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Uptake of applied silica by rice plants in relation to level of nitrogen application

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Summary

To investigate the relationship between the recovery rate of applied silica of calcium silicate fertilizer (CS) by rice plant and application rates of nitrogen (N), a pot plant experiment was conducted under different CS and N application rates. Treatments were CS application as basal fertilizer (Si+) and no silica application (Si−) and the both treatments were grown with three nitrogen (N) application levels, i.e., low (Nl), middle (Nm), and high (Nh). Higher nitrogen application rates improved the plant dry weight significantly, regardless of Si− or Si+ treatment. In comparison with Nl values, the total dry weight in Si− and Si+ plants increased by 31 and 35% in Nh and 19 and 21% in Nm treatments. The difference of silica content between Si+ plants and Si− plants was significant, but there was no significant difference in silica content among nitrogen treatments. The recovery rates of applied silica by rice plants in Nl, Nm, and Nh were 23.9, 32.4 and 30.6%, respectively, but there were no significant differences in recovery rates of silica among the different nitrogen application rates Therefore, it seemed that the recovery rate of applied silica of CS was not affected by nitrogen application rate and plant growth.

Key words：calcium silicate, silica uptake, N application, recovery rate, rice

Introduction

Applying silica to rice plants, a high silica-accumulating plant, increases the yield and quality of the rice by improving plant growth (Ma and Takahashi 2002), and resistance or tolerance to biotic and abiotic stress (Ma 2004). Silica in rice plants is derived from paddy soils, irrigation water, and applied fertilizer. Silica fertilizer is required to get the benefits if the silica concentration of the shoot is less than 110 g kg^{-1} at harvest (Imaizumi and Yoshida 1958).

Because the amount of silica in the plant derived from soil reaches a ceiling, silica concentration of rice plant decreases with increasing dry weight of the rice plant (Sumida 1992). In Japan, rice farmers apply nitrogen fertilizer to increase yields, and the nitrogen application rate is closely related to the dry weight of the plant (Sumida 1992). Therefore, silica fertilizer should be applied to compensate for any silica shortage. However, no information is available on the relationship between the uptake of applied silica and nitrogen application.

In this paper, we investigated the relationship between nitrogen application and uptake (recovery rate) of applied silica from a calcium silicate fertilizer in a pot plant experiment.

Materials and Methods

Paddy soil was collected from the plowed layer (0-15 cm) of rice fields in 2006 at the University

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Farm, Faculty of Agriculture, Yamagata University (Takasaka). The soil was dried in a greenhouse and sieved (10-mm mesh size). Physico-chemical properties of the Takasaka soil are provided in Table 1. In Japan, calcium silicates (CS) made from slag have been applied to paddy fields as a silica source. Therefore, CS was used as a silica supplement in this experiment. The silica content of CS was 30% when evaluated by 0.5 M HCl extraction. The following experiments had five replicates.

Table 1. Physico-chemical properties of Takasaka soil.

Soil type	Aquent
Soil texture	Clay Loam
[1]pH(H_2O)	5.1
Total Carbon (g kg^{-1})	15.4
[2]CEC (cmol(+) kg^{-1})	28.6
[3]Available silica (mg kg^{-1})	204.4
[4]CSDA	
a value (mg L^{-1})	15.9
b value (mg L^{-1})	5.0
Easily soluble silica (mg kg^{-1})	72.9

[1]Measured in 1:2.5 soil:water

[2]CEC:Cation exchangeable capacity (Wada and Harada 1969)

[3]Extracted by phosphate bufer (pH6.2, 0.04M) method (Kato 1998)

[4]CSDA:Characteristics of silicon dissolution and adsorption (Sumida 1991)

Three kg (as air dry soil) of the Takasaka soil were put into 1/5000a Wagner pots. Treatments were silica application as a basal fertilizer (Si+) or no silica application (Si−). The silica application rate in the Si+ treatment was 9.0 g CS (2.7 g of 0.5 M HCl soluble silica) per pot. Both treatments were grown with three nitrogen (N) application levels, given as basal and topdressed ammonium sulfate, i.e., low (Nl, 0 and 30 mg pot^{-1}), middle (Nm, 60 and 90 mg pot^{-1}), and high (Nh, 90 and 189 mg pot^{-1}). CS, N, 180 mg phosphate (as P_2O_5), and 180 mg potassium (as K_2O) were initially applied to the pots as basal fertilizer. The pots were then submerged and puddled by hand. One day after puddling, one hill (five seedlings) of rice seedlings (Oryza sativa L. cv. Haenuki, three leaf age) were transplanted to the pots. The pots were kept submerged with tap water throughout the experiments. Sixty mg of potassium (as K_2O) and the three N application rates (Nl, Nm, andNh) were applied to pots as topdressing 34 days after transplanting (DAT).

