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Combined Application of Biochar and Silicon Fertilizer for Improved Soil Properties and Maize Growth

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ABSTRACT

Biochar can be a good soil amendment to reduce the soil pH, increase crop growth rate, and improve the efficient use of fertilizer. Other than that, silicon fertilizer also would promote photosynthetic ability on plant development that would help to produce high yield. In this work, a series of experiments was conducted to observe the effect of rice husk biochar and silicon fertilizer on the maize growth rate and soil pH. A 45-day pot experiment in the greenhouse with three replicates of 9 experimental treatment combinations of RHB at two rates (5 and 2.5 t.ha⁻¹) with silicon fertilizer at three rates (125%, 100%, 75%), sole biochar (10 t.ha t.ha⁻¹), sole silicon fertilizer (100%) and control (NPK) to observe the best rate and combination to improve growth rate and change in soil chemical in acid soil. The result showed that the co-application of sole biochar and biochar with Silicon significantly improved growth development, increased photosynthesis rate, altered soil pH, and reduced Fe concentration compared to control. The plant height increased 88.35% from T4 (5 t.ha⁻¹ RHB + 100% Si) compared to the control and the conductance was higher in T4 (0.53) followed by T8 (0.438) while T1 (0.071) recorded the lowest conductance. The shoot fresh weight was higher in T4 (127.83 g) followed by T8 (57.14 g). However, the weight increased by 343.7% at T4 followed by T8 (2.5 t.ha⁻¹ RHB + 75% Si) at 98.33%. The highest pH increment of 1.24 units (T1 = 5.53, T4 = 6.77) of soil pH was noted from T4 (5 t.ha⁻¹ RHB + 100% Si) compared to control (NPK), and the highest total Fe in soil was observed from T1 (442.30 mg.kg⁻¹). The current study results showed that T4 (50% RHB + 100% Silicon) was the best treatment over the other rates of RHB and silicon increased plant height, photosynthetic rate, and biomass.

INTRODUCTION

The maize plant (*Zea mays*) is a common type of crop that is being cultivated in many countries as the staple food for humans and the source of animal feed (Urassa 2015). Countries with a large population of people without a sufficient supply of rice declare maize as an important source of crop in the country such as Ghana, Bangladesh, and Pakistan (Shashi et al. 2018, Abukari 2014, Khan et al. 2017). Other than that, it is also widely used as a feed mill and thus can be classified as the major supply of energy for poultry (Dei & Herbert 2017). Unfortunately, the soil acidity has caused many problems with the cultivation of maize and also other crops (Shetty & Prakash 2020, Mosharrof et al. 2021).

One study records that the production of biochar has started to rise in Asia. In 2011, Malaysia recorded around 592,477 tons of rice husk and 32,000 tons of rice husk biochar produced from paddy plant waste (Manickam et al. 2015). The productivity of biochar depends on the type of organic residue used and the condition of pyrolysis applied and it is also high content of carbon (Oni et al. 2019). It has also been proven that high application of biochar as a soil amendment would bring a better impact on the crop (Shashi et al. 2018) increase soil organic carbon, nitrogen, and sulfur, and decrease soil bulk density to a favorable level (Islam et al. 2018).

On the other hand, silicon gives benefits to plant growth and plants promote the development of plants by increasing plant resistance and tolerance to various biotic and abiotic stresses (Kostic et al. 2017, Yongchao et al. 2015). Moreover, silicon is listed as the fourth most important element after nitrogen (N), phosphorus (P), and potassium (K) by the International Soil Classification system (Swe et al. 2021). It also can be used to stimulate photosynthesis, enhance tissue strength, and reduce the plant transpiration rate (Xie et al. 2014).

Increasing the rate of application of rice husk biochar would also increase the crop morphology growth and biomass of plants (Shetty & Prakash 2020, Islam et al. 2018). Furthermore, the nitrogen and total organic have been observed to increase with the presence of biochar (Abukari 2014). Moreover, various mineral stresses should be reduced in plants to support growth in acidic conditions (Pontigo et al. 2015). The required pH can be maintained through basic cation additions and H⁺ consumption (Mosharrof et al. 2021) and it was found that biochar can reduce the acidity of the soil through this mechanism (Islam et al. 2018). Rahman et al. (2022) state that the pH can be increased to reduce the acidity on a large scale (6.5 to 8.8) which takes around a 26% increase. The micronutrient concentration in the plant was not affected by the application of biochar but affected the macronutrient (NPK) (Ullah et al. 2018). The addition of fertilizer such as silicon would affect the mass and the height of the crop (Younas et al. 2021). The efficient nutrient management will respond to the crop cycle and its productivity (Gandahi et al. 2015).

