Sustainable orchard management in semi-arid areas to improve water use efficiency and soil fertility

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Abstract

Due to the impact of climate changes (mainly increased temperature and precipitation changes) as combined with poor orchard management (e.g. continuous tillage, use of mineral fertilisers) on soil fertility, orchard management should be revised. Improvement of orchard management practices aimed at increase soil fertility traits (e.g. soil organic carbon, microbial community, soil porosity) will be beneficial for soil conservation and also for improvement of water use efficiency at farm scale through improved soil water holding capacity.

This paper mainly focuses on some effects on orchards grown under semi-arid environment of changed soil management practices from conventional (soil tillage, mineral fertilisers, burning of pruning residues) to sustainable (no-tillage, pruning residues and cover crop retention, compost application) on soil microbial biomass, organic carbon (SOC), mineral nutrients availability and water use efficiency.

Results show that a 7/10-year period of changed practices significantly increased SOC concentration and soil microbial biomass at Mediterranean fruit tree orchards and that yield was improved by 30-50% as compared with that recorded in conventional managed orchards. The positive effect of carbon addition on reserves of soil nutrients (N, P, K, Ca, Mg) is also reported. Seasonal volumes of irrigation water are reduced by ~30% in orchards under sustainable management practices, contributing to improve water use efficiency.

Keywords: climate change, irrigation, mineral nutrition, soil carbon

INTRODUCTION

Climate changes (mainly increased temperature and precipitation changes) will have agricultural consequences due to the interrelations between climate and soil degradation, land and water use, landscape changes. Improvement of orchard management practices aimed at increasing soil fertility traits (e.g. soil organic carbon, microbial community, soil porosity) will be beneficial also for improvement of water use efficiency at farm scale through improved soil water holding capacity.

This paper mainly focuses on some effects of changed soil management practices in a semi-arid environment from conventional (soil tillage, mineral fertilisers, burning of pruning residues) to sustainable (no-tillage, pruning residues and cover crop retention, compost application) on soil microbial biomass, organic carbon (SOC) and volumes of irrigation water supplied.

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IMPROVEMENT OF SOIL FERTILITY

Soil organic carbon

Increased C inputs boost soil fertility by raising soil organic C content which, in turn, enhances a number of soil nutrition and hydrological proprieties (e.g. soil porosity, soil water infiltration rate and retention, soil structural stability) (Bhogal et al., 2009). Significant changes in SOC in response to sustainable managements are variable and can take up to10 years (Monreal and Janzen, 1993). In a previous study at a Mediterranean apricot and kiwifruit orchards (Montanaro et al., 2010), values of SOC were not significantly affected after four years of increased C inputs (8-9 t ha^{-1} $year^{-1}$). This suggests that longer periods of time are required to enhance SOC in the upper soil layers under these conditions. More recently it has been proved that a 7-year period of changed practices from conventional (i.e. soil tillage, use of mineral fertilisers, burning of crop residues) to sustainable practices (i.e. no-tillage, compost application, recycling of pruning residues) significantly increased SOC level at the upper soil layer (Figure 1). In addition, the increase of SOC is beneficial for the C budget of the orchard and for life cycle assessments when soil carbon changes are included (Petersen et al., 2013).

