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Effects of N rates on N uptake and yield in erect panicle rice

Guiyun Song[1], **Zhengjin Xu**[2*], **Hengshan Yang**[1]

[1]Agricultural College, Inner Mongolia University for the Nationalities, Tongliao, China
[2]Northern Japonica Rice Cultivation and Breeding Research Center, Shenyang Agricultural University, Shenyang, China;
[*]Corresponding Author: xuzhengjin@126.com

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ABSTRACT

The field experiment was conducted in 2005 and 2006 at Northern Japonica Rice Cultivation and Breeding Research Center, Shenyang Agricultural University, Shenyang, northeast China. Shennong 265 (typical erect panicle rice cultivar), and Liaojing 294 (traditional semi-erect panicle rice cultivar) were grown under different N rates to assess N uptake and N use efficiency. Nitrgen (N) uptake of two rice cultivars increased in their response to N improvement. Grain N of Liaojing 294 predominantly came from root absorption on low N treatments, while grain N of Shennong 265 mainly came from root absorption and had less N re-transferring from vegetative organs under high N rates. Shennong 265 produced less N uptake before heading and more N uptake after heading than Liaojing 294. GY was highly related with N fertilizer rate ($r^2 = 0.870^{**}$ for Shennong 265, $r^2 = 0.613^{*}$ for Liaojing 294). Shennong 265 was a N-unefficient genotype, since it produced low yield at low N levels and responded well to N application. Liaojing 294 was a N-efficient genotype producing high yield at both low and high N rates. NNG and NFUE exhibited positive correlation with N application rates, but NUEPG showed negative correlation with N application rates; GY as well as BIO and N uses efficiency parameters (TN, NNG, NFUE) which were all positively correlate, while the correlation between GY as well as BIO and the other N efficiency indicators expressed negative correlation. The relationship between GY and TN as well as BIO and TN was observed with significant difference ($r^2 = 0.824^{**}$, $r^2 = -0.858^{**}$).

Keywords: N Use Efficiency Parameters; Erect Panicle Rice; Biomass

1. INTRODUCTION

Donald first put forward "Ideotype" of wheat. Yin noticed that erect spike of wheat was attributed to the photosynthesis of its spike and other vegetative organs, and the increase of extinction coefficient of rice might be owing to its curved spike in late grain-filling stage. In addition, curved or half-curved spike rice (like Tiejing 4 and Liaojing 294) easily led to lodgeg and reduced yield [1,2]. Therefore, erect panicle was one of important agronomic traits in designing "New Plant Type" of super high yield rice [3,4]. In 1996, Shenyang Agricultural University successfully developed a super-high-yield, erect panicle, japonica rice, Shennong 265, and its grain yield reached 12 t·ha^{-1}. This cultivar has been grown successfully through the northern China. Several other super-high-yield japonica rice cultivars with the erect panicle have also been successfully developed [5]. Many studies have provided evidence that light diffusion in different part (canopy, middle, and low part) of erect panicle rice is reasonable especially in late grain-filling stage. Erect panicle rice utilizes solar energy effectively, accelerates CO_2 diffusion, improves its growing ecological conditions especially in its middle and low part of rice, and increases population growth rate after heading, which all contribute to higher biomass and yield [6,7]. Currently, the super rice of erect panicle is grown on 1,300,000 ha throughout China, in an area ranging from the Yangzi River to the Songliao Plain [8,9].

N is usually the most yield-limiting nutrient in rice cropping systems worldwide [10-12]. Chinese farmers were likely to broadcast more N fertilizer than needed in an attempt to increase the grain yield. China is currently the world's largest consumer of N fertilizer, and irrigated rice accounts for nearly 7% of global N consumption. Average rate of N application for rice production in

China is high and N-use efficiency is low compared with other major rice growing countries [13,14]. Low fertilizer-N use efficiency of irrigated rice increased environmental pollution through rapid losses of applied N by volatilization, denitrification and nutrient leaching from farms [15-18]. The average apparent N losses with the optimum N rates were less than 15 kg·N·ha^{-1}, whereas the farmers' conventional N application rate resulted in losses of more than 100 kg·N·ha^{-1}. The study identified genotypes which possess promising traits for improved N uptake and use efficiency [19-21]. The remobilized N was the largest contributor of N to the grain, and total N accumulation during the grain filling period could be the greater contributor to yield provement [22]. The yield of rice can be improved by optimising the plant's N uptake through increased N recovery efficiency [23-25]. Therefore, optimizing N use for crop considerably reduced N losses to the environment without compromising crop yields [26,27].

With increasing awareness regarding the need for environmental protection, it is important to improve N use efficiency in the rice crop in the world and especially in China. However, little effort has been made to explore the potential panicle variability in N uptake and use efficiency in northern China. The objective of this study was to determine effects of different rates of N fertilizer on N absorption and N use efficiency indicators of different panicle rice cultivars grown under irrigated condition in northeast China. The hypothesis tested was that Shennong 265 had potential to produce high yield through improving N use efficiency relative to Liaojing 294. This study provides information needed for future studies on breeding and cultivation of northern japonica rice in China and the decrease of the N pollution.

2. MATERIAL AND MATHODS

2.1. Experimental Site

The study was conducted in 2005 and 2006 at the Northern Japonica Rice Breeding and Cultivation Research Center, Shenyang Agricultural University, Shenyang, Northeast China (123˚28′E, 42˚41′N, and elevation 40 m above sea level). The region is characterized by a temperate sub-humid continental climate with average temperature ranging from 6 to 11˚C, 2554 h of sun-shine, 61% - 65% of average relative humidity, 706 mm of annual precipitation, 24 d of average rainy days, and 150 - 170 d of frost-free period. During growing season, air temperature began to decrease gradually from late August to October. Air temperature during growth season was stable (**Figure 1**).

The study sites were located on clay loam, meadow soil. The soil on the study sites had pH (1:5 soil/water) 5.7, organic matter content 21.6 g/kg, available N 84.5 mg·kg^{-1} (**Table 1**).

2.2. N Experiments

Cultivars Shennong 265 (typical erect panicle rice) and Liaojing 294 (traditional semi-erect panicle rice) were grown under irrigated condition with different N rates in 2005 and 2006. These two cultivars had different N characteristics and were selected from several years of field experiment conducted before 2005. In 2005 and 2006, a field experiment was laid out as a randomized complete block design with three replications. In 2005, each plot was 5 m × 2.7 m. N treatments included 0 (N_0), 100 (N_1), 180 (N_2), 260 (N_3) kg·N·ha^{-1}. In 2006, the treatments consisted of two levels of N: 0 (N_0), 180 (N_1) kg·N·ha^{-1} with three replications, each plot was 5.2 m × 2.7 m. On each treatment, the N fertilizer (urea: 46% of N by equivalent weight) was applied as four-time split. In addition, 124 kg·ha^{-1} of K fertilizer (potassium chloride: 55% of K_2O equivalent by weight) and 105 kg·ha^{-1} of P fertilizer (ordinary super phosphate: 14% of P_2O_5 by equivalent weight) were also applied. 30% of the N and 100% of the P and K fertilizers were applied to the soil before transplanting. The second 30% of the N fertilizer was applied at tillering stage, 20% at panicle initaiation, and the final 20% at heading stage. Also, 15 kg·ha^{-1} of zinc sulfate (24% of Zn equivalent by weight) was applied before transplanting. The Polyethylene plastic board was inserted into the underground to isolate between plots.

The dates of sowing and transplanting were summarized in **Table 2**. There were 28 hills·m^{-2} (27 cm × 13.3 cm spacing in 2005) and 20 hills (30 cm × 16.5 cm spacing in 2005), and two seedlings per hill. Weeds, insects and diseases were controlled by applying herbicides, insecticides, and fungicides according to commonly management practices for rice crops in the northeast of China.

2.3. Plant Sampling

Ten hills were randomly selected at each N treatment plot to measure tiller number, leaf age, and plant height every 7 days from June 10 to August 12.

Periodic harvesting (June 26, July26, August 6, September 8, October 4) of six hills from each plot were done during growing season. After measuring leaf area, the plant samples were separated into leaf, leaf sheath, culm, panicle (stem panicle rachis, and grain), then each fraction was placed into a drying oven at 105˚C and dried for half an hour, which was followed by drying at 80˚C to a constant weight. After drying, all plant samples were weighted and ground to pass through 2 mm sieve, ground again to pass through 0.25 mm sieve, and stored in sealed bottle until chemical analysis. Leaf, leaf sheath, culm, stem panicle rachis, and grain (caryopsis hull) were analyzed separately for total N by using the Kjelda-

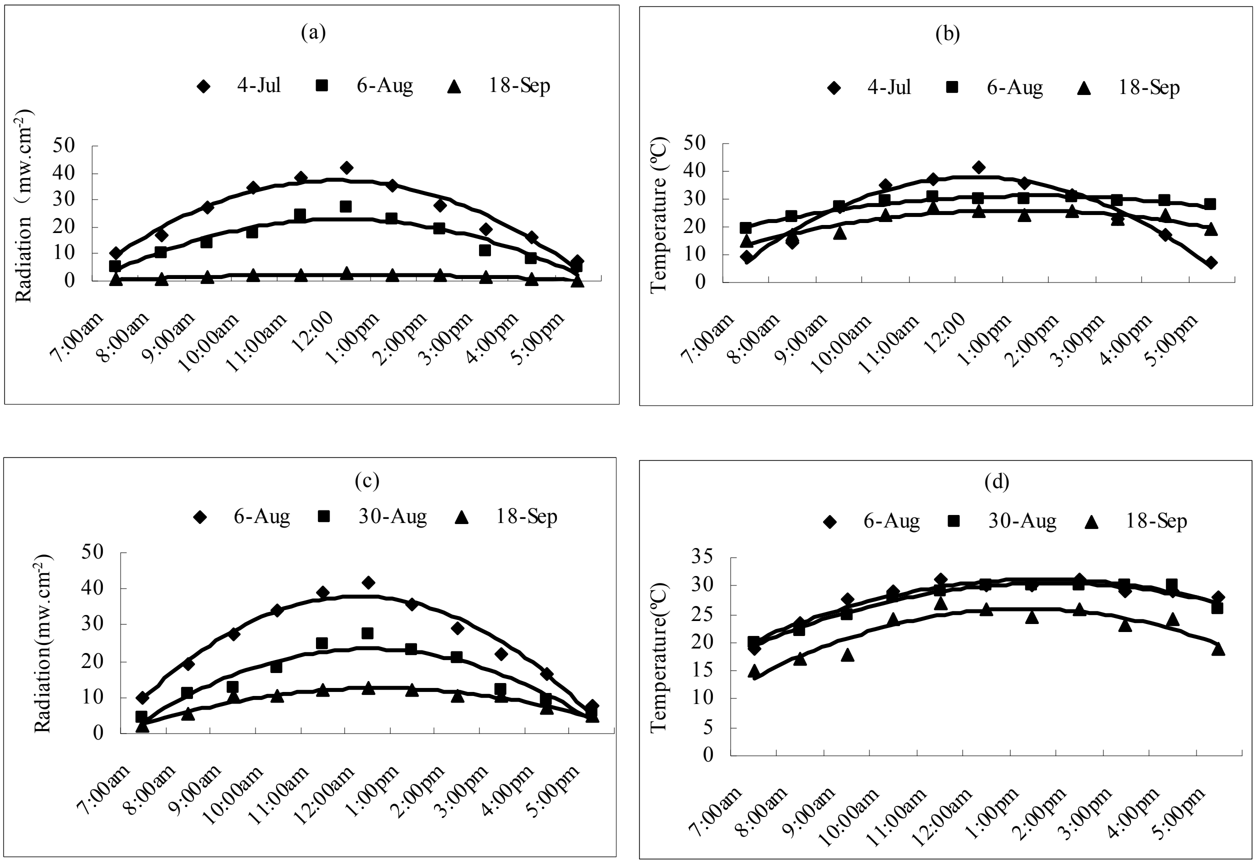

Figure 1. Temperature (a) and radiation (b) in 2005 and temperature (c) and radiation (d) in 2006 at different time of a day during rice growing season.

Table 1. Soil physical and chemical properties of the 0 - 20 cm layer in experimental sites in April in 2005 and 2006.

