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Effects of rice husk biochar and sugarcane bagasse fertilizer on the chemical and biological properties of soil and the productivity of hybrid maize

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Abstract

Addition of biochar or organic fertilizers to the soil is very beneficial for enhancing the soil's quality and promoting plant development. The objective of this study was to identify the effects of applying biochar and sugarcane bagasse fertilizer alone or in combination on the improvement in soil properties and the productivity of hybrid maize in two consecutive crops. Field experiments were carried out in completely randomized block design with four treatments and five replications on Autumn 2020 and Summer 2021 crops. Treatments were control without application of rice husk biochar or sugarcane bagasse, application of 10 ton/ha of biochar, application of 10 tons/ha of sugarcane bagasse and combined 5 tons/ha of biochar and 5 tons/ha of sugarcane bagasse. The results in two consecutive crops showed that application of biochar, sugarcane bagasse fertilizer alone or in combination improved pH, increased available N, P and percentage of carbon in soils as well as increased the microbial density. Rice husk biochar alone or in combination with sugarcane bagasse fertilizer improved yield of hybrid maize. The findings of the research indicated that biochar application with 5-ton ha^{-1} combined with 5-ton ha^{-1} of sugarcane bagasse fertilizer increased plant biomass and seed yield of hybrid maize.

Keywords: Catalase activity; organic fertilizers; microbial density

Introduction

Maize (*Zea mays* L.), also called corn, is an important cereal for human consumption, animal feed, and industrial raw material. In the world, approximately 50% of raw materials for animal feed is maize (Ranum *et al*., 2014). In Mekong Delta (Vietnam), maize is one of the attractive crops to grow in rotation with rice due to its relatively high economic return. Maize has brought a stable income for maize growers in several countries in the world (Hellin *et al*., 2017; Ahmadu and Edeoghon, 2018; Wongnaa *et al*., 2019). Most farmers in Mekong Delta have been using inorganic fertilizers excessively, and not much attention has been paid to organic fertilizers for maize. Therefore, the yield of maize trends to decrease by years. The excessive use of inorganic fertilizers has been found to have a negative impact on soil health and quality, such as soil degradation, acidification, nutritional imblance, and environmental pollution (Liu *et al*., 2010; De Meyer *et al*. 2011). For example, the excessive use of nitrogen fertilizer has been linked to a decrease in soil organic matter in cereal crops that are high yielding and nutrient demanding (Oladele, 2019). High nitrate accumulation in soil has caused several problems, including low N use efficiency and environmental contamination in intensive agricultural systems (Cui *et al*., 2008). Combining inorganic fertilizer with organic fertilizer or biochar has been improving soil fertility, organic content, and soil degradation (Jannoura *et al*., 2014; Petter *et al*., 2016). Biochar is a carbon-rich material, produced by controlled burning of organic material, and it has been used to increase soil fertility and crop productivity (Agegnehu *et al*. 2016; Kätterer *et al*., 2019). Long-term benefits of biochar application to soil include improved soil exchange sites and nutrient retention capacity, gradual release of nutrients and hence their improved availability to plants, improved water availability to crops, and improved microbial functions (Frimpong *et al*., 2021). Previous studies on the effects of biochar inputs to soils have been shown to increase pH,

