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An approach to nitrogen balance in olive orchards

R. Fernández-Escobar[a,*], J.M. García-Novelo[a], C. Molina-Soria[a], M.A. Parra[b]

[a] Departamento de Agronomía, Universidad de Córdoba, Edificio C 4, Campus Universitario de Rabanales, Ctra. Madrid-Cádiz km. 396, 14071 Córdoba, Spain
[b] Departamento de Ciencias y Recursos Agrícolas y Forestales, Universidad de Córdoba, Edificio C 4, Campus Universitario de Rabanales, Ctra. Madrid-Cádiz km. 396, 14071 Córdoba, Spain

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ABSTRACT

The nitrogen balance was estimated in two olive orchards at two different localities in order to provide data for rational fertilization practices for olive orchards, to account for the lack of response of olive trees to nitrogen fertilization, and to study the environmental impact of the current practices of nitrogen fertilization. The experiments were established in 1994, and the nitrogen balance was determined for 2001–2007 on unfertilized plots and on fertilized plots that received annual applications of 1 or 1.15 kg N tree^{-1} applied to the soil and split in two times in early spring. The nitrogen balance was estimated as the difference between nitrogen inputs and nitrogen outputs. Nitrogen applied with fertilizers, provided by rainwater and supplied by irrigation water were determined as nitrogen inputs. Nitrogen lost by leaching and by ammonia volatilization, and nitrogen removed by crop and pruning, represent nitrogen outputs determined in this work. Also, nitrogen from the net mineralization or immobilization was determined as an input or output, respectively. The nitrogen balance was close determining the difference between inorganic nitrogen (NO_3^--N and NH_4^+-N) contents in the soil at the end and at the beginning of each year. Results indicate that, under natural conditions represented by unfertilized plots, nitrogen removed by crop and pruning was equivalent to nitrogen mineralization of soil organic matter. Since nitrogen lost by leaching was very low under these conditions, ammonia volatilization was almost insignificant, and nitrogen supplied by rainwater was higher than these outputs, the results could explain why leaf nitrogen concentrations remained above deficiency for many years in these orchards without nitrogen applications. These results suggest that in fertile soils annual applications of nitrogen are not necessary to produce a good crop. When nitrogen was applied annually to these orchards, nitrogen net mineralization was significantly reduced and nitrogen net immobilization into soil organic matter increased. Simultaneously, nitrogen losses by leaching and ammonia volatilization also significantly increased. These results reveal the disruption of the nitrogen balance when unnecessary nitrogen fertilizers are applied to the orchards, which may cause environmental damage.

1. Introduction

Long-term studies dealing with the optimization of nitrogen fertilization in olive (*Olea europaea* L.) orchards have demonstrated that annual applications of nitrogen fertilizers are not necessary to maintain high productivity and growth (Fernández-Escobar et al., 2009a,b). These studies recommend that the best strategy to optimize nitrogen fertilization in olive orchards is the application of nitrogen fertilizers only when the previous season's leaf analysis indicates that leaf nitrogen concentrations have dropped below the deficiency threshold. This threshold corresponds with the critical leaf nutrient concentration below which growth or yield of a tree decreases when compared with others that have higher thresholds (Ulrich, 1952). The deficiency threshold for olive trees has been established at 1.4% leaf dry weight for July samples (Beutel et al., 1983). However, no reduction in yield or growth was found in trees with a nitrogen concentration in leaves below 1.4%, suggesting that the deficiency threshold in olive trees must be lower (Fernández-Escobar et al., 2009b; Molina-Soria and Fernández-Escobar, 2010). In the former reference, it was also reported that leaf nitrogen concentrations in non-fertilized control trees did not drop below 1.2% after 13 years of monitoring, it being difficult to establish a precise deficiency threshold with these experimental data. According to these reports, the question is: Why did leaf nitrogen concentrations not drop below 1.2% and trigger nitrogen deficiencies after this long span without nitrogen applications? The only plausible explanation is that other sources of plant-available nitrogen increase the soluble nitrogen fraction in the soil. Therefore, in order to explain these results, it becomes necessary to establish the nitrogen balance in orchards.

* Corresponding author. Tel.: +34 957 218 498; fax: +34 957 218 569.
E-mail address: rfernandezescobar@uco.es (R. Fernández-Escobar).

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The nitrogen balance is the difference between nitrogen inputs and nitrogen outputs, and represents the gain or loss of nitrogen in an orchard. The nitrogen balance is positive when nitrogen inputs are higher than nitrogen outputs and negative when nitrogen inputs are lower. The nitrogen cycle in an olive orchard is complex because of the various processes that interact, many of which are not fully understood. Plant-available nitrogen, that is, the fraction of soil nitrogen in the root zone that can be taken up by plants, comes from the mineralization of soil organic matter (the largest pool of soil nitrogen unavailable to plants), from the application of nitrogen fertilizers, nitrates present in irrigation water and rainwater, ammonium released from clays, and the natural fixation of atmospheric nitrogen. All these nitrogen sources are considered nitrogen inputs. Nitrogen outputs consist of leaching (the major source of nitrogen loss from agricultural soils), and also gaseous loss of nitrogen to the atmosphere by denitrification, ammonia volatilization, nitrogen immobilization in organic matter, ammonium fixation in clays, erosion, and nitrogen removal by crop and pruning.

Nitrogen balance analysis is also helpful for increasing the sustainable production of an orchard since it allows the design of management strategies to reduce the environmental impact of nitrogen losses and the negative effect of excess nitrogen on the tree and its crop, and to guarantee optimal tree growth and productivity. Taking into account the large surface area occupied by olive trees globally, about ten million hectares, 98% of them in the Mediterranean (Civantos, 2008), an approach to determine nitrogen balance in olive orchards could be of great interest. The objective of the present work was to establish an approach to the nitrogen balance in two olive orchards in two different localities.

