Investigation of negative effects of rice husk silica on komatsuna growth using three experiments

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Abstract

Purpose This study aims to evaluate the potential negative effects of rice husk as a source of fertilizer on plant growth.

Methods Growth tests were conducted on komatsuna (*Brassica rapa* var. *perviridis*) using three types of experiment. A pot experiment was conducted to compare different fertilizers on an individual basis. A second pot experiment was conducted to compare different mixtures of fertilizers. Finally, a field experiment was performed to determine the effects of the application of different quantities of silica.

Results The results showed that komatsuna grew better with the application of silica mixed with fertilizer, and that there was an optimal quantity of silica to be used, when used on its own. It was found that, in all cases, the silica in the rice husk ash did not have any measurable negative effects on the growth of the komatsuna.

Conclusions We, therefore, conclude that rice husk silica can undoubtedly be used for plant cultivation.

Keywords Rice husks · Ash silica · Fertilizer · Negative effects · Komatsuna · Growth

Introduction

Rice husks are one of the most trusted forms of biomass because of their sustainable generation and abundance. Rice husks are valuable sustainable resources for two purposes: energy recovery and material recovery. Their energy content is approximately 12 MJ kg⁻¹ and they are a good source of fuel for producing hot water and steam. Rice husks contain silica, which can be a useful fertilizer for rice plants. This means that an ideal complete recycling scheme can be pursued (Fig. 1). Rice straw, which is generated along with rice husks, does not cause any problems in Japan because it

is plowed into the soil; although, several recent researches have studied the recycling of rice straw (Kaur et al. 2019; Kadian et al. 2019).

The silica in rice husk is very useful and many researchers have reported its varied applications. Beside its numerous industrial applications, silica is quite beneficial for plants. Multiple researchers have reported the benefits of silica in rice husks, leading to the healthy growth of plants. Raven (1982) reported a comprehensive study on the total energy of silicon transport and its function in plants. Foy (1992) concluded that silicon causes an increase in phosphorus (P) efficiency, leaf size and chlorophyll content, and alleviation of aluminum (Al), iron (Fe), and manganese (Mn) in plants. The effect of silicon on the physical strength of plants, such as in their cell walls, was discussed by Guerriero et al. (2016). Most recently, silicon's role in tropical forest soils (Schaller et al. 2018) and its influence on numerous plants, such as maize, lettuce, wheat, carrot, and pea have been reported (Greger et al. 2018). Silicon fertilizers show improvements in crops, such as improved tolerance of biotic and abiotic stresses, and higher yields (Vasanthi et al. 2014). Effects of silica on specific plants have been investigated. Henriot et al. (2006) investigated the effect of silica on banana plants, and Dorneles et al. (2018) investigated its effect on potato plants. Silicon was found to

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Fig. 1 Ideal agriculture loop based on rice husk recycling

play an important role in these crops. Silicon has also been reported to have good effects on humans; it improves bone health and accelerates healing (Henstock et al. 2015) as well as improves the immune response and tissue health (Farroq and Dietz 2015). Since 1950s, there have been numerous researches on how silicon affects rice production (Yoshida et al. 1959, 1962; Krishnarao and Godkhindi 1992; Savant et al. 1996; Klotzbücher et al. 2015; Ito et al. 2015; Siregar et al. 2016; Waseem et al. 2016; Song et al. 2017).

The purpose of this study is to investigate the negative effects of silica in rice husk ash on the komatsuna plant using three different experiments. Komatsuna is a standard plant used in the evaluation of negative effects on plants in Japan. Kato et al. (2008) studied nitrate concentrations in komatsuna in an andisol. Furthermore, the flux of N_2O from komatsuna influenced by slag fertilizers has been investigated (Singla and Inubushi 2015). The uptake of tellurium and cesium from the soil by komatsuna plants has also been reported (Fujiwara et al. 2017).

Sekifuji and Tateda (2017) investigated the negative effect of silica in rice husks on the taste of rice and found that no such effect was evident when using silica as a fertilizer. This was done to confirm that there is no negative

effect of the rice husk silica on plants; thereby, promoting various applications of silica, especially recycling of rice husk silica. Moreover, rice husks could then be regarded not as waste but as a resource, which would help to promote a greener society in rice-producing countries.

Materials and methods

Rice husks of Koshihikari (*Oryza sativa* L.) were used for the following experiments. Rice husk ash was obtained by burning the husks in a field-scale boiler system (incineration capacity: 100 kg rice husks h^{-1}) (Fig. 2).