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nutrient availability, cation-exchange capacity (Liang *et al*., 2006, Dempster *et al*., 2012), water-holding capacity, soil structure, soil microbial diversity, and mycorrhizal activity (Hall and Bell, 2015), as well as to decrease nutrient leaching, nitrous oxide emissions, and soil tensile strength (Cernansky, 2015). Plant-based biochar is frequently nitrogen and phosphorus deficient. As a result, it must be used in conjunction with compost, manure, or inorganic fertilizer (Frimpong *et al*., 2021). Sugarcane bagasse is an agricultural by-product derived from the milling process and can be used as organic fertilizer with high N, P, and Ca content (Yaduvanshi and Yadav, 1990; Dotaniya *et al*., 2016). The use of bagasse has shown positive effects in terms of crop growth and yield (Muhieldeen *et al*., 2014; Chacha *et al*., 2019) as well as environmental quality. Sugarcane bagasse application to soils can improve the physicochemical qualities of the soil. When applied to degraded soils, it can boost organic matter content, water-holding capacity, and the concentrations of nutrients that are needed for plant growth (Dotaniya *et al*., 2016; Xu *et al*., 2021). The amount of compost or biochar for one hectare, applied alone or in combination, varies from 5 to 10 tons (Filiberto *et al*., 2013; Rahmad *et al*., 2019; Frimpong *et al*., 2021). In Mekong Delta, little is known about the effects of biochar or sugarcane bagasse, applied alone or in combination, on soil chemicals, microbial content, and the productivity of hybrid maize. The objective of this study is to identify the effects of applying biochar and sugarcane bagasse alone or in combination on the improvement in soil properties and the productivity of hybrid maize in two consecutive crops.

Table 1: Chemical components of biochar and sugarcane bagasse fertilizer

Component	Biochar	Sugarcane bagasse fertilizer
$pH_{(H2O)}$ (1:2.5)	9.92 ± 0.04	8.33 ±0.08
Carbon (% C)	36.7 ±0.44	30.0 ±0.72
(% N)	0.86 ±0.42	2.50 ±0.18
(% P_2O_5)	1.36 ±0.41	3.00 ±0.63
(% K_2O)	1.50 ±0.66	1.68 ± 0.50
(% CaO)	0.18 ±0.09	7.61 ±0.01

Table 2: Original soil properties

No	Properties	Value
1	pH_{H2O} (1:2.5)	4.97 ± 0.23
2	Carbon (% C)	1.15 ± 0.19
3	CEC (C mol kg^{-1})	12.01 ± 1.67
4	(% N)	0.15 ± 0.02
5	(% P_20_5)	0.37 ± 0.05
6	Echangeable K (meq $100g^{-1}$)	0.73 ± 0.15
7	(%)	
	Clay	33.71 ± 0.14
	Loam	54.62 ± 0.94
	Silt	11.67 ± 0.09
8	Bulk density (g cm^{-3})	1.18 ± 0.23
9	Bacteria (log_{10}CFU g^{-1})	5.80 ± 0.21
10	Fungi (log_{10}CFU g^{-1})	3.83 ± 0.35

n=14.

Table 3. List of treatments

Treatments	Biochar (ton ha^{-1})	Sugarcane bagasse (ton ha^{-1})
Control	0	0
B10-SBF0	10	0
B0-SBF10	0	10
B5-SBF5	5	5

Notes: All plots were fertilized with the same amount of inorganic fertilizer (180 N, 90 P_20_5, and 80 K_20 kg ha^{-1}).

Materials and Methods

Materials

Fertilizer: Urea (46% N), phosphorus (16% P_2O_5), and potassium chloride (60% K_2O) were used. Biochar from burned rice husk was produced by a top-lit updraft (TLUD) gasifier at 400–600^{0}C. Sugar bagasse was collected from the sugar factory in Vi Thanh, Hau Giang, and decomposed for the experiment. The main components of biochar and sugarcane bagasse fertilizer are listed in Table 1.

Maize variety*:* F1 hybrid LVN 10 was used. This variety has a high productivity, is vigorous, and adapts well to drought. The average yield per crop is 6–8 tons ha^{-1}, with a maximum yield of 10–12 tons ha^{-1}.

Experimental setup: The experiments were conducted in two consecutive crops from Autumn 2020 to Summer 2021 in the experimental site at Can Tho University (10^{0}01'45"N, 105^{0}45'9"E). The soil is fluvisol , categorized as silty with a high clay and loam content (soil taxonomy of the United States Department of Agriculture [USDA]) and a low bulk density of 1.20 g cm^{-3}. The density of soil bacteria was higher than the density of fungi in Table 2.

Methods

Field design: The experiment was carried using a randomized complete block design (RCBD) with 4 treatments and 5 replications. The area for each plant was 60 x 30 cm, with 1 seed per sowing hole. Each plot was 5 x 12 m. The plots were separated by a trench (30 cm wide and 20 cm depth) for drainage. All treatments are listed in Table 3.

