



Improvement of Rice Husk Residue Silicon Availability for Replenishing Available Silicon in Paddy Soil

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Authors' contributions

This work was carried out in collaboration between all authors. Author IMN performed the pot experiment, plant analysis and statistical analysis, wrote the draft of the manuscript. Author KS managed soil analyses. Author TT analyzed the rice husk biochar samples. Author SK managed preparation of rice husk biochars and contributed to pot experiment design. Author TM made over all study design, data analysis and wrote the manuscript with author IMN.

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ABSTRACT

Increasing agricultural land area has proven beyond every reasonable doubt that it is not the solution to low yield in agricultural produce. Soil management strategies could improve the productivity and also enhance sustainability. Today's soil management strategies depend solely on inorganic chemical-based fertilizer which is inaccessible to many small-scale farmers, due to its high cost. The use of rice husk biochar (RHB) from rice husk residue (RH), produced through the process of pyrolysis, could be one of the possible cost-effective soil management strategies in rice-based farming system. In this study, a pot experiment was conducted in the Experimental Glasshouse,

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Shimane University, Japan (35°29'14.30N and 133°04'07.92E) during the summer season (June to September 2017) to investigate how changes in nutrient compositions of RH pyrolyzed at different temperatures (300°C, 400°C, 500°C, 600°C and 700°C) influence rice plant agronomic parameters, soil available silica and plant silica uptake. The experimental units were replicated three times and arranged in a completely randomized design. The RH and RHB used were slightly acidic to alkaline (6.8 – 10.7). They contained elevated nutrients in comparison to the soil. The RHB treatments were found not to have much influence on the plant agronomic parameters this time. The soil available silicon after harvest could be improved or at least maintained with RHB treatments. For instance, RHB at 400°C increased the soil available Si by 61% compared to the original content (93.8 mg SiO₂ pot⁻¹). This implies that RHB could create a potential biogenic silicon pool in a paddy field. The RHBs increased soil Si availability for rice growth through an increment of plant Si uptake and soil available Si against the control. The highest increment against the control during the cropping season was found in RHB at 500°C (455.9 mg SiO₂ pot⁻¹). Finally, charring of RH by controlling the heating temperatures is an effective way of improving RH as Si amendment.

Keywords: Biochar; pyrolysis; rice husk; silicon uptake; soil available silicon.

1. INTRODUCTION

Silicon (Si) the second most abundant element of the earth's crust and is commonly found as silica (SiO₂) or as silicates [1]. Despite silicon's long-standing history on plant growth, it has long been neglected by ecologists. This is because it was not considered an essential nutrient for plants [2]. However, in recent years, researchers have shown its beneficial effect on the growth of many plants especially rice, wheat and barley [3]. Plants vary in their ability to accumulate silicic acid. Rice stands are the greatest accumulator of silicic acid and can accumulate SiO₂ in the stem and leaves up to 10% in its dry weight with the application of a large quantity of silicon fertilizer [4]. Silicon plays a crucial role in maintaining stable rice production by increasing the resistance of rice plant to fungal diseases (e.g., rice blast, brown spot and sheath blight), insect attacks and abiotic stresses including drought and lodging [5,6].

Rice is a staple food for more than half of the world's population [7]. More than 3.5 billion people depend on rice for their 20% daily calories [8]. Apart from the Asians whose, global rice consumption rate is about 90%, Africa's rice demand especially in the Sub-Saharan region recently has been on a continuous increase [8]. To meet up with the booming demand for rice in Sub-Saharan Africa (SSA), there is a need for urgent intervention in the area of fertilization. To maintain a sustainable rice production system, a large silicon supply is needed from soil, irrigation and external inputs such as fertilizer [9,10]. In Japan, silicate materials such as calcium silicate slag are being applied widely to the paddy fields [11]. Silicate material was first recognized as a

