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**RESEARCH ARTICLE**

# Effect of applying Banana Waste Biochar on soil properties and growth of cultivated plants in sandy soil

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## Abstract

Three pot experiments were conducted during three successive seasons to study the effects of Banana trees residues biochar at a level of 0 , 0.5, 1, 2 and 5% on the soil properties, N, P, and K availability as well as, growth, nutrient uptake of different crop plants under this study The results showed that, additions of banana waste biochar to the soil led to an increase in the organic matter content, pH , EC , total nitrogen, available phosphorus, and available potassium in the soil. On the other hand, it led to a decrease in the percentage of the total calcium carbonate in the soil. These effects increase with increasing the rate of biochar added to the soil. In addition, the use of banana waste biochar at low rates (0.5 and 1%) led to an increase in the plant height, root length, dry matter yield of plants and N, P and K uptake by plants compared to other treatments. On the other hand, application of banana biochar at rates 2 and 5% gave significant decreased in the height of plants, root length, dry matter yield and N, P and K uptake by plants compared to other treatments. These results show that, additional research is required to determine the short- and long-term effects of adding banana waste biochar treatments on the characteristics of the soil and available nutrients as well as plant growth and nutrients uptake under field conditions and extensive trials.

**Keywords:** Banana waