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CHEMICAL PROPERTIES, SOIL MICROBIAL ACTIVITY AND CORN PRODUCTIVITY OF SOIL ENRICHED WITH CORN COB BIOCHAR

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ABSTRACT

With the growing research interest in utilizing nutrient-enriched biochar as alternative slow-release fertilizer, a study was conducted to examine the alterations in soil chemical properties and microbial activity following the use of fertilizer enriched corn cob biochar (FEB) in clay loam soil (*Typic Eutrudepts*) at ASI-CAFS, U.P. Los Baños in November 2020. The agronomic and physiological responses of corn grown in soil with treatments: no fertilizer (T1), corn cob biochar alone (T2), recommended rate of chemical fertilizer (T3), and FEB at the rate of 5.0 (T4), 7.5 (T5) and 10.0 (T6) tons ha^{-1} were evaluated. The application of FEB improved the chemical soil properties and soil microbial activity due to the presence of higher levels of soil organic carbon and essential macronutrients. The corn plants applied with the FEB had the highest leaf chlorophyll content. The FEB with the lowest rate (5 tons ha^{-1}) significantly increased corn plant biomass and fruit yield. Moreover, FEB application significantly enhanced the N, P and K concentration on corn stalk and fruit. Significant positive correlations were obtained between the total N, available P and exchangeable K in soil and the total N, P and K concentration in plants. These findings provide a novel opportunity for the use of FEB as an efficient soil ameliorant.

Key words: Fertilizer enriched biochar, nutrient concentration, yield, efficient fertilizer

INTRODUCTION

Agricultural waste accumulation, such as corncobs, rice husks, rice straws, empty fruit bunches from oil palms, wheat straw, and sugarcane bagasse, amounts to about 2 billion tons globally (Millati et al. 2019). The USDA (2021) reported that 1133 million metric tons (MMT) of corn were produced globally in 2021 and the total corncob generation is expected to be around 249 MMT. In agricultural production systems, incorporation of crop residues and application of manure and chemical fertilizers in soil are general procedures to enhance soil fertility through improving nutrient availability, retention, and cycling (Kizito et al. 2019). Due to various threats such as increasing world population, declining food security owing to decreasing agrarian production, water shortage, recurring fuel crises, and global warming (World Bank 2022), the biochar applications have motivated various research finding answers for urgent elucidation.

Biochar has a high carbon (C) content that is produced by heating biomass with limited or without oxygen. It is used to provide carbon to soil, increase soil fertility, and promote plant development. Within a short time of being applied to the soil, biochar interacted with microorganisms, plant roots, soil minerals and organic materials (Joseph et al. 2010). Because biochar can preserve soil fertility and increase crop productivity, its use for improving soil is becoming more and more popular (Lehmann et al. 2003). The limitation of biochar are obscure effects in cultivated soil although it improves yield capacity of crops grown in infertile soil (Hussain et al. 2017). The biochar should be incorporated with chemical fertilizer to enhance yield in fertile soil (Sadaf et al. 2017). This biochar-fertilizer combination may improve the accessibility and uptake of plant nutrients present in chemical fertilizer (CF) and mitigate nutrient losses by reducing the chemical fertilizer requirement. Enhancing the economic and environmental benefits of biochar can be achieved by using nitrogen (N) derived from both organic and inorganic sources (Clough et al. 2013).

Nutrient-enriched biochar is becoming popular in ecological engineering studies as a slow-release fertilizer substitute (Gwenzi et al. 2018). Crop growth and yield were positively impacted using nutrient-enriched biochar. Biochar's ability to absorb nutrients and release them gradually, thereby decreasing possible leaching, has been linked to an increase in crop cultivation and production (Kizito et al. 2019).

Biochar can impact the composition and function of diverse microbial communities in soils. Biochar encourages the diversity and activity of soil microbes by its properties such as porosity, high sorption and cation exchange capacity (Zheng et al. 2013). The molecular structure of biochar dominated by aromatic C blocks make it invulnerable to microbial decomposition compared to uncharred organic matter and perseverance in the soil ranging from 1000 to 10,000 years thus improvising C storage of soil (Warnock et al. 2007). Soil amendment with enriched biochar appears to have influence on many microorganisms compared with the use of fertilizer resulting in an intricate reorganization of the community's structure and association (Joseph et al. 2015).

The effects of applying enriched corn cob biochar on the development and yield of corn planted in acidic clay loam soil, as well as the ensuing modifications to soil microbial activity and chemical characteristics, are not well understood. This study attempted to assess the impact of enriched biochar application on corn growth and yield cultivated in an acidic clay loam soil, as well as the alteration in soil chemical characteristics and microbial activity following the application.

MATERIALS AND METHODS

Corn cob biochar production and enrichment. Corn cob feedstock was collected from previous corn experiment at the Agricultural System Institute Demonstration and Composting Area, Pili Drive, University of the Philippines Los Baños (U.P. Los Baños) in November 2020. The clean raw corn cobs (4-6 cm in size) were oven-dried (60°C) with 10-15% moisture (w/w) prior to pyrolysis. They were loaded loosely inside a biochar-producing stove and allowed to char at 300–650°C. The biochar was allowed to cool in the holding container and moved to a cooling netted filter for air drying.

The air-dried char was pulverized using a spice and herb grinder IC-50B. The fertilizers urea (46-0-0), di-ammonium phosphate (18-46-0) and muriate of potash (0-0-60) were used in the enrichment process. The enriched biochar was prepared by mixing thoroughly 500 grams of 25-10-10 grade fertilizer per 1 kilogram of biochar following the procedures of Rose et al. (2016).

The chemical properties of the corn cob biochar were characterized using standard procedures: organic carbon by Walkley and Black method (Jackson 1958), total N by Kjeldahl method (Greweling and Peech 1960), total P by the Vanadomolybdate method (Kitson and Mellon 1944), total K by flame photometer method (Greweling and Peech 1960), and pH using potentiometric method (Black 1965).

Soil and pot preparation. An acidic clay loam soil of volcanic origin (*Typic Eutrudepts*) was collected from an upland farm (14º8'52" N; 121º15'37" E) at Los Baños, Laguna, Philippines. The collected soil was air-dried, clean of vegetative material and subjected to a 2mm sieve prior to its utilization in the experiment. Plastic pots with a 30.0 cm internal diameter, 26.0 cm deep (24 L capacity volume), and with holes at the base, were used. 20 kg of air-dried soil was added into each pot. The lowest biochar application rate was 5 tons ha^{-1} which was equivalent to 10 grams per 20 kilograms soil.

Treatments and design. Randomized complete block design with seven replications was employed to organize the treatments. The treatments are: T1 - Control (no biochar added); T2 - Corn cob biochar (5 tons ha^{-1}); T3 - Recommended rate of chemical fertilizer (120-90-90 kg N-P_2O_5-K_2O ha^{-1}); T4 - FEB (5 tons ha^{-1}); T5 - FEB (7.5 tons ha^{-1}); and T6 - FEB (10 tons ha^{-1}).

Management of the corn plant. Three seeds of corn (*Zea mays* L. cv Sweet Pearl), an early maturing hybrid waxy sweet white corn were planted into each pot. One healthy seedling per pot was achieved with thinning seedlings. All pots were set up in a screenhouse at Agricultural Systems Institute (ASI), UP Los Baños, Philippines, and re-arranged every month to avoid bias that may arise because of location. Soil moisture was supplied using distilled water and maintained at field capacity.

Plant growth and yield parameters. Measurements of plant height and total leaf count per plant were taken every week, commencing from 14 days after sowing (DAS) to tasseling stage. The chlorophyll content was measured using a SPAD-502 Chlorophyll Meter from Konica Minolta, Tokyo. The measurements were gathered at the milking stage and at harvest (2 weeks after milking stage). Taking care to avoid veins and the midrib, duplicate readings were taken for each measurement on the leaf that was attached to the ear (fruit) and the second leaf from the ear leaf, about halfway along the leaf. The ear of each plant was harvested at maturity (71 days). Yield parameters were recorded after harvest. Following a 72-hour period of oven drying at a temperature of 70°C, plant samples were obtained for chemical analysis. The above-ground parts of the plants were weighed to calculate the biological yield per pot.

Chemical analyses of soil and plant tissue. The initial and final soil samples were subjected to the following conventional procedures for their chemical properties: pH by using potentiometric method (Black 1965), soil organic carbon by Walkley and Black method (Jackson 1958), cation exchange capacity (CEC) by ammonium acetate method (Black 1965), total N by Kjeldahl method (Greweling and Peech 1960), available P by Bray method (Bray and Kurtz 1945), and exchangeable K by flame photometer method (Black 1965). The total N concentration in the corn plant tissue was determined by the Kjeldahl method (Grewling and Peech 1960). The total P and K concentration were analyzed using the vanadomolybdate method (Kitson and Mellon 1944) and flame photometer method (Greweling and Peech 1960), respectively.

Soil microbial activity. Using the fluorescein di-acetate (FDA) hydrolysis method, which was reported by the University of Toledo Laboratory of Environmental Pathogens Research, Department of Environmental Sciences (2004), total microbial activity was assessed at the milking stage. 20 ml of 60 mM potassium phosphate buffer pH 7.6 were poured into three 50 ml falcon tubes containing two grams of fresh soil each (two duplicates and one control). To initiate the reaction, 0.1 ml of FDA stock solution (2000 µg ml^{-1}) was added. Blanks without the addition of FDA substrate and another blank containing FDA (no sample) were prepared. The flasks were then placed in an orbital incubator set at a speed of 100 revolutions per minute and a temperature of 30 °C for a duration of 45 minutes. Following the incubation, the fluorescein was extracted using a 20 ml mixture of chloroform and methanol in a ratio of 2:1 and shaken thoroughly by hand. The supernatant was obtained after centrifugation at 5000 rev min^{-1} for approximately 5 min and filtration. After filtering and centrifugation at 5000 rev min^{-1} for about 5 min, the supernatant was collected. Using a spectrophotometer (Implem NanoPhotometer) and a standard curve made from fluorescein concentration, fluorescein activity was measured at 490 nm.

Data and statistical analysis. Data were reported as the mean accompanied by standard deviation. The experimental data were analyzed by the analysis of variance using software Statistix 8.1 (Analytical Software, Tallahassee, USA). Pearson's correlation coefficients were used to evaluate the correlation between the soil chemical properties, soil microbial activity and corn productivity. The Least Significant Difference (LSD) test was used at a 5% level of significance to assess any significant differences between treatment means.

RESULTS AND DISCUSSION

Characteristics of corn cob biochar and fertilizer enriched biochar (FEB). Biochar is simply the charred remains formed when organic material is heated in an oxygen free environment. The nutrient concentrations in the corn cob biochar are very low with 0.63% N, 0.18% P_2O_5, and 1.92% K_2O (Table 1). After enhancing this biochar with inorganic fertilizer materials, its pH level was modified from 8.60 to 7.85. Though the concentration of organic carbon was maintained at 8.44%, the amount of total NPK in the FEB boosted to 16, 9 and 6%, respectively.

Table 1. Chemical properties of corn cob biochar and N-P-K enriched biochar.

Parameter	Corn cob biochar	Fertilizer enriched biochar
pH	8.60	7.85
Organic carbon (%)	8.44	8.44
Nitrogen (%)	0.63	15.94
Phosphorus, P_2O_5 (%)	0.18	9.14
Potassium, K_2O (%)	1.92	6.12

Chemical characteristics of soil. The pH level of the soil before planting was 4.9 that can be interpreted as strongly acidic (Table 2) (Horneck et al. 2011). Though the cation exchange capacity was categorically high, the soil organic carbon, total N, available P and exchangeable K were at low concentration.

Table 2. Initial properties of the experimental soil.

Parameter	Value	Critical Nutrient Range	Interpretation
pH	4.80	4.5-5.0	Strongly acid
Cation Exchange Capacity ($cmol^{(+)}kg^{-1}$ soil)	30.30	<25.0	high
Soil Organic Carbon (%)	1.96	<2.00	Low
Total nitrogen (%)	0.16	0.10-0.20	Low
Available phosphorus (ppm)	1.00	1.0-3.0	Very deficient
Exchangeable potassium ($cmol^{(+)}kg^{-1}$ soil)	0.46	0.30-0.50	Moderately deficient

The application of corn cob biochar (T2) and FEB (T4, T5, T6) significantly increased the soil pH from its initial level of 4.8 after cropping (Table 3). This may be attributed to the inherent property of biochar which is highly alkaline or due to increased ash accretion which can neutralize acidic soils (Nigussie et al. 2012). There was a slight change in the acidity level of the control treatment whilst a significant upswing on soil pH happened with the addition of mineral fertilizer. Tkaczyk et al. (2020) explained that such results may be attributed to many factors such as the removal of acid and basic cations from the sorption complex that favored active acidity, absorption by plants of NH_4^+, secretion of H^+, nitrification and ammonium volatilization.

The amount of soil organic carbon (SOC) and total N exhibited significant differences across treatments. Both SOC and total N levels were high in soil applied with corn cob biochar and FEB at varying rates. Such results are aligned with other studies (Bruun et al. 2012; Mukherjee and Zimmerman 2013) that the increased level of SOC may be due to the microbial degradation of organic carbon confined in the biochar's porous structure that were released later in the soil. There were also notable variations among treatments in terms of the quantity of total N that remained in the soil after cropping. A study of Kizito et al. (2019) reported that the application of 10 tons ha-^{1} of digestate-enriched corn cob can increase total N by 137%. The main benefit from biochar is its capacity to provide nutrients to the soil, reduce nutrient loss through leaching, and improve nutrient absorption by plants (Lehmann and Joseph 2009).

The FEB application significantly increased the soil available P and exchangeable K after harvest and the increments were directly proportional to FEB application rates. The control treatment consistently showed the least concentration of these major nutrient elements in soil. The elevated P concentration in soil can be attributed to the chemical composition of the fertilizer materials added to biochar that can enhance the availability of P in soil through its liming effect. (Xu et al. 2013).

The movement of soil K in soil varied. It is important to note that the level of exchangeable K of the initial soil was moderately deficient (0.46 $cmol^{(+)}kg^{-1}$) and the CEC (30.30 $cmol^{(+)}kg^{-1}$) was high. After cropping the influence of FEB on the level of exchangeable K demonstrated significant differences with the other treatments. It increased its level from 0.70 to 2.57 $cmol^{(+)}kg^{-1}$ with T1 (control) and T6 FEB 10 tons ha $^{-1}$, respectively, whereas no significant change on CEC between treatments was observed. Such results are consistent with the reports of Kizito et al. (2019) that the simultaneous use of biochar with NPK fertilizers resulted in higher levels of macronutrients particularly potassium, compared to treatments using NPK fertilizers only.

Table 3. Chemical properties of soil at harvest.

Treatments		pH	Soil Organic Carbon	Cation Exchange Capacity	Total Nitrogen	Available Phosphorus	Exchangeable Potassium
			%	**cmol(+)/kg soil**	**%**	**ppm**	**cmol(+)/kg soil**
T1-	Control	4.77±0.21 c	1.43±0.02 b	30.14±2.82 *ns	0.15±0.03 c	4.17±0.25 b	0.70±0.06 c
T2-	Corn cob biochar (5 tons ha^{-1})	4.93±0.06 bc	2.08±0.27 a	31.20±2.98	0.17±0.46bc	4.80±0.70 b	0.77±0.14 c
T3-	Recommended rate of chemical fertilizer	4.33±0.06 d	2.01±0.22 a	30.56±3.89	0.15±0.38 c	6.57±1.10 b	0.79±0.07 c
T4-	FEB (5 tons ha^{-1})	4.89±0.10 c	2.08±0.30 a	30.94±2.21	0.19±0.52ab	16.63±2.40 b	1.55±0.42 b
T5-	FEB (7.5 tons ha^{-1})	5.17±0.23 ab	2.15±0.09 a	32.24±1.34	0.20±0.15 a	38.47±8.31 a	1.93±0.34 b
T6-	FEB (10 tons ha^{-1})	5.20±0.26 a	2.29±0.06 a	30.74±2.43	0.22±0.10 a	46.97±22.12 a	2.57±0.25 a
	Pr>F	0.0002	0.0046	0.9664	0.0030	0.0004	<0.0001
	CV%	2.84	9.65	9.62	9.11	46.05	16.77

In column, means ± SD followed by the same letter(s) do not differ significantly at 5% level by Least Significant Difference test.

Total microbial activity of the soil. Biochar is a habitat for soil microorganisms which can modify the physical and chemical characteristics of biochar, as well as altering the soil physico-chemical characteristics. In the present study, the soil FDA activity ranged from 4.02 to 5.53 ug fluorescein g^{-1} soil (Fig. 1). Across treatments, the soil applied with biochar (T2 and FEB T4-T6) demonstrated a positive impact on the soil microbial activity than in treatments without biochar (T1 and T3).

In a study of Bera et al. (2016), the soil FDA activity in the topsoil was greater by 63% in the NPK + biochar treatment compared to that in NPK treatment. The vast surface area of biochar provides a home for microbial colonization (Luo et al. 2013); and its presence affects soil microbial activities and biomass (Lehmann and Joseph 2009). These findings may be related to the combined effect of labile C and mineral N in the biochar that served as stimulus in enhancing the microbial activities (Chen et al. 2015). El-Naggar et al. (2020) reported that the applications of biochar may increase cropland soil microbial activity and hasten the mineralization of N in the soil.

