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Wheat response to nitrogen splitting applied to a Vertisols in different tillage systems and cropping rotations under typical Mediterranean climatic conditions

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ABSTRACT

The application of an adequate rate and splitting of nitrogen (N) is essential for the efficient use of N fertiliser and to maintain the economic sustainability of cropping systems. A 3-year field experiment was conducted on a Vertisol under Mediterranean conditions to determine the effect of tillage systems, crop rotation, and variations in N timing on the grain yield and N recovery of ^{15}N-labelled fertiliser (N_R) in hard red spring wheat (*Triticum aestivum* L.). The experiment was designed as a randomised complete block with a split–split plot arrangement and 3 replications. The main plots were tillage system (no-tillage [NT] and conventional tillage [CT]), and the subplots were the preceding crop with 2-year rotations (wheat–sunflower [WS], wheat–chickpea [WC], and wheat–faba bean [WFB]). Sub-subplots were the N timing (all at the same rate of 100 kg N ha^{-1}), and the fertiliser was applied 50% at sowing and 50% at stem elongation and 50% at tillering and 50% at stem elongation. The area of each basic plot was 50 m^2 (5 m × 10 m). The residual NO_3–N content (0–90 cm) was significantly higher in CT than in NT, the opposite occurring with grain yield. The N_R of NT was greater than that of CT. According to the previous crop, the N_R was WS > WFB = WC. The soil nitrate content was twice as much when the preceding crop was a legume compared with sunflower and the wheat yields were as follows: WFB > WC > WS. Although the N timing did not have an effect on overall grain yield, the interactions with year, tillage system and previous crop were significant. The average recovery of ^{15}N fertiliser by wheat was 44.6%, with 33.7% obtained in the grain (41% in stem elongation, 32% in tillering and 27% in sowing). The habitual use of high rates of N fertiliser and the frequency of dry years in the agrosystem studied generated a progressive accumulation of residual in the soil profile. This can represent an important source of mineral N for the cereal and can reduce the need to apply N fertiliser to the crop.

1. Introduction

Cereal yields are low and vary in response to inadequate and erratic seasonal rainfall under Mediterranean conditions. Available soil water is the principal constraint to the yield potential of wheat and its response to N (Garabet et al., 1998). According to Campbell et al. (1993), there is a strong interaction between the use of soil water and the response of crops to fertilisers in semi-arid regions. The agronomic efficiency of N fertiliser in a Mediterranean climate may be lower than that in temperate zones.

The response of wheat to N fertiliser is also influenced by factors including N fertiliser management, soil type, crop sequence, and the supply of residual and mineralised N. The effect of N fertiliser on cereal during wet years was more marked in wheat rotations without legumes. Conflicting reports exist regarding the N balance and use efficiency of crops grown under no till systems compared with conventional tillage (CT) systems. Some researchers have reported that conservation tillage systems have increased fertiliser N rates to prevent yield limitations from short-term N immobilisation (Fageria and Baligar, 2005). However, Torbert et al. (2001) reported that there was no indication of N limitations in no-tillage (NT) systems compared to other tillage systems. Several studies reviewed by Hansen et al. (2011) report decreases of N mineralisation in non inverted soils compared with conventionally tilled soils. Direct-drilled crops may therefore require greater N inputs compared with crops in ploughed systems, although Thomsen and Christensen (2007) concluded that conversion from mouldboard ploughing to shallow tillage had little influence on fertiliser N balance. Malhi et al. (2009), Giacomini et al. (2010) and Hansen et al. (2011) have observed that tillage system had little effect on fertiliser N dynamics of the soil in spring cereals.

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Over the past several decades, numerous researches have sought to improve nitrogen-use efficiency (NUE) by developing fertiliser management strategies based on a better synchronisation between the supply of N and its requirement by a given crop (Ladha et al., 2005). Many studies have shown that split applications of N fertiliser result in higher rates of plant recovery and higher grain yields than under single applications. However, the proportions of the split should be determined locally, with due consideration of the initial soil fertility (Campbell et al., 1993; Mahler et al., 1994; Stockdale et al., 1997; Recous and Machet, 1999). López-Bellido et al. (2000) maintain that under dry Mediterranean conditions, a small application of N could be used at seeding, and additional N fertiliser could be applied as a top dressing at the end of tillering or at the beginning of stem elongation, depending on the winter rainfall, the previous culture in the rotation, and the amount of residual N in the soil at the end of winter.

The isotopic labelling method provides the most accurate measure of the relative contributions of soil N and fertiliser N to plant uptake. Numerous studies on the split application of N suggest that top-dressing applications in spring, whether during stem elongation and/or tillering (depending on the weather), improve the recovery of N fertiliser and the NUE when compared to application at sowing only (Sowers et al., 1994; Tran and Tremblay, 2000; Blankenau et al., 2002; Jia et al., 2011). Under a Mediterranean climate and in semi-arid regions, the amount of ^{15}N recovered is less than 50% (Garabet et al., 1998; Grageda-Cabrera et al., 2011). In a study on dry Vertisols in southern Spain, López-Bellido et al. (2005) obtained recovered ^{15}N values that, on average, did not exceed 40% and found that more ^{15}N-labelled fertiliser was recovered following a split N application than after an application of N during the fall.

