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Full Length Research Paper

Genotype variation in grain yield response to basal N fertilizer supply among different rice cultivars

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Considering the great amount of basal N fertilizer but lower uptake ability at rice seedling, it was essential to increase the N use efficiency of basal fertilizer and reduce N pollution. So, a field experiment was conducted at Wuxi, China, under non-basal N and basal N fertilizer conditions, to identify the variation of grain yield response to basal fertilizer among 199 rice varieties with different genetic background, and finally choose the suitable rice varieties for us to increase basal N fertilizer efficiency and reduce N fertilizer pollution. The results show that highly significant genotype differences for grain yield and almost yield parameters existed in 199 rice varieties, and there were also great differences for agronomic N use efficiency (ANUE) and apparent recovery of applied basal N fertilizer (AR) among 199 rice varieties. Little response rice varieties HJY, 80-4, L454, SXJ, Daesong, WNZ and DXW2, and great response rice varieties NJ1X, HC106, QYDD, YTDBM, YJ2H, 4020 and 4024 were also screened in this study. Our results also show that the effects of basal fertilizer were mainly reflected on the early period of rice growth but not on the grain yield. This study identified genotype variation in grain yield response to basal N fertilizer supply and great ANUE and AY differences among the 199 rice cultivars, and also explored the reasons for these phenomena, which would provide us good information in increasing basal fertilizer efficiency and reducing N pollution.

Key words: Basal fertilizer, rice varieties, response, nitrogen, grain yield.

INTRODUCTION

Rice is an important cereal crop in the world, ranking the second to wheat in terms of surface area. Nitrogen is usually the most limiting nutrient for rice, and the cost of mineral N fertilizer accounts for a major portion of the total cost of rice production (Tirol-Padre et al., 1996). Unfortunately, fertilizer resources are not utilized efficiently in agricultural systems, and plant uptake of fertilizer-N seldom exceeds 50% of the N applied. One of the principal reasons for the poor efficiency of fertilizer use is that a proportion of N applied (up to 89%) is lost from the plant-soil system (Shukla et al., 1998). When any N compound is applied to a submerged paddy field, it is lost through leaching, denitrification, volatilization and runoff (Ghosh and Ravi, 1998). All of these worsen the environment quality.

China is one of the countries with large amount of nitrogen fertilizer application. However, generally, fertilizer nitrogen efficiency used by field crop is estimated to be between 30 to 35%, while 30 to 50% is lost through different pathways, such as volatilization, leaching and nitrification/denitrification (Zhu, 2000). The amount of nitrogen use in one season is 27.6% more than the international generally accepted standard, which resulted in serious environment pollution (Luo et al., 2003). Basal fertilizer accounts for about 50% of total nitrogen fertilizer applications for whole plant growth process in China. Therefore, it is very important to

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Table 1. Characteristics of the soil used in experiments.

Site	pH	Organic carbon (g/kg)	Total nitrogen (g/kg)	Total phosphorus (g/kg)	Total potassium (g/kg)	Soluble ammonium (mg/kg)	Soluble nitrate (mg/kg)	Available phosphate (mg/kg)	Available potassium (mg/kg)
Anzhen, Wuxi	6.5	38.3	1.83	0.88	18.3	1.166	6.365	8.29	101.3

Each value was the average of three replicates.

Table 2. Fertilizer nitrogen application designations in the field experiment (kgN ha^{-1}).

Parameter	Non-basal fertilizer	Basal fertilizer
Basal	0	54
Tiller fertilizer (5-6 leaves stage)	54	54
Spike fertilizer (the last 4 leaves stage)	36	36
Spike fertilizer (the last 2 leaves stage)	36	36
Total amount	126	180

increase the efficiency of basal fertilizer in order to get more yields and improve environments. Strategies could be adopted to increase nitrogen use efficiency through proper timing, rate, placement, and use of modified forms of fertilizer. However, acceptance and adoption of N-management strategies, which have been often associated with high labor requirements, has been discouraging. Genetic selection and plant breeding techniques helped to develop rice varieties that are most efficient in nitrogen uptake and utilization. This could increase nitrogen efficiency and reduce nitrogen fertilizer pollution.

