

The Effect Of Biochar As An Organic Amendment For Soil Health And Cropping System

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ABSTRACT

Soil degradation and declining fertility are major constraints to sustainable maize (*Zea mays* L.) production in arid and calcareous soils of Pakistan, particularly in Balochistan. The excessive burning and mismanagement of agricultural wastes, such as banana residues, further aggravate environmental pollution while valuable organic resources remain underutilized. Biochar, a stable carbon-rich material produced through pyrolysis of organic waste, has emerged as a promising soil amendment for improving soil physicochemical properties and crop productivity. This study aimed to evaluate the effects of banana leaf derived biochar on soil properties and growth performance of maize under controlled pot conditions. A greenhouse experiment was conducted at the Department of Soil Science, Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Balochistan. Six treatments comprising control (T1) and biochar application rates of 5%, 10%, 15%, 20%, and 25% (T2–T6) were arranged in a completely randomized design with three replications. Biochar was produced from banana waste through slow pyrolysis. Soil samples were analyzed for pH, electrical conductivity, organic matter, total nitrogen, available phosphorus, and potassium before and after harvest. Agronomic parameters including plant height, stem girth, and biomass production were also recorded. Results revealed that biochar application significantly improved soil organic matter, total nitrogen, available phosphorus, potassium, stem girth, and biomass production, while changes in soil pH

and electrical conductivity remained statistically non-significant. The highest biochar rate (25%) consistently produced superior soil fertility status and maximum maize biomass. Overall, banana-derived biochar proved to be an effective soil amendment for enhancing soil quality and maize productivity. The study concludes that recycling banana waste into biochar offers an environmentally sustainable and agronomically beneficial strategy for improving maize production in calcareous soils.

Introduction

Most of the Pakistan's impoverished people work in agriculture, and 75% of them live in rural regions (Ghafoor et al., 2010; UNDP, 2019). Lack of seed for other crops and state regulations prohibiting the allocation of additional land to crops other than wheat, rice, cotton, and maize limit farmers' access to other sources of income. The importance of smallholder farmers for food security and rural income is highlighted by the fact that 93% of farmers are smallholders and that small farms occupy around half of Pakistan's arable land (UNDP, 2019; PBS, 2019). Despite a rise in the agricultural gross domestic product, rural poverty is worsening, especially for small holders (Qasim & Knerr 2013). The agricultural gross domestic product has increased, but rural poverty is worsening, especially for smallholders (Qasim & Knerr 2013). When the earnings of smallholder farmers stagnate or decline, less capital is invested in small farms, which further lowers productivity, endangering food security and livelihoods (Qasim & Knerr 2013).

The present crop yield level is quite lower than the potential of our current varieties. The primary inhibitions to increasing maize yield are poor plant density, improper fertilizer application, insufficient water availability, weed growth, insect pest activity, and the selection of cultivars that are not suitable for a particular combination of conditions. Compared to conventional varieties of maize, adopting suitable hybrids with high yields improves grain quality and yield while raising income per hectare (Abbas, 2001). Compared to earlier hybrids, maize hybrids of today have more yield (Russel, 1986). The selection of high-potential, widely adoptable variety is crucial, as the yield potential of our current kinds is declining daily. In addition to their ability to withstand both biotic and abiotic challenges, contemporary hybrids' high yields are probably due to the fact that they have more ear bearing plants per unit land area without sacrificing the number of kernels per ear. Despite increased inputs of insecticides and fertilizer over the past ten years, Pakistan's crop productivity has been falling. This is because hybrid varieties have greater potential than synthetic or composite kinds, which are the reason for this (Njeru, 1983). The current study was created to measure the production potential of several hybrids of maize that are currently on the market and to choose one that would provide the highest possible yield under the specific conditions of Faisalabad.

Soil related issues are one of the most significant obstacles to agricultural production in Pakistan. Poor land resource management raises the threat, resulting in desertification and decreased output. Certain consequences of land loss are more drastic in term of manifestation. To boost soil productivity and sustainability, several method and approaches have been used, with biochar being the most successful. The rate of decomposition of organic materials in soil is far too high. As a result, biochar is better soil management option. Because of its considerable recalcitrance, biochar

can last for several years in the soil. There are many factors and problems which are affecting agricultural lands and needs amendments for enhancing crop productivity. Biochar is one of best solution for improving soil productivity and sustainability. Crop cultivation and output are greatly impacted by the physical and chemical composition of the soil. According to studies, applying biochar increased the physical, chemical, and biological qualities and therefore the crop yield. Biochar is an absorptive material with a high surface area that provides shelter to soil microbes against stress. It is well known that biochar is a porous carbonaceous substantial formed by the breaking (pyrolysis). Pyrolysis is the burning of organic material in the deficiency of oxygen (Elnour et al., 2019). Biochar application with straw residues improves their efficiency for nutrient release. In this context, the aim of the current research is to observe how straw residues and biochar together affected maize production. In developing nations, maize is grown both in the spring and summer for hay and grain production.

Biochar has the potential to boost through the restoration of degraded soils, agricultural production by improving soil fertility and providing protection against specific foliar and soil borne diseases. For sustainable crop production in the agricultural sector, biochar is being utilized as an alternative organic fertilizer in addition to chemical fertilizer because of its remarkable agronomic properties and yield potential in poor, damaged soils. Biochar is reported to improve crop biomass, soil nutrient availability, and water holding capacity. A huge amount of banana waste produced in Balochistan every year is wasted. But sadly, they are not appropriately used; instead, they are directly burned outside, which releases smoke and CO₂. Therefore, it was suggested that using biochar and straw made from banana leaves can assist improve soil qualities and crop output in alkaline calcareous soil while also being environmentally beneficial. The study's goal was to enhance biochar made from banana leaves using low pyrolysis and assess how it affected maize growth and soil output. Following this, improvements in soil characteristics and maize growth both contributed equally to the improvement of maize's biological and grain yield, which is further corroborated by the strong and positive relationship between soil characteristics and grain yield. Piece, this proponent of biological nutrient sources for soil fertility restoration is sufficient with moderate cropping intensity, with more extensive cropping, it becomes unsustainable without fertilizer input. Plant health and soil fertility are two interconnected issues that concern the types and availability of nutrients in soils.

Material and Methods

Biochar Production

Biochar was produced using the collected rice straw and banana waste. Prior to using the material to produce biochar, it was air dried and pulverized. The material was then heated for three hours after grinding in a tank used to produce biochar. The biochar production tank was used to gather the prepared biochar, which were placed in plastic bags. The experiment was carried out at the Lasbela University of Agriculture, Water and Marine Sciences, Uthal Lasbela, Balochistan, at the Department of Soil Science.

Pot preparation

A rich soil layer (plough layer) was then collected from the uthal experimental farm at Lasbela University of agriculture, water and marine sciences. Before the dirt is put in the pot, it was allowed to air dry and then sieved through a 2 mm screen. Plastic pots with a drainage hole at the bottom hold five kilograms of air dried soil. The trial was employed six treatments, three of which were then replicated through a fully randomized design. The experiment's details are as follows: T1 = Control, T2= (5% biochar), T3 = (10% biochar), T4= (15% biochar), T5= (20% biochar), T6 = (25% Biochar)

Soil sampling and analysis

To evaluate nutrient availability, soil samples were then collected from each pot both prior to and following the maize harvest. Following soil properties were studied: The pH of the soil was then tested using a calibrated pH meter and a soil to water ratio of 1:2.5 suspensions. In a 100 mL beaker, 20 g soil was mixed with 50 mL distilled water and agitated for 30 minutes. A pH meter was then used to measure the concentration. The electrical conductivity of (1: 2.5) soil water suspensions was measured. 50 mL distilled water was then added to 20 g air dried soil and mechanically agitated for 30 minutes. The suspension was then allowed to rest for 30 minutes. An EC meter was used to measure conductivity. Organic matter (%) walkley Black procedure (Nelson and Sommers, 1996) was then used to determine the organic matter.

Total nitrogen (%) the method adopted by Lu, (2000) was utilized to evaluate the total nitrogen, nitrate nitrogen, ammonium nitrogen in collected soil samples. Soil total phosphorus was then determined by cliometric method and available phosphorus were checked by molybdenum antimony anti-cliometric method. The total potassium concentration in the samples was then determined by NaOH, melt flame Spectrophotometry and soil available potassium was determined by flame photometric method.

Agronomic observation

The following agronomic parameters were then recorded before harvesting of maize crop. Planting of maize ten seeds of the Akber maize crop were sown in each pot. The seedlings were thinning to five per pot after development. Harvested during the tasseling stage, the maize plants received the necessary amount of irrigation. Stem girth (cm) a measuring tape is often wrapped around the stem, positioned at the correct height and perpendicular to the trunk's axis. The data was averaged with respect to 3 randomly chosen plants. Plant height (cm) the height of after that, measurements were taken of the randomly chosen plants in each treatment from top to bottom using a measuring tape once the crop reached maturity. Biomass production plant^{-1} to determine the biomass production per plant, the total biomass of the randomly chosen tree plant was weighed on an electrical balance.

Calculation and statistics

The data from the treatment and control groups was then analyzed using one way analysis of variance (ANOVA) is performed using the Statistical Package for Social

Scientists (SPSS 20.0). Duncan's Multiple Range Test was used for mean comparisons, and $P < 0.05$ was the cutoff point for statistical significance.

Result and Discussions

Site Description

In the Department of Soil Science at Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Balochistan, a greenhouse experiment was conducted in a warehouse under natural conditions to ascertain the effects of banana biochar on the development of maize (*Zea mays* L.). A substitute potassium source for plant productivity in sustainable agriculture is banana biochar. It significantly improves the physiochemical characteristics of soil, which benefits agriculture and the ability to clean up contaminated soils. prior to applying the biochar to the plot, the plough layer, or fertile soil, was gathered, let to air dry, then pulverized and sieved through a 4 mm garden screen. Four biochar concentrations were used in the experiment, which was set up using a Completely Randomized Design (CRD) and three replications: T1 Control, T2 Biochar (5%), T3 Biochar (10%), T4 Biochar (15%), T5 Biochar (20%), and T6 Biochar (25%). A total of twelve maize seeds were distributed to each allocation and planted. Once the seedlings had germinated, they were cut to six plants per container. to fertilize the soil, urea (46% N), which contains the necessary doses of nitrogen for maize, was applied in three separate splits: once during seed bed preparation, once during the first irrigation, and once during the second irrigation. Furthermore, Potassium and phosphorus as one superphosphate (18% P_2O_5) in the form of sulphate of potash (50% K_2O) were both treated only once as the seedbed was being prepared.

pH

As an important measure of the chemical condition of any solution, pH can affect microbial activity, chemical behavior, biological processes, and nutritional availability. Data recorded for pH is shown in table 0.1, which reveals that the response to biochar doses was non-significant ($P > 0.05$). Kakar et al. (2021) reported that applying various regimes of banana-based biochar treatment had no discernible effect on pH, which validated our findings. Because of its high pH, which prevents minerals, especially phosphorus and micronutrients, from being available, calcareous soil in arid environments has low fertility and production (Rengel, 2015; Bityutskii et al., 2017; Abbaszadeh-Dahaji et al., 2020).

Banana derived biochar given to maize crop at 25% biochar produced pH of maximum 8.6, closely followed by the 20% and 15% biochar with pH 8.4 and 8.3 respectively (as presented in figure 0.1). Maize crop receiving zero quantity of biochar resulted in reduced pH 7.0. The application of biochar may have changed the physiological functions of plants, the availability of nutrients, and the properties of the soil, which raised the pH (Naeem et al., 2017). Similar findings were noted by Kumari et al., (2018) where it was observed that pH value was increased with an addition of biochar.

