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Estimating Rice Yield Based on Normalized Difference Vegetation Index at Heading Stage of Different Nitrogen Application Rates in Southeast of China

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Abstract: China is major fertilizer consumer with very low nitrogen use efficiency. Assessment of crop nitrogen requirement when a crop response is expected may improve use efficiency and profitability. Nondestructive determination of crop nitrogen (N) content is important for timely estimation of nutrient requirement at nutrient sensitive growth stages. It is a good way to estimate the rice grain yield based on NDVI at different key growth stages in southeast China. There were six N application rates: (N_0) 0 kg ha^{-1} N fertilizer, (N_{90}) 90 kg ha^{-1} N fertilizer, (N_{112}) 112.5 kgha^{-1} N fertilizer, (N_{135}) 135 kg/ha^{-1} N fertilizer, (N_{157}) 157.5 kg ha^{-1} N fertilizer, (N_{180}) 180 kg ha^{-1} N fertilizer. Grain yield and its components were determined, and NDVI at key stages were obtained by using Greenseeker™. The result showed that the grain yield of rice increased significantly with increasing N rate, its relationship could be fitted by quadratic curve, and the equations of early and late rice showed significant correlation (R^2 0.88 and 0.65, respectively). There were large changes among NDVI values from tillering to filling stage of early and late rice, but they reached to 0.25 at heading and filling stage and did not change substantially. The regression equation between N rates and NDVI at heading stage was robust and was proved well by validation experiment. The grain yield of rice could be predicted more accurately by using NDVI at heading stage, and therefore, NDVI values ranging from 0.28-0.31 at heading stage can be considered enough to obtain more than 9 t ha^{-1} rice grain yield.

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1. Introduction

Rice (*Oryza sativa* L.) is the staple food for billions of people worldwide. China is the world's largest rice producer in the world, with approximately 31 million ha paddy rice cultivation in the country (Lin et al., 2009). But it is difficult to increase the grain yield of rice under traditional rice management. One of the important reasons is the deficiency of precise fertilization, especially the application technology of nitrogen (N) fertilizer.

Nitrogen is the most important nutrient in rice production (Cassman et al., 1998), and higher yield of rice are usually associated with excessive applications of N fertilizers. China is currently the world's largest consumer of N fertilizers, and about 7% N was applied to irrigated rice (Peng et al., 2006), but N use efficiency for rice is lower than 30-35% and N losses in China are more than 50% (Qin, et al., 2001). Optimal N fertilization exerts a strong influence on rice growth and grain yield due to competitive relationship between vegetative and reproductive development. However, excessive N application to rice in China has caused environmental pollution, increased the cost of rice farming, reduced grain yield and contributed to global warming (Peng et al., 2006).

Nitrogen is an essential element for plant growth and yield formation in agronomic crops. Previous research indicated that the grain yield of rice could be increased substantially when N fertilizer was applied; however, there was diminishing returns phenomenon in N fertilization. The yield and N-recovery were increased when N-application rate was low, they were reached to the highest at moderate N level, but they were not improved with further increase in N level (Zhang et al., 2003, Xie et al., 2011). The relationship between N amount and rice grain yield was a parabolic equation (quadratic curve) (Zheng et al., 2006; Fageriaa et al., 2010). Therefore, it is necessary to study how to improve N efficiency is required.

Spectral determinations have provided an effective, quick and nondestructive method of assessing crop biomass and nutrient status. The normalized difference vegetation index (NDVI) is the function of reflectance of red and near infrared (NIR) bands, which are the most extensively used bands. It is one of the most extensively applied vegetation indices related to leaf area index (LAI), biomass and to predict yield (Das et al., 1993; Ma , et al., 1996; Inman D et al.2007). Wang et al. (2003) and Guo et al. (2008) found that there were significant positive correlations between chemical contents, N nutrition of leaves and NDVI in rice and corn. Li et al. (2008) suggested there was exponential function relationship between N absorption and NDVI in wheat. NDVI measurement has been successfully applied to diagnose the nutrient, particularly N status for the growth period of many crops such as rice and wheat (Zhu et al., 2008), hence the grain yield of rice could be assessed effectively by NDVI (Xue et al., 2005; Harrell et al., 2011).

Therefore, it is a good way to estimate rice yield under different N rates based on NDVI at key growth stages in southeast of China. The objectives of this study were (1) to examine the effects of different N rates on grain yield of rice, (2) to identify the trend of NDVI at key growth stages under different N rates to assess grain yield of rice, and then (3) to find better value of NDVI at key growth stages for higher grain yield of rice.

2. Material and Methods

2.1 Site description

The field experiment was conducted in 2012 at the Jiangxi Institute of Red Soil, Jinxian County (116°17’ 57″E，28 ° 35’ 30″ N, 31 m above sea level), Jiangxi province, China (Figure 1). This site is under a typical subtropical climate with a distinct arid (July–September) and a humid (March–June) season. The mean annual temperature and rainfall are 17.2 °C and 1549 mm, respectively. The soil was developed from Quaternary red clay. Soil properties were analyzed using a procedure described earlier (Bao, 2000), and the soil contained 9.4 g of organic C kg^{-1}, 0.98 g of total N kg^{-1}, 0.62 g of total P kg^{-1}, and 11.4 g of total K kg^{-1}, with a pH of 6.0.

2.2 Experimental 1 (relationship construction)

Six N treatments were applied: (N0) no N fertilizer, (N90) 90 kg ha^{-1} N fertilizer, (N112) 112.5 $kgha^{-1}$ N fertilizer, (N135) 135 kg ha^{-1} N fertilizer, (N157) 157.5 kg ha^{-1} N fertilizer, (N180) 180 $kgha^{-1}$ N fertilizer.

2.3 Experimental 2 (validation)

There were four amounts of N fertilizer in experiment 2, the treatments were included: (VN0) no N fertilizer both in early and late rice, (VN90-105) 90 kg ha^{-1} N fertilizer in early rice and 105 kg ha^{-1} in late rice, (VN120-130) 120 kg ha^{-1} N fertilizer in early rice and 130 kg ha^{-1} in late rice, (VN150-175) 150 kg ha^{-1} N fertilizer in early rice and 175 kg ha^{-1} in late rice, (VN180-195) 180 kg ha^{-1} N fertilizer in early rice and 195 kg ha^{-1} in late rice.

In both experiments 1 and 2, all of the treatments were applied with 75 kg ha^{-1} P_2O_5 (superphosphate, P_2O_5 12%) and 150 kg ha^{-1} K_2O (potassium sulfate， K2O 60%) and both P and K fertilizers were applied one time as basal fertilizer. While for N, 40% N fertilizer, as per treatment described above, was applied as basal fertilizer, and 60% at tillering stage.

In 2013, variety of early hybrid rice Denong-88 was sown on 22nd March, and transplanted on 23rd April, whereas hybrid rice variety Shanyou 456 was sown on 20th June as late rice, and transplanted on 24th July. Planting density of 25 hills m^{-2} was maintained with row-to-row and hill-to-hill spacing of 20 cm ×20 cm. Experimental plots, each of 20 m^2 (5 m × 4 m), were separated by constructing the bunds (the height was 40 cm over the soil surface). Experimental plots were arranged in a randomized complete block design (RCBD) with three replications.

2.4 Measurement

2.4.1 Spectroradiometer

The measurement instrument was the Greenseeker Hand Held Optical Sensor Unit, Greenseeker^{TM} (Model 505) manufactured by NTech Industries, Inc., Ukiah, CA, USA. The wavelength bands are in the visible (RED, 671±6 nm) and near-infra-RED (NIR, 780±6 nm) regions of the spectrum. Half-power bandwidths are approximately 25 nm. Reflectance values (the unit of NDVI was 1) on 671 nm (RED) and 780 nm (NIR) were used to calculate the NDVI (Deering et al., 1975).

$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} \quad (1)$$

Where, NIR and RED denote the reflectance of near infrared and red channels, respectively.

