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Utilization of Rice Husk Ash and Bamboo Leaf Compost to Increase Available Silica in Paddy Soil for Rice Production

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ABSTRACT

Silica is an essential nutrient for rice plants. Rice takes up Si in large quantities. The low Si content in paddy soils is caused by the intensive rice cultivation practices. Rice husk and bamboo leaves contain high silica, so that the addition of rice husk ash and bamboo leaf compost on paddy soils can increase the availability of Si in the soils. This study was arranged in a Randomized Complete Block Design (RCBD) with two factors, namely the sources of Si (rice husk ash and bamboo leaf compost) and dosages of Si-souces (0, 2.5, 5.0, 7.5, and 10 Mg ha^{-1}). The results showed that the application of rice ask hush at 10 Mg ha^{-1} increased available Si, Si uptake, soil organic matter content, total number of productive tillers and weight of 1000 grains.

Keywords: Silicon, rice ask hush, bamboo leaf

ABSTRAK

Silika adalah unsur hara esensial bagi tanaman padi. Tanaman padi menyerap Si dalam jumlah yang cukup banyak. Kandungan Si yang rendah pada tanah sawah dapat disebabkan oleh praktik penanaman padi yang intensif. Sekam padi dan daun bambu merupakan bahan yang memiliki kandungan Si yang tinggi sehingga aplikasi abu sekam padi dan daun bambu pada tanah sawah dapat meningkatkan ketersediaan Si di dalam tanah. Penelitian ini menggunakan Rancangan Acak Kelompok Lengkap (RAKL). Faktor yang diuji adalah Faktor I, yaitu sumber Si (abu sekam padi dan daun bambu) dan Faktor II, yaitu dosis sumber Si, yaitu 0; 2,5; 5,0; 7,5 dan 10 Mg ha^{-1}. Hasil penelitian menunjukkan bahwa aplikasi abu sekam padi pada dosis 10 Mg ha^{-1} dapat meningkatkan ketersediaan Si, serapan Si, kandungan bahan organik tanah, jumlah total anakan tanaman padi dan bobot 1000 butir beras.

Kata kunci: abu sekam padi, daun bambu, silika

INTRODUCTION

Rice is the staple food of Indonesian, the increse of population in Indonesia leads to the increase of rice consumption. The consumption of rice in Indonesia is relatively high, *i.e.* about 124 kg per capita year^{-1} (BPPT 2016). The increase of rice consumption in 2007 up to 2015 (BPS 2015) has lead to the continuous practice of rice cultivation. One of the obstacles to increase rice productivity intensively is the low silica (Si) content in paddy soils. The intensive rice cultivation causes the depletion of silica content in paddy soils (Darmawan *et al*. 2006). Munawar (2011) showed that silica is an essential nutrient for gramineae, especially rice. Plants supplied with sufficient Si has strong and erect cell walls to avoid pest attacks, increase tolerance to heat and drought and prevent Fe and Mn poisoning in plants.

One of the efforts to improve the amount of available silica in soil is by applying rice husk ash and bamboo leaf compost. Rice husk ash and bamboo leaves have been proven to contain silica. Previous study has shown that rice husk ash contains high amount of silica (Kiswondo 2011), whereas the bamboo leaves contain the highest amount of silica among the bamboo plant organs including stems and branches (Ding *et al*. 2008). The application of silica-containing fertilizers can increase Si uptake and maximum number of tiller of rice plants, soil pH, and available P and K in soil (Yohana *et al*. 2013).

The current study was conducted on Entisol soil in which the Entisol is a newly developed soil from infertile parent materials or contains toxic elements for plants or other organisms (Hardjowigeno 1993). Entisol has not undergone intensive weathering processes so that the silica in this soil is mainly present in the form of primary minerals or undissolved forms. Consequently, this soil contains limited amount of available silica for plants. Therefore, it is necessary to apply silica-containing fertilizers such as rice husk ash and bamboo leaf compost, which may help to increase the amount of available Si and subsequently the growth and yield of rice grown on this soil.

MATERIALS AND METHODS

Study Site

A field experiment was conducted on a paddy field in Klaten, Central Java, Indonesia from April until Desember 2016.

