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The amount of nitrogen applied and nutritional status of olive plants affect nitrogen uptake efficiency

R. Fernández-Escobar*, M.F. Antonaya-Baena, M.A. Sánchez-Zamora, C. Molina-Soria

Departamento de Agronomía, Universidad de Córdoba, Edificio C 4, Campus Universitario de Rabanales, Ctra. Madrid-Cádiz km. 396, 14071 Córdoba, Spain

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ABSTRACT

Mist-rooted 'Picual' olive cuttings were used to test the hypothesis that both the amount of nitrogen applied and the nutritional status of olive plants may affect nitrogen uptake efficiency (NUE). Plants were placed in a greenhouse at 30/15 °C (day/night) with a 14 h photoperiod. Two different experiments were developed. In the first, plants were subjected to the application of 0, 50, 100, 200, 400, 600 or 800 ppm N. In the second experiment, the aim was to obtain three groups of plants differentiated by the nutritional status. Each group received 0, 50 or 100 ppm N, according to the results obtained in the first experiment. When plants of each group differed in their nitrogen content, they were subjected to additional nitrogen application either via foliar or to the soil. At the end of each experiment, plants were harvested and nitrogen was determined in leaves, stems and roots to obtain the nitrogen uptake by the plants. Nitrogen uptake efficiency (NUE) was estimated as NUE = (N uptake/N applied) × 100. Nitrogen content of the plant, vegetative growth and leaf chlorophyll content increased from 0 to 100 ppm N applied, decreasing at higher doses of N application. Consequently, NUE exponentially decreases with the amount of N applied above 100 ppm, with values ranging from 45.9% at 100 ppm to 4.1% at 800 ppm N. The method of nitrogen application, foliar or to the soil, does not affect nitrogen uptake, but the contrary occurs with the nutritional status of the plant. Nitrogen deficient plants were able to uptake more fertilizer nitrogen that well-nourished plants, with a significant reduction in NUE. Consequently systematic, annual applications of large amounts of fertilizer nitrogen may cause nitrogen over-fertilization and negative effects in both the plant and the environment.

1. Introduction

Nitrogen is usually required in large amounts by plants and, therefore, is the mineral element most commonly used in the fertilization programmes of horticultural crops. However, the relatively low cost of nitrogen fertilizers and the perception that an increase in nitrogen fertilization always results in increased yield, has led to excessive application of nitrogen fertilizers. For instance, common practices in olive orchards include high rates of fertilizer nitrogen application, up to 350 kg N ha^{-1} annually (Fernández-Escobar et al., 1994), even when no correlation between the amount of nitrogen applied and orchard productivity have been found (Fernández-Escobar et al., 2009). This practice may cause environmental degradation (Fernández-Escobar et al., 2012) and negative effects on olive tree and oil quality (Fernández-Escobar et al., 2006).

It is important an efficient and responsible use of nitrogen fertilizers in order to maintain high yield rates and product quality, and to practice an environmental friendly, sustainable agriculture. Under this context, one of the objectives of fertilization programmes should be to maximize nitrogen use efficiency. Several definitions have been developed to measure nitrogen use efficiency, depending on the crop and the processes that the researcher wants to analyze. Good et al. (2004) show until eight different formulae to describe nitrogen use efficiency, including those to measure the increase of yield or biomass per unit of nitrogen content in the plant, or per unit of nitrogen applied; the efficiency of converted applied nitrogen to fruits; the efficiency of capture of nitrogen from soil; and so forth. Under the point of view of the fertilization practice it is important to know the efficiency of the application, that is, the amount of fertilizer nitrogen recovered by the plant related to the total amount of fertilizer nitrogen applied. This process is known as nitrogen uptake efficiency (NUE) which may vary between 25 and 50% in crop plants, showing tree crops the lowest values (Weinbaum et al., 1992).

Nitrogen uptake efficiency is affected by several factors. According to Weinbaum et al. (1992), NUE is inversely related to the amount of fertilizer nitrogen applied, to the presence of nitrogen in the soil or to the excess of irrigation water; could be improved by splitting fertilizer applications and drip irrigation; and be affected

* 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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by the alternate bearing phenomenon, soil management and timing of fertilizer application. Much attention has been paid recently to the timing of fertilizer nitrogen application in different fruit tree species such as peaches (Nario et al., 2003), hazelnuts (Braun and Gillman, 2009) or citrus (Martínez-Alcántara et al., 2012), but no information is available on the effect of nutritional status of the plant on nitrogen uptake efficiency. This is an important factor to take into consideration in the fertilization programmes of fruit tree crops since systematic nitrogen applications is a common practice in many orchards, sometimes or frequently applied to well-nourished trees (Fernández-Escobar et al., 2009). On these crops, the aim of fertilization is to increase efficiently nutrient content in the tree for later utilization and we can hypothesize that NUE could be affected by the nutritional status of the tree. The objective of the present work was, therefore, to study the effect of the amount of nitrogen applied and the nutritional status of olive plants on nitrogen uptake efficiency.

