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Determination of optimal nitrogen rate for rice varieties using a chlorophyll meter

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Abstract

Site-specific N management (SSNM) such as real-time N management (RTNM) and fixed-time adjustable-dose N management (FTNM) improve fertilizer-N use efficiency of irrigated rice. This study was conducted to compare the N response and fertilizer-N use efficiency of Shanyou63 (SY63) and Liangyoupeijiu (LYP9) under a wide range of N rates. SY63 and LYP9 were the most popular hybrid varieties in the late 1980s and late 1990s in China, respectively. The overall objective was to develop optimal N management for LYP9 using SSNM. The two varieties were grown under eight and six N treatments in 2004 and 2005, respectively, in Hubei, China. N treatments included a zero-N control, an FTNM, and several RTNM with different chlorophyll meter (SPAD) thresholds. SPAD readings were taken weekly on the topmost fully expanded leaves. Grain yield, yield attributes, total N uptake, and components of fertilizer-N use efficiency were measured in both years. Both FTNM and RTNM can be used to improve N management for SY63 and LYP9, but the optimal SPAD threshold for determining the timing and rate of N application was 2 units higher in LYP9 than in SY63 because LYP9 has thicker leaves. The two varieties required a minimum total N rate of 120–150 kg N ha^{-1} for producing maximum grain yield. The difference in maximum grain yield was very small between the two varieties, although LYP9 had the potential to produce higher grain yield than SY63. The two varieties did not show a clear difference in fertilizer-N use efficiency. When excessive N was applied (195–275 kg N ha^{-1}), grain yield of LYP9 was 13% higher than that of SY63 in both years because they responded differently to the high N inputs. Our study suggests that the planting of a variety insensitive to high N input such as LYP9 would lead to over-application of fertilizer-N by rice farmers if knowledge-intensive N management technology such as FTNM and RTNM were not used.

Keywords: Agronomic-N use efficiency; Fixed-time adjustable-dose N management; Grain yield; Hybrid rice; Internal-N use efficiency; N recovery efficiency; Real-time N management

1. Introduction

Poor fertilizer-N use efficiency for rice production in China is an accepted fact (Wang et al., 2001; Peng et al., 2002). Wang et al. (2001) reported that agronomic-N use efficiency (AE_N) of the farmers' N-fertilizer practice was 6.4 kg kg^{-1} for the irrigated rice crop in Zhejiang. Peng et al. (2006) conducted on-farm experiments in four major rice-growing provinces in China and found that AE_N of the farmers' N-fertilizer practice ranged from 3.1 to 8.2 kg kg^{-1}. A well-managed rice crop should have an AE_N of 15–25 kg kg^{-1} under irrigated conditions if the N input is optimal (Dobermann and Fairhurst, 2000). Excessive N input was the major cause of the poor fertilizer-N use efficiency in China (Peng et al., 2006). China's national average N rate for rice was 145 kg ha^{-1} in 1997 (IFA, 2002). Based on data from 1995 to 1997, the average rate of N application for rice production in China was 180 kg ha^{-1} (FAO, unpublished data, 2001). On-farm experiments in four major rice-growing provinces revealed that farmers applied 180–240 kg N ha^{-1} to their rice crops (Peng et al., 2006). In Jiangsu Province, the average N rate reached 300 kg ha^{-1} in some counties (Q. Zhu, personal communication, 2001). Furthermore, excessive N is applied mostly in the vegetative stage during the early growing season. Farmers applied 56–85% of total N in the first 10 days after transplanting

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(Peng et al., 2006). The improper timing of N application also contributed to the poor fertilizer-N use efficiency for rice production in China. It is unknown whether some varieties with strong lodging resistance and insensitivity to N input currently used by farmers in China could cause the excessive N use in rice production.

The International Rice Research Institute (IRRI) developed site-specific N management (SSNM) such as real-time N management (RTNM) and fixed-time adjustable-dose N management (FTNM) to increase the fertilizer-N use efficiency of irrigated rice (Peng et al., 1996; Dobermann et al., 2002). In RTNM, a certain rate of N-fertilizer is applied only when leaf N content is below a critical level (Peng et al., 1996). Therefore, the timing and number of N applications and total N rates vary across seasons and locations. Leaf N content can be estimated non-destructively with a chlorophyll meter (SPAD) or leaf color chart (LCC) (Tao et al., 1990; Peng et al., 1996; Balasubramanian et al., 1999; Yang et al., 2003).

In FTNM, yield response to N application was estimated based on the difference between grain yield with a zero-N control and the target yield (Dobermann et al., 2002; Buresh et al., 2005; IRRI, 2006). The target yield was usually set at 85% of climatic yield potential. Total N rate was estimated based on the yield response and the target AE_N. Total N was applied split at basal, midtillering, panicle initiation, and heading. The rates of N topdressing at the key growth stages were adjusted according to leaf N status measured with SPAD or LCC. In this approach, the timing and number of N applications are fixed while the rate of each N application varies across seasons and locations.