Limited sources of good soil have reduced the possibility of cultivating maize on a large scale. Biochar is now being considered as an application to improve the soil properties together with the growth rate. Singh et al. (2018) reported that biochar could contribute to the enhancement of soil nutrients and improve crop productivity. It also plays a vital role in improving the soil structure, nutrient uptake, and root elongation. Biochar single application or with compost can enhance soil quality and improve maize yield (Mensah & Frimpong 2018). On the other hand, silicon would stimulate plant growth under acid-growth considerations (Pitann et al. 2021). The application of biochar and silicon fertilizer helps to reduce soil acidity and improve maize growth and nutrient uptake. Limited research has reported on the effect of biochar and silicon on maize production in acidic soil especially in Malaysia. Hence the main objective of the study was to evaluate the effect of Biochar and silicon on the growth, and nutrient uptake of maize plants in acidic soil.

MATERIALS AND METHODS

Experimental Site

A pot experiment was conducted for 45 days (May to June 2022) in the greenhouse UPM at 2°98'36.6" N (north) latitude and 101°73'81.9" E (east) longitudes with an elevation of 56.8 m from sea level at the west coast of Peninsular Malaysia.

Experimental Design and Treatments

The pot experiment was laid out in a completely randomized design (CRD) with three replications having a pot size of 38 cm (height) and 32 cm (diameter). The Bungor (Typic Paleudult; Order: Ultisol) soil series was collected in depth

from 0-20 cm from Taman Pertanian, UPM, Puchong, Selangor (2°58'59.7" N latitude; 101°38'47.5" E longitude). It was air-dried and sieved through a 2 mm before chemical analysis. For the greenhouse experiment, the soil was sieved to 4 mm and applied in all of the pots at a rate of 20 kg of soil pot⁻¹. The biochar treatment was applied to the soil based on the dose required with a recommended rate of 10 t.ha⁻¹ and mixed well and left for about one week before adding silicon 150 kg.ha⁻¹ recommended as the optimal amount for maize by (Xie et al. 2014) (Table 1). Additional NPK based on MARDI recommendation fertilizer: 120 kg N/Ha in the form of urea, 80 kg Phosphorus in the form of triple superphosphate, and 100 kg Potassium in the form of Muriate of potash was applied. In this experiment, the F_1 Hybrid Sweet Corn variety was collected from a local market as a test crop and it is also a common variety used by Malaysian farmers. The maize seedling was put and watered regularly to maintain a soil moisture content of 60-70% of water holding capacity during the growth period, and just they were about to be destructively harvested 45 days after planting.

Physicochemical Properties of Initial Soil

The soil textural class was determined using the pipette method (Teh & Talib 2006). Soil pH was determined in water at a soil-to-solution ratio of 1:10 (TAN 1995). Leco CHNS Analyzer (LECO Truspec Micro Elemental Analyzer CHNS, New York) was used to determine the total Carbon and Nitrogen. Available phosphorus in soil was determined by the method described by (Olsen et al. 1954). Exchangeable cation was extracted using ammonium acetate (Schollengberger & Simon 1945) and the concentration of K, Ca and Mg in the solutions was determined by using inductively coupled plasma-atomic emission spectrometry (ICP). Determination of total Mn and Iron of soil was carried out using the aqua-regia extraction method (Zarcinas et al. 1987, McGrath & Cunliffe 1985). Table 2 shows the initial soil properties.

No	Treatment
1.	Control (NPK)
2.	100% RHB
3.	100% Si
4.	50% RHB + 100% Si
5.	50% RHB + 75% Si
6.	50% RHB + 125% Si
7.	25% RHB + 100% Si
8.	25% RHB + 75% Si
9.	25% RHB + 125% Si



Parameter	Value
Texture	Sand- 69.27%, Silt- 2.28%, Clay-28.44% (Sandy clay loam)
Moisture %	6.94 ± 1.14
pH	4.22±0.063
Available P (mg kg ⁻¹)	0.5±0.222
Total C %	1.03±0.016
Total N %	0.03±0.02
Total S %	0.01±0.013
Exc K (cmol.kg ⁻¹)	0.38±0.007
Exc Ca (cmol.kg ⁻¹)	3.2±0.068
Exc Mg (cmol.kg ⁻¹)	0.46±0.024
Exc Al (cmol.kg ⁻¹)	0.104±0.02
Total Mn (mg.kg ⁻¹)	0.5±0.023
Total Fe (mg.kg ⁻¹)	422.6±8.3

Table 2: Physicochemical properties of initial soil.

