 15 g C m^{-2} yr^{-1} for S_{mng} and C_{mng}, respectively (Table 1), the latter was related to weed growth which occurred during two consecutive tillage operations. In this study, the soil coverage was due to spontaneous understorey 'grass', however, a double cover crops biomass (and in turn carbon sequestration by the ecosystem) could be achieved when it is sowed (Xiloyannis et al., 2007).

Accounting also for the cover crops biomass a total NPP of approx. 810 and 630 g C m^{-2} yr^{-1} was reached for S_{mng} and C_{mng} plots, respectively (Table 1). Values of NPP are in the magnitude of that reported for apple orchards (785-960 g C m^{-2} yr^{-1}) grown at higher densities (approx. 2,600-3,300 p ha^{-1}) in a more temperate area (Panzacchi et al., 2012; Zanotelli et al., 2013). Information on NPP for Mediterranean (deciduous) orchards are still limited preventing in-depth examination of results. In 50-100-year old Mediterranean olive ecosystems with a lower planting density, an annual NPP has been estimated ranging from 324 (rainfed, 107 p ha^{-1}) to 1,030 g C m^{-2} yr^{-1} (irrigated, 156 p ha^{-1}) (Almagro et al., 2010; Palese et al., 2013), while the NPP was on average 540 g C m^{-2} yr^{-1} in an orange orchard (Liguori et al., 2009).

Analysis of NPP in agricultural ecosystems should separately account for evergreen and deciduous fruit trees mainly because evergreens (such as olives, oranges and lemons) have a year round activity (Nardino et al., 2013), in addition as a Mediterranean endogenous species olives have some peculiar functional and anatomical traits likely affecting its carbon capture ability (Dichio et al., 2006 and 2013). To explain, at least in part, the NPP variability existing among various fruit tree species grown in different environments (temperate, Mediterranean), apart from intrinsic variable factors (e.g. training system, plant density, soils, tree age, disturbance/management events), the different balance between photosynthesis and respiration could be evoked.

Reduction of growth rates of new organs and tree stands (and in turn in NPP) may occur as a result of reduced C supply via photosynthesis or an increase of C demand due to an increase of the respiratory load (Sala et al., 2012). Under Mediterranean growing environmental conditions (e.g. air temperature and relative humidity) photosynthetic activity may be limited during summer by metabolic impairments of photosystem II (Montanaro et al., 2009) causing a decrease of C supply with a reasonable negative impact on NPP. Air temperature is also influential on respiratory demand of tree organs (Grossman and DeJong, 1994), this in turn could reduce NPP under Mediterranean type environmental conditions where the temperature is relatively high.

3.2 Soil respiration

Diurnal change of R_s is mainly driven by changes of soil temperature and plant activity (Kuzyakov, 2006) hence, it is expected that continuous (automated) measurements of CO_2 soil emissions are required to collect a whole h-24 determination of emissions. However, there is evidence that a daily (and in turn seasonal) flux could be estimated with a manual sampling schedule of late morning measurements. In this study, we adopted the approach proposed by Savage and Davidson (2003) to capture the most important variation of seasonal flux of CO_2 from the soil starting from late-morning samplings, even if eventual site-specific bias of the method remains to be tested.

On the basis of a whole season, diurnal CO_2 efflux rates showed a similar pattern in both S_{mng} and C_{mng} plots with the lowest values of approx. ~1 g CO_2 m^{-2} d^{-1} recorded in winter time (i.e. January and December) according to the lowest soil temperatures and the conceivably negligible tree physiological activity (Fig. 2). During the firts 4 months of the year, emissions steeply increased in both treatments but were significantly more pronounced in the S_{mng} peaking at ~7 (S_{mng}) and ~5.6 g CO_2 m^{-2} d^{-1} (C_{mng}) at the end of springtime, however a transient decrease of R_s was recorded in early April.

The initial rapid increase in emissions occurred at the same time of the season as new plant organs (shoots, roots, leaves, flowers, fruits) develop rapidly (Rufat and DeJong 2001; Basile et al., 2007) implying a rise in canopy photosynthesis and root metabolism which are drivers of soil respiration (Tang et al., 2005).

From May, emissions fell toward a minimum in mid-July (the hottest driest period). In mid-September, rates recovered to reach values similar to the earlier peaks, thereafter these emissions declined again and by mid-December they were comparable to those in January (Fig. 2).

