Sustainable Apricot Orchard Management to Improve Soil Fertility and Water Use Efficiency

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Keywords: crop residues, land use, organic matter, soil carbon input, SOC, Mediterranean soil

Abstract

This 4-year on-farm study reports the effects of different agricultural practices on yield and carbon input in an apricot orchard grown in Mediterranean area. Groups of plants under local orchard management (L_{OM}) practices (i.e., soil tillage, removing of pruning residues, mineral fertilisers) were compared with plots under sustainable orchard management (S_{OM}) actions (i.e., cover crop, no-tillage, compost application, mulching of pruning residues). In the S_{OM} blocks, fertilization was based on plant demand and soil availability and irrigation volumes were calculated on the evapotranspiration values basis, while in the L_{OM} plots fertilization and irrigation were empirically managed. Results show that yield was enhanced by 28% by S_{OM}. In comparison with L_{OM} plots, changed practices increased the amount of N, P, K annually incorporated into soil thus increasing their reservoir in the soil. The study demonstrates that appropriate crop management can increase the mean annual carbon soil inputs from about 1.5 t ha^{-1} to 9.0 t ha^{-1} per year.

INTRODUCTION

In Mediterranean cultivated soils, intensive agricultural practices (continuous tillage, high inputs of mineral fertilisers, irrigation method and application of low-quality irrigation water, removal of pruning residues) combined with the aggressive climate characteristics (i.e. low precipitation, high evapotranspirative demand) have dramatically degraded some soils and reduced soil organic carbon (SOC) to about 1% in several areas (Trinchera et al., 1999; Bastida et al., 2006). Such poor soil condition negatively affects a large number of soil characteristics creating unfavourable conditions for plant physiology and preventing the achievement of high yield and fruit quality.

It is widely known that the increase of SOC content can be achieved by both raising the carbon input through sustainable practices (e.g. manure and organic additions, adequate fertilization, return of crop residues to the soil, crop rotations, optimal fallow frequency), and curtailing soil carbon emission by reducing soil disturbance (i.e. minimum or no tillage) (Reeves, 1997; Kong et al., 2005). However, in some cultivated Mediterranean areas suffering water shortages, soil tillage is currently perceived as essential to minimise the competition for water and nutrients between weeds and crops, reducing considerably the appeal of conservation tillage and hampering soil fertility remediation. Quantitative information on biomass input and on the potential increases of the carbon stocks in fruit tree orchards under improved management practices is relatively scarce. Therefore, the present study was intended to quantify carbon input in an apricot orchard under S_{OM} practices in contrast to conventional ones.

MATERIALS AND METHODS

This study was conducted in Southern Italy during four growing seasons (2004 through 2007) in a private 22-year-old apricot orchard. The plants (cv. S. Castrese grafted on Myrabolan) were trained to "palmette" (740 p ha^{-1}) and drip irrigated (16 L h^{-1} per

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plant). Maximum mean annual temperature in this region is 36°C and rainfall averages 550 mm y^{-1} (SAL Service, ALSIA Basilicata Region). The research compared the Local Orchard Management (L_{OM}) practices with Sustainable Orchard Management (S_{OM}) actions (see below and Table 1 for details) in an experimental area of 2 ha with three replications per treatment.

In the S_{OM} treatment, soil was left untilled and weeds mowed to 3-4 cm height in March, May and September. Fertilization was based on plant demand and on availability of the various essential plant nutrients in the soil (Xiloyannis et al., 2006). Table 2 reports the annual amount of N, P and K applied in the different plots. In particular, the concentration of N (NO_3^-) was monitored (Nitracheck®) and N distributed via fertigation whenever the concentration in the top 40 cm of soil fell below 20 ppm. Each year in January, 15 t ha^{-1} (fresh weight, 24.8% moisture content) of compost containing, on a dry matter basis, 2.02% total N, 1.8% organic N, 1.86% K_2O, and 0.9% P_2O_5 (see Table 2 for doses annually applied) were distributed (22.2 C/N; Eco-Pol SpA - Italy). Pruning was performed every year (November-December) and the resulting biomass was subsequently chipped and evenly distributed on the soil surface as mulch.

In the L_{OM} plots, soil was tilled including the tree row using an 18-disc plough, 4 times per year to 10-20 cm depth. Pruning residues were removed and burnt. The mean annual L_{OM} treatment fertiliser rates are reported in Table 2.

Irrigation volumes for the S_{OM} plots were calculated on the basis of ETo values (potential evapotranspiration) measured at a standard meteorological station located within 500 m (Regional Meteorological Service, ALSIA) and using the following crop coefficients (Kc) (May - September): 0.4, 0.5, 0.6, 0.3, 0.3. In the L_{OM} blocks, irrigation volumes were determined empirically according to local commercial practice.