Fertilizer and timing: Sugar bagasse fertilizer and rice husk biochar and phosphorus fertilizer were added before planting. Nitrogen and potassium were added at different stages.

Fertilizer schedule*:* 10 days after sowing (DAS), 3–4-leaf stage: 1/3 N and 1/2 K_2O. 20 DAS, 9–10-leaf stage: 1/3 N. 45 DAS, before flowering, 5–7 days: 1/3 N and 1/2 K_2O.

Data collection

Soil samples before the experiment were collected at a depth of 0–20 cm. Five samples were collected in the field and mixed well as a representative sample.

Soil samples at harvesting were collected for each treatment. Before the analysis, the soil was air dried and screened with a net of 2 x 0.5 mm. pH, EC, organic carbon, available N (NH_4^+ and NO_3^-), phosphorus, total microbial count (bacteria and fungi), and the activity of catalase enzyme were measured.

Yield (ton ha^{-1}), consisting of all seeds, was weighed, and the measured weight was converted to the weight at 13% seed humidity.

Number of leaves per plant was counted as all leaves on 30 plants per replication at the R6 stage.

Above-ground biomass of plants was harvested and dried at 70^{0}C for 72 hours. Dry biomass was converted to dry biomass per hectare.

Soil analysis

Soil chemical properties: The soil extraction method 1:2.5 (soil:water) was used. The pH and EC of the extracted liquid were measured by meters. Soil organic content was measured by the Walkley–Black method. The carbon content of biochar was identified by the dry combustion method at 830^{o}C in 24 hours (Chintala *et al.*, 2013). Soil cation exchange was measured by EDTA 0.01 M and atomic absorption. Exchangeable potassium cations were extracted by non-buffer $BaCl_2$ 0.1 M. Total N was determined by the Kjeldahl method, after the samples were treated with K_2SO_4:$CuSO_4$:Se (100:10:1). For the total phosporus content, the samples were treated with a high concentration of H_2SO_4 and $HClO_4$ before being analyzed by spectrocopy.

Soil physical properties: Soil bulk density was measured by the methods of Blake and Hartge (1986). The soil coring ring was 98.125 cm^3. The soil particles were separated by the Robinson method (Klute, 1986).

Soil biological properties: Microbial density was recorded by counting colonies on growing medium. The media selected Tryptone Soya Agar for total bacteria count and potato dextrose agar (PDA) for total fungi count using dilution plate technique (Martin, 1950). Catalase enzyme in soils were determined by using titration methods.

Statistical analysis

The data presented in this paper are the mean values of five replications. All data were analyzed using one-way analysis of variance (ANOVA) using SPSS software package version 13.0 and comparison for significant differences for treatment effects using LSD's test at $p \leq 0.05$.

Results

Effects of sugarcane bagasse and rice husk biochar on soil chemical properties in two consecutive hybrid maize crop cycles

The results in Figure 1 show that when biochar and sugarcane bagasse fertilizer were added to the soils, the soil pH increased significantly and was different from that in the control treatment without application of biochar or sugarcane bagasse fertilizer. The treatment with 10 tons of sugarcane bagasse fertilizer improved the pH more than the treatment with rice husk biochar or the treatment with a combination of 5 tons of biochar and 5 tons of sugarcane bagasse fertilizer. Figure 1 also shows that the pH increased to a higher value in Summer 2021 than in Autumn 2020.