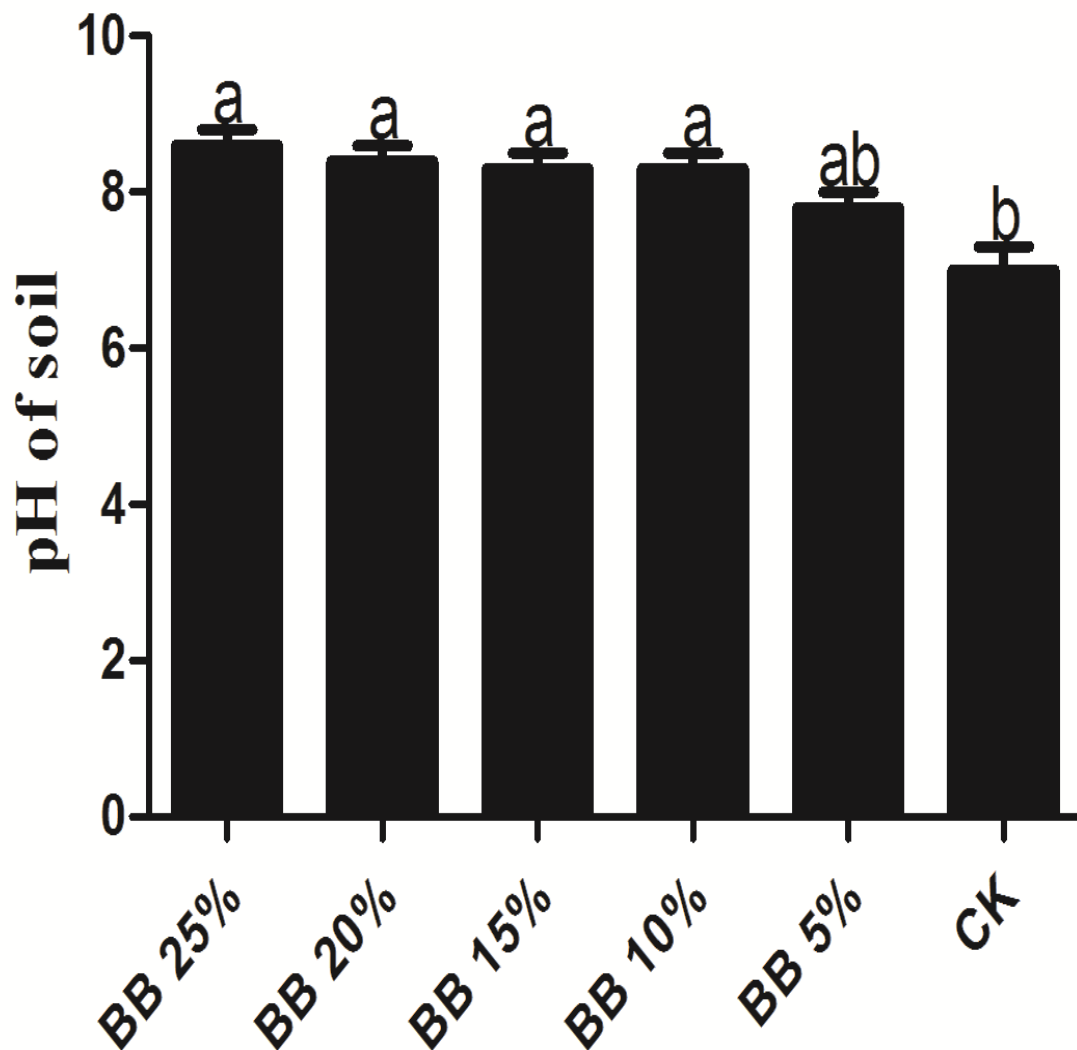


Figure 1: Effects of the banana derived biochar on pH of maize crop (Arrows on bars represent standard error).

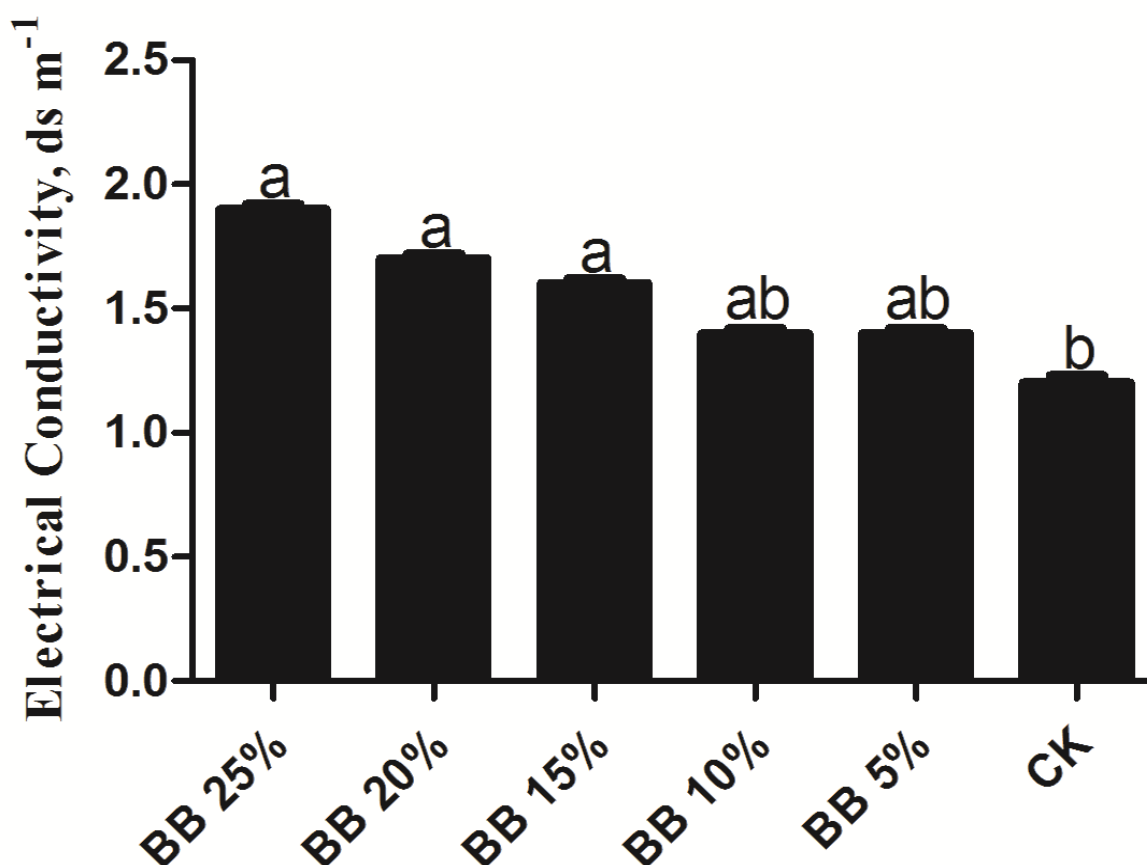
Electrical conductivity (ds m^{-1})

An electrical conductivity measurement refers to a physically quantifiable parameter that is used in a variety of industrial processes where it refers to the ease with which electricity can pass through a substance. Data recorded for electrical conductivity is shown in table 0.2, which reveals that the response to biochar doses were not significant ($P>0.05$). Kakar et al. (2021) reported that EC was not affected significantly when different regimes of banana-based biochar treatment applied which supported the findings of our work.