fertilizer in 1955 and since then 1.5 to 2 t ha⁻¹ has been applied to silicate deficient paddy soils till date. An increase of about 5 to 15 % in rice yield has been reported as a result of this application [12]. Nowadays, countries like South Korea, Taiwan, Thailand, China and the USA also use silicate fertilizer in their paddy fields [13, 14]. But in other regions especially in SSA, the use of silicate fertilizer has never been a concern even with the potential risk of Si deficiency found in the highly weathered soil widely distributed in the SSA [15]. This could be attributed to the unawareness about the importance of silicate fertilizer in rice production. Besides this, the cost of silicate fertilizers makes them unaffordable for farmers. To maintain sustainable rice production in this region, there is a need to research on alternative silicon sources which are locally available and affordable.

The use of plant residue through recycling could be a possible alternative. According to Tuck et al. [16], rice husk is one of the agriculturally processed high-volume residues. For every five tonnes of harvested rice, one tonne of husk is produced, amounting to 1.2 x 10⁸ tonnes of rice husk per year across the globe. This huge amount of waste, if not well managed could lead to environmental nuisance. Hence, developing uses for this waste resource will enhance the global sustainable development. Rice husk and straw are considered as good organic sources of silicon [17,18]. They are considered as valuable silicon resources because they have the capacity to partly replenish silicon in the paddy fields. However, decomposition of these materials in the flooded field is always related to the emission of methane which is a greenhouse gas. Globally rice base system contributes an estimate of 9 –

19% of this gas [19,20]. Therefore, converting the rice residue (rice straw and husk) into biochar could be a way to address this environmental issue while maintaining the nutrient efficacy of the soil. According to Kajiura et al. (2015) [21], the use of biochar charred at a high pyrolysis temperature (>500°C) on agricultural fields causes a greater reduction in a cumulative CO₂ release. In humid tropics, high stability of biochar in soil plays an active role in improving the soil fertility of poor soils [22].

Presently, researchers working in this area have found that applying biochar to soil may be beneficial to rice production. This is because of biochar's potential to increase soil organic carbon (SOC), nutrient supply, plant growth and other soil properties [23,24]. However, little attention has been given to the effectiveness of biochar in relation to increasing silicon availability in the rice field. Based on this, the study intends to (1) give an overview of the chemical composition of rice husk residue pyrolyzed at different temperature; (2) test the agronomical effect of the pyrolyzed rice husk residue on rice plant; (3) evaluate the potentials of the pyrolyzed rice husk residue on improving soil available silicon and plant silicon uptake.

2. MATERIALS AND METHODS

2.1 Soil and Biochar

The soil used for the experiment was collected from a paddy field in Matsue, Shimane Prefecture, Japan (35°30'29.67N and 133°06'42.46E). The soil had its available silicon above the critical level (86 mg SiO₂ kg⁻¹) [25]. The bulk soil was air-dried, homogenized, crushed and passed through 2 mm sieve prior to pot experiment. The selected soil properties are presented in Table 1. Rice husk residue (RH) was used for the experiment. Prior to the pyrolysis, RH was first characterized for its chemical compositions (Table 1). The RH was air-dried and 10 kg of it was inserted into an experimental electric furnace (Meiwa Co. Ltd Kanazawa, Japan) and pyrolyzed for 10 minutes after the inside chamber reached the targeted temperatures. The unpyrolyzed RH and the pyrolyzed RH (RHB) were ground to less than 0.5 mm in diameter using a stainless steel ball grinder and a manual agate mortar and pestle respectively.

