

Evaluating Banana-Derived Biochar for Enhancing Soil Fertility and Growth Performance of Maize (*Zea mays* L.) in Calcareous Soils

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ABSTRACT

Pakistan faces numerous challenges involving calcareous soils in dry regions, including poor organic content, diminished nutrient levels, and soil degradation, which all threaten the potential for sustainable agricultural practices. Climate smart biochar soil amendments are currently changing the face of agriculture in improving soil and crop health. To this point, the use of banana biochar as a soil and crop enhancement supplement has undergone limited research. The current study reports the impact of banana biochar on soil health and the growth of maize (*Zea mays* L.) during a greenhouse trial conducted at the Lasbela University of Agriculture, Water and Marine Sciences (LUAWMS), Uthal, Pakistan. The study followed a Complete Randomized Design in which 6 biochar amendments (0% (control), 15%, 20%, 25%, 30%, and 35%) were replicated three times. The study analyzed agronomic responses associated with crop growth and soil amendments, and these included soil pH, electrical conductivity, organic matter, total nitrogen, and phosphorus and potassium availability as well as stem girth, plant height, and crop biomass. The results indicated

that the use of biochar positively impacted all of the examined soil health indicators of organic matter, total nitrogen, available phosphorus, and potassium ($P < 0.01$), with peak outcomes achieved with the 25%-35% biochar amendments. Even though soil pH and electrical conductivity increased, changes were too small as to be statistically significant, whereas large enhancements in nutrient availability were achieved. Biochar improved stem girth and biomass production, with 35% biochar leading to the greatest stem girth (4.1 cm) and biomass (50.4 g). Although plant height improved, the change was not statistically significant ($P > 0.05$). Ultimately, biochar enhanced soil fertility and the growth of maize, highlighting the value of banana biochar as a sustainable soil amendment for increasing the productivity of crops in the nutrient-deficient calcareous soils of Pakistan.

Keywords: Banana-Derived Biochar, Soil Fertility, Maize, Organic Matter, Nitrogen, Phosphorus, Potassium, Soil Ph, Electrical Conductivity, Biomass, Stem Girth, Climate-Smart Agriculture And Calcareous Soils.

INTRODUCTION

Pakistan's economy depends heavily on agriculture, and it's the primary source of livelihood for the majority of the rural populace. Approximately 75% of the poor live in rural areas, and almost 93% of the farming population consists of smallholders, who manage half of the country's arable land (UNDP, 2019). Though the agricultural sector contributes to the economy's GDP, there is an increasing rural poverty rate, particularly for small-scale farmers (Qasim and Knerr, 2013). Low agricultural yields continue to arise from poor quality seeds, poorly utilized fertilizers, pest infestations, and inappropriate crop varieties. Although resource depletion and inefficient resource use remain the primary constraints, the productivity and income potential of hybrid maize varieties is significant (Njeru, 1983).

One way to address declining soil fertility is to use biochar. Biochar is a carbon-rich stable substance created through a process called pyrolysis, which is when organic material is heated with limited oxygen and trapped to prevent burning. Different feedstocks like crop residues, wood chips, and manure can be used to produce biochar (Lehmann et al., 2006). Additionally, biochar is non-decomposable meaning it can stay in the soil for decades, and it can continue to improve the soil carbon, fertility, and structure (Gao et al., 2021). Furthermore, other similar materials, like charcoal, were historically used to improve the fertility of terra preta soils in the Amazon (Glaser et al., 2001). Today, modern applications of biochar are focused on improving soil and capturing carbon for climate-smart sustainable farming practices (Day et al., 2004).

Biochar increases the retention of nutrients, the storage of water, and the activity of microbes, all contributing to the health and productivity of soil and crops (McCormack et al., 2013). It minimizes the loss of nutrients and supports soil sustaining beneficial microbes to sustain soil nutrient and fertilities (Fierer, 2017). While many works emphasize the effect of biochar on macronutrients, the effect of biochar on microcontinents, especially on alkaline soils has been barely studied (Karimi et al., 2020). Biochars can be produced from different feedstocks like rice husk, farmyard manure, or sugarcane filter cake, and each may have unique

consequences to soil and crops (Tomczyk et al., 2020).