Physicochemical Properties of Rice Husk Biochar (RHB)

The pH of biochar was determined in water at a ratio of 1:10 of biochar to solution (TAN 1995). Leco CHNS Analyzer (LECO Truspec Micro Elemental Analyzer CHNS, New York) was used to determine the total Carbon and Nitrogen. Total phosphorus in biochar was determined by the dry ash method followed by ICP-OES (Cottenie 1980). Exchangeable cation was extracted using ammonium acetate (Schollengberger & Simon 1945) and the concentration of K, Ca & Mg in the solutions was determined by using inductively coupled plasma-atomic emission spectrometry (ICP). Table 3 shows the Rice Husk Biochar properties.

Plant Material Analysis

Number of leaves and plant height analysis: The number of open leaves was counted at (15 DAS, 30 DAS and 45DAS) and the plant height was determined using a measuring tape

Table 3: Physicochemical properties of Rice Husk Biochar (RHB).

Properties	RHB
Moisture	2.93
pH	7.77
Total c %	24.86
Total n %	1.13
Total s %	0.15
Exc K (cmol.kg ⁻¹)	17.45
Exc Ca (cmol.kg ⁻¹)	19.46
Exc Mg (cmol.kg ⁻¹)	13.96
Total P (mg.kg ⁻¹)	3098.4

at harvest (15 DAS, 30 DAS and 45DAS) from the base to the tip of the longest leaf (Lai 2019).

Leave chlorophyll and conductance: The leaf chlorophyll content was measured using a portable chlorophyll meter (SPAD-502 Konica Minolta, Inc., Tokyo, Japan). The Chlorophyll reading was taken from the middle part of the largest leave of each plant using a meter (SPAD-502, Konica Minolta, Osaka, Japan) (Alarefee et al. 2021) and the conductance reading was recorded at the same time.

Shoot Fresh weight and biomass (g): After harvest, the shoot (stem and leaves) were washed and dammed with tissue paper before each shoot was weighed and then it was placed into envelopes and dried in an oven at 60 °C for 72 h and weighed again for the biomass (Mosharrof et al. 2021)

Shoot nutrient Uptake (ppm): The dried shoot was blended and again dried in a crucible in an oven and then put in a glass desiccator before 0.25 g was taken to extract the macro element of the shoot by using the drying ashing method (Yuan et al. 2016). The concentration of P, K, Ca and Mg were determined using inductively coupled plasma-atomic emission spectrometry (ICP) The result was then converted into (ppm)

Nutrient concentration (ppm) = Mean (mg/L)

 $\times \left(\frac{\text{mark up volume(50ml)}}{\text{weight(0.25g)}}\right)$

The maize nutrient uptake was later calculated by multiplying the respective dry weight oven-dry weight of the plant part with the nutrient content (Alarefee et al. 2021) as the formula below

Nutrient Uptake = Nutrient Content (ppm) × Biomass (g)

Post-Harvest Soil Analysis

Acidity (pH): Soil pH was determined in water at a soil-tosolution ratio of 1:10 (TAN 1995). 1 g oven-dried soil sample was placed into a vial and 10 Ml Distilled water was added to it. It was shaken thoroughly for 5 minutes and allowed to stand for 2 hours and the pH of the suspension was then measured using a pH meter for soil samples respectively.

Determination of total carbon and nitrogen: Leco CHNS Analyzer (LECO Truspec Micro Elemental Analyzer CHNS, New York) was used to determine the C and N of soil that were air-dried and sieved through a 2 mm mesh

Exchangeable cation (magnesium, potassium and calcium): Exchangeable cation was extracted using 100 mL of 1N ammonium acetate (Schollengberger & Simon 1945). Ashless cotton was put down at the hole of the leaching tube to prevent the soil from passing through the tube and covered with filter paper of small size before putting the 10 g soil

sample. Another filter paper was put on the soil sample to prevent the soil from being inverted when the solution was poured. The leaching valve was adjusted to make sure that the ammonium acetate flowed through the soil sample slowly with the speed of one drop to another drop around 6 to 8 seconds. The concentration of K, Ca and Mg in the solutions was determined by the inductively coupled plasma-atomic emission spectrometry (ICP).