2.2 Pot Experiment

The pot experiment was set up in the Experimental Glasshouse, Shimane University,

Japan (35°29'14.30N and 133°04'07.92E) during the summer season (June to September 2017). Plastic pots (12 cm in diameter and 14 cm in height) were filled with 680 g of soil and amended with biochar at 10 g pot⁻¹ (at the rate of 15 t ha⁻¹). The pots were fertilized with a basal dose of 1.42 g pot⁻¹ of (NH₄)₂SO₄ as the source of nitrogen (N) fertilizer (at transplant and at panicle initiation) and 1.32 g pot⁻¹ of KH₂PO₄ as potassium (K) and phosphorus (P) fertilizer sources (at transplant only). Each treatment was replicated three times and arranged in a complete randomized design. All the experimental pots were irrigated with deionized water up to 5 cm above the soil level. The pots were allowed to stay overnight after which one *Koshihikari* rice seedling per pot was planted. The average temperature during the period of the experiment was 26°C with the minimum of 20°C and maximum of 38°C during the experimental period. Regular watering was done daily to maintain the waterlogged condition required for lowland rice production.

On the 56th day after transplantation, the plant height was measured and tiller numbers were counted. Three months after the transplanting date, the above-ground biomass (shoot) of the plants was harvested and air-dried in the greenhouse. Two weeks after, the grains were separated from the shoot and the shoot was oven dried at 60°C in a paper bag until a constant weight was reached. The root was also harvested, washed thoroughly with deionized water and oven dried at 60°C in paper bags until a constant weight was gained. The dried samples were ground with a stainless steel ball mill grinder and stored in zip lock bags at room temperature prior to plant-silica analysis. The soil from each pot was air-dried and thoroughly mixed. The air-dried soil was passed through a 2 mm sieve to remove any visible roots in the soil.

2.3 Chemical Analysis

The pH and EC of biochar were measured in 1:20 w/v biochar - water extracts (modification in ratio) [26] using pH and EC meters (Models D-15 and D-24 Horiba, Kyoto Japan, respectively). Total carbon and nitrogen were determined by dry combustion method using NC analyzer (Model Sumigraph NC-22 Analyzer, Tokyo Japan). Available P was extracted by NaHCO₃ and was determined by the molybdenum blue method [27]. Available silicon from the biochar was extracted using 0.5M HCl (1:50 ratio, shake for 1 hour, filter) (modification in ratio) [28]. This

Table 1. The physio-chemical properties of the soil used for the pot experiment and the rice husk residue

Properties	Soil	Rice Husk residue (RH)
Clay (%)	35.05	-
Silt (%)	19.56	-
Sand (%)	45.39	-
Olsen-P ₂ O ₅ (mgkg ⁻¹)	248.3	605.0
EC (mSm ⁻¹)	6.8	33.1
pH (H ₂ O)	4.7	6.5
Total C (gkg ⁻¹)	15.0	410.9
Total N(gkg ⁻¹)	1.0	2.7
Ash (%)	-	11.5
Available Si (mg SiO ₂ kg ⁻¹)	138.1	109
Exchangeable Ca (cmol _c kg ⁻¹)	3.49	-
Exchangeable Na(cmol _c kg ⁻¹)	0.15	-
Exchangeable K(cmol _c kg ⁻¹)	0.25	-
Exchangeable Mg(cmol _c kg ⁻¹)	1.07	-
Total Si (g SiO ₂ kg ⁻¹)	-	20.7

extraction method was used because biochar in this context was considered as a silica fertilizer. According to Ma and Takahashi, [29] and NIAES, [30], the official method for gauging Si availability in slag which is the most common silica fertilizer is by extracting its silica with 0.5 M HCl. The silicon concentrations from the supernatant were determined by the molybdenum blue method and measured with a spectrophotometer (Model UV 1800, Shimadzu Kyoto Japan) at a wavelength of 810 nm. For the total Si concentration, 0.1 g of biochar was extracted using diluted hydrogen fluoride solution [31] and the Si supernatant was determined with molybdenum yellow method at a wavelength of 400 nm [32].

For soil analysis, the pH and electrical conductivity were measured in 1:2.5 w/v and 1:5 w/v of soil – water using pH and EC meters (Model D-15 and D-24 Horiba, Kyoto Japan respectively). Soil total carbon and nitrogen were determined using dry combustion methods (Sumigraph NC-22 analyzer). Available phosphorus was determined using Bray 2 extraction method [33]. Total exchangeable bases were extracted with 1M ammonium acetate (pH 7.0) and measured by Inductively Coupled Plasma Spectroscopy (ICPE-9000 Shimadzu Kyoto, Japan). Available silicon was extracted by acetate buffer (pH 4.0) (ratio of 1:10), with intermittent shaking for 5 hours at 40°C. The Si supernatant was determined using the molybdenum blue method [34]. For the plant analysis, the total silica from the rice plant parts was extracted using a diluted hydrogen fluoride solution [31]. The Si supernatant was determined

with molybdenum yellow method at a wavelength of 400 nm [32]. The uptake of Si by the rice plant from each pot was calculated as follows:

$$\text{Uptake (g pot}^{-1}\text{)} = \text{Si concentration in plant} \times \text{the plant dry weight in each pot}$$

2.4 Statistical Analysis

Analysis of Variance (ANOVA) and Duncan's multiple range tests were done to determine the statistical significance of the RH and RHB treatments effect on rice plant growth performance, soil available Si and plant silica uptake using SPSS IBM 20.0 and 5% probability ($p < 0.05$) was considered to be statistically significant.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Biochar

As shown in Table 2, the nutrient content of the produced biochar increased with increasing pyrolysis temperature. The biochar had high pH values attributed to high ash content (Table 2) [35]. Biochar with high ash content can provide more mineral nutrients such as K, Ca, Na and Mg which increase pH values [36]. The EC of the biochar produced from RH showed an increasing trend with an increase in pyrolysis temperature. This trend is due to the loss of volatile materials at higher temperature while promoting the relative concentration of salts in the ash fraction [37]. Available phosphorus and silicon increased with increase in pyrolysis temperature. The increase obtained in available P is because,

during pyrolysis, there is disproportionate volatilization of carbon. This leads to the splitting of organic P bonds and hence results in biochar with high soluble P salts [38]. The increase obtained from silicon with increasing pyrolysis temperature (Table 2) might be as a result of a change in the form of silica relative to the time of charring.

3.2 Effect of Biochar on Rice Plant Growth, Yield and Yield Components

Table 3 shows the effect of RH and RHB on rice growth, yield and yield components. The tiller number, shoot and root biomass showed significant differences ($p < 0.05$) among the treatments while the plant height and grain yield did not. It is evident from the result that plants treated with RH gave the lowest root biomass (7.7 g pot⁻¹), shoot biomass (27.3 g pot⁻¹), root/shoot ratio (0.268), tiller numbers (~19) and grain yield (16.3 g pot⁻¹). This is because the incorporation of plant residue with high C/N ratio might cause N immobilization in the soil, resulting to low yield. Application of residue with low C: N ratio encourages mineralization but applying residue with a high C: N ratio advances N immobilization [39].

Comparison between control (no biochar amendment) and the RHB treated pots showed that control has higher root biomass (16.3 g pot⁻¹) than RHB treatments while the tiller numbers and the shoot biomass showed no significant difference. This implies that smaller root biomass in RHB treatments did not limit the shoot growth. This is because biochar has the ability to retain nutrients to improve productivity [40]. Thus, RHB treatment reduces the need for root elongation in search of the nutrients. Although no statistical difference was observed in tiller number and shoot biomass, pots amended with RHB at 700°C gave the highest tiller number (~25) and shoot biomass (33.3 g pot⁻¹) against control. The grain yield also showed no significant difference in this experiment. Neglecting the significance level of the statistical analysis, lowest grain yield was observed from the pot amended with RH. This supports the findings of Li et al. [41], which states that applying amendments with high C: N ratio reduces annual rice yield. In general, RHB application did not significantly influence plant growth in this experiment. This was because the soil had enough level of available Si for plant growth and the plant was grown under stress - free condition such as pest, disease, drought and so on.

