PHILIPP AGRIC SCIENTIST
Vol. 106 No. 2, 103-115
June 2023

ISSN 0031-7454

# Corn Cob and Corn Husk Biochars Enhance the Growth of Corn (*Zea mays* L.) in Fertilized Clay Loam Soil

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Received: April 29, 2022/ Revised: March 14, 2023/ Accepted: March 22, 2023

**Biochar is a carbon (C) rich material that improves soil quality, increases crop yield, and is produced from biomass pyrolysis under a limited oxygen environment. An experiment laid out in a split-plot, a completely randomized design (CRD) and was conducted to investigate the growth responses of corn-to-corn cob biochar (CCB) (15 t ha$^{-1}$), and corn husk biochar (CHB) (15 t ha$^{-1}$) in a Lipa clay loam soil (*Typic Eutrudepts*) applied with organic fertilizer (OF) (10 t ha$^{-1}$) and inorganic fertilizer [recommended rate (RR):120 N;60 $P_2O_5$-60; $K_2O$ per ha]. The results showed that CCB and CHB are rich in macro- and micro-essential elements. The Brunauer-Emmett-Teller (BET) analysis showed the high average surface area, high pore radius, and pore volume of biochars. The field emission-transmission electron microscopy (FE-TEM) and X-ray energy dispersive spectroscopy (EDS) showed a very high concentration of C (88 – 90%) and other elements (Cu, Na, K, Cl, S, Si, P, Ca, O) for the biochar. The CCB and CHB applied with organic and inorganic fertilizers improved the pH, EC, and nutrient status of the clay loam soil. This was evident in the enhanced growth of the plants (corn ear biomass, root biomass, and plant height) and increased leaf chlorophyll concentration. The CCB and CHB with organic and inorganic fertilizer applications are recommended for clay loam soil as they improve both the soil health and the plant growth.**

**Keywords:** corn cob, corn husk, biochar properties, fertilizer, clay loam

**Abbreviations:** BET—Brunauer-Emmett-Teller, CEC—cation exchange capacity, CCB—corn-to-corn cob biochar, CHB—corn husk biochar, EC—electrical conductivity, EDS—energy dispersive spectroscopy, FE-TEM—field emission-transmission electron microscopy, HAABF—high angle annular bright field, MC—moisture content, OC—organic carbon, OM—organic matter, SBD—soil bulk density, WHC—water holding capacity

## INTRODUCTION

One of the current global challenges is supplying food for the growing population while maintaining the integrity and sustainability of natural resources such as the soil systems. The research findings of Lehmann et al. (2011) suggest that biochar improves soil health, sequesters soil carbon (C), and enhances plant growth. Biochar is a carbon-rich material produced by biomass pyrolysis under limited oxygen (Lehmann et al. 2011; Villegas-Pangga 2021). It is composed of recalcitrant C structures that prevent decomposition and help sequester C in soils, improving soil and agronomic properties (Lehmann et al. 2011). Additionally, biochar has a large charged surface area with a great potential to adsorb heavy metals and organic contaminants. Its application decreases the bioavailability, toxicity, and mobility of organic and inorganic pollutants (Nartey and Zhao 2014). Thus, biochar can improve the quality of cultivated soils and enhance crop yields.

As a soil amendment, biochar is known to improve physical, chemical, and biological properties in soil. Biochar application increases soil pH, porosity, and water holding capacity (WHC) and stabilizes soil organic matter (OM) through increased soil aggregation as well as reduced soil bulk density (SBD) and tensile strength (Hussain et al. 2016). Furthermore, increased soil WHC, decreased SBD, and increased soil porosity by biochar application are soil physical improvements that can help achieve better root growth and development through improved soil structure. The effect of biochar on SBD is found to be positive in heavy soils (Ventura et al. 2012). The increased soil porosity and water holding capacity of the soil due to the high surface areas of biochars increased the soil-available water where the nutrients are suspended, thus increasing the nutrient uptake by plants (Hseu et al. 2014).

While biochar application improves soil pH, it also increases soil nutrient retention capacity, increasing $NH_4^+$ and P concentrations, and decreasing $NO_3^-$ in soil (Adekiya et al. 2020). Reduction of the leaching of nutrients from the soil translates to increased soil productivity and soil quality by removing the contaminants, improving nutrient cycling and bioavailability for plants, changing the microbial populations, and stimulating the soil's microbial activity (Surampalli et al. 2015). Increased microbial biomass promotes the mineralization of the more labile components of biochar, making it available for plants over the short term. Over the long term, the biochar-soil interaction may improve soil C, affecting nutrient cycling (Villegas-Pangga 2021). Previous studies have also shown that biochar stimulates plant growth and increases fertilizer efficiency, especially when added to organic fertilizers such as compost. Retaining the nutrients in the soil from other sources is effective when mixed with biochar. Research findings suggest positive effects of biochar on the growth of crops if nutrient sources such as inorganic and organic fertilizers are used (Liu et al. 2022; Rivelli and Libutti 2022). For instance, maize grain yields were significantly improved by the amount of biochar applied at 2.5 t $ha^{-1}$ and 5 t $ha_{-1}$ with three application rates of N, P, and K (90-60-600, 45-30-30, and 0-0-0 respectively) (Yeboah et al. 2016). Rivelli and Libutti (2022) indicated that the co-application of biochar and vermicompost improves Swiss chard yield while preserving its nutritional and health qualities. Other findings suggest that biochar, with different levels of chemical NPK fertilizers, can better retain N and C in the soil while reducing N loss. Biochar can also boost N uptake by maize, in which N recovery rates of 74 – 80% were observed in treatments with 3 and 6 t $ha^{-1}$ biochars combined with chemical fertilizers, resulting in a significant annual increase of maize yields (Peng et al. 2021). Thus, biochar may have a significant potential to improve maize yield especially if the associated type of fertilizer is carefully considered (Peng et al. 2021).

Previous studies stated the benefits of biochar, however, there is a limited data about the effects of biochar physico-chemical properties, specifically in clay loam soil and the crops planted in it (Blanco-Canqui 2017). This study was conducted to determine the effect of corn cob biochar and corn husk biochar applications on the growth of corn grown in a clay loam soil with organic and inorganic fertilizers. Specifically, this study hypothesized that adding CCB and CHB along with organic and inorganic fertilizers would enhance corn growth.

## MATERIALS AND METHODS

### Soil and Pot Preparation

A sample of Lipa clay loam soil (*Typic Eutrudepts*) of volcanic origin was collected from an uncultivated site in Barangay Tranca, Los Baños, Laguna, Philippines. The soil was air-dried and organic debris was removed, sieved (2 mm), and placed in pots within 3 wk from collection. The pots were 30 cm diameter x 30 cm height x 20 cm base with a perforated bottom to drain excess moisture. Each pot was filled with 12 kg of soil.

### Feedstock Collection and Biochar Production

Corn cobs and corn husks were collected from the Agricultural Science Institute (ASI) Composting and Demonstration Area, Pili Drive, University of the Philippines Los Baños (UPLB). The corn cobs and corn husks were air-dried for 7 d to remove the excess moisture. After drying, the corn cobs were chopped into small pieces (3 – 5 cm) before heat treatment. Four kilogram air-dried corn cobs (13.00% moisture content [MC]) and 1 kg corn husk (11.90% MC) were slowly pyrolyzed in the biochar-producing cookstove for 60 and 30 min heating residence time, respectively. The inlet of the cookstove vessel controlled the air entry maintaining the temperature ranging from 300 – 650°C (Villegas-Pangga 2021). The heating temperature was measured at different time intervals using the K-type thermocouple (Villegas-Pangga 2021). The percentage biochar yield on a dry basis was computed using the equation:

$$Yield_{biochar}\ (\%) = [M_{biochar}/M_{raw}] \times 100$$

where $Yield_{biochar}$ is the mass yield of biochar (%), $M_{biochar}$ is the mass of biochar (kg), and $M_{raw}$ is the mass of raw feedstock biomass (kg).

### Fertilizers and Biochar Application

Inorganic and organic fertilizers and biochars were weighed based on the recommended rates of inorganic fertilizer (RR:120N–60 $P_2O_5$–60 $K_2O$ kg/ha); organic fertilizer (OF) (10 t $ha^{-1}$) produced from agrowastes with chemical analysis of OC (4.97%), total N (1.23%), total P (4.43%) total K (2.94%), total Ca (5.40%), and total Mg (0.26%); CCB (15 t $ha^{-1}$); and CHB (15 t $ha^{-1}$), respectively, using a 0.1 mg accuracy, 160 g laboratory digital balance scale (Table 1). The organic fertilizer and the biochars (CCB and CHB) were added to the soil before planting as a basal application. For the inorganic fertilizer treatments, (P) phosphorus and (K) potassium were added as a basal application before planting together with CCB and CHB, while a split application of N fertilizer was made a week after the seedling emergence and 30 d after sowing with 50% of the total (N) nitrogen volume per application, respectively.

## Chemical Analyses of Soil, Biochars, Organic Fertilizer, and Plant Tissues

The clay loam soil was analyzed for organic carbon (OC), available phosphorus (P), exchangeable potassium (K), cation exchange capacity (CEC), electrical conductivity (EC), biochars for pH, OC, total P, total K, total calcium (Ca), total magnesium (Mg) and micronutrients iron (Fe), zinc (Zn), copper (Cu), manganese (Mn) organic fertilizer for total nitrogen (N), total P, total K, total Ca, total Mg, and plant tissue for total N, total P, and total K. Soil pH was measured using a soil-water mixture ratio of 1:1 w/v, while biochar pH was measured using a 10:1 biochar-water ratio (w/v) for CCB and CHB using a glass electrode pH meter. Soil EC was measured at soil-water ratio 1:1 (w/v) (Piper 1942). The CEC was measured by the ammonium acetate method (Peech 1945), organic matter (OM), and organic C by the Walkley and Black method (Jackson 1958), available P using the Olsen method (Jackson 1958; Bray and Kurtz 1945) and Bray method (Bray and Kurtz 1945), and exchangeable K using a flame photometer (Peech 1945).

Total soil N was measured by the Kjeldahl method (Grewling and Peech 1960), total P by the Vanadomolydate method (Kitson and Mellon 1944), total K by flame photometer (Peech 1945), total Ca by the Ethylenediaminetetraacetic Acid (EDTA) method (Cheng and Bray 1951), total Mg by Titration of Calcium plus Magnesium with EDTA (Cheng and Bray 1951), and elements (Fe, Zn, Cu, and Mn) were measured using an atomic absorption spectrophotometer (Russel et al. 1957).

The chemical properties of soil, CCB, CHB, OF, and plant tissues were analyzed at the Analytical Service Laboratory, UPLB, Laguna, Philippines.

## Brunauer–Emmett–Teller (BET) and Transmission Electron Microscope (TEM)-TEM Imaging and Energy Dispersive X-ray Spectroscopy (EDS) of CCB and CHB

The BET analysis for corn cob and corn husk biochars was performed to determine the physical adsorption of gas molecules on their solid surfaces, which serves as the basis for a critical analysis technique for measuring the average surface area, pore size, and pore volume of corn cob and corn husk biochars. The Quanta Chrome Nova 22200BET automated N multilayer physisorption system was used in the analysis at the Nanotechnology Laboratory, University of the Philippines Los Baños (UPLB). The larger biochar sample was thoroughly mixed and then oven-dried for 24 h at 105°C. A 100 mg dried subsample was transferred to a round bottom powder cell sample holder and then subjected to an automated degassing system at 300°C at varying times. After the degassing, the subsample was subjected to a multi-point BET to determine the average surface area, average pore radius, and average pore volume.

The TEM imaging was performed to determine the composition of C and other abundant essential elements located in discrete spots on the CCB and CHB surfaces by obtaining the high angle annular bright field (HAABF) images. The surface morphology of biochar samples was viewed at different magnifications from 1,000 – 40,000x using the JEOL JEM-2100F FE-TEM at the Materials Science Division, Industrial Technology Development Institute - Department Science and Technology, General Santos Avenue, Bicutan, Taguig City Philippines.

## Corn Cultural Management

The corn variety planted was "Macho F1" sweetcorn, which matures 70 – 75 d from planting. Two seeds of corn were directly sown per pot and thinned after 7 d after sowing, leaving one plant in each pot. The pots were watered every day and maintained at 45 – 50% soil water holding capacity by allowing the excess water to drain naturally from the pots to attain the field capacity. Pots were randomly arranged equidistantly to each other to have uniform spacing for equal exposure to sunlight.

## Plant Parameters

A measure of the greenness of the corn leaves was measured as a surrogate for chlorophyll concentration using a Minolta SPAD 502 chlorophyll meter. This handheld device is used for rapid, accurate, and non-destructive chlorophyll concentration determination by measuring the difference between a red (650 nm) and an infrared (940 nm) light through the leaf generating the SPAD values (Uddling et al. 2007). Plant height was measured using a meter stick at a weekly intervals. Fresh corn ears obtained at harvest as one of the yield components were weighed. The fresh vegetative shoot and root systems were also weighed. The corn ears, vegetative shoot, and root systems were then oven-dried at 60°C for 72 h and weighed. All weight measurements were made using a Cole-Parmer Symmetry PR-Series

Precision Toploading Balance (4200g x 0.01g). The corn ear and vegetative shoot weights were added to obtain the total shoot weight, adding the total shoot and root biomass to obtain the whole corn plant biomass.

Morphological measurements were conducted at harvest time. A TS Pro USB Digital Microscope 20 – 200 Magnification, UM012B, was used to visualize the root and root hairs. The plant samples were air-dried to remove partial moisture and later oven-dried at 60°C until a constant dry weight was achieved.

### Experimental Design

The experiment was laid out in a split-plot organic vs. inorganic fertilizer in a completely randomized design (CRD). The treatments with specific amounts of biochars and fertilizers were computed based on respective recommended rates are shown in Table 1.

### Data and Statistical Analysis

The data were analyzed using a two-way analysis of variance (ANOVA) for fertilizer and treatment within fertilizer and fertilizer x treatment interactions and the least significant differences (LSD) through the Statistical Tool for Agricultural Research (STAR) 2.0.1 software developed by the International Rice Research Institute. The differences between treatment means within a type of fertilizer were determined at a 5% level of significance by LSD.

**Table 1. Experimental treatments of potted corn setup.**

| Treatments | | Biochar (g) | Organic Fertilizer | Inorganic Fertilizer (g) | | |
|---|---|---|---|---|---|---|
| | | | | N | $P_2O_5$ | $K_2O$ |
| Inorganic Fertilizer + Biochars | | | | | | |
| T1 | Control (soil alone) | - | - | - | - | - |
| T2 | Recommended Rate (RR) (120-60-60) | - | - | 0.72 | 0.36 | 0.36 |
| T3 | CCB (15 t $ha^{-1}$) + RR | 90 | - | 0.72 | 0.36 | 0.36 |
| T4 | CHB (15 t $ha^{-1}$) + RR | 90 | - | 0.72 | 0.36 | 0.36 |
| Organic fertilizer + Biochars | | | | | | |
| T1 | Control (soil alone) | - | - | - | - | - |
| T2 | Organic fertilizer (OF) (10 t $ha^{-1}$) | - | 60 | - | - | - |
| T3 | CCB (15 t $ha^{-1}$) + OF | 90 | 60 | - | - | - |
| T4 | CHB (15 t $ha^{-1}$) + OF | 90 | 60 | - | - | - |

**Table 2. Initial load weight, residence time, moisture content, biochar yield and weight of CCB and CHB obtained.**

| Feedstock | Corn Cob | Corn Husk |
|---|---|---|
| Feedstock moisture (%) | 13.00 | 11.90 |
| Initial load weight (kg) | 4 | 1 |
| Residence time (min) | 60 | 30 |
| Biochar yield (%) | 43.75 ± 0.30 | 56.20 ± 0.03 |
| Weight of biochar yield (kg) | 1.75 ± 0.01 | 0.56 ± 0.02 |

## RESULTS

### Biochar Production

The slow pyrolysis characteristics for the production of corn cob and corn husk biochars are shown in Table 2. It took more time for corn cobs to be pyrolyzed into CCB because they were denser than leafy corn husks. There were variations in the initial load weights of the different feedstocks due to the varying bulkiness of the material. The quality and recovery of biochar after burning varied due to the different natures of the feedstocks. The CHB, a leafy feedstock, had higher recovery (56%) than CCB (43%).

### Soil Chemical Properties

The Lipa clay loam soil had a 5.9 pH and was interpreted as moderately acidic (Table 3). It had moderate OM content at 2.99%, low available P, and total Ca and Mg, and high exchangeable K. Moreover, the micro-essential elements showed high concentrations of Fe, Zn, Mn, and a low concentration of Cu. The cation exchange capacity (CEC) was considerably high at 30.51 meq 100 $g^{-1}$ soil.

### Chemical Properties of Biochars

The pH of CCB and CHB ranges were 9.8 and 10.1, respectively (Table 4). Both biochars contained high macro-essential elements such as P, K, Ca, and Mg. Micronutrients such as Fe, Zn, Cu, and Mg were high in both biochars. This study showed that the chemical properties of biochars vary depending on the nature of feedstock and residence time.

### Organic Fertilizer Chemical Properties

The OF had high OC and very high total N, K, and Ca at 4.97, 1.23, 2.94, and 5.40 %, respectively (Table 5). However, both total of P and Mg were low at 4.43 and 0.26%. Many soil characteristics such as soil color, CEC, nutrient turnover, and stability, which affect water relations, aeration, and workability, were influenced by OC, making the OC content of organic fertilizer of equal or greater importance than its N and P contents.

#### CCB and CHB BET Physisorption Analysis

The surface areas of CCB and CHB were 10 $m^2/g$ and 3 $m^2/g$, respectively (Table 6 and Fig. 1). Varying surface areas could be related to the pyrolysis temperature residence duration depending on the characteristic of the feedstock material. The pore sizes of CCB and CHB were 21 Å and 19 Å, respectively. A slight difference between the pore sizes of both biochars was observed but generally possess high average pore sizes. Surface area increases with higher pyrolysis temperatures linked to creating pores and cracks in the biochars' basal-structural sheet.

**Table 3. Chemical properties of Lipa clay loam soil.**

| Chemical Properties | pH | OC | P | K | Ca | Mg | CEC | Fe | Zn | Cu | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | meq 100 $g^{-1}$ soil | | | | ppm | | | |
| Lipa clay loam | 5.90 | 1.74 | 7.20 | 1.44 | 9.63 | 6.16 | 30.51 | 113 | 6 | 12 | 103 |

**Table 4. Chemical properties of CCB and CHB obtained using the slow pyrolysis biochar-producing cookstove.**

| Biochars | pH | N | OC | P | K | Ca | Mg | Fe | Zn | Cu | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | | | | | ppm | | | |
| CCB | 10.10 | 1.37 | 8.76 | 0.67 | 2.70 | 0.22 | 0.51 | 1024 | 220 | 14 | 85 |
| CHB | 9.80 | 0.74 | 6.07 | 0.27 | 1.35 | 0.11 | 0.06 | 324 | 53 | 12 | 20 |

## CCB and CHB TEM Analysis

The analysis of the biochar particles using TEM showed heterogeneity in both the presence of dominant elements as indicated in the TEM images and the percent by weight of each component (Fig. 2 c-d and 3 c-d). Both CCB and CHB are highly heterogeneous, and different particles have unique and complex compositions. The properties of CCB and CHB are a function of the initial feedstock of heating duration and heat treatment temperature as well as the environment within the biochar-producing cookstove. The high angle annular bright-field (HAABF) spectrum on the areas of interest A of the biochar sample revealed that C is the most abundant element in CCB (88.4%) and CHB (90%) analyzed with EDS in weight percent (wt %) (Fig. 2c and 3c). The EDS also revealed the presence of some essential micro-elements such as Si, Cu, and K.

A significant increase in soil pH was observed with the application of both biochars mixed with organic or inorganic fertilizers (Table 7). The highest pH value (6.4) was observed with OF application (OF alone (T2) and CCB + OF (T3) and inorganic fertilizer (RR) with CCB (T3), followed by CHB + OF (pH 6.3), CHB + RR (pH 6.2), while RR alone (T2) had the lowest pH value among treatments (6.0). Among RR treatments, RR alone was lower than the control while CHB + RR was higher than the control and was different from CHB. Among OF treatments, OF and CCB were higher than the control but were not different from CHB. The fertilizers x treatments interaction was significantly different, where the OF treatments were significantly higher than the RR treatments ($p \leq 0.05$).

**Table 5. Chemical Properties of the organic fertilizer.**

| Parameters | Concentration (%) |
|---|---|
| Organic C (OC) | 4.97 |
| Total N | 1.23 |
| Total P | 4.43 |
| Total K | 2.94 |
| Total Ca | 5.40 |
| Total Mg | 0.26 |

**Table 6. Summary of results of BET characterization on CCB and CHB average surface area ($m^2$/g), average pore size/ radius (Å), and average pore volume ($cm^3$/g) shown in Fig. 1.**

| Biochars | Average Surface Area ($m^2$/g) | Average Pore Size/Radius (Å) | Average Pore Volume ($cm^3$/g) |
|---|---|---|---|
| CCB | 10.416 | 21.496 | 0.002 |
| CHB | 3.445 | 19.182 | 0 |

Only treatments within the inorganic fertilizer group were significantly different from the control for OC. Combining both RR and CCB significantly increased soil OC (2.33% OC), which was the highest among treatments (Table 7). A significant decrease of OC was observed from the soil with the RR compared to the control (soil alone), while CCB + RR (T3) was significantly higher than the control. In contrast, biochars combined with organic fertilizers were not significantly different.

The available P of all OF treatments were significantly different from the control but not from each other with or without biochar (Table 7). The CHB + OF (84.00 mg $kg^{-1}$) was the highest compared to all treatments with an 81% increase over the control, followed by CCB + RR and CCB + OF at equal concentrations (76.00 mg $kg^{-1}$) (64%), then OF (73.00 mg $kg^{-1}$) (57%). Overall, CCB and CHB mixed with OF had significantly higher available P than CCB and CHB mixed with RR.

A significant difference was observed in the total K for both CCB and CHB mixed with RR and OF compared to the controls and fertilizer alone for types of fertilizers (Table 7). The RR value was lower since OF treatments were significantly higher than the RR treatments for the fertilizers x treatments interaction. Generally, exchangeable K increased among all treatments, except for RR which was lower than the corresponding control. This could be related to the high slow-release total K content of organic fertilizer and biochars compared to readily available K in RR which is easily absorbed or lost. The CCB + RR had the highest K (2.15 meq 100 $g^{-1}$ soil), followed by CHB + OF (1.95 meq 100 $g^{-1}$ soil), CHB + RR (1.86 meq 100 $g^{-1}$ soil), CCB + OF (1.80 meq 100 $g^{-1}$ soil), OF (1.51 meq 100 $g^{-1}$ soil), control (1.45 meq 100 $g^{-1}$ soil), and lastly, RR (meq 100 $g^{-1}$ soil). The exchangeable K

**Table 7. Chemical properties of Lipa clay loam after planted with corn.**

| Chemical Properties | pH (1:1) soil: water | OC (%) | P (mg kg$^{-1}$) | K (meq 100 g$^{-1}$) | EC (mS m$^{-1}$) |
|---|---|---|---|---|---|
| Inorganic fertilizer + Biochars | | | | | |
| T1 Control (soil alone) | 6.23$^{b}$ | 2.16$^{b}$ | 46.33$^{b}$ | 1.45$^{c}$ | 356.00$^{b}$ |
| T2 Recom-mended Rate (RR) (120-60-60) | 6.00$^{c}$ | 1.93$^{c}$ | 8.33*$^{c}$ | 1.24$^{d}$ | 339.00$^{b}$ |
| T3 Corn cob biochar (CCB) (15 t ha$^{-1}$) + (RR) | 6.40$^{a}$ | 2.33$^{a}$ | 76.00$^{a}$ | 2.15$^{a}$ | 423.00$^{a}$ |
| T4 Corn husk biochar (CHB) (15 t ha$^{-1}$) + (RR) | 6.20$^{b}$ | 2.07$^{bc}$ | 56.33$^{b}$ | 1.86$^{b}$ | 441.33$^{a}$ |
| Organic fertilizer + Biochars | | | | | |
| T1 Control (soil alone) | 6.23$^{b}$ | 2.16$^{a}$ | 46.33$^{b}$ | 1.45$^{b}$ | 356.00$^{b}$ |
| T2 Organic fertilizer (OF) (10 t ha$^{-1}$) | 6.40$^{a}$ | 2.18$^{a}$ | 73 .00$^{a}$ | 1.51$^{b}$ | 409.33$^{b}$ |
| T3 Corn cob biochar (CCB) (15 t ha$^{-1}$) + (OF) | 6.40$^{a}$ | 2.18$^{a}$ | 76.00$^{a}$ | 1.80$^{a}$ | 501.33$^{a}$ |
| T4 Corn husk biochar (CHB) (15 t ha$^{-1}$) + (OF) | 6.30$^{ab}$ | 2.11$^{a}$ | 84.00$^{a}$ | 1.95$^{a}$ | 485.00$^{a}$ |
| Fertilizers x Treatments | | | | | |
| Inorganic Fertilizer (RR) | a | ns | a | a | a |
| Organic Fertilizer (OF) | b | ns | b | b | b |
| Significance | | | | | |
| Fertilizers | * | * | * | *** | * |
| Treatments | * | * | * | *** | * |
| Fertilizers x Treatments | * | ns | * | *** | * |

Values are means (n = 3). Different letters indicate significant differences among treatments within fertilizer types ($p \leq 0.05$;LSD Test); * F test significant at ( $p \leq 0.05$); *** F test significant at ($p \leq 0.001$).

*For soil available P, treatment with pH ≤ 6.1 was analyzed using P Bray method while treatments with pH ≥ 6.2 were analyzed using Olsen method (T2 = 8 mg kg $^{-1}$*P* was analyzed using the Bray method).

increases of CCB + RR, CHB + OF, and CCB + RR were 49, 35, and 29 % higher over the initial soil K, respectively.

Electrical conductivity was significantly influenced by CCB and CHB for both RR and OF mixtures (Table 7). There were significant differences between the biochars and control and fertilizer alone for each type of fertilizer mixture. Overall, in the fertilizers x treatments interaction, OF treatments were significantly higher than RR treatments. The CCB and OF (501.33 mS m$^{-1}$) had the highest EC, followed by CHB and OF (485.00 mS m$^{-1}$), control (356.00 mS m$^{-1}$), CHB + RR (441.33 mS m$^{-1}$), CCB + RR (423.00 mS m$^{-1}$), OF (409.33 mS m$^{-1}$), and RR (339.00 mS m$^{-1}$). This observation is similar to that of Shetty and Prakash (2020), where soil EC increased by applying at 20 t ha$^{-1}$ (1%). In this study, CCB + OF and CHB + OF applied at 15 t ha$^{-1}$ increased EC by 40 and 36 %, respectively, as compared to the untreated soil.

## Plant Tissue Chemical Analysis

The OF and RR mixed CCB and CHB mixture applications did not significantly affect the total N or P concentrations within both fertilizer types (Table 8). However, the fertilizers x treatments interaction in total P was significantly different, where RR treatments were significantly higher than OF treatments. On the other hand, RR and OF applications alone and with CHB significantly increased corn K concentration, which was likely due to the beneficial impact of biochar on the plant -available K in the soil after application. Although total N, P, and K in biochars may not automatically indicate the actual availability of these nutrients to plants, these may be linked to available N, P, and K.

## Physiological and Morphological Characteristics of Corn Plants

Highly significant differences ($p \leq 0.001$) in treatments within fertilizer types were observed in the chlorophyll content (SPAD values) for corn leaves (Fig. 4). The CHB + RR mixture had the highest chlorophyll content at 27% (significantly different from all other RR treatments and control) followed by lower SPAD values for the RR and CCB + RR treatments, which were significantly different

**Table 8. Chemical properties of corn plant tissue.**

| Inorganic fertilizer + Biochars | Total N (%) | Total P (%) | Total K (%) |
|---|---|---|---|
| Control (soil alone) | 1.31$^{a}$ | 0.14$^{a}$ | 1.72$^{c}$ |
| (RR) (40-60-40) | 1.30$^{a}$ | 0.15$^{a}$ | 1.89$^{a}$ |
| CCB (15 t ha$^{-1}$) + RR | 1.55$^{a}$ | 0.15$^{a}$ | 1.78$^{bc}$ |
| CHB (15 t ha$^{-1}$) + RR | 1.20$^{a}$ | 0.18$^{a}$ | 1.83$^{ab}$ |
| Organic fertilizer + Biochars | | | |
| Control (soil alone) | 1.31$^{a}$ | 0.14$^{a}$ | 1.72$^{c}$ |
| (OF) (10 t ha$^{-1}$) | 1.22$^{a}$ | 0.12$^{a}$ | 2.02$^{a}$ |
| CCB (15 t ha$^{-1}$) + OF | 1.44$^{a}$ | 0.15$^{a}$ | 1.81$^{bc}$ |
| CHB (15 t ha$^{-1}$) + OF | 1.60$^{a}$ | 0.14$^{a}$ | 1.88$^{ab}$ |
| Fertilizers x Treatments | | | |
| Inorganic fertilizer (RR) | ns | a | ns |
| Organic fertilizer (OF) | ns | b | ns |
| Significance | | | |
| Fertilizers | ns | *** | ns |
| Treatments | ns | ns | * |
| Fertilizer x Treatments | ns | ** | ns |

Values are means (n = 3). Different letters indicate significant differences among treatments within fertilizer types ($p \leq 0.05$;LSD Test); * F test significant at $p \leq 0.05$); **F test significant at ($p \leq 0.01$); *** F test significant at ($p \leq 0.001$)