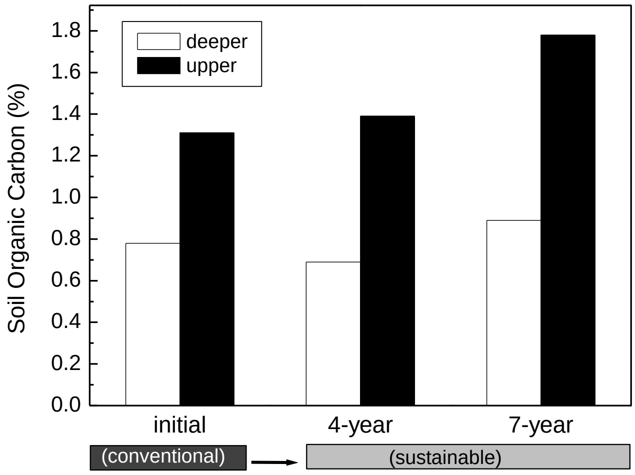

Figure 1. Variation of soil organic carbon (%) recorded at deeper (~ 30-40 cm depth) and upper (~ 15 cm depth) soil layers of fruit tree orchards after 4-year (kiwifruit, cultivar Hayward) and 7-year (peach, cultivar Supercrimson) of changed practices from conventional to sustainable. Redrawn from Xiloyannis et al. (2015).

Mineral nutrients

In a recent comparative study carried out at a peach orchard, the use of sustainable practices considerably improved soil reserves of the macronutrients (N, P and K) compared with those measured at locally conventional plot (Montanaro et al., 2012) (Figure 2). This is because of the relative abundance of macronutrients in the recycled biomass (mainly pruning and cover crop residues) and compost application. Hence, sustainable orchards requires low (or none) external chemical fertilisers which contribute to off-set CO_2 emissions related to their production and transportation. Organic amendments (e.g. compost) can increase yield, effectively replacing mineral fertilisers in the nutrient management of commercial fruit tree orchards through associated increases in organic matter and total N, P and K (Baldi et al., 2010). Montanaro et al. (2010) also documented that improvement of soil macronutrients reservoirs (via increasing carbon input) enhances crop yields. That is, a 30-50% increased yield was recorded in sustainable managed plots (apricot, kiwifruit, peach) receiving from 4.2 to 9 t ha^{-1} y^{-1} C inputs (mainly crop residue retentions and compost additions) has been documented in fruit tree orchards (Montanaro et al., 2010; Dichio et al., 2011).

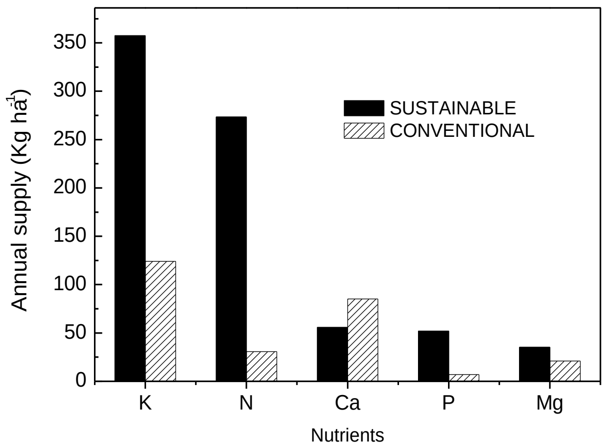

Figure 2. Average nutrients (kg ha^{-1}) contained into the organic raw material annually recycled at orchards under sustainable and conventional local practices. Adapted from Montanaro et al., 2012.

Soil microbiology

Quantitative and qualitative response of soil microbial communities to alternative agricultural management systems often helps to identify sustainable agricultural practices aimed at improve soil fertility. Recently, it has been evaluated the positive effect of sustainable agricultural management systems on genetic, functional, and metabolic diversity of soil microbial communities by using a combination of culture-dependent and –independent methods (Sofo et al., 2010, 2013). It has been also documented the positive effect of sustainable practices on the number of soil bacteria and fungi in the sustainable plots (higher C inputs) compared with conventional management (Table 1). The positive effects of minimum tillage and organic carbon input on soil bacteria are likely due to increased soil aeration, cooler and wetter conditions, temperature and moisture buffering capacity of the soil, as well as higher carbon content in surface soil (Brady and Weil, 2008). Recently, it has been observed that the phyllosphere and carposphere communities at an olive grove were affected by the type of the agricultural practices. That is, the number of bacterial species from olive fruit pulp collected at a sustainable orchard management was 15-fold of that of conventional one (Pascazio et al., 2015).

