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Managing the seeding rate to improve nitrogen-use efficiency of winter wheat

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ABSTRACT

This study was conducted to determine whether grain yield and nitrogen-use efficiency (NUE) of winter wheat (*Triticum aestivum* L.) could be improved by managing the seeding rate. During the 2010–2011 and 2011–2012 crop seasons, two winter wheat cultivars (Tainong18 with lower tillering capability and Shannong15 with higher tillering capability) were evaluated to investigate the effect of seeding rate on grain yield and NUE. Significant increases in root length density (RLD), absorbed N from fertiliser (N_f) and soil (N_s), above-ground N uptake (AGN), N uptake efficiency (UPE), NUE and grain yield, as well as a significant reduction in N utilisation efficiency (UTE), were observed as the seeding rate increased from 135 to 405 seeds m^{-2} for Tainong18 and from 90 to 345 seeds m^{-2} for Shannong15. NUE was positively correlated with UPE but not with UTE, indicating that optimising the seeding rate improved NUE mainly by raising UPE due to increased AGN as a result of optimised RLD and a synchronous increase in N_f and N_s. Therefore, the seeding rate could be a factor useful to obtain higher grain yield and NUE in winter wheat.

1. Introduction

Nitrogen (N) is the most essential nutrient for winter wheat (*Triticum aestivum* L.) growth, productivity and grain quality among all fertilisers (Fageria and Baligar, 2005; Frink et al., 1999). Currently, the worldwide recovery efficiency of N fertiliser in wheat systems is 30–50% (Raun and Johnson, 1999; Raun et al., 2002), although higher values have been described (50–60%) with even much higher values reported in some countries with high potential conditions (Barraclough et al., 2010). N remaining in the topsoil profile results in an unnecessary cost to farmers and negative environmental impacts in association with groundwater pollution through nitrate leaching, eutrophication of rivers and lakes from surplus N, along with global warming resulting from N_2O emissions associated with the denitrification of nitrate and nitrification of ammonium by soil bacteria (Sylvester-Bradley and Kindred, 2009).

NUE is defined as grain dry matter yield per unit of N available (from soil and fertiliser) and is divided into two components such as N-uptake efficiency (above-ground N uptake [AGN]/N available [UPE]) and N-utilisation efficiency (grain dry matter yield/AGN [UTE]; Moll et al., 1982). UPE is a reflection of the capacity of N to recover from fertiliser and soil and is most affected by the root length density (RLD), storage capacity of N in plants and the activities of key N assimilation enzymes. As a reflection of grain production per unit of AGN, UTE can also be calculated by the ratio of the N harvest index (NHI) to grain N concentration (GNC) and is influenced positively by NHI but negatively by GNC (Foulkes et al., 2009).

Previous researchers have investigated the relationship among NUE, UPE, UTE, AGN, RLD, NHI and GNC. Muurinen et al. (2006) and Van Sanford and MacKown (1986) indicated that UPE was the most important component of NUE. The efficient capture of available N requires high RLD (Barraclough et al., 2010; Thorup-Kristensen et al., 2009). However, other studies have found that variability in NUE is mainly related to differences in UTE under low (Gaju et al., 2011) or high (Le Gouis et al., 2000) N availability. Higher AGN would account for lower UTE (Delogu et al., 1998; López-Bellido and López-Bellido, 2001) and lower NHI (Ehdaie and Waines, 2001; Wuest and Cassman, 1992a,b). Barraclough et al. (2010) found a near-functional inverse relationship between UTE and GNC, assuming a constant NHI. Sadras and Lawson (2013)

Abbreviations: AGN, above-ground nitrogen uptake; GNC, grain nitrogen concentration; LAI, leaf area index; N_f, absorbed nitrogen from fertiliser; N_s, absorbed nitrogen from soil; NHI, nitrogen harvested index; NUE, nitrogen-use efficiency; RLD, root length density; UPE, nitrogen uptake efficiency; UTE, nitrogen utilisation efficiency.

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indicated that GNC accounted for 85% of the variation in UTE across cultivars and environments.

The optimum seeding rate is key to maximising yield in most crops (Hiltbrunner et al., 2007). Seeding rate of winter wheat is a factor of particular importance in wheat production systems because it can be easily controlled (Lloveras et al., 2004). Higher grain yield and quality require the use of an appropriate seeding rate (Geleta et al., 2002). Significantly linear (Geleta et al., 2002; Lloveras et al., 2004) or positive quadratic (Carr et al., 2003) responses in grain yield have been observed as seeding rate increases. Unchanged (Hemmat and Taki, 2001) or reduced (Fang et al., 2010) grain yields have occasionally been reported with increased seeding rates. N uptake was highest with the optimum seeding rate and lower or higher seeding rates failed to increase N uptake in wheat (Blankenau and Olfs, 2001). However, linear increases in N uptake have been reported in durum wheat (*Triticum durum* Desf.; Arduini et al., 2006). In addition, increased (Tompakins et al., 1991a,b), unchanged (Ozturk et al., 2006) or reduced (Geleta et al., 2002) GNC values have been observed with increased seeding rates in previous studies. However, the effect of seeding rate on NUE has been relatively poorly studied. Investigating how wheat recovers more N from soil and fertiliser (better UPE) and how to use the absorbed N to make more grain (better UTE) by managing the seeding rate without differences in available N could be an alternative to improve NUE and provide an opportunity to identify key traits influencing and restricting the improvement of NUE for future field strategies.