**Multi-Point BET Data**

| Relative Pressure [P/Po] | Volume @ STP [cc/g] | 1 / [ W((Po/P) - 1) ] | Relative Pressure [P/Po] | Volume @ STP [cc/g] | 1 / [ W((Po/P) - 1) ] |
|---|---|---|---|---|---|
| 5.03120e-02 | 1.2068 | 3.5124e+01 | 2.03551e-01 | 2.5875 | 7.9030e+01 |
| 1.00989e-01 | 1.8962 | 4.7399e+01 | 2.54369e-01 | 2.8317 | 9.6392e+01 |
| 1.51140e-01 | 2.2726 | 6.2686e+01 | 3.04006e-01 | 3.0191 | 1.1576e+02 |

**BET summary**
Slope = 318.036
Intercept = 1.631e+01
Correlation coefficient, r = 0.997370
C constant = 20.495
**Surface Area = 10.416**

**(a)**

**BJH Pore Size Distribution Desorption Data**

| Radius [Å] | Pore Volume [cc/g] | Pore Surf Area [m²/g] | dV(r) [cc/Å/g] | dS(r) [m²/Å/g] | dV(logr) [cc/g] | dS(logr) [cc/g] |
|---|---|---|---|---|---|---|
| 15.3348 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 17.1328 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 19.1571 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 21.4952 | 1.1266e-04 | 1.0483e-01 | 4.4771e-05 | 4.1657e-02 | 2.2134e-03 | 2.0594e+00 |
| 24.3733 | 1.1266e-04 | 1.0483e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 28.0031 | 1.1266e-04 | 1.0483e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 32.5185 | 1.1266e-04 | 1.0483e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 38.6763 | 1.1266e-04 | 1.0483e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 47.4358 | 1.1266e-04 | 1.0483e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 61.3498 | 1.1266e-04 | 1.0483e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 88.2346 | 1.7752e-04 | 1.1953e-01 | 1.7938e-06 | 4.0660e-04 | 3.5929e-04 | 8.1440e-02 |
| 151.5766 | 5.0640e-04 | 1.6292e-01 | 3.6329e-06 | 4.7935e-04 | 1.2293e-03 | 1.6221e-01 |
| 338.4845 | 1.3793e-03 | 2.1450e-01 | 3.0814e-06 | 1.8207e-04 | 2.2542e-03 | 1.3320e-01 |
| 728.6082 | 1.9576e-03 | 2.3037e-01 | 1.1635e-06 | 3.1938e-05 | 1.8739e-03 | 5.1437e-02 |

BJH desorption
Surface Area = 0.230 m²/g
Pore Volume = 0.002 cc/g
**Pore Radius Dv(r) = 21.495**

**(b)**

**Fig. 1a-b. BET Surface Area and Pore Size Analysis (a). Multi-Point BET Data of CCB surface area at 10.416 m$^2$ g$^-$; (b) BJH method Desorption dV (log r) of CCB pore size at 21.495 Å.**

**Multi-Point BET Data**

| Relative Pressure [P/Po] | Volume @ STP [cc/g] | 1 / [ W((Po/P) - 1)] | Relative Pressure [P/Po] | Volume @ STP [cc/g] | 1 / [ W((Po/P) - 1)] |
|---|---|---|---|---|---|
| 4.63870e-02 | 0.5781 | 6.7326e+01 | 2.00040e-01 | 0.9334 | 2.1435e+02 |
| 9.60670e-02 | 0.7256 | 1.1718e+02 | 2.51363e-01 | 1.0113 | 2.6564e+02 |
| 1.47292e-01 | 0.8443 | 1.6370e+02 | 3.01071e-01 | 1.0657 | 3.2341e+02 |

**BET summary**

| | |
|---|---|
| Slope = | 991.117 |
| Intercept = | 1.977e+01 |
| Correlation coefficient, r = | 0.999299 |
| C constant= | 51.121 |

**Surface Area = 3.445**

**(c)**

**BJH Pore Size Distribution Desorption Data**

| Radius [Å] | Pore Volume [cc/g] | Pore Surf Area [m²/g] | dV(r) [cc/Å/g] | dS(r) [m²/Å/g] | dV(logr) [cc/g] | dS(logr) [cc/g] |
|---|---|---|---|---|---|---|
| 15.3322 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 17.1501 | 1.3554e-05 | 1.5807e-02 | 7.0966e-06 | 8.2759e-03 | 2.7995e-04 | 3.2647e-01 |
| 19.1815 | 1.1180e-04 | 1.1824e-01 | 4.5632e-05 | 4.7579e-02 | 2.0133e-03 | 2.0992e+00 |
| 21.5273 | 1.3061e-04 | 1.3572e-01 | 7.4121e-06 | 6.8862e-03 | 3.6698e-04 | 3.4094e-01 |
| 24.3436 | 1.3061e-04 | 1.3572e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 27.9544 | 1.3061e-04 | 1.3572e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 32.5169 | 1.3061e-04 | 1.3572e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 38.8115 | 1.3061e-04 | 1.3572e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 47.8340 | 1.3061e-04 | 1.3572e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 62.4511 | 1.3061e-04 | 1.3572e-01 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 | 0.0000e+00 |
| 88.5103 | 1.7475e-04 | 1.4570e-01 | 1.3240e-06 | 2.9918e-04 | 2.6662e-04 | 6.0246e-02 |
| 148.4852 | 2.4739e-04 | 1.5548e-01 | 8.3867e-07 | 1.1296e-04 | 2.7842e-04 | 3.7501e-02 |
| 309.5403 | 4.0511e-04 | 1.6567e-01 | 6.6973e-07 | 4.3273e-05 | 4.5336e-04 | 2.9293e-02 |
| 585.1112 | 4.4844e-04 | 1.6715e-01 | 1.3728e-07 | 4.6924e-06 | 1.8038e-04 | 6.1655e-03 |

BJH desorption summary
Surface Area = 0.167 m²/g
Pore Volume = 0.000 cc/g
**Pore Radius Dv(r) = 19.182 Å**

**(d)**

**Fig. 1c-d. BET Surface Area and Pore Size Analysis (c) Multi-Point BET Data of CHB biochar surface area at 3.445 m$^2$g$^-$; (d) BJH method Desorption dV (log r) of CHB pore size at 19.182 Å.**

from the control. All three OF treatments were significantly higher than the control but not different from each other. The highest chlorophyll concentration found in CHB + RR correlated to the highest weight of fresh corn ear biomass (Fig. 4), and the same was observed in the CCB + OF. This finding suggests that chlorophyll concentration in the corn leaf is related to its fresh corn ear biomass production. The fertilizers x treatments interaction was also highly significant ($p \leq 0.001$) with treatments of OF higher than RR. Thus, the quality application of biochar can promote the chlorophyll content of maize leaves.