The details of the boiler system are described by Tateda et al. (2016b). The silica in the ash was confirmed as amorphous using an X-ray diffraction analysis (XRD). The solubility of the silica was more than 50%, thereby, indicating its amorphous state. The solubility percentage of silica is an official indicator, which is highly correlated with the amorphous state of silica. Higher the solubility percentage, the more amorphous the state will be. Details of the solubility measurements are described by Tateda et al. (2016a). Komatsuna (*Brassica rapa* var. *perviridis*), a Japanese

Fig. 2 Diagram of the boiler

mustard spinach, was used for all the experiments. Possible contamination by radioactive cesium in the rice husk ash was also analyzed, because all the experiments were conducted after a severe incident involving an explosion at a nuclear power plant that had been damaged by the strong earthquake, which hit the northern area of Japan on March 11th, 2011. Levels of radioactive cesium (Cs-134 and Cs-137) were measured using the standard method for measuring radioactive cesium in fertilizers (MAFF 2011).

Pot experiment for comparison with different individual fertilizers

The purpose of this experiment was to investigate the negative effects of rice husk ash as a fertilizer for komatsuna compared to other common fertilizers and compost, using cultivation pots. The experimental procedure followed the standard method for solubility tests of silica (MAFF 2007). Neubauer pots (10^{-6} ha; inner diameter 11.3 cm $\times$ height 6.5 cm) were used for the experiment. Diluvium was used as the base soil, and its characteristics are shown in Table 1. For comparison, a dried cell fertilizer and farm compost were used, and their characteristics are shown in Table 2. Because nitrogen content was less than 2% for SF and CF2, an application of 5 g (dry base) was set as the standard. For CF1, 100 mg of nitrogen was set as the standard because the nitrogen content was more than 2% (dry base). The experimental design of the fertilizer and compost applications are shown in Table 3. The cultivation was conducted in a glass room and the room temperature was kept above 15 °C, with

germination and growth observations conducted on days 5 and 9, and on days 14 and 21, respectively.

Pot experiment for comparison with different mixtures of fertilizers

The purpose of this experiment was to investigate the negative effects of rice husk ash mixed with compost on komatsuna using cultivation pots. The experimental procedure followed the standard method for solubility tests of silica (MAFF 2007). Neubauer pots (10^{-6} ha; inner diameter 11.3 cm $\times$ height 6.5 cm) were used for the experiment. Komatsuna was cultivated in a glass room at an average room temperature of 25 °C. Compost produced by mixing bark, poultry manure, tea dregs, pruned branches and/or leaves, and urea was used for making the bed materials for komatsuna growth. Tea dregs consisted of leaves left over from brewing tea, which is one of the most popular drinks in Japan. The experimental design is summarized in Table 4. Bed materials A, B, and C are compost products that are commercially available. Volcanic ash subsoil was used as the base soil. 150 ml of the bed materials was added to the base soil (350 ml), which was 71 g, 70 g, 45 g, 61 g, 50 g, 49 g, 57 g, 51 g, and 45 g for pots #1, 2, 3, 5, 6, 7, 8, and 9, respectively. 360 g of base soil was used for the control.

Field experiment with different quantities of silica

The purpose of this experiment was to investigate the negative effects of rice husk ash on komatsuna in field cultivation. Two greenhouses were used for the experiments. The configuration of the greenhouses and the experimental design are shown in Fig. 3.

Elemental components of the base soil in greenhouses A and B, and the pH of each section are shown in Tables 5 and 6. The pH of the soil in each section (Table 6) was measured by dissolving the soil in tap water (pH 7.31) at ratio of 2:1 (soil:water) by weight. Resistance values to lodging were also obtained to evaluate the negative effects of the rice husk ash on komatsuna (Fig. 4). Seeding was conducted at the end of November 2013 and harvesting was conducted at the beginning of February 2014.

Table 1 Physical characteristics of the base soil (diluvium)

Type of soil	Values
pH (soil:water = 1:2.5)	6.3
Exchangeable acidity	0.3
Electric conductivity (mS cm^{-1})	0.15
Cation exchange capacity ($\text{mol}_c \text{ kg}^{-1}$)	19.1
Phosphate adsorption coefficient (g kg^{-1})	28.6
Air-dried fine soil volume weight (g 500 ml^{-1})	413
Maximum water holding capacity (g kg^{-1})	1100

