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Organic plum cultivation in the Mediterranean region: The medium-term effect of five different organic soil management practices on crop production and microbiological soil quality

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ABSTRACT

Organic farming practices recommended by European regulations offer an alternative to conventional soil management, but these practices should be analyzed in greater depth to assess their effectiveness on different plants and in different local conditions. Accordingly, this study evaluates the efficacy of five different organic management strategies on an organic plum farm in Southeastern Spain. This study was conducted for a period of six years and the five different organic treatments were applied in triplicate in 256 m^2 plots randomly distributed in three blocks (15 plots in total); each plot had 16 plum trees. Every year crushed pruning wastes were incorporated into the soil in all the experimental plots. One triplicated plot only received this aforementioned treatment (crop biomass treatment, CB). The rest of the plots also received one of the following treatments: (i) the addition of a commercial product for organic agriculture based on bacteria (biofertilizer), composed of *Azospirillum brasilense* (bacteria fixing N) and *Pantoea dispersa* (bacteria with a capacity for solubilising phosphates and stimulating plant growth) (biofertilizer treatment, B); (ii) the annual addition of 20 t/ha of certified commercial organic compost (annual compost treatment, AC); (iii) the biennial addition of 20 t/ha of certified commercial organic compost (biennial compost treatment, BC); and (iv) the sowing and subsequent incorporation of a mixture of 60% *Avena sativa* and 40% *Vicia sativa* (green manure treatment, GM). Each year the following indicators of ecosystem sustainability related to soil microbiological characteristics and carbon fixation were measured after harvest, in addition to plum yield: organic carbon (C_{org}), water soluble C, humic substances and humic acid C, microbial biomass C, respiration, ATP, dehydrogenase activity and hydrolase enzymes (alkaline phosphatase, urease and beta-glucosidase) activities. The two way ANOVA of the results indicated that all the above parameters were significantly affected ($p \leq 0.001$) by both, treatment and time. The interaction of treatment and time also significantly affected all of these parameters, except for yield and dehydrogenase activity. Composts not only produced better results than green manure cover crops and biofertilizer treatments in terms of plum yields, but they also brought about higher increases in the soil C pool and greater improvements in soil microbiological characteristics. In the six years of the study, compost-treated soils showed higher average plum yields and higher organic carbon, humic substance and humic acid contents than the rest of treatments. The size and activity of microbial population was also greater in the compost-treated soils, reflected in the higher values found in these soils for microbial biomass C, soil respiration, ATP (adenosine-tri-phosphate) content and dehydrogenase and hydrolases activity. Nevertheless, yields when compost was added biennially (BC) tended to be higher than in the annual compost treatment (AC) in most years as well as on average, although the differences were usually not significant. Yields in the sixth crop showed a high positive correlation with soil humic substances and humic C content ($p \leq 0.01$), as well as with C_{org}, microbial biomass C and phosphatase and urease activity ($p \leq 0.05$).

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1. Introduction

In the Mediterranean regions, negative effects on the soil resulting from inadequate agricultural management practices are aggravated by inherent environmental factors, such as lithological substrate, significant relief in the landscape and a semiarid climate (Lopez Bermudez and García Gómez, 2005). In fact, many areas within Mediterranean countries already show a high degree of desertification, and others areas, such as agricultural zones, are at high potential risk of desertification (López Bermúdez and García Gómez, 2005).

Given this context, organic farming represents a promising alternative for farmers in the Mediterranean region. According to its defining principles (Council Regulation EC 834/2007), organic farming should contribute to maintaining and even increasing soil fertility, thus preventing soil degradation processes (Arnhold et al., 1914). Organic farming practices are based on the use of multi-annual rotation; the addition of organic matter (green manure including legumes, composts, farmyard manure, etc.); the use of biofertilizers; the avoidance of synthetic fertilizers and synthetic pesticides; and the reduced use of high energy-consuming feedstuffs (Fliebach et al., 2007).

Among the organic production practices recommended by current legislation, the application of composted organic matter is one of the most widely used in organic farming to maintain and increase soil fertility. Nevertheless, other soil management practices, such as the application of cover crops, green manure, or biofertilizers or the incorporation of crop residues, are emerging as either alternative or complementary strategies to compost use.

It is known that the application of composted organic matter has a positive impact on soil and plant nutrition, improving the soil physical, chemical and microbiological characteristics (Baldi et al., 2010). In addition, the composting process provides stabilized organic material (compost) that is easier to handle and apply than the uncomposted organic material (Pascual et al., 2010).