Year	Available N (mg·kg^{-1})	Available P (mg·kg^{-1})	Available K (mg·kg^{-1})	Organic matter (g·kg^{-1})	pH water (1:5)
2005	84.5	38.3	138.9	21.6	5.7
2006	82.5	35.3	131.6	20.5	5.7

Table 2. The key dates of the rice growth season in 2005 and 2006.

Year	Sowing date	Transplanting		Heading date	Harvest date
		date	density(hills·m^{-2})		
2005	April 20	May 28	28	August 1	October 6
2006	April 15	May 20	20	August 2	October 4

hl method [28].

2.4. Soil Sampling and Analysis

Composite soil samples (five individual sample) from 0 to 20 cm depth were taken for analysis from each treatment plot prior to transplanting in April. Separate soil samples were also taken for soil pH. Available P was determined by the Olsen method (0.5 M $NaHCO_3$ extract at pH 8.5)，total N was determined by Kjeldahl digestion, distillation, and titration, available N was measured by 1.8 M NaOH hydrolysis, H_3BO_3 absorption, available K (1 M NH_4AC extract at pH 7) was determined by flame spectrometry [29].

2.5. Note List about the Abbrevations

BIO is the abbrevation of biomass,
GY is the abbrevation of grain yield,
TN is the abbrevation of total N uptake,

TS is the abbreviation of tiller stage,
HS is the abbreviation of heading stage,
HT is the abbreviation of harvest time.

2.6. N Use Efficiency Indicators

1) N Needed by 100 kg Grain, NNG:

$$\mathrm{NNG} = \frac{\mathrm{TN}}{\mathrm{GY}} \times 100$$

2) N Physiological Efficiency, NPE: $\mathrm{NPE} = \frac{\mathrm{BIO}}{\mathrm{GY}}$

3) N Use Efficiency of Producing Grain, NUEPG:

$$\mathrm{NUEPG} = \frac{\mathrm{GY}}{\mathrm{TN}}$$

4) N Fertilizer Use Efficiency, NFUE:

$$\mathrm{NFUE} = \frac{\mathrm{GY_F} - \mathrm{GY_0}}{\mathrm{N_F}}$$

BIO is total aboveground dry weight on a dry-weight basis (at 80˚C),
TN is total plant N uptake at harvest time,
$\mathrm{GY_0}$ is grain yield without N application,
$\mathrm{GY_F}$ is grain yield with N application,
$\mathrm{N_F}$ is N application rate,
All of the above quantities are expressed in $\mathrm{kg \cdot ha^{-1}}$.

2.7. Statistical Analyses

Data was analyzed as a randomized compete block design with three replications using Excel 2003 [30] and DPS-98 (Data Processing Software) [31]. Significance of differences among treatments was determined by the least significant difference (LSD) caculated at $P < 0.05$.

3. RESULTS

3.1. N Uptake Pattern

The N uptake by three rice cultivars increased significantly with increase of N rate [**Figure 2(a)**]. N uptake in the treatment without N application (N_0) was lower than that in treatment with N application. N uptake rate increased sharply from tiller stage to heading stage, more than half of N uptake accumulated from tiller stage to heading stage. A limited change in N uptake at tiller stage at different N treatments might be due to slower growth after transplanting shock and low temperature in May in northeast China. Shennong 265 showed a smaller rate of N accumulation amount (11.61 - 21.43 $\mathrm{g \cdot m^{-2}}$ in 2005 and 10.47 - 17.63 $\mathrm{g \cdot m^{-2}}$ in 2006) and N accumulation percent (8.91% - 29.34% in 2005 and 15.37 - 17.4% in 2006) than those (12.29-24.31 g $\mathrm{m^{-2}}$ in 2005 and 11.66 - 18.06 $\mathrm{g \cdot m^{-2}}$ in 2006) and (11.12% - 27.16% in 2005 and 16.52% - 17.36% in 2006) of Liaojing 294 at TS.

Liaojing 294 accumulated 61.64% - 80.12% in 2005 and 63.63% - 68.38% in 2006 of total N from TS to HS, while Shennong 265 achieved 43.35% - 63.97% (in 2005) and 55.51% - 67.69% (in 2006) of total N from TS to HS. Liaojing 294 built up 8.76% - 21.42% in 2005 and 14.6% - 21.16% in 2006 from HS to HT, while Shennong 265 obtained 23.37-27.12% (in 2005) and 16.94% - 27.09% (in 2006) from HS to HT. Shennong 265 was 1.61% - 16.70% higher of total N than that of Liaojing 294 from HS to HT Under different N treatments, and Shennong 265 accumulated 0.69% - 18.18% less of total N than that of Liaojing 294 [**Figure 2(b)**].

Total N uptake of Shennong 265 was more under high N application (N_2, N_3 treatment in 2005 and N_1 treatment in 2006) at HT comparing with Liaojing 294. The relationship between GY as well as BIO and total N uptake at HT of two rice cultivars were observed significant difference ($r^2 = 0.824^{**}$, $r^2 = -0.858^{**}$, respectively). Lower N uptake was taken up for Shennong 265 in 2006 compared with in 2005 (**Figure 2**). The remarkable difference of N uptake was observed between N_3 and N_1 as well as N_2 and N_1 rate for Shennong 265 and Liaojing 294 at HS and HT in 2005, between N_1 and N_0 for Shennong 265 at HS and at HT for Liaojing 294 in 2006 ($P < 0.01$). N uptake were also remarkable between N_1 and N_0 for Shennong 265 at TS and HT, and at TS and HS for Liaojing 294 in 2006 ($P < 0.05$).