2. Materials and methods

2.1. Experimental design and plant measurements

Two separate experiments were conducted with olive plants growing in a greenhouse. In the first experiment, mist-rooted, four-month-old ‘Picual’ olive cuttings were growing in a 1.1 L pots containing a mixture of sand and peat (3:1 by volume). The plants were placed in a greenhouse at 30/15 °C (day/night) with a 14 h photoperiod. Plants were watered once a week with 150 ml of water per pot during an acclimation period of 20 days. The experiment was arranged in a randomized complete block design with seven treatments and eight replications. The treatments consisted on the application of 0, 50, 100, 200, 400, 600 or 800 ppm N. Urea (46% N) was used as nitrogen source. One application of 150 ml of N solution per pot was applied weekly alternating with an application of 150 ml of tap water. A nutrient solution without nitrogen was applied every four weeks to prevent nutritional deficiencies. This solution was composed of: 2 mM $MgSO_4$, 1 mM KH_2PO_4, 20 μM Fe-ethylenediamine-di-*o*-hy-drosyphenylacetic acid, 5 mM $CaCl_2$, 5 mM KCl, 12.5 μM H_3BO_3, 0.2 μM $(NH_4)6Mo7O_{24}4H_2O$, 1 μM $MnSO_4H_2O$, 1 μM $ZnSO_47H_2O$ and 0.25 μM $CuSO_45H_2O$. Total vegetative growth was measured weekly. At the end of the experiment, leaf chlorophyll content was determined by a Minolta spectrophotometer on representative leaves, obtaining the SPAD values from seven readings per leaf. The experiment finished after 17 weeks, when significant differences among treatments were found on vegetative growth. The experiment was repeated in the range of 0–400 ppm.

In the second experiment, mist-rooted ‘Picual’ olive cuttings were transferred to 2 L pots containing a mixture of sand and peat (2:1 by volume). The plants were placed in a greenhouse at 30/15 °C (day/night) with a 14 h photoperiod. In a first phase that lasted eight weeks, the aim was to obtain plants with an adequate size of 18–20 cm. The plants were watered with 100 ml of a nutrient solution as described above. During this time the lateral shoots were removed to favour vertical growth. The aim in a second phase was to obtain three groups of plants differentiated by the nutritional status. For these purpose, we established three groups of 26 plants which received 0, 50 or 100 ppm N, according to the results obtained in the first experiment. Urea (46% N) was used as nitrogen source. One application of 150 ml of N solution per plant was applied weekly alternating with one or two applications of 150 ml of tap water, depending on plant requirements. To prevent nutritional deficiencies the above nutrient solution without nitrogen was applied every four weeks. This phase lasted fifteen weeks, and nitrogen was determined in different plant organs of selected plants at the end of this phase. During the last phase of the experiment, half of the remaining plants of every treatment received foliar applications of nitrogen while in the other half nitrogen was applied to the soil. Foliar applications was carried out spraying 40 ml of the urea solution at a concentration of 1.36%, avoiding spraying onto the soil, so each plant received 0.25 g of N and application. The same amount of N was applied to the soil through irrigation water. These treatments were applied during three weeks alternating with an application of 100 ml tap water per week. After 26 weeks, when plants ceased grow, the experiment was finished.

2.2. Nitrogen determination

At the end of both experiments plants were harvested and leaves, stems and roots were removed separately from each plant, washed on distilled water, dried at 80 °C for 72 h, ground and stored in an oven at 60 °C until analysis. Nitrogen was determined with a EuroVector EA3000 CHN analyser by the Dumas procedure (Dumas, 1831).

Nitrogen uptake efficiency (NUE) was estimated according to the following formula:

$$NUE = \frac{\text{N uptake}}{\text{N applied}} \times 100.$$

where N uptake = nitrogen in total plant − nitrogen in plant with 0 ppm N. N applied = nitrogen applied as fertilizer.

2.3. Statistical analyses

Analyses of variance were performed on the data to compare the treatments effects. All percentage values were transformed using the arc sin of the square root before analysis. Where a significant F was observed, mean separation between treatments was obtained by polynomial contrasts for quantitative factors.

3. Results

3.1. Influence of the amount of N applied on NUE

Nitrogen content increase linearly in the range of 0–100 ppm of nitrogen applied in leaf, stem and root, and also in the total plant (Fig. 1). Increasing the amount of nitrogen applied did not increase nitrogen content in the plant, showing a tendency to be stabilized. Nitrogen accumulated mainly in leaves instead stems or roots, but at the highest amounts of nitrogen applied there was a decrease in N content in the leaves and an increase in stems.

The accumulated vegetative growth showed a significant quadratic response ($R^2 = 0.91$) indicating a reduction in growth

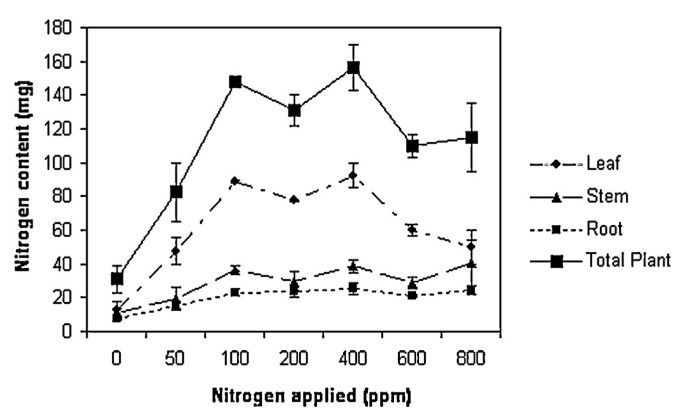

Fig. 1. Nitrogen content in leaf, stem, root and total plant according to the nitrogen applied.