Table 1. Effect of sustainable management practices in peach and olive orchards on bacterial and fungal amount in soil (Sofo et al., 2010 and 2013) and on number of bacterial species in olive fruit pulp (mesocarp) (Pascazio et al., 2015) after ~10 (olive soil), 13 (olive fruit pulp) and 7-year (peach) period of application of sustainable practices.

Management treatment	**Soil (colony forming units × g^{-1} dry soil)**			**Fruit pulp (N)**
	Peach	Olive		Olive
	bacteria	fungi	bacteria	bacteria species
Sustainable	1.13 E+07	21.4 ×10^4	35.6 ×10^6	30
Conventional	1.06 E+07	2.9 ×10^4	10.0 ×10^6	2

WATER USE EFFICIENCY

Improving soil C content may be beneficial also for irrigation management, because of some effects on soil hydrological properties. For example, the soil water vertical infiltration rate measured for the top ~10 cm soil layer at a sustainable olive orchard (i.e. not-tilled, pruning materials retention and cover crops) was about 10-fold of that of conventional one (i.e. tilled, removal of pruning materials), allowing a greater water reservoir of 1,000 m^3 ha^{-1} (2 m depth) compare with conventional plot at the end of winter time (Palese et al., 2009). Note that at the tilled plot the presence of a plough pan was recognized at ~13 cm depth.

Generally, in those fields managed under sustainable practices aimed at improving annual C input (mainly through recycling of pruning residuals and compost application) and properly manage irrigation (regulated deficit irrigation) and canopy (e.g. summer pruning), amount of irrigation water supplied per year is reduced by ~30% (Figure 3). However, in case of highly water demanding crop (e.g. kiwifruit), the better soil condition induced by increased SOC could lead to an increase of irrigation volumes likely due to more foliage produced, but considering the increased yield of sustainable fields, amount of irrigation water per unit of yield is lower. For example in a 4-year experiment, the mean incidence of irrigation water was 258 m^3 (sustainable) and 302 m^3 (conventional) per ton of fruit (Montanaro et al., 2010).

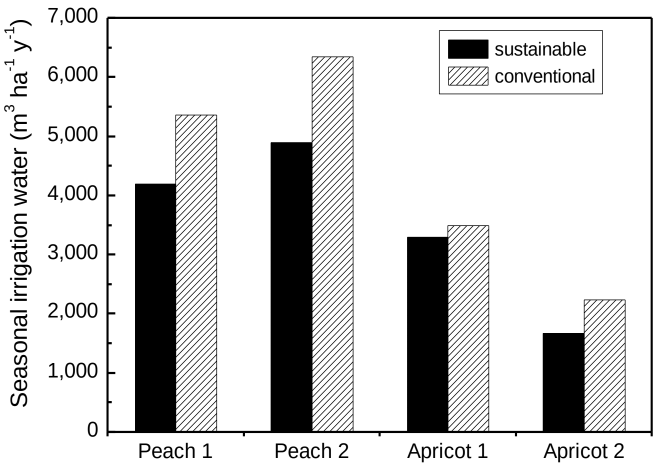

Figure 3. Seasonal irrigation volumes (m^3 ha^{-1} $year^{-1}$) recorded in various peach and apricot orchard under conventional and sustainable practices. Peach 1, Apricot 1 from Dichio in preparation; Peach 2 from Dichio et al., 2011; Apricot 2 from Montanaro et al., 2010. Data are the means of 4-7 seasons.

CONCLUSIONS

Improvement of soil fertility traits (i.e. SOC, microbial biomass, soil water holding capacity) is an affordable task for resources conservation (soil/water). Irrigation volumes are reduced by ~30% compared to conventional fields. This result is at least in part due to improved soil hydrological features. Sustainable management practices aimed at improving soil carbon content lead to agronomic advantages (higher nutrients availability, increased yield). In addition, sustainable practices are valuable for the whole society, because such practices contribute to mitigate increasing atmospheric CO_2 through increase of carbon stored into soil as recycled biomass or external inputs (e.g. compost).

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