Europ. J. Agronomy 44 (2013) 38–45

Contents lists available at SciVerse ScienceDirect

European Journal of Agronomy

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

As durum wheat productivity is affected by nitrogen fertilisation management in Central Italy

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ARTICLE INFO

Article history:
Received 8 May 2012
Received in revised form 26 July 2012
Accepted 13 August 2012

Keywords:
Triticum durum
N fertilisation
N splitting
N source
N leaching

ABSTRACT

Optimisation of N fertilisation is a central issue and goal of applied research in agricultural systems. Site-specific management techniques are needed in order to closely match availability with requirement throughout crop cycle and to reduce as much as possible environmental dispersion of N. Lysimeter experiments were conducted in central Italy in two subsequent seasons to investigate the response of two commercial durum wheat cultivars to different N fertilisers applied before seeding and at topdressing, and to split applications of N. Grain yield and yield components, N uptake and N leaching were determined. Ammonium sulphate (AS) and urea containing the nitrification inhibitor 3,4-dimetihyl pyrazole phosphate (Entec® 46) were applied before seeding; AS, ammonium nitrate sulphate containing the nitrification inhibitor 3,4-dimetihyl pyrazole phosphate (Entec® 26), and urea were applied at 5th leaf unfolded stage. Six N-fertiliser treatments with a total N amount of 180 kg N ha^{-1} were tested, consisting of splitting application before seeding, at GS15 and GS30 respectively of 0-180-0, 0-90-90, 30-150-0, 30-75-75, 60-120-0 and 60-60-60 kg N ha^{-1}. In both years, fertiliser splitting affected durum wheat grain yield and N concentration; variations due to splitting reached 1 t in grain yield and 7 g kg^{-1} in N concentration of grain, corresponding to 4% increase in protein content. Highest grain yield, protein concentration, nitrogen use efficiency (NUE), and nitrogen uptake efficiency (NUpE) were obtained with the application of 30 kg N ha^{-1} before seeding. The yield advantage was related to higher number of kernels per spike, resulting from higher number of fertile spikelets per spike. Grain yield was not affected by nitrogen source applied before seeding, but was modified by topdressing N fertiliser. Yield increased by 0.4 t ha^{-1} with urea, compared to AS and Entec® 26, owing to a greater number of kernels per spike. Nitrogen leaching was closely related to rainfall: total amount of N lost during wheat cycle was almost entirely accounted for N leaching in winter, before topdressing N application. As a consequence, the quantity of N lost by leaching increased with the increase of N rate applied before seeding, while topdressing fertiliser did not affect losses.

1. Introduction

Optimisation of mineral N fertilisation aimed to increase N use efficiency is a central issue and goal of applied research in agricultural systems. Nitrogen use efficiency of worldwide cereal crops was estimated to be near 33% (Raun and Johnson, 1999), ranging from 14 to 59% in wheat (Melaj et al., 2003; López-Bellido et al., 2005); which suggests that current N strategies are extremely inefficient.

Nitrogen use efficiency (NUE) in cereal grain production may be low owing to losses of N by volatilisation, denitrification and leaching. Ammonium-based nitrogen fertiliser products are susceptible to volatilisation losses of nitrogen if surface-applied and not incorporated. Bouwman et al. (2002) estimated that NH_3 volatilisation losses from synthetic N fertilisers applied to both winter and summer crops amounts to 7% in industrialised countries. In Europe, fertiliser N losses via denitrification were estimated at 0.2–2.9% of the N applied to cereals (Kaiser et al., 1996).

