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Effect of Biochar and Silicon with Different Phosphorus Levels on Maize Yield and Soil Chemical Properties

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ABSTRACT

Silicon fertilizer combined with biochar improved the utilization of phosphorus fertilization applications. The experiment was carried out with eight treatment combinations with varying proportions of rice husk biochar, silicon, and phosphorus in a completely randomized design with 75 days of growth in the greenhouse. To identify the optimum rate of phosphorus combined with rice husk biochar and Si for maximizing maize yield and soil chemical properties. This experiment showed that the application of biochar combined with silicon has the potential to reduce the amount of phosphorus fertilizer requirement. The application of 5 t ha-1 RHB + 100% Si + 25% TSP showed the highest pH compared to other treatments. While application of 2.5 t ha-1 RHB + 100% Si + 100% TSP showed the highest exchangeable K, Ca and Mg. Moreover, the application of 5 t ha-1 RHB + 100% Si + 100% TSP recorded the highest dry biomass compared to other treatments. Lastly, the application of 5 t ha-1 RHB + 100% Si + 50% TSP Showed the highest cob length(cm), cob weight(g), no of grain per cob, and grain yield ($t.ha^{-1}$) compared to other treatments. The combined application of biochar and silicon, along with 50% phosphorus, is recommended for improving maize yield and soil health in greenhouse conditions.

INTRODUCTION

Maize is one kind of important crop that is being used in daily life and has started to increase in demand all around the world (He et al. 2023). The cultivation of this crop has to face many problems in today's world that cause its production to be reduced and fail to fulfill the demand (Ali et al. 2023). The available soil mostly being affected by a few factors such as alkalinity, acidity, imbalance of nutrient toxicity, and water stress (Msimbira & Smith 2020).

This suffering by crops in soil because the acidic soil is high in hydrogen ions with a high concentration of Al content (Neina 2019). Adding cation (Mg, K & Ca) by application of chemical fertilizer can be one of the solutions to reduce soil acidity (Shankara et al. 2022). Other than that, adding silicon would also be practical to reduce the effect of aluminum and manganese while at the same time handling the P deficiency problem in acidic soil (Pontingo et al. 2015). Thus, as an alternative to single silicon, biochar should be applied together to improve its function (Sattar et al. 2022). Moreover, applying biochar together with the fertilizer would promote N retention and C stability together with improving N uptake and minimizing the loss of N (Peng et al. 2021). The biochar would also improve phytoremediation and lower health risks caused by fertilizer (Ibrahim et al. 2016). Different types of biochar would have different content of elemental compositions (i.e., wood mixture biochar has a higher content of H, O, N, and S than biochar from maize and meadow grass) (Ullah et al. 2018).

To solve the problem regarding acidity in the soil, the focus needs to be given to the functional group (carboxylic and phenolic) that needs to be neutral (Mosharrof et al. 2022). Unfortunately, freshly prepared biochar has low carboxylic and phenolic groups that give less effect to the neutralization (Mia et al. 2017). Most researchers agree that biochar combined with other compounds would have a beneficial effect in lowering the acidity effect and raising the pH (Islam et al. 2021, Haque et al. 2021, Mosharrof et al. 2022), soil carbon removal (Zheng et al. 2020), promote rapid growth, (Brennan et al. 2014), adjust soil structure together with improvement nutrient uptake (Peng et al. 2019), and some biochar also seemed to be practical to remove few types of pollutant(i.e., blue, tetracycline, pesticide and phosphate)(Li et al. 2020). Biochar is also applicable to reduce the effect of Al & Fe concentration that causes the effect to increase in pH (Shetty & Prakash 2020).