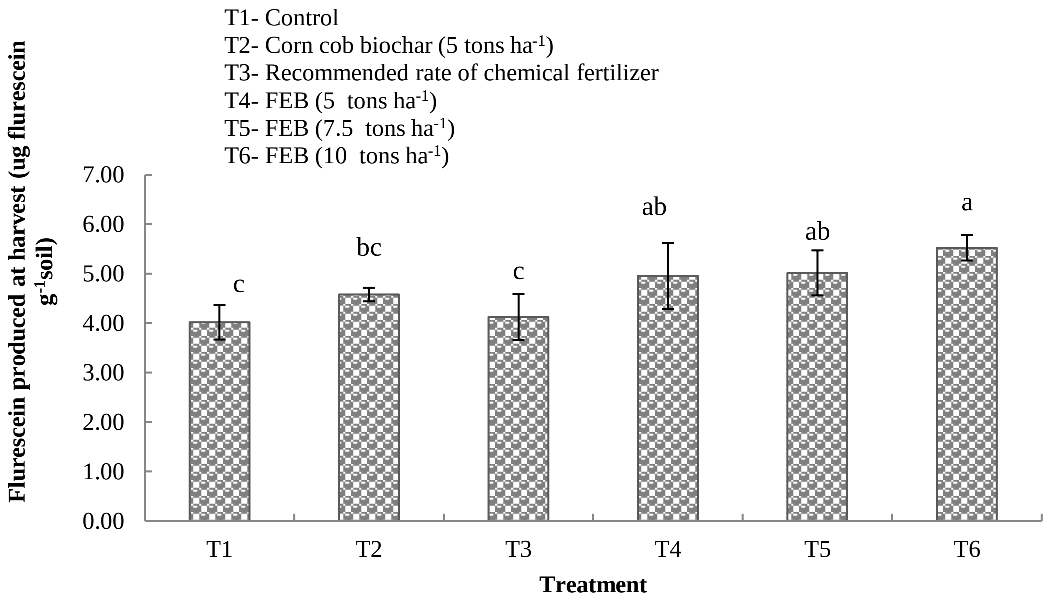

Figure 1. Comparison of the total microbial activity in the soil applied with FEB at the milking stage of corn plant. (*the same letter(s) do not differ significantly at 5% level by Least Significant Difference test).

Corn productivity. The corn plant height displayed normal growth patterns with gradual increase from 14 DAS to 42 DAS (Fig. 2). The significant differences were evident at 14 and 42 DAS ($P<0.05$) and 21 and 28 DAS ($P<0.01$). The tallest plants were observed from the FEB treated pots (T4 and T5) at different growth stages compared with other treatments. Since biochar is neither a fertilizer nor an agricultural chemical (Lehmann and Joseph, 2009), it is evident that T2 had the least plant height. Biochar needs to be applied with a fertilizer to ensure healthy crop growth. Earlier study of Syuhada et al. (2016) supports the present findings that biochar alone cannot give enough nutrients for corn to flourish, and additional fertilizer application are required.

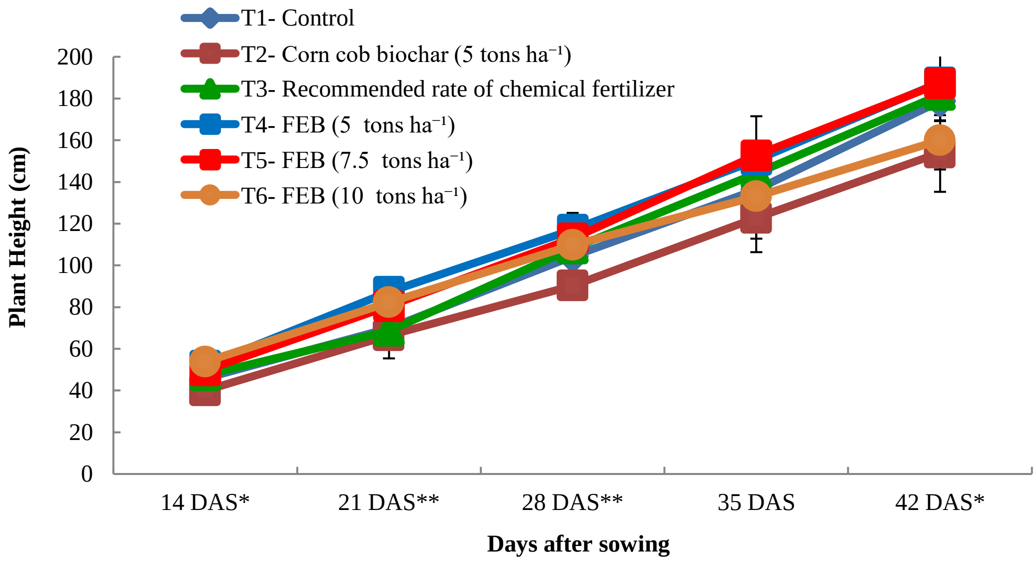

Figure 2. Plant height at different growth stages of corn. (** and * - significant at 1% and 5% level by Least Significant Difference test).

Similarly, the increasing rate of FEB resulted in a continuous increase in leaf numbers at different stages of growth (Fig.3). The least corn leaf numbers were from corn cob biochar treated pots (T2). There was a noticeable distinction among the treatments at 21 and 49 DAS. The highest number of leaves were produced by the plants receiving different rates of FEB (T4, T5, and T6) and recommended rate of chemical fertilizer (T3).