3.2. Grain N

N absorbed by rice during the vegetative growth stage contributes to reproductive growth and grain filling through N re-transferring [32]. Shennong 265 contained 3.18 - 4.66 $\mathrm{g \cdot m^{-2}}$ N (**Figure 3**) in the grain which came from N re-transferring from vegetative organs, and 4.32 - 8.04 $\mathrm{g \cdot m^{-2}}$ N received from root absorption in reproductive stage under different N rates, which accounted for 28.33% - 50.48% and 49.52% - 71.67% of total N in grain, respectively. Liaojing 294 had 4.08 - 8.53 $\mathrm{g \cdot m^{-2}}$ N from N re-transferring and 2.09 - 3.35 $\mathrm{g \cdot m^{-2}}$ N from root absorption in the grain in 2005. The N amounts taken up by root of Shennong 265 were consistently lower in 2006 than in 2005, there was 3.84 - 6.21 $\mathrm{g \cdot m^{-2}}$ N from root taken up, which accounted for 49.45% - 59.42% of total N in grain, and the rest was from N re-transferring from vegetative organs in 2006. Liaojing 294 got 3.37 - 7.21 $\mathrm{g \cdot m^{-2}}$ N from re-transferring, and 3.64 - 3.75 $\mathrm{g \cdot m^{-2}}$ N from root taken up in 2006. Liaojing 294 had less difference in N between root taken up and re-transferring from vegetative organ under low N level, but less root uptake and more N re-transferring from vegetative organs under high N rates.

There was remarkable in the N re-transferring amount between N_3 and N_1 treatment for Liaojing 294 in 2005, and in the root uptake amount between N_3 and N_2 rate in 2005 and N_1 and N_0 treatment in 2006 for Shennong 265 in grain filling stage (**Figure 3**) ($P < 0.01$). High N rates

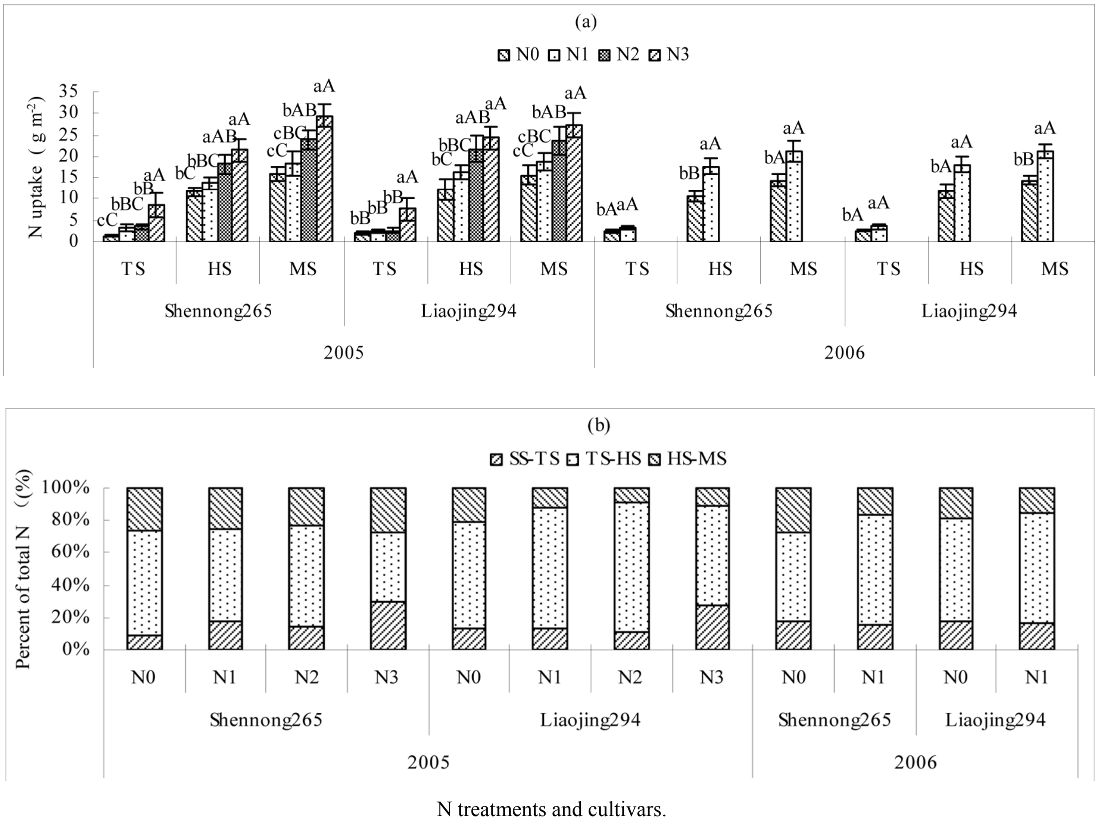

Figure 2. Total N uptake determined at three different stages by Shennong 265 and Liaojing 294.

led to an increase of N re-transferring from vegetative organs, while low N levels improved N uptake by root. The only exception was Shennong 265 at N_3 treatment in 2005 where N uptake amount and percent by root of Shennong 265 were significantly greater relative to the Liaojing 294. This indicates that Shennong 265 might has an advantage since no lodging occurred at harvest, and root could absorb more nutrients than that of Liaojing 294 during grain-filling stage.

3.3. Effects of N Fertilizer on Yield and HI

GY and BIO of two rice cultivars were highly correlated with N fertilizer rate (except of the correlation between BIO and N rate for Liaojing 294) (**Table 3**). GY and BIO of Shennong 265 and Liaojing 294 in 2006 increased significantly with the rise of N rate application. The maximum GY and BIO of Shennong 265 was obtained at N_3 treatment in 2005 and N_1 rate in 2006. Liaojing 294 reached the highest BIO and GY at N_1 rate in 2006. The greatest GY and BIO of Liaojing 294 was observed at N_2 treatment in 2005, and this cultivar did not respond well to additional N fertilizer. Liaojing 294 cultivar exhibited a significant decrease in GY from N_2 to N_3 treatment, and 2/3 of plants lodged before harvest under N_3 treatment. The GY and BIO of Shennong 265 between N_3 and N_2 level in 2005, N_1 and N_0 treatment in 2006 reached significant different. Notable difference was also observed between N_2 and N_1 treatment for Liaojing 294 in 2005, and N_1 and N_0 rate for Liaojing 294 in 2006. Singh [33] grouped rice genotypes in N-efficient and N-inefficient types based on GY response to N supply. N-efficient genotypes that produced high yield at both high and low N rates was Liaojing 294, and lack of response to N application might be due to lodging. N-inefficient genotype that produced low yield at low N levels but responded well to N application was Shennong 265.