During the past decades, many investigations have been reported, related to nitrogen efficiency of different plant genotypes (Zhang et al., 1997; Liu et al., 1999; Fang and Wu, 2001; Fang et al., 2004). Field experiments have shown that genetic variability for N use efficiency exists in rice (Broadbent et al., 1987; De Datta and Broadbent, 1993; Tirol-Padre et al., 1996; Singh et al., 1998; Inthapanya et al., 2000). However, genetic selection to improve the rice crop’s N use efficiency has not yet been widely applied (Singh et al., 1998). Significant differences among genotypes were observed in grain yield and N uptake efficiency and partitioning parameters (Singh et al., 1998; Inthapanya et al., 2000). Therefore, plant breeders need to develop cultivars that can exploit N more efficiently, in order to minimize loss of N from the soil and make more economic use of the absorbed N, which could increase rice yield and improve environments. The main goals for rice production systems are to get more grain yield, to reduce the production cost and to minimize the pollution risk for the environment. Thus, it is essential to study rice yield response to nitrogen fertilizer, especially basal fertilizer and yield response factors. The research about yield and N in response to basal fertilizer was seldom reported.

The objective of this study was to identify yield variation in response to nitrogen fertilizer basal dressing in 199 rice cultivars, select suitable rice cultivars to improve the environment and at the same time get high yield and finally compare and analyze the relative importance of those yield components that cause variation in yield response to basal fertilizer.

MATERIALS AND METHODS

Rice cultivars/lines

199 representative varieties/lines of japonica rice were chosen because of their contrasting agronomic traits. These rice varieties included 63 short-duration cultivars (less than 120 days), 77 medium cultivars (121 to 140 days) and 59 long-duration cultivars (above 140 days). Rice seeds were germinated in the dark and sowed in seedling-bed with uniform nutritional conditions until 3-leaf stage for transplanting.

Experimental site

The experiment was conducted at Wuxi city of Jiangsu province in China (31° 37’ 19.4’’ N latitude, 120° 30’ 52.2’’ E longitude). The test soil was typical paddy soil (yellow-brown soil developed from lacustrine deposits of Taihu lake) in that region, and its basic characteristics are listed in Table 1.

Experimental design

The experiment was conducted with a splitplot design, with non-basal fertilizer and basal fertilizer (Table 2) as main plots, and genotypes as subplots in 3 replications. Nitrogen fertilizer as urea was applied. Total phosphorus of 35 kg/ha as superphosphate, and total potassium of 130 kg/ha as KCl were applied in all treatments and all basal-dressed. The field experiment was divided into six plots, with two nitrogen treatments and three replicates. Each plot was subdivided into three subplots again according to rice growing

Table 3. Percentage contribution of genotypes (G), basal fertilizer (BF) and G × BF sum of squares to the total sum of squares and significance of their F values for the measured and derived parameters.

Parameter	F value and the significance of F value		
	G	BF	G × BF
Grain yield	92**	0ns	8ns
Straw weight	93**	1**	6ns
Tiller	79**	5**	16**
1000-grain weight	95**	1**	4**
Plant height	97**	1**	2ns
Grain N uptake	91**	0ns	9ns
Straw N uptake	85**	3**	12ns
Total N uptake	88**	2**	10ns
Grain N%	92**	0ns	8ns
Straw N%	83**	3**	14ns
GNUE	84**	2**	14**
PNUE	89**	2**	9ns
NHI	87**	1**	12**
HI	85**	0ns	15**

**, Significant at 1% level; *, significant at 5% level; ns, not significant.

duration of short, medium and long. Both plots and subplots were arranged at Latin arrangement. Each subplot was separated with polyethylene film by laying 30 cm underground, to avoid nutrients surface flow between subplots. Independent irrigation and drainage system was arranged for each subplot. Seedlings for every cultivar/line were transplanted into 1 m^2, with 20 cm width between lanes and 15 cm width between individual plants. Only single seedling was transplanted into each hole, and a total of 30 plants from every cultivar/line were grown in every 1 m^2.