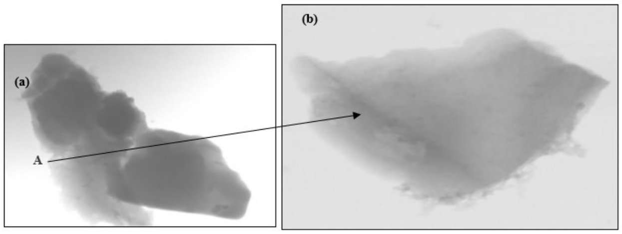


**Fig. 2. TEM image at 10,000x magnification (a); Bright field TEM image of CCB particle at 30,000x magnification (b).**

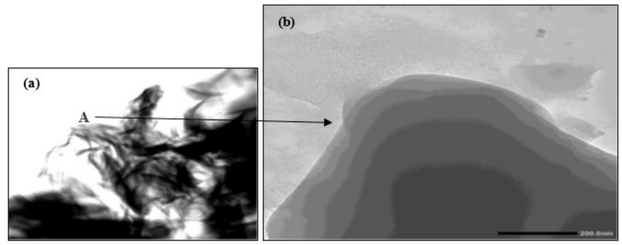


**Fig. 3. TEM image at 10,000x magnification (a); Bright field TEM image at 30,000x magnification (b).**

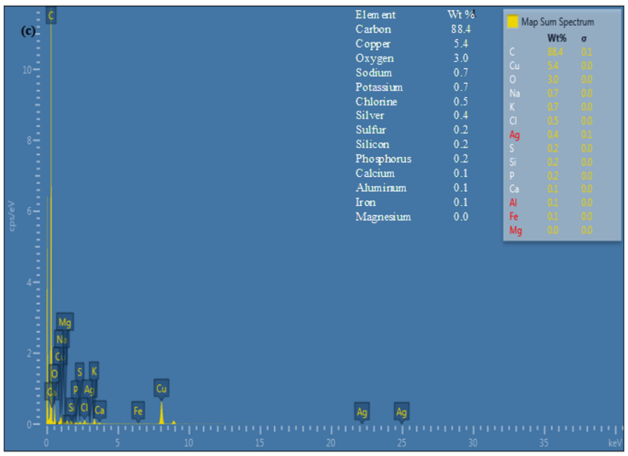


**Fig. 2c. High angle annular bright field (HAABF) image and spectrum of CCB particle.**

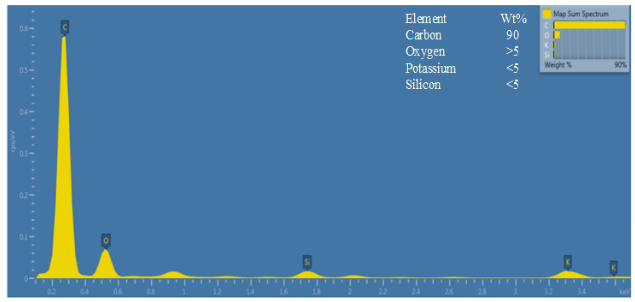


**Fig. 3c. High angle annular bright-field (HAABF) image and spectrum of CHB particle.**

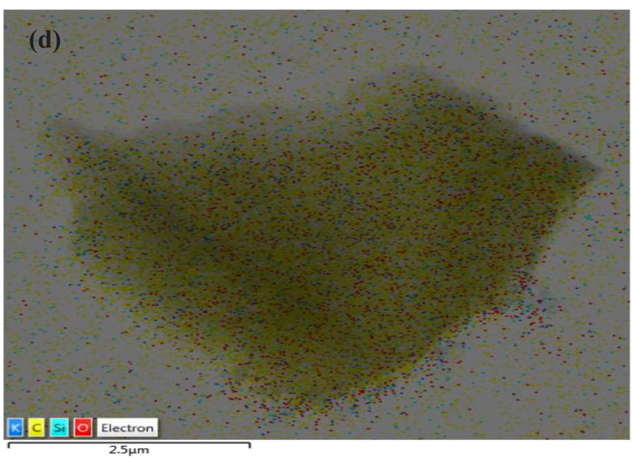


**Fig. 2d. HAABF elemental map from area of interest A of CCB particle (Bulfa et al. 2021).**

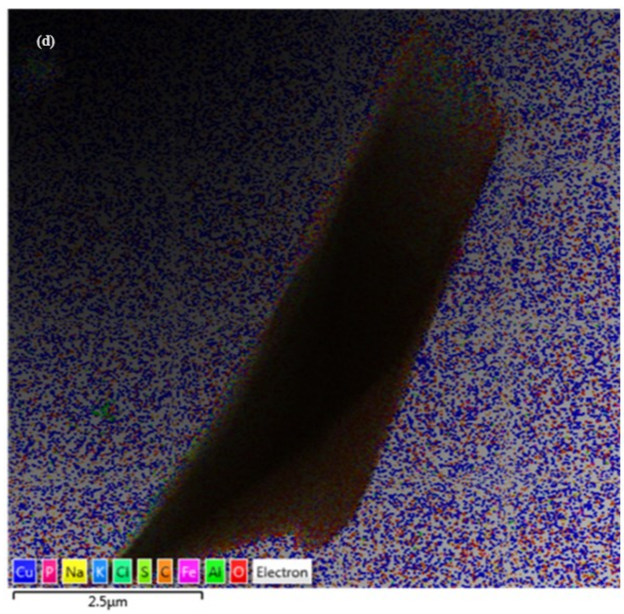


**Fig. 3d. HAABF elemental map from area of interest A of CCB particle.**

Among the treatments, the high significant increase in total oven-dried corn biomass (shoot and root) was consistent with both CCB and CHB mixed with RR and OF. This increase had the highest total oven-dried corn biomass, fresh corn ear, and oven-dried root biomass values (Fig. 5, 6, 7). In OF treatments, the CHB + OF had the highest oven-dried total biomass, followed by CCB + OF and then OF (Fig. 5). The CHB and OF treatments were significantly different ($p \leq 0.001$) and were all significantly higher than the control. In RR treatments, the CHB + RR had the highest oven-dried biomass, followed by CCB + RR and then RR. The CHB + RR and RR treatments were also significantly different ($p \leq 0.001$) and all RR treatments were significantly higher than the control. However, in the fertilizers and treatments interaction, only a slight, non-significant difference was observed. This observation suggests that CHB and CCB are better applied with organic and inorganic fertilizers. In this study, CHB mixed with OF and RR increased biomass by 42 and 30 %, respectively, while CCB

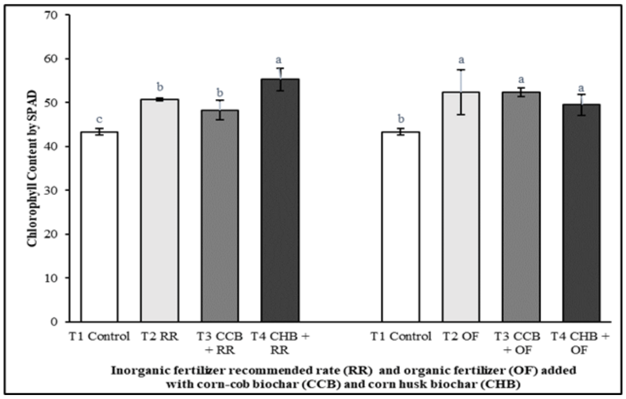


**Fig. 4. Corn leaf chlorophyll content by SPAD 502 Plus Chlorophyll Meter after CCB and CHB mixed with RR and OF applications. Values are means (n = 3) ± standard errors. Different letters above histograms indicate significant differences among treatments within fertilizer types ($p \leq 0.05$; LSD Test); Fertilizers x treatments interaction is significant ($p \leq 0.05$; LSD test), F test significant at $p \leq 0.001$.**

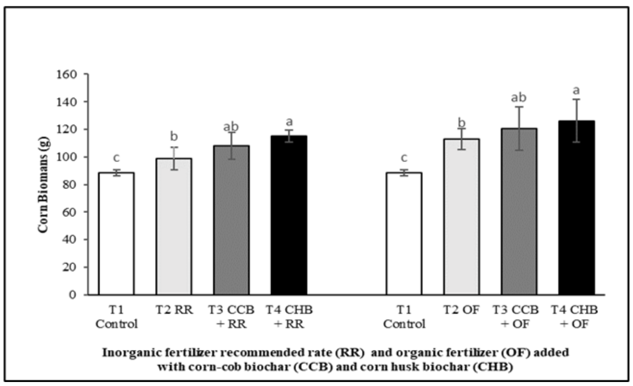


**Fig. 5. Total oven-dried corn biomass (shoot and root) production after CCB and CHB mixed with RR and OF applications. Values are means (n = 3) ± standard errors. Different letters above histograms indicate significant differences among treatments within fertilizer types ($p \leq 0.05$; LSD Test); F test significant at $p \leq 0.001$.**

combined with OF and RR increased the biomass by 36 and 22 %, respectively.