Table 2. The chemical and elemental properties of the rice husk residue and its biochar at different pyrolysis temperatures

Rice Husk Biochar	pH (H ₂ O)	EC	Biochar yield	Ash content	Available P	Available Si (SiO ₂)	Total SiO ₂
		mS m ⁻¹	%	%	mg kg ⁻¹	g kg ⁻¹	
RHB 300°C	6.8	9.04	55	21.8	225	86	13.9
RHB400°C	8.6	13.36	44	27.5	347	117	15.5
RHB500°C	10.4	22.9	36	32.8	994	190	13.6
RHB600°C	10.6	31.1	35	33.9	1298	263	13.2
RHB700°C	10.7	40.05	35	35.6	1842	475	14.5

Values represent mean of (n=3)

Table 3. Effect of rice husk (RH) and rice husk biochar (RHB) applications on rice growth, yield and yield components

Treatments	Plant height (cm pot ⁻¹)	Tiller number	Shoot weight	Root weight	Root/shoot	Grain weight
					g pot ⁻¹	
Control	87.7a	24.0ab	30.7ab	16.3a	0.52a	19.8a
RH	90.3 a	19.0 b	27.3 b	7.7 c	0.268 c	16.3 a
RHB 300°C	89.0 a	24.0 ab	31.3 ab	10.0 bc	0.324 bc	19.7 a
RHB400°C	83.6 a	23.0 ab	31.3 ab	14.3 ab	0.450 ab	18.0 a
RHB500°C	84.8 a	25.0 ab	31.0 ab	12.0 abc	0.380 bc	18.7 a
RHB600°C	83.5 a	23.0 ab	30.3 ab	10.7 bc	0.353 bc	20.0 a
RHB700°C	85.2 a	25.0 a	33.3 a	14.0 ab	0.419 ab	20.0 a
CV (%)	5.9	13.3	8.2	28.1	25.0	13.4

Mean (n=3) followed by the same letter(s) within each column were not significantly different at 5% level in Duncan's Multiple Range test

3.3 Effect of Biochar on Soil Available Si

Fig. 1 shows the effect of RH and RHB on soil available Si after harvest. The soil available Si after harvest ranged from 87 to 151 mg pot⁻¹ with an increment from 0.2 to 56 mg pot⁻¹ compared with the initial soil Si status (calculated from Fig. 1). Soil amended with RHB at 400°C gave the highest soil available Si ($p < 0.05$) after harvest compared to RH and other RHB treatments. Although the RH and RHB had an increase in soil available Si after harvest compared with the control, the increase is not statistically significant. This result implies that RH and RHB could serve as a Si source as its effect on soil available Si remained after harvest. In this study, a trend of increase was observed in soil available Si with increasing pyrolysis temperature from RH (112 mg pot⁻¹) to RHB at 400°C (151 mg pot⁻¹). However, at higher pyrolysis temperature (RHB > 400°C), the soil available Si fluctuated (Fig. 1). This result contradicts the trend found in the available Si of the used biochar amendment, which shows continuous increase with increasing pyrolysis temperature (Table 2). This might be because Si release behaviour of the biochar is strongly controlled by Si speciation and content as well as the interaction between Si and carbon structure of the biochar [42]. According to Wang et al. [43], the amount of Si release from a pure Si-rich biochar increase with increasing pyrolysis temperature but the degree of the increase slightly decrease. This might be related to the balance between the re-adsorption of silicic acid by the pores of the biochar carbon structure and the release of Si from the Si component of the biochar. This implies that from the results obtained in this study (Fig. 1), part of the reason for the observed fluctuation in soil available Si among RHBs might be to due re-adsorption of the silicic acid by the pore of the RHB carbon structure at higher pyrolysis temperature (RHB > 400°C). Another possible reason which could cause the variation in soil Si concentration might be the uniqueness of the RHB at 500°C and 700°C. This is due to the dissolution of Si and sorption reactions between soluble Si and soil components as well as the biochar surface [44]. Biochar performance in relation to the extractable Si release rate might have led to high plant Si uptake obtained in RHB at 500°C. Also, it led to less soil Si availability after harvest. Haynes et al. [45] found that a negligible quantity of the very high total Si content (29.1%) of fly ash was in extractable form compared with steel slag and processing mud, which had the lowest total Si

contents but relatively high extractable Si. The present study indicates that RHB at 500°C has the highest Si release rate (18.2%) compared to that from other RHB amendments.

