Effect of Slow Release Fertilizer on Yield and Yield Components in Chinese High-Yielding Rice Cultivars

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Abstract

The effect of slow release fertilizer on yield and yield components in Chinese high-yielding rice cultivars were evaluated and analyzed to avoid over-fertilization in China. Two different types, linear (L) and sigmoid (S) fertilizer as a nitrogen (N) source were applied at basal dressing, in comparison with split applications of ammonium chloride (C type). The application of the slow release fertilizer increased the brown rice yield significantly in Chinese high-yielding cultivars, Yangdao 4 (YD) and Wuyugen 3 (WY), and was more effective at low N conditions than at high N conditions. Maximum yield was achieved in YD grown at 21 g N m^{-2} by S type, and in HH grown at 21 g N m^{-2} by L type. This indicates that about 30 % of N fertilizer could be saved by the application of the slow release fertilizer. These effects on yield resulted from the increase in sink size (the number of spikelets m^{-2} multiply one grain weight) due to the increase in the number of spikelets m^{-2}. The effect of the S type slow release fertilizer was more effective on the increase in sink size and the number of spikelets $panicle^{-1}$ than that of L type. Grain filling percentage in WY and HH decreased with the increase in sink size, while it was slight in YD. Therefore, the increase in sink size was important for YD to improve the yield production. These responses to the N supply were different between YD and WY, suggesting that the optimum amount of N fertilizer applied should be varied with these cultivars.

Keywords: Chinese high-yielding cultivar, Nitrogen fertilizer application, rice, slow release fertilizer, yield

Introduction

In Jiangsu province in China, one of the representative rice-producing areas, high-yielding rice cultivars are widely used for breeding and cultivation with applying a large amount of nitrogen (N) fertilizer more than 30 g m^{-2} to achieve high-yield (Peng *et al.* 2006). These cultivars have large yield potentials (Amano *et al.* 1993; Wang *et al.* 1995; Yao *et al.* 2000) and require the application of large amounts of nutrients, especially nitrogen (N). However, an excess fertilizer application causes not only an increase of costs but also an outflow of nutrients with an environmental burden. This requires an appropriate management of the fertilizer application and an improvement of fertilizer use efficiency (brown rice yield / the amount of N fertilizer application) in the rice cultivation. The method of fertilizer application has been improved by changing the amounts and timings of fertilizer application (Peng *et al.* 2006), and by using farmyard manure (Liu *et al.* 2008) and supplemental nitrification inhibitor (Huang *et al.* 1996) to raise the fertilizer use efficiency. As one of the effective solutions for high fertilizer recovery rate, a slow release fertilizer has been commonly used in Japan for the rice cultivation. However, there are few studies in Chinese high-yielding cultivars (Ju *et al.* 2006). As recent high-yielding cultivars can achieve high yield even in a small quantity of fertilizer application (Hasegawa 2003; Taylaran *et al.* 2009), the optimum fertilizer condition should be examined by using the slow release fertilizer. In this study, effects of different types of the slow release fertilizer on yield in Chinese high-yielding rice cultivars were evaluated and analyzed to determine effective methods and amounts of N fertilizer application.

Materials and Methods

Experiments were conducted in 2006 to 2009 (Exp.1) and 2010 (Exp.2) in a paddy field of Faculty of Agriculture, Kochi University, Japan. Three treatments were designed by types of N fertilizer applied. Ammonium chloride was applied as conventional N fertilizer (C type) for basal and top-dressing at each growth stage (basal:20 days after transplanting : 20 days before heading : 10 days before heading : heading = 2 :1:1:1:1). Two types of the slow release fertilizer, linear type (LP coat 100, L type) and sigmoid type (LP coat SS 100, S type) were applied as basal dressing all at once, except for the S type in 2006 and 2007, in which both 6 g m^{-2} of sigmoid type and 4 g m^{-2} of ammonium chloride were mixed at basal dressing and 2 g m^{-2} of ammonium chloride was additionally applied at 20 days after transplanting to promote early growth. In Exp.1, Chinese high-yielding Indica cultivar, Yangdao 4 (YD), Chinese high-yielding Japonica cultivar, Wuyugen 3 (WY) and conventional Japonica cultivar, Hinohikari (HH) were grown at the rate of 12 g N m^{-2} for each types of N fertilizer. In Exp.2, three different amounts of N, 12, 21, 30 g m^{-2} for each type of fertilizer were applied in YD and HH. The same amounts of P_2O_5 and K_2O as N in both experiments were applied at basal dressing and at each growth stage (basal : 20 days before heading : 10 days before heading =4:1:1), respectively. All treatments were arranged with 2 replications by a randomized block design. Yield and yield components were determined by using 20 hills sampled at maturity.

Results and Discussion

The effect of the slow release fertilizer on brown rice yield

Brown rice yield significantly increased with the application of slow release fertilizer in Exp.1 (Table 1). The effect of the slow release fertilizer on yield did not differ significantly among cultivars, but the average increasing percentage in YD and WY (6 to 15%) was higher than that in HH (0 to 5%). This result agreed with reports by Sato *et al.* (1993; 1997) in which the yield increased by 33 to 55% and 12 to 14% respectively.

The effect of the slow release fertilizer on yield was not significant in Exp.2 (Table 2). However, the increasing percentage at 12 g N m^{-2} was higher than that at 30 g N m^{-2} in both cultivars, showing that the slow release fertilizer was more effective on yield in low N fertilizer conditions than in high N fertilizer conditions. In addition, this effect was significantly different between cultivars, and the increasing percentage in YD was higher than that in HH. Maximum yield was obtained in YD grown at 21 g N by S type (781 g m^{-2}), and in HH grown at 21 g N by L type (539 g m^{-2}), which were higher than those grown at 30 g N by C type. This result indicates that the slow release fertilizer saves about 30% of N fertilizer applied, compared with the conventional fertilizer.

Table 1. Yield and yield components of rice cultivars in Exp.1 (the average value of 2005-2009)

Cultivar	Types of N fertilizer	Grain yield ($g\ m^{-2}$)				Sink size ($g\ m^{-2}$)				Spikelet number (m^{-2})				Panicle number (m^{-2})				Spikelet number ($panicle^{-1}$)				Grain filling percentage (%)				1000 grain weight (g)			
YD	O	692	*100*	ab		831	*100*	abc		29115	*100*	c		188	*100*	d		153	*100*	b		83.2	*100*	a		28.6	*100*	a	
	L	731	*106*	a	A	888	*107*	ab	A	32051	*110*	bc	B	195	*104*	d	C	161	*105*	ab	A	82.2	*99*	ab	A	27.8	*97*	ab	A
	S	732	*106*	a		915	*110*	a		34044	*117*	ab		198	*104*	d		172	*113*	a		79.9	*96*	ab		27.0	*94*	bc	
WY	O	600	*100*	bc		762	*100*	cd		28696	*100*	c		332	*100*	c		87	*100*	e		79.2	*100*	ab		26.6	*100*	c	
	L	646	*108*	abc	B	856	*112*	abc	A	34251	*119*	ab	AB	369	*111*	ab	B	93	*107*	de	B	75.1	*95*	bc	B	25.1	*94*	d	B
	S	687	*115*	ab		915	*120*	a		36778	*128*	a		355	*107*	bc		104	*120*	c		75.2	*95*	bc		25.0	*94*	d	
HH	O	563	*100*	c		690	*100*	d		29295	*100*	c		352	*100*	bc		83	*100*	e		81.5	*100*	ab		23.6	*100*	e	
	L	599	*105*	c	C	774	*112*	cd	B	35179	*120*	ab	A	400	*113*	a	A	88	*106*	e	B	76.1	*93*	bc	B	22.0	*93*	f	C
	S	563	*100*	c		806	*117*	bc		37343	*127*	a		376	*107*	ab		100	*120*	cd		69.6	*85*	c		21.7	*92*	f	
ANOVA	Cultivar (C)	***				***				*				***				***				***				***			
	Type (T)	*				***				***				***				***				***				***			
	Year (Y)	***				***				***				n.s.				***				n.s.				**			
	C*T	n.s.				n.s.				n.s.				n.s.				n.s.				*				n.s.			
	C*Y	n.s.				n.s.				n.s.				n.s.				***				***				**			
	T*Y	n.s.				n.s.				n.s.				n.s.				***				n.s.				n.s.			
	C*T*Y	n.s.				n.s.				n.s.				n.s.				n.s.				n.s.				n.s.			

Note: Italic values indicate the increasing percentage by the slow release fertilizers.
Values with different small letters indicate significant differences at the 5% level among methods of the fertilizer application and cultivars.
Values with different capital letters indicate significant differences at the 5% level among varieties.
*, **, ***; Significant at 5, 1, 0.1% levels by ANOVA, respectively; ns is Not significant.

