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The effects of cultivar and nitrogen management on wheat yield and nitrogen use efficiency in the North China Plain

Dianjun Lu[a], Feifei Lu[a], Junxiao Pan[a], Zhenling Cui[a,*], Chunqin Zou[a], Xinping Chen[a], Mingrong He[b], Zhenlin Wang[b]

[a] Center for Resources, Environment and Food Security, China Agricultural University, Beijing 100193, China
[b] Collaborative Innovation Team of Shandong Wheat-Corn Crops, National Key Lab. of Crop Biology, Key Lab. of Crop Ecophysiology and Farming System, Ministry of Agriculture, Agronomy College of Shandong Agricultural University, Tai'an 271018, Shandong, China

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A B S T R A C T

Understanding the inherent characteristics of cultivars with different spike types based on biomass and biomass partitioning with optimal nitrogen (N) management is important to achieve both high wheat yield and N use efficiency (NUE). A field experiment was conducted over 3 years using five N rates and two winter wheat cultivars (a larger spike cultivar (TN) and a multiple spike cultivar (LX)) in the North China Plain (NCP) to evaluate whether larger spike cultivar can accumulate more post-anthesis biomass and achieve higher yields and to determine the optimal N management strategies for the two cultivars. In both cultivars over 3 years, the optimal N rate (ONR) based on in-season root zone N management (INM) reduced the N rate by 140 kg N ha^{-1} from 300 to 160 kg N ha^{-1} without any yield losses, while it increased the N uptake efficiency from 32% to 64% compared with typical farmer's N practice (FNP). Furthermore, under ONR treatment, the grain yield and N physiological efficiency of TN significantly was higher 6 and 10% over 3 years than that of the multiple spike cultivar LX, respectively. The yield increase of TN was attributed mainly to the increased harvest index (7%) and similar total biomass. The higher 11% leaf N concentration at anthesis and 10% grain number m^{-2} of TN significantly increased the post-anthesis biomass by 24% under ONR, which played an important role in increasing the harvest index (HI). In addition, the grain yield of 70% ONR significantly decreased by 12% and 8% for TN and LX over 3 years, respectively, while no significant increase in grain yield was observed for 130% ONR, suggesting that the ONR was optimal in practice. Changes in N management may not be required for the two cultivars, because the ONR according to INM is close to the economically optimal N rate (EONR) based on grain yield response curves. In conclusion, selecting a larger spike cultivar with optimal N management could be a useful strategy to achieve high yield and high NUE for wheat production in the NCP, especially using optimal crop management practices.

1. Introduction

Even with recent productivity gains since the Green Revalua-tion, contemporary agriculture still faces considerable challenges due to increasing populations and the current stagnation status of crop yield in many regions (Foley et al., 2011; Rosegrant and Cline, 2003; Tilman et al., 2011). Considerable increases in wheat yields have been attributed mainly to genetic improvement in biomass partitioning (harvest index, HI) in the past decades via the wide adoption of dwarfing genes (Calderini et al., 1995; Reynolds et al., 2009). In recent years, many studies have reported the importance of increasing biomass production by improving photosynthesis while maintaining current HI (Reynolds et al., 2000; 2009). For tiller crop wheat, the magnitude of biomass and biomass partitioning is determined mainly based on population quantity (stem number per square) and spike quality (spike fertility) within the crop growing season (Lu et al., 2014; Moragues et al., 2006). In practice, the contribution of biomass and HI to increasing grain yield varied considerably among cultivars (Álvaro et al., 2008; Calderini et al., 1997), crop management (Meng et al., 2013) and environmental conditions (Moragues et al., 2006). Understanding cultivar characteristics in biomass accumulation and partitioning over time in

Abbreviations: N, nitrogen; NUE, nitrogen use efficiency; RUE, radiation use efficiency; NCP, North China Plain; TN, Tainong 18; LX, Liangxing99; ONR, optimal N rate; FNP, farmers' N practice; UE, N uptake efficiency; PE, N physiological efficiency; *Pn*, photosynthetic rate.

* Corresponding author. Tel.: +0086 10 62733454; fax: +0086 10 62731016.
E-mail address: cuizl@cau.edu.cn (Z. Cui).

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different spike type cultivars under optimal nitrogen (N) management is crucial for improving both wheat yield and N use efficiency (NUE).

Many studies have shown that the total biomass for high-yielding cultivars did not change or increased only slightly during breeding (Acreche et al., 2008; Slafer et al., 1990a,b), because radiation use efficiency (RUE) has not improved significantly (Calderini et al., 1995, 1997) in the past decades. A recent examination of yield improvement in irrigated winter wheat revealed a close correlation between yield and post-anthesis biomass among the most recent cultivars in China (Ye et al., 2011). Miralles and Slafer (1997) found that modern high-yield lines in irrigated environments have higher biomass accumulation and RUE compared with old cultivars after anthesis, but not before. Similar results were reported in the oat and six-row barley by Muurinen and Peltonen-Sainio (2006), who observed differences in post-anthesis biomass between old and modern oat and six-row barley cultivars under high latitude growing seasons. Consequently, methods to improve post-anthesis biomass production are required to further increase the wheat yield potential through breeding and crop management.