Total soil micronutrient (iron and manganese): Determination of macronutrients and micronutrients of soil was carried out using the aqua-regia extraction method with the mix of concentrated hydrochloric acid HCl and nitric acid HNO₃in the ratio of 3:1 (Zarcinas et al. 1987, McGrath & Cunliffe 1985). 1 g soil sample was put into the digestor tube. 1 mL 1.2% nitric acid and 3 mL concentrated hydrochloric acid were added to the soil and handshake gently. The digestor block was prepared to heat at 110 degrees before the tube was put in and the mixture heated until a white precipitate formed. The supernatant was then left to cool down. After that around 20 mL of distilled water was added and heated in a digestor block at 80 degrees Celsius for 30 minutes and all of the mixture was clear and transferred to a 50 mL beaker to mark up it. The concentration of iron and manganese in the solutions was determined by inductively coupled plasma-atomic emission spectrometry (ICP).

Soil Available P

0.5M sodium bicarbonate, NaHCO₃, was prepared (21g of sodium bicarbonate was dissolved in about 450 mL distilled water and was adjusted to 8.5 pH with 1N NaOH and marked up to volume). 1 g of soil sample was weighed into the plastic vial, and 20 mL of the 0.5M sodium bicarbonate was added. It was shaken for 30 minutes, filtered by filter paper No. 2 and sent to ICP for phosphorus analysis (Olsen et al.1954).

Table 4: Maize growth development.

Soil Exchangeable Aluminum

1N KCL solution was prepared. Then 5 g of soil in plastic vial, added with 50 mL KCL solution, the cap was closed and the solution was shaken for 30 minutes. After that, the supernatant was slowly passed through the Whatman no 42 filter paper and sent to ICP for aluminum analysis.

Percent Relative Data

The relative data of the value were expressed as percentages, relative to control for each element by the following formula proposed by (Ashraf & Waheed 1990):

Relative data
$$(\%) =$$

$$\left(\frac{\text{Treatment value} - \text{ control value}}{\text{control value}}\right) \times 100$$

where the treatment value was the biochar and silicon amended treatment, and the control value was treatment with only NPK.

Statistical Analysis

Analysis of Variance (ANOVA) procedure was used to analyze all of the data, and Tukey's Honestly Significant Difference (HSD) test was used to separate the means. Repeated measures analyses were performed on all parameters using John's Macintosh Project (JMP) Analysis Software, ($p \le 0.05$).

Result and Discussion

The effect of biochar and silicon on the plant height and leaf number of maize on three different days after sowing (15 DAS, 30 DAS & 45 DAS): Table 4 demonstrated

Treatment	Leaf number			Plant Height		
	15 DAYS	30 DAYS	45 DAYS	15DAY	30 DAYS	45 DAYS
T1	4±0.333ab	5±0.33a	6±0.33b	7.30±0.21e	8.03±0.88c	27.17±0.14d
Т2	3±0.33b	5±0.33a	6±0.33b	7.57±0.09de	8.90±0.86bc	28.57±0.73d
Т3	4±0.33ab	6±0.58a	8±1ab	10.80±0.35bc	12.70±2.10abc	31.57±1.23d
T4	4ab	6±0.33a	10±0.68a	9.75±0.72cde	15.70±2.05abc	54.30±0.52a
Т5	5±0.33a	7±0.67a	9±0.33a	13.70±1.04a	20.83±3.47a	37.27±1.3c
Т6	4ab	6±0.33a	9±0.33ab	11.50±0.06abc	15.53±1.87abc	46.10±1.46b
Τ7	4±0.33ab	6±0.58a	9±0.58a	10.03±0.58cd	16.53±1.97abc	38.37±1.13c
Т8	5a	6±0.67a	10±0.33a	12.80±0.44ab	17.47±0.61ab	51.43±0.6a
Т9	5±0.33a	6±0.33a	9a	11.70±0.4abc	18.13±0.90a	42.13±1.24cd

Means within the same column followed by the different letters are significantly different at $p \le 0.05$; (Tukey's HSD test). The column represents the mean values \pm standard error. T1 = Recommended rate of NPK (t.ha⁻¹), T2=10 t.ha⁻¹ RHB, T3= 150 kg.ha⁻¹ Si, T4= 50 %RHB + 100 % Si, T5= 50 % RHB + 75 % Si, T6= 50 %RHB + 125 % Si, T7= 25 % RHB + 100 % Si, T8= 25 % RHB + 75 % Si, T9= 25 % RHB + 125 % Si.