Unproductive land management, nutrient loss, and decline in soil fertility have become major challenges for the sustainability of crop production in Pakistan. However, the burning of agricultural wastes, like banana leaves, can become a thing of the past by transforming them into biochar. The use of banana leaf biochar can positively impact the alkaline soil by improving its physiochemical properties and boosting the availability of nutrients and maize production. With this in mind, this study is designed to assess the impact of banana leaf biochar on soil fertility, nutrient status, and the physical and chemical properties of soil in and around Faisalabad to promote climate-smart sustainable crop production and soil fertility management in Pakistan.

MATERIAL AND METHODS

Biochar Production

Biochar production occurred during the collection of rice straw and banana waste from the study site. The biomass was air-dried, ground, and fed into the biochar production tank, where it was slow-pyrolyzed for about 3 hours at sub-zero oxygen levels. It was then cooled, and the biochar was collected, vacuum packed into sterile plastic and kept for future processing. Analytical Biochar production practices occurred within the Soil Sciences Department in Lasbela University of Agriculture, Water and Marine Sciences (LUAWMS), UThal.

Pot Experiment Setup

Topsoil (0-15 cm) was gathered from the Uthal Experimental Farm, LUAWMS. The soil also air-dried, mixed, and then was sieved using 2 mm mesh to remove particular artifacts. Polypropylene pots with drainage holes were packed with 5 kg of the soil prepared previously. Experimental design was a Completely Randomized Design (CRD) with six biochar treatments each replicated three times, in all receiving:

T1: Control (0% Biochar)

T2: 15% Biochar

T3: 20% Biochar

T4: 25% Biochar

T5: 30% Biochar

T6: 35% Biochar

Each soil treatment was designed to contain the treatment design biochar ratio.

Soil Sampling and Analyzing the Data Collected from Laboratories.

In order to assess the physical and chemical properties of the soil, the soil samples were harvested from the pots two times; one before the sowing started, and the other after the maize were harvested.

Soil Sampling and Analyzing the Data Collected from Laboratories.

Soil pH was measured using the digital pH meter, while it was in suspension in water, ratioing 1:2.5 of soil to water. First, 25 grams of soil is to be mixed with 55 milliliters of distilled water, and after it has been shaken for 30 minutes, the pH should be measured.

Electrical Conductivity (EC) of the soil-water extract (1:2.5) was determined using an EC meter. A mixture of 20 grams of air-dried soil, and 50 milliliters of distilled water is to be shaken for 30 minutes and after that precluded to stabilization before it is measured. Equally, the Organic matter portion was determined Walker, as well as Black as an oxidation method to be applied wet (Nelson & Sommers, 1996).

Total nitrogen was determined using the Kjeldahl digestion method as described by Lu (2000). Nitrate-N and ammonium-N were also assessed following standard procedures. After extraction and following the standard protocols, available phosphorus was measured by means of the molybdenum blue colorimetric technique. After extraction, available potassium was analyzed using a flame photometer. Total potassium was determined using NaOH fusion followed by spectrophotometric analysis.

Agronomic Measurements

Planting of Maize

Each pot was allocated ten seeds of the maize variety Akbar. Following germination, seedlings were uniformly thinned to five per pot. Uniform crop management practices were applied across treatments, and pots were irrigated as needed.

Stem Girth (cm)

Stem girth was measured at the mid-stem level using a tape measure. Measurements were averaged across three stem girth samples per pot.

Plant Height (cm)

The height of each plant was measured at the time of maturity with a tape measure, from the soil level to the apex of the plant.

Biomass per Plant (g)

At the tasseling stage, three plants were harvested from each pot. Biomass was measured with a weighing scale to find the fresh weight, and average biomass per plant was determined.