Banana derived biochar given to maize crop at 25% biochar produced electrical conductivity of maximum 1.9, closely followed by the 20% and 15% biochar with EC 1.7 and 1.6 respectively (Figure 0.2). Maize crop receiving zero quantity of biochar resulted in reduced EC 1.2 Electrical conductivity may have increased as a result of biochar treatment's effects on soil properties, plant physiological processes, and nutritional availability (Naeem et al., 2017). Similar findings were noted by Kumari et al., (2018) where it was observed that EC value was increased with an addition of biochar.

Figure 2: Effects of the banana derived biochar on EC of maize crop (Arrows on bars represent standard error).

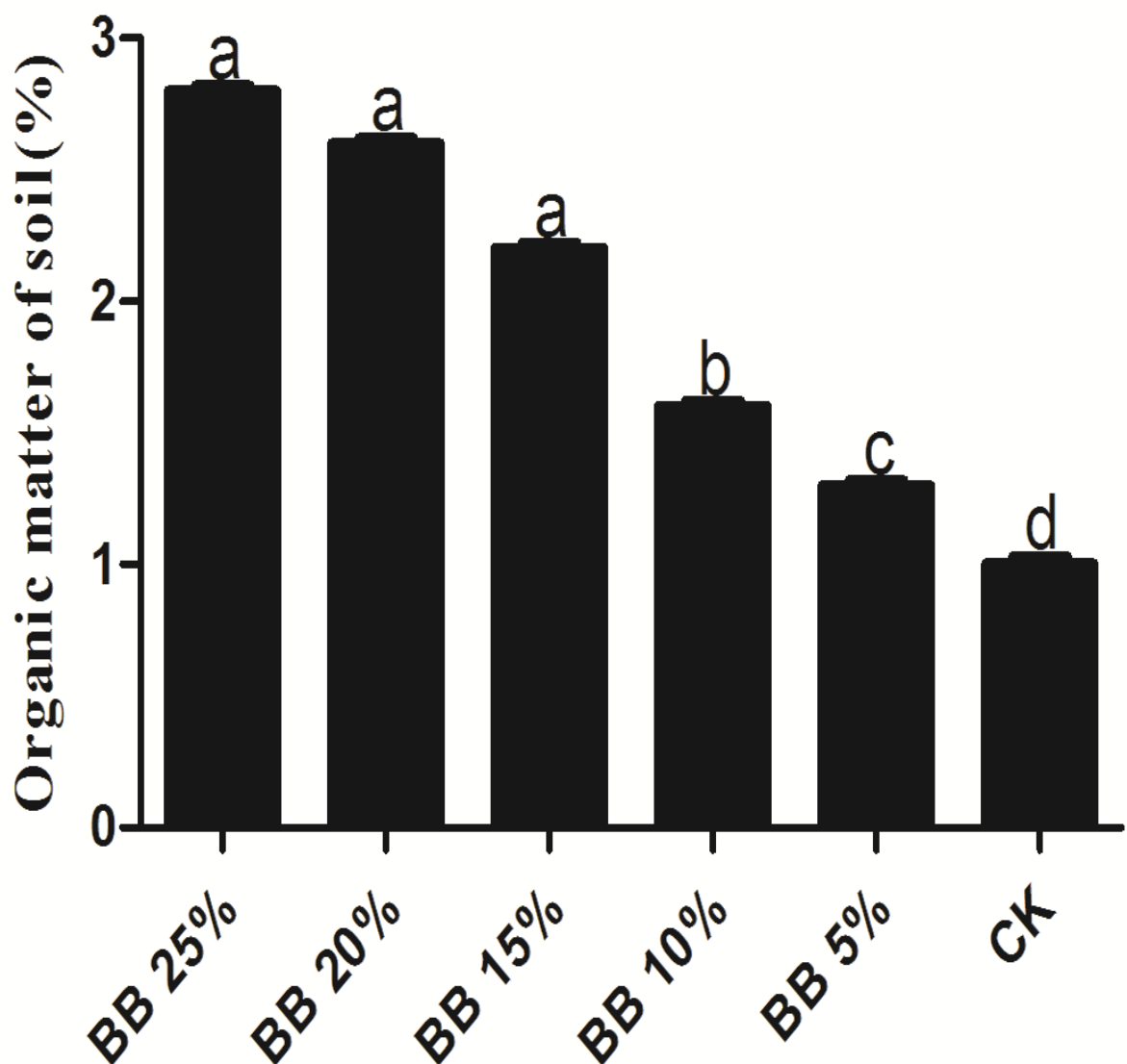
Organic matter (%)



Soil with better organic matter has a better structure, which facilitates water infiltration following rains and increases soil's water holding capacity and growth of roots into max permeable soil which results in good growth of plant and permits absorption of moveable soil nutrients to the roots. Data recorded for organic matter is shown in table 0.3, which reveals that the response to biochar doses was significant ($P < 0.01$). Kakar et al. (2021) reported that organic matter was not affected significantly when different regimes of banana-based biochar treatment applied which supported the findings of our work. The low fertility and productivity of calcareous

soil in arid environments are caused by a lack of organic matter, which makes nutrients especially phosphorus and micronutrients unavailable (Rengel, 2015; Naeem et al., 2017; Bityutskii et al., 2017; Kumari et al., 2018; Abbaszadeh-Dahaji et al., 2020). Additionally, a decrease in microbial activity results from the low level of organic matter in the soil, which impacts the quality and health of the soil (Khadem & Raiesi, 2017). To enhance the physical, chemical, and biological qualities of calcareous soil, organic matter must be added (Bizuhoraho et al., 2018).