Leaching losses occur when rainfall exceeds crop evapotranspiration and downward water movement through the soil profile takes place, which corresponds to the fall-winter period in humid Mediterranean climate (Arregui and Quemada, 2006). Leaching N–NO_3 losses from durum wheat crop were estimated in central Italy at 21–32 kg N ha^{-1} yr^{-1}, corresponding to 12–22% of the total N applied (Ercoli et al., 2012). Nitrate leaching in a 3-year crop rotation wheat–barley–rapeseed in similar conditions in Spain was

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1161-0301/$ – see front matter
http://dx.doi.org/10.1016/j.eja.2012.08.005

estimated at 31–35 kg N ha^{-1} y^{-1}, or 25–29% of the total N applied (Arregui and Quemada, 2006). Thus, as a general rule, N leaching in Mediterranean climate can be regarded as the greatest source of N loss and the major determinant of low N utilisation efficiency.

Durum wheat is widely cultivated throughout the Mediterranean region, where the crop is typically planted in November and harvested at the beginning of July. Heavy rainfall and low crop evapotranspiration rates can be expected between November and March, resulting in higher risk of N leaching losses. To reduce leaching losses, fertiliser application should aim to match as much as possible the requirement of plant N with the available nitrogen in soil, minimising the excess of N in soil useless to the plant. Thus, application should be the latest possible compatible with the stage of development that still permits rapid N uptake, in order to reduce the opportunities for N losses of unused N (Raun et al., 2008).

A number of experiments in winter cereal have shown that split applications of N fertiliser involving equal quantities of N applied before and after seeding are agronomical strategies to improve N utilisation efficiency (Alcoz et al., 1993; Delogu et al., 1998; López-Bellido et al., 2005, 2012; Dilz, 1988). Sowers et al. (1994) and Strong (1995) found that the N fertiliser applied in autumn, owing to increased N leaching, had a lower efficiency than when the nitrogen was splitted in fall and spring. Garrido-Lestache et al. (2004) observed that timing and splitting of N fertiliser influenced grain protein content, which peaked when half or one-third of the N rate (150 kg N ha^{-1}) was applied at stem elongation, and in some cases when N was applied only at tillering. However, the effect of splitting N rate on grain quality was unclear in other studies (Ayoub et al., 1994; Garrido-Lestache et al., 2005). Fuertes-Mendizábal et al. (2010) found that the splitting of the same N rate in three amendments (stages GS20, GS30, and GS37, according to Zadoks scale) instead of two (stages GS20 and GS30) did not modify grain yield but improved grain protein content, indicating that a late N application may have more impact on N metabolism and N remobilisation than on biomass accumulation and grain yield. Ottman et al. (2000) showed higher grain protein contents with the application of high N rates at anthesis.

Another strategy to reduce N leaching losses and to increase N utilisation efficiency is the use of fertilisers releasing reduced and controlled amount of nitric N. Several studies have shown beneficial effects of the use of slow and controlled-release fertilisers, stabilised fertilisers and/or nitrification and urease inhibitors to enhance productivity of agricultural and horticultural crops (Prasad and Power, 1995; Pasda et al., 2001; Carreres et al., 2003). In other studies, however, no positive results have been reported following the application of fertilisers that delay nutrient availability (Cartagena et al., 1995; Diez et al., 1997; Arregui and Quemada, 2008). Inconsistencies in results may appear since soil properties and/or climatic conditions affect both nutrient-release rates from fertilisers and processes leading to leaching and denitrification losses and immobilisation in soil.

The present work was undertaken to determine the effects of different sources of N fertiliser distributed before seeding and topdressing and split applications of N on grain yield, yield components, N uptake and N leaching of durum wheat, and to identify N fertiliser and type of splitting that optimised N uptake and retention in Mediterranean environments.

2. Material and methods

Lysimeter experiments were conducted in two successive growing seasons, 2008–2009 and 2009–2010 at the experimental station of the Department of Scienze Agrarie, Alimentari e Agroambientali of the University of Pisa, Italy, that is located at a distance of approximately 10 km from the sea (43°40′ N, 10°19′ E) and 3 m above sea level. The climate of the site is cold, humid Mediterranean with mean annual maximum and minimum daily air temperatures of 20.2 and 9.5 °C, respectively (Moonen et al., 2001). For both years, daily weather data were obtained from a meteorological station located within 100 m from the experimental fields.