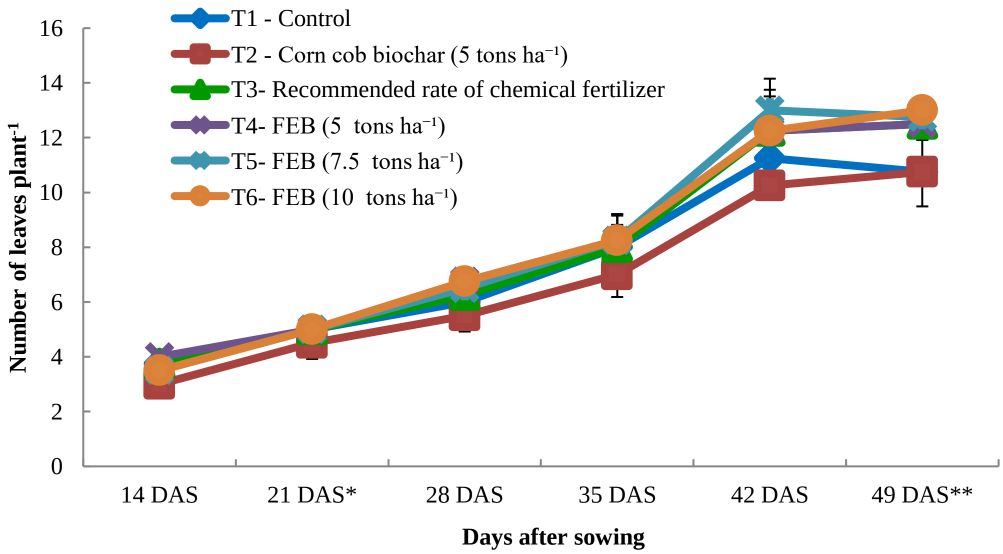

Figure 3. The number of corn leaves at different growth stages. (** and * - significant at 1% and 5% level by Least Significant Difference test).

The relative greenness of corn leaves at milking stage differed significantly between treatments at P<0.01 level of significance (Fig. 4). This study revealed that the chlorophyll content was significantly greater on plants applied with lower FEB (5 tons ha^{-1}) than FEB 7.5- and 10-tons ha^{-1} both at milking stage and at harvest. Results such as these were explained by Gul et al. (2015) that the application of biochar can improve plant photosynthesis rates and the amount of biochar applied will affect the synthesis of food into chemical energy essential to promote plant growth.

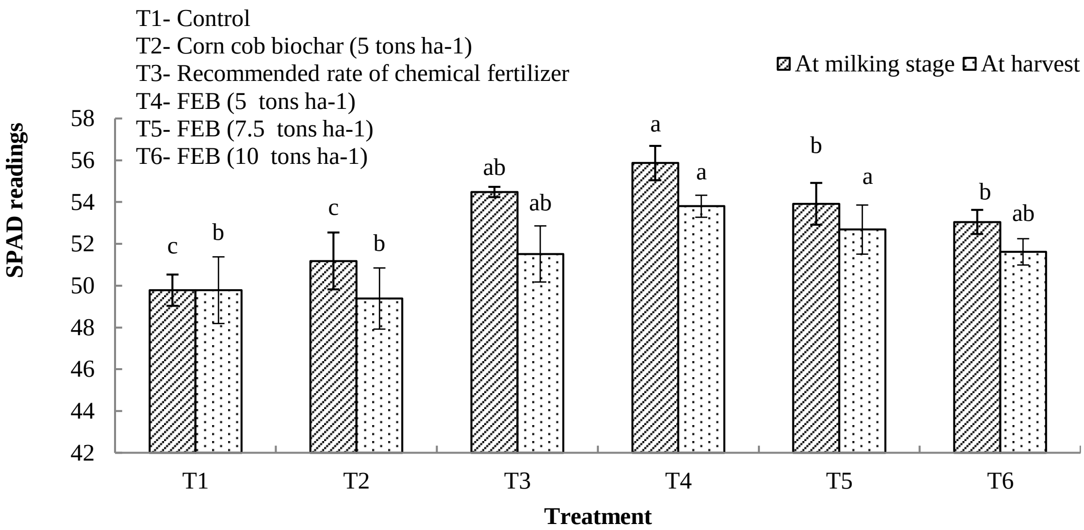

Figure 4. SPAD readings at different growth stages of corn plant. (*the same letter(s) do not differ significantly at 5% level by Least Significant Difference test).

The effects of different treatments on yield components are presented in Table 4. The corn plant with the longest fruit was observed on FEB 5 tons ha^{-1} (T4) treated pots with 141.02 mm. The value was statistically identical with FEB 7.5 tons ha^{-1} (T5) with 133.13 mm. The number of kernels per row varied significantly between treatments. A similar pattern was shown by FEB treatments with the highest number of kernels per row and the heaviest fruit both from FEB 5 tons ha^{-1} (T4). As an indicator of the crop's response to the application of N fertilizer and soil nutrient condition, the leaf chlorophyll content is correlated with the concentration of N in green plants (Minotta and Pinzauti 1996). Fresh fruit weight was lowest in the control (T1), followed by corn cob biochar (T2) with 88.67g $plant^{-1}$. The plant biomass ranged from 19.22 to 32.92 g $plant^{-1}$ with a mean value of 27.27 g $plant^{-1}$ (Fig. 5). Among the treatments, T4 and T6 provided higher plant biomass. Consequently, the corn plants applied with FEB displayed greener foliage than those treatments without N fertilizer (T1 and T2). The application of higher rates of biochar with fertilizers resulted in an increased leaf chlorophyll content which enabled the enhancement of plant biomass and yield. Such findings may be attributed to the improved availability of soil N and consequently transported into the corn leaves yielding high N content (Hua et al. 2012). In this study, the soil amended with FEB enhanced the mobility of soil N that eventually increased the leaf chlorophyll and other related corn yield parameters.