Aboveground parts of the rice plants were collected on DAT102 (mature stage) and separated into leaf, stem, and panicle. After drying at 80℃ for 2 days, dry weights of the plants were measured. All samples were then milled, and silica in the samples extracted using 1.5 M hydrofluoric acid − 0.6 M hydrochloric acid, and the silica concentration in the extracts was measured by colorimetric methods (Saito *et al.* 2005). The amount of silica in the rice plant derived from applied silica was estimated by subtracting the no silica treatment and recovery rate of applied silica to the amount of 0.5 M hydrochloric acid-soluble silica applied to the soil.

To evaluate effects of treatment on dry weight and the amount of silica in rice plants and its interaction, two-way ANOVA was carried out. Tukey-Kramer's multiple comparison was conducted to determine significant differences among nitrogen treatments using Statcel2 (Yanai 2004).

Results

Higher nitrogen application rates improved the plant dry weight significantly, regardless of Si− or Si+ treatment (Table 2). Total plant dry weight of Si− and Si+ were 51.1 and 53.4 g pot^{-1} in Nl, 60.7 and 64.8 g pot^{-1} in Nm, and 67.2 and 72.3 g pot^{-1} in Nh, respectively. In comparison with Nl values, increased percentage of the total dry weight in Si− and Si+ plants were 19 and 21% in Nm and 31 and 35% in Nh treatments. CS application improved

Table 2. Effects of nitrogen and/or calsium silicate application on dry weight of rice plants.

Silica application	N application	Dry weight Shoot	Panicle	Total
		(g pot^{-1})		
Si-	Nl	[a]30.6 ± 0.82	20.5 ± 0.31	51.1 ± 0.92
	Nm	37.6 ± 0.80	23.1 ± 1.34	60.7 ± 1.52
	Nh	44.4 ± 0.41	22.8 ± 1.39	67.2 ± 1.52
Si+	Nl	31.8 ± 0.49	21.6 ± 1.26	53.4 ± 1.66
	Nm	38.5 ± 1.31	26.3 ± 0.62	64.8 ± 1.46
	Nh	43.5 ± 0.76	28.8 ± 1.57	72.3 ± 2.13
	N	***	**	***
	Si	ns	**	**
	N ×Si	ns	ns	ns

[a]Mean ±standard error of five replication.
*** p<0.01, ** p<0.001, ns p≥0.05.

Table 3. Effects of nitrogen and/or calsium silicate application on silica concentration and absorption of rice plants.

Silica application	N application	Silica concentration Shoot	Panicle	Silica content Shoot	Panicle	Total silica
		(g kg^{-1})		(g pot^{-1})		
Si-	Nl	[a]47.4 ± 0.78	30.9 ± 1.83	1.45 ± 0.06	0.63 ± 0.25	2.09 ± 0.04
	Nm	37.9 ± 0.66	26.1 ± 1.29	1.42 ± 0.04	0.60 ± 0.30	2.02 ± 0.05
	Nh	34.4 ± 0.25	23.2 ± 1.59	1.53 ± 0.02	0.52 ± 0.31	2.05 ± 0.02
Si+	Nl	58.0 ± 0.86	41.0 ± 1.07	1.85 ± 0.05	0.88 ± 0.04	2.73 ± 0.08
	Nm	51.8 ± 0.64	34.4 ± 0.93	1.99 ± 0.08	0.91 ± 0.03	2.90 ± 0.07
	Nh	47.2 ± 0.81	28.8 ± 1.45	2.05 ± 0.04	0.83 ± 0.05	2.88 ± 0.04
	N	***	***	*	*	ns
	Si	***	***	***	***	***
	N ×Si	ns	ns	ns	ns	ns

[a]Mean ±standard error of five replication.
*** p<0.01, ** p<0.001, ns p≥0.05.

the total and panicle dry weight significantly, while the shoot dry weight was not affected by CS application (Table 2). The increased percentages of the total dry weight by CS application were 5%, 7% and 8% in Nl, 7% in Nm and 8% in Nh, respectively. Compare to Si− treatments, panicle dry weight in Si+ treatments increased 5% in Nl, 14% in Nm, and 27% in Nh. The shoot dry weight was not affected by CS application.

Silica concentration in shoot and panicle decreased with increasing of N application rate regardless of CS application (Table 3).

The amount of silica in Si− rice plants was 2.02-2.09 g pot^{-1} and in Si+ plants that was 2.73-2.90 g pot^{-1} (Table 3). The difference in the amount of silica in rice plant between Si+ and Si− plants was significant. Increasing with nitrogen application rate, the shoot silica contents were increased and panicle silica contents were decreased. There was no significant difference in total silica content among nitrogen treatments.

The recovery rates of applied silica by rice plants in Nl, Nm, and Nh were 23.9, 32.4 and 30.6%, respectively, but there were no significant differences in recovery rates of silica among the different nitrogen application rates (Figure 1).