These suggest that biochar could help to reduce the acidity effect and improve production. The effects of biochar with silicon should be further enhanced because both have the same function to control the acidity of soil through alkaline and cation properties. The combining of both of these materials should have more impact on the soil quality (Pontigo et al. 2015, Abukari 2014). Moreover, previous studies showed that the silicon application would benefit by increasing the pH (De Sousa et al. 2019), boosting the photosynthesis rate (Pitann et al. 2021), and supporting plant development (Zhiming et al. 2014). To get optimal outcomes, the rate of biochar and silicon needs to be justified. Other than that, low pH values can be highly caused by phosphorus deficiency and high potential for N2O emissions (Xie et al. 2020). Mensah and Frimpong (2018) report that in sub-Saharan Africa (SSA), soil also faces problems through continuous cultivation and rapid organic matter mineralization that will affect the properties of soil. However, these studies were conducted in various rates of biochar and silicon without the reduction of any supply of NPK fertilizer.

The application of biochar and silicon fertilizer helps to reduce the phosphorus fertilizer application and improve the maize growth and soil properties. Hence, the main objective of the study was to examine the performance of maize after the application of biochar with silicon fertilizer and with variable rates of P fertilizer.

MATERIALS AND METHODS

Experimental Site

A pot experiment was conducted for 75 days (October to December 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 (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 4mm 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 $t.ha^{-1}$, mixed well, and left for about one week before adding silicon 150 $kg.ha^{-1}$ was recommended as the optimal amount for maize by Xie et al. (2014). Additional N & K based on MARDI recommendation fertilizer: 120 kg $N.Ha^{-1}$ in the form of urea and 100 kg Potassium in the form of Muriate of potash 45 (MOP) was applied. Two recommended treatments from previous studies (Bakar et al. 2024). It was (50% RHB+ 100%Silicon) and (25% RHB+ 100%Silicon) and continues to implement together with various rates (0%,50%,75% & 100%)

Table 1: Treatments for conducting the experiment.

	Treatment
1.	(50% RHB) + (100% Si) + (0%P)
2.	(50% RHB) + (100% Si) + (25%P)
3.	(50% RHB) + (100% Si) + (50%P)
4.	(50% RHB) + (100% Si) + (100%P)
5.	(25% RHB) + (100% Si) + (0%P)
6.	(25% RHB) + (100% Si) + (25%P)
7.	(25% RHB) + (100% Si) + (50%P)
8.	(25% RHB) + (100% Si) + (100%P)

Table 2: Equivalent amount in the experiment setup.

Element	Application	Recommended rate [$kg.ha^{-1}$]	Experiment setup rate (g/20kg soil)
Biochar	Rice Husk	10000	700
Silicon	Silicon (SiO:40%)	150	1
Nitrogen	Urea	120	0.8
Phosphorus	Triple Superphosphate (TSP)	60	0.4
Potassium	Muriate of Potash (MOP)	90	0.6

of Triple Superphosphate (TSP) for this research. In this experiment, the F1 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 being destructively harvested 75 days after planting. Tables 1 and 2 show the treatment combination:

Post-Harvest Soil Analysis

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

Soil available P: 0.5M sodium bicarbonate, $NaHCO_3$, 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 min, filtered by filter paper no. 2, and sent to ICP for phosphorus analysis (Olsen et al. 1954)

Exchangeable cation(magnesium, potassium & calcium): The exchangeable cations were extracted using 100 mL of 1N ammonium acetate (Schollenberger & 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 10g 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).

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

Plant Material Analysis

Leave number and plant height analysis: The leave number of open leaves was counted at (75 DAS), and the plant height was determined using a measuring tape at harvest (75 DAS) from the base to the tip of the longest leaf (Lai 2019).

Leaf photosynthesis rate (µmol $CO_2m^{-2}s^{-1}$) and conductance (moL H_2O $m^{-2}s^{-1}$): 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 the meter (SPAD-502, Konica Minolta, Osaka, Japan) (Alarefee et al. 2021), and the conductance reading was recorded at the same time.

