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Mid-season nitrogen application strategies for rice varieties differing in panicle size

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ABSTRACT

Application of nitrogen (N) during the mid-season is an important practice in rice production. However, little is known if its timing should vary with the varieties differing in panicle size. We investigated the effectiveness of various mid-season N applications on the grain yield and nitrogen use efficiency (NUE) for rice varieties differing in panicle size. Three high-yielding japonica rice varieties, Yangfujing-8, Lianjing-7 and Huaidao-9 with a small, medium and large panicle size respectively, were grown in the field. Four N treatments during the mid-season, applied at the stages of panicle initiation (PI), spikelet differentiation (SD), heading time (HT) or all the three stages, were adopted with no N application as control. Results show that their effectiveness on grain yield and NUE varied substantially with the variety panicle size. For Yangfujing-8, N applied at PI was the most effective in increasing yield and NUE, while for Huaidao-9, N applied at SD or HT was the most effective. The effectiveness was similar for Lianjing-7 when N applied at PI, SD or N split application at PI, SD, and HT. Nitrogen applied at SD markedly increased crop growth rate during the 15-day period proceeding heading and pre-anthesis non-structural carbohydrate accumulation in the stem at heading. While N applied at HT significantly increased the photosynthesis of leaves. Both treatments of N applied at SD and HT could increase activities of sucrose synthase and adenosine diphosphoglucose pyrophosphorylase in the inferior spikelets of HD-9 at the mid and late grain filling stages. According the results, a mid-season N application strategy is suggested: applying N at PI to increase sink capacity for a variety with a small panicle size, at SD or HT to increase filling efficiency for a variety with a large panicle size, and at either PI or SD for a variety with a medium panicle size.

1. Introduction

Nitrogen (N) is among the most important elements required in agricultural systems to produce food and to supply protein for the increasingly world population (Follett and Hatfield, 2001). In the last 50 years, crop yields in the world have continuously increased, partly because of the increase in fertilizer nutrient input, especially N fertilizer (Cassman et al., 2003; Peng et al., 2010). Rice (*Oryza sativa* L.) is one of the most important crops in the world, and the foremost staple food in Asia, providing 35–60% of the dietary calories consumed by more than 3 billion people (Fageria, 2003). It is estimated that, by the year 2025, it will be necessary to produce about 60% more rice than what is currently produced or to increase the yield more than 1.2% per year to meet the food needs of a growing world population (Fageria, 2007; Normile, 2008). To meet such a requirement, efficient application of N fertilizers is an important approach, and meanwhile to minimize negative effects on the environment in rice production (Hirel and Lemaire, 2005; Tylaran et al., 2009).

In high-yielding rice cultivation, the nitrogenous fertilizers are usually recommended to be split into basal application, top-dressing during early-tillering and three top-dressing times during the mid-season (Ghaley, 2012; Matsushima, 1980). Nitrogen fertilizers applied as base-dressing at pre-transplanting and top-dressed during early-tillering after transplanting are mainly used for increasing the number of panicles. The three top-dressing times during the mid-season, i.e., the fertilizers top-dressed at panicle initiation (PI), initial of spikelet differentiation (SD) and heading

Abbreviations: AE_N, agronomic N use efficiency; AGPase, adenosine diphosphoglucose pyrophosphorylase; CGR, crop growth rate; DAH, days after heading; DPA, days post anthesis; HT, heading time; IE_N, internal N use efficiency; LAD, leaf area duration; LAI, leaf area index; NSC, nonstructural carbohydrate; NUE, nitrogen use efficiency; PE_N, N physiological efficiency; PFP_N, N partial factor productivity; PI, panicle initiation; RE_N, apparent recovery efficiency of N fertilizer; SD, spikelet differentiation; SuSase, sucrose synthase.

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time (HT), are usually used to increase the number of differentiated spikelets, prevent differentiated spikelets from degeneration and increase the percentage of filled grains, respectively (Matsushima, 1980). There are reports that, among these three top-dressing times, N fertilizers top-dressed at PI are the most effective in increasing grain yield (Ling, 2007; Xue et al., 2010). However, Fu et al. (2011) observed that the grain yield of newly bred super rice was increased more under the treatment of N applied at SD than under the treatment of N applied at PI when compared with that under no N application during the mid-season. The discrepancies between the studies are probably attributed to the difference in rice varieties and plant growth conditions. The mechanism is not understood.

The grain yield of rice can be defined as the product of yield sink capacity and filling efficiency (Kato and Takeda, 1996). However, there is often a negative correlation between spikelet number per panicle and the percentage of filled grains (Fageria, 2007; Venkateswarlu and Visperas, 1987). Previous studies have shown that a rice variety with a small panicle size (small number of spikelets per panicle) usually has a higher percentage of filled grains, and grain yield could be increased by increasing the number of spikelets (Cao et al., 1992). On the other hand, a rice variety with a large panicle size (with numerous spikelets per panicle) often exhibits a lower percentage of filled grains, and an improvement in grain filling could increase grain yield (Cao et al., 1992; Fu et al., 2011). These results imply that, to achieve a higher grain yield, N application timing during the mid-season would be different for the varieties differing in panicle size.