3.4 Effect of RH and RHB on Plant Si Concentration and Uptake

The Si concentration of the matured rice straw differed significantly ($p < 0.05$) among the treatments (Table 4). They ranged from 56.5 g SiO₂ kg⁻¹ to 72 g SiO₂ kg⁻¹. The highest straw Si concentration was from pot amended with RHB at 500°C (72 g SiO₂ kg⁻¹). The Si concentration of the matured rice husk also showed a significant difference at $p < 0.05$ among the treatments (Table 4). They ranged from 18.5 g SiO₂ kg⁻¹ to 20.0 g SiO₂ kg⁻¹. The highest rice husk Si concentration was reported from pot amended with RHB at 500°C (20.0 g SiO₂ kg⁻¹). The lowest Si concentration from both straw and husk were from the control pots (56.6 g SiO₂ kg⁻¹ and 18.5 g SiO₂ kg⁻¹ respectively). This also reflects the potentiality of RH and RHB as Si source. Among the treatments, the rice husk Si uptake differed significantly at $p < 0.05$ while the rice straw Si uptake did not (Table 4). The rice husk Si uptake ranged from 98 to 133.5 mg SiO₂ pot⁻¹. The highest was from pot amended with RHB at 700°C (133.5mg SiO₂ pot⁻¹) while the lowest was from pot amended with RHB at 400°C (98 mg SiO₂ pot⁻¹). In all experimental pots, the amount of Si taken up by plants was much higher than the available Si in the initial soil, RH and RHB. They ranged from 1971.7 to 2478.8 mg SiO₂ pot⁻¹ (calculated from Table 4 and Fig. 1) as opposed to the cumulative available Si supply from the initial soil and biochar which ranged from 94.8 to 98.7 mg SiO₂ pot⁻¹ (calculated from Table 2 and Fig. 1). The result implies that the effect of RH and RHB application on plant Si uptake was not only through the initial available Si supply but also through the continuous release of Si from the materials (biochar) and other mechanisms such as silicon dissolution in soil minerals. It is known that Si dynamics is also regulated by adsorption of silicic acid (soluble Si) by biochar [43] and reaction with other elements in the soil like Ca, Mg, Fe, Zn etc [46] which may accelerate or retard Si release. According to Marxen et al. [47] plant-silicon-uptake accelerates the release of the dissolved Si in soil by weathering of phytoliths in the biochar and soil minerals.