Analysis of yield components

These effects of the slow release fertilizer on yield resulted from the increase in sink size (the number of spikelets m^{-2} multiply one grain weight, Venkateswarlu and Visperas, 1987) due to the increase in the number of spikelets m^{-2} in both experiments, although 1000 grain weight significantly decreased with the increase in the number of spikelets m^{-2} (Table 1, 2). The increase in the number of spikelets m^{-2} was attributed to the increase in both the number of panicles m^{-2} and the number of spikelets $panicle^{-1}$. The effect of the S type slow release fertilizer was more effective on the increase in sink size and the number of spikelets $panicle^{-1}$ than that of L type. Kamekawa (1990) reported that sink size increased with the application of the slow release fertilizer of linear type mainly due to the increase in the number of panicles m^{-2} in Japanese cultivars. These results show that there is a difference of the effect on the yield components between L and S types.

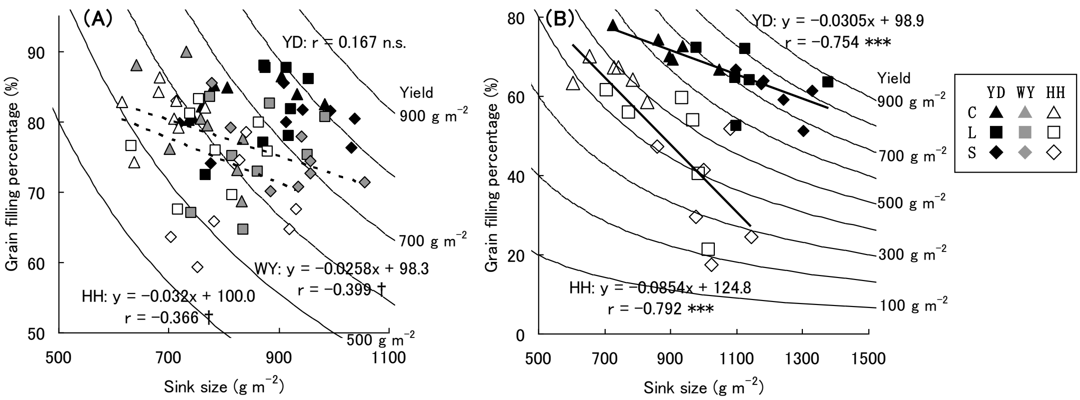
The increase in sink size resulted in the decrease in grain filling percentage in both experiments. However, Tanaka (1988) and Nakanishi *et al.* (1990) reported that grain filling percentage increased despite the increase in the number of spikelets m^{-2} with applying the slow release fertilizer at panicle neck-node differentiation stage. This result may be because of late fertilizer application in comparison with our study.

A negative relationship between sink size and grain filling percentage was observed in WY and HH (P<0.10), but not observed in YD in Exp.1 (Figure 1A). A similar trend was observed in Exp.2; the decrease in grain filling percentage in YD was less than that in HH when grown with high N fertilizer conditions (Figure 1B). Yang *et al.* (2002) reported that grain filling percentage in recent Chinese cultivars did not always decrease with the increase of the number of spikelets $panicle^{-1}$. These results show that YD maintains high grain filling percentage with high sink size in response to high N conditions, resulting in high fertilizer use efficiency. However, Chinese high-yielding Japonica cultivar, WY had a different trend with YD, and showed the significant decrease (P<0.10) in grain filling percentage with the increase in sink size. This indicates that the optimum amount of fertilizer application should be different between YD and WY.

Table 2. Yield and yield components of rice cultivars in Exp.2 (2010)

