Scientia Horticulturae 158 (2013) 45–51

Contents lists available at SciVerse ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Soil nitrogen availability in olive orchards after mulching legume cover crop residues

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ARTICLE INFO

Article history:
Received 21 January 2013
Received in revised form 22 April 2013
Accepted 26 April 2013

Keywords:
Soil N dynamic
In situ incubation
Capped tubes
Olea europaea
Hairy vetch
White lupine

ABSTRACT

A natural source of nitrogen (N) is needed to increase soil fertility in traditional olive orchards and to maintain the N nutritional status of olive trees. With this aim, we studied the introduction of legume cover crops in two olive orchards, which were converted into mulches and left on the ground as phytomass after they had been cut. The experiments were carried out in Suçães and Qta do Carrascal, NE Portugal, from October 2009 to January 2012. In Suçães, the ground-cover treatments were lupine (*Lupinus albus* L.), a mixture of 11 self-reseeding annual legume species, natural vegetation fertilized with 60 kg N hm^{-2} and natural vegetation not fertilized. The treatments imposed in Qta do Carrascal were lupine, hairy vetch (*Vicia villosa* Roth.), a mixture of 11 self-reseeding annual legumes and natural vegetation. Soil N availability in the year following the establishment of the mulches was monitored by an *in situ* incubation technique. Olive yields and tree nutritional status were also measured. A peak of net N mineralization was recorded early in the autumn in the plots where the legume cover crops had been grown in the last season, in comparison with the natural vegetation plot. In the next spring, soil N availability was negligible even in the plots previously cropped with legume species. The effect of the legume cover crops on soil inorganic-N availability seems to have been slight and short-lived taking into account the high amounts of N contained in the mulched phytomass. The effect of legume cover crops on olive yield and leaf N concentration was statistically significant only in few occasions. The results of these experiments recommended some caution in the management of pure legume cover crops as a mulch in olive orchards due to the reduced transfer of N from legumes to olive trees.

1. Introduction

Nitrogen is the most frequently deficient nutrient in non-legume cropping systems (Havlin et al., 2005). The dynamic of N in the soil-plant system often does not allow its accumulation in the soils in forms readily usable by plants. This requires that N has to be applied every growing season to supplement the lack of naturally available N in soils. The high crop response usually observed after N application has encouraged an excessive use of N-fertilizers in agriculture, reducing N use efficiency and causing diverse environmental problems (Raun and Schepers, 2008). The high price of N and the environmental issues have been pressing for the development of more sustainable farming systems with less reliance on synthetic-N fertilizers.

A reduction in the use of expensive off-farm inputs is of particular importance in marginal agricultural lands, such as the rainfed olive orchards of the Mediterranean basin, having a weak response to external inputs and low returns. Nevertheless, a source of N is always needed, either mineral or organic, without which there will be no proper crop growth and yield. Commercial organic fertilizers are not a solution that could be used widely. Their availability in the market is limited and their prices are high in comparison to their agronomic value (Rodrigues et al., 2006). Farmyard manures and other agricultural and livestock wastes are important fertilizer resources that can fully or partially balance the lack of N in agricultural soils. However, due to the specialization of the agricultural and livestock activities, occurring mainly in the twentieth century, there is a great distance between the sources of organic waste and the soils where they could be recycled. There are nowadays huge

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http://dx.doi.org/10.1016/j.scienta.2013.04.035

environmental problems in regions of intensive livestock production caused by an excessive use of animal waste as a fertilizer (Burton, 2009; Centner, 2011), and, on the other hand, large areas of agriculture where there are not any significant available on-farm sources of organic matter to apply to the soil. In the latter case, a natural source of N must be sought. Legume species, for instance, are able to fix atmospheric N, meeting their own needs and transferring N to a non-legume crop after their N-rich tissues have been mineralized (De Varennes et al., 2007; Russelle, 2008). Legume species can be grown either as main crops in rotation and/or as cover crops or green manures in annual and perennial tree crops.

Organic N sources, such as manures or green manures, are more difficult to manage than the inorganic-N fertilizers, since it is very difficult to predict when their N will become available in the soil. The mineralization of the organic substrates depends on their composition, the C:N ratio in particular (Paul and Clark, 1996; Havlin et al., 2005), and on the environmental conditions affecting microbial activity, such as temperature (Jenkinson and Ayanaba, 1977; Gaiser et al., 1994) and soil moisture (Stanford and Epstein, 1974), making the process unpredictable. It may be, for example, that the N release from the organic residues is not coincident with the periods of active nutrient uptake by the non-legume crops. Furthermore, in particular situations, the environmental damage of using these organic residues can be of similar concern as that associated with the use of synthetic-N fertilizers (Beegle et al., 2008; Sims and Stehouwer, 2008).

In situ incubation methods have been used in the past to monitor N flows in soils under field conditions. They can provide information about the time and rate in which N becomes available in the soil, determining its agronomic and environmental value. The buried polyethylene bag (Eno, 1960; Monaco et al., 2010) and capped PVC or metallic tubes (Raison et al., 1987; Subler et al., 1995; Durán et al., 2012) methods have been the most widely used. Many others, however, have interesting features. An incubation technique using ion exchange resins below intact soil cores for adsorbing inorganic-N leached from the core was used by Di Stefano and Gholz (1986) and Wienhold (2007). Hatch et al. (1990) and Bhogal et al. (1999) incubated soil cores in the field in sealed containers with acetylene to inhibit nitrification and thereby minimize losses of N through denitrification to better measure net rates of mineralization. Rodrigues (2004) incubated soil cores collected by PVC tubes in glass jars buried in the soil to simplify the sampling process and increase the field replications. In general, the techniques using undisturbed soil cores provide reliable quantitative estimates of N transformations in the soil (Raison et al., 1987; Hook and Burke, 1995).