The total pruning biomass obtained from the apricot sites was measured each year on 10 plants per plot (30× treatment). Trees for sampling were selected from the middle of treatment plots to avoid border effects. The same plants were used to measure yield and determine canopy biomass annually by collecting total leaves at leaf fall. For each mowing operation, a weed biomass sample was taken from a 1-m^2 sample-area randomly distributed on each plot (3× plot). Subsamples of about 500 g for each tree component and weed were oven-dried at 70°C until a constant dry weight was reached. The dried samples were weighed and ground in a mixer ball mill to a fine powder which was used for carbon determination (dry combustion method, LECO-SC). Carbon inputs were calculated for each biomass component by multiplying the carbon fraction by the amount of biomass (dry matter) produced per component and expressed as kg ha^{-1} y^{-1} using the respective tree densities. On the same dried samples, concentrations of K and P were spectrophotometrically determined (Varian, AA-40) on the acid digested samples (H_2SO_4 + HNO_3), while N was assayed using Kjeldhal's method.

RESULTS AND DISCUSSION

Throughout this 4-year experiment, the sustainable management practices increased cumulative yields in the S_{OM} treatment by 28% compared to the L_{OM} (Table 3). In each year of this experiment, the total annual carbon input (t ha^{-1}) induced an additional yield of 0.2 - 1.0 t ha^{-1} y^{-1}. Additional inorganic nitrogen is essential to promote nutrient release from crop residues by mineralization processes and adequately sustain crop productivity (Gebrekidan et al., 1999; Loveland and Webb, 2003). In this experiment, the S_{OM} techniques induced a yield increase of 28%; it is likely that increasing the rate of mineral nitrogen application (i.e. more than 17 kg ha^{-1} y^{-1}) may sustain a higher increase of yield.

The positive yield response to residue addition is in accordance with findings in annual crop systems of Wilhelm et al. (1986), Gebrekidan et al. (1999), and Mesfine et al. (2005) who reported a significant linear relationship between crop residue returned to the soil and grain production in corn and soybean. Carbon inputs play an important role in supplying plant nutrients (via mineralization) that are critical to adequately sustain crop production (Wilhelm et al., 1986; Kong et al., 2005). Therefore, for the present research the improved soil reservoir of some nutrients (Table 2), conceivably due to the abundance of carbon inputs as coupled with irrigation, can explain the increased yield in S_{OM} treatments despite a lower mineral fertilization rate (Table 2).

Annual nitrogen incorporated in the soil of S_{OM} plots was approximately 28% higher than L_{OM} treatments, while phosphorous and potassium increased by about 70 and 55% respectively (Table 2). However, these supplemental mineral nitrogen applications are essential especially during the first years of the supply of residue and organic fertilisers that are largely used by soil microorganisms to effect decomposition (Gebrekidan et al., 1999). Generally, in soil under the S_{OM} treatment, nitrogen (NO_3^-) was detected at a mean concentration lower than that observed in L_{OM} treatment soils (i.e. about 20-30 ppm) (not shown). In addition, we noted that nitrogen concentration in S_{OM} treatments was quite stable throughout the growing season (except in some occasions), while in L_{OM} soils it was more variable and peaked at 90-110 ppm, increasing the leaching risk. This suggests a better balance between release and use of nitrogen in the S_{OM} compared with the L_{OM} system.

Figure 1 reports the allocation of the above-ground annual carbon observed in the plots. The sustainable agricultural actions significantly increased the biomass of weeds, while the pruning material and leaves biomass were comparable. Mean annual carbon inputs from biomass were 4.5 (S_{OM}) and 1.3 (L_{OM}) t ha^{-1} y^{-1} (Fig. 2). Grass mowing and pruning residues retention accounted for 62 and 17% of that input in the S_{OM} plots. A limited amount of weed biomass (0.1-0.2 t ha^{-1}) was incorporated also in the L_{OM} plots due to within-tillage weed growth.

Application of compost caused the total carbon input to be as high as 9.6 t ha^{-1} y^{-1}. It has been reported that under conservative land use, a minimum load of carbon from crop residues left to decompose on the soil surface of 6-12 t ha^{-1} y^{-1} is required to maintain soil quality (Reeves, 1997), therefore the amount of carbon returned to soil in the L_{OM} plots is presumably not enough to prevent the decline of soil fertility.

The Mediterranean area is characterised by a dry summer with little or no precipitation (Fig. 1), consequently, irrigation is typically used to compensate for inadequate rainfall for most of cultivated plants. At the end of the 4th year, cumulative irrigation volume reached approximately 8,900 (S_{OM}) and 6,700 (L_{OM}) m^3 ha^{-1} (Table 3). It appears that S_{OM} practices induced higher water consumption; however, to correctly interpret the treatment effects on that consumption, irrigation volumes may well be related to yield. That is, the analysis of water use efficiency (amount of water per unit of yield) reveals that such efficiency was similar in both treatments (125-130 m^3 per tonne of harvested fruit) (Table 3).

CONCLUSIONS

This study focused on the critical issue of increasing SOC in croplands through the addition of crop residues, organic amendments and the reduction in soil disturbance. Under those practices, the mean annual carbon input was increased from approximately 1.5 t ha^{-1} to 9.0 t ha^{-1} without significant effect on SOC content (not shown), while yield increased by 28%. It could be concluded that the sustainable actions positively affect the yield and increase the soil carbon input that reasonably represents a prerequisite to maintain and increase SOC pools (Reeves, 1997).