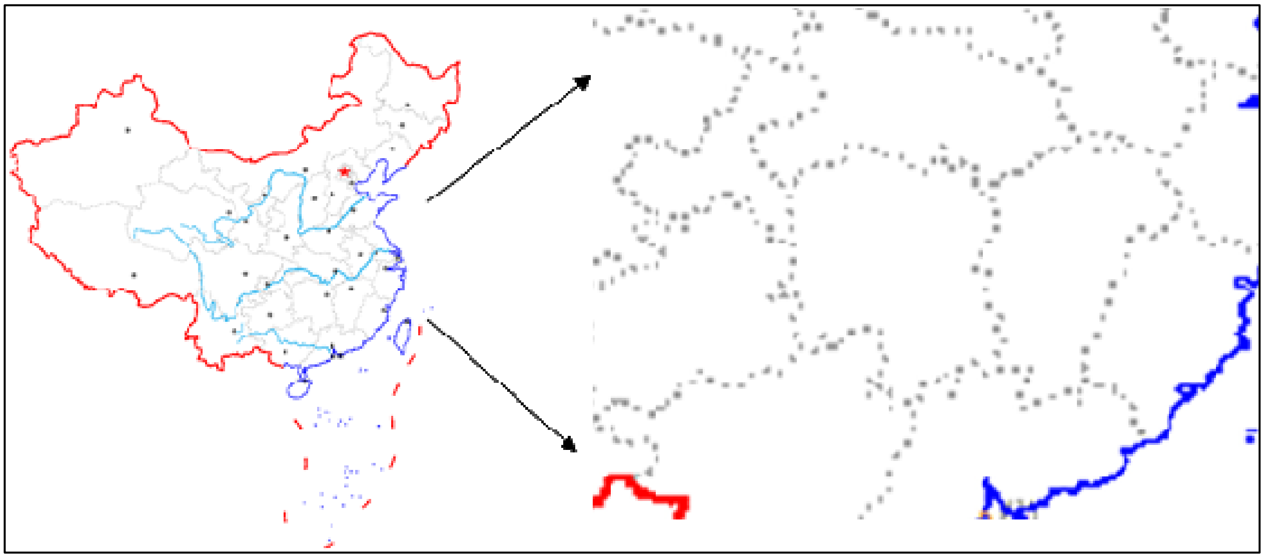

Figure 1. Geographic location of experimental site

2.4.2 Canopy reflectance measurements

Rice canopy reflectance measurements were made using Greenseeker Hand Held Optical Sensor Unit. It was held at a height of 45 cm above the rice canopy, under cloudless conditions and as close to solar noon as possible. The measurements were made at the tillering (22nd May, 30 DAT), booting (11th June, 49 DAT), heading (21st June, 59 DAT) and grain filling stages (1st July, 69 DAT) in early rice and the tillering (15th August, 21 DAT), booting (31st August, 36 DAT), heading (26th September, 62 DAT) and filling stages (15th October, 81 DAT) in late rice. Before each measurement, a dark current and a white-panel correction were performed. Ten canopy spectral reflectance measurements were obtained in each plot, then averaged.

2.4.3 Grain yield and its components

Grain yield was determined by harvesting an area of 5 m2 from each plot and grain yield was adjusted to a moisture content of 13.50%.

For analyzing yield components, ten hills were sampled from each plot at maturity in early and late rice. In order to ensure the representativeness of the sampling, 50 hills from 3 different locations were counted in each plot before sampling and recorded the tiller number for each hill. Then, based on the tiller number distribution of the 50 hills, ten representative hills were reselected and destructively sampled to analyzing yield components, In proceeding of measure, plant height, panicles m^{-2}, panicle length, spikelet per panicle, grain Filling rate and 1000-grain weight, panicles were hand-threshed and the filled spikelets were separated by submerging them in tap water. The filled spikelets were then oven-dried at 80oC to constant weight for determining 1000-grain weights. Spikelets per panicle, grain-filling percentage and spikelets per m^2 were calculated.

2.4.4 Model validation

The validity of the models was estimated from the R^2 (coefficients of determination), RER (range error ratio), and RMSE (Root Mean Square Error).

$$RER = \frac{X_0 - X_S}{X_0} \times 100\% \qquad (2)$$

$$RMSE = \sqrt{\frac{\sum (X_0 - X_S)^2}{n}} \qquad (3)$$

Here, X_0 and X_S are the measured and estimated values, respectively.