In this study, several legume cover crops were grown in two olive orchards in NE Portugal in an attempt to supply the N needs for the trees. The legume species were cut in spring and left on the ground as a mulch. This would avoid soil tilling and eliminate the consequent damage of the olive tree roots. The dynamic of N in the soil in the year after the establishment of the mulches was monitored by using an *in situ* incubation technique. The effect of the ground-cover treatments on olive yield and N nutritional status of trees was also determined as an indirect measure of the transfer of N from legumes to olive trees. It is expected that using all these sources of information it will be possible to draw a reliable picture of what happened in the soil when the legume cover crop residues are left on the ground as a mulch.

2. Materials and methods

2.1. Site characterization

Two field experiments were carried out in Suçães, Mirandela (41° 29′ N, 7° 15′ W), and Qta do Carrascal, Vila Flor (41° 16′ N, 7° 5′ W), in NE Portugal. The region benefits from a Mediterranean type climate with average annual temperature and precipitation of 14.3 °C and 509 mm, respectively. Weather data recorded in Qta do Carrascal during the experimental period are presented in Fig. 1.

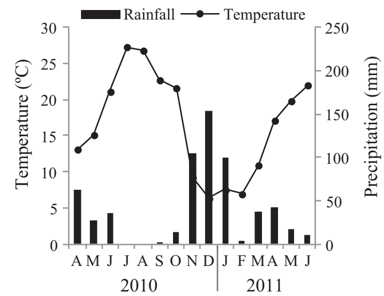

Fig. 1. Mean daily temperature and monthly precipitation from April 2010 to June 2011 recorded at a weather station located in Carrascal, Vila Flor.

The orchard of Suçães was ~20 years old, the olive trees of cv. Cobrançosa and rainfed managed. The soil is a Leptosol derived from schist, sandy loam (13.1% clay, 26.6% silt, 60.3% sand) textured, pH (H_2O) 4.1, organic carbon (C) 7.9 g kg^{-1} and extractable phosphorus (P) and potassium (K) (Egner-Riehm) 21.0 and 96.3 mg kg^{-1}, respectively. In the years before the establishment of the experiment, the farmer used to control the weeds through an annual application of a glyphosate-based herbicide, usually applied in May. The farmer also used to apply the fertilizers beneath the trees' canopy at rates equivalent to 60 kg N, P_2O_5 and K_2O hm^{-2} and 15 g B per tree. Shortly before the trial started 1500 kg hm^{-2} of lime (88% $CaCO_3$ and 5% $MgCO_3$) and 250 kg hm^{-2} of superphosphate (18% P_2O_5) were applied. The orchard of Qta do Carrascal was ~15 years old and the olive trees of cv. Negrinha de Freixo. It is drip-irrigated and organically managed. The soil is also a Leptosol derived from schist. The texture is sandy loam (11.8% clay, 32.0% silt, 56.2% sand), pH (H_2O) 5.7, organic C 8.3 g kg^{-1} and extractable P and K 33.2 and 41.5 mg kg^{-1}, respectively. In the years before the establishment of the experiment, the farmer used to control the weeds by tillage. The fertilization regime usually used by the farmer consisted of the application of a small amount of on-farm compost, supplemented by one or two applications per year of foliar sprays or soluble fertilizers in irrigation water. After the trial started, no fertilizers were added to the trees.

2.2. Experimental layout and orchard management

In each olive orchard four different ground-cover treatments were imposed. In each orchard there were delimited four plots of 0.4 and 0.6 hm^{-2}, respectively in Suçães and Carrascal. The treatments laid out in the Suçães orchard were: lupine; a mixture of 11 pasture legumes (*Ornithopus compressus* L. cv. Charano; *O. sativus* Brot. cvs. Erica and Margurita; *Trifolium subterraneum* L. ssp *subterraneum* Katzn. and Morley cvs. Dalkeith, Seaton Park, Denmark and Nungarin; *T. resupinatum* L. ssp *resupinatum* Gib and Belli cv. Prolific; *T. incarnatum* L. cv. Contea; *T. michelianum* Savi cv. Frontier; and *Biserrula pelecinus* L. cv. Mauro); natural vegetation fertilized with 60 kg N hm^{-2} (ammonium nitrate, 20.5% N, spread evenly throughout the plot area with a centrifugal seeder); and natural vegetation left unfertilized. The treatments applied in the Carrascal experiment were: lupine, a mixture of 11 pasture legumes (the same of Suçães); hairy vetch; and natural vegetation not fertilized. The legume cover crops were sown in October 14th, 2009. Lupine and hairy vetch were respectively seeded at rates of 180 and 30 kg seed hm^{-2}. The mixture of the legume pasture species was sown at a rate of an 11th of that recommended for each individual species if it was seeded alone in pure culture. The sowing