Statistical Analysis

Statistical analysis was performed by means of one-way Analysis of Variance (ANOVA) using SPSS (Version 20.0). For the purpose of the study, statistically significantly different treatment means were determined using the Duncan's Multiple Range Test (DMRT) at $P < 0.05$ level.

RESULTS AND DISCUSSIONS

Site Description

The research was conducted in the greenhouse located at the Department of Soil Science of Lasbela University of Agriculture, Water and Marine Sciences (LUAWMS), based in Uthal, Balochistan. The objective was to determine how banana biochar impacts the growth of maize (*Zea mays* L.). Soil was collected, air dried, crushed, and passed through a 4 mm sieve. The experiment was designed in a Completely Randomized Design framework with six different treatments

(T1Control=0%, T2=15%, T3=20%, T4=25%, T5=30% and T6=35% biochar) and three replications per treatment showed in figure 1. Each pot contained twelve maize seedlings, which were later thinned to 6 seedlings per pot post germination. The nutrient sources for the seedlings were applied in the form of urea, single superphosphate and sulphate of potash based on the required doses for each treatment.

pH

The pH level in soils greatly affects how microbes within the soil behave, how nutrients are accessed, and the overall soil fertility. According to the results, the different dosages of biochar had little effect on pH balance, which is consistent with Kakar et al. (2021). In arid regions, calcareous soils have higher pH, which results in reduced phosphorus and micro nutrient levels (Shareef et al., 2016). As illustrated in Figure 2A, the highest pH of 9.1 was recorded during the 35 percent biochar treatment (Figure 1A). The control had the lowest recorded pH of 8.1. The increase could be related to the changes in the soil chemical balance and nutrient (Naeem et al., 2017; Kumari et al., 2018) unit.

Electrical Conductivity (dS m⁻¹)

Electrical conductivity (EC) is used to show how well the soil conducts electric current and is also used to determine the concentration of soluble salts. It was found that the use of biochar did not significantly affect EC ($P>0.05$), which is consistent with Kakar et al. (2021). As showed in figure 2A, the highest EC (2.65 dS m⁻¹) was taken at 35 percent biochar (Figure 1A) and the control registered 1.75 dS m⁻¹. This trend is possible because of enhanced nutrient availability and chemical characteristics of the soil (Naeem et al., 2017). Kumari et al. (2018) also reported similar results, who concluded the EC to be increased with the addition of biochar.

Organic Matter (%)

Organic matter is important for improving soil structure, facilitating the flow of water, and increasing the nutrients that are available to plants. The results showed that biochar had a significant influence on organic matter levels ($P<0.01$), though Kakar et al. (2021) did not find any significant changes with banana-based biochar. Soils in arid environments, especially calcareous ones, have low organic matter and thus provide less fertility and support for soil microorganisms (Zhao et al., 2022). The most organic matter (2.7%) occurred at 35% biochar as shown in Figure 1A, with the control having only 1.0% as shown in Figure 2A. Bizuhoraho et al. (2018), who studied the influence of biochar on improving soil fertility and structure, reached the same conclusions.

Total Nitrogen of Soil

Total, nitrate, and ammonium nitrogen forms in the soil were assessed using the methodology from Lu (2000). Results showed that biochar had a strong effect on the total nitrogen value ($P<0.01$), but those from banana-based biochar were insignificant (Kakar et al., 2021). Nitrogen-poor, calcareous soil in the arid regions affects the soil fertility and the microbial activity negatively (Shareef et al., 2016). As showed in Figure 1A, with 35 percent biochar, the most nitrogen of 3.2 g was recorded whereas

in the control it was 2 g as seen in Figure 2A. Findings from Bizuhoraho et al. (2018) were parallel when he stated that soil biochar improves soil fertility and increases nitrogen supply over a sustained period.

Available Phosphorus (%)

All plants need phosphorus to carry out various functions. Phosphorus is one of the primary nutrients used to produce ATP during photosynthesis. Different levels of biochar significantly affected available phosphorus ($P < 0.01$). However, Kakar et al. (2021) did not find significant changes with different banana-based biochar treatments. Figure 2B shows that the highest phosphorus value (35%) was recorded at 20% biochar compared to the control value of 29% in Figure 1A. In calcareous soils, phosphorus fixation limits its availability. However, biochar application can release and enhance soil phosphorus (Novak et al., 2012). This shows that biochar improves accessibility of phosphorus, which is important for plant uptake.

Available Potassium (%)

Potassium is necessary for managing water balance, activating enzymes, and forming ATP, proteins, and starch, all of which affect photosynthesis and growth. Our data suggests biochar has a major effect on available potassium ($P < 0.01$) while Kakar et al. (2021) did not see any significant effect across differing banana-based biochar treatments. As indicated in Figure 5B, the highest level of potassium (153%) was recorded at 25% biochar (figure 1B) while 35% (figure 2B) was recorded at 148% biochar, 20% biochar had 131%, 15% was recorded 110%, 10% was recorded 99% and respectively, while the control had 89%. Sarfaraz et al. (2017) has congruent findings that biochar increases potassium availability and uptake of maize grown on calcareous soils.

Girth Measurement (cm)

Stem girth indicates plant activity and biomass storage, and calculating the girth assists in estimating the growth efficiency and structural resilience of the plant. The biochar made a significant impact on the girth of the stems ($P < 0.01$) which corresponds with the scenario of Kakar et al. (2021) where the maize responded in the same manner with banana-based biochar. As showed in figure 1B, the largest stem girth of 4.1 cm was recorded on 35% (figure 2B) biochar, with 4.7 cm on 30% biochar, and in 3.9 cm on 25% biochar, and the control was the lowest with 3.1cm. The stems may be thicker as a result of the increased nutrient absorption and vegetative growth contributed by biochar as was also the finding of Sarfraz et al. (2017).

Plant Height Measurement (cm)

Plant height corresponds with perfection biomass, determines the spacing of plants in the field, and magnitude the amount of lodging and resistance to collapse the plant. The height of the plants is also significant in determining the amount of fertilizer to be applied and in response that the plants will be able to exhibit.

It has been documented as highly heritable in maize with repercussions on stalk lodging (Peiffer et al., 2014; Li et al., 2007). The reports did note that the application

of biochar did not significantly impact the height of the plants ($P>0.05$), which is also consistent with Masood et al. (2014). The tallest plants (139 cm) were recorded with 35 percent biochar in figure 2B whereas the control recorded the shortest height (103.5 cm) in figure 1B. The height is attributed to increased vegetative growth which subsequently increases the rate of nutrient absorption with higher levels of biochar (Sarfraz et al., 2017). However, the variations in reports can also be attributed to the type of biochar, the condition of the soil, and the rates of application.

Biomass Production per Plant (g)

The use of plant biomass as an energy source contributes to the advancement of sustainable agriculture. Biochar positively impacted maize biomass ($P<0.01$), consistent with findings in Irfan et al. (2021). In figure 2B, the 35 percent biochar dosage produced the most biomass (50.4 g). This was followed by 45 g and 40.9 g at 30 percent and 25 percent dosage levels, respectively, while the control only produced 22.0 g (figure 1B). Increases in biomass from banana-based biochar may be due to improvements in soil fertility and the rate at which soil nutrients are made available to plants (Jeffery et al., 2011). This demonstrates that biochar contributes to positive plant growth and overall biological yield.

