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Nutrient dynamics during decomposition of the residues from a sown legume or ruderal plant cover in an olive oil orchard

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A B S T R A C T

Spanish olive oil groves are undergoing a marked change in the way that inter-row land is managed. The current recommendation encourages the use of plant cover to increase plant residue input to the soil to improve fertility and reduce erosion. However, there is no quantitative information on the temporal trend and magnitude of nutrient release during decomposition of plant cover residues after the annual topping of vegetation. Decomposition rates and nutrient dynamics (C, N, P and K) were examined for aboveground residues from two types of plant cover (a sown legume and ruderal plant species) and in fine roots. Litterbag experiments were designed to evaluate the effects of the type and location of plant residues (above- or belowground) by placing litterbags of aboveground plant residues on the soil surface or within the soil, which were sampled over a whole year. The highest decomposition rates for above- or belowground residues were found in spring, and were higher for buried plant residues, regardless of plant cover type. After one year, the remaining C, K and P in the soil was about 30%, 20% and 30% of that added, respectively and therefore plant cover could be a useful strategy to improve C sequestration and increase soil nutrient content in olive groves. Decomposition of plant residues left on the soil surface immobilised N, whereas this was not the case when they were buried. The remaining C, N, P and K content in belowground residues was similar to aboveground samples with around 21%, 27%, 23% and 15%, respectively. This study highlighted the importance of plant cover for retaining nutrients when tree demand was low, but releasing a significant proportion of the nutrients in early spring when tree demand was high, especially when residues were incorporated into the soil.

1. Introduction

Olive oil production in Andalusia (southern Spain) and other Mediterranean olive oil producing countries all face a heavy loss of potential productivity linked to excessive soil erosion (Rodríguez-Lizana et al., 2007). The main reason for this is that soil in the area between the rows of trees in olive orchards is mostly bare fallow and vulnerable to soil erosion. Erosion of up to 25.6 tonnes of soil per hectare per year has been reported in some areas of Andalusia (Francia et al., 2006). To try to reduce this loss of soil fertility, regional authorities introduced a policy of *Good Agricultural Practice*, which consists of linking the subsidy for growing the olive crop to the requirement to provide/permit additional cover plants for soil protection against erosion. Since then, a reduction in soil erosion of some 80% has been reported (Francia et al., 2000) as well as reducing runoff by about 90% (Gómez et al., 2009). In addition, it was found that ground cover plants improve water infiltration (Pastor, 1989). Consequently, the use of cover plants in olive groves is increasing.

Cover plants are mainly comprised of ruderal (i.e. natural) vegetation which grows during early autumn and throughout the winter in the area between the olive tree rows, thereby covering up to 75% of the soil surface. Few olive oil groves grow actively sown plants, such as legumes, to increase nitrogen inputs. In around 35% of Andalusian olive crops (in southern Spain), cover plant growth is allowed during most of the year. The growth of cover plants is then usually disrupted by tillage and/or herbicides in late March or early April. Or, after topping the cover plants, the plant residues may be left on the soil surface or mechanically mixed into the first 10 cm depth of soil. Both approaches are currently used and are realistic land management options. Most previous studies relating to the effectiveness of cover plants in olive oil orchards were designed to evaluate this practice as a means of mitigating the effects of soil erosion.

The presence of ruderal vegetation or legumes (in the case of sown cover crops) might also, however, influence the

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nutrient dynamics of the olive oil agroecosystem which is still only poorly understood. Any available nutrients in the area between rows, which have not been taken up by the olive trees, may additionally be retained by the ruderal plant species, thereby reducing the risk of overall nutrient loss from the orchard (Santa Regina et al., 1997). Furthermore, during plant residue decomposition, nutrient re-release could support some of the requirements of the olive crop. However, to our knowledge there are currently no studies investigating the magnitude and timing of nutrients taken up during the development of a cover plant understorey, or the subsequent nutrient release during decomposition of the plant residues in olive groves. The soils in olive groves generally have a low content of organic C. In the Mediterranean regions, Álvarez et al. (2007) observed that soil C may decrease by up to 50% in olive groves, compared with adjacent areas colonized by natural vegetation. We hypothesize that returning the ruderal plant residues to the soil could help to maintain or enhance C storage/content in these poor soils. However, the extent to which this actually occurs remains to be quantified.

Plant litter decomposition is a process which has been widely studied in most ecosystems, i.e. those under tropical and subtropical (Pandey et al., 2007), semiarid (Tateno et al., 2007), temperate (Cookson et al., 2007), and Mediterranean climates (Moro and Domingo, 2000; Sirulnik et al., 2007). However, whilst substantial research on litter decomposition and nutrient release has been conducted in forest and agricultural crop systems (Magill and Aber, 2000; Chaves et al., 2004; Quemada and Cabrera, 1995), the decomposition of litter in olive groves and the associated dynamics of nutrient release have received little or no attention. There is some published information about cover plant residue decomposition under laboratory conditions (García-Ruiz and Baggs, 2007), but there is no information available on the decomposition of different types of cover plant residues in olive oil groves under field conditions and under different cover plant management options. Plant litter in olive oil orchards consists of residues derived from aboveground (mainly leaves and shoots) and belowground (mainly fine roots) components. The annual supply (in terms of dry mass) of this plant litter is generally slightly lower or very similar to the yields that can be expected from olive fruit production (García-Ruiz et al., 2011). Processes involved in the decomposition of leaves have already been extensively studied (e.g. Laskowski et al., 1995). However, the detailed understanding of patterns of root decomposition and the accompanying nutrient release is still more limited than that of leaf decomposition, particularly in quantitative terms. For example, some studies indicated that root materials decompose more slowly than leaves (Lehmann et al., 1995), whereas in others, it was found that their decomposition was faster (Ostertag and Hobbie, 1999).