In both crop seasons, the soil organic carbon followed the same trend (Figure 2). The percentage of carbon in the control treatment was significantly lower than the percentage in the treatment supplemented with biochar or sugarcane bagasse fertilizer, alone or in combination. The highest

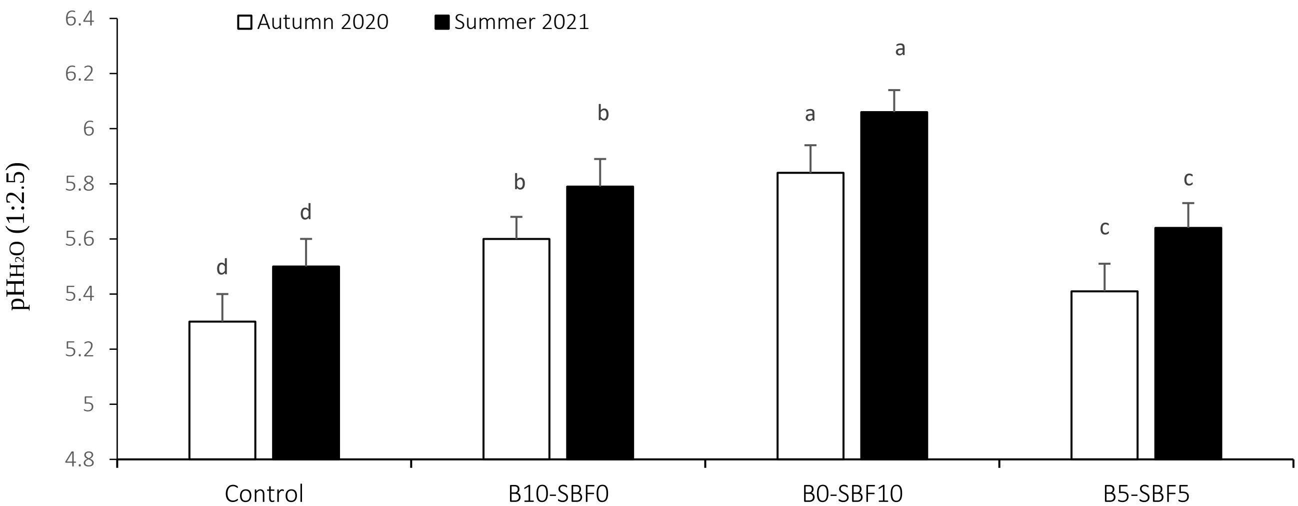

Figure 1: Effects of sugarcane bagasse and rice husk biochar on soil pH

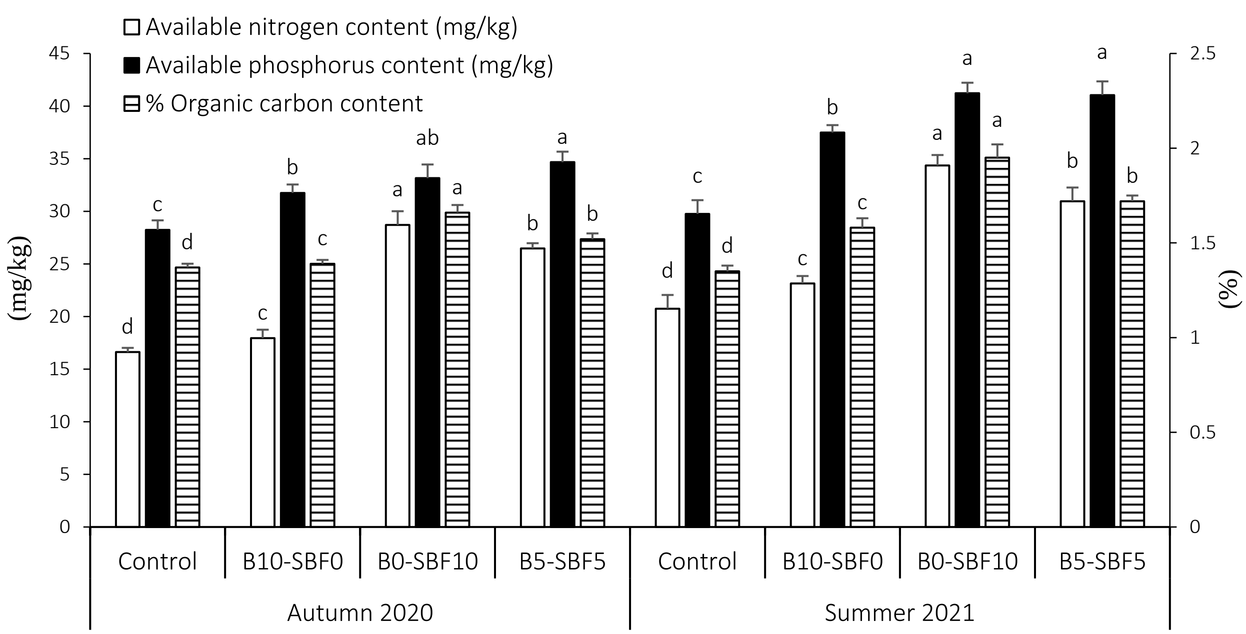

Figure 2: Effects of sugarcane bagasse and rice husk biochar on soil organic carbon and available nitrogen and phosphorus contents in two consecutive seasons

content of available nitrogen was seen in the sugarcane bagasse fertilizer treatment, and the lowest in the inorganic fertilizer treatment (B0-SBF10 > B5-SBF5 > B10-SBF0 > Control). Biochar alone or sugarcane bagasse fertilizer alone increased the phosphorus content in soil. The highest content of available phosphorus was obtained by a combination of 5 tons of biochar and 5 tons of sugarcane bagasse fertilizer (B5-SBF5), and the lowest content was obtained in the control treatment. There was no difference between combining 5 tons of biochar with 5 tons of sugarcane bagasse fertilizer and 5 tons of biochar with 10 tons of sugarcane bagasse fertilizer in both seasons. In Autumn 2020, the treatment of 10 tons of

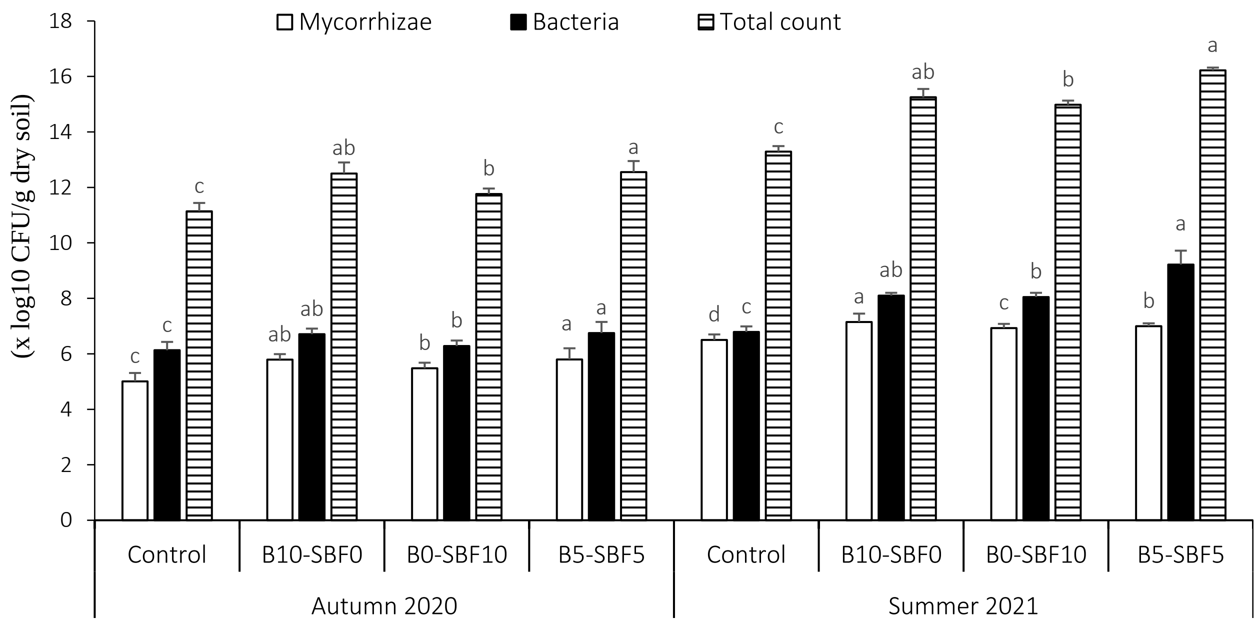

Figure 3: Effects of sugarcane bagasse fertilizer and rice husk biochar on soil microbial counts in maize in two consecutive seasons