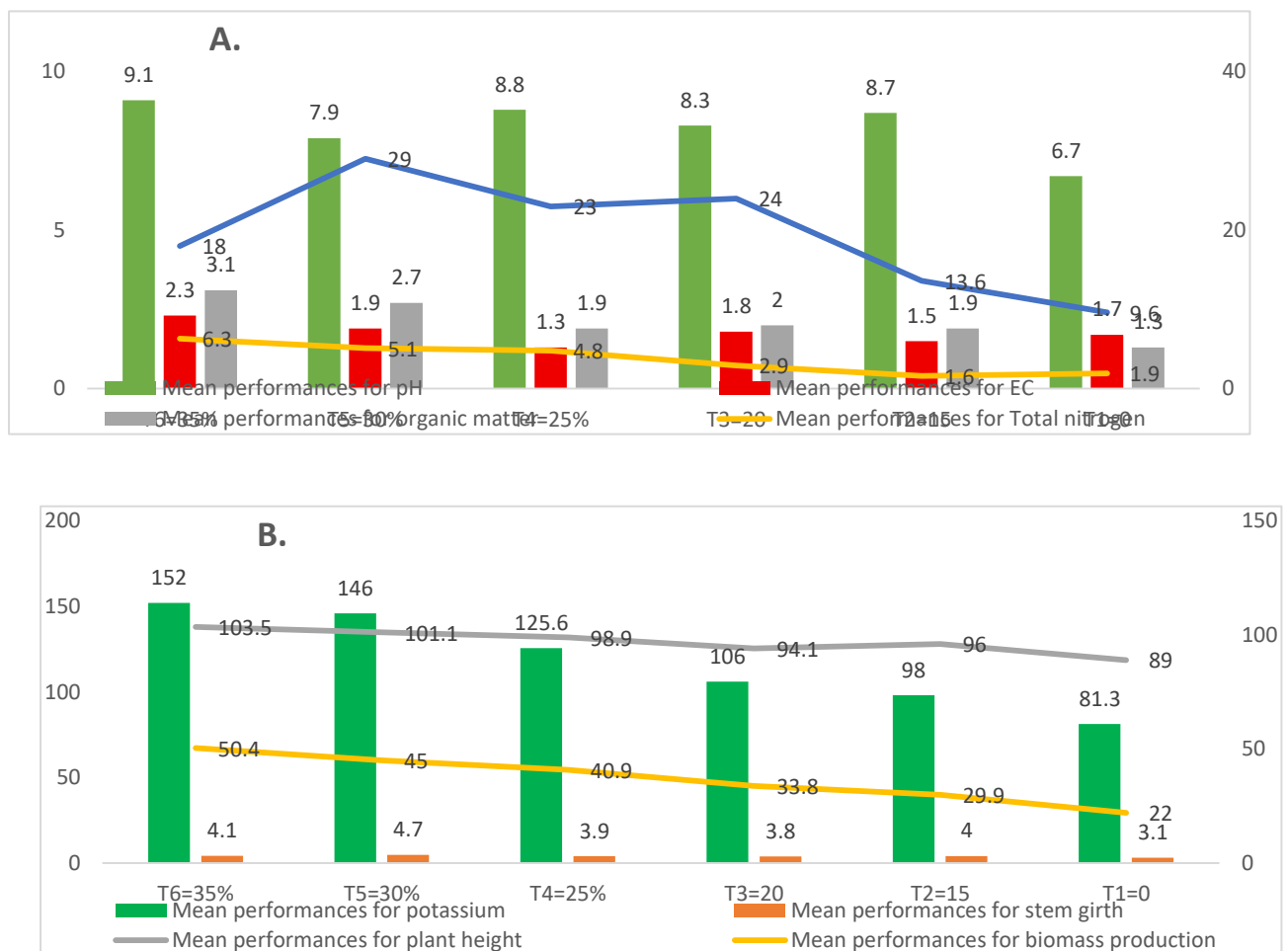


Figure 1: Mean performance of maize crop for organic matter, total nitrogen, potassium, stem girth and plant height under four biochar doses. Bars with different alphabets indicate significant differences based on the LSD test at $P < 0.05$.