Banana derived biochar given to maize crop at 25% biochar produced organic matter of maximum 2.7, closely followed by the 20% and 15% biochar with organic matter 2.5 and 1.2 respectively (Figure 0.3). Maize crop receiving zero quantity of biochar resulted in reduced organic matter 1.3 and 1.0. Increasing the amount of soil organic



matter is essential for enhancing soil fertility over the long term. (Bizuhoraho et al.,

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2018) where they noted similar results for organic matter.

Figure 3: Effects of the banana derived biochar on organic matter of maize crop (Arrows on bars represent standard error).

Total nitrogen of soil:

Total nitrogen, nitrate nitrogen, and ammonium nitrogen were measured in soil samples that were obtained using the methodology developed by Lu (2000). Soil that is more complete nitrogen gas has a superior structure that makes it easier for water to seep in after rain, boosts the soil's ability to retain water, and encourages root growth in the most permeable soil, which promotes healthy plant growth and allows the roots to absorb nutrients from the movable soil. Table 0.4 displays the organic matter data, which indicates that the response to the dosages of biochar was substantial ($P < 0.01$). In line with our findings, Kakar et al. (2021) found that the application of several regimes of banana based biochar treatment had no discernible effect on total nitrogen. The low levels of total nitrogen in calcareous soil in arid environments result in low fertility and productivity because they prevent the availability of nutrients, particularly micronutrients and phosphorus (Rengel, 2015; Naeem et al., 2017; Bityutskii et al., 2017; Kumari et al., 2018; Abbaszadeh Dahaji et al., 2020). The low quantity of total nitrogen in the soil also causes a decline in microbial activity, which affects the soil's quality and health (Khadem & Raiesi, 2017). According to Bizuhoraho et al. (2018), total nitrogen must be added to calcareous soil in order to improve its physical, chemical, and biological properties.

Banana derived biochar given to maize crop at 25% biochar produced soil nitrogen of maximum 6.1g closely followed by the 20% and 15% biochar with soil nitrogen 4.7g and 3g respectively (Figure 0.4). Maize crop receiving zero quantity of biochar resulted in reduced soil nitrogen 2g and 1.7g. Increasing the amount of nitrogen in the soil is essential for enhancing soil fertility over the long term. (Bizuhoraho et al., 2018) where they noted similar results for organic matter.

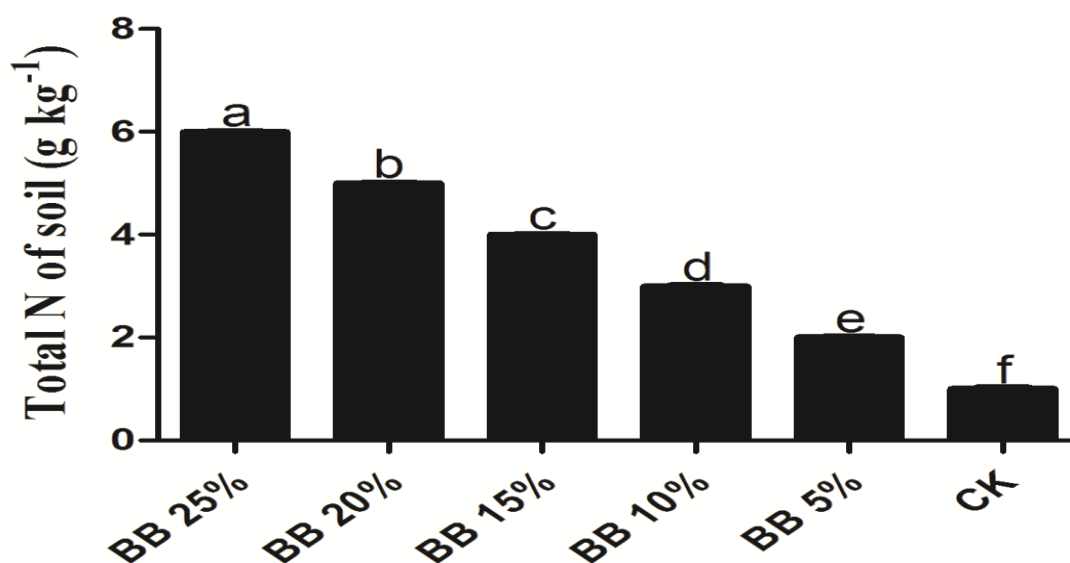


Figure 4: Effect of the banana derived biochr on Total nitrogen in soil of maize

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crop (Arrows on bars represent standard error).

Available phosphorus (%)

The element phosphorus plays an important role in the synthesis of ATP, which is the plant's main source of energy. As a result of photosynthesis, ATP is formed and contains phosphorus, and it is used by seedlings to grow and mature. For this reason, phosphorus is vital for the growth and health of all plants. Data recorded for available phosphorus is shown in table 0.5, which reveals that the response to biochar doses was significant ($P < 0.01$). Kakar et al. (2021) reported that phosphorus was not affected significantly when different regimes of banana-based biochar treatment applied which supported the findings of our work.

Banana derived biochar given to maize crop at 25% biochar produced phosphorus of maximum 29, closely followed by the 20% and 15% biochar with phosphorus 27 and 25 respectively. Maize crop receiving zero quantity of biochar resulted in reduced phosphorus 14.3 and 8.3 (as shown in figure 0.5). Phosphorus fixation is strong in calcareous and acidic soils, making it unavailable to plants. Ferrell et al. (2014) claim that adding biochar as a soil amendment greatly increased the availability of phosphorus. It has long been known that biochar contains a significant quantity of phosphorus, and that when biochar is put to soil, P is released from it (Gaskin et al., 2008).