Table 2 Characteristics of fertilizers used

Short name	Name	Materials	Fertilizer effective components (%)				
			Water content	N	P_2O_5	K_2O	C/N
SF	Sample fertilizer	Rice husk ash	6.1	0.11 (0.12)	0.19 (0.20)	1.92 (2.05)	112
CF1	Comparison fertilizer 2	Dried cell fertilizer	7.1	5.08 (5.47)	2.27 (2.44)	0.19 (0.20)	6
CF2	Comparison fertilizer 1	Farm compost	45.4	1.00 (1.82)	1.32 (2.42)	1.53 (2.81)	17

Values in parentheses indicate the percentage in dry base

Table 3 Design of fertilizers

Short name	Application design	Application amount (g pot ⁻¹)	Fertilizer effective components (mg pot ⁻¹)		
			N	P ₂ O ₃	K ₂ O
SF					
SFS	Standard	5.3	6 (25)	10 (50)	102 (25)
SFD	Double	10.7	12 (25)	20 (50)	205 (25)
SFT	Triple	16.0	18 (25)	30 (50)	307 (25)
SFQ	Quadruple	21.3	23 (25)	41 (50)	409 (25)
CF1					
CF1S	Standard	2.0	100 (25)	45 (50)	4 (25)
CF1D	Double	3.9	200 (25)	89 (50)	7 (25)
CF1T	Triple	5.9	300 (25)	134 (50)	11 (25)
CF1Q	Quadruple	7.9	400 (25)	179 (50)	15 (25)
CF2					
CF2S	Standard	9.2	92 (25)	121 (50)	140 (25)
CF2D	Double	18.3	183 (25)	242 (50)	280 (25)
CF2T	Triple	27.5	275 (25)	363 (50)	420 (25)
CF2Q	Quadruple	36.6	366 (25)	484 (50)	561 (25)
	Control		25	50	25

Values in parentheses indicate the amounts of ammonium sulfate, superphosphate, and potassium chloride used for N, P₂O₃, and K₂O, respectively

Table 4 Experimental design and physical states

Pot # name	Components of bed materials	Mixing percentage by weight (%)		Physical states		
		Bed material	Rice husk ash	Water content (%)	pH	Electric conductivity (mS cm ⁻¹)
1						
A10	A	90	10	51.8	8.4	1.3
2	Bark 94.0%					
A30	Poultry manure 5.0%	70	30	52.5	8.8	0.9
3	Urea 1.0%					
A50		50	50	35.6	9.0	2.0
4						
B10	B	90	10	53.4	7.8	1.4
5	Bark 52.3%					
B30	Tea dregs 22.5%	70	30	53.8	8.6	1.6
6	Pruned branches and leaves 22.5%					
B50	Poultry manure 2.2%	50	50	46.9	9.0	1.7
7	Urea 0.5%					
C10	C	90	10	53.4	6.2	1.7
8	Tea dregs 50.0%					
C30	Pruned branches and leaves 50.0%	70	30	51.2	6.6	1.7
9						
C50		50	50	45.4	7.6	2.0
	Control	—	—	149.5 ^a	6.4 ^b	0.13 ^c

Values of a, b, and c are from Saito et al. (1987)

^aMaximum water holding capacity

^bpH

^cElectric conductivity of volcanic ash subsoil

Fig. 3 Configuration of the experimental sections in the fields

Greenhouse A:
Field with no rice husk ash applied.

Greenhouse B:
Field with rice husk ash applied.

20 kg 100 m ⁻²	15 kg 100 m ⁻²	10 kg 100 m ⁻²	5 kg 100 m ⁻²
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Table 5 Soil analysis (%)

Elements	Soil in greenhouse A	Soil in greenhouse B
Fe	43.2	43.1
Si	33.8	33.5
Ca	8.1	9.1
K	7.5	6.5
Ti	2.8	3.1
Ba	2.1	0.7
Mn	0.6	0.9
Zn	0.4	0.4
Sr	0.4	0.3
Zr	0.4	–
Cr	0.2	0.2
Rb	0.2	0.2
Ag	0.2	–
Y	0.1	–
S	–	1.9

Table 6 pH of the soil in each section

Soil	pH
Soil in greenhouse A	5.17
Soil in greenhouse B	5.38
Soil in the section of 5 kg 100 m ⁻²	5.12
Soil in the section of 10 kg 100 m ⁻²	5.40
Soil in the section of 15 kg 100 m ⁻²	5.28
Soil in the section of 20 kg 100 m ⁻²	5.48

Results and discussion

Pot experiment for comparison with mixed single fertilizer (experiment 1)

Germination occurred in all the application designs, and showed equal or much better results, as compared to the control (data not shown). Abnormalities were not seen in

