The agro-ecosystemic benefits of sustainable management in an Italian olive grove

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Abstract

Biotic and abiotic stresses are the main causes of decreased productivity and yield losses for crop species. Conventional agricultural management of fruit orchards (excessive soil tillage, empirical fertilization, burning of pruning material) generates a progressive reduction in organic matter and general soil impoverishment, contributing to agrosystem vulnerability and the appearance of plant disease. The well-being of the plant and the biotic complexity of the whole orchard system are the first "obstacles" to pathogen diffusion. In this study, we experimented with some agronomic methods aimed at increasing microbiological soil fertility and soil water storage capacity, applying sustainable agronomic management (soil cover by spontaneous vegetation, light and annual pruning and reuse of pruning residues within the orchard, irrigation with treated wastewater). We compared the results of conventional and sustainable fruit orchard managements. The experiment was carried out in a mature olive grove ('Maiatica di Ferrandina') and the two experimental plots (conventional and sustainable) were followed for more than 10 years. Adoption of sustainable agricultural practices increased the soil organic matter content by 1.1% in the 0-40 cm soil layer and the water infiltration rate 10-fold with respect to conventional management. Soil microbiota in the sustainable plot showed higher biomass and biodiversity. The findings demonstrated that the application of sustainable agricultural practices in fruit orchards has positive results in terms of soil fertility and biodiversity, with benefits to the whole agroecosystem stability.

Keywords: organic matter, cover crops, fertigation, biodiversity, water resource

INTRODUCTION

Agricultural land supports not only the production of food and fibre, but also a variety of socially valuable non-market goods and services (Noel et al., 2009). Non-market goods and services include aesthetics of the landscape, mitigation of anthropogenic carbon emissions and many environmental benefits.

In semi-arid Mediterranean agricultural lands, conventional horticultural management is characterized by frequent and intensive soil tillage, reduced or no organic matter input and use of excessive chemical fertilizers. These practices induce soil organic matter losses and increased groundwater contamination, accumulation of detrimental mineral elements in the soil, and nutritional imbalances in plants (Gruhn et al., 2000).

The use of sustainable agricultural techniques can preserve environmental resources, restore or improve soil quality and increase orchard productivity (Lal, 2004; Kushwaha et al., 2000; Jagadamma et al., 2008; Palese et al., 2014; Montanaro et al., 2017). Particularly, in fruit growing, besides adequate irrigation, fertilization and pruning, it is advisable to use minimum tillage or no tillage, permanent cover cropping and mulching, soil amendment with stabilized exogenous organic matter (compost, manure), and recycling of carbon sources internal to the fruit grove (pruning material).

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Therefore, the purpose of this study was to summarize and report the effects of different soil management strategies performed in an olive grove managed for more than 10 years through sustainable criteria. To achieve our goal, we measured physical, chemical and microbiological soil features in order to confirm that the well-being of the plant and the biotic complexity of the whole orchard system are the first "obstacles" to pathogen diffusion.

MATERIALS AND METHODS

Experimental design and field management

The studied olive grove was located in Basilicata Region (southern Italy). The climate is semi-arid according to UNESCO-FAO classification, with an average annual rainfall of 525 mm. The experiment was carried out in a mature olive grove, and the two experimental plots (conventional and sustainable) were followed for more than 10 years. Olive trees (*Olea europaea* L. 'Maiatica di Ferrandina', a double-aptitude cultivar, >50 years old) were vase trained and planted at a distance of about 8×8 m. The soil of the experimental fields is a sandy loam, classified as a Haplic Calcisol (FAO, 1998). The sustainable plot was irrigated with municipal wastewater treated by a pilot unit according to simplified schemes (Palese et al., 2009). The reclaimed wastewater was generally distributed from May to October by drip irrigation (six self-compensating drippers per plant delivering 8 L h^{-1}). Irrigation volume applied during the annual growth season averaged 293 mm (2000-2010). The sustainable plot soil surface was covered by spontaneously growing weeds and grasses and mowed at least twice a year. Irrigated trees were lightly pruned each year to improve fruiting potential by controlling the amount of fruiting wood and enhancing flower bud differentiation. Crop residues and pruning material (4.4 t ha^{-1} $year^{-1}$ organic carbon, mean 2000-2010) were left on the ground as mulch. Fertilizers were applied throughout the growing season by guided fertigation, taking into account wastewater and soil chemical composition, and mineral element balance in the orchard system (cover crops and pruning material contributions, amount of fruit removed from the olive grove). Particularly, the average annual amounts of organic C, N, P and K distributed by the treated wastewater were respectively 124, 54, 3 and 50 kg ha^{-1} $year^{-1}$. An integrative amount of 40 kg ha^{-1} nitrate nitrogen per year was distributed by fertigation during the fruit set and pit hardening phase to entirely satisfy olive nutrient needs, as reported in previous studies, in which the amount of mineral elements coming from leaves, fruits and pruning residues were calculated (Palese et al., 2012).

Pest and disease control was performed according to the regional service recommendations for commercial olive groves. The conventional plot was grown under rain-fed conditions and managed according to traditional horticultural practices of the area, that is, by tillage performed two to three times per year and mineral fertilization carried out once a year, in early spring, using ternary fertilizer (NPK, 20-10-10) at doses ranging from 300 to 500 kg ha^{-1} $year^{-1}$. In the conventional plot, heavy pruning was performed every 2 years, and pruning residues were burned out of the field.

RESULTS AND DISCUSSION

Sustainable management and microbial activity

Sustainable agricultural management practices stimulate and select naturally soil microorganisms such as those involved in the carbon and nitrogen cycles, and those that promote plant growth and/or that act as a deterrent against pathogenic microorganisms (for attack directed against pathogens, production of natural antibiotics, and stimulation effects the endogenous defences and the plant "immune system").

Microorganisms are able to influence the quality of the soil and the growth of plants, by regulating the availability and recycling of nutrients. For this reason, the microbial complexity of a soil constitutes a trustworthy fertility index. The microbial diversity of the soil is the basis of the fundamental role played by microorganisms in the function of terrestrial ecosystems. In fact, the greater the degree of intra- or interspecific biodiversity of a functional agricultural ecosystem, the greater the tolerance of the latter to perturbations and its resilience (understood as the ability to recover following a disturbance) to unfavourable environmental factors.

The composition, complexity, genetic diversity and use of nutrients of soil microbial communities are positively influenced by a sustainable management system. This is the case of olive managed for 12 years with sustainable practices, which showed greater functional and metabolic genetic diversity, and a larger number of microbial species, compared with conventional management. These effects were mainly due to the periodic input of organic matter produced in situ.

Microbiological analyses revealed significant changes in soil microbial communities in response to sustainable farming practices (Table 1). The management mode of the land has a significant effect on the number and biodiversity of soil fungal and bacterial populations. According to Sofo et al. (2010, 2014), the diversification of microbial communities is probably enhanced by inputs to the soil of different qualities of organic material. Furthermore, a soil fertility indicator (the ratio Nc/Nk) was selected in order to analyse nitrogen dynamics related to the microbial component responsible for biochemical processes of transformation of the different forms of soil N in the experimental olive grove. Preliminary results revealed a positive effect of sustainable agricultural practices and irrigation on soil quality of the olive grove (Pascazio et al., unpublished data).

Table 1. Effect of sustainable management practices in the olive grove on amounts of bacteria and fungi in soil (Sofo et al., 2010, 2014) after 10 years of application of sustainable practices.

Olive grove management	Soil (CFU g^{-1} dry soil)	
	Fungi	Bacteria
Sustainable	21.4×10^4	35.6×10^6
Conventional	2.9×10^4	10.0×10^6

Accumulation of rainwater in the soil

If managed in a sustainable way, arable soils can store large quantities of rainwater. The roots of woody plants, without any chemical or mechanical impediments, can grow up to depths of 2-3 m settling in a volume of soil capable of storing 4000-5000 m^3 ha^{-1} in the medium soil.

Several scientific studies have shown that grape plants subjected to water stress are more susceptible to bacteria attacking the xylem (McElrone et al., 2001; Thorne et al., 2006; Choi et al., 2013). Therefore, it is necessary to keep the plants at appropriate water status; this is also the case for olive trees.

Cover crops favour infiltration of rainwater into the soil, reducing losses through runoff. Data relating to the effect of the two types of soil management on the speed of water infiltration are reported in Table 2. Greater accumulation of rainwater in the ground brings several advantages, such as reduced need for water for irrigation, increased production of olive-growing systems in dry farming, less sensitivity to attack by pathogens, reduction of soil erosion and consequently less transport of sediments and pollutants (fertilizers, herbicides, pesticides) in water basins, and reduced flow of water in rivers, allowing control of floods.

Table 2. Soil water vertical infiltration in two types of soil management (reproduced from Palese et al., 2014).

Olive grove management	Soil water vertical infiltration (mm day^{-1})
Sustainable	160
Conventional	13[1]

[1] Determined at 12 cm depth (point of soil compaction due to tillage).

Increase of carbon in the soil

Sustainable management implies an increase of carbon in the soil. Research showed that the recovery of carbon in the soil is a relatively slow process, and it takes 7-10 years before it is evident. This aspect, in view of the speed with which soil carbon can be mineralized, underscores the urgency of promoting actions for its recovery. With sustainable techniques, the carbon content in the surface layer of soil (0-15 cm) may increase significantly after 7 years (Figure 1). Furthermore, since deep layers accumulate carbon more slowly, it could be considered a one-time processing (e.g., soil tillage every 10 years) to move deeper into the accumulated carbon.

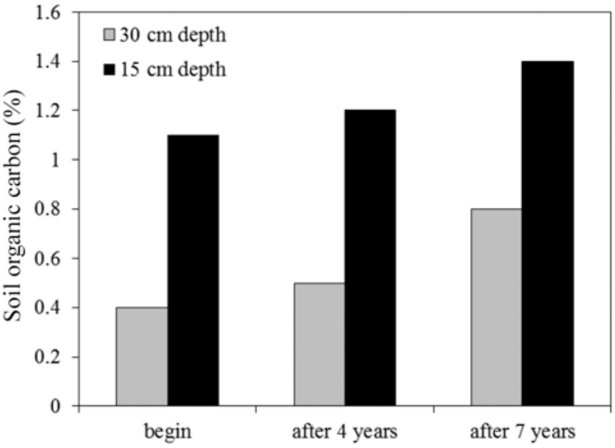

Figure 1. Total soil organic carbon measured in soil of the sustainable plot at different depths (15 and 30 cm) and after 4 and 7 years of cultivation.

Increase in microbial biodiversity in leaves and fruit

The interface between the aerial parts of plants and the atmosphere (the phyllosphere for leaves and carposphere for fruits) constitutes a very specific habitat for epiphytic microorganisms, and is normally colonized by a variety of bacteria, yeast and fungi. In both the phyllosphere and carposphere, bacteria are by far the most numerous organisms. The microorganisms that live in this particular microenvironment respond positively, in terms of abundance of microbial diversity, to different agroecosystem management practices. On this basis, the bacterial communities of the phyllosphere and carposphere of plants subjected for several years to two different management systems (conventional and sustainable) were characterized recently (Pascazio et al., 2015). From this study, it emerged that sustainable soil management significantly modified the composition of the bacterial communities of the phyllosphere and carposphere, increasing their biodiversity. For instance, the number of predominant species of bacteria present inside the drupes of the sustainable system was 31, against the two observed in the conventional system (Pascazio et al., 2015). Moreover, preliminary results in other experimental fruit orchards revealed that different management practices also affected the metabolomic and ionomic profiles of fruits. In particular, fruits picked in the sustainable orchard showed a higher gluconic acid content than fruits collected from conventional orchards. In addition, the ionomic profile of fruits was slightly different between the two orchard management systems, highlighting that the concentration of some mineral elements (e.g., Mn, Ni, Cu and Zn) could be associated with different management options.

CONCLUSIONS

The adoption of sustainable management can increase soil quality and its capacity to generate benefits for the environment. Through our experimental design, we studied the effects of changes in agricultural practices (conventional versus sustainable) on soil quality, soil water vertical infiltration and microbiodiversity of soil and canopy. The results demonstrated that the application of sustainable agricultural practices in olive orchards has positive results in terms of soil fertility and biodiversity, with benefits to the stability of the whole agroecosystem.

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