Research Design

The experiment was arranged in a Completely Randomized Block Design (RCBD) with two factors and three replications. The first factor was silica sources including rice husk ash (S1) and bamboo leaf compost; and the second factor was the dose of silica sources consisting of 0 Mg ha^{-1} (D0), 2.5 Mg ha^{-1} (D1), 5 Mg ha^{-1} (D2), 7.5 Mg ha^{-1} (D3), and 10 Mg ha^{-1} (D4). From these two factors, there were 10 treatment combinations, namely: S1D0 (rice husk ash 0 Mg ha^{-1}), S1D1 (rice husk ash 2.5 Mg ha^{-1}), S1D2 (rice husk ash 5 Mg ha^{-1}), S1D3 (rice husk ash 7.5 Mg ha^{-1}), S1D4 (rice husk ash 10 Mg ha^{-1}), S2D0 (bamboo leaf compost 0 Mg ha^{-1}), S2D1 (bamboo leaf compost 2.5 Mg ha^{-1}), S2D2 (bamboo leaf compost 5 Mg ha^{-1}), S2D3 (bamboo leaf compost 7.5 Mg ha^{-1}), and S2D4 (bamboo leaf compost 10 Mg ha^{-1}).

Soil Chemical Analysis

The soil samples were taken before and after the experiment, then the soil samples were analyzed in the Laboratory of Soil Chemistry and Soil Fertility, Faculty of Agriculture, Universitas Sebelas Maret and in Indonesian Centre of Biodiversity and Biotechnology. The soil characteristics including organic-C (Walkley and Black) and Cation Exchange Capacity/CEC (NH_4OAc 1 N pH 7), and available Si were determined.

Rice Planting

The seeds of IR 64 variety (in accordance with the variety of rice used by farmers around the study site) were germinated in a plot. After 21 days of seed planting, the rice seedlings were transplanted with spacing of 25cm × 25cm in plots with the size of 2m × 3m. The rice husk ash and bamboo leaf compost were applied along with the preparation of the land by the local farmers. The data of plant parameters were collected from 5 plant samples per plot. The plant height was measured started from the soil surface to the end of the longest leaf at the maximum vegetative growth of rice plants. The number of tillers, number of productive tillers, and rice yields were also determined.

Data Analysis

The data were analyzed using one-way ANOVA test followed by the Duncan's Multiple Range Test at 5% significance level ($p<0.05$) to compare the average values obtained from each treatment. In addition, a correlation analysis was also performed to understand the correlation between variables.

Table 1. Initial soil characteristics.

Soil Characteristic	Unit	Value	Criteria
pH	-	6.81	Neutral
CEC	cmol(+) kg^{-1}	20.36	Moderate
Organic matter	%	1.06	Low
Available Si	ppm	4.37	
Texture:			Loamy sand
Sand	%	70.89	
Silt	%	23.34	
Clay	%	8.31	

Note: * The criteria proposed by Eviati and Sulaeman (2009).

RESULTS AND DISCUSSION

Initial Soil Characteristics and Initial Available Silica in Soil

Table 1 shows that the soil pH before planting was neutral. Cation Exchange Capacity of the soil was low, *i.e.* 20.36 me 100 g^{-1}. According to Tan (1982), cation exchange capacity is defined as the ability of soil to adsorb and exchange cations. The level of organic matter content in the soil was very low (1.06%). Organic matter is defined as the organic carbon content in soil derived from dead plants or dead animals. According to Munawar (2011), most soils contain 2% to 10% of organic matter, if the organic matter content is less than that number indicates that the rate of addition is lower than the rate of decomposition.

The initial available Si in the soil was about 4.37 ppm. Silica is an essential nutrient, especially for the growth of rice. According to Go (1984) *in* Amrullah *et al.* (2014), among other nutrients, Si is the most predominantly taken up by rice plants. Silica uptake by rice plants is about 10 times N uptake, 20 times P uptake, 6 times K uptake, and 30 times Ca uptake. Although Si is not an essential nutrient, Si is often able to increase crop production because it improves the physical properties of plants and affects the solubility of P in the soil. The soil generally contains about 31% total silica, in which in soil solution Si is mainly present in the form of monosilicate acid (H_4SiO_4) and in plant tissue is in SiO_2 form. The monosilicate acid in the soil solution is found at a concentration of 0.1 *mM* to 0.6 *mM* or may increase to 0.8 *mM* if the pH of the soil solution is below 9.