Among the many other variables, the decomposition rate of plant residues is highly dependent on their quality as a substrate to the decomposer community. Indeed, many researchers have demonstrated relationships between these initial litter quality characteristics and subsequent decomposition rates for a range of plant species (Berg and Staaf, 1981; Sariyildiz and Anderson, 2003). The polyphenol content and the carbon to nitrogen ratio (C:N) in particular, have been shown to be good indices of the susceptibility of litter to degradation (Mafongoya et al., 2000). In general, plant litter with a low C:N ratio decomposes faster than litter with a high C:N ratio (Adams and Atwill, 1982). However, when the C:N ratio exceeds 75–100, other indices such as the lignin to N ratio and polyphenol to N ratio have been shown to be more appropriate predictors of decomposition rates (Heal et al., 1997).

In addition to these variations in substrate quality, there are obvious differences in the location of where the initial decomposition commences for either root or leaf material. Leaf litter is initially deposited on the soil surface, where the first stages of decomposition begin, and then continues below ground when the residues are incorporated in the soil, whereas root litter decomposition takes place entirely below ground. Thus, root and leaf decomposition proceed at varying depths above and within the soil matrix in ecosystems. The different locations in the soil present different physico-chemical features (Tian et al., 1997) with specialized decomposer communities (Osono, 2006), which together with litter substrate quality are the major factors controlling decomposition.

Different models have been used to describe the loss of biomass from decomposition of organic matter in natural ecosystems. There are several mathematical functions that may be used to describe the litter mass–loss process (Howard and Howard, 1974). The most widely used model in the past was the single exponential model (Dossa et al., 2009), which is often used and most suitable to describe the very early stages of litter mass loss, but is frequently unable to fit observations from the later phases of decomposition (Wieder and Lang, 1982). A slightly more complex model uses a double exponential with two decay rate constants. These models can relate to two different components of litter, or to two different phases of decay (Lousier and Parkinson, 1976).

In the present study, we considered the utilization of sown legume or ruderal plant species as cover plants and two current management options comparing plant residues left on the soil surface, versus incorporation into the soil after topping. We also quantified the aboveground and belowground decomposition processes in terms of mass loss rate and nutrient (C, N, P and K) release patterns of plants compared with residues from a sown legume plant (*a priori* of different quality) which were placed in the area between the rows of trees in an olive oil orchard.

2. Materials and methods

2.1. Collection of plant residues and experimental set up

Above- and belowground plant biomass collection and the in situ decomposition experiment were undertaken at an organic olive oil farm (37°19′8″N, 3°34′8″W, Deifontes, Granada). The site was selected because during the last eight years ruderal plants were allowed to grow in the inter-canopy area of the olive grow. Trees were 20 years of age with a tree density of 165 trees per hectare, on a shallow (<5%) sloping landscape. The soil was a Calcium Cambisol. Management of this olive oil farm was standard for olive oil organic farming. Organic fertilization consisted of biannual applications of sheep/horse manure at a rate of about 5500 kg wet weight ha^{-1}, within 1-m of the tree trunk. Harvest took place in November and tree pruning in February. No herbicides, fungicides or other chemicals were used. Annual rainfall and mean temperature were 625 mm and 16.1 °C, respectively, during the study period, and were similar to the 50 years' average. At this site, two types of vegetation were already growing in 0.1 ha experimental plots in the two years before the experiment started: natural vegetation (NV, hereafter) and a sown legume *Vicia sativa* (VS, hereafter). Natural vegetation consisted of allowing ruderal plant growth from April in one year to April of the following year (2007); whereas, in the other 0.1 ha experimental plot, 15 kg ha^{-1} of seeds of *Vicia sativa* were sown in the previous October. Soils were not tilled during the study in either treatment. The most abundant plant species in the NV plot included *Hordeum murinum*, *Calendula arvensis*, *Diplotaxis virgata* and *Erodium cicutarium*, whereas *V. sativa*, *Bromus diandrus*, *H. murinum*, *Senecio vulgaris* and *E. cicutarium* were the dominant plant species in the VS plot. *V. sativa* accounted for about 37% of the cover of the VS plot (Guzman-Casado and Foraster, 2011). Aboveground biomass in the experimental units was topped in the second week of April of the following year. Dry biomass collected in the NV and VS plots averaged 1570 and 2113 kg ha^{-1} (coefficient of