This seasonal trend agrees substantially with evaluations of R_s in orange (Liguori et al., 2009), apple (Panzacchi et al., 2012) and olive groves (Almagro et al., 2009).

Annual R_s totalled 1.51±0.06 (SE) and 1.63±0.21 kg CO_2 m^{-2} yr^{-1} in conventional and sustainable managed plots, respectively (Fig. 2). Such a difference of ~10% was not statistically significant. However, our interpretation is that R_s at the S_{mng} plot had a tendency to be higher likely because of the increased root and microbial activity as it is expected under increased C supply conditions (mainly due to the application of an organic amendment and the return of crop residues in this study) (Han et al., 2007).

It is difficult to compare results of R_s against studies performed in similar Mediterranean ecosystems due to limited information existing. In a less dense (107 tree per ha) rainfed and regularly tilled Mediterranean olive groves, annual R_s has been estimated to approach 2.1 kg CO_2 m^{-2} yr^{-1} as a mean value of areas beneath the canopy and inter-row positions (Almagro et al., 2009). Annual CO_2 respiration reported in the present study is in the range also of that of apple ecosystems grown in a more temperate environment (1.2 – 2.9 kg CO_2 m^{-2} yr^{-1}) (Wu et al., 2012; Zanotelli et al., 2013).

The mean annual R_h was not significantly affected by treatment being estimated at 335.5±42.8 and 310.6±13.0 g C m^{-2} yr^{-1} for the S_{mng} and C_{mng} plots, respectively (Table 2). Consistency of C flux estimates in forest ecosystems has been appraised through a series of ratios between the C fluxes including R_h/NPP ratio (Luyssaert et al., 2009). At the S_{mng} plot, half of NPP (excluding fruit exports) has been respired by heterotrophs (R_h/NPP = 0.5) (Table 2) suggesting a good agreement between fluxes (Luyssaert et al., 2009); at the C_{mng} plot the R_h/NPP ratio increased up to 0.78 because of the removal of fruit and wood and due to the exporting of pruning residuals, this fits with a similar increase in R_h/NPP ratio recorded in managed forests (Luyssaert et al., 2009).

Heterotrophic respiration was not directly measured in this study but calculated from measurements of total soil respiration assuming a R_h/R_s ratio equal to 0.75 according to Matteucci et al. (2015) who partitioned R_h throughout a relatively long period (~ 1 year) in a Mediterranean pine forest. A similar R_h/R_s ratio equal to 0.77 has been found when accounting for space variability of soil CO_2 respiration in apple orchards (Zanotelli et al., 2013), this further supports the R_h/R_s ratio adopted in this study which tends to be 15-20% higher than that used in other studies (Ceccon et al., 2011; Scandellari et al., 2015). Emissions of CO_2 from soil vary with space (and time) particularly in drip irrigated orchards where water is supplied only along the row differentiating soil moisture across the alley throughout the whole irrigation season (Montanaro et al., 2012; Lardo et al., 2015). Consequently, root distribution is affected by localised irrigation causing root mass density at inter-row to be very low compare to that of row (~0.2 and 15 kg DM m^{-3}, respectively) (Xylogiannis E., in preparation). The "regression approach" proposed to separate the various components of soil CO_2 efflux is based on the assumed linear relationship between root biomass and the amount of CO_2 respired by roots and rhizosphere microorganisms (Kuzyakov, 2006). Accordingly, considering the abovementioned very low root mass density at the inter-row, the R_h/R_s ratio reasonably sited at ≅1 at that position, this further supports the mean R_h/R_s value equal to 0.75 we adopted. However, more efforts are required to elucidate the space variability of R_h in Mediterranean orchards under localised irrigation.

3.3 Net Ecosystem Production

Net ecosystem production (NEP) is the balance of net primary production (NPP) and heterotrophic respiration (i.e. NEP = NPP-R_h) and reflects the ecosystem metabolism as it responds to variations in environmental variables (e.g., soil, water availability, weather) and to disturbing events (including anthropogenic management) (Chapin III et al., 2006). Net ecosystem production estimated in this study was significantly affected by management and ranged from ~320 to ~475 g C m^{-2} yr^{-1} in C_{mng} and S_{mng} plot, respectively (Table 2).

Again results are comparable with those reported in apple orchards (380 g C m^{-2} yr^{-1}) even if for apple ecosystem NEP could be as high as ~630 g C m^{-2} yr^{-1} (Panzacchi et al., 2012; Zanotelli et al., 2013). In Mediterranean orange orchards, NEP ranged from 240 to 330 g C m^{-2} yr^{-1} (Liguori et al., 2009), while in irrigated olive ecosystems an annual net ecosystem exchange (equivalent to NEP) ranging from 760 to 1,250 g C m^{-2} yr^{-1} has been estimated (Testi et al., 2008; Nardino et al., 2013).

Net carbon gain among orchards appears to be roughly variable. Similarly, net ecosystem carbon exchange in forest ecosystems has been reported to be variable to the extent that annual carbon balances range from an uptake of 660 g C m^{-2} yr^{-1} to a release of ~100 g C m^{-2} yr^{-1} (Valentini et al., 2000). The observed variation in NEP has been explained by the different relative importance of ecosystem respiration (autotrophic + heterotrophic) that changes consistently across the sites as influenced by the temperature-induced soil and biome respiration (Valentini et al., 2000). Hence, isolation of the ecosystem respiration in various ecoregions could be beneficial for an accurate and more comparable assessment of the carbon balance of orchards.

3.4 Lateral transport of carbon

Although farmers decide on the options of tillage or cover crops having an anthropogenic nature, the C fluxes related to cover crops biomass were included in the NEP calculations. Increased supply of C to soil (through compost, retention of pruning residuals, mulch of cover crops) supported the increased yield (fresh weight) up to 23.2±2.03 t ha^{-1} under S_{mng} (averaged over seven years), whilst it was 17.9±2.3 t ha^{-1} under C_{mng} likely because of the availability of improved nutrients and the overall soil fertility as discussed in Montanaro et al. (2012). The equivalent C fluxes exported with fruit from the field was approx. 93 and 134 g C m^{-2} yr^{-1} for the C_{mng} and S_{mng} plots, respectively (Table 3).

Average pruning material was 3.1 t ha^{-1} DM at the C_{mng} equivalent to -138±20.7 g C m^{-2} yr^{-1} transferred out of the plot (see Table 3). Pruning material of the S_{mng} plot (mean annual 2.6 t ha^{-1} DM) was entirely mulched *in loco.* Hence, it was not reported neither as export nor as import because it was already accounted for in the tree NPP. Hence, sustainable management caused the S_{mng} plot to be a net importer of C with approx. 260 g C m^{-2} yr^{-1} mainly due to the compost supply (approx. 390 g C m^{-2} yr^{-1}) that compensated fruit export. The S_{mng} plot was therefore a net importer and will be in favour of the increased SOC (see below), by contrast, the C_{mng} plot was a net exporter of about -230 g C m^{-2} yr^{-1} (Table 3).

3.5 Net Ecosystem Carbon Balance

Agricultural fields are managed ecosystems, therefore external (anthropogenic) drivers are significant to determine whether an orchard is a C-sink or C-source. This study determined the NECB in a Mediterranean peach orchard accounting for the net of all C imports to and exports from the orchard according to the conceptual framework proposed by Chapin III et al., (2006). However, some components of C fluxes (e.g. exudation from roots, mycorrhyzas demand) were not considered because are there intrinsic difficulty of measuring as in most estimating NPP exercises (Luyssaert et al., 2009).

Table 3 reports the NECB determined for both management options considered in this study showing that apart from the exports of yield, some orchard management practices impacted the lateral transports of C and in turn the NECB. Anthropogenic disturbances (or mismanagement) of the orchard ecosystems at the C_{mng} plot contributed to maintain the NECB at ~89 g C m^{-2} yr^{-1} (Table 3). That level of NECB is comparable to that recently calculated in apple orchards (~70 g C m^{-2} yr^{-1}), where the import of C as organic fertiliser was less than 10% of that supplied in the present study (Zanotelli et al., 2014). Despite the positive value of NCEB, the conventionally managed plot remains highly susceptible to becoming a source (i.e. NECB <0), for example after an increased yield as occurred in a multi-year experiment in apple orchards (Zanotelli et al., 2014). The adoption of sustainable practices increased the NECB up to 734 g C m^{-2} yr^{-1}, which was attributable to NEP (65%) and to a net anthropogenic lateral transport of C (35%) (Table 3).