GY of rice could also be expressed as product of BIO and HI. The HI for Shennong 265 was consistently higher than that of Liaojing 294, with the only exception of N_0 treatment in 2006 (**Table 3**). The highest BIO always resulted in consistently lower HI. The highest HI of two rice varieties appeared at low N rates (N_0 or N_1 treatment), while the lowest HI showed at the highest N rate might be attributed to longer vegetative phase with excessive N. HI of Liaojing 294 at all N rates ranged from 46% - 52%, while Shennong 265 ranged from 48% - 56% (**Table 3**).

3.4. N Use Efficiency Parameters

The NPE, NFUE, NNG, and NUEPG showed that two rice cultivars exhibited a significant difference with

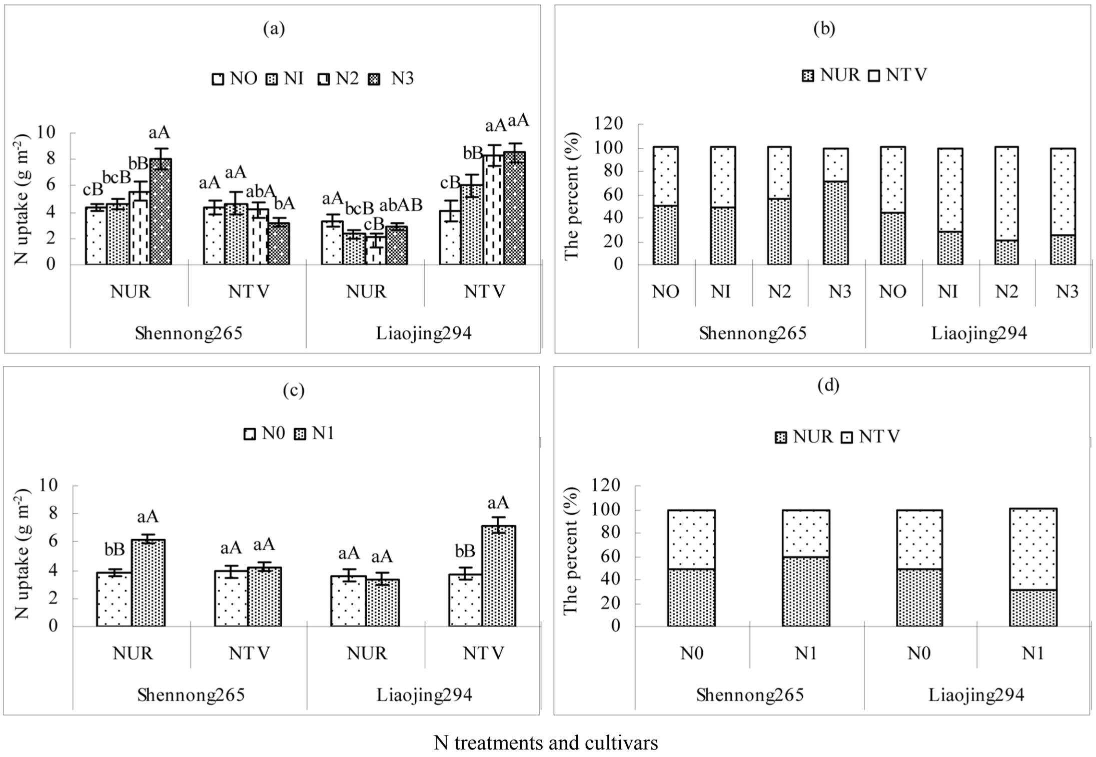

Figure 3. N uptake and re-transferring amount and percent by Shennong 265 and Liaojing 294 cultivars in grain-filling stage; (a), (b) in 2005 and (c), (d) in 2006.

Note: NUR = N uptake amount by root; NTV = N re-transferring from vegetative organ. N re-transferring from vegetative organ = total N uptake at heading stage in vegetative organs—total N uptake at maturity in vegetative organs; N uptake by root at grain-filling stage = total N in grain—N re-transferring amount from vegetative organs—total N in grain at heading stage.

Table 3. Yield indicators of Shennong 265 and Liaojing 294 cultivars at four rates of N fertilizer.

Year	Cultivars	N level	GY ($t \cdot ha^{-1}$)	BIO ($t \cdot ha^{-1}$)	HI (%)
2005	Shennong 265	N_0	8.01 ± 0.44 cB	15.10 ± 1.56 cC	53.6 ± 3.4 abA
		N_1	8.43 ± 0.49 bcB	15.29 ± 0.11 cC	55.1 ± 3.4 aA
		N_2	8.96 ± 0.21 bB	18.26 ± 0.96 bB	49.1 ± 1.5 bcA
		N_3	10.22 ± 0.60 aA	21.12 ± 0.91 aA	48.4 ± 1.0 cA
	Liaojing 294	N_0	8.17 ± 0.53 cB	16.99 ± 0.35 cB	49.4 ± 2.2 aAB
		N_1	8.85 ± 0.73 bcB	17.22 ± 1.31 cB	50.8 ± 0.5 aA
		N_2	10.31 ± 0.10 aA	20.63 ± 0.21 aA	50.1 ± 0.2 aAB
		N_3	9.03 ± 0.24 bAB	18.84 ± 0.10 bAB	46.9 ± 0.8 bB
2006	Shennong 265	N_0	6.96 ± 0.73 bB	13.52 ± 0.90 bB	51.5 ± 2.0 aA
		N_1	9.47 ± 0.47 aA	19.35 ± 0.60 aA	49.9 ± 0.5 bA
	Liaojing 294	N_0	6.82 ± 0.17 bB	13.17 ± 0.62 bB	51.8 ± 1.3 aA
		N_1	8.59 ± 0.53 aA	17.21 ± 0.93 aA	48.9 ± 1.0 bA

Note: HI = GY ($t \cdot ha^{-1}$) / BIO ($t \cdot ha^{-1}$); "A, B, C, D" significant at 1% level, "a, b, c, d" significant at 5% level, the same as the below.

varying N application rates (**Table 5**). For example, NUEPG of two rice cultivars decreased with the increase of N application rate. Significant correlations were observed between NUEPG and N rates for Shennong 265 ($r^2 = -0.661^*$) and for Liaojing 294 ($r^2 = -0.844^*$). The highest and lowest NUEPG of two rice cultivars were observed at the lowest and the highest N rate, respectively. The Liaojing 294 had higher NUEPG at different N rates in contrast to Shennong 265. This also might show that NUEPG might be useful parameters (in addition to GY) in identifying N-efficient genotypes. The NUEPG ranged from 33.56 to 63.18 $kg \cdot kg^{-1}$ for Shennnong 265, from 32.13 to 55.12 kg·kg^{-1} for Liaojing 294. There was remarkable in NUEPG between N_0 and N_2 level as well as N_2 and N_3 treatment for Shennong 265, and between N_0 and N_3 treatment for Liaojing 294 in 2005 ($P < 0.01$).