Soil Organic Matter Content

Table 2 shows the application of bamboo leaf compost (S2) resulted in higher soil organic matter content (1.55%) than rice husk ash (S1) and control (D0). Application of bamboo leaf compost resulted in higher organic matter content in soil because bamboo leaves have lower lignin content than rice husk ash (Gusmailina and Suwardi, 1988). Saptiningsih and Haryati (2015) showed that the contents of lignin and cellulose influence whether or not a material easily to decompose.

The dosage of fertilizer resulted in significant effect on soil organic matter content ($p<0.05$). Table 3 shows that the application of 10 Mg ha^{-1} resulted in the highest soil organic matter content (1.79%). Pane *et al.* (2014) indicated that rice husk ash can increase the content of soil organic matter and the application of leaf litter (bamboo leaves) is an effort to increase soil organic matter content (Ruhnayat 2007).

Tabel 2. The effects of Si-containing fertilizers on organic matter content, CEC, and available Si and pH of soil.

Si-source	Organic matter (%)	CEC (cmol(+) kg^{-1})	Available Si (ppm)	pH
Control (D0)	1.15 a	21.89 a	7.71 a	6.49
Rice husk ash (S1)	1.36 b	24.05 c	9.49 c	6.57
Bamboo leaf compost (S2)	1.55 c	23.32 b	9.24 b	6.75

Note: The numbers followed by the same letters in the same column are not significantly different according to DMRT test at 5% significane level.

Tabel 3. The effects of fertilizer dose on organic matter content, CEC, and available Si in soil.

Dosage of fertilizer (rice husk ash and bamboo leaf compost) (Mg ha^{-1})	Organic matter (%)	CEC (cmol(+) kg^{-1})	Available Si (ppm)
0 (D0)	1.15 a	21.89 a	7.70 a
2.5 (D1)	1.22 a	22.02 a	7.91 b
5.0 (D2)	1.36 b	22.64 b	8.02 b
7.5 (D3)	1.45 b	23.63 c	10.25 c
10.0 (D4)	1.79 c	26.45 d	11.31 d

Note: The numbers followed by the same letters in the same column are not significantly different according to DMRT test at 5% significane level.

Cation Exchange Capacity

The highest cation exchange capacity (CEC) of the soil was measured in the application of rice husk ash (S1), *i.e.* 24.05 cmol(+) kg^{-1} followed by CEC in the soil applied with bamboo leaf compost (S2), *i.e.* 23.32 cmol (+) kg^{-1} (Table 2). The lowest CEC was measured in the control treatment (D0), *i.e.* 21.89 cmol(+) kg^{-1}. The soil CEC in the rice husk ash application is higher than that in the bamboo leaf compost treatment because rice husk ash has high organic matter content. Ilyas *et al.* (2000) showed that the content of organic matter in rice husk ash is about 11.18%. Atmojo (2003) indicated that adding organic matter can increase the negative charge of soil so that it will increase the cation exchange capacity.

The cation exchange capacity of the soil before treatment is about 20.36 cmol(+) kg^{-1}, which further increased after the application of rice husk ash and bamboo leaf compost with the highest CEC was found in the application of 10 Mg ha^{-1} (D4), *i.e.* 26.45 cmol(+) kg^{-1} and the lowest CEC was in the application of 0 Mg ha^{-1} (D0), *i.e.* 21.89 cmol(+) kg^{-1}. The CEC in the application of 10 Mg ha^{-1} is considered high, while that in the application of 0 Mg ha^{-1} is considered moderate (Balai Penelitian Tanah 2009). The increase of soil CEC is influenced by the amount of rice husk ash and bamboo leaf compost applied on the soil. The application of 10 Mg ha^{-1} resulted in the highest soil CEC because the decomposition processes of rice husk ash and bamboo leaf compost will increase the negative charge of the soil colloids, so that the positive charge cations can be exchanged. Therefore, increasing dosage of the fertilizers may increase the soil CEC because many cations are exchanged in the exchange complex.

Soil pH

The results of ANOVA test showed that the application of Si-containing fertilizers (rice husk ash and bamboo leaf compost) significantly affected the soil pH (p<0.05). The soil pH in the application of rice husk ash (S1) was 6.57, in bamboo leaf compost application (S2) was 6.75 and in the control treatment was 6.49. After treatments, the pH of the soil is still neutral, in which in this condition the plants are able to take up nutrients optimally. The application of bamboo leaf compost resulted in higher soil pH than that in the control treatment and rice husk ash application. This is because rice husk ash contains higher amount of monosilicate acid (H_4SiO_4) as a soluble form of silicate in soil compared to bamboo leaf compost. The silicic acid contained in the ash of rice husk will affect the solubility of the H^+ cation in the soil. According to McKeague and Cline (1963), the concentration of dissolved silica in soil will decrease with increasing soil pH.