Although values of NEP could be comparable among various orchards because of a similar biome metabolism, final NECB could greatly differ mainly because of different net import/export C fluxes caused by different management strategies. For example, although results on NEP presented in this study for the S_{mng} plot are comparable to that measured in apple ecosystems, the value of NECB was ~10-fold greater, such a difference was mainly related to the differences in C exported with yields (418 *vs* ~134 g C m^{-2} yr^{-1}) and imported with organic fertilisers (36 *vs* ~394 g C m^{-2} yr^{-1}) (see Table 3 this study and Zanotelli et al., 2014). In addition, we note that C export associated to yield would generally be lower in Mediterranean ecosystems because most of the cultivars ripen early in the season and therefore would have a reduced size and biomass compared to those which ripen later (Policarpo et al., 2002).

3.6 Carbon sequestration in soil and litter

Generally, the C sequestration rate by the ecosystem is related to C input as influenced by the management practices adopted (see Aguilera et al., 2013a). In this study, the amounts of C input rate reached approx. 900 and 270 g C m^{-2} yr^{-1} in S_{mng} and C_{mng} treatments, respectively which was in the range (up to 2,400 g C m^{-2} yr^{-1}) reported in a recent meta-analysis covering various Mediterranean cropping systems (Aguilera et al., 2013a). In addition, changes of soil management could impact soil bulk density which requires an appropriate sampling programme to avoid inaccuracy of soil C stock calculation (Lee et al., 2009). However, in this study, bulk density values were all in the range of 1.38-1.55 t m^{-3} and not different for S_{mng} and C_{mng} treatments (Table 4). This is substantially in line with results gathered at tilled and no-tilled Mediterranean olive groves (Palese et al., 2014) and after a 10-year period of changed soil management practices in a corn field (Blevins et al., 1983). On the contrary, Lee et al. (2009) report a significant effect of tillage on bulk density. This apparent discrepancy could be explained considering that in the present study a relatively longer time (~5 months) elapsed from the last tillage and soil sampling compared to Lee et al. (2009). In addition to the longer time, the rains may have also contributed to mask the effect of tillage on bulk density.

In this study, to improve C stock estimations, the total bulk density was corrected (not shown) to account for its soil coarse fraction (see Methods section). This 7-year period experiment allowed the detection of a significant increase of SOC concentration only in the 0.1 m soil profile at the S_{mng} plot while it remained roughly stable at the other depths (Table 4) according to the stratification of SOC with soil depth and management documented by Franzluebbers (2002). Interpretation of results of the analysis of variance (main effects and interaction) (Table 4) further confirmed that the application of changed management practices was not significantly influential on SOC (and others parameters) changes when the whole 0-40 cm soil profile is considered, at least in a 7-year period.

The increase of SOC is a slow process usually not detectable within 2-5 years after changing to a conservative management (e.g. organic residue application and no tillage) (Franzluebbers and Arshad, 1996; Montanaro et al., 2010). The analytical SOC change reported here for the S_{mng} plot fits with the idea that response of SOC to a change in management practices may only be expected from as ~10 year perspective (Al-Kaisi and Yin, 2005). This may explain why in relatively short-time experiments (1-2 years) the variations of SOC are considered negligible and thus the C flux analysis of orchard do not account for that negligible SOC (Almagro et al., 2010). This study reveals that sustainable management practices allow a net storage of approx. 5.8 t ha^{-1} of more stable C into soil (0.40 m depth) at a mean rate of approx. 82.5 g C m^{-2} yr^{-1}, and the upper 10 cm soil layer accounted for most of these C changes (Table 5). The increased mean annual SOC accumulation rate was approx. 9% of mean annual soil C input (including compost) which is comparable to the fraction of biomass to be transformed in a stable C into soil proposed by Ventura et al., (2009).