In both years a full factorial of two durum wheat varieties, two N fertilisers before sowing, three topdressing N fertilisers and six split applications of N was replicated two times and arranged in a randomised, complete-block design. The durum wheat (*Triticum durum* Desf.) varieties were Latinur and Svevo, currently used in local production. The two N fertilisers before sowing were ammonium sulphate (AS), and urea containing the nitrification inhibitor 3,4-dimetihyl pyrazole phosphate (Entec® 46). The three topdressing N fertilisers were AS, ammonium nitrate sulphate containing the nitrification inhibitor 3,4-dimetihyl pyrazole phosphate (Entec® 26), and urea, and were applied at the 5th leaf unfolded stage. Total N amount of 180 kg ha^{-1} was split among pre-seeding, at 5th leaf unfolded stage and at pseudo stem erection as follows: 0-180-0, 0-90-90, 30-150-0, 30-75-75, 60-120-0 and 60-60-60 kg N ha^{-1}. Growth stages of 5th leaf unfolded and pseudo stem erection were individuated following the scale of Zadoks (Zadoks et al., 1974), corresponding respectively to GS15 and GS30.

Open-air lysimeter installation consisted of 144 lysimeters of 0.50-m length, 0.50-m width and 0.4-m height (100-L volume), arranged in four rows of 36, spaced 20 cm and embedded in expanded clay to smooth daily fluctuations in soil temperature. Lysimeters were filled with a soil tamped to about original soil bulk density, and were attached to a 3-cm rigid PVC drain that ended in a central collection facility. Soil chemical–physical properties were: 68.5% sand (2 mm > Ø > 0.05 mm); 25.9% silt (0.05 m > Ø > 0.002 mm); 5.6% clay; 7.0 pH; 2.0% organic matter (Walkley and Black method); 0.8 g kg^{-1} total nitrogen (Kjeldahl method); 26.0 mg kg^{-1} available P (Olsen method); 76.3 mg kg^{-1} available K ($BaCl_2$ + TEA method).

Phosphorus and potassium were hand applied preplanting as triple mineral phosphate and potassium sulphate at a rate of 150 kg ha^{-1} P_2O_5 and 150 kg ha^{-1} K_2O. Nitrogen was hand applied before seeding and at GS15 according to the treatments and at GS30 as urea.

The durum wheat varieties, Latinur and Svevo, were sown on 18 November 2008 and 25 November 2009, within the optimum planting time for wheat production in Central Italy. A rate of 100 viable seeds per container, corresponding to 400 viable seeds m^{-2}, in rows spaced 15 cm apart, was applied. Plant emergence was recorded on 5 December 2008 and 9 December 2009. Weed control was performed throughout wheat cycle by hand hoeing.

Leachates from each lysimeter were collected during the entire research period in both years after each major rainfall event in a 20-L PVC tank. Leachate volumes were measured and their $N–NO_3$ concentrations were determined with an Orion ion analyser model 502A (Orion Research Inc., Boston, MA, USA). Accumulated monthly leachate volumes were calculated and the monthly flow-weighted $N–NO_3$ concentrations were determined by summing up $N–NO_3$ mass collected for each rainfall event in a month divided by the total leachate volume collected in the month. Averagely, a concentration of 2.4 mg $N–NO_3$ L^{-1} was determined in rainfall. For all treatments, timing of stage of 1st leaf emergence (GS10), 5th leaf unfolded (GS15), pseudo stem erection (GS30), inflorescence emergence (GS50), and physiological ripening (GS90) were recorded, expressing in thermal time the duration of the periods between stages (Table 1). Thermal time was calculated following McMaster and Wilhelm (1997), assuming 2 °C as base temperature (Porter and Gawith, 1999). At GS90 (22 June 2009 and 30 June 2010) plants from each container were manually cut at ground level and were partitioned into culms, leaves, chaff and grain. For dry weight