The NPE and NNG of two rice cultivars expressed a reversed trend in comparison to NUEPG (**Table 5**). The NPE and NNG improved with increasing N rates. Liaojing 294 cultivar had higher NNG than Shennong 265 at same N rate in 2005, while Shennong 265 had higher NNG than Liaojing 294 in 2006. The highest NNG and NPE of two rice crops were observed at the highest N application rate. The NNG was significantly correlated to the N application rate for Shennong 265 ($r^2 = 0.701^{**}$) and for Liaojing 294 ($r^2 = 0.797^{*}$) (**Table 4**). The NFUE observed for these two rice cultivars varied substantially among the N rates (**Table 5**). NFUE of Shennong 265 improved with the increase of N application, but Liaojing 294 exhibited a reversed trend in 2005. Shennong 265 needed high N levels, while Liaojing 294 need low N levels to reach an ideal NFUE. NFUE of Shennong 265 differed between years, and it was consistently lower in 2005 than in 2006. The correlation coefficient between NFUE and N application rate for Shennong 265 and Liaojing 294 in 2006 was significant ($r^2 = 0.715^{**}$, $r^2 = 0.996^{**}$). Remarkable difference were observed in NPE between N_0 and N_1 treatment for Liaojing 294, and in NNG between N_3 and N_1 level as well as N_1 and N_0 treatment for Shennong 265, and between N_3 and N_1 treatment for Liaojing 294 in 2005 ($P < 0.01$).

Differences in N use efficiency among the genotypes were best characterized by correlating yield and the amount of N fertilizer to N use efficiency parameters. The relationships between GY and N use efficiency parameters (TN, NNG, NFUE) were all positive, while the correlation between GY as well as BIO and the other N efficiency indicators were negative. Significant difference were also observed between GY and TN as well as BIO and TN ($r^2 = 0.824^{**}$, $r^2 = 0.858^{**}$) (**Table 4**).

4. DISCUSSION

4.1. N Fertilizer Requirement for Maximum Yield and HI

The result of this study showed that the yield of Liaojing 294 was observed to be suppressed with increasing N fertilizer, while the yield of Shennong 265 increased with the increasing of N application rate in 2005. This indicates that excess N fertilizer had a detrimental effect on the yield of Liaojing 294. This is in conformity with an experiment by Tirol *et al.* and Ohnishi *et al.* [19,23], who grouped rice genotypes in N-efficient and N-inefficient types based on GY response to N supply. Cultivars that did not respond to increasing N-application rates and obtained relatively low grain yield with low N supply were considered inferior types. Efficient genotypes might be described as those which produce high GY at suboptimal N levels through increased N uptake/or a more efficient utilization of the N taken up for GY.

From the results in this experiment we might conclude that Liaojing 294 was N-efficient genotypes because it produced high yield at both high and low N rates, and lack of response to N application might be due to lodging. Shennong 265 was N-inefficient genotype that produced low yield at low N levels but responded well to N application.

Based on the overall results of this experiment, it was revealed that application of appropriate N fertilizer produced higher values for yield of different panicle rice cultivars. N_2 treatment will be appropriate for Liaojing 294 in enhancing GY and BIO. While N_3 rate will be suitable for Shennong 265 in improving GY and BIO. Therefore, application of N fertilizer beyond 180 kg·ha^{-1} will not be economical for half-erect panicle rice, while 180 - 270 will be appropriate in enhancing the yield of erect-panicle rice, Shennong 265.

GY and BIO for two rice cultivars basically increased and the HI decreased with the improving of N fertilizer rate. Increased HI largely accounted for enhanced GY potential of high yielding rice cultivars. The present experiment suggested that the HI declined significantly with increasing N rate indicating that if we wanted to further improve the yield, we should increase BIO or optimize combination of BIO and HI. This is in conformity with the experiment reported by Chen *et al.* [34].

4.2. N Use Efficiency Indicators of Rice Cultivars

Responses of N use efficiency indicators differed largely among two rice cultivars studied. NUEPG decreased with the increase of N rates. Lower N uptake and higher N use efficiency indicators (except NFUE, NPE, and NNG) were attained at low N application rate. This means that to achieve high N efficiency, low N fertilizer and straw N concentration are needed. NNG and NPE increased with the increase of N rates, therefore, the increase of NNG and NPE could be at the expense of N application. These results indicated that excessive N application in China might be inconsistent with the physiological requirement of the rice, thereby leading to low N use efficiency indexes (NUEPG) and high NNG and NPE.

Genotypes with superior NUEPG and consistent GY at suboptimal N levels have been identified. Among all these N use efficiency indicators, NUEPG appeared to be a more promising indicator for quantifying and ranking N-efficient genotypes, and NFUE seemed to be the least suitable indicator because these two rice cultivars both

Table 4. Correlation coefficients between yield parameters and N use efficiency indicators as well as between N application rates and N use efficiency indicators for rice cultivars used in this study.

N use efficiency indicators	Yield parameters			N application amount (kg·ha^{-1})	
	BIO	GY	HI	Shennong 265	Liaojing 294
TN	0.858^{**}	0.824^{**}	-0.633^{*}	0.868^{**}	0.901^{**}
NNG	0.561	0.485	-0.600^{*}	0.701^{**}	0.797^{*}
NPE	−0.457	−0.348	0.673^{*}	0.146	−0.387
NUEPG	−0.518	−0.452	0.575	-0.661^{**}	-0.844^{**}
NFUE	0.396	0.372	−0.239	0.715^{**}	0.548

Note: **significant at 1% level, *significant at 5% level.

Table 5. Nitrogen efficiencies of different panicle rice cultivars at four rates of N fertilizer.