The aim of this study was to examine the effect of the seeding rate on grain yield and NUE in two cultivars under field conditions. We also investigated UPE, AGN, UTE, NHI and GNC of winter wheat to elucidate the processes involved in increasing NUE by optimising the seeding rate. The reasons for the changes in AGN, NHI and GNC and their relationship to variation in NUE are discussed.

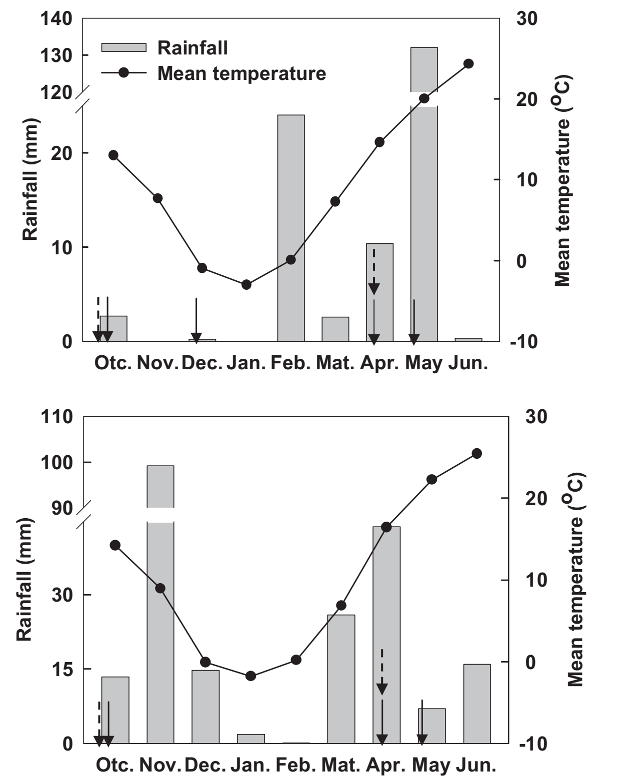

Fig. 1. Rainfall and mean temperature (°C) recorded during the period of winter wheat growth (October to next June) in 2010–2011 (top) and 2011–2012 (bottom). The arrows with real line and broken line represented the time of irrigation and fertilisation, respectively.

2. Materials and methods

2.1. Site and growing conditions

Field experiments were carried out in 2010–2011 and 2011–2012 at the experimental station of Dongwu Village (35°57′ N, 117°3′ E), in Dawenkou Town, Daiyue District, Tai'an, Shandong, P.R. China. The soil type was sandy loam, and soil pH was 8.25 (Typic Cambisols; FAO/EC/ISRIC, 2003). Total rainfall during the entire growing season was slightly less than the 40-year average (188.31 mm) in 2010–2011 (172.2 mm) and much higher in 2011–2012 (221.8 mm; Fig. 1); however, a significantly different distribution was observed during each season. A rainless autumn and winter provided little precipitation except during February compared to moderate rainfall after anthesis accounting for 76.66% of the total precipitation in 2010–2011. In contrast, pluvial autumn and winter brought excess water to wheat, a drought in January and February, followed by a very rainy March and April, but a relatively dry grain filling stage in 2011–2012.

Soil samples from the 0 to 100-cm layer were taken before any fertiliser was applied and the straw of the previous summer maize was returned each year. The soil samples were divided into two parts. One part was frozen as a fresh sample (lowest temperature, −30 °C to −35 °C) and the other part was dried in a ventilated and shady room and stored as a dry sample. The fresh samples were analysed for soil N_{min} (mineralised N in soil, including NO_3–N and NH_4–N), which was carried out by shaking 12 g of fresh soil sample in 1 M KCl for 1 h. After filtering, the extract solution was analysed for NO_3–N and NH_4–N using a continuous flow analyser (Bran + Lubbe, Norderstedt, Germany). The NO_3–N concentrations were determined by colourimetric cadmium reduction (Wagner, 1974) and those of NH_4–N were determined with a spectrophotometric method by which a coloured complex of NH_4–N and sodium salicylate was formed in the presence of prussic acid and chloride (Benesch and Mangelsdorf, 1972). The dried soil samples were analysed for organic matter content (Walkley and Black method; Walkley and Black, 1934), total N (semi-micro Kjeldahl method; Kjeltec^{TM} 8200 Auto Distillation Unit, Foss, Hillerød, Denmark; Bremner, 1960; Yuen and Pollard, 1953), available phosphorus (Olsen method; Zandstra, 1968) and available potassium (Dirks-Sheffer method; Melich, 1953).

The N_{min} values in the top 100-cm soil profile were 198 and 185 kg ha^{-1} in 2010–2011 and 2011–2012, respectively. The status of the other nutrients before sowing during the 2 years is listed in Table 1.

2.2. Experimental design and treatments

Two widely planted cultivars, Tainong18 (a cultivar with bigger ears and lower tillering capacity) and Shannong15 (a cultivar with middle-sized ears and higher tillering capacity), were selected as the experimental plants (henceforth referred to as "T18" and "S15", respectively). Seeding rates of 135, 270, 405 and 540 seeds m^{-2} were designed for T18, and 90, 172.5, 345 and 517.5 seeds m^{-2} were used for S15. The experiments were established in a split-plot design of three replicates (24 subplots), with cultivar as the main plot and seeding rate as the subplot. The size of each subplot was 20.0 m × 3.0 m (12 rows spaced 25 cm apart).

Previous crops were summer maize, and all straw and leaves were returned to the soil before tillage during both years. Basal fertilisation of each subplot included N as urea, phosphorus as calcium superphosphate and potassium as potassium chloride at rates of 120 kg ha^{-1} N, 105 kg ha^{-1} P_2O_5 and 150 kg ha^{-1} K_2O,