The increased SOC rate falls in the range of C sequestration in agricultural top soils (5-100 g C m^{-2} yr^{-1}) generated by the adoption of the recommended management practices (e.g. conservation tillage with cover crops and crop residue mulch, use of compost and manure) (Lal, 2004). In a recent meta-analysis on C sequestration rate in various Mediterranean cropping systems, after compost supply and the adoption of cover crops the SOC was accumulated with a rate variable from ~50 up to ~300 g C m^{-2} yr^{-1} (0.27 m mean soil depth) (Aguilera et al., 2013a). Hence, the C accretion rate detected in this study could potentially increase in forthcoming years likely upon (*i*) a higher incorporation of surface residues into the soil through improved soil fauna activity, (*ii*) a potential increase of SOC at deeper layers and (*iii*) a reduced bulk density of soil (Six et al., 2004; Brown and Cotton, 2011).

In cultivated land (annual and perennial crops), the dead organic matter (litter and dead wood) still represents a significant C pool (IPCC, 2006). Management options (mainly the retention of pruning residuals) allowed a C storage in the litter at a mean rate of ~62 g C m^{-2} yr^{-1} at the S_{mng} plot while it was just 4 g C m^{-2} yr^{-1} at the C_{mng} one conceivably due to the erratic fall of dead shoot/branch residuals (Table 5). A lower production of the above-ground litter equal to 12 g C m^{-2} yr^{-1} was estimated in an olive grove (Almagro et al., 2010) likely because of a different pruning intensity compared to the present study. Considering both SOC and litter, the mean amount of C sequestered reached 145 g C m^{-2} yr^{-1} at the S_{mng} plot whilst it was only ~5% of that at the C_{mng} plot (Table 5).

Based on the finite nature of SOC, it conceivably appears that its increasing rate could slow down in future decades approaching a new equilibrium value (Powlson et al., 2012). However, this would not be relevant for the next centuries for Mediterranean soils because of currently low levels of SOC (~1%) (Romanyà and Rovira, 2011). The issue of the permanence of C in soil as a stable SOC remains debatable because C could be re-emitted in the atmosphere upon mismanagement (e.g. future introduction of tillage) and/or increased soil respiration due to increasing air/soil temperature making soil a roughly unstable C stock (Smith et al., 2007; Luke and Cox, 2011). In this respect, it could be suggested to till the soil *una tantum* to move the soil with a higher C content (SOC and woody detritus) to deeper largely anaerobic layers which mimic the wood burial strategy proposed for the forestry sector (Zeng, 2008).

3.7 Lifetime C sequestration in standing biomass

The Kyoto Protocol has renewed the interest in growing trees to sequester C particularly in the forestry sector and some regulations have developed accordingly (Cannel et al., 1999; EC, 2013). In this study, the total C sequestered by trees has been calculated considering a 14-year period which is on average the commercial lifetime of orchards in the area. As the standing biomass of trees was not significantly affected by the treatment (not shown), the S_{mng} and C_{mng} data on the lifetime C sequestration were combined. The quantification of the C removed from the atmosphere by the orchard throughout the lifetime revealed that approx. 25 t C ha^{-1} were stored in tree biomass (Table 6). That C removal capacity is approx. 20% higher than that of peach and plum orchards after a 15-20 year lifetime (i.e.

~20 t C ha^{-1}) estimated by Kroodsma and Field (2006) from wood and roots removed and commercialised by private companies in California. However, the permanence of that C conservation over a much longer period of time depends on the fate of that biomass. As noted by Aguilera et al. (2014) when fruit tree plantations are renewed the resulting biomass can be harvested and then burned in substitution of fossil fuels or sequestered as wood products.

4. Conclusions

The contribution to climate change mitigation options requires a range of strategies involving all producing sectors including agriculture to effectively keep the atmospheric CO_2 concentration as low as below the critical level. In this paper, the role of sustainable commercial peach orchards has been documented, showing the positive impact of S_{mng} practices on C fluxes via removal and storage of C in both soil and tree biomass. The adoption of S_{mng} practices promoted accretion of soil C pools such as SOC (approx. 82 g C m^{-2} yr^{-1}) and litter (approx. 62 g C m^{-2} yr^{-1}) which could be beneficial also for soil structure and functions on Mediterranean cultivated land (e.g. the soil water holding capacity and biodiversity). The supply of compost could also potentially be beneficial for the reduction of some non-CO_2 GHG emissions (Aguilera et al., 2013b; Palese et al., 2014; Garcia-Franco et al., 2015). Increasing the compost supply to fields would also contribute to the circular economy of those Mediterranean areas (e.g. Southern Italy) where organic raw materials are poorly separated from urban waste and not usually composted (Cementero et al., 2014).

