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Accumulation and utilization of nitrogen, phosphorus and potassium of irrigated rice cultivars with high productivities and high N use efficiencies

Min Li[a,b], Hongcheng Zhang[a,*], Xiong Yang[a], Mengjie Ge[a], Qun Ma[a], Haiyan Wei[a], Qigen Dai[a], Zhongyang Huo[a], Ke Xu[a], Deqiang Luo[b,c]

[a] Innovation Center of Rice Technology in Yangtze Rice Valley, Ministry of Agriculture/Key Laboratory of Crop Genetics and Physiology of Jiangsu Province, Yangzhou University, Yangzhou 225009, China
[b] Rice Research Institute of Guizhou Province, Guiyang 550006, China
[c] Key Laboratory of Crop Physiology and Ecology in Southern China, Nanjing Agricultural University, Nanjing 210095, China

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ABSTRACT

In the Jiangsu province of Southeast China, high irrigated rice yields are supported by high nitrogen (N) fertilizer inputs and low fertilizer N use efficiencies. A little attention has already been paid to the combined increase of rice yield and N use efficiency, however, the accumulation and utilization of N, phosphorus (P) and potassium (K) of irrigated rice genotypes with high yield and N use efficiency is still obscure. Field experiments were conducted in 2010 and 2011 where two cultivars with low productivity and low N use efficiency (LPLNE), two cultivars with high productivity and medium N use efficiency (HPMNE) and two cultivars with high productivity and high N use efficiency (HPHNE) were grown separately under their respective optimum N application to achieve maximum attainable yields. Accumulation and utilization of N, P and K as well as their interacting relationships were studied. The results showed that: (i) When values were averaged across cultivars and years, compared with LPLNE, HPMNE and HPHME showed 18.1, 25.3, and 9.6% higher N, P, K accumulations at maturity, respectively. The N grain production efficiency (NGPE) and K grain production efficiency (KGPE) were both higher, although P grain production efficiency (PGPE) showed no consistent tendencies; (ii) When values were averaged across cultivars and years, in comparison with HPMNE, HPHNE achieved a 1.7% lower total N accumulation, but a 6.5% higher N accumulation during the period from heading to maturity. At maturity, N accumulation in leaves increased by 3.5% and that in grains decreased by 4.0%. Total P and total K accumulation increased by 2.5% and 2.8%, respectively, which was mainly attributed to greater accumulation after panicle initiation, especially in the period from heading to maturity. At maturity, P accumulation in leaves increased by 11.5% and that in stems and grains did not differ significantly, K accumulation in stems increased by 4.2% and that in leaves and grains did not differ significantly. The N, P and K accumulation in grains at maturity did not explain the higher N use efficiency of HPHNE. This study suggested that a decrease of N accumulation before panicle initiation and increase of N, P, K accumulation during the period from heading to maturity may be helpful to combine the high yield and high N use efficiency in rice.

1. Introduction

Rice is one of the most important staple food crops in China, accounting for ~28% of the total grain-sown area and 43% of total grain production (Huang et al., 2001). With the ever increasing population and reducing farmland, it is critical to ensure food safety through continually improving grain yield per unit area (Peng et al., 2006). Nitrogen (N) is the most important nutrient element in irrigated rice production and current high yields of irrigated rice are associated with large applications of fertilizer N (Cassman et al., 1998). Although N supply drives productivity, very low fertilizer N use efficiency is a major characteristic of irrigated rice systems (Cassman et al., 1996; Peng et al., 2006). According to statistics, Chinese fertilizer N application in rice production amounts to 37% of the global total. As high as 270–330 kg N ha^{-1} is applied to achieve the high yield of japonica rice in the Jiangsu province, and the N

* Corresponding author. Tel.: +86 514 87979220; fax: +86 514 87979220.
E-mail address: hczhang@yzu.edu.cn (H. Zhang).

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Table 1
Properties of the rice cultivars used in the experiments.

Group[a]	Cultivar	Year of release	Female parent	Male parent	Days to flowering (d)	Days to maturity (d)	Plant height (cm)
LYLNE	Zhendao158		Zhendao5406	Wuyujing3	110	158	102
	Suxiangjing1	1997	Xiangnuo3007	Dan125	110	159	104
HYMNE	Zhendao413	2010	Zhendao88	Wuyunjing8	110	160	109
	Wu2645	2010	Yingyu7034	Zhongjing9016	110	160	105
HYHNE	Changjing09-5		93-63	Zhongwanjing06	109	159	112
	Changjing09-6	2012	93-63	Yin04-2	110	160	111

[a] LPLNE: low productivity and low N use efficiency rice; HPMNE: high productivity and medium N use efficiency rice; HPHNE: high productivity and high N use efficiency rice.

recovery efficiency (NRE) is only 30–35% (Peng et al., 2002; Zhang et al., 2010), causing a series of problems including N losses, production profit declination and environmental pollution (Peng et al., 2006). How to improve N use efficiency at the same time as increasing the rice yield is imperative.