Treatment	Shoot fresh weight (g)	Biomass (g)	Photosynthesis rate	Conductance
T1	28.81±0.49c	2.37±0.26e	23.65±1.91c	0.071±0.01e
T2	39.03±0.09bc	3.94±0.1de	25.03±2.03c	0.148±0.002d
Т3	40.30±0.4bc	4.12±0.46	29.63±1.79bc	0.264±0.01c
T4	127.83±5.62a	12.04±0.55a	45.5±3.68a	0.53±0.02a
Т5	56.12±2.37b	5.92±0.51cd	40.87±2.6a	0.438±0.02b
Т6	48.16±3.85bc	4.36±0.16de	38.47±1.04ab	0.416±0.02b
Τ7	46.34±2.85bc	7.77±0.47bc	38.1±2.52ab	0.4089±0.002b
Т8	57.14±4.35b	8.72±0.57b	41.2±2.57a	0.464±0.01ab
Т9	47.31±6.41bc	7.45±0.71bc	36.53±0.59ab	0.423±0.01b

Table 5: Plant morphological and physiological parameters.

Means within the same column followed by the different letters are significantly different at $p \le 0.05$; (Tukey's HSD test). The column represents the mean values \pm standard error. T1 = Recommended rate of NPK (t.ha⁻¹), T2=10 t.ha⁻¹ RHB, T3= 150kg.ha⁻¹ Si, T4= 50 %RHB + 100 % Si, T5= 50 %RHB + 75 % Si, T6= 50 %RHB + 125 % Si, T7= 25 %RHB + 100 % Si, T8= 25 %RHB + 75 % Si, T9= 25 %RHB + 125 % Si.

the effect of different treatments on leaves of maize plant recorded in three different phases 15 DAS, 30 DAS and 45 DAS. The leaf number of maize in 15 DAS is significantly affected by the different doses of biochar and silicon. The highest number was shown by T5, T8 and T9 (5) followed by other treatments with four leaves and the lowest showed by T2 (3). Biochar and silicon did not significantly affect the leaf number at 30 DAS of the maize plant. While at 45 DAS of the maize plant, the number of leaves was significantly affected by the treatment application. The highest leaves were shown by T4 & T8 (10) and followed by other treatments ranging from 8 to 9 and the low was shown by T1 & T2 (6).

Table 4 shows the Plant height (cm) of the maize measured at 15 DAS, 30 DAS and 45 DAS. The plant height varied significantly among different amounts of biochar and silicon. In general, the heights were measured higher at 45 DAS compared with 15 and 30 DAS. At 15 DAS T1 showed the shortest high (7.30 cm) compared to other treatments. All the remaining treatments result in higher heights ranging from 7.57 cm to 13.70 cm. At the 30 DAS tallest height was recorded in T5 (20.83 cm) identically followed by T8 (18.13 cm). T1 resulted in the shortest height (8.03 cm) closely followed by T2 (8.90 cm). The remaining treatments resulted in intermediate height ranging from 12.70 cm to 17.47 cm. For the height measure at 45 DAS, the tallest was recorded by T4 (54.30) followed by t8 (51.43 cm). While t1 (27.17 cm) showed the shortest height. T4 showed a 99.85% increase compared to the control. This finding was the same as to result obtained by Shashi et al. (2018) with the highest RHB dose (20 t.ha⁻¹) producing the tallest height (44.83 cm) and Alarefee et al. (2021) also recorded an increase in height with the application of biochar compare to control and NPK application. The height increases together with the increase of biochar may be caused by the high

content of phosphorus in biochar that helps the development of the plant cell (Mosharrof et al. 2021) and high silicon dose increases the development and growth of plants by increasing the plant resistance to various abiotic and biotic stresses (Kostic et al. 2017).

The effect of biochar and silicon on the shoot fresh weight, shoot dry weight, photosynthesis rate and conductance of maize: In this study, it was noticed that shoot fresh weight was significantly affected by biochar and silicon application (p<0.05) (Table 5). The shoot fresh weight was higher in T_4 (127.83 g) followed by T_8 (57.14 g) while T_1 (28.81 g) recorded the lowest weight. However, the weight increased by 343.7% at T4 followed by T8 at 98.33%. The treatment also significantly affected the plant biomass of maize (p<0.05) (Table 5). The maize biomass (g) for treatment was ranging from 2.37 to 12.04 g. T1 has the lowest weight (2.37 g) followed by T2 (3.94 g). The highest weight was recorded by T4 (12.04 g) followed by T7 (7.77 g). T4 showed a 40.8% increase compared to the control. This finding was quite same with one study concluding that the application of 80 kg ha⁻¹ Si with chitosan shows the highest weight of dry shoot compared to the control and single silicon application (Younas et al. 2021). On the other hand, Amin et al. 2018 agree that silicon application on maize plants would increase their growth rate by improving the photosynthetic rate and lowering transpiration. Thus, biochar applied together with silicon seemed to increase nutrient availability, help the development of the tissue and increase plant Biomass (Xie et al. 2014, Shetty & Prakash 2020).