With respect to the use of biofertilizers, Villaverde et al. (2008) indicated that certain biofertilizers can be substitutes for conventional soluble fertilizer without decreases in production and with a remarkable reduction in soil and plant nitrate levels. Bonaterra et al. (2003) observed an increase in the growth of cuttings in the genus Prunus with the addition of *Azospirillum pantotea*. Likewise Terry et al. (2005) observed improved tomato production with the combined addition of *Azospirillum* and mycorrhizae of the genus *Glomus* in comparison to tomatoes fertilized with synthetic products. However, Kohler et al. (2010) have suggested that the beneficial effects of certain rhizobacteria and mycorrhizae on soil properties are limited, resulting in no significant differences in terms of production.

The use of green manure cover crops followed by the main crop is considered an important agronomic technique in Mediterranean cultivation for improving soil characteristics and crop production (Mancinelli et al., 2013). Several benefits of using green manure cover crops are known, such as the fact that they reduce dependence on mineral fertilizers and maintain organic matter in the soil, providing nutrients for plant growth (Yadav et al., 2000). Green manure cover crops also increase the size and activity of soil microbial communities (Tejada et al., 2008).

To assess the sustainability of an agricultural system, we must consider parameters that tell us the soil carbon balance and its binding capacity, parameters reflecting soil microbiological activity and agronomic parameters indicative of crop quality (Lima et al., 2013; Fliebach et al., 2007). The level of soil quality depends on a large number of physical, chemical and, microbiological properties. However, microbiological properties are the most sensitive since they respond quickly to any environmental change (Trasar-Cepeda et al., 1998; Ros et al., 2002) and therefore are considered as the most appropriate for assessing soil quality.

As a general rule, certain proportion of soil organic matter is mineralized annually, and this process of mineraliszation is accelerated in the Mediterranean area due to weather conditions (temperature, humidity) and excessive soil aeration caused by tillage (Martín-Lammerding et al., 2013). The amount of organic matter lost should be compensated for returning new organic matter to the soil to prevent the progressive loss of soil fertility. With this in mind, we have determined certain parameters related to fractions of soil organic matter in this work, such as total organic carbon (C_{org}), a significant determinant of soil quality and productivity under semiarid conditions (Srinivasarao et al., 2012); water soluble carbon (WSC), indicator of the labile fraction of organic matter; carbon in humic acids (HA), representative of the stable organic matter; and microbial biomass carbon (C_{mic}) (Garcia et al., 2000).

Microbial biomass carbon (C_{mic}) is considered to be an indicator of changes in soil organic matter (Powlson and Jenkinson, 1981) and is thus, highly useful in studying the response of ecologically cultivated soils to the contributions of organic materials of different natures. The C_{mic} content reflects the size of the total soil microbial population, while respiration, dehydrogenase activity and ATP provide information about microbial activity (Nannipieri et al., 1980). At the biochemical level, enzyme activities are the parameters that provide the most sensitive information regarding any changes and are considered to be a true reflection of the potential of the soil to perform specific biochemical processes. Among the soil enzymes, extracellular hydrolases related to the cycles of N (urease), P (alkaline phosphatase) and C (βglucosidasa) stand out in particular as indicators of change (García et al., 2002). Other enzyme activities provide more general knowledge about microbial activity. For example, García et al. (1994) indicated that dehydrogenase activity (intracellular enzyme) is a clear indicator of the microbiological status of soils subjected to degradation and desertification in semiarid areas.

Several researchers (Perez-Romero et al., 2014) have indicated lower production levels under organic cultivation than under conventional cultivation. It is thus necessary to deepen our knowledge of the effects of the different organic management practices on crop yield and soil quality in order to adopt those practices that increase crop production while maintaining or increasing the beneficial effects of organic farming on soil characteristics. In the semiarid Mediterranean Spanish area where this study was conducted, the incorporation of pruned branches from the trees in the same field is a typical crop management strategy in organic plum tree cultivation. This practice aims to attain self-sustainability in the agrosystem. However, other soil management practices such as those used in this work have been introduced in order to increase fruit production.

Although there are many studies dealing with the differences between conventional and organic practices (Aranda et al., 2011; Palmer et al., 2013), there have been few comparative studies of crop productivity and soil quality within the different organic practices themselves (Veum et al., 2011). The aim of this study was thus to perform a comparative evaluation of the influence of some of the most typical soil management practices in organic plum cultivation, on soil characteristics and crop production, in order to establish which organic management strategy is the most suitable for organic plum tree cultivation in semiarid regions.