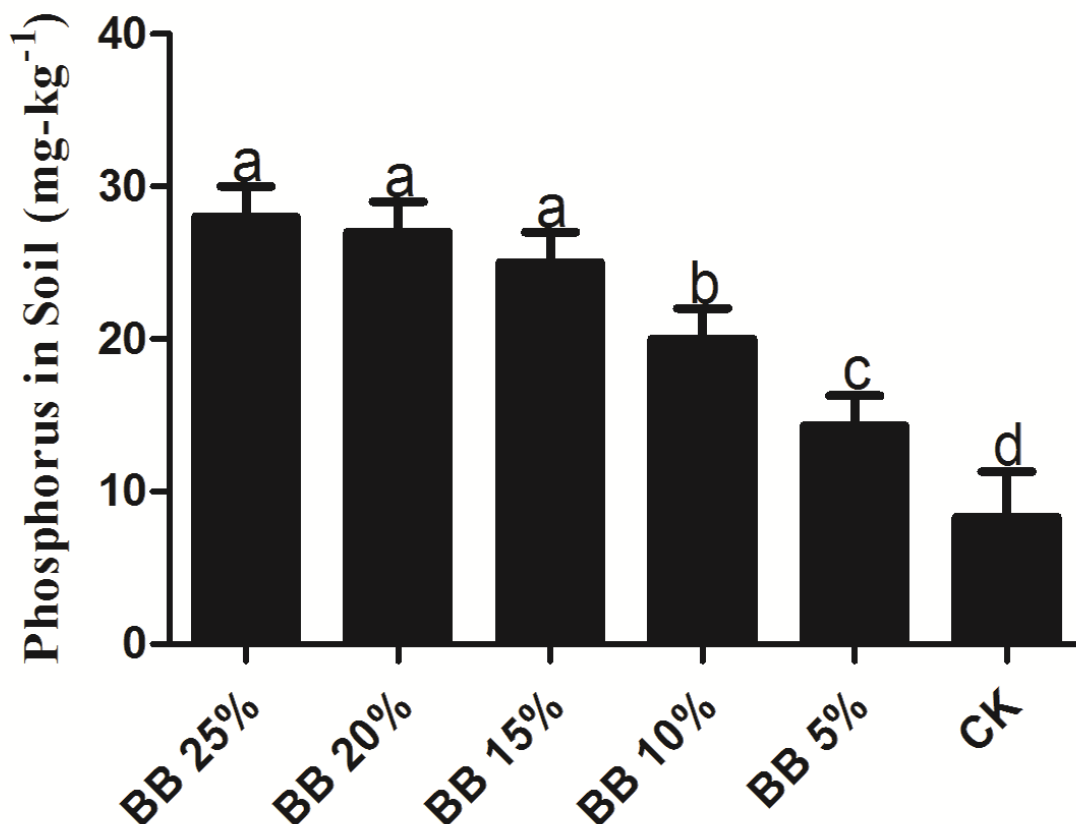
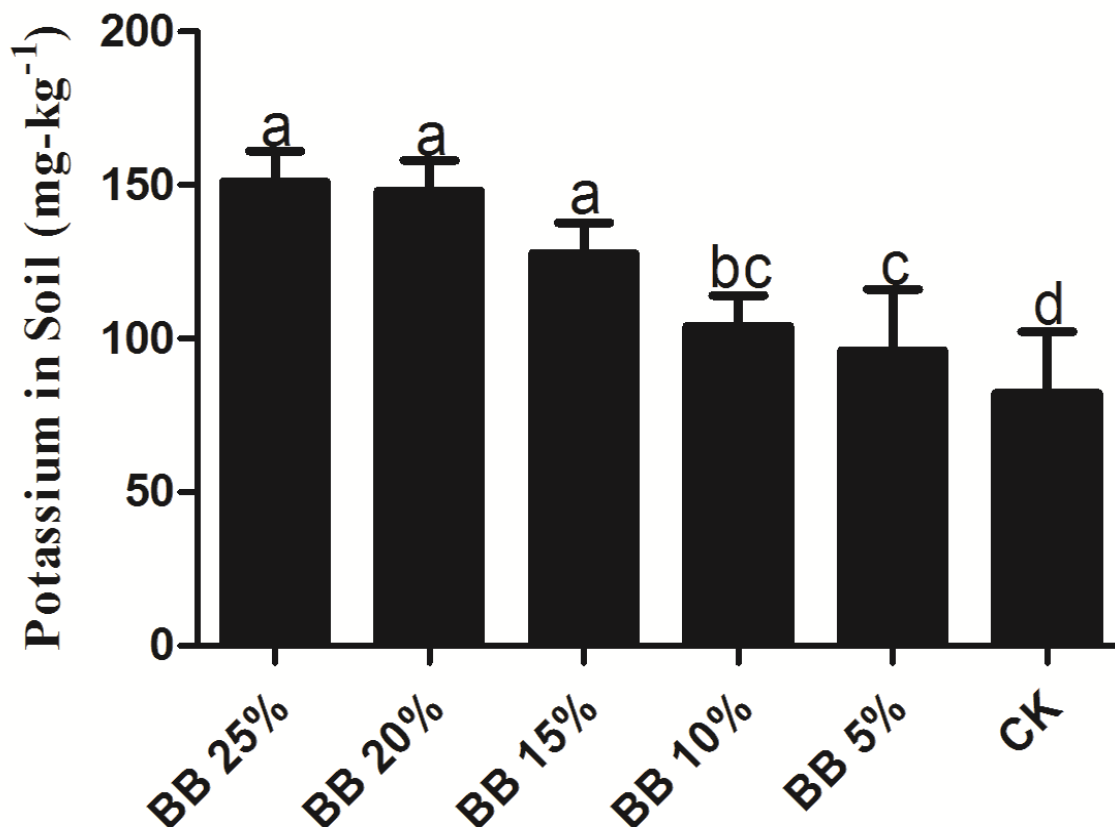


Figure 5: Effects of the banana derived biochar on phosphorus of maize crop (Arrows on bars represent standard error).



Available potassium (%)

Potassium is associated with water, mineral, and carbohydrate movement in plant tissue. It has an effect on the manufacture of Adenosine Triphosphate (ATP), protein, and starch, which can control the rate of photosynthesis and is involved in the activation of plant enzymes. Data recorded for available potassium is shown in table 0.6, which reveals that the response to biochar doses was significant ($P < 0.01$). Kakar et al. (2021) reported that potassium was not affected significantly when different regimes of banana based biochar treatment applied which supported the findings of our work.