The maize photosynthesis rate was significantly affected by the application of biochar and silicon fertilizer (p<0.05) (Table 5) The highest photosynthesis rate was recorded by T8 (41.2) and the lowest was T1 (23.65). The highest T8

Treatment	С (%)	N (%)	CN	S (%)
T1	0.609±0.01g	0.029±0.001b	20.75±0.38d	0.016±0.002a
Τ2	0.635±0.05g	0.013±0.002d	49.29±1.08c	0.016±0.002a
Т3	3.969±0.06a	0.046±0.005a	86.92±4.54b	0.015±0.003a
T4	2.409±0.4b	0.03±0.00008b	79.51±1.27b	0.019±0.002a
Т5	1.187±0.04f	0.008±0.001d	143.22±6.29a	0.013±0.001a
Т6	1.539±0.015e	0.022±0.001c	71.17±1.6b	0.019±0.001a
Τ7	1.830±0.01d	0.025±0.002bc	72.17±3.53b	0.019±0.002a
Т8	2.184±0.05c	0.028±0.0003b	78.43±2.09b	0.014±0.001a
Т9	2.039±0.002c	0.046±0.005a	44.85±2.97c	0.013±0.001a

Table 6: CNS concentration and CN ratio.

Means within the same column followed by the different letters are significantly different at $p \le 0.05$; (Tukey's HSD test). The column represents the mean values \pm standard error. T1 = Recommended rate of NPK (t.ha⁻¹), T2=10 t.ha⁻¹ RHB, T3= 150 kg.ha⁻¹ Si, T4= 50% RHB + 100% Si, T5= 50%RHB + 75% Si, T6= 50%RHB + 125% Si, T7= 25%RHB + 100% Si, T8= 25%RHB + 75% Si, T9= 25%RHB + 125% Si.

relatively increased double compared to the control. All of the treatment shows more than 30 photosynthesis rates except for the control (T1), single silicon (T2) and single biochar (T3) applications. This shows that the biochar and silicon together can increase the rate of photosynthesis rate in the leaf. While Mosharrof et al. (2022) showed a rise in photosynthesis rate with the combining of biochar with lime. On the other hand, Xie et al. (2014) showed that Silicon can be used to stimulate the photosynthesis rate by rise up the chlorophyll content and biochar would help with carbon sequestration and increase carbon storage that would support the photosynthesis process in plants (Mensah & Frimpong 2018).

In this study, it was noticed that conductance (gl) from maize leaf was significantly affected by biochar and silicon application (p<0.05) (Table 5). The conductance was higher in $T_4(0.53)$ followed by $T_8(0.438)$ while $T_1(0.071)$ recorded the lowest conductance. However, the conductance increased by 64.6% at T4 followed by T8 51.7%. This finding was also against Gao et al. (2006) who concluded that the Si application significantly lowered the conductance and transpiration rate from the leaf. The control in this experiment was the lowest conductance caused by the stress of the plant. While the silicon has potential to reduce stress and cause the stomata to open larger at the same time increase plant activity (Yongchao et al. 2015) at the same time biochar helps to maintain the soil water content and reduce the stress causing the increase of conductance (Rogovska et al. 2014).

The effect of biochar and silicon on soil carbon, nitrogen, sulfur content and CN ratio: It was noticed that C and N content from post-harvest soil were significantly affected by biochar and silicon application (p<0.05) (Table 6). The highest content was recorded by T3 C (3.969%) and N (0.046%). Followed by T4 for C (2.409%) and T9 for N (0.046%) while the lowest C (0.609%) was recorded by T1 and the lowest N was recorded by T2 (0.013%). Both control and sole Silicon showed low C & N content. A few studies have proved that biochar application would raise the soil's organic carbon and nitrogen (Islam et al. 2018, Abukari 2014).