Furthermore, the FEB and mineral fertilizer treatments produced heavier ears than the control and biochar alone (Fig. 6). The application of biochar and NPK fertilizers that resulted in a significant increase in corn growth parameters is suggesting a robust synergistic interaction between biochar and NPK fertilizer. The increase in the yield of maize has a direct correlation with the use of biochar (Faloye et al. 2017). The corn fruit weight ranged from 23.88 to 42.14 g $plant^{-1}$. The FEB 5 tons ha^{-1} (T4) exhibited longer and heavier fresh fruits with greater number of kernels than other treatments. Though the difference between FEB treatments and T3 was not significant, the corn plants did not respond positively to higher rates of added fertilizers. Yao et al. (2012) explained that the negatively charged surface of the biochar is not limitless for all these cationic nutrients from the fertilizers be adsorbed in the exchange sites, hence, there is an incomplete utilization of nutrients by plants.

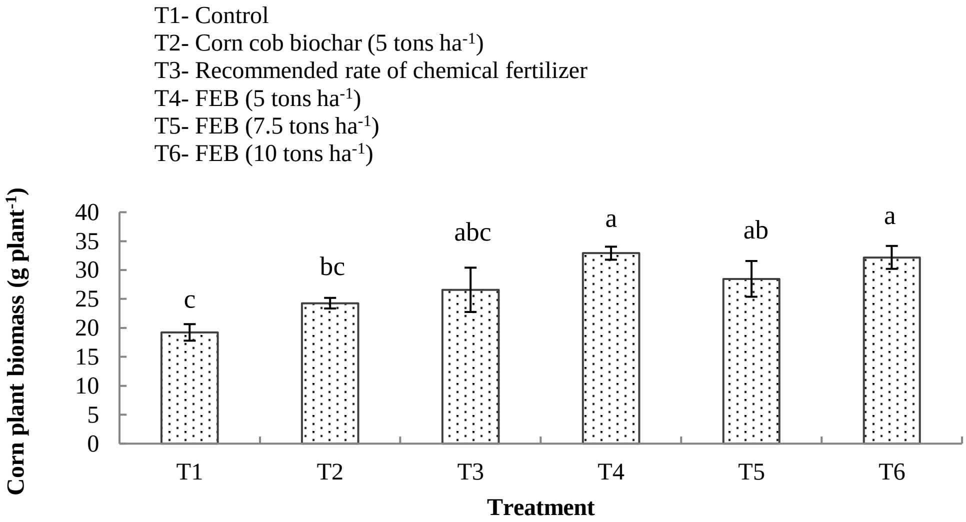

Figure 5. Corn plant biomass at harvest. (*the same letter(s) do not differ significantly at 5% level by Least Significant Difference test).

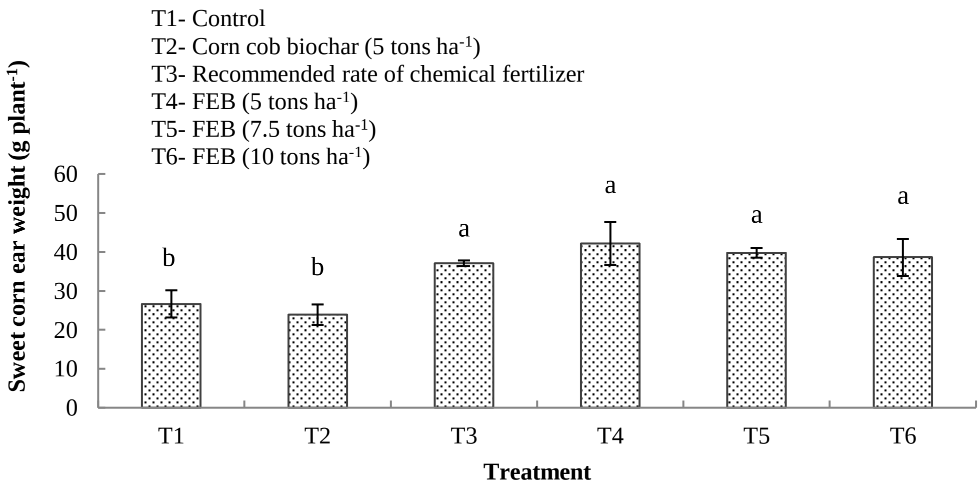

Figure 6. Corn weight. (*the same letter(s) do not differ significantly at 5% level by Least Significant Difference test).

Table 4. Yield and yield components of corn.

	Treatments	Ear Diameter (mm)	Ear Length (mm)	No. of kernels row^{-1}	No. of rows ear^{-1}	Fresh Ear Weight (g plant^{-1})
T1-	Control	52.27±7.16	116.49±6.56 bc	14.47±1.41 c		106.00±15.10b c
T2-	Corn cob biochar (5 tons ha^{-1})	43.03±8.22	101.19±13.27 c	14.67±1.78 c	9.50±1.00	88.67±1.15 c
T3-	Recommended rate of chemical fertilizer	53.73±7.20	127.02±8.30 ab	19.20±3.76 ab	10.50±1.00	126.00±13.11 ab
T4-	FEB (5 tons ha^{-1})	58.91±2.18	141.02±10.25 a	20.44±3.36 a	11.25±1.50	144.67±11.72 a
T5-	FEB (7.5 tons ha^{-1})	57.87±2.15	133.13±9.32 a	18.91±3.92 ab	10.75±0.96	139.33±5.77 a
T6-	FEB (10 tons ha^{-1})	53.80±10.18	111.21±13.99 bc	16.63±4.45 bc	10.67±0.94	132±14.42 a
	Pr>F	0.0820	0.0010	0.0167	0.4390	0.0019
	CV%	13.55	8.83	14.43	11.96	10.11

In column, means ± SD followed by the same letter(s) do not differ significantly at 5% level by Least Significant Difference test.