Plant sampling and yield parameters

At physiological maturity, 8 plants in the middle region among 30 plants for every cultivar/line were cut at ground level. Tiller number, plant height, grains per panicle, one thousand-filled grain weight and dry weight of straw and grain were determined. Samples were ground in a Beater cross grinder. Straw and grain (caryopsis + hull) were analyzed separately for total N. Nitrogen concentration of grain and straw from every cultivar/line were determined with Kjeldahl method. At final harvest, plants were threshed manually. Grain (unhulled) yield was determined from eight plants. Total grain dry weight was determined, and final grain yield was adjusted to 14% moisture content (MC). Total straw weight was determined after drying at 70°C to a constant weight. The following parameters were calculated using the following equations: grain N use efficiency (NUEg) = grain yield / total N uptake; physiological nitrogen use efficiency (NUEp) = biomass above ground / total N uptake; nitrogen harvest index (NHI) = Grain N uptake / total N uptake; harvest index (HI) = grain yield / biomass above ground; agronomic N use efficiency (ANUE) = (GY_b - GY_0) / N_F, [GY_b (grain yield under basal fertilizer), grain yield under non-basal fertilizer (GY_0), fertilizer N applied (N_F)]; AR (apparent recovery of applied basal N fertilizer) = (TN_b - TN_0) / N_F, [TN_b (total N uptake under basal fertilizer), TN_0 (total N uptake under non-basal fertilizer)].

Statistical analysis

Statistical analysis for the experimental data was analyzed using Microsoft® Excel 2000 and the Statistical analysis system (SPSS 11.5). Simple (phenotypic) correlations for selected parameters were generated using rice varieties means.

RESULTS

Genotype variability in yield parameters under basal fertilizer and non-basal fertilizer

Analysis of variance revealed highly significant ($p < 0.01$) differences among 199 genotypes for all parameters (Table 3). The main effects of basal fertilizer were significant for all parameters except for grain yield, grain N uptake, grain N% and HI (Table 3), which indicated that basal fertilizer had fewer effects on the later period of rice growth. The G × BF interaction effects were highly significant only for tiller, 1000 filled grain weight, GNUE, NHI and HI (Table 3); because of these differences, basal fertilizer partitioning and efficiency may be different among different genotypes.

Grain yield response to basal fertilizer

Based on grain yield response in relation to N supply, genotypes were distinguished as efficient, inefficient, and inferior types (Gerloff, 1976; Gourley et al., 1993; Shukla et al., 1998). The categorization of superior germplasm into N-efficient and N-ineffcient genotypes was based on significant differences in grain yield at non-basal fertilizer supply. Higher than 20% mean yield and lower than 20% mean yield were defined to be high yield and low yield, respectively. Efficient genotypes that produced high

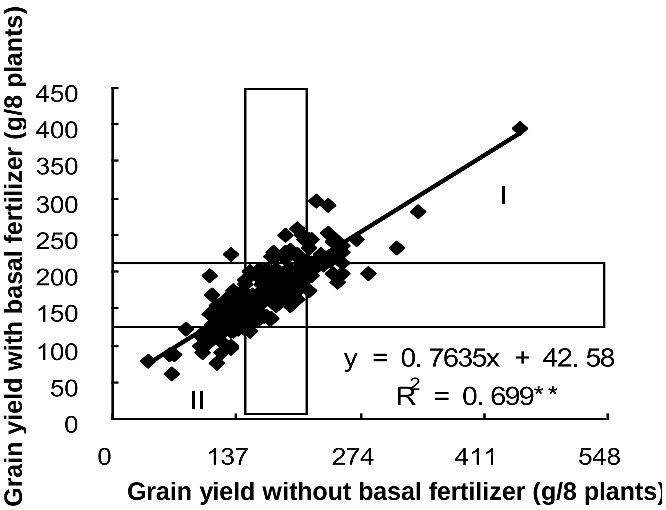

Figure 1. Comparison of grain yield production of 199 rice varieties under non-basal and basal fertilizer conditions.

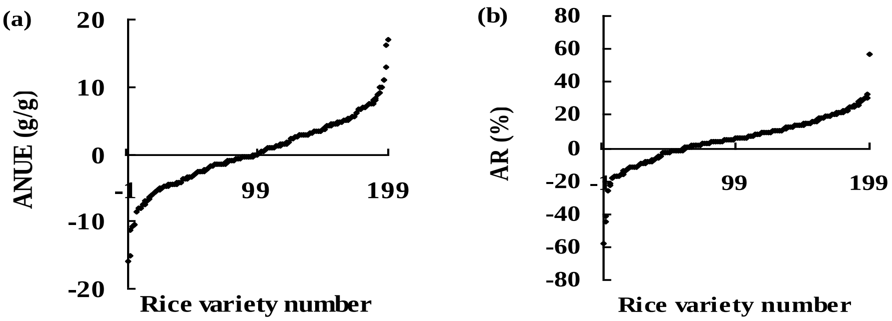

Figure 2. Differences in (a) ANUE and (b) AR among the 199 rice varieties.