Through the NECB framework, the role of appropriate management practices (e.g. destiny of pruning residuals, supply of external organic material, adoption of cover crops) has also been emphasised to sustain the ecosystem resilience. In this context, the present study showed the influence of sustainable practices on NECB of the S_{mng} orchard which was approx. 734 g C m^{-2} yr^{-1}, in this way the ecosystem operated as a sink. At the C_{mng} plot, the NECB remained approx. 90 g C m^{-2} yr^{-1}, hence because NECB>0 the C_{mng} plot was a (weak) sink, too. However, C_{mng} orchard remains susceptible to be a source (NECB<0) because the NECB may easily become negative, for example in case of increased lateral transport due to increased yield as occurred at an apple orchard (Zanotelli et al., 2014). Results on the lifetime C sequestration reflected the biological ability of the orchard to sequester atmospheric C under Mediterranean conditions (up to 25 t C ha^{-1}) which is a clear potentially achievable GHG mitigation capacity of orchards depending on the fate of that woody product.

This study could be supportive for analysing and accounting C fluxes in Mediterranean orchard ecosystems if a wide range of land use possibilities are to be explored for a more solid contribution of agriculture sector to GHG mitigation.

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Table 1 - Allocation of the mean (±SE) annual Net Primary Production (NPP, g C m^{-2} yr^{-1}) in various above- and below-ground components of tree and cover crops grown under sustainable (S_{mng}) and local conventional (C_{mng}) management practices. Δ_{WOOD} and Δ_{ROOT} indicate the increase of the NPP of standing above-ground and coarse root (including stump) biomasses, respectively. Comparing the values for S_{mng} and C_{mng} within the same component * indicates significant differences.

			S_{mng}	C_{mng}
TREE	Above	Fruit	134.6 ±5.3*	93.2 ±3.7
		Summer pruning	100.4 ±27.1	99.5 ±26.8
		Leaves	60.3±3.0*	84.5 ±4.6
		Thinned fruit	15.8±3.2	14.9 ±4.0
		$Shoot_{CURRENT-YEAR}$	106.0±7.4	107.8 ±7.5
		Δ_{WOOD}	116.2±9.3	108.9 ±6.7
	Below	$Root_{CURRENT-YEAR}$	67.5±5.4	58.1 ±4.6
		Δ_{ROOT}	54.1±2.7	48.7 ±2.9
		Total tree NPP	**654.9±52.3**	**615.6±39.2**
COVER CROPS	Above	mowed biomass	135.0±8.1*	13.5 ±0.6
	Below	Root	20.3±1.5*	2.0 ±0.2
		Total orchard NPP	**810.2±62.1 ***	**630.9±40.1**

Table 2 – Mean (±SE) net ecosystem production (NEP=NPP-R_h) (g C m^{-2} yr^{-1}) and R_h/NPP ratio in peach orchards under sustainable (S_{mng}) and local conventional (C_{mng}) management practices. Note that for the R_h/NPP ratio values of the NPP have been reduced considering the removal of fruit and pruning materials (see Table 3). Comparing the values for S_{mng} and C_{mng} within the same parameter * indicates significant differences.

	S_{mng}	C_{mng}
NPP	810.2±62.1*	630.9±40.1
R_h	335.3±42.8	310.6±13.0
NEP	474.9±43.4*	320.3±17.8
R_h/NPP	0.5	0.78

Table 3 – Annual mean (±SE) fluxes (g C m^{-2} yr^{-1}) of lateral transport of carbon (LTC, compost supply, pruning residuals and fruit harvest), net ecosystem production (NEP) and net ecosystem carbon balance (NECB = NEP+LTC), recorded at the sustainable (S_{mng}) and conventional (C_{mng}) plots. Note that negative values indicate an export of C from the orchard ecosystems, *na*= not applicable. Comparing values for S_{mng} and C_{mng} within the same parameter * indicates significant differences.