Several steps are required to improve the N use efficiency of rice. At first, a reasonable amount of N application for a rice cultivar should be determined. Too low an amount of N application cannot achieve full yield potential, and too high an amount will lead to luxury N absorption, lodging, yield losses and low N use efficiency (Jiang et al., 2004; Fan et al., 2005; Jing et al., 2007). Even the 'super' hybrid rice varieties do not necessarily require more N fertilizer to produce high grain yield (Zhang et al., 2009). Second, N fertilizer application strategies should be improved which means fine tuning the supply-demand balance of crop and soil by improving fertilizer application patterns (Cassman et al., 1998; Jing et al., 2007), which depends on the accurate diagnosis and evaluation of the N status of the soil and crop (Ohnishi et al., 1999; Russell et al., 2006). With proper N management, up to 53 kg grain per kg N uptake of N physiological efficiency (NPE) can be achieved (Peng et al., 1996). When N fertilizer was applied in the proper amount and at the proper time, up to 50–70% N recovery efficiency (NRE) could be achieved (Schnier et al., 1990; Peng et al., 1996; Peng and Cassman, 1998). However, a higher panicle N fertilizer fraction is useful to increase NRE, while resulting in a decrease of NPE (Jiang et al., 2004). Third, the genotype differences of rice in N accumulation and utilization should be explored (Singh et al., 1998; Koutroubasa and Ntanos, 2003). Many reports in previous researches indicated that different rice cultivars had different responses to N management in accumulation and redistribution of N (Bufogle et al., 1997; Souza et al., 1998; Ntanow and Koutroubas, 2002; Koutroubas and Ntanos, 2003; Jiang et al., 2004; Anzoua et al., 2010), and many studies have been conducted to determine the morphological and physiological characteristics associated with N use efficiency (Ying et al., 1998; Jiang et al., 2004; Mae et al., 2006). However, only a few have focused on the combined increase of rice yield and N use efficiency, such as Atita 63, a large-grain cultivar from Japan exhibiting high yield as well as high N physiological efficiency (Mae et al., 2006). To date, little information is known about the accumulation and utilization characteristics of N, phosphorus (P) and potassium (K) in rice genotypes with high yield and high N use efficiency. In addition, there is a lack of study on superior genotypes under optimum N rates and proper N management.

Therefore in this study, 50 japonica cultivars with similar growth durations were selected which were widely planted and suitable for the region where the experiments were conducted, and seven N fertilizer levels were applied to ensure that each cultivar could reach its highest yield. All other managements were carried out as high-yielding-cultivation methods. The specific N level was then defined as the optimum N application for highest yield (ONAHY) and the corresponding yield as the highest productivity (HP) for the cultivar (Li et al., 2012).

With the premise that each cultivar fully exhibited its HP under its respective ONAHY, some of the tested cultivars were screened out and classified into three groups by HP and N use efficiencies, i.e., low productivity and low N use efficiency cultivars (LPLNE), high productivity and medium N use efficiency cultivars (HPMNE) and high productivity and high N use efficiency cultivars (HPHNE). The main objective of this study was to determinate the characteristics and relationships of N, P and K accumulation and utilization of HPHNE cultivars in comparison with LPLNE and HPMNE cultivars, expecting to provide very useful information for rice breeding and cultivation of high yield and high N use efficiency varieties.

2. Materials and methods

2.1. Materials

According to research in 2008 and 2009, Zhendao 158 and Suxiangjing 1 were selected to represent the LPLNE group, Zhendao 413 and Wu 2645 the HPMNE group, and Changjing 09-5 and Changjing 09-6 the HPHNE group. All six cultivars are japonica genotypes. Detailed information about these cultivars is given in Tables 1 and 2. As for the ONAHY, the two HPMNE cultivars were 300 kg N ha^{-1}, while the other four cultivars were 262.5 kg N ha^{-1} (Fig. 1).

Under their respective ONAHYs (Table 3), when values were averaged across cultivars and years, HPHNE and HPMNE cultivars produced 24.6% more grain yield than LPLNE cultivars, and compared with LPLNE, HPMNE and HPHNE showed an increase of 26.6 and 12.3% in NRE, and an increase of 40.7 and 16.7% in NPE, respectively. All the differences were significant ($P < 0.05$), demonstrating the importance of revealing the productivity diversities among cultivars and the N use efficiency differences among high productivity cultivars.

Table 2
Susceptibility to the major local diseases and insects of the rice cultivars used in the experiments.

Group[a]	Cultivar	Rice sheath blight	Rice neck blast
LYLNE	Zhendao158	Moderate susceptibility	Slight susceptibility
	Suxiangjing1	Moderate susceptibility	Slight susceptibility
HYMNE	Zhendao413	Slight susceptibility	Slight susceptibility
	Wu2645	Moderate susceptibility	Slight susceptibility
HYHNE	Changjing09-5	Moderate susceptibility	Slight susceptibility
	Changjing09-6	Slight susceptibility	Slight susceptibility

This table does not show the information of the bacterial leaf blight, false smut, rice leafroller, and rice planthopper which did not occur on the tested cultivars in the experiments.

[a] LPLNE: low productivity and low N use efficiency rice; HPMNE: high productivity and medium N use efficiency rice; HPHNE: high productivity and high N use efficiency rice.