Plant fresh weight and biomass(g): After harvest, the shoot (stem and leaves) were washed and dammed with tissue paper before being dried in an oven at 60°C for 72 h and weighed again for the biomass with consistent weight (Mosharrof et al. 2021a)

Shoot nutrient uptake (ppm): The dried shoot was blended and again dried in the crucible in an oven, then put in a glass desiccator before 0.25g 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 is then converted into (ppm) by this formula:

$$Nutrient\ concentration(ppm) = Mean(mg/L) \times \left(\frac{mark\ up\ volume(50mL)}{weight(0.25g)}\right)$$

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

$$Nutrient\ Uptake = Nutrient\ Content(ppm) \times Biomass(g)$$

Cob Yield Component

Cob length, weight, grain per cob, and grain yield: The cob length was measured before destroying the plant. While the cob weight(g) was measured using weight balance after harvest. Then, total grain weight and 100-grain weight per cob were measured to calculate the grain per cob. Lastly, the grain yield was recorded as stated in the formula below:

$$\text{grain yield}\,\frac{\text{t}}{\text{ha}} = \left(\frac{\text{Total grain weight per cob } \times (3x10^6 KgSoil\ per\ Ha}{20KgSoil}\right)$$

Statistical Analysis

Analysis of Variance (ANOVA) procedure was used to analyze all of the data, and Tukey's Honestly

A 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 ($p \leq 0.05$).

RESULTS AND DISCUSSION

Effect of RHB, Silicon Fertilizer, and Varying Doses of Phosphorus on the Post-Harvest Soil Properties

It was noticed that pH from post-harvest soil was significantly affected by biochar and silicon with varied phosphorus fertilizer applications ($p<0.05$) (Table 3). The available pH was higher in T2(6.70) followed by T1, T3 & T7(6.47). This finding was similar to Mosharrof et al. (2021b), which observed 6.14 pH with the application of recommended RHB and phosphorus. The acidity also reduced with the low dose of phosphorus may be caused by the effectiveness applied after reducing the Al and Fe stress, making the pH increase and improving the plant development (Xiong et al. 2024, Bakar et al. 2024, Ahmad et al. 2018). The available P was significantly affected by the application of different rates of biochar, silicon, and phosphorus fertilizer. The highest P was recorded by T7(10.75), followed by T8(8.85), while T6(2.3) recorded the lowest P. Biochar application would increase phosphorus availability (Seleiman et al. 2020). Thus, the low dose of phosphorus with an application of biochar still shows high results (Glaser & Lehr 2019). The combining of silicon and fertilizer would become an agent to make a binding that will make the fertilizer embedded in soil that would reduce the leaching of it, and remain available in the soil (Nguyen 2021).

The application of Silicon, biochar and phosphorus fertilizer significantly affected the Al content in soil. The highest total Al in soil was observed from T_2(0.031), followed by T_1(0.023/kg), and the lowest was recorded by T6(0.001 $CmoL.kg^{-1}$). One finding shows that the application of rice husk with high silicon would reduce the phytotoxicity (Wang et al. 2019). The lower dose of phosphorus seemed to be still effective in reducing the Al may be caused by the addition of silicon with the presence of its silicate surface would absorb and reduce the Al effect (Pontigo et al. 2015, Haynes 2014).

The application of different rates of phosphorus with biochar and silicon fertilizer significantly affected the exchangeable cation of the soil (Ca, K, and Mg). The highest Exchangeable Ca, K & Mg recorded by T8(2.96, 2.09 & 1.94) $cmoL.kg^{-1}$ and lowest K & Ca recorded by T2(1.52 & 0.67) $cmoL.kg^{-1}$. While the lowest exchangeable Mg was recorded by T5(0.42 $cmoL.kg^{-1}$). This cation may increase through the high consumption of H^+ promoted by biochar (Mosharrof et al. 2021b), and applying biochar and silicon together seemed to be the medium to change the property of hydrophilic into hydrophobic. That would delay nutrient release from the soil (Weeks & Hettiarachchi 2019)