		S_{mng}	C_{mng}
LTC components	Compost	393.8±2.8	*na*
	Pruning	*na*	-138.2±20.7
	Yield	-134.6±7.5*	-93.2±3.2
	Total LTC	259.2±9.1*	-231.4±25.4
	NEP	474.9±43.4*	320.3±17.8
	NECB	734.1±47.7*	88.9±6.2

Table 4 – Mean values and standard errors (±SE) of total soil bulk density (BD) (t m^{-3}), SOC concentration (%) and C stock (t ha^{-1}) measured at the beginning (initial) and at the end (final) of the experiment in various soil layers at the sustainable (S_{mng}) and conventional (C_{mng}) plots. For each parameter, comparing data within the same group (initial or final), different small letters represent statistically significant differences; comparing data within the same layer different capital letters represent statistically significant differences. The underlined values represent those significantly different.

The two-way analysis of variance (main effects and interactions) for BD, SOC and C stock involved the management (C_{mng}, S_{mng}) and the depth (0-10, 10-20 and 20-40 cm) as factors.

	Bulk Density				SOC concentration				C stock			
Soil layer (cm)	C_{mng}		S_{mng}		C_{mng}		S_{mng}		C_{mng}		S_{mng}	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
0-10	1.38aA	1.40aA	1.42aA	1.44aA	1.30aA	1.31aA	1.30aA	**1.78bB**	12.62aA	12.88aA	12.94aA	**17.94bB**
	(±0.13)	(±0.15)	(±0.08)	(±0.12)	(±0.19)	(±0.20)	(±0.18)	(±0.11)	(±1.87)	(±1.82)	(±1.85)	(±1.06)
10-20	1.46aA	1.49aA	1.51aA	1.50aA	1.10aA	1.10aA	1.10aA	1.09aA	11.22aA	11.42aA	11.55aA	11.38aA
	(±0.80)	(0.13)	(±0.10)	(±0.08)	(±0.17)	(±0.16)	(±0.20)	(±0.15)	(±1.76)	(±1.08)	(±0.78)	(±1.51)
20-40	1.55aA	1.55aA	1.52aA	1.52aA	0.80aA	0.78aA	0.80aA	0.89aA	8.59aA	8.38aA	8.45aA	9.40aA
	(±0.09)	(±0.07)	(±0.09)	(±0.08)	(±0.21)	(±0.23)	(±0.19)	(±0.17)	(±1.25)	(±1.33)	(±1.29)	(±1.75)

		Bulk Density		SOC concentration		C stock	
MAIN EFFECTS	df	*F*	*p*	*F*	*p*	*F*	*p*
management	1	0.1249078	0.7255	1.9677413	0.1680	3.0758374	0.0868
depth	2	3.5622245	0.0572	22.994095	**<0.0001**	25.442464	**<0.0001**
INTERACTION							
management × depth	2	0.3375608	0.7154	1.5165329	0.2312	1.7172691	0.1919

Table 5 – Values of mean (±SE) carbon stock changes (t C ha^{-1}) in the 0-40 cm soil profile and in litter in both the sustainable (S_{mng}) and conventional (C_{mng}) plots, and the annual carbon accumulation rates (g C m^{-2} yr^{-1}) calculated considering the 7 year duration of the experiment; * indicates significant differences between treatments.

	Soil		Litter	
	C_{mng}	S_{mng}	C_{mng}	S_{mng}
stock change	0.24±0.1	5.78±0.32*	0.28±0.01	4.38±0.16*
accumulation rate	3.42±0.21	82.52±3.7*	4.00±1.6	62.57±4.7*

Table 6 – Carbon accumulated in above- and below-ground standing biomass (t C ha^{-1}) during the 14-year lifetime of the orchard. Data for the 15-year old orchard are the mean of that collected at the sustainable and conventional plots, the 1-year-old data were retrieved from Xiloyannis et al. (2007).

	1-year-old	15-year-old	Lifetime removal
Above-ground	0.02	17.21	17.19
Below-ground	0.01	8.15	8.14
Total	0.03	25.36	25.33

FIGURE LEGENDS

Figure 1 – Relative partitioning (%) of the annual net primary production (NPP) in various above- and below-ground components in trees grown under (A) sustainable and (B) conventional managements. Δ_{WOOD} and Δ_{ROOT} indicate the increase of NPP of standing above-ground and coarse root (including stump) biomasses, respectively.