Nutrient concentration in corn. The incorporation of high rate of fertilizers has led to significant and greater concentrations of major essential nutrients, and FEB T6 gave the highest concentration of total N and P in both stalk and fruit (Fig. 7 and Fig. 8). There was no notable variation in the nutrient concentrations between other treatments. The response of corn plant to applied FEB T6 (10 tons ha^{-1}) may be associated to the combination of biochar and high amount of mineral fertilizers that directed to an increased absorption of available N by plants, surpassing the effects of applying either fertilizer or biochar alone (Ibrahim et al. 2020). The simultaneous utilization of fertilizer and biochar was exhibited to improve plant N uptake, and this may be due to the enhanced retention of NH_4 by biochar (Van Zwieten et al. 2010).

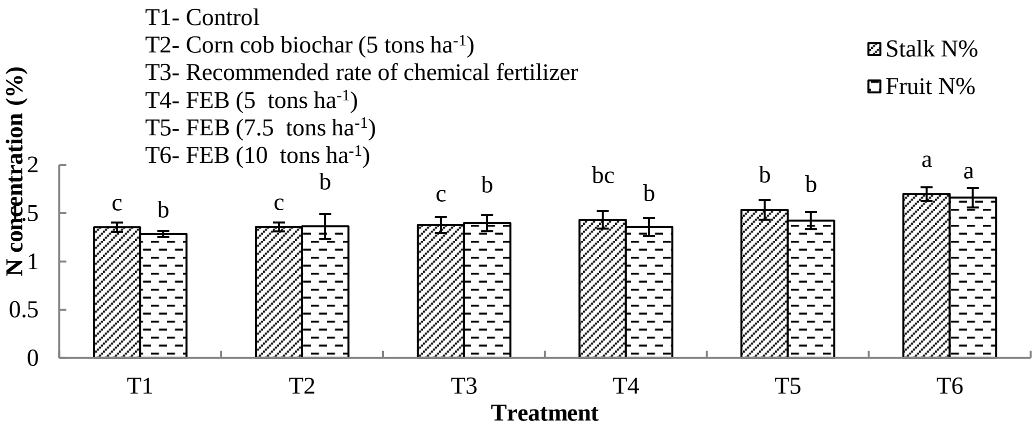

Figure 7. Nitrogen concentration of corn at harvest. (*the same letter(s) do not differ significantly at 5% level by Least Significant Difference test).

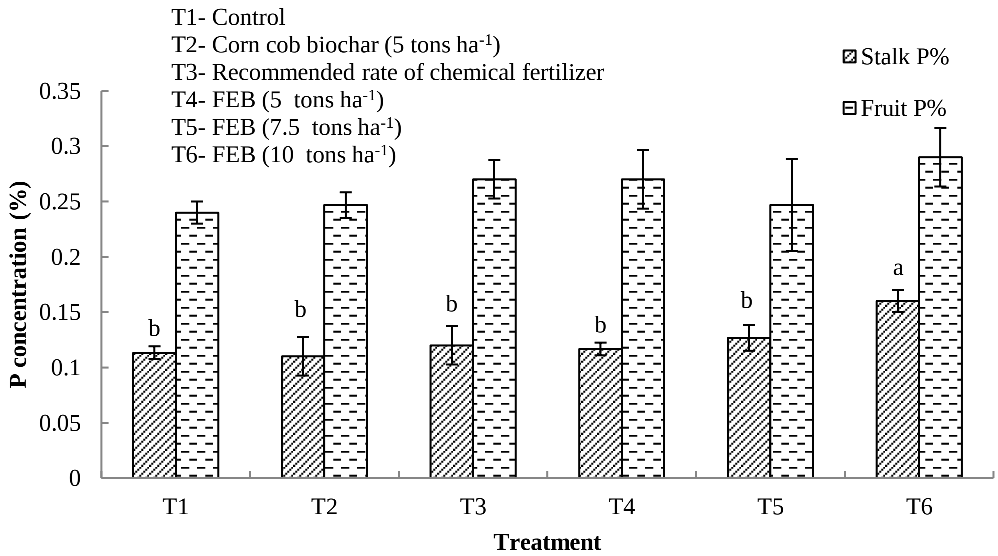

Figure 8. Phosphorous concentration of corn at harvest. (*the same letter(s) do not differ significantly at 5% level by Least Significant Difference test).

A substantial influence of applied FEB on the uptake of total K in the corn stalk and fruit is shown in Figure 9. Analogous to total N and total P concentration in corn plant, the FEB T6 displayed the highest amount of total K in both corn stalk and fruit. Kizito et al. (2019) reported that the utilization of enriched biochar headed to a greater supply of macronutrients, leading to better uptake of P and K.

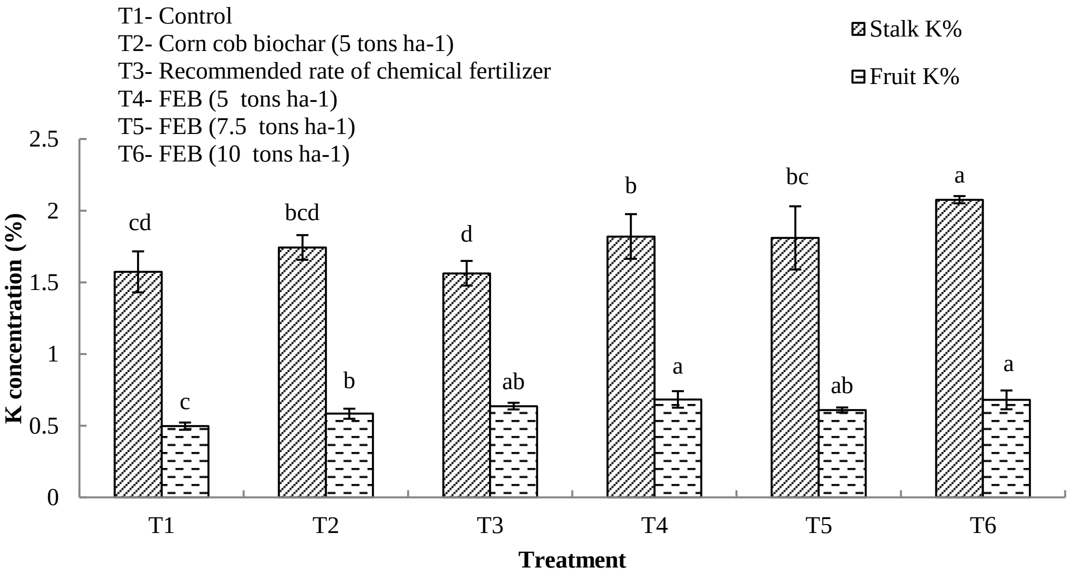

Figure 9. Potassium concentration of corn at harvest. (*the same letter(s) do not differ significantly at 5% level by Least Significant Difference test).