2.5 Statistical analysis

Data were subjected to analysis of variance (ANOVA) using SPSS 16.0 software package for Windows XP (IBM Corporation, New York, USA) and differences between treatments means were compared

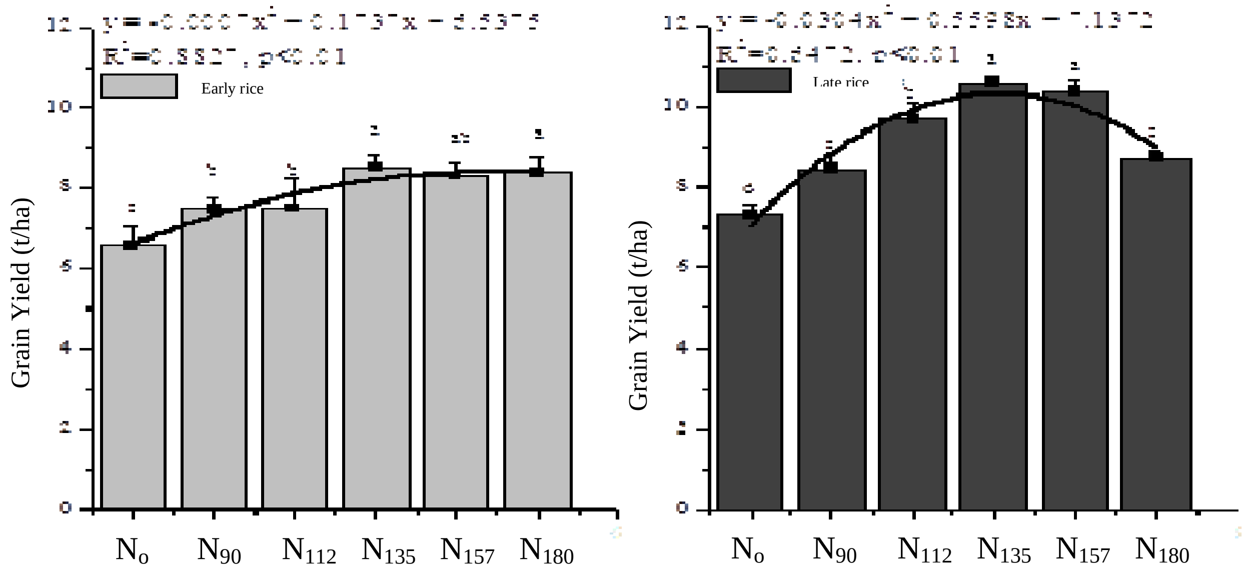

Figure 2. Grain yield of rice in response to different nitrogen rates. Means with different letters at early or late rice differ significantly among N fertilization treatments at P < 0.05 (with LSD test). ; The meaning of abbreviations for each treatment is indicated in the text. N_0 was 0 kg ha^{-1} N fertilizer, N_{90} was 90 kg ha^{-1} N fertilizer, N_{112} was 112.5 kg ha^{-1} N fertilizer, N_{135} was 135 kg ha^{-1} N fertilizer, N_{157} was 157.5 kg ha^{-1} N fertilizer, N_{180} was 180 kg ha^{-1} N fertilizer.

by using least significant difference (LSD) test at 0.05 probability level. The regressions between N fertilizer and grain yield of rice or NDVI were made with binary quadratic equations by Origin software (Origin Lab Corporation, Massachusetts, USA).

3. Results

3.1 The regression between N rates and grain yield of rice

The rice grain yield increased significantly when N fertilizer was applied (Figure 2); however, maximum grain yield (8 t ha^{-1}) was achieved in early rice when 135 -180 kg ha^{-1} N was applied, while the maximum grain yield (10 t ha^{-1}) in late rice was obtained when 135-157.5 kg ha^{-1} N was applied. Moreover, the rice yield increased from N_0 treatment to N_{135} and then there was a decrease or non-significant increase from N_{135} to N_{180}. The relationship between N rates and rice yield could fit quadratic curve, and the equation of early rice was: $y = -0.0007x^2 + 0.1737x + 6.5375$ ($R^2 = 0.8827$), late rice was $y = -0.0304x^2 + 0.5598x + 7.1372$($R^2 = 0.6472$). Both were significantly correlated.

3.2 Yield components of rice in response to different N rates

Panicle per m^{-2} and grain filling rate of early rice with different N rates were higher than those without N application (Table 1). There was no significant difference in plant height, panicle length and spikelet per panicle of early rice in different treatments. This indicated that yield components of early rice were affected weakly by different N rates.

However, there was a significant difference in yield components of late rice under different treatments (Table 1). Plant height, panicle number m^{-2}, panicle length and spikelet per panicle with N fertilizers application were higher than those without N fertilizers application N_0, and the maximum values of these indexes are from N_{135} treatment, which suggested that 135 kg ha^{-1} N fertilizers was the best application rates in late rice.

3.3 The change of NDVI at key growth stages under different N rates

The NDVI values at key stages showed significant difference under different treatments (Table 2). In early rice, NDVI values under N rate treatments of were higher than those without N fertilizer (N_0). The highest NDVI value was observed in N_{180} at tillering stages, while highest values at jointing and heading stages were observed under N_{135} and NDVI values at filling stage were higher than others in N_{180}. This indicated that the NDVI values were higher at jointing, heading and filling stages when the amount of N rate was 112.5 kg ha^{-1} or more than it. The result of late rice was not similar to early rice, the highest NDVI value was observed in N_{157} at tillering stages, while the highest values at jointing, heading and filling stages were observed under N_{180}. These suggested that the NDVI value was higher at jointing, heading and -filling stages when the amount of N rate was 112.5 kg ha^{-1} or more than it.

There were large changes in NDVI values from tillering to filling stage of early and late rice (Figure 3). The average value of NDVI increased from tillering to jointing in early rice, then, it decreased gradually, and it was about 0.25 and did not change substantially at heading and filling stage. In late rice, the average value of NDVI was decreased gradually from tillering to heading, and it was also 0.25 and keep steady at heading and grain filling stage.

Table 1. Yield components of early and late rice in response to different N rates

Treatments	Plant height	Panicles	Panicle length	Spikelet per panicle	Grain filling rate	1000-grain weight
	cm	$m^{-2`}$	cm		%	g
			Early rice			
N_0	93.33 a	248.00 b	20.48 a	109.63 a	90.32 b	28.04 ab
N_{90}	98.00 a	288.00 a	20.23 a	111.13 a	94.88 a	28.47 a
N_{112}	99.67 a	290.67 a	20.84 a	119.40 a	95.00 a	27.18 b
N_{135}	95.67 a	298.67 a	20.33 a	112.73 a	94.64 a	28.47 a
N_{157}	95.17 a	277.33 a	20.54 a	114.17 a	94.10 a	28.21 a
N_{180}	98.67 a	290.67 a	20.27 a	114.82 a	94.82 a	27.95 ab
			Late rice			
N_0	91.67 c	226.67 c	22.77 b	140.33 b	73.13 a	27.47 a
N_{90}	93.67 bc	226.00 c	23.12 ab	146.00 ab	72.00 a	26.96 a
N_{112}	95.00 bc	275.33 b	23.77 ab	153.00 ab	76.16 a	28.02 a
N_{135}	99.00 a	312.00 a	24.52 a	159.00 ab	77.71 a	27.62 a
N_{157}	95.67 ab	277.33 b	23.72 ab	170.50 a	74.66 a	26.91 a
N_{180}	92.67 bc	229.33 c	24.24 ab	165.33 a	72.69 a	28.17 a

Data within a column followed by different letters at early or late rice differ significantly among fertilization treatments at P < 0.05 (with LSD test). Treatments as explained in the Fig. 2 footnote. The meaning of abbreviations for each treatment is indicated in the text.