Banana derived biochar given to maize crop at 25% biochar produced potassium of maximum 149. closely followed by the 20% and 15% biochar with phosphorus 148 and 127.6 respectively (Figure 0.6). Maize crop receiving zero quantity of biochar resulted in reduced potassium 104 and 82.3. Kakar et al. (2021) reported similar outcomes, with the application of biochar fertilizer resulting in the treatment's greatest K uptake. These outcomes are in line with those of Sarfaraz et al. (2017), who tested biochar made from vineyard pruning at a pyrolysis temperature of 400°C on maize crops grown in calcareous soil.

Figure 6: Effects of the banana derived biochar on potassium of maize crop (Arrows on bars represent standard error).

Stem girth (cm):

One of the most often used metrics for assessing the commercial and environmental advantages of woody vegetation (such as wood or biomass products, carbon sequestration, and landscape repair) is stem girth. The thickness or width of the stem is called the girth of the stem which is increased due to lateral meristem. Similarly, biomass of cereals is directly dependent upon the components such as stem girth etc. Data regarding stem girth of maize plant is presented in table 0.7. Statistical results indicated that the performance of stem girth against different biochar doses was significant ($P < 0.01$). Similar results were obtained by Kakar et al. (2021), who estimated the response of maize plants by studying stem girth under the influence of amendments based on banana leaves. They discovered a substantial variation in stem girth.

Maximum stem girth with a value of 4.4 cm was obtained under the 25% biochar dose. Similarly, other plants achieved the girth of 4.3 cm and 4.2 cm when biochar doses were applied at the rate of 20% and 15% respectively. However, minimum girth was noted in control reaching just up to 3.6 and 3.5 cm. Data regarding stem girth of maize plant is presented in (figure 0.7). More vegetative development, which resulted in enhanced mutual shadowing and internodal extension, might account for the increase in plant height brought on by increased use of biochar. This increase in stem girth is the result of applying more biochar made from banana extracts have been confirmed by the previous findings of (Sarfraz et al., 2017). Furthermore, stem girth of maize plants was significantly affected by interactive effect of banana derived biochar rates.

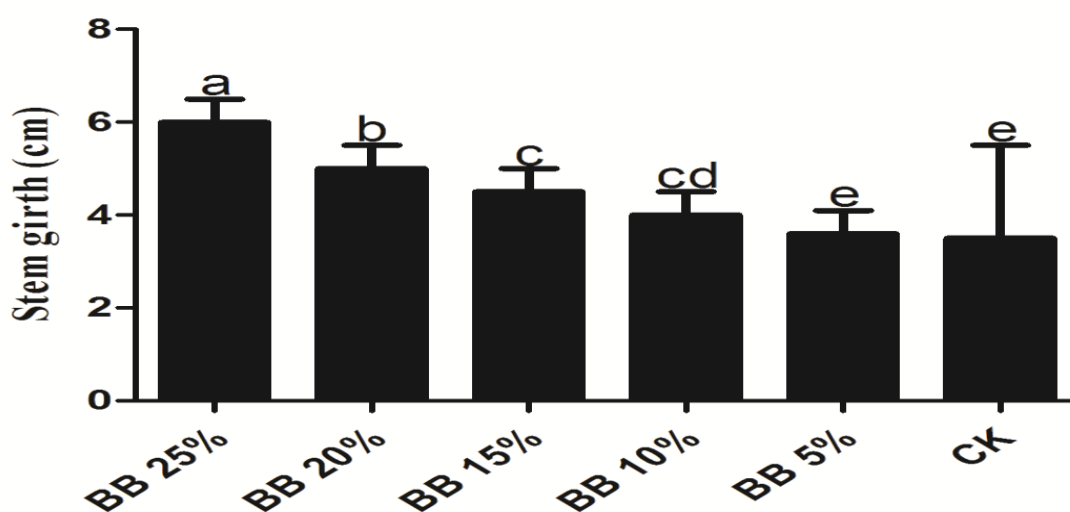


Figure 7: Effects of the banana derived biochar on stem girth of maize crop (Arrows on bars represent standard error).

Plant height (cm):

Plant height, which is one of the most crucial morphological parameters that tells weather any plant is susceptible to lodging or not. In a similar vein, plants with shorter stature respond better to fertilizer. Typically, crops with greater height are thought to have better biological yields. preferred by local farmers because they don't only need maize grains, but along with huge straw yield to feed their cattle. Plant height in corn is considered a crucial characteristic due to its high heritability (Peiffer et al., 2014), easily measurable and influences the stalk lodging (Li et al., 2007). Statistical results indicated that the performance of plant height against different banana derived biochar doses were not significant ($P > 0.05$). Similar results were obtained by Kakar et al. (2021) and Masood et al. (2014), who investigated plant height in response to amendments based on banana leaves in order to estimate the reaction of maize plants. They discovered that there was no significant variation in plant height (Table 0.8). However, when biochar rates were coupled with nitrogen fertilizers, Sarfraz et al. (2017) found that plant height increased by 73.4 percent over control. The production of biochar from various feedstocks using varying pyrolysis temperatures, as well as variable soil types and most importantly the rates at which biochar was applied, are the reasons for the inconsistent results on maize plant height under biochar additions.

Maximum plant height with a value of 104.8 cm was obtained under the 25% biochar dose as shown in (figure 0.8). Similarly, other plants achieved the height of 104.6 cm, 98.6 cm and 95.3 cm and 94.6 cm when biochar doses were applied at 20%, 15% and 10% respectively. However, minimum plant height was noted in control reaching just up to 87 cm. The increase in plant height brought on by increased biochar application may be explained by more vegetative development, which led to improved mutual shadowing and internodal extension. Previous research has indicated that applying higher rates of biochar made from banana extracts causes an increase in plant height (Sarfraz et al., 2017; Akbar et al., 2002). These results, however, run counter to Genter and Camper's (1973) earlier findings, which indicated that plant height increased with decreasing plant densities. Due to competition for light caused by the mutual shadowing effect, plant height increased with higher plant densities. Additionally, the interactive effect of biochar rates had a substantial impact on the height of maize plants.

