Introduction

In Liaoning province of China, many rice cultivars with semi-erect panicles, are planted annually on large-scale area. The experimental and productive results show that grain yield of varieties with semi-erect panicles exceed those of cultivars with curved panicles because rice plants with semi-erect panicles are resistant to lodging and tolerant to deficiency of soil nutrients (Wang et al., 1999b). The nutrition status in the plants is affected by cultural measures. Many studies on rice nutrition and fertilization have been conducted (Yoshida, 1981; Vance, 2001) and the results indicate that nitrogen, phosphorus and potassium are essential nutrient elements for the growth and development of rice plants. However, nutrient status in rice plants with semi-erect panicles has not yet been examined. The objective of this study is to identify the nutrient status of N, P and K in rice plants with semi-erect panicles and provide strategies for optimizing plant fertilization.

Materials and Methods

In the paddy experiments, semi-erect panicle rice variety of Shendao 3 was used in 2003-2007, and Shendao 9 in 2006-2007. The experiments were conducted in the Agricultural Experimental Station of Shenyang Agricultural University. The design for canonical analysis was used in the experiment (Montgomery, 1976). Five treatment factors tested in the experiments were seeding rate, hill spacing, and amounts of applied N, P, and K fertilizers. And five treatment levels were coded with –2, -1, 0, 1 and 2, respectively. The seeding rates in the nursery bed (x_1) were 240, 360, 480, 600, and 720 g m^{-2}; hill spacings (x_2) were 5, 10, 15, 20 and 25 cm (row spacing was 30 cm); the amounts of N (x_3) were 90, 120, 150, 180 and 210 kg ha^{-1}; the amounts of P (x_4) were 13.1, 26.2, 39.3, 52.4 and 65.5 kg ha^{-1}; and the amounts of K (x_5) were 49.8, 99.6, 149.4, 199.2 and 249.0 kg ha^{-1}, respectively. In addition, 15 t ha^{-1} of farmyard manure was applied uniformly in the entire experimental field. The experiments comprised total 38 treatment combinations, including two controls (only manure applied, and without any chemical fertilizers and manure applied), manure and blank.

The relationship between the grain yield and treatment factors was analyzed with the method of response surface methodology.

The *AE* of chemical N, or P and K, is estimated with the difference between -2 and 0, or -2 and 2, level of the nutrient amount.

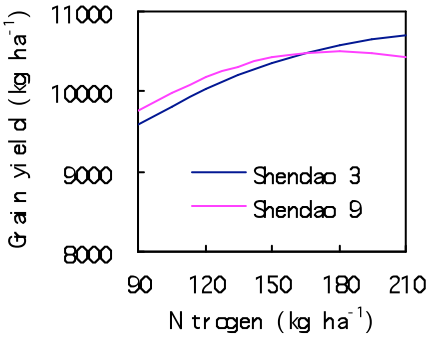
Results

Grain yields of rice plants under the treatments

In the experiments, grain yields of different plant populations of Shendao 3 were 6666.7-11814.8 kg ha^{-1}. The statistical results showed that the grain yield was affected by treatment factors. Based on the result of response surface methodology, the parabola effect of nitrogen fertilizer on the yield of Shendao 3 was very significant. The yield increased along with the raising of N fertilizer and reached the highest level when N fertilizer was treated at the code 2. The quadratic effect of P fertilizer on grain yield was significantly negative. And that of K was negative too but not remarkable. High yield could be obtained when P and K were treated at code 0 and –2, respectively. Insufficient or over application of N, P and K could decrease the grain yield of rice plants. Meanwhile, the positive interact between hill spacing and N fertilizer was significant. It meant the transplanting density should be decreased when N fertilizer increased.

For Shendao 9, grain yields of different plant populations were 7078.2-11666.7 kg ha^{-1}. The first order effect of N fertilizer was significantly positive, the second negative but not remarkable. The independent effect of P, or K, fertilizer was not significant. Under the

experimental condition, the response of Shendao 9 to N and P fertilizers in grain yield were lower than that of Shendao 3. But the positive interact between seedling rate and the amount of K applied on grain yield of Shendao 9 was significant. It indicated that the response of Shendao 9 to K fertilizer in grain yield was more sensitive than that of Shendao 3. When N, P and K were treated at code 1, 0 and –2 for Shendao 9, high yield could be obtained.



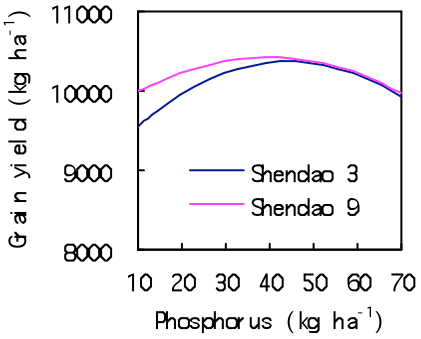


Fig.1The grain yield in response to N **Fig.2 The grain yield in response to P**

For two cultivars, the second order effect of hill spacing on grain yield was significantly negative. For Shendao 9, the negatively quadratic effect of seeding rate on grain yield was significant, and for Shendao 3, the effect was close to significant level. These indicated that there were suitable transplanting density and seeding rate.

Agronomic efficiency of N, P and K

The *AE* of chemical N, P and K fertilizers calculated by the difference between -2 and 0, or -2 and 2, level of the nutrient amount is presented in Table 1. From –2 to 0 level of treatment, the AE_N (i.e., *AE* of N), AE_P, and AE_K for Shendao 3 were 18.33 kg grain kg^{-1} N, 20.61 kg grain kg^{-1} P, and 1.31 kg grain kg^{-1} K, and those for Shendao 9 were 9.50 kg grain kg^{-1} N, 0.76 kg grain kg^{-1} P, and -2.91 kg grain kg^{-1} K, respectively. Increasing the application level of the fertilizers from very low (code -2) to very high (code 2), the *AE* of N, or P, decreased substantially but that of K changed little.

Table 1 *AE* of the chemical N, P and K applied (kg grain kg^{-1} nutrient)

Treatment level	Shendao 3			Shendao 9		
	N	P	K	N	P	K
From -2 to 0	18.83	20.61	1.31	9.50	0.76	2.91
From -2 to 2	15.25	3.63	0.15	6.33	-4.96	3.26

Discussion

Rice is a main crop in China and Asia. To increase grain yield of the plant and to remain N, P and K balance in the soil, fertilizers, especially chemical fertilizer, are sufficiently applied. But mean agronomic efficiency in rice production was low (Peng et al, 2005). These results indicate that interacts among plant density and nutrients could influence the grain yield. The effective way to increase grain yield of rice and agronomic efficiency of fertilizer, including N, P and K, is to combine with plant density. When the seeding rate was 360-480 g m^{-2}, the plants were transplanted at 15-17 cm of hill spacing, and 150-180 kg of N, 30-40 kg of P and 40-50 kg of K per ha were applied, high yield and good economic benefit could be obtained.

Applying the nutrient fertilizers in a balanced manner is one of cultural measures. In which the important factor is N fertilizer management (Kenneth et al, 1997; Herbert, 2005).

The results of this experiment indicate that over-application of N, P and K could decrease grain yield of rice and the agronomic efficiency of fertilizer. It may be associated with nutrient equilibrium in rice plant (Sumner and Beaufils, 1977; Wang et al, 1999a). The mechanism needs to be studied further.

Acknowledgements

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