Effect of RHB, Silicon Fertilizer, and Varying Doses of Phosphorus on Plant Height, Leaf Number, Conductance, Photosynthesis Rate and Dry Biomass of Maize Plant

Different availability of phosphorus significantly together with silicon and biochar application affected (Appendix F1) the plant height(cm) of the maize measure at 65 DAS. T5 showed the shortest height(119.63cm) compared to other treatments. All the remaining treatments resulted in higher height, ranging from 154.27 cm to 180.23 cm in 65 days. It was noticed that the Biomass of maize was significantly affected by the availability of biochar with biochar and silicon application ($p<0.05$) (Table 4). The highest biomass was recorded by T4(81.47), Followed by T5(76.74), while the lowest biomass was recorded by T1(52.13). One research recorded that the maize treated with Silicon 40 kg ha-1 and 80 $kg.ha^{-1}$ showed results of shoot heights 130.4cm and 133.5 cm while 128.5 cm for control (Younas et al. 2021). While

Table 3: Post-harvest soil properties.

Treatment	pH	P[$Mg.kg^{-1}$]	EXC Ca	EXC K	EXC Mg	Al [$CmoL.kg^{-1}$]
T1	6.47ab±0.07	7.75ab±0.49	2.54b±0.04	1.08bc±0.02	0.96b±0.02	0.023ab±0.004
T2	6.7a±0.06	8.1ab±1.91	1.52c±0.04	0.67e±0.02	0.43f±0.01	0.031a±0.001
T3	6.47ab±0.07	5.9ab±0.29	2.63ab±0.04	1.04bc±0.02	0.67cd±0.01	0.005c±0.001
T4	6.33ab±0.07	3b±1.50	2.60ab±0.20	1.10b±0.04	0.71c±0.01	0.012bc±0.004
T5	5.2d±0.00	8.53ab±0.18	1.54c±0.06	0.88d±0.01	0.42f±0.003	0.012bc±0.001
T6	6.27bc±0.07	2.3b±0.12	1.83c±0.02	0.76e±0.01	0.49e±0.01	0.001c±0
T7	6.47ab±0.07	10.75a±0.38	2.43b±0.04	0.97cd±0.01	0.65d±0.004	0.006c±0.002
T8	5.87c±0.18	8.85ab±3.15	2.96a±0.02	2.09a±0.03	1.94a±0.02	0.007c±0.002

Means within the same column followed by the different letters are significantly different at $p \leq 0.05$ (Tukey's HSD test). The column represents the mean values ± standard error. T1 = (50% RHB) + (100% Si) + (0%P), T2=(50% RHB) + (100% Si) + (25%P), T3= (50% RHB) + (100% Si) + (50%P), T4= (50% RHB) + (100% Si) + (100%P), T5= (25% RHB) + (100% Si) + (0%P), T6= (25% RHB) + (100% Si) + (25%P), T7= (25% RHB) + (100% Si) + (50%P), T8= (25% RHB) + (100% Si) + (100%P).

Table 4: Plant morphological and physiological parameters.

Treatment	Plant height	Leaf no	Conductance (mol H_2O $m^{-2}s^{-1}$)	Photosynthesis rate [μmolCO_2 $m^{-2}s^{-1}$]	Dry biomass
T1	174.07b±0.31	11a±0.25	0.206b±0.001	32.5a±0.31	52.13d±0.98
T2	157.37d±0.37	10b±0.00	0.268a±0.003	32.7a±0.95	64.86c±1.59
T3	166.40c±1.14	11a±0.00	0.136c±0.001	28.5b±0.49	54.22d±1.22
T4	154.27d±0.43	10b±0.00	0.146c±0.004	23.8c±0.78	81.47a±0.30
T5	119.63e±0.19	10b±0.00	0.274a±0.006	30.6ab±0.01	76.74b±0.43
T6	174.60ab±2.87	10ab±0.00	0.174bc±0.017	33.4a±1.18	67.97c±1.01
T7	180.23a±1.54	11a±0.47	0.208b±0.001	18.8d±0.00	69.05c±0.69
T8	168.87bc±1.10	11a±0.50	0.211b±0.023	24.4c±0.06	66.90c±0.58