2. Materials and methods

2.1. Location and experimental design

The experiments were established in 1994 with the goal of determining rational nitrogen fertilization practices in olive orchards from a sustainability perspective. A detailed description of the experiment can be found in Fernández-Escobar et al. (2009b). One experiment was located in Cabra, Province of Córdoba, Spain (37.28N, 4.26W), which has a mean annual precipitation of 702 mm and a mean annual temperature of 16 °C. The soil is clay loamy to sandy clay with organic matter ranging from 0.8 to 1.0% and a pH ranging from 8.1 to 8.3. For the present work, non-irrigated, 12-year-old 'Picual' olive trees spaced 7 m × 7 m apart were arranged in a randomized block design with four blocks and two treatments, one unfertilized control and the annual application of 1 kg N tree^{-1} (as urea) homogeneously distributed on soil surface within each experimental plot and split in two applications in the early spring. The experimental plot consisted of four trees bordered by a guard row. The second experiment was located in Mengibar, Province of Jaen (37.58N, 3.48W), which has a mean annual precipitation of 524 mm and a mean annual temperature of 17 °C. The soil is silty clay loam with an average organic matter of 1% and a pH ranging from 8.2 to 8.3. For the present work, 50-year-old 'Picual' olive trees spaced 12 m × 12 m apart were arranged in a randomized block design with four blocks and two treatments, one unfertilized control and the annual application of 1.15 kg N tree^{-1}. All the details of the experiment were as for the other, with the exception that these trees were irrigated once a week during the vegetative period.

2.2. Nitrogen balance

The nitrogen balance was estimated based on data obtained during the period 2001–2007. Applied over one year, the nitrogen balance can be expressed as follows:

$$\text{Nitrogen balance} = N_{\text{inputs}} - N_{\text{outputs}} = N_{\text{inorganic final}} - N_{\text{inorganic initial}} = \Delta N_{\text{inorganic}} \quad (1)$$

With:

$\Delta N_{\text{inorganic}}$ = the difference in inorganic, soluble nitrogen contents in the soil at the end and at the beginning of the agricultural year in question.

Therefore:

$$\Delta N_{\text{inorganic}} = N_{\text{fert}} + N_{\text{rain}} + N_{\text{irr}} + N_{\text{min}} + N_{\text{fix}} + N_{\text{clay rel}} + N_{\text{dry dep}} - N_{\text{leach}} - N_{\text{prun}} - N_{\text{crop}} - N_{\text{vol}} - N_{\text{inm}} - N_{\text{eros}} - N_{\text{den}} - N_{\text{clay fix}} \quad (2)$$

With:

N_{fert}, N applied with fertilizers; N_{rain}, N provided by rainwater; N_{irr}, N supplied by irrigation water; N_{min}, mineralized N; N_{fix}, N fixed by microorganisms; $N_{\text{clay rel}}$, N release from clays; $N_{\text{dry dep}}$, dry deposition of N; N_{leach}, N lost by leaching; N_{prun}, N removed by pruning; N_{crop}, N removed by the fruit; N_{vol}, N lost by ammonia volatilization; N_{inm}, N immobilized into organic matter; N_{eros}, N lost by erosion; N_{den}, N lost by denitrification; $N_{\text{clay fix}}$, N fixed in clays.

2.3. $N_{\text{inorganic final}}$ and $N_{\text{inorganic initial}}$

Inorganic nitrogen contents (NO_3^--N and NH_4^+-N) were determined in the top 100 cm of soil in October, at the end of the vegetative period and before significant rainfall occurred, during 2003–2007 in order to determine the average for one agricultural year. Soil sampling was taken under each tree canopy at 0–20, 20–40, 40–60, 60–80, and 80–100 cm depth. At each depth, soil samples were taken using a 4-cm diameter Edelman auger, and pooled as a single sample per plot. The soil samples were air-dried, sieved (<2.0 mm), and stored at 4 °C until subsequent analysis. The extractable NO_3^--N and NH_4^+-N were measured in the 2 M KCl extract (10 g soil in 100 mL of extractant). The soil suspension was shaken for 1 h, decanted for 30 min, and filtered through a Whatman No. 42 filter. Concentrations of NO_3^--N and NH_4^+-N were determined by colorimetry using a Bran & Luebbe II AutoAnalyser.

2.4. Nitrogen supplied by rainwater and by irrigation water (N_{rain} and N_{irr})

Nitrogen provided by rainwater was measured after each rainfall in water samples collected in different rain gauges at each location. As indicated above, only trees growing in Mengibar were irrigated. These trees received an average of 13,188 L tree^{-1} year^{-1}, which corresponds to a deficit irrigation practice to alleviate the drought conditions of this area. Water samples were frozen until analysis. Nitrogen was determined by steam distillation (Bremner and Keeney, 1965).

2.5. Net mineralized (N_{min}) and net immobilized (N_{inm}) nitrogen

Differences between mineralization and immobilization of nitrogen in soil (net mineralization or immobilization) was determined in the top 10 cm of soil using the method of accumulating inorganic nitrogen in the upper part of a closed cylinder (Hart et al., 1994). Incubation was carried out every three months in order to estimate the amount of seasonal net nitrogen mineralization or immobilization. Four PVC cylinders 4.5 cm in diameter and 12 cm in length were installed in each plot, one under each tree, at a depth of 10 cm, leaving 2 cm above the soil to facilitate extraction. Those placed in the fertilized plots were treated directly, applying the