Many approaches have been suggested for increasing NUE, such as using the optimal time, rate, and method of application for matching N supply with crop demand. Because some of the main factors, such as climate controlling crop needs for N, are largely outside farmer control, it remains difficult to predict the amount of N to apply for optimum growth. Appropriately managing N fertiliser for wheat production in dry areas is critical to obtaining the maximum economic yield and for improving water efficiency. As a consequence, we investigate agronomic factors and strategies of fertiliser N application that we hypothesised may influence the N fertiliser dynamic. The present study sought to determine in hard red spring wheat cultivated on a Mediterranean Vertisol under dry conditions: (i) fractionation of the N fertiliser rate more appropriate for better fertiliser efficiency and (ii) the effects of tillage system, crop rotation, and variation in N timing on the grain yield and N recovery of ^{15}N-labelled fertiliser.

2. Material and methods

2.1. Location and experimental design

Field experiments were conducted in Cordoba in southern Spain (37°46N, 4°31W, 280 m a.s.l.) on a Vertisol (Typic Haploxererts) typical to the Mediterranean region, where rainfed cropping is the standard practice. The study took place over a 3-year period (2003–2004, 2005–2006 and 2006–2007) within the framework of a long-term experiment named "Malagón", which started in 1986. The year 2004–2005 was not considered in the study because of bad growing season: only 263 mm of rain, most of which occurred in the fall-winter period, were precipitated in the area causing crop failure.

The properties of the Vertisol used in our field experiments were collected by López-Bellido et al. (1997). The experiment was designed as a randomised complete block with a split–split plot arrangement and 3 replications. The main plots were the tillage system (NT and CT), and the subplots were the preceding crop with 2-year rotations (wheat–sunflower [WS], wheat–chickpea [WC], and wheat–faba bean [WFB]). The sub-subplots were the N timing by the application of 100 kg N ha^{-1} at 50% between sowing and stem elongation (50–0–50) and between tillering and stem elongation (0–50–50). The area of each basic plot was 50 m^2 (5 m × 10 m) with a total size of 1800 m^2.

2.2. Crop management

The NT plots were seeded with a no-till drill (Great Plains). Weeds were controlled with glyphosate + MCPA at a rate of 0.5 + 0.5 l a.i. ha^{-1} prior to sowing. Conventional tillage treatment included mouldboard ploughing as well as disc harrowing and/or vibrating tine cultivation to prepare a proper seedbed. Information on cultivar, planting and herbicides applied during the growing season is provided in Table 1. Nitrate values before the start of the experiment were: 131 kg N ha^{-1} and 123 kg N ha^{-1} in faba bean rotation, 134 kg N ha^{-1} and 117 kg N ha^{-1} in chickpea rotation and 45 kg N ha^{-1} and 46 kg N ha^{-1} in sunflower rotation for CT and NT, respectively. Nitrogen fertiliser only was applied to wheat plots, as ammonium nitrate (34.5% N). When the 50% was applied before sowing, the N was incorporated by disc harrowing in conventional tillage and surface broadcast in no-tillage plots. The remaining N was applied as top dressing at tillering corresponding to stage 21 of Zadoks' scale (Zadoks et al., 1974) and stem elongation (stage 31 of Zadoks' scale) depending on N timing. Every year, wheat plots were also supplied with P fertiliser at a rate of 65 kg ha^{-1}; this was incorporated in conventional tillage following the standard practice and banded with drilling in no-tillage plots. Soil-available *K* was adequate (530 mg kg^{-1}). Wheat was harvested early in June each year, using a 1.5 m wide Nurserymaster elite plot combine. For each plot, a total area of 30 m^2 was collected from two adjacent strips of 15 m^2 (1.5 m × 10 m) each.

2.3. Plant and soil analysis

Soil samples were collected at a depth of 0–90 cm prior to wheat sowing. Soils were analysed for nitrate content using the Griess–Illosvay colourimetric method as modified by Barnes and Folkard (1951), with a Bran and Luebbe II Auto Analyser. At harvest, a biomass portion of 0.5 m^2 at the centre of each wheat sub-subplot was sampled to determine the N content of straw and grain using the Dumas combustion method (Leco FP-428 analyser).

2.4. Labelled nitrogen experiment

72 microplots (1 m × 2 m each) were established within the main experiment area to monitor the uptake of ^{15}N-labelled fertiliser. Microplots were arranged in a randomised complete block with 3 replications of 4 treatments. All microplots received 100 kg N ha^{-1}, with the following application timings: (1) 50% sowing (^{15}N-labelled)–50% top dressing (TD) at stem elongation; (2) 50% sowing–50% TD at stem elongation (^{15}N-labelled); (3) 50% TD at tillering (^{15}N-labelled)–50% TD at stem elongation, and (4) 50% TD at tillering–50% TD at stem elongation (^{15}N-labelled). The data from treatments (1), (2), (3), and (4) were combined to determine the total contribution of sowing-applied and top-dressed N fertiliser to plant N from this application regime. Fertiliser solutions were formulated with ammonium nitrate (34.5% N) and ^{15}N-enriched ammonium nitrate (2.5 atom% excess ^{15}N) for sowing and TD applications. Sowing applications were implemented immediately after this, and top dressings were implemented at the stages of tillering (stage 21 of Zadoks' scale) and stem elongation (stage 31 of Zadoks' scale), depending on N timing (Zadoks et al., 1974).