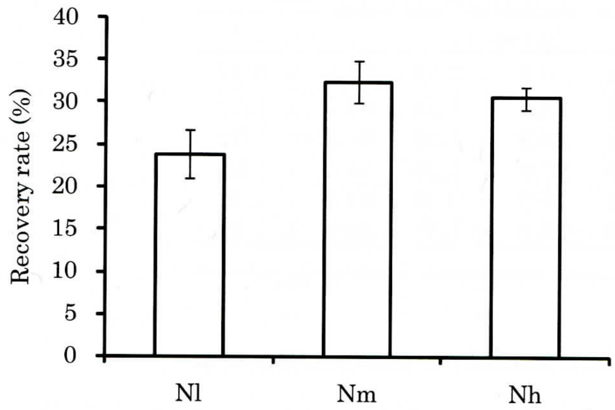

Figure 1. Effects of nitrogen application level on recovery rate of applied silica by rice plants.
*Bars in the figure indicate standard error.

Discussion

Okuda and Takahashi (1961) reported that effect of silica on panicle dry weight of rice was larger than that of shoot. It was reported that increase of grain yield by CS application under high nitrogen condition was larger than that of under low nitrogen application condition (Ma and Takahashi 2002). The increased percentage of panicle dry weight by CS application was the highest in Nh treatment which had the lowest silica concentration among Si- treatments (Table 2, 3). Therefore our result also suggested that silica application needs to increase silica concentration in rice plant and to improve yield of rice.

Silica uptake by rice plants at earlier growth stages is inhibited by ammonium through a decline in the absorption ability of rice roots, and Si uptake increases under no added ammonium conditions (Takahashi and Nishi 1982). Root dry weight of rice increases with nitrogen application (Kawada *et al.* 1977). Those reports suggest that nitrogen application affects silica absorption ability of rice plant. Sumida (1992) reported that the main limiting factor for silica uptake by rice plants under abundant nitrogen cultivation is the silica supply from the paddy field at the later growth stages, and the amount of silica available from CS fertilizer is affected by pH (Kato and Owa 1996). Rhizosphere soil pH is lower than non-rhizosphere soil pH (Kimura *et al.* 1977). Dry weight of roots and shoots is increased by nitrogen application (Tanaka *et al.* 1993). These data suggest that nitrogen application accelerates silica dissolution from CS fertilizer by improving growth of rice roots. However, different amounts of ammonium sulfate applied as basal and topdressing fertilizer changed the dry weight of the rice plants but did not change the uptake of applied silica at the maturing stage (Table 1 and Figure 1). Therefore, it is suggested that changes of physiological and morphological factors, such as the silica absorption ability of rice plants and rhziosphere pH, in relation to nitrogen application were insufficient to affect the uptake of applied silica from CS in this experiment.

According to data from Yamagata Prefecture (2007), the recommended total basal and topdressed nitrogen application rate for Haenuki is 70-80 kg ha^{-1}. Mean rice grain yield of municipalities in Yamagata Prefecture were 5.4-6.5 t ha^{-1} and the difference of the grain yield between maximum and minimum value was about 20% (Tohoku Regional Agricultural Administration Office 2007). The total amount of nitrogen applied in the Nh treatment corresponds to 135 kg ha^{-1} in field conditions. Comparing the Si+Nl treatment with the Si+Nh treatment, the maximum increase in rice total dry weight was 35% with increased N application. Therefore, it seems that the uptake of applied silica from CS was not affected by nitrogen application rate in conventional rice fields in Yamagata Prefecture.

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水稲による施用ケイ酸の吸収と窒素施用量の関係

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摘　要

施用ケイ酸の吸収に対する水稲生育量の影響を明らかにするために，施用ケイ酸の利用率と窒素施用量の関係をポット試験で検討した．処理区はケイ酸石灰施用区(Si+)とケイ酸石灰無施用区(Si-)に窒素施用量3水準(低窒素区(Nl)，標準窒素区(Nm)，高窒素(Nh))を組み合わせた計6処理区とした．ケイ酸施用の有無に関わらず，成熟期における水稲の地上部乾物重は窒素施用によって有意に増加し，Nlに対する増加割合はNmで19〜21%，Nhで31〜35%であった．成熟期の水稲地上部ケイ酸含有量はSi-よりSi+で有意に大きかったが，同一のケイ酸処理区では窒素施用量に関わらず一定であった．施用ケイ酸の利用率は23.9〜34.6%であり，窒素施用処理区間に有意な差は認められなかった．以上のことから，施用ケイ酸の吸収量は水稲生育量に影響されないことが示唆された．

キーワード：ケイ酸石灰，ケイ酸吸収，窒素施用，利用率，水稲