yields at both non-basal fertilizer and basal fertilizer supply were distributed in I region (Figure 1) among the 199 rice cultivars. On the other hand, inefficient genotypes that had significantly lower yield than efficient genotypes at both non-basal fertilizer and basal fertilizer were distributed in II region (Figure 1). As shown in Figure 1, there was a significant positive relationship with r = 0.8362 between yield, under basal and non-basal fertilizer conditions. Therefore, the production ability of rice cultivars in yield was mainly affected by genotypes themselves and not by the application of basal fertilizer. While grain yield was strongly related between basal and non-basal fertilizer (Figure 1), great genotype differences for ANUE and AR in response to basal fertilizer were observed among 199 cultivars (Figure 2). ANUE and AR changed from -0.65 to 1.77 (Figure 2a), and -57 to 57% (Figure 2b), respectively. Considering this, we could make full use of this kind of differences among different rice varieties to reduce the environment pollution of basal fertilizer by increasing ANUE and AR.

Also, because of great differences in ANUE and AR among 199 rice varieties, we analyzed the relationships between them and selected parameters (Figure 3). As shown in Figure 3A, there were significant positive relationships for straw weight, NUEg, NUEp, NHI, HI, grain N uptake and straw N uptake with ANUE but significant negative relationships for straw N% with ANUE. Moreover, grain N uptake and straw weight had more important effects on ANUE. The results in Figure 3B show that there were significant positive relationships for 1000-grain weight, plant height, straw weight, grain N%, straw N%, grain N uptake, straw N uptake with AR but significant negative relationships for NUEg and NUEp with AR. It was interesting that grain N uptake and straw weight had also more important effects on AY like ANUE. In order to further understand the selected parameter effects on grain yield and N uptake, we compared the correlation of selected variables with grain yield and N

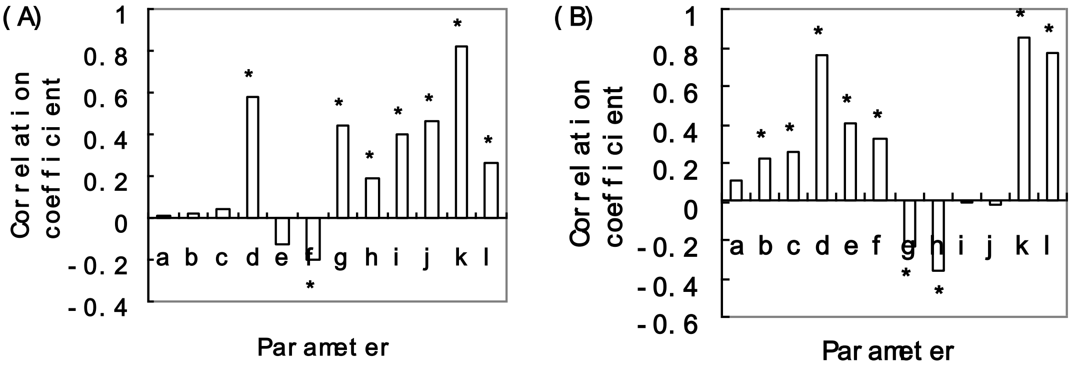

Figure 3. Correlation analysis for ANUE (A) or AR (B) with selected parameter increase after basal fertilizer was applied. a, tiller; b, 1000-grain weight; c, plant height; d, straw weight; e, grain N%; f, straw N%; g, NUEg; h, NUEp; i, NHI; j, HI; k, grain N uptake; l, straw N uptake. * = significant at 1% level.

Table 4. Correlation of selected variables with grain yield and N uptake.