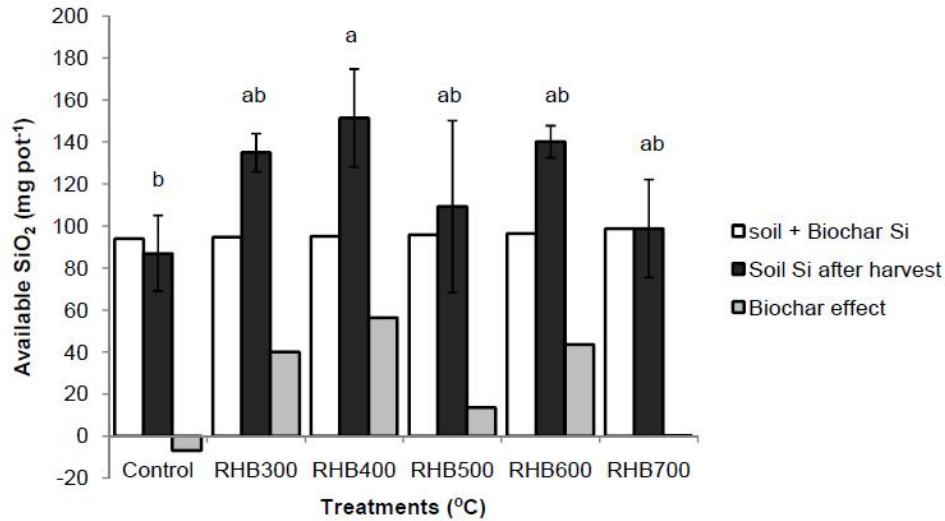


Fig. 1. The biochar effect of the rice husk biochar at different pyrolysis temperature on soil available silica

Table 4. Effect of rice husk (RH) and rice husk biochar (RHB) pyrolyzed at different temperatures on silicon concentration and uptake in rice

Treatments	Silicon Concentration (g SiO ₂ kg ⁻¹)		Silicon uptake (mg SiO ₂ pot ⁻¹)	
	Straw	Husk	Straw	Husk
Control	56.5b	18.5b	1794.5a	132.5a
RH	61.0ab	19.0b	1749.5a	111.0bc
RHB300°C	70.0a	20.0a	2216.0a	118.5ab
RHB400°C	63.5ab	19.0b	1951.0a	98.0c
RHB500°C	72.0a	20.0a	2237.5a	132.0a
RHB600°C	61.5ab	19.0b	1772.5a	131.5a
RHB700°C	59.0ab	18.5b	1852.5a	133.5a
CV (%)	10.6	3.5	13.1	11.4

Mean (n=3) followed by the same letter(s) within column were not significantly different at 5% level in Duncan's Multiple Range test

3.5 Effect of RHB on Soil Si Dynamics and its Si Release Rate

Fig. 2 shows the effect of RHB application on soil Si availability for rice growth, the increment of plant Si uptake and soil available Si at harvest. The increment in RHB treatments ranged from 30.6 to 455.9 mg SiO₂ pot⁻¹ against control. This improvement was at least partly due to the available Si release from RHB [29]. The improvement also might be due to the biochar cumulative Si release rate during the cropping season [45]. This Si release rate is a function of cumulative available Si from plant and soil over the total Si from the RHB (calculated from Fig.2 and Table 2). They ranged from 14.2% to 18.2 % with the maximum Si release rate found in RHB

at 500°C (18.2%). Another possible mechanism for the increment of Si uptake in plant and availability in soil might be due to the enhancement of available Si release from the soil through the effect of RHB on soil physiochemical properties [48,49]. In this study, the trend of Si release as a function of soil available Si after harvest and plant Si uptake differ with the available Si from RHB at a different pyrolysis temperature (Table 2). This is because Si availability in the soil is dependent on many controlling factors such as pH, soil redox potential and the type of existing metals in the soil [46]. Among all the factors listed, soil redox potential is the principal factor in flooding condition like lowland paddy field. It reported that with an increased submerged time of soil, a

corresponding reduction in soil redox potential is accompanied by an increase in the solubility of soil Si [50]. This is because sufficient reduction of soil redox potential permits Fe-reducing bacteria to be activated. Thereby causing increased dissolution of Fe oxide especially those attached to Si, hence the release of Si [51]. This supports the finding in this study since RHB application had higher soil available Fe compared to control (Fig. 3), which indicates that RHB possibly enhances the reduction of soil redox. However, the concentration of soil available Fe did not differ significantly among the RHB treatments and thus, does not explain the difference on cumulative SiO₂ of plant Si uptake and soil available Si. This indicates that Fe dissolution is not the main mechanism but Si release from the RHB and other factors could likely be the major controlling factor of the increment of Si

availability in the present study condition. Another possible mechanism could be the adsorption of silicic acid (soluble Si) by the pores of the biochar. According to Wang et al. [43], pores on the surface of the biochar may be effective sites for silicic acid adsorption. This is because the surface of the Si-rich biochars was found to be porous after Si release. The open pores on the surface of biochar are then occupied by silica or phytolith because of similarity in size [43]. Porosity is a function of temperature increase in biochar. This supports the reduced cumulative available Si obtained from the study in RHB at 600°C and 700°C. Brewer et al. [52] also found that biochar produced from grass using slow pyrolysis process had its porosity increased with increasing temperature with the highest recorded at 700°C.