The dose of Si-containing fertilizers significantly affected the soil pH. The pH of the soil applied with Si-containing fertilizer at a level of 10 Mg ha^{-1} (D4) was significantly different from other doses of 0 Mg ha^{-1} (D0), 2.5 Mg ha^{-1} (D1), 5 Mg ha^{-1} (D2) and 7.5 Mg ha^{-1} (D3). The addition of dosage of rice husk ash and bamboo leaf compost could increase the soil pH. The soil pH before treatment is about 6.81 (neutral) and increased after treatment, especially in 10 Mg ha^{-1} (D4), but did not show an increase in other treatments.

Available Si

The application of rice ash husk resulted in the highest amount of available Si in the soil (9.49 ppm), followed by the bamboo leaf compost application (9.24 ppm) and the control treatment (7.71 ppm) (Table 2). The result showed that the rice husk ash contains higher amount of silica than the bamboo leaves. Sa'diyah *et al.* (2016) indicates that the Si content in the rice husk ash (93.2%) is higher than that in bamboo leaves (75.90% - 82.60%).

The fertilizer dose significantly affected available Si in the soil. Application of rice husk ash and bamboo leaf compost significantly affected the availability of Si in paddy soil. The highest available Si was measured at a dose of 10 Mg ha^{-1} (11.31 ppm), while the lowest available Si was measured at the dose of 0 Mg ha^{-1} (7.71 ppm) (Table 3). Application of higher Si-containg fertilizer rate can increase the availability of Si in soil (Yulfianti 2011).

Number of Productive Tiller of Rice

The results of ANOVA test showed that the type of Si-containing fertilizer significantly affected the number of productive tiller of rice. The highest number of productive tiller was obtained in the treatment of rice husk ash (22.67) followed by that in the bamboo leaf compost (20.17) (Table 4). The lowest number of productive tiller was observed in the control treatment (16.33). The application of rice husk ash resulted in the highest number of productive tiller because of the ash of rice husk can improve the soil physical properties and soil fertility. The addition of rice husk ash can release nutrients into the soil that will increase rice production (Kusuma *et al*. 2013)

Table 4. The effect of Si-containing fertilizers on the yield of rice.

Si-source	Number of Productive Tillers	Weight of 1000 Grains (g)	Dry weight of Grains (g)	Dry Weight of Milled Grains (g)	Si Uptake (g plant^{-1}
Rice husk ash (S1)	16.33 a	17.74 a	26.06 a	18.04 a	4.26 a
Bamboo leaf compost (S2)	22.67 c	20.57 b	39.37 b	27.92 b	7.65 b

The addition of dosage of rice husk ash and bamboo leaf compost caused an increase in the number of productive tiller (Table 5). The number of productive tiller will reach maximum at 49-50 days after seedling. Anggraeni *et al.* (2013) showed that plants that grow well can produce more number of tiller.

Weight of 1000 Grains

The highest weight of 1000 grains was measured in the treatment of rice husk ash, *i.e.* 20.57 g (Table 4). This result is probably due to the rice husk ash contains essential nutrients, such as Ca, Mg, K, and Na. The nutrient content in the rice husk ash can increase cell metabolisms and further increase seed weight (Haryoko 2012).

The dose of Si-containing fertilizers of 10 Mg ha^{-1} (D4) resulted in the highest weight of 1000 grains (Table 5). The addition of dose of rice husk ash and bamboo leaf compost contributes to the amount of nutrients in soil that can be utilized by plants (Table 3). Manurung *et al*. (2016) indicated that the optimum crop production will be reached if the nutrients needed by plants are available in sufficient quantities.

Dry Weight of Grains

Application of Si-containing fertilizers has significantly affected the dry weight of rice grains at harvest (p <0.05). The dry weight of grains in the application of rice husk ash was significantly different from that in the bamboo leaf compost and control treatments (Table 4). Rice husk ash is capable to provide nutrients to plants so that the addition of rice husk ash can increase the availability of nutrients in soil (Manurung *et al.* 2016). Supplying sufficient nutrients to rice crops can improve their growth and grain yield (Supartha *et al.* 2012).