Some treatments within fertilizer types were significantly different ($p \leq 0.05$) for fresh corn ear production. Moreover, the fertilizers x treatments interaction was significantly different ($p \leq 0.05$). Fresh corn ear production, as indicated by biomass, was significantly increased by most biochars mixed with inorganic and organic fertilizers (Fig. 6). Within RR treatments, CHB + RR and CCB + RR were significantly higher than the control. Both were significantly different from RR, but not significantly different from each other. RR was slightly higher than but was not significantly different from the control. All OF treatments were higher than the control but were not significantly different from each other. The highest increase in production when compared to the corresponding control was observed in CHB + RR (54%), followed by CCB + OF (49%), CCB + RR (40%), CHB + OF (39%), OF (32%), and RR (10%). Overall, in the fertilizers and treatments interaction, OF treatments were significantly higher than RR. In this study, a CCB or CHB biochar application rate (15 t $ha^{-1}$) increased fresh corn ear production to over 50% when applied with RR and OF in clay soil.

A very significant increase in the oven-dried root weight ($p \leq 0.001$) was observed in the treatments within different fertilizer types, especially in CHB + OF (87%), followed by CCB + OF (49%), and OF (38%) (Fig. 7). All OF treatments were significantly higher than the control, but OF and CCB + OF were not significantly different from each other. All RR treatments were significantly higher than the control, but RR and CCB + RR were not significantly different from each other. Specifically, CHB + RR, RR, and CCB + RR were 41, 34, and 21 % respectively, higher than the control. Although OF

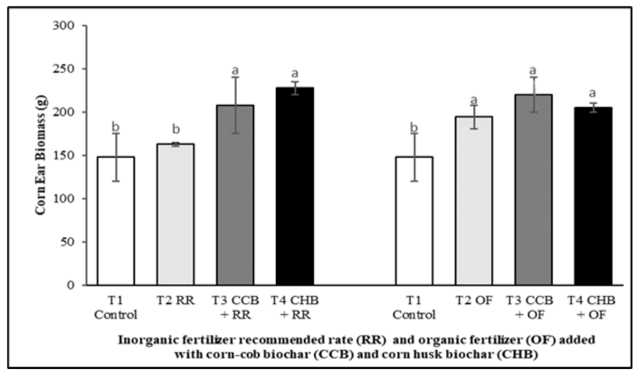


**Fig. 6. Fresh corn ear biomass after CCB and CHB mixed with RR and OF applications. Values are means (n = 3) ± standard errors. Different letters above histograms indicate significant differences among treatments within fertilizer types ($p \leq 0.05$; LSD Test) with F test significant at $p \leq 0.001$. Fertilizers x treatments interaction is significant ($p \leq 0.05$; LSD test) with F test significant at $p \leq 0.05$.**

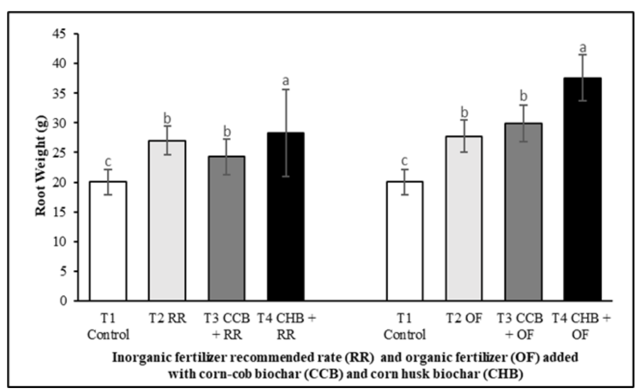


**Fig. 7. Root oven-dried biomass production by corn after CCB and CHB mixed with RR and OF applications. Values are means (n = 3) ± standard errors. Different letters above histograms indicate significant differences among treatments within fertilizer types ($p \leq 0.05$;LSD Test); F test significant at $p \leq 0.001$.**

treatments were slightly higher than RR in the interaction between fertilizers and treatments, they were not significantly different. The CCB and CHB had better effects on plant roots when added with OF than RR. However, biochars mixed with OF and RR significantly improved root weight.

None of the plant heights with different treatments were statistically significant compared to the controls (Fig. 8). There was only a trend in increased height with CCB and CHB treatments.

Only the fresh biomass R/S from treatments within OF were significantly different ($p \leq 0.001$) (Fig. 9). However, the interaction of fertilizers x treatments was highly significant ($p \leq 0.001$), where OF treatments were significantly higher than RR treatments. The highest R/S ratio was observed in CHB + OF, followed by OF, while the lowest was observed in CCB + OF, which was lower than the control.

### Corn Root Attraction with Biochars

In this study, corn treated with biochars mixed with organic and inorganic fertilizers produced more healthy roots and root hairs. The roots attached to the biochar exhibit a white coloration, showing active water absorption (Fig. 10).

## DISCUSSION

### Biochar Properties

The elemental composition of biochars varies among studies (Jeffery et al. 2011; Lehmann et al. 2011; Ding et al. 2016). The nature of raw feedstock, properties, and the pyrolysis residence time significantly affect the chemical composition of the biochars produced. The CCB and CHB generally have high pH, similar to the pH ranges reported for biochar made from rice straw, water hyacinth, mahogany flower receptacle, sugarcane bagasse, sugarbeet, cauliflower leaf, and orange peel wastes (Villegas-Pangga 2021). These biochars have high OC while containing high essential macro-elements (N, P, K Ca, Mg) and micro-elements (Fe, Zn, Cu, Mn) required for plant growth. It is worth noting that biochar with a high pH could benefit the soils that need a liming effect because its application increases soil pH (Wang et al. 2014). The increase in soil pH may determine cation exchange capacity and nutrient availability. Rajkovich et al. (2012) indicated that biochars have ash contents ranging from 0.35 to 59.05% and are rich in available nutrients, especially cationic elements such as K, Ca, Mg, and Na, similar to what was observed in this study. In addition, high organic C in fresh biochars and its well-developed pore structure may enhance water retention

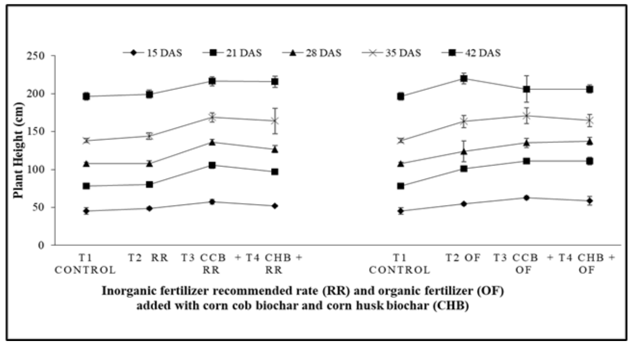


**Fig. 8. Corn plant height (cm) after CCB and CHB mixed with RR and OF applications. Values are means (n = 3) ± standard errors.**

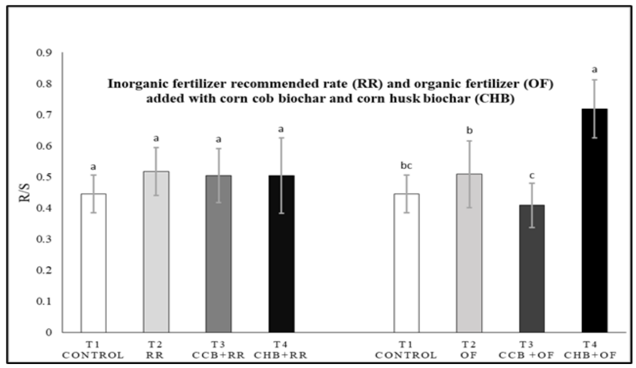


**Fig. 9. Fresh root-shoot ratio as affected by CCB, CHB mixed with RR and OF. Values are means (n = 3) ± standard errors. Different letters above lines indicate significant differences among treatments within fertilizer types ($p \leq 0.05$; LSD Test); F test significant at $p \leq 0.001$. Fertilizers x treatments interaction is significant ($p \leq 0.05$; LSD test) with F test significant at $p \leq 0.001$.**