The treatment significantly affected the CN ratio of postharvest soil. The CN ratio range for treatment was 20.75 to 143.22. T1 has the lowest ratio (20.75). The highest ratio was recorded by T5 (143.22) followed by T3 (86.93). T5 showed 59.02% and T3 showed a 31.89% increase compared to the control. The S% content was not significant.

The effect of biochar and silicon on pH available P, macro-nutrient exchangeable (K, Ca & Mg) and total micro-nutrients (Mn & Fe) & exchangeable Al: The soil pH was significantly affected by the application of biochar and silicon fertilizer. The highest pH was recorded by T_4 (6.77) followed by T_5 (6.73) while T_1 (5.53) recorded the lowest pH. Thus, the pH increased by 21.69% at T4 and followed by T8 by 21.7%. Islam et al. (2018) also found that biochar is potentially strong enough to change the soil from acidic to slightly acidic. This low pH may be caused by the reduced levels of Fe in the soil by the release of carbon and cation activity by the biochar (Galindo et al. 2021, Sheng et al. 2016).

It was noticed that available P (mg.kg⁻¹) from postharvest soil was significantly affected by biochar and silicon application (p<0.05) (Table 7). The available P (mg. kg⁻¹) was higher in T₃(13.75) followed by T₅(8.8) while T₁ (0.15) recorded the lowest available P (mg.kg⁻¹). However, the available P increased by 90.67% at T3 followed by T5 at 57.67%. One pot experiment proved that the highest P available in 45 days (16.43 mg.kg⁻¹) with 10 t.ha⁻¹ RHB



Table 7: Post-harvest soil properties.

Treatment	рН	P (mg.kg ⁻¹)	K (cmol. kg ⁻¹)	Ca (cmol. kg ⁻¹)	Mg (cmol. kg ⁻¹)	Mn (mg. kg ⁻¹)	Fe (mg.kg ⁻¹)	Al (cmol.kg ⁻¹)
T1	5.53±0.07c	0.15±0.03c	0.84±0.02f	$2.35 \pm 0.02 f$	3.24±0.12d	0.481±0.02a	442.30±1.23a	0.028±0.002b
T2	6.4±0.00ab	0.157±0.03c	$0.69 \pm 0.03 f$	2.89±0.01d	4.36±0.2c	0.491±0.05a	334.47±2.02f	0.056±0.002a
Т3	6.63±0.03a	13.75±0.26a	6.24±0.02a	3.24±0.06b	7.83±0.19a	0.59±0.06a	305.13±1.77g	0.074±0.006a
T4	6.77±0.09a	4.25±1.07bc	3.60±0.02b	3.42±0.01a	7.36±0.14a	0.606±0.01a	313.97±0.88g	0.061±0.002a
T5	6.73±0.07a	8.8±0.46b	1.25±0.01e	2.75±0.03e	5.40±0.13b	0.549±0.04a	408.73±0.26b	0.016±0.00bcd
T6	6.43±0.17ab	7.15±2.57b	3.70±0.03b	2.94±0.02d	7.58±0.20a	0.570±0.04a	338.27±4.28f	0.007±0.003cd
T7	6.1±0.15b	7.35±1.41b	1.92±0.01d	2.65±0.01e	5.72±0.09b	0.596±0.05a	364.97±2.14e	0.004±0.001d
Т8	6.13±0.07b	5.9±1.96bc	1.41±0.06e	3.14±0.01bc	5.66±0.14b	0.529±0.05a	396.73±1.95c	0.016±0.014bcd
Т9	6.33±0.07ab	7.85±0.55b	3.21±0.07c	3.09±0.01c	7.56±0.11a	0.487±0.04a	381.53±0.39d	0.027±0.014bc

Means within the same column followed by the different letters are significantly different at $p \le 0.05$; (Tukey's HSD test). The column represents the mean values \pm standard error. T1 = Recommended rate of NPK (t.ha⁻¹), T2=10 t.ha⁻¹ RHB, T3= 150 kg.ha⁻¹ Si, T4= 50 %RHB + 100 % Si, T5= 50 %RHB + 75 % Si, T6= 50 %RHB + 125 % Si, T7= 25 %RHB + 100 % Si, T8= 25 %RHB + 75 % Si, T9= 25 %RHB + 125 % Si. Table 8: Plant nutrient uptake.