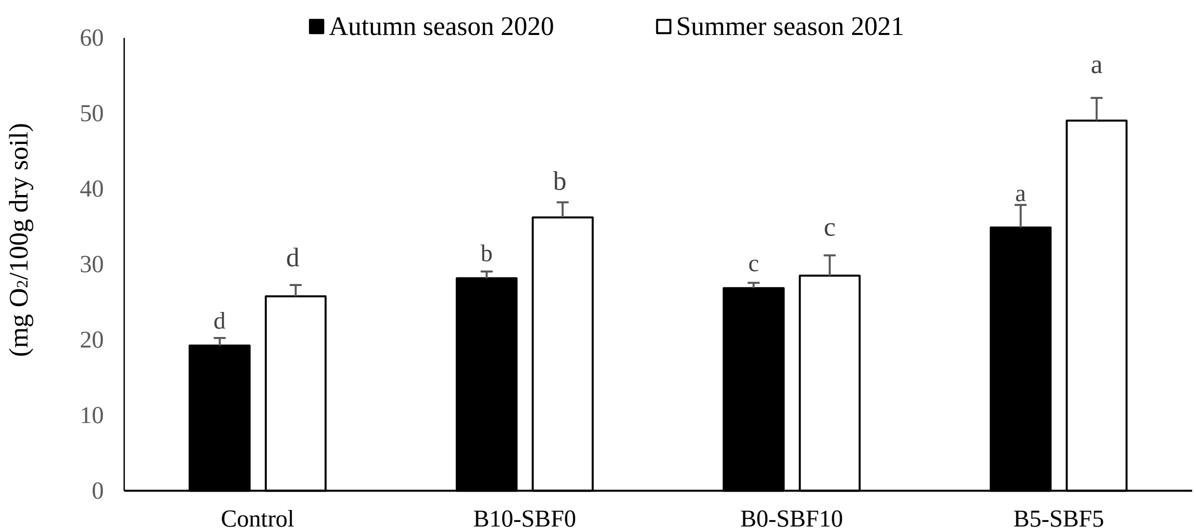

Figure 4: Effects of sugarcane bagasse fertilizer and rice husk biochar on soil catalase activity

biochar and 10 tons of sugarcane bagasse fertilizer yielded similar results regarding available phosphorus. However, in Summer 2021, there was a difference between these two treatments. Figure 2 shows that biochar with or without organic fertilizer increased the soil pH, organic carbon, available nitrogen, and phosphorus content.

Effects of sugarcane bagasse fertilizer and rice husk biochar on soil microbial counts in two consecutive seasons

The results in Figure 3 show that soil supplemented with biochar and sugarcane bagasse fertilizer, alone or in combination, had an increased microbial density. The total number of bacteria in the second-season crop was higher than that in the first-season crop. In the second season, the microbial count was higher. The highest microbial count was seen in the combination of biochar and sugarcane fertilizer (B5-SBF5), and the lowest count was observed without biochar or sugarcane bagasse fertilizer.

Effects of sugarcane bagasse fertilizer and rice husk biochar on catalase activity in two consecutive seasons

The results in Figure 4 show that the application of biochar and sugarcane bagasse fertilizer improved the activity of catalase in soil. Catalase activity was higher in 2021 than in 2020. The highest activity of catalase in the soil when the soil was applied with 5 tons/ha of biochar and 5 tons/ha of sugarcane bagasse fertilizer. The activity of catalase in biochar treatment alone was higher in sugarcane bagasse fertilizer treatment.

Effects of sugarcane bagasse fertilizer and rice husk biochar on maize yield in two consecutive seasons

Adding sugarcane bagasse fertilizer or biochar increased the seed yield of hybrid maize in both seasons (Figure 5). Ten tons of sugarcane bagasse fertilizer (B0-SBF10) gave the highest yield. There was no difference between adding 10 tons of biochar and combining 5 tons biochar with 5 tons of sugarcane bagasse fertilizer. Compared with the control group, the combination of sugarcane bagasse fertilizer and biochar increased the yield. In this study, application of biochar or organic fertilizer (alone or in combination) increased the microbial activity and nutrient mineralization in soil and the overall plant productivity.