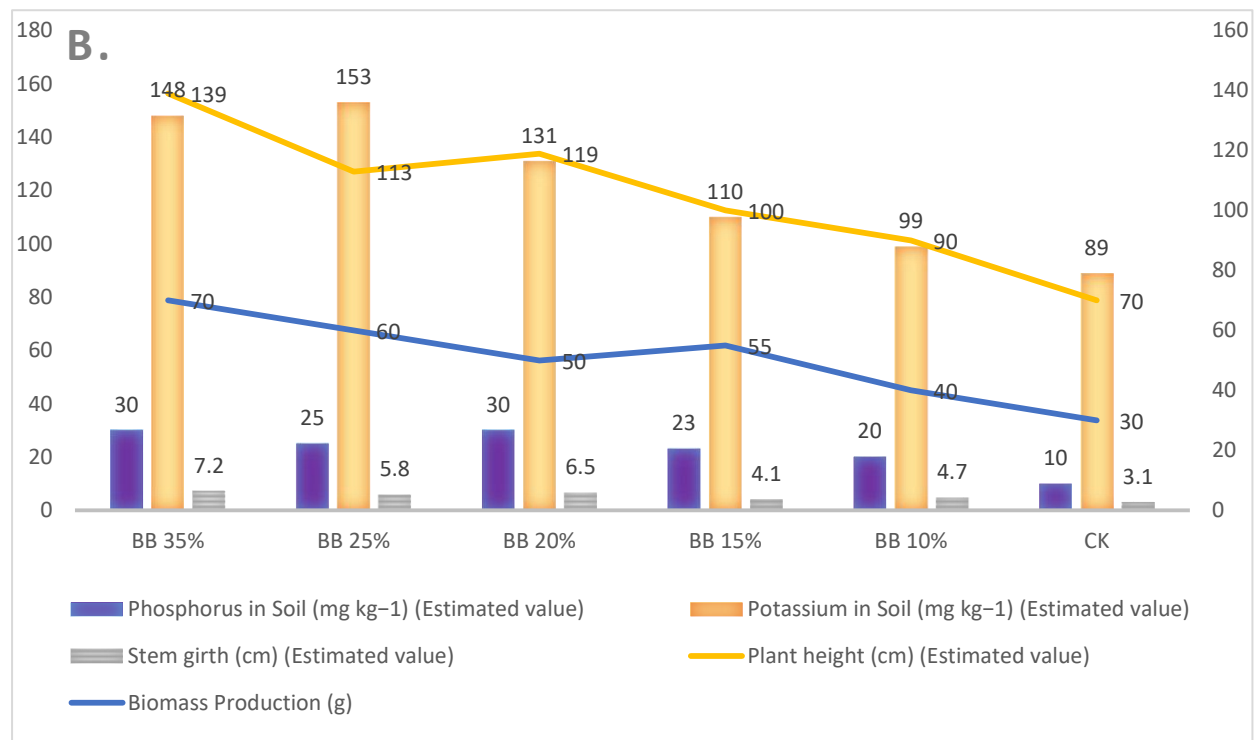


Figure 2: Effects of Banana-Derived Biochar on Soil Physicochemical Properties and Growth Performance of Maize (*Zea mays* L.), Including pH, EC, Organic Matter, Nitrogen, Phosphorus, Potassium, Plant Morphology, and Biomass Production.

Conclusion

This research shows that using banana waste-derived biochar is a cost-effective strategy for amending calcareous soils in arid ecosystems. Application of biochar especially at the higher ends of the rate spectrum (25-35% biochar), positively impacted the organic carbon, total nitrogen, and available phosphorous and potassium contents of the soils, that impacted plant growth positively. The higher potassium and nitrogen contents of the soils promoted more stem girth, higher maize nitrogen uptake and more biomass production. Although the soils and plant growth slightly resulted in pH and electrical conductivity increases, that were of no detrimental effect to nutrient dilution/deficiency. Improving soils for plant growth is a major contribution to agricultural practice, and the biomass production is a major plus in promoting climate positive smart or climate resilient agriculture. The major agricultural contribution is the environmentally sound and waste reducing approach to biochar production from banana agricultural residues. The ability of banana-derived biochar to enhance plant productivity, reduce agricultural chemical dependency, and rehabilitate depleted soils,

is a clear climatic positive agricultural practice for Pakistan. Banana-derived biochar positively enhances agricultural sustainability and promotes agricultural productivity for the brunch soils.

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