Table 2. NDVI (unit was 1) at key stages in response to different N rates

Treatments	Tillering	Jointing	Heading	Filling
Early rice	**30 DAT**	**49 DAT**	**59 DAT**	**69 DAT**
N_0	0.0380 d	0.3401 d	0.2096 c	0.1971 c
N_{90}	0.2860 c	0.3959 c	0.2248 c	0.2334 b
N_{112}	0.3153 b	0.3414 b	0.2626 ab	0.1870 c
N_{135}	0.3067 b	0.4698 a	0.2726 a	0.2757 a
N_{157}	0.3510 ab	0.4442 ab	0.2482 b	0.2627 a
N_{180}	0.3728 a	0.4638 a	0.2365 b	0.2789 a
Late rice	**21 DAT**	**36 DAT**	**62 DAT**	**81 DAT**
N_0	0.2160 b	0.3036 c	0.1771 c	0.1523 c
N_{90}	0.4487 ab	0.3722 b	0.2846 b	0.2610 b
N_{112}	0.4713 a	0.4073 ab	0.3269 a	0.2853 ab
N_{135}	0.4385 ab	0.4140 ab	0.3055 ab	0.3047 a
N_{157}	0.4754 a	0.4107 ab	0.2840 b	0.2823 ab
N_{180}	0.4749 a	0.4461 a	0.3353 a	0.3150 a

Data within a column followed by different letters at early or late rice differ significantly among fertilization treatments at P < 0.05 (with LSD test). Treatments as explained in the Fig. 2 footnote. The meaning of abbreviations for each treatment is indicated in the text.

Table 3. Errors of the correlations at heading stage in validation experiment

Treatments	Estimated value	Measured value	Range error ratio	r^2	RMSE
		Heading stage in early rice			
VN_0	0.207	0.180	-13.248	0.918	0.017
VN_{90-105}	0.249	0.263	5.471		
$VN_{120-130}$	0.253	0.273	7.862		
$VN_{150-175}$	0.251	0.248	-1.205		
$VN_{180-195}$	0.245	0.235	-3.947		
		Heading stage in late rice			
VN_0	0.155	0.190	22.786	0.992	0.018
VN_{90-105}	0.294	0.291	-1.223		
$VN_{120-130}$	0.307	0.305	-0.663		
$VN_{150-175}$	0.309	0.296	-4.032		
$VN_{180-195}$	0.301	0.290	-3.738		

The meaning of abbreviations for each treatment is indicated in the text. Treatments as explained in the Fig. 2 footnote.

3.4 The regression between N rates and NDVI at heading stage of rice

There was a significant difference in NDVI at heading stage of different N rates (Figure 4). The NDVI value increased gradually when N rate was added from 0 to 120 kg ha^{-1}, but not improved significantly when N rate was more than 120 kg ha^{-1}. The regression equation in early rice was $y=0.207+7.24E\text{-}4x - 2.86E\text{-}6x^2$, ($R^2 = 0.6856$, $p<0.05$), and late rice was $y=0.155+0.0020x - 6.41E\text{-}6x^2$ ($R^2 = 0.8364$, $p<0.05$). This showed that there was significant correlation between N rates and NDVI at heading stage.

In validation experiment, the errors were little between measured and estimated values of NDVI at heading stage both in early and late rice (Table 3). Their RMSE values were 0.017 and 0.018, respectively, so NDVI at heading stage both in early and late rice could be predicted better by N amounts through the regression equation in Figure 4.

3.5 Estimating grain yield of rice based on NDVI at heading stage

NDVI at heading stage could reflect the changes of yield in different N rates, and the relationships between NDVI at other stages and yield were not significant and did not fitted better by equations. The results showed that the yield of rice did not increase gradually along with NDVI at heading stage (Figure 5). The grain yield of rice was less than 6 t ha^{-1} when NDVI was lower than 0.25, and it was 6 t ha^{-1} - 9 t ha^{-1} when NDVI was 0.25-0.28, then, it was higher than 9 t ha^{-1} when NDVI was 0.28-0.31, but it was less than 9 t ha^{-1} when NDVI was more than 0.31. The regression equation was: $Y=7.50 + 3.03 \exp\{-0.5[(x-0.30)/0.02]^2\}$ between NDVI at heading stage and grain yield. This indicated that when NDVI value reached to 0.28-0.31 at heading stage, so, the higher yield of rice could be obtained.