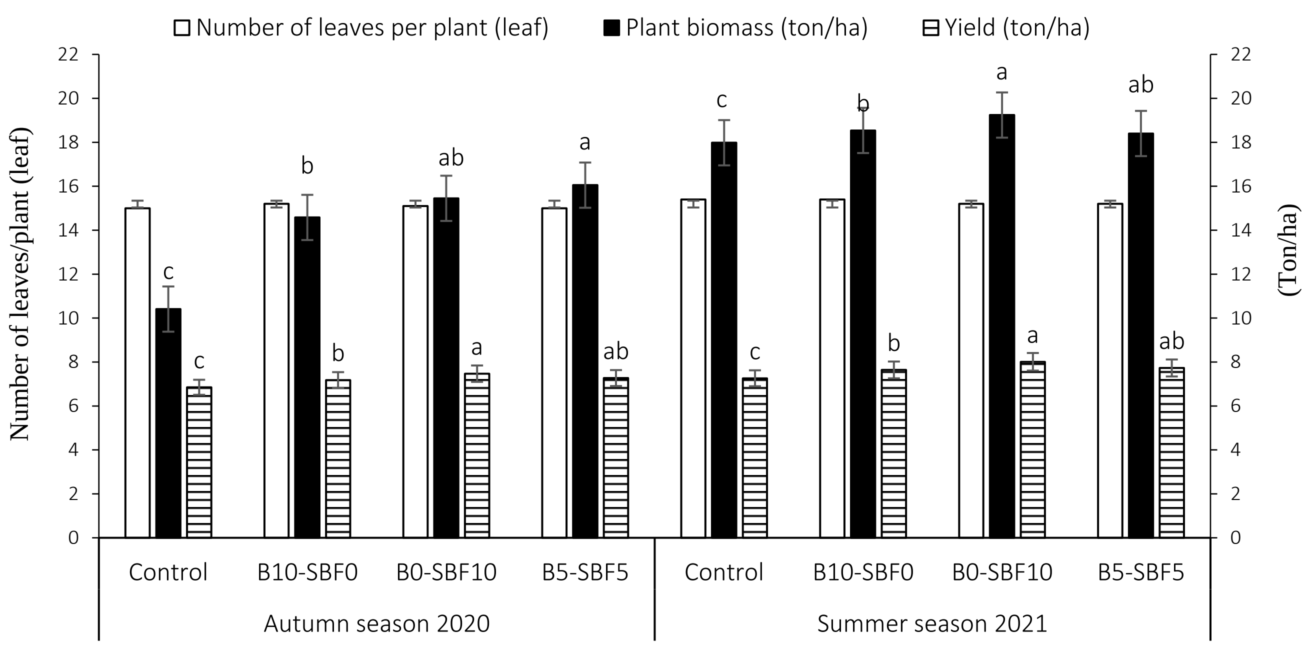

Figure 5: Effects of sugarcane bagasse fertilizer and rice husk biochar on maize yield

Discussion

The results in two consecutive hybrids maize LVN 10 showed that application of biochar, sugarcane bagasse fertilizer alone or in combination to improve the soil pH significantly. This result is similar to the result of a study by

Frimpong *et al*. (2021), in which biochar or biochar in combination with organic fertilizers was applied. Like the findings of Kätterer *et al*. (2019), our findings also gave similar results when biochar was applied at different locations. Sugarcane bagasse fertilzer and biochar had a high pH (Table 1); therefore, it is reasonable that the soil treated with rice husk biochar and sugarcane bagasse fertilizer also had a high pH. Biochar also contained a high amount of carbonate Agusalim *et al*. (2010); Nigussie *et al*. (2012). The large surface area of biochar and organic fertilizer increased the soil CEC and weakened the Al and Fe links to the soil. Biochar increased the soil pH by 0.79–2.21 units (Ouyang *et al*. (2014). The soil pH is important for nutrient availability and nutrient absorption by plants (Silber *et al*. 2010) and for the PO_4^{3-} and NH_4^+ release from soil particles (Zheng *et al*. 2013).