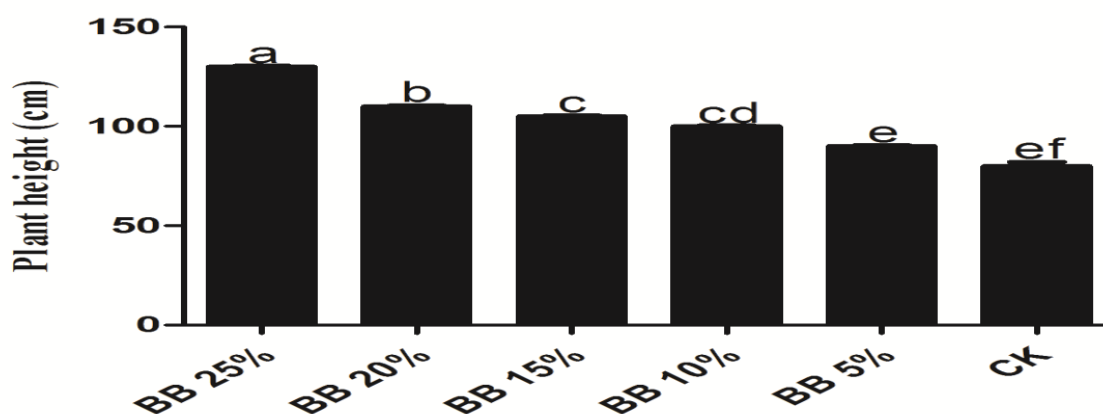


Figure 8: Effects of the banana derived biochar on plant height of maize crop (Arrows on bars represent standard error).

Biomass production per plant (g)

Plant biomass is a type of energy that is renewable, environmentally friendly, abundant, and clean. It can help to reduce reliance on fossil fuels while also addressing the issue of pollution. An application of the biochar can improve the fresh shoot weight of maize plants up to 97% as against control. Crops with enlarged and broad biomass are normally considered as higher biological yield, which is also preferred by local farmers because they don't only need maize grains, but along with huge straw yield (locally known as Bhoosa) to feed their cattle. Data recorded on plant biomass of maize is shown in table 0.9, which reveals that the response to biochar doses was significant ($P < 0.01$). Our findings are consistent with those of Sarfraz et al. (2017), who found that the application of biochar had a substantial impact on the biomass production of maize plants. According to Abbas et al. (2020), biochar made from crops is a frequent waste product that is acquired from the manufacturing of agricultural products with enormous annual returns. Our findings support those of Rajkovich et al. (2012), who found comparable biomass production outcomes when biochar was applied to maize crops.

Results reflected that a greater plant biomass 48.4g were produced when crop was fed with a 25% biochar. This was closely followed by an insignificant difference in plant biomass 48.3g and 42g and at banana derived biochar dosages of 20% and 15% respectively whereas, a smaller plant biomass production 34g and 21.6g were observed under control (Figure 0.9). Compared to no treatment (control), the application of biochar made from banana extracts is thought to increase biomass because the extracts include nutrients that are released into the soil for maize plants. According to Masood et al. (2014), who verified our findings, biomass value seemed to rise with more biochar treatment. Accordingly, in our study, the optimum maize performance under T5 was caused by better soil conditions brought about by this treatment. An increase in biomass could be the consequence of better soil properties, plant physiological processes, and nutritional availability brought about by biochar treatment (Jeffery et al. 2011).

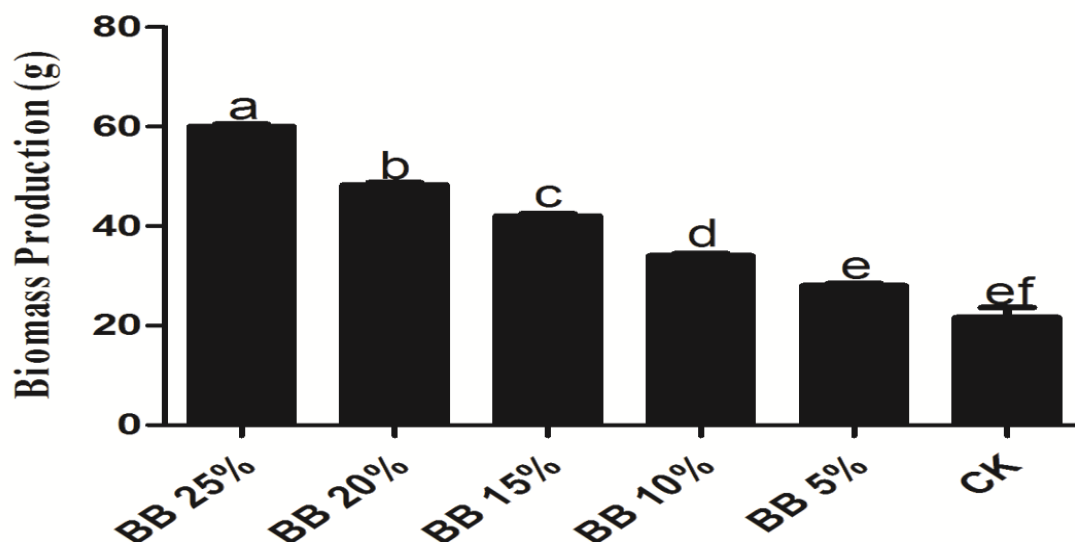


Figure 9: Effects of the banana derived biochar on biomass production of maize crop (Arrows on bars represent standard error).

Conclusion

Biochar made from bananas is among the finest ways to increase soil sustainability and production, particularly for maize crops. The current experiment demonstrated that applying biochar enhanced the crop's biological yield by improving its physical, chemical, and biological characteristics. Significant variations were found between stem girth, biomass output, P, K, and organic matter, according to analysis of variance. Average results showed that T6 (25% biochar) enhanced development and growth in the vast majority of the plant characteristics under study. As a result, it is advised that 25% biochar made from bananas play a significant role in feeding the maize crop according to several metrics.

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