Year	Cultivar	N levels	NPE (kg·kg^{-1})	NUEPG (kg·kg^{-1})	NNG (100 kg·kg^{-1})	NFUE (kg·kg^{-1})
2005	Shennong 265	N_0	96.16 ± 2.87 aA	50.62 ± 1.22 aA	1.98 ± 0.05 cB	
		N_1	83.76 ± 2.86 bB	46.12 ± 1.29 bA	2.17 ± 0.06 cB	64.85 ± 3.74 aA
		N_2	76.68 ± 0.43 cBC	37.62 ± 1.32 cB	2.66 ± 0.09 bA	45.94 ± 1.07 bB
		N_3	71.65 ± 4.99 cC	34.75 ± 1.65 cB	2.88 ± 0.13 aA	39.29 ± 2.28 cC
	Liaojing 294	N_0	109.27 ± 2.22 aA	52.96 ± 1.92 aA	1.90 ± 0.18 cB	
		N_1	92.03 ± 2.37 bB	47.39 ± 1.70 bB	2.11 ± 0.07 bcB	68.06 ± 5.61 aA
		N_2	86.89 ± 1.72 bB	43.94 ± 0.89 cB	2.30 ± 0.30 bB	52.85 ± 0.54 bB
		N_3	69.28 ± 1.44 cC	33.20 ± 0.51 dC	3.01 ± 0.05 aA	34.72 ± 0.93 cC
2006	Shennong 265	N_0	90.44 ± 2.33 aA	46.17 ± 2.50 aA	2.17 ± 0.21 aA	
		N_1	87.93 ± 2.987 bA	43.88 ± 1.59 aA	2.28 ± 0.26 aA	39.83 ± 2.96
	Liaojing 294	N_0	90.77 ± 2.17 aA	47.02 ± 1.92 aA	2.13 ± 0.28 aA	
		N_1	86.41 ± 2.64 aA	42.26 ± 2.85 aA	2.27 ± 0.43 aA	40.78 ± 3.84

had the highest NFUE when they got maximum GY.

Shennong 265 exhibited significantly higher NPE, and NFUE as well as lower NNG comparing with Liaojing 294 under the highest N level, and the reverse trend expressed at low N rates. This indicates that Shennong 265 might have some advantages in contrast to Liaojing 294 only at high N rates.

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REFERENCES

[1] Zhang, X.J., Li, H.J., Li, W.J., Xu, Z.J., Chen, W.F., Zhang, W.Z. and Wang, J.Y. (2009) The lodging resistance of erect panicle japonica rice in northern China. *Scientia Agricultua Sinica*, **42**, 2305-2313.

[2] Xu, Z.J., Zhang, S.L., Zhou, S.Q. and Liu, L.X. (2004) Primary analysis of relationship between rice panicle type and lodging resistance. *Plant Physiological Correspondence*, **40**, 561-563.

[3] Chen, W.F., Xu, Z.J., Zhang, W.Z., Zhang, L.B. and Yang, S.R. (1991) Creation of new plant type and breeding rice for super high yield. *Acta Agronomica Sinica*, **27**, 665-674.

[4] Cheng, S.H., Cao, L.Y., Zhuang, J.Y., Chen, S.G., Zhan, X.D., Fan, Y.Y., Zhu, D.F. and Min, S.K. (2007) Super hybrid rice breeding in China: Achivements and prospects. *Journal of Integrative Plant Biology*, **49**, 805-810. doi:10.1111/j.1744-7909.2007.00514.x

[5] Zhang, W.Z., Xu, Z.J., Zhang, L.B., Chen, W.F., Qiu, F.L., Shao, G.J. and Hua, Z.T. (2002) Aalysis on evolution for the erect panicle type varieties of rice. *Journal of Shenyang Agricultural University*, **33**, 161-166.

[6] Gao, S.J., Chen, W.F., Xu, Z.J. and Zhang, L.B. (2000) The studies of erect-panicle rice: II. The influence of enviroment on grain weight of erect-panicle rice. *Journal of jilin Agricultural Sciences*, **25**, 3-6.

[7] Tan, W., Chen, Z.W. and Tan, S. (2001) Discussion on main characters and breeding techniques of erect panicle rice. *Journal of Shenyang Agricultural University*, **32**, 13-

16.

[8] Chen, W.F., Pan, W.B. and Xu, Z.J. (2006) Current situation and trends in production of japonica rice in China. *Journal of Shenyang Agricultural University*, **37**, 801-805.

[9] Yan, C.J., Zhou, J.H., Yan, S., Chen, F., Yeboah, M., Tang, S.Z., Liang, G.H. and Gu, M.H. (2007) Identification and characterization of a major QTL responsible for erect panicle trait in Japonica rice (*Oryza sativa* L). *Theoretical and Applied Genetics*, **115**, 1093-1100. doi:10.1007/s00122-007-0635-9

[10] Cassman, K.G., Peng, S., Olk, D.C., Ladha, J.K., Reichardt, W., Dobermann, A. and Singh, U. (1998) Opportunities for increased nitrogen-use efficiency from improved resource maNNGement in irrigated rice systems. *Field crops Research*, **56**, 7-39. doi:10.1016/S0378-4290(97)00140-8

[11] Sun, Y.J., Ma, J., Sun, Y.Y., Xu, H., Yang, Z.Y., Liu, S.J., Jia, X.W. and Zheng, H.Z. (2012) The effects of different water and nitrogen managements on yield and nitrogen use efficiency in hybrid rice of China. *Field Crops Research*, **127**, 85-98. doi:10.1016/j.fcr.2011.11.015

[12] Kropff, M.J., Cassman, K.G., Vanlaar, H.H. and Peng, S. (1993) Nitrogen and yield potential of irrigated rice. *Plant and Soil*, **155-156**, 391-394. doi:10.1007/BF00025065

[13] Peng, S.B., Buresh, R.J., Huang, J.L., Yang, J.C., Zou, Y.B., Zhong, X.H., Wang, G.H. and Zhang, F.S. (2006) Srategies for overcoming low agronomic nitrogen use efficiency in irrigated rice systems in China. *Field Crops Research*, **96**, 37-47. doi:10.1016/j.fcr.2005.05.004

[14] Zhang, Q.C., Wang, G.H. and Xie, W.X. (2006) Soil organic N forms and N supply as affected by fertilization under intensive rice cropping system. *Pedosphere*, **16**, 345-353. doi:10.1016/S1002-0160(06)60062-3