Evaluation of RTNM in many Asian rice-growing countries has generally shown that the same rice yield could be achieved with about 20–30% less N-fertilizer applied, but increases in yield were rare (Peng et al., 1996; Balasubramanian et al., 1999, 2000; Hussain et al., 2000; Singh et al., 2002). However, across eight sites in Asia, average grain yield increased by 11% and average N recovery efficiency (RE_N) increased from 31 to 40% by using FTNM compared with farmers' N-fertilizer management (Dobermann et al., 2002). It has also been shown that both RTNM and FTNM could improve fertilizer-N use efficiency of rice production in China (Peng et al., 2006).

Stimulated by IRRI's new plant type breeding program, China established a nationwide mega project on the development of "super" rice in 1996 (Cheng et al., 1998). The "super" rice variety should outyield widely grown local check varieties by 10% with acceptable grain quality and pest resistance. Another goal of "super" rice is to produce 100 kg grain ha^{-1} d^{-1} (Yuan, 2001). As of 2001, seven inbred and 44 hybrid varieties that meet the "super" rice criteria have been released by the provincial or national seed board (Min et al., 2002). Among these "super" rice varieties, Liangyoupeijiu (LYP9), an intersubspecific hybrid rice, was grown on a total of 2.23 M ha until 2002 in 13 provinces in China because it had high yield and good grain quality (D. Zhu, personal communication). Shanyou63 (SY63), an intrasubspecific hybrid rice, was the most popular variety in the late 1980s in China. It was gradually replaced by the "super" rice varieties, including LYP9, starting in the late 1990s. Some farmers still plant SY63 because of its yield stability and wide adaptability and rice breeders still use it as a check variety in China.

Previous studies on "super" rice varieties focused on their yield potential and morpho-physiological traits at the maximum N input (Zong et al., 2000; Yao et al., 2000; Chen et al., 2002; Wang et al., 2002; Ou et al., 2003). Most studies on improving fertilizer-N management were conducted using only one variety (Peng et al., 1996; Wang et al., 2001; Dobermann et al., 2002). Studies are limited on the optimization of N management for "super" rice varieties. It is not clear whether "super" rice varieties have a different N response and fertilizer-N use efficiency compared with ordinary rice varieties. The objectives of this study were (1) to develop optimal N management for LYP9 using RTNM and FTNM, (2) to compare grain yield between LYP9 and SY63 over a wide range of N rates, and (3) to determine whether LYP9 and SY63 had different N use efficiency.

2. Materials and methods

Experiments were conducted in 2004 and 2005 in two adjacent fields at Xusan village, Xinpu township, Xiaonan County, Hubei Province, China (30°59′N, 113°56′E, 28 m asl). The soil of the two fields had the following properties: pH 6.1, 6.9 g kg^{-1} organic C, 0.83 g kg^{-1} total N, 7.3 mg kg^{-1} available P, 0.35 cmol kg^{-1} exchangeable K, 12.6 cmol kg^{-1} cation exchange capacity, 32.3% clay, 64% silt, and 3.8% sand. The soil test was based on samples taken from the upper 20 cm of the soil.

Treatments were arranged in a split-plot design with N rates as main plots and varieties as subplots. The experiment was replicated four times and subplot size was 25 m^2. The varieties were two hybrids, Shanyou63 (SY63) and Liangyoupeijiu (LYP9). SY63 is an intraspecific hybrid rice developed with Zhenshan97A as the female parent and Minghui63 as the male parent using the three-line method (Xie, 1987). The two parents are indica type and Zhenshan97A is a cytoplasmic male sterile line. LYP9 is an intersubspecific hybrid rice developed with Pei'ai64S as the female parent and 9311 as the male parent using the two-line method (Yuan, 2001). Pei'ai64S is a thermosensitive genetic male sterile line and belongs to the intermediate type between indica and japonica. The restorer line 9311 is a typical indica type. SY63 and LYP9 were the most popular hybrid varieties in the late 1980s and late 1990s in China, respectively. LYP9 is still being widely grown and SY63 is being used as a check variety by rice breeders in China.

Eight and six N treatments were used in 2004 and 2005, respectively. In 2004, there were six real-time N management (RTNM) treatments with SPAD thresholds of 35–42.5 at an interval of 1.5 for both varieties. In 2005, there were four RTNM treatments with SPAD thresholds of 34–40 at an interval of 2 for SY63 and 36–45 at an interval of 3 for LYP9. The details of the RTNM approach were described by Peng et al. (1996). A chlorophyll meter [SPAD-502, Soil-Plant Analysis Development (SPAD) Section, Minolta Camera Co., Osaka, Japan] was used for measurements on 15 topmost fully expanded leaves per plot weekly from 15 days after transplanting (DAT) to 94 DAT in 2004 and to 79 DAT in 2005. In these RTNM treatments, N in the form