Many studies have attributed pleiotropic effects to improved partitioning driven by the enhanced sink size (Calderini et al., 1997; Fischer et al., 1998), i.e., number of developing grains, due to breeding. Different spike type cultivars use different approaches to increase grain number and establish sink size for achieving a high yield (Lu et al., 2014). For example, in China, larger spike cultivars characterized by high HI generally produced more grains per spike with less spike numbers per square, while multiple spike cultivars with lower HI depended more on productive spike number and less on the grains per spike (Lu et al., 2014; Peng et al., 2008). Meanwhile, there are increasing reports showing that the larger spike cultivars perform better based on grain yield due to the higher grain number (Yang et al., 2007a,b; Peng et al., 2008). In practice, due to the emphasis on spike number, "the greater the spike number, the higher the wheat yield", the multiple spike cultivars are cultivated predominantly in most farmers' fields and high yielding systems for irrigated wheat in China (Lu et al., 2014; Wang et al., 2001). Meanwhile, a commonly observed phenomenon for the multiple spike cultivar is increased lodging caused by excessive spike number, especially after widespread over-application of N fertilizer in the North China Plain (NCP) (Cui et al., 2010; Zhang et al., 2012), which limits the improvement of grain yield and NUE.

Recent studies on optimal N management to improve NUE highlighted the need for greater synchrony between crop N demand and N supply throughout the growing season (Cassman et al., 2002; Chen et al., 2006). For instance, in China, lots of field experiments demonstrated the optimal N management based on in-season root zone N management and rapid soil test realized reasonable match between N supply and crop N uptake, and embodied the better effect of increasing wheat yield and saving N fertilizer rate (Cui et al., 2011; Chen et al., 2014). However, it is unclear whether the optimal N management is equally applied to the different spike type cultivars, because N management may be needed to be adjusted for different cultivars due to genetic differences in biomass production or N uptake capacity (Calderini et al., 1995). Larger spike cultivars depend more on grains per spike to increase yield, suggesting that the N uptake after stem elongation may be greater and important for yield improvement. Many studies have shown that an increased dressing N rate prior to stem elongation generally leads to an increased grain number per spike (Abbate et al., 1995). On the contrary, N demand of multiple cultivars during the early tillering period should be higher due to more stems per square and increased biomass (Lu et al., 2014). In addition, N management during the period from stem elongation to anthesis is important for ensuring higher tiller survival (Meng et al., 2013), especially for the multiple spike cultivars. Understanding differences between the two types of cultivars is helpful to improve related N management strategies.

Here, we hypothesized that using a suitable cultivar and the corresponding N management strategy can simultaneously achieve high yield and high NUE. The objective of this study was to evaluate grain yield and NUE of cultivars differing in spike type and N management, to quantify the dry matter and N accumulation over time for the two cultivars under optimal N management (especially post-anthesis), and to determine the optimal N management strategy for these two cultivars.

2. Material and methods

Field experiments were conducted from 2012 to 2014 in Quzhou, Hebei province, China, in a long-term N level study initiated in 2007. The climate is warm-temperate, subhumid, continental, and monsoonal; winters are cold and summers hot. The rainfall ranged from 121 mm during the growing season of 2013–2014 to 134 mm during the growing season of 2011–2012 (Fig. 1). To achieve high wheat yield, irrigation was applied up to three times: before the winter, around stem elongation, and during the early grain filling stage, with 90 mm applied each time. The soil is clay loam with an organic matter content of 14.2 g kg^{-1}, total N of 0.83 g kg^{-1}, Olsen-P of 7.2 mg kg^{-1}, NH_4OAc-K of 125 mg kg^{-1}, pH 8.3, and a soil bulk density of 1.36 g cm^{-3}.

2.1. Experimental design

The field experiment was designed as a split-plot experiment with N level as the main plot and cultivar as the split-plot, with four replicates. The N treatments included 0 N control, 70% optimal N rate (ONR), ONR based on in-season root zone N management (see

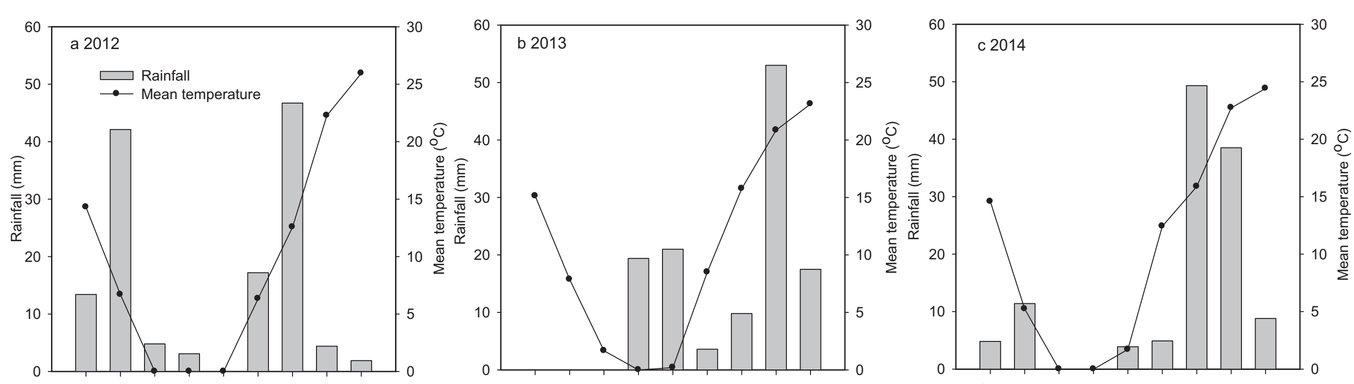

Fig. 1. Rainfall amounts and mean temperatures during the winter wheat growing season (October to June) in 2012 (a), 2013 (b), and 2014 (c).