Parameter	Non-basal fertilizer				Basal fertilizer			
	Grain yield	Total N uptake	Grain N (%)	Straw N (%)	Grain yield	Total N uptake	Grain N (%)	Straw N (%)
Grain yield	-	0.82**	-0.36**	-0.62**	-	0.80**	-0.23**	-0.54**
Straw weight	0.73**	0.80**	-0.41**	-0.42**	0.63**	0.77**	-0.34**	-0.38**
Tiller	0.02ns	0.11ns	0.02ns	0.12ns	-0.02ns	0.06ns	0.06ns	0.00ns
1000-grain weight	0.13ns	0.02ns	-0.01ns	-0.21**	0.21**	0.19**	0.19**	-0.22**
Plant height	0.39**	0.51**	-0.12ns	-0.34**	0.28**	0.51**	0.12ns	-0.38**
Grain N uptake	0.84**	0.88**	0.17*	-0.45**	0.82**	0.84**	0.34**	-0.43**
Straw N uptake	0.42**	0.71**	-0.26**	0.12ns	0.40**	0.73**	-0.23**	0.12ns
Total N uptake	0.82**	-	0.00ns	-0.27**	0.80**	-	0.11ns	-0.24**
Grain N (%)	-0.36**	0.00ns	-	0.37**	-0.23**	0.11ns	-	0.22**
Straw N (%)	-0.62**	-0.27**	0.37**	-	-0.54**	-0.24**	0.22**	-
GNUE	0.62**	0.08ns	-0.65**	-0.74**	0.57**	0.03ns	-0.48**	-0.65**
PNUE	0.53**	0.14*	-0.87**	-0.72**	0.44**	0.13ns	-0.82**	-0.69**
NHI	0.35**	0.11ns	0.33**	-0.53**	0.30**	0.02ns	0.49**	-0.44**
HI	0.32**	-0.02ns	0.05ns	-0.30**	0.27**	-0.11ns	0.17*	-0.14*

**, significant at 1% level; *, significant at 5% level; ns, not significant.

uptake under basal fertilizer and non-basal fertilizer (Table 4). The results for grain yield were similar to the results for ANUE in Figure 3A. There were significant positive relationships for plant height, straw weight, NUEg, NUEp, NHI, HI, grain N uptake and straw N uptake with grain yield but significant negative relationships for straw N % and grain N (%) with grain yield under basal and non-basal fertilizer; but with total N uptake, there were significant positive relationships for grain yield, plant height, straw weight, grain N uptake, straw N uptake but significant negative relationships for straw N% under basal and non-basal fertilizer. With grain N% and straw N%, there were negative relationships for almost all parameters under basal and non-basal fertilizer.

Selected typical rice varieties by different grain yield response to basal fertilizer

After the extremely obvious difference in ANUE and AY, response to basal fertilizer was found among the 199 rice varieties (Figure 2); typical rice varieties for different grain yield response to basal fertilizer were screened (Table 5). Little response rice varieties HJY, 80-4, L454, SXJ, Daesong, WNZ, DXW2 and great response rice varieties NJ1X, HC106, QYDD, YTDBM, YJ2H, 4020, 4024 are listed in Table 5 from 13 typical rice varieties,

Table 5. Typical rice varieties for different grain yield response to basal fertilizer.

Variety	Little response rice variety			Variety	Great response rice variety		
	-BF	+BF	Increase (%)		-BF	+BF	Increase (%)
HJY	173.1±10.3	181.6±8.5	5	NJ1X	130.2±16.5	222.7±30.6	71
80-4	193.6±19.3	203.9±17.0	5	HC106	80.5±6.2	123.3±28.5	53
L454	176.5±16.5	186.8±4.7	6	QYDD	190.2±18.7	250.1±37.0	32
SXJ	150.8±18.9	164.5±24.8	9	YTDBM	226.1±10.8	296.4±49.3	31
Daesong	138.8±21.6	143.9±7.0	4	YJ2H	146.6±27.1	183.3±12.4	26
WNZ	210.8±0.0	215.9±24.8	2	4020	162.7±30.6	203.9±18.4	25
DXW2	203.9±29.0	222.8±90.7	9	4024	238.1±44.9	291.2±43.6	22

Each value was the average of three replicates ± SE.

respectively. The mean increase (%) for great response rice varieties was 37%, whereas that for little response rice varieties was only 6%. Relationships between grain yield and yield parameters for typical rice varieties were also compared (Table 6). Straw weight, total N uptake, NUEg and NUEp were significantly correlated with grain yield under both basal fertilizer and non-basal fertilizer for little response rice varieties. For great response rice varieties, only straw weight and total N uptake were significantly correlated with grain yield. However, considering the absolute value of correlation coefficient, NUEg was the main effect on grain yield for little response rice varieties, whereas straw weight and total N uptake were the main effects on grain yield for great response rice varieties.