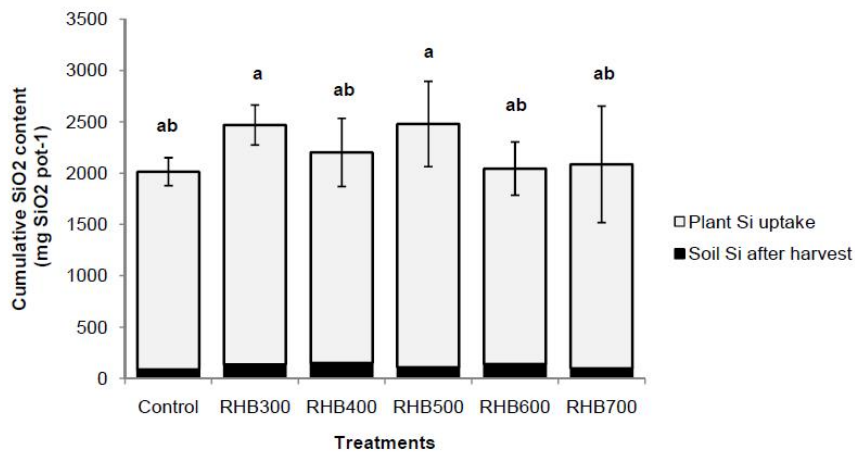


Fig. 2. The effect of RHB at different pyrolysis temperatures on cumulative Si content during rice growth

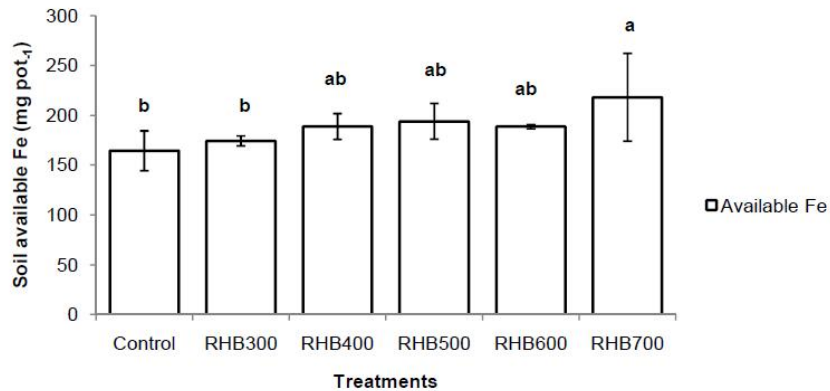


Fig. 3. The effect of RHB at different pyrolysis temperatures on soil available Fe

4. CONCLUSION

This study suggests that pyrolysis increases the Si availability in RH. The degree of the Si increment differs at different pyrolysis temperatures. Application of RHB increases plant Si uptake but had insignificant influence on plant growth and yield in this experiment. The enhancement of soil available Si was also observed through the post-harvest effect on soil available Si. The percentage Si release was much higher in RHB treatments than RH during the cropping season. Finally, this study supports the application of RHB as Si releasing agent to increase plant-available Si in the soils that will improve rice plant health.

5. RECOMMENDATION

This study recommends pyrolysis of rice husk by controlling the heating temperatures as an effective way of improving RH as Si amendment. RHB at 500°C is recommended. Though RHB at 400°C gave the best post-harvest effect on soil available Si, RHB at 500°C is the best option because of its cumulative available Si in both soil and rice plant Si uptake. It is suggested that further studies should focus on how long RHB will continuously release Si in paddy soil.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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