Biochar and sugarcane bagasse fertilizer are carbon-rich materials (Table 1). The same results were seen by Trupiano *et al*. (2017) when testing the effects of biochar on soil. The presence of sugar bagasse fertilizer and biochar might help reduce nitrogen leaching and the volatilization or minilarization of NH_3 due to a higher pH. The same effects of biochar and organic fertilizer on reducing nitrogen loss in soil were seen in other studies (Abujabhah *et al*., 2015; Scotti *et al*., 2015). Biochar alone or sugarcane bagasse fertilizer alone increased the phosphorus content in soil (Figure 2). The Figure 2 shows that the content of available N and P and the percentage of carbon in soil increased in the biochar treatment. These results were similar to those of a study by Kätterer *et al*. (2019), in which biochar was applied to soil. These effects can be explained by the higher pH caused by the application of biochar and sugarcane bagasse fertilizer (Hopkins and Ellsworth, 2005). The increased pH of acidic soil can improve phosphorus availability and absorption (Nigussie *et al*., 2012; Agegnehua *et al*., 2015). According to Sasmita *et al*. (2017), biochar application and available phosphorus in soil had a positive linear relationship.

Microbial activities take up to 80% to 90% of ecological cycles in soil (Pepe-Ranney *et al*. 2016). Biochar and organic fertilizer improve the soil structure, aeration, and nutrient availability, which is beneficial for microorganisms. Biochar has been used to improve the growth of bacteria and fungi (Watts *et al*., 2010, Zimmerman *et al*., 2011; Jannoura *et al*., 2014 ; Abujabhah *et al*., 2015). Microbial density is important for cycling nutrients in soil and for maintaining a healthy environment for plant growth (Rodrigues *et al*. 2013).

Catalase is a group of intracellular enzymes involved in the oxidation–reduction process of soil. Catalase activity is used as an indicator for the oxidation–reduction of soil. Soil enzymes catalyze key biochemical processes in organic matter decomposition and nutrient cycles and are regarded as indicators of soil quality (Du *et al*., 2014). Soil organic content is proportional to the activity of catalase in soil and the nitrogen mineralization in aerated soil (Uzun and Uyanöz, 2011). Catalase indicates microbial activity in soil (Öhlinger, 1996). Soil catalase activity is linked to soil organic carbon, microbial biomass, oxygen diffusion, and the activity of other enzymes, such as dehydrogenase, amidase, glucosidase, and esterase (Frankenberger *et al*., 1983; Glinski *et al*., 1986; Margesin *et al*., 2000).

Adding sugarcane bagasse fertilizer or biochar increased the seed yield of hybrid maize in in two consecutive seasons. There was no difference between adding 10 tons of biochar and combining 5 tons biochar with 5 tons of sugarcane bagasse fertilizer. These results were similar to those of a study by Major *et al*. (2010). The high plant biomass and yield could be the result of enhanced soil microbial activity, mineralization, and nutrient availability (N and P). Compared with the control group, the combination of sugarcane bagasse fertilizer and biochar increased the yield. A higher C and N content in soil also supports plant growth. The interaction between biochar and sugarcane bagasse fertilizer may be beneficial (Adekiya *et al*., 2019). In this study, application of biochar or organic fertilizer (alone or in combination) increased the microbial activity and nutrient mineralization in soil and the overall plant productivity.

Conclusions

Adding biochar or organic fertilizer to soil is recommened for improving physical and chemical properties, nitrogen and phosphorus availability, and organic carbon content in soil for growing maize. Microbial growth and catalase activity were significantly enhanced in biochar and sugarcane bagasse fertilizer treatments. The yield of maize was higher with biochar and organic fertilizer treatments. No yield difference was observed between biochar with or without organic fertilizer.

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