Means within the same column followed by the different letters are significantly different at $p \leq 0.05$ (Tukey's HSD test). The column represents the mean values ± standard error. T1 = (50% RHB) + (100% Si) + (0%P), T2=(50% RHB) + (100% Si) + (25%P), T3= (50% RHB) + (100% Si) + (50%P), T4= (50% RHB) + (100% Si) + (100%P), T5= (25% RHB) + (100% Si) + (0%P), T6= (25% RHB) + (100% Si) + (25%P), T7= (25% RHB) + (100% Si) + (50%P), T8= (25% RHB) + (100% Si) + (100%P).

Opala (2017) stated that a high rate of phosphorus would have more impact on the Plant height after 6 weeks. The application of biochar and silicon increases the development of plants by promoting a rise in solubilizing organic phosphate, mineralizing inorganic phosphate, and nutrient uptake (Raza et al. 2021).

In this study, it was noticed that the silicon and biochar with different phosphorus availability significantly affected (Appendix F3) ($p<0.05$) the conductance (mol H_2O $m^{-2}s^{-1}$) from maize leaf (Table 4). The conductance was higher in T5(0.274), followed by T2(0.0.268), while T3(0.136) recorded the lowest conductance. Phosphorus application on the soil would probably tend to improve the stomata opening and increase the conductance (Zangani et al. 2021). Although the dose of phosphorus in this research was not constant, still outcome with not high range in the conductance may be caused by the presence of silicon that covers the function of phosphorus to reduce chlorophyll synthesis and lower the the leaf water potential (Rehman et al. 2021).

Effect of RHB, Silicon Fertilizer, and Varying Doses of Phosphorus on Cob Length, Cob Weight, Number of Grains Per Cob, and Grain Yield

Cob length, Cob weight, number of grains per cob, and grain yield of maize were enhanced significantly (Appendix F6, F7, F8 & F9) by various treatments (Table 5). A longer but statistically similar cob length was observed in T3, T4, and T5 (up to 20.77 g), while the lightest was observed in T5 (16.4g). The maximum cob weight, No of grain, and yield grain were noted in T3 (160.56 g, 417.08 g, and 14.6 $t.ha^{-1}$, respectively), while the lowest rate of biochar, silicon, and phosphorus recorded the lowest T5(61.23g, 120.24 g, and 4.21 $t.ha^{-1}$). Application of biochar with NPK would produce a high yield compared to sole biochar (Arif et al. 2012), and higher doses would produce a higher yield (Islam et al. 2018). Biochar improves the soil structure, root growth, and nutrient uptake and promotes high yield (Liu et al. 2021). Although biochar has a high content of phosphorus, TSP fertilizer still needs to be implied as targeted for the high yield because

Table 5: Cob development and maize yield parameters.

Treatment	Cob length [cm]	Cob weight [g]	No grain per cob	grain yield [$t.ha^{-1}$]
T1	19.4ab±1.15	112.21b±8.14	360.14a±7.89	12.60a±0.28
T2	19.13ab±0.91	135.76ab±14.41	180.11bc±24.99	6.30bc±0.87
T3	21.27a±0.52	160.56a±7.12	417.08a±11.84	14.60a±0.41
T4	20.77a±0.318	151.87ab±12.76	400.38a±15.24	14.01a±0.53
T5	16.4b±0.25	61.23c±7.95	120.24c±22.41	4.21c±0.78
T6	20.77a±0.63	125.96ab±7.61	218.8b±2.70	7.66b±0.09
T7	18.73b±1.07	119.22ab±10.32	337.36a±16	11.81a±0.56
T8	19.53ab±1.08	118.79ab±6.0	339.38a±19.25	11.88a±0.67

Means within the same column followed by the different letters are significantly different at $p \leq 0.05$ (Tukey's HSD test). The column represents the mean values ± standard error. T1 = (50% RHB) + (100% Si) + (0%P), T2=(50% RHB) + (100% Si) + (25%P), T3= (50% RHB) + (100% Si) + (50%P), T4= (50% RHB) + (100% Si) + (100%P), T5= (25% RHB) + (100% Si) + (0%P), T6= (25% RHB) + (100% Si) + (25%P), T7= (25% RHB) + (100% Si) + (50%P), T8= (25% RHB) + (100% Si) + (100%P).