[15] Singh, U., Patil, S.K., Das, R.O., Padilla, J.L., Singh, V.P. and Pal, A.R. (1999) Nitrogen dynamics and crop growth on an alfisol and a vertisol under rainfed lowland rice-based cropping system. *Field Crops Research*, **61**, 237-252. doi:10.1016/S0378-4290(98)00166-X

[16] Eagle, A.J., Bird, J.A., Horwath, W.R., Linquist, B.A., Brouder, S.M., Hill, J.E. and Kessel, C.V. (2000) Rice yield and nitrogen utilization efficiency under alternative straw management practices. *Agronomy Journal*, **92**, 1096-1103. doi:10.2134/agronj2000.9261096x

[17] Liu, C., Watanabe, M. and Wang, Q.X. (2008) Changes in nitrogen budgets and nitrogen use efficiency in the agroecosystems of the Changjiang River basin between 1980 and 2000. *Nutrient Cycling Agroecosystems*, **80**, 19-37. doi:10.1007/s10705-007-9118-2

[18] Singh, B., Sing, Y. and Sekhon, G.S. (1995) Fertilizer-N use efficiency and nitrate pollution of groundwater in developing countries. *Journal of Contaminant Hydrology*, **20**, 167-184. doi:10.1016/0169-7722(95)00067-4

[19] Tirol, P.A., Ladha, J.K., Singh, U., Laureles, E., Punzalan, G. and Akita, S. (1996) Grain yield performance of rice genotypes at suboptimal levels of soil N as affected by N uptake and utilization efficiency. *Field Crops Research*, **46**, 127-143. doi:10.1016/0378-4290(95)00095-X

[20] Timsina, J., Singh, U., Badaruddin, M., Mersner, C. and Amin, M.R. (2001) Cultivar, nitrogen, and water effects on productivity, and N-use efficiecy and balance for rice-wheat sequences of Bangladesh. *Field Crops Research*, **72**, 143-161. doi:10.1016/S0378-4290(01)00171-X

[21] Deng, M.H., Shi, X.J., Tian, Y.H., Yin, B., Zhang, S.L., Zhu, Z.L. and Kimura, S.D. (2012) Opmizing nitrogen fertilizer application for rice production in the Taihu lake region, China. *Pedosphere*, **22**, 48-57. doi:10.1016/S1002-0160(11)60190-2

[22] Lin, X.Q., Zhou, W.J., Zhu, D.F., Chen, H.Z. and Zhang, Y.P. (2006) Nitrogen accumulation, remobilization and partitioning in rice (*Oryza sativa* L.) under and improved irrigated practice. *Field Crops Research*, **96**, 448-454. doi:10.1016/j.fcr.2005.09.003

[23] Ohnishi, M., Horie, T., Homma, K., Supapoj, N., Takano, H. and Yamanoto, S. (1999) Nitrogen management and cultivar effects on rice yield and nitrogen use efficiency in Northeast Thailand. *Field Crop Research*, **64**, 109-120.

[24] Walker Timothy, W., Bond Jason, A., Ottis Brian, V., Gerard Patrick, D. and Harrell Dustin, L. (2008) Hybrid rice response to nitrogen fertilization for midsouthern United States rice production. *Agronomy Journal*, **100**, 381-386. doi:10.2134/agrojnl2007.0047

[25] Thakuria, D., Talukdar, N.C., Goswami, C., Hazarika, S., Kalita, M.C. and Bending, G.D. (2009) Evaluation of rice-legume-rice cropping system on grain yield, nutrient uptake, nitrogen fixation, and chemical, physical, and biological properties of soil. *Biology Fertility Soils*, **45**, 237-251. doi:10.1007/s00374-008-0320-4

[26] Cui, Z.L., Chen, X.P., Li, J.L., Xu, J.F., Shi, L.W. and Zhang, F.S. (2006) Effect of N fertilization on grain yield of winter wheat and apparent N losses. *Pedosphere*, **16**, 806-812. doi:10.1016/S1002-0160(06)60117-3

[27] Zheng, Y.M., Ding, Y.F., Wang, Q.S., Li, G.H., Wu, H., Yuan, Q., Wang, H.Z. and Wang, S.H. (2007) Effect of nitrogen applied before transplanting on NUEPG rice. *Agricultural Sciences in China*, **6**, 842-848. doi:10.1016/S1671-2927(07)60120-5

[28] Bao, S.D., Jiang, R.F., Yang, C.G. and Han, X.R. (2003) The measurement of N in plant. In: Bao, S.D., Ed., *Soil Agrichemical Analysis*, China Agricultural Press, Beijing, 263-267.

[29] Bao, S.D., Jiang, R.F., Yang, C.G. and Han, X.R. (2003) Analysis of soil N, P, K, and S. In: Bao, S.D., Ed., *Soil Agrichemical Analysis*, China Agricultural Press, Beijing, 39-113.

[30] Zhang, J.Z. and Chi, R.L. (2009) Using excel 2003 system processing examination data method. *Calculation and Measurement Technology*, **36**, 48-51.

[31] Yuan, K.J., Zhang, D.H., Li, Z.S. and Sun, R.H. (1999) The introduce of Research data processing software DPS-98. *Computer and Agriculture*, **4**, 21-24.

[32] Wei, D., Cui, K.H., Pan, J.F., Ye, G.Y., Xiang, J., Nie, L.X. and Huang, J.L. (2011) Genetic dissection of grain nitrogen use efficiency and grain yield and their relationship

in rice. *Field Crops Research*, **124**, 340-346. doi:10.1016/j.fcr.2011.07.003

[33] Singh, U., Ladha, J.K., Castillo, E.G., *et al.* (1998) Genotypic variation in N use efficiency in medium- and long-duration rice. *Field Crops Research*, **58**, 35-53. doi:10.1016/S0378-4290(98)00084-7

[34] Chen, W.F., Xu, Z.J. and Zhang, L.B. (2003) Physiological basis of rice breeding for super high yield. In: Zhang, L.B., Ed., *The Analysis of Yield Components for Rice Varieties in Liaoning Province*, Liaoning Science and Technology Publishing House, Shenyang, 24-75.