Fig. 4 Resistance values test (leaf stem) **Fig. 5** Leaf length, fresh weight, and fresh weight index observed on the 21st day

any of the application designs. Growth observations on the 21st day are graphed in Fig. 5. The fresh weight index shows the proportion of fresh weight for each sample, taking the value of control (6.9 g) as 100. For both leaf length and fresh weight, all the application designs showed larger values than the control. In the case of leaf length, SF and CF2 showed an increase with increasing application of ash, though the values were almost the same for CF1. For fresh weight, CF2 showed an increase with increasing application of ash, and the increase was significant. In the case of SF, the standard and quadruple applications showed minimum values. A similar trend was seen in CF1. The status of growth of komatsuna is shown in

Fig. 6 Growth observation; left: germination on the 9th day; right: growth on the 21st day

Fig. 7 Nutrient contents for each sample

Fig. 6; CF2 had grown significantly compared to SF and CF1 by the 21st day. Figure 7 shows that the sample CF2 had significant growth in terms of fresh weight, because its N, P_2O_3 , and K_2O were very high compared with the other samples. SF and CF1 contained small amounts of N, P_2O_3 , and K_2O , which might be a reason that they did not grow as much as CF2 did.

Pot experiment for comparison with mixed multiple fertilizers (experiment 2)

The growth tests for abnormality revealed no abnormality in any of the pots (results not shown). In all the pots, normal growth of komatsuna was confirmed throughout the experiments, and 100% germination was observed for all applications, which was better than the control (Fig. 10). Leaf length, fresh weight, and fresh weight index are graphed in Fig. 8, and the chlorophyll content in the leaves was measured as SPAD (Fig. 9). The fresh weight index shows the proportional fresh weight for each sample, taking the value of control (2.8 g) as 100. Bed material A had a greater influence than bed materials B and C; however, all three produced far better growth than the control (Fig. 8). In bed material A, sample A30 had the highest fresh weight, and A50 decreased substantially to become

Fig. 8 Leaf length, fresh weight, and fresh weight

Fig. 9 Chlorophyll content of the leaves index observed on the 21st day

the smallest in group A. Group A showed the highest fresh weight, followed by group B; the least fresh weight was seen in group C. In groups B and C, no significant difference was observed among the samples. It can be said that fresh weight was influenced by the types of fertilizer. Figure 10 shows the status of growth for all pots; the control grew less than the other pots. The SPAD values of control were the highest (Fig. 9), which may be attributed to the fact that its leaves remained small; hence, the chlorophyll content showed a higher value.

Fig. 10 Growth observation of each pot after the 9th and 21st day

Field experiment with different quantities of silica (experiment 3)

Figure 11 shows that there were no significant negative effects caused by the use of rice husk ash, compared with the control sample. There were also no significant positive effects from the application of ash, compared to the control sample. The addition of $20 \text{ kg } 100 \text{ m}^{-2}$ of ash might reduce the total sellable weight of komatsuna. In Fig. 5, SF is the

sample with only rice husk ash addition; comparing the fresh weight of SF in Fig. 5 with the total weight in Fig. 11, the same trend of the samples with $1\times$, $2\times$, $3\times$, and $4\times$ ash can be seen. The values increased with increasing ash amount, but decreased in the sample with $4\times$ the ash, although the controls for each showed different trends. In the field experiment, control showed a better performance in all parameters compared to the other samples (Fig. 11); but in the pot experiments, control showed the least amount of growth,

Fig. 11 Results of growth tests in the field

Fig. 12 Resistance values of leaves and leaf stems

compared to all the samples (Fig. 5). The resistance values of the leaves were not significant for all samples; however, for the leaf stems, the sample with 10-kg ash application showed the highest value (Fig. 12). The results imply that the addition of ash to the soil did not cause weakening of the leaves or leaf stems of komatsuna.

Conclusions

To evaluate negative effects of rice husk ash application on komatsuna crops, three experiments were conducted. The following conclusions were obtained.

1. Komatsuna grew significantly when the ash was used in combination with a fertilizer.
2. Application of the ash without fertilizer did not result in significant improvement in the growth of komatsuna.
3. Rice husk ash did not have a negative effect on the komatsuna, whether applied with or without fertilizer, in pot or field experiments.

Because of a previous experiment, which showed that rice husk ash did not impair the taste of rice (Sekifuji and Tateda 2017), it was concluded that it can be used safely for komatsuna. Thus, rice husk ash can be used for any kind of vegetables, without having negative effects on the plants. With fertilizers, ash had significantly positive effects on komatsuna, and the plants became healthier.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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