DISCUSSION

Genotype differences for N efficiency have been extensively studied in the past decades. However, genotype differences for basal N fertilizer were scarcely studied. In this study, we demonstrated that significant genotype differences for grain yield and almost yield parameters existed in 199 rice varieties. At the same time, there were great differences for ANUE and AR among 199 rice varieties. These results provide us with very good information to increase the efficiency of basal N fertilizer and reduce the pollution of basal N fertilizer by making full use of the different characteristics of rice varieties in nature. The present study also showed that genotypes had more essential effects on yield and yield parameters than basal fertilizer, whereas basal fertilizer also played very important roles in rice growth early period. Therefore, we could conclude that genotype functions are far more important than basal fertilizer. This gave us a very good idea that different rice genotypes could be used to increase yield and N efficiency, instead of the applied basal fertilizer.

It was well-known that basal fertilizer occupied the big proportion of total fertilizer application in plant full growth period. However, Basal fertilizer could result in relatively serious environmental pollution, since rice seedling had a weaker ability to take up nutrient because of small root system. Hence, it was essential for us to increase the N use efficiency of basal fertilizer and reduce the environmental pollution. In the present study, rice varieties HJY, 80-4, L454, SXJ, Daesong, WNZ and DXW2 were selected as little response rice varieties and rice varieties NJ1X, HC106, QYDD, YTDBM, YJ2H, 4020 and 4024 were selected as great response rice varieties. The data here could help us reduce N pollution of basal fertilizer. Once genotypic variation in nitrogen-utilization efficiency is found, the reasons for this kind of variation should be further analyzed. Physiological or morphological factors might result in this kind of phenomenon (Inthapanya et al., 2000). In this study, great genotype differences for ANUE and AR in response to basal fertilizer were observed among the 199 cultivars. Moreover, we found that straw weight and grain N uptake were both significant, having positive relationships with ANUE and AR; this was a very interesting result. ANUE could well reflect the productivity of basal fertilizer and AR could represent the uptake ability of rice varieties for basal fertilizer. The formation of straw weight was mainly in the early period of rice growth, and basal fertilizer had important roles in this period. Grain N uptake relied on the late period of rice growth, and it was essential for high AR. Therefore, both high straw weight and high grain N uptake were vital as yield components for high ANUE and AR. Furthermore, we found that grain N% and straw N% had negative relationships with almost all parameters under basal and non-basal fertilizer.

Identification of these components responsible for yield and improvement of these specific components are important for breeders to choose the most efficient selection criteria, and for rice growers to adopt the appropriate cultural practices for achieving high yield and nitrogen exploitation. The identification of the factors that determine grain yield and nitrogen utilization in rice production systems is necessary to optimize their productivity and reduce the pollution risk for the environment (Koutroubas and Ntanos, 2003). It was more important for us to distinguish the reasons for the great

Table 6 Relationships between grain yield and yield parameters for typical rice varieties grown under non-basal (-BF) and basal (+BF) fertilizer conditions. All kinds of yield components were compared with grain yield respectively.

Parameter	Little response rice varieties		Great response rice varieties	
	-BF	+BF	-BF	+BF
Straw weight	0.5866*	0.5595*	0.7014 *	0.7301*
Total N uptake	0.6038*	0.6787*	0.6852 *	0.7776 *
NUEg	0.7139**	0.7761**	0.3494ns	0.1311ns
NUEp	0.4490ns	0.5957*	0.2147ns	0.1281ns

Note: ** - significant at 1% level, * - significant at 5% level, ns- not significant (n=13).

difference of response to basal fertilizer between little response rice varieties and great response rice varieties. The results here indicate that NUEg was the main effect on grain yield for little response rice varieties, whereas straw weight and total N uptake were the main effects on grain yield for great response rice varieties. Therefore, high straw weight and high N uptake could result in high response to basal fertilizer. The results of the present work suggest that genotypic variation for yield response to basal was significant, and we could use this kind of difference to increase basal fertilizer efficiency and reduce N pollution of basal fertilizer on the base of higher yield. The reduction of N fertilizer pollution could benefit from the spread of these viewpoints in this study.

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