The result was proved by validation experiment; the errors were little between measured and estimated values of grain yield of early and late rice (Table 4). Their RMSE values were 0.192 and 0.507, so grain yield of rice could be predicted better by NDVI at heading stage through the regression equation in Figure 4.

4. Discussion

Fertilizer application, especially N is one of the most important factors responsible for rice yield variability (Mueller, et al., 2012). In our study, N fertilizers could improve rice yield in paddy soil. However, in all treatments maximum yield (8 t ha^{-1}) in early rice was achieved under 135 -180 kg ha^{-1} N, while it was 10 t ha^{-1} in late rice when 135 -157.5 kg ha^{-1} N was applied. Then, the grain yield of rice did not increase with further addition of N fertilizer. The relationship between N rates and yield was similar to Zhao et al. (2009), who found that the highest N amount was associated with decreases in grain yield, N use efficiency and water use efficiency; therefore, optimizing N application rate is important to increase yield in paddy soil.

In our study, the results showed that the optimal N rate was 135 -180 kg ha^{-1} in early rice and 135 - 157.5 kg ha^{-1} in late rice in southeast of China. Many studies proved that there was the law of diminishing returns between yield and N fertilizer (Zhang et al., 2003; Fageriaa et al., 2010; Wei et al., 2013). In present study, the relationship between N fertilizer and rice yield could fit the quadratic curve (Figure 2), the equation in early rice was $y = -0.0007x^2 + 0.1737x + 6.5375$($R^2$ was 0.8827), and late rice was $y = -0.0304x^2 + 0.5598x + 7.1372$($R^2$ was 0.6472). The result of equations was similar to other reports (Zheng et al., 2006; Xie et al., 2011).

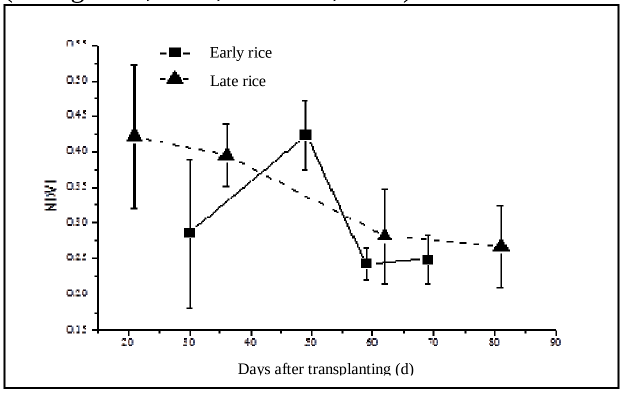

Figure 3. The average value of NDVI at key stages in different rates of nitrogen fertilizer

NDVI is one of the most extensively applied vegetation indices related to LAI and biomass (Das et al., 1993; Inman et al., 2007; Raun et al., 2001; Ma et al., 2001; Ata-Ul-Karim et al., 2014ab). NDVI measurement had been applied to diagnose the nutrient status, particularly N status for the growth period of many crops such as rice and wheat (Li et al. , 2008; Zhu et al., 2008), and the grain yield could be assessed by using NDVI at key stages (Wang et al., 2012; Liu et al., 2014). In our study, NDVI values at tillering stage has significant differences between early rice and late rice under N_0. These differences might be due to the different tillering time between early and late rice, the tillering stage in early rice reached 30 days after transplantation (DAT) while in late rice it reached 20 DAT. Moreover, the meteorological conditions were different in early and late rice.

In our study area, the rainfall at tillering stage in early rice was more than late rice, but solar radiation and temperature were higher at tillering stage in late rice. The NDVI values at key stages were significantly increased when N was applied (Table 2), and values were higher at jointing, heading and filling stages when the amounts of N fertilizer was more than 135 kg ha^{-1}. NDVI was about 0.25 and did not change substantially at heading and filling stage in early and late rice. This result was similar to study of Xue, et al. (2009), it also proved that judicious N amounts could improve NDVI at key stages and promoted rice growth.

There was a direct relationship between grain yield and NDVI, and strong correlations were observed between NDVI measurements and plant biomass, total green area, green area without yellow spikes, aboveground N content (Cabrera-Bosquet et al., 2011). There was a significant correlation between N rates and NDVI at heading stage (Figure 4).