Table 6: Nutrient uptake.

Treatment	Uptake P [ppm.g^{-1}]	Uptake K[ppm.g^{-1}]	Uptake Ca[ppm.g^{-1}]	Uptake Mg[ppm.g^{-1}]
T1	378.59de+20	17337.2d+18.22	2138.24d+8.67	578.76f+14.71
T2	422.15de+15.4	20789.1b+28.5	3221.23b+7.33	984.65bc+13.2
T3	698.09b+7.09	17129.6d+38.1	2346.87cd+2.11	812.15e+8.88
T4	426.27d+8.81	26980.9a+31.2	4273.6a+18.63	1074.65ab+34.57
T5	510.1c+3.98	20713.9b+16.6	3270.59b+7.91	980.95bc+16.89
T6	363.46de+9.15	18525.3c+20.7	2672.78c+3.75	915.23cd+20.74
T7	352.79e+18.79	19286.9c+9.16	2618.04c+1.72	863.91de+9.2
T8	1143.62a+22.82	21050.1b+9.47	2543.41cd+1.1	1135.4a+32.1

Means within the same column followed by the different letters are significantly different at $p \leq 0.05$; (Tukey's HSD test). The column represents the mean values ± standard error. T1 = (50% RHB) + (100% Si) + (0%P), T2=(50% RHB) + (100% Si) + (25%P), T3= (50% RHB) + (100% Si) + (50%P), T4= (50% RHB) + (100% Si) + (100%P), T5= (25% RHB) + (100% Si) + (0%P), T6= (25% RHB) + (100% Si) + (25%P), T7= (25% RHB) + (100% Si) + (50%P), T8= (25% RHB) + (100% Si) + (100%P).

biochar will act as slow-releasing phosphorus (P) fertilizers and will increase P use efficiency (Li et al. 2020).

Effect of RHB, Silicon Fertilizer, and Varying Doses of Phosphorus on P, K, Ca & Mg Uptake of Maize Plant

There was a significant difference in plant nutrient uptake of maize, represented in Table 6. With T8, the total uptake of P(1143.62 ppm.g^{-1}) and Mg (1135.4 ppm.g^{-1}) taken up by the maize plant was statistically higher than other treatments. The highest uptake of K (26980.9 ppm.g^{-1}) and Ca (4273.6 ppm.g^{-1}) was obtained from T4 (50% RHB + 100% Si + 100% TSP). The lowest Uptake of P was recorded by T7(352.79 ppm.g^{-1}), the lowest uptake of K was showed by T3(17129.6 ppm.g^{-1}), lowest Ca and Mg were recorded by T1(2138.24 ppm.g^{-1} & 578.76 ppm.g^{-1}). The high phosphorus and potassium uptake is observed with the application of biochar as the treatment (Ullah et al. 2018). According to Zaidun et al. (2019), the application of biochar would increase the exchangeable K together with the increasing dose of biochar. The high uptake of K shows that the good sign to help improve photosynthesis, carbohydrate metabolism, and protein formation, then affect the good development of yield (Mikkelsen 2017).

CONCLUSIONS

To conclude, treatment 3, the combined application of biochar and silicon, along with 50% phosphorus, is recommended for enhancing the pH, K and Ca uptake, biomass, and yield. This treatment is practical and can be applied for further trials in field plots to get more stable results. This approach will help for conducive application, environmental benefits, and gain more profit for farmers.

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