Cultivar	Types and amounts of N fertilizer	Grain yield (g m^{-2})	Sink size (g m^{-2})	Spikelet number (m^{-2})	Panicle number (m^{-2})	Spikelet number (panicle^{-1})	Grain filling percentage (%)	1000 grain weight (g)
YD	C12	599 *100* abcd	794 *100* defg	28412 *100* e	178 *100* e	160 *100* cd	76.2 *100* a	27.9 *100* a
	L12	759 *127* ab	1054 *133* abcdef	38221 *135* abcde	207 *117* e	186 *116* abc	72.0 *95* a	27.6 *99* a
	S12	737 *123* abc	1136 *143* abc	41958 *148* abcd	211 *119* e	199 *125* a	64.9 *85* abc	27.1 *97* a
	C21	653 *100* abc	921 *100* cdefg	32360 *100* de	211 *100* e	154 *100* d	71.0 *100* a	28.5 *100* a
	L21	719 *110* abc A	1118 *121* abcd A	40907 *126* abcd A	222 *105* de B	185 *120* abc A	64.3 *91* abc A	27.3 *96* a A
	S21	781 *120* a	1255 *136* ab	46898 *145* a	237 *112* de	198 *129* a	62.6 *88* abc	26.7 *94* a
	C30	664 *100* abc	971 *100* abcdef	34440 *100* bcde	207 *100* e	166 *100* bcd	68.5 *100* ab	28.2 *100* a
	L30	725 *109* abc	1239 *128* abc	44718 *130* abc	233 *113* de	192 *116* ab	58.0 *85* abc	27.7 *98* a
	S30	696 *105* abc	1273 *131* a	46824 *136* a	252 *121* de	186 *112* abc	55.2 *81* abcd	27.2 *96* a
HH	C12	422 *100* cde	629 *100* g	27158 *100* e	307 *100* cd	89 *100* ef	66.7 *100* ab	23.2 *100* b
	L12	435 *103* bcde	741 *118* fg	33478 *123* bcde	374 *122* abc	90 *101* ef	58.7 *88* abc	22.1 *96* b
	S12	407 *97* cde	930 *148* bcdefg	42587 *157* abcd	385 *125* abc	111 *125* ef	44.3 *66* bcde	21.8 *94* b
	C21	487 *100* abcde	779 *100* efg	33470 *100* bcde	352 *100* bc	95 *100* ef	63.0 *100* abc	23.3 *100* b
	L21	539 *111* abcde B	953 *122* abcdefg B	42313 *126* abcd A	433 *123* ab A	98 *103* ef B	56.7 *90* abc B	22.6 *97* b B
	S21	423 *87* cde	1029 *132* abcdef	47101 *141* a	429 *122* ab	110 *116* ef	40.7 *65* cde	21.8 *94* b
	C30	502 *100* abcde	765 *100* efg	32712 *100* cde	392 *100* abc	84 *100* f	65.7 *100* ab	23.4 *100* b
	L30	302 *60* de	1001 *131* abcdef	45270 *138* ab	444 *113* a	102 *122* ef	30.7 *47* de	22.1 *95* b
	S30	229 *46* e	1065 *142* abcde	50302 *154* a	440 *112* ab	114 *137* e	21.0 *32* e	21.6 *92* b
ANOVA	Cultivar (C)	***	***	n.s.	***	***	***	***
	Type (T)	n.s.	***	***	***	***	***	***
	Amount (A)	n.s.	***	***	***	n.s.	***	n.s.
	C*T	*	n.s.	n.s.	n.s.	***	**	n.s.
	C*A	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	T*A	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	C*T*A	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Note: Italic values indicate the increasing percentage by the slow release fertilizers.
Values with different small letters indicate significant differences at the 5% level among methods of the fertilizer application and cultivars.
Values with different capital letters indicate significant differences at the 5% level among varieties.
*, **, ***; Significant at 5, 1, 0.1% levels by ANOVA, respectively; ns is Not significant.



***, †; Significant at 0.1 % and 10 % levels, respectively. n.s.; Not significant.

Figure 1. Relationship between sink size and grain filling percentage in Exp.1 (A) and Exp.2 (B).

Yearly differences

The effect of the slow release fertilizer on yield was minimum in 2006 (-1%) and maximum in 2009 (12%) on average of cultivars in Exp.1. This yearly differences of the slow release fertilizer was because of the decreasing rate in grain filling percentage and the increasing rate in sink size due to the increase in the number of spikelets panicle^{-1}. That is, the remarkable decrease in grain filling percentage and the slight increase in sink size were observed in 2006, while the opposite trend was observed in 2009.

Conclusion

From the above results, the application of the slow release fertilizer increased the brown rice yield significantly, especially in YD and WY, and was more effective at low N fertilizer conditions than at high N fertilizer conditions. Maximum yield was achieved in YD grown at 21 g N m^{-2} by S type, and in HH grown at 21 g N m^{-2} by L type. Therefore, about 30% of N fertilizer could be saved by the application of the slow release fertilizer without any decrease in yield, in comparison with the conventional fertilizer. This resulted from the significant increase in sink size due to the increase in the number of spikelets m^{-2}. The slow release fertilizer of S type was more effective on increases in sink size and the number of spikelets panicle^{-1} than that of L type. The increase in sink size resulted in the decrease in grain filling percentage in WY and HH, while it was negligible or slight in YD, which contributed to the increase in the yield production. These responses to the N supply were different between YD and WY, both Chinese high-yielding cultivars. Therefore, the amount of N fertilizer applied should be varied with these cultivars.

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