	P (g.Plant ⁻¹)	K (g.Plant ⁻¹)	Ca (g.Plant ⁻¹)	Mg (g.Plant ⁻¹)	Si (g.Plant ⁻¹)
T1	0.798±0.09d	9.57±1.153e	0.894±0.12d	0.407±0.06f	0.145±0.02a
T2	0.808±0.01d	12.266±0.39e	1.474 ±0.05 cd	0.604±0.02ef	0.163±0.01a
Т3	1.936±0.34cd	19.153±2.19de	1.378±0.14d	0.740±0.08def	0.227±0.02a
T4	7.164±0.10a	49.169±1.18a	3.676±0.07a	1.723±0.04ab	0.603±0.02a
Т5	3.226±0.23bc	31.519±2.54bc	2.246±0.23bc	1.339±0.11bc	0.332±0.06a
Т6	2.241±0.15c	21.114±1.90cde	1.654±0.13cd	0.916±0.06cde	0.873±0.6a
Т7	4.540±0.50b	40.72±4.99ab	2.825±0.24b	1.697±0.16ab	0.351±0.02a
Т8	6.003±0.41a	39.20±2.75ab	2.905±0.21ab	2.007±0.14a	0.357±0.03a
Т9	2.256±0.13c	24.61±1.36cd	2.616±0.18b	1.191±0.07cd	0.335±0.03a

Means within the same column followed by the different letters are significantly different at $p \le 0.05$; (Tukey's HSD test). The column represents the mean values \pm standard error. T1 = Recommended rate of NPK (t.ha⁻¹), T2=10 t.ha⁻¹ RHB, T3= 150 kg.ha⁻¹ Si, T4= 50 %RHB + 100 % Si, T5= 50 %RHB + 75 % Si, T6= 50 %RHB + 125 % Si, T7= 25 %RHB + 100 % Si, T8= 25 %RHB + 75 % Si, T9= 25 %RHB + 125 % Si.

application (Mosharrof et al. 2021). The Reduction of Fe and Al activity and, the increase of cation and pH cause the P availability to rise (Mensah & Frimpong 2018).

The application of biochar and silicon fertilizer significantly affected the exchangeable cation of the soil (ca,k, mg). The highest exchangeable Ca was recorded by T_4 (3.42 cmol.kg⁻¹) and the lowest was recorded by T_1 (3.42 cmol.kg⁻¹). The highest exchangeable K & Mg was recorded by sole biochar T_3 (6.24 cmol.kg⁻¹) & (7.83 cmol. kg⁻¹) and the lowest was T_1 (0.84 cmol.kg⁻¹) & (3.24 cmol. kg⁻¹). The increase of the three cations (Ca²⁺, K⁺, and Mg²⁺) causes the decreasing concentration of exchangeable H⁺ and Fe with the increase in pH (Zhang et al. 2018).

The highest total Fe in soil was observed from T (442.30 mg/kg) and the lowest was recorded by sole biochar¹ T (305.15 mg.kg⁻¹). Mosharrof et al. (2021) reported that the a³_plication of rice husk biochar decreases the extractable

of Fe in soil compared to the control and soil-applied NPK and (Xu et al. 2022) also found a similar thing but the application of rice straw biochar as a potential to reduce soil Fe bioavailability.

The effect of biochar and silicon on plant nutrient uptake by maize: There was a significant difference in plant nutrient uptake of maize, represented in Table 8.

With T1, T2 and T3 the concentration and total uptake of P, K, Ca, and Mg taken up by the maize plant were statistically lower than those of biochar and siliconamended treatments (T4 to T9). The highest uptake of P ($6.003 \text{ g.plant}^{-1}$) and Mg ($2.007 \text{ g.plant}^{-1}$) was obtained from T8 (25%RHB + 75% Si); the highest K ($49.169 \text{ g.plant}^{-1}$) was noted from T4 (50%RHB + 100% Si); but the treatment does not give a significant different on the Silicon uptake of the plant. Mosharrof et al. (2021) found that the application of biochar and dolomitic limestone was higher compared to the control and recommended NPK application. The effect of silicon and rice husk on the phosphorus available reduces the effect of acidity that increases the base's cation and raises the nutrient uptake (Frank et al. 2021).

CONCLUSION

The current study results showed that T_4 (50% RHB + 100% Silicon) was the best treatment over the other rates of RHB and Silicon increased plant height, photosynthetic rate and Biomass.

We found that biochar with silicon increased soil pH, exchangeable K, Ca and Mg, and decreased total Fe. Thus T_4 (50% RHB + 100% Silicon) was continued to implement together with various rates of TSP (50%,75% & 100%) together with T_7 (25% RHB + 100% Silicon).

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