The objective of this study was to investigate what mid-season N application strategies should be for rice varieties with a small, medium or large panicle size, and what the mechanism is involved in which N application timing during the mid-season affects grain yield. Three rice varieties differing panicle size were grown in the field and six N application treatments were conducted. Some agronomic and physiological traits associated with rice grain yield, i.e., yield components, leaf area index (LAI), leaf area duration (LAD), leaf photosynthetic rate, nonstructural carbohydrate (NSC) in the stem at the heading time and its remobilization during grain filling, were compared among the varieties and N treatments. Since the activities of some key enzymes involved in sucrose-to-starch conversion in grains, such as sucrose synthase (SuSase, EC 2.4.1.13) and adenosine diphosphoglucose pyrophosphorylase (AGPase, EC 2.7.7.27), can reflect sink activity (Ishimaru et al., 2005; Kato, 1995; Liang et al., 2001; Yang et al., 2004), activities of SuSase and AGPase in grains were also investigated to understand the biochemical mechanism underlying the effectiveness in increasing grain yield subjected to various N application treatments.

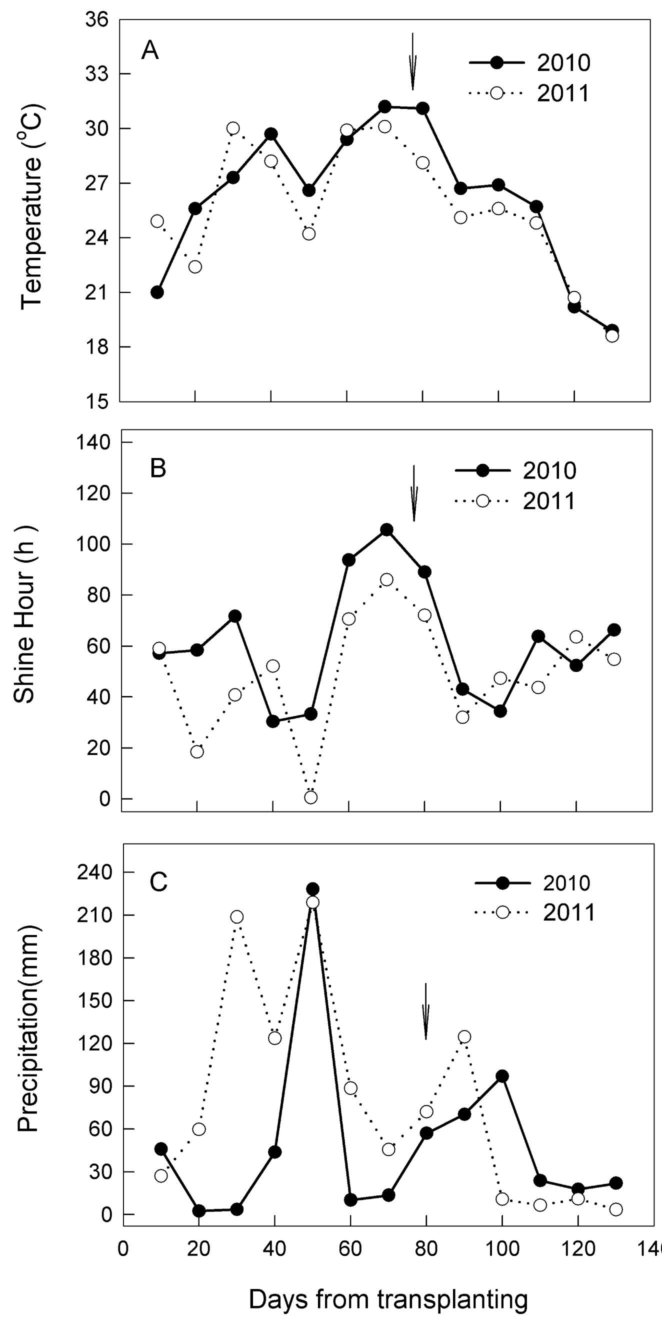

Fig. 1. The mean temperature (A), sunshine hours (B), and precipitation (C) during the growing season of rice in 2010 and 2011 at the experiment site of Yangzhou, Southeast China. Data are means of per 10 days from the transplanting of rice. Arrows indicate the heading time.

2. Materials and methods

2.1. Plant materials and growth conditions

The experiment was conducted at a farm belonging to Yangzhou University, Jiangsu Province, China (32°30′N, 119°25′E) during the rice growing season (May to October) of 2010, and repeated in 2011. The soil was a sandy loam [Typic fluvaquents, Etisols (U.S. taxonomy)] with 24.5 g kg^{-1} organic matter, 103 mg kg^{-1} alkali hydrolysable N, 34.5 mg kg^{-1} Olsen-P, and 67.8 mg kg^{-1} exchangeable K. The field capacity soil moisture content, measured after constant drainage rate and made gravimetrically, was 0.189 g g^{-1}, and bulk density of the soil was 1.34 g cm^{-3}. The average air temperature, precipitation, and sunshine hours during the rice growing season across the two study years measured at a weather station close to the experimental site are shown in Fig. 1.

Three high-yielding japonica rice (*Oryza sativa*. L) varieties currently used in local production, Yangfujing-8 (YFJ-8), Lianjing-7 (LJ-7) and Huaidao-9 (HD-9, super rice), were grown in the paddy field. The number of spikelets per panicle is usually less than 130 for YFJ-8 (small panicle size), 130–160 for LJ-7 (medium panicle size) and more than 200 for HD-9 (large panicle size) when N rate was 240–300 kg ha^{-1} according to local practice. The three varieties have a similar growth period ranged from 150 to 152 days from sowing to physiological maturity. The seeds of all the three varieties were obtained from Yangzhou Seed Company (Yangzhou, Jiangsu, China). Across the two years, seedlings were raised in the seedbed with sowing date on 10–11 May and transplanted on 9–10 June at a hill spacing of 0.20 m × 0.20 m with two seedlings per hill. Phosphorus (30 kg ha^{-1} as single superphosphate) and potassium (40 kg ha^{-1} as KCl) were applied and incorporated