The dose of Si-containing fertilizers significantly affected the dry weight of grains at harvest (p <0.05). The application of 10 Mg ha^{-1} of fertilizer resulted in the highest dry weight of grains among other doses (Table 5). The addition of dose of fertilizers to rice crops can increase the dry weight of grains. According to Teti (2014), the higher the dose of fertilizer applied, the higher the amount of nutrients taken up by plant is, so that the plant growth is improved.

Dry Weight of Milled Grains

Application of Si-containing fertilizers resulted in a significant effect on the dry weight of milled grains (p <0.05). The dry weight of milled grains in the treatment of rice husk ash was significantly higher than that in the treatment of bamboo leaf compost and control (Table 4). This is because the treatment of rice husk ash resulted in the highest available Si in soil compared to other treatments. High available Si in soil is able to increase the amount of available P in soil. Ilyas (2000) showed that the dissolved Si in soil solution will react to form monosilicate acid and replace phosphate in the exchange complex, so that the phosphorus becomes more available.

The fertilizer dosage significantly affected the dry weight of milled grains (p<0.05). The highest

Table 5. The effect of Si-containing fertilizer dosage on the yield of rice.

Si-containing fertilizer dosage (Mg ha^{-1})	Number of Productive Tillers	Weight of 1000 Grains (g)	Dry weight of Grains (g)	Dry Weight of Milled Grains (g)	Si Uptake (g plant^{-1})
0 (D0)	16.33 a	17.37 a	26.06 a	18.04 a	4.26 a
2.5 (D1)	17.83 b	17.51 a	29.09 b	19.36 b	4.95 b
5.0 (D2)	20.83 c	19.64 b	35.63 c	25.14 c	5.75 c
7.5 (D3)	22.17 c	20.18 c	41.58 d	29.71 d	6.98 d
10.0 (D4)	24.83 d	23.21 d	47.96 e	33.81 e	8.22 e

dry weight of milled grains was obtained at the application of 10 Mg ha^{-1} of fertilizers, *i.e.* 33.81 g (Table 5). This is because the increase of fertilizer dosage can increase the number of productive tillers, thus increasing the number of grains (Sari 2017).

Si Uptake by Rice

The highest Si uptake by rice was measured in the treatment of rice husk ash (7.65 g $plant^{-1}$), then in the treatment of bamboo leaf compost (5.30 g $plant^{-1}$) and control treatment (4.26 g $plant^{-1}$) (Table 4). The distribution of Si plant is influenced by certain types of plants, for paddy plants, most Si are found in the upper parts. Higher plants take up Si in varying amounts depending on Si content in soil and the type of plants. The highest Si uptake in the treatment of rice husk ash is due to the rice husk ash contains higher Si (about 97%) than the bamboo leaves (around 82%).

The Si uptake by rice measured in the treatment of fertilizer rate at 10 Mg ha^{-1} was significantly different from that at 7.5 Mg ha^{-1}, 5 Mg ha^{-1}, 2.5 Mg ha^{-1} and 0 Mg ha^{-1}. The highest Si uptake was measured at 10 Mg ha^{-1} fertilizer application (*i.e.* 8.22 g $plant^{-1}$) and the lowest Si uptake was at 0 Mg ha^{-1} fertilizer application (*i.e.* 4.26 g $plant^{-1}$) (Table 5). The addition of doses of rice husk ash and bamboo leaf compost can increase the uptake of Si by plants due to the increase of available Si in the soil. The increase of available Si in the form of monosilicate acids (H_4SiO_4) can increase the Si uptake by plants.

CONCLUSIONS

Application of rice husk ash increased available Si in soil up to 9.49 ppm and the application of rice husk ash at 10 Mg ha^{-1} resulted in the highest available Si in the soil, *i.e.* 11.31 ppm. The amount of Si uptake by rice in the application of rice husk ash was about 7.65 g $plant^{-1}$. The application of rice husk ash at 10 Mg ha^{-1} increased significantly Si uptake by rice up to 8.22 g $plant^{-1}$. Application of rice husk ash at 10 Mg ha^{-1} increased number of productive tillers and yield of rice including weight of 1000 grains, dry weight of grains at harvest, and dry weight of milled grains.

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Further research is needed with the same dose of fertilization, the same rice varieties (*Oryza sativa* L.) but in different growing seasons and different locations, resulting in different data and can be used as a comparison.

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