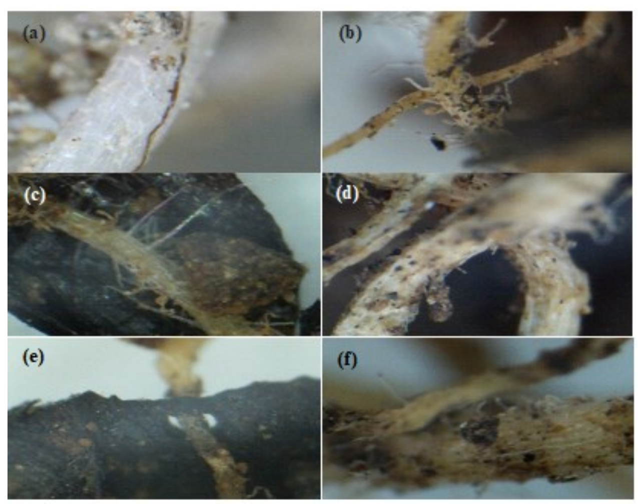


**Fig. 10. Corn root affinity with biochars in clay soil applied with organic and inorganic fertilizers; (a)-inorganic fertilizer (RR); (b)-OF; (c) CCB +RR (d) CCB + OF; (e)-CHB + RR; (f) CHB + OF.**

and provide a shelter for soil microorganisms. Microbial activity that relies on fresh biochars' easily mineralizable organic content improves nutrient retention and cycling (Ding et al. 2016).

Jeffery et al. (2015) indicated the benefits of biochar application to soils on crop productivity, especially in acid soils. It has numerous applications for enhancing agriculture and the environment, and its nutrient-retention abilities and persistence in soil make it a suitable soil amendment to improve agricultural yields (Lehmann and Joseph 2015). Jeffery et al. (2017) also documented that biochar application increased yield at an average of 25% in the tropics. Because tropical soils typically have low fertility and low fertilizer inputs, biochar was used in the tropics to boost output with lime and fertilizer applications.

The physisorption analysis reveals high porosity of both biochars that could indicate retention of water in tiny pores, consequently increasing water holding capacity and helping infiltrate excess water through larger pores. The highly porous composition and large surface area is the fundamental physical feature of most biochars (Villegas-Pangga 2021). The surface chemistry of biochar becomes critical because the interfaces between biochar and the aqueous phase provide essential sites for elemental sorption and reaction, including surface functional groups, surface radicals, and surface charge (Xiao et al. 2018). Thus, these properties show the biochar potential to improve soil health and quality.

Similarly, Jeffery et al. (2011) added that the ability of biochars to increase water holding capacity is a possible mechanism for yield improvements. Ding et al. (2016) also noted that the well-developed pore structure would enhance water retention and provide a home for soil organisms, hence, plant nutrients will be retained, recycled, and improved. Atkinson et al. (2010) stated that this structure can provide refuge for beneficial soil microorganisms, influencing nutrient retention. This retention can enhance the availability of macronutrients such as N and P. These findings are related to the current research results in which available P was highly increased compared to the control.

The X-ray EDS of both CCB and CHB samples show the presence of essential elements (C, Cu, Na, K, Cl, S, S, Si, P, Ca, O). However, it is worth noting that C is 88 – 90 (wt %) as revealed in the HAABF spectrum in the areas of interest of both biochar samples. Rajkovich et al. (2012) showed that the ash content of biochars is rich in the cationic form of available nutrients such as $K^+$, $Ca^{2+}$, $Mg^{2+}$, and $Na^+$. With the soluble nutrients and mineralizable fraction of biochar, Ding et al. (2016) indicated that it could be used as a source of nutrition for plants as it increases soil fertility depending on the pyrolysis temperature.

## Biochars Effect on Soil Chemical Properties and Plant Growth

Generally, soil parameters such as pH, OC, available P, exchange K, EC, and CEC are improved by biochars mixed with organic and inorganic fertilizer applications in Lipa clay soil. Wang et al. (2014) stated that biochar application could increase pH, which is an essential factor affecting nutrient availability. The improvement of nutrient availability in the soil, especially P and K, depends on the increase of soil pH by biochar application (Atkinson et al. 2010). In addition, improvement in soil pH could help release nutrients from unavailable form making them readily adsorbable by roots. The improvement of soil properties is highly related to the specific physicochemical properties of biochar, such as high surface area, the magnitude of functional groups, and the liming effect (Ding et al. 2016).

Both biochars added with fertilizers significantly improve the plants' physiological and morphological responses. Chlorophyll concentration (SPAD values), upper and lower plant biomass, and root-shoot ratio show positive response with biochars mixed with organic and inorganic fertilizers. These results are consistent with the literature indicating that biochar can increase corn growth, at least under some conditions (Jeffery et al. 2015; Jeffery et al. 2017). Also, biochar application improves soil chemical and physical characteristics such as nutrient or water availability, pH, or aeration, likely enhancing root growth (Lehmann et al. 2011). Plant roots respond to soil amendment because in addition to providing phosphorus (P) to the soil and plants, biochar particles supply soil nitrogen (N) in the form of nitrate (Prendergast-Miller 2014). The indirect effect of biochar on soil nutrient availability is increased N retention in the rhizosphere. The abundant roots and root hairs produced by corn treated with biochars were evident in its increased weight. In the field trials, research findings show that biochar application enhanced soil quality, improved production, and promoted plant growth (Ding et al. 2016). A 54% increase in the fresh corn ear biomass in this study recorded from 15 t $ha^{-1}$ CHB + RR application rate and 49% increase from CCB + OF. Furthermore, CHB mixed with OF and RR increased total oven-dried biomass by 42 and 30 %, and CCB mixed with OF and RR recorded an increase of 36 and 22 %, respectively. However, depending on biochar properties, a decrease in crop yield may happen due to high volatile matter and harmful substances in the biochar (Ding et al. 2016).

## CONCLUSION

This study was conducted to determine the effect of corn-to-corn cob biochar (CCB) and corn husk biochar (CHB) applications on the growth of corn grown in a clay loam soil with organic and inorganic fertilizers. The X-ray energy dispersive spectroscopy and high angle annular bright field spectra showed that CCB and CHB are abundant in carbon and other essential elements, and Brunauer-Emmett-Teller analysis confirmed their high average surface areas, pore sizes, and pore volumes. Results showed that CCB and CHB applied with organic and inorganic fertilizers improve characteristics of a clay loam soil, such as soil pH, cation exchange capacity, electrical conductivity, and nutrient status, which enhanced growth of the plants as indicated by increased leaf chlorophyll concentration, corn ear biomass, root biomass, and plant height. The CCB and CHB with organic or inorganic fertilizer applications are recommended for clay loam soil as they improve soil health and plant growth. Biochar is a low-cost organic soil amendment with several environmental and agricultural benefits. Its application is highly recommended to address the common concern of boosting crop yield in local acid soils.

## ACKNOWLEDGMENT

The authors would like to thank the German Academic Exchange Service and Southeast Asian Regional Center for Graduate Study and Research in Agriculture for the research funds.

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