Relationships between soil chemical properties, soil microbial activity and corn productivity. The relationship between soil chemical characteristics, soil microbial activity, and corn productivity, influenced by FEB treatment is presented in Table 5. Positive relationship was observed between soil microbial activity and pH ($P<0.05$) and total nitrogen, available phosphorous and exchangeable potassium ($P<0.01$). Results such as these were supported by the reports of Bera et al. (2016) that biochar addition had significant effects on soil chemical, biochemical and microbiological properties. The highest correlation (r = 0.99**) was found between microbial activity and soil total nitrogen. A positive relationship was observed between soil properties and corn yield. Corn yield was significantly and positively correlated with ear diameter, ear length, and number of kernels row^{-1} (r=0.95**, r=0.84* and r=0.87*). However, no significant differences existed between yield and number of rows ear^{-1} though they were positively correlated.

Moderate positive relationships were observed between SOC with other soil parameters (r = 0.5-0.7), while high correlation was found with both total N and soil microbial activity (r = >0.7). Total nitrogen, available phosphorous and exchangeable potassium exhibited a substantial and positive correlation with one other ($P<0.01$).

The study found a positive correlation between soil characteristics and nutrient concentration in corn after harvest as influenced by different application rates of FEB (Table 6). Soil total nitrogen was highly correlated with nitrogen and potassium concentration in corn stalk (r=0.91* and r=0.97**). A strong positive relationship was detected between total P and total N concentration in corn stalk and fruit; total P concentration in stalk; and total K concentration in stalk. However, only moderate correlation occurred between available P content in soil and phosphorous concentration in fruit. Exchangeable K content in soil was significantly related to total N in all plant parts, total P and total K in stalk. There was a high and moderate correlation between total P concentration in fruit and other parameters.

Table 5. Correlation between soil chemical properties, soil microbial activity and corn productivity.

	pH	SOC	CEC	TN	Av.P	Ex.K	FDA	ED	EL	NKR	NRE
SOC	0.42										
CEC	0.55	0.57									
TN	0.85*	0.74	0.50								
Av.P	0.75	0.65	0.49	0.93**							
Ex.K	0.75	0.68	0.40	0.97**	0.98**						
FDA	0.82*	0.79	0.47	0.99**	0.89**	0.94**					
ED	0.10	0.13	0.19	0.36	0.47	0.50	0.30				
EL	-0.14	0.08	0.26	0.10	0.13	0.18	0.06	0.90*			
NKR	-0.14	0.47	0.34	0.26	0.26	0.32	0.26	0.78	0.89*		
NRE	0.00	-0.38	-0.26	0.07	0.17	0.23	0.01	0.82*	0.68	0.38	
Yield	0.19	0.44	0.30	0.55	0.61	0.66	0.52	0.95**	0.84*	0.87*	0.63

SOC-Soil organic carbon, CEC-Cation exchange capacity, TN-Total nitrogen, Av.P-Available phosphorous, Ex.K-Exchangeable potassium, FDA – Fluorescein diacetate, ED-Ear diameter, EL-Ear Length, NKR-No. of kernels row^{-1}, NRE-No. of rows ear^{-1}, ** and *-significant at 1% and 5% level.

Table 6. Pearson's correlation coefficient among soil properties and nutrient concentration in corn after harvest.

	TN	Av.P	Ex.K	SN	FN	SP	FP	SK
Av.P	0.93**							
Ex.K	0.97**	0.98**						
SN	0.91*	0.96**	0.97**					
FN	0.78	0.83*	0.84*	0.93**				
SP	0.77	0.87*	0.87*	0.96**	0.97**			
FP	0.54	0.51	0.62	0.67	0.80	0.75		
SK	0.97**	0.85*	0.92**	0.90*	0.84*	0.81*	0.62	
FK	0.65	0.54	0.65	0.58	0.65	0.54	0.85*	0.65

TN-Total nitrogen, Av.P-Available phosphorous, Ex.K-Exchangeable potassium, SN-Stalk N%, FN-Fruit N%, SP-Stalk P%, FP-Fruit P%, SK-Stalk K%, FK-Fruit K%, ** and *-significant at 1% and 5% level.

CONCLUSION

The FEB can be prepared using locally available materials. Enriched biochar greatly enhanced the soil quality by increasing soil organic carbon levels and providing essential macronutrients, in contrast to unenriched biochar, chemical fertilizer, and control treatments. It can also improve the soil microbial activity. Consequently, corn applied with nutrient enriched biochar, even at a lower application rate achieved better growth and higher yield than chemical fertilizer alone. The enrichment of biochar with chemical fertilizers stimulated nutrient concentration and improved soil nutrient balance more effectively than the application of biochar or fertilizer alone. The utilization of FEB enhanced the nutritional levels of the corn plant in the stalk and fruit. This study has demonstrated a novel way to use fertilizer enriched biochar as a highly effective soil ameliorant. In a corn-based production system, it is recommended to apply a fertilizer enriched biochar at the rate of 5 tons ha^{-1} for increased yield and improved soil quality. Nevertheless, this study was conducted over a limited period. Therefore, additional cross-disciplinary investigations are necessary to evaluate the long-term and field-scale impacts of FEB on plant productivity.

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