Table 4 Errors of the correlations of grain yield in validation experiment

Treatments	Grain yield in early rice		Range error ratio	r^2	RMSE
	Estimated value	Measured value			
VN_0	7.500	7.571	0.942	0.917	0.192
VN_{90-105}	8.028	8.271	3.025		
$VN_{120-130}$	8.682	8.511	-1.978		
$VN_{150-175}$	7.606	7.804	2.604		
$VN_{180-195}$	7.515	7.640	1.658		
		Grain Yield in late rice			
VN_0	7.500	7.310	-2.533	0.980	0.507
VN_{90-105}	10.221	9.920	-2.949		
$VN_{120-130}$	10.450	9.723	-6.951		
$VN_{150-175}$	10.477	9.813	-6.335		
$VN_{180-195}$	10.174	9.740	-4.265		

Treatments as explained in the Fig. 2 footnote. The meaning of abbreviations for each treatment is indicated in the text.

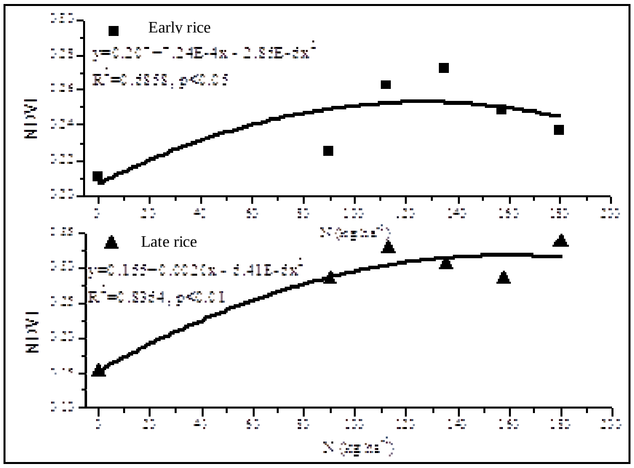

Figure 4. The regression between nitrogen rates and NDVI at heading stages in early and late rice.

The regression equation in early rice was y = 0.207 + 7.24E-4x – 2.86E-6x^2, (R^2 = 0.6856, $p<0.05$), and late rice was y = 0.155 + 0.0020x – 6.41E-6x^2 (R^2 = 0.8364, $p<0.01$). This indicated that the response of N fertilizer on rice could be analyzed with NDVI at heading stage.

NDVI were highly correlated with final grain yield and grain N uptake across all locations and it would also perform well when predicting grain yield and grain N uptake in winter wheat (Mogesa et al., 2005). In the results of Figure 5, the regression equation was: Y=7.50 + 3.03exp {-0.5[(x-0.30)/0.02]^2} between NDVI at heading stage and grain yield. And the grain yield of rice was more than 9 t ha^{-1} when the NDVI value was 0.28-0.31 at heading stage. It suggested that the better value of NDVI at heading stage was 0.28-0.31 in southeast of China, and the grain yield of rice was more than 9 t ha^{-1}.

5. Conclusions

The result showed that the grain yield was higher when 135 kg ha^{-1} N fertilizer was applied in paddy soil, especially in late rice. NDVI was steady at heading and grain filling stage of rice. The regression equation between NDVI at heading stage and N rates in early rice was y=0.207+7.24E-4x – 2.86E-6x^2, and late rice was y=0.155+0.0020x – 6.41E-6x^2. This showed that there was significant correlation between N rates and NDVI at heading stage. The regression equation was Y=7.50 + 3.03exp {-0.5[(x-0.30)/0.02]^2} between NDVI at heading stage and grain yield. It suggested that the at heading stage of rice 0.28-0.31 was better range of NDVI to obtain more than 9 t ha-1 yield under agro climatic conditions of Southeast China,.

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Abbreviations

DAT: Days after transplantation
LAI: Leaf area index
LSD: Least significant difference
N: Nitrogen
NDVI: Normalized difference vegetation index
R^2: Coefficients of determination
RCBD: Randomized complete block design
RER: Range error ratio
RMSE: Root mean square error.

Competing Interests

All authors declare that they have no competing interests.

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