Figure 2 – Seasonal trend of the daily soil CO_2 respiration (R_s) (g m^{-2} d^{-1}) and soil temperature (°C) (dashed line) recorded at the conventional and sustainable plots during the year 2010. Vertical bars indicate the standard error of the mean temperature and respiration value (n=30) and the filled areas indicate the annual CO_2 emissions (kg m^{-2} yr^{-1}). Comparing values of R_s for sustainable and conventional treatment * indicates significant differences. DOY = day of year.

Figure 1
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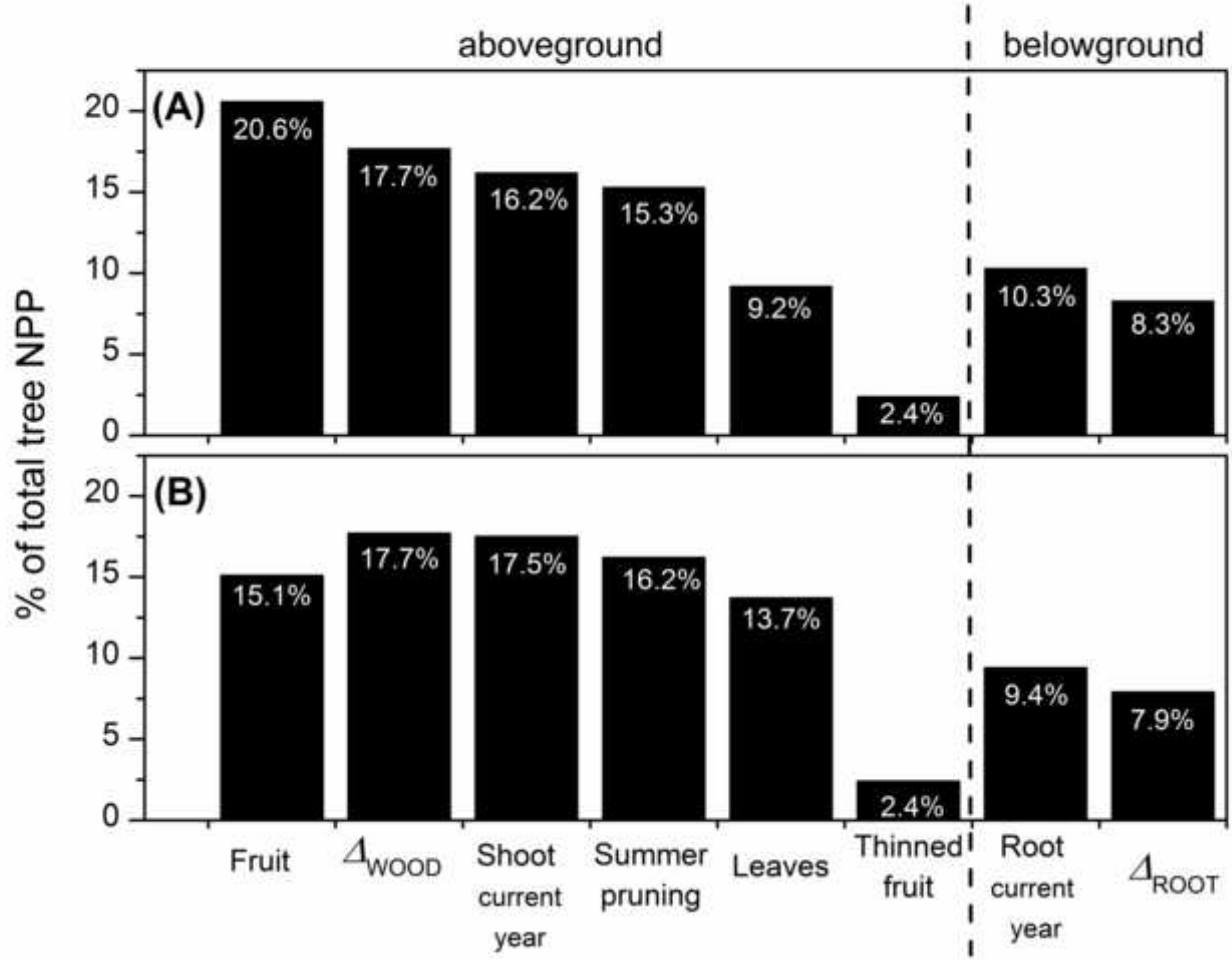

Figure 2
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