ACKNOWLEDGEMENTS

The study was financially supported by the Italian Ministry of University and Scientific Research. Special grants BRIMET.

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Tables

Table 1. Different practices adopted during the trial in the blocks under sustainable (S_{OM}) and local (L_{OM}) orchard management.

	S_{OM}	L_{OM}
soil	not tilled, cover crop	tilled
irrigation	based on ETo and Kc	calculated empirically
fertilization	based on plant demand and on N availability, compost (15 t ha^{-1})	calculated empirically, mineral fertilization
pruning material	mulched in situ	removed and burnt

Table 2. Mean annual amount of mineral elements (kg ha^{-1}) from different sources and incorporated/applied to field under sustainable (S_{OM}) and local (L_{OM}) orchard management practices.

	S_{OM}			L_{OM}		
	N	P	K	N	P	K
Irrigation water	1.0	trace	30.0	0.6	trace	22.0
Weed residues*	9.5	3.3	97.7	6.6	0.8	3.5
Crop biomass	24.8	3.2	30.0	2.0	0.3	12.7
Mineral fertilization	17.0	-	-	90.0	22.0	108.0
Compost	75.0	33.0	70.0	-	-	-
Total	127.3	39.5	227.8	99.2	23.1	146.2

*note that minerals by weed residues come from the upper layer of the soil, thus they could not be considered as ex novo application.

Table 3. Cumulative yield (fresh weight, t ha^{-1}) and irrigation volume (m^3 ha^{-1}) throughout the 4-year experiment, mean annual specific water use efficiency (m^3 water per t yield) in the sustainable orchard management (S_{OM}) and local (L_{OM}) plots. Comparing treatments in the same parameter * indicates a significant difference at P < 0.05 (Student's *t*-test).

Yield (t)		Irrigation (m^3)		Water use efficiency (m^3 t^{-1})	
S_{OM}	L_{OM}	S_{OM}	L_{OM}	S_{OM}	L_{OM}
69.0	53.5 *	8,937	6,679 *	129.5	124.8

Figures

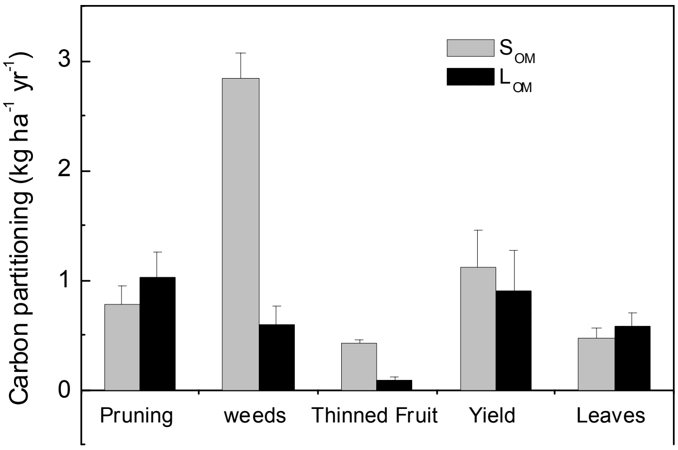

Fig. 1. Annual carbon allocation (kg ha^{-1} y^{-1}) in different components of an apricot orchard under sustainable (S_{OM}) and local management practices (L_{OM}). Data are 4-year mean ± SE.

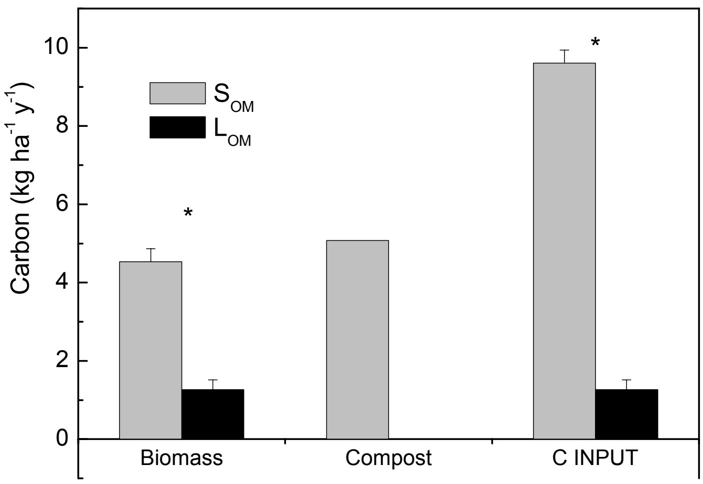

Fig. 2. Total annual carbon (kg ha^{-1} y^{-1}) (C INPUT) from above-ground weed and tree residues (biomass) and compost in an apricot orchard under sustainable (S_{OM}) and local management (L_{OM}). Data are 4-year mean ± SE; comparing treatments in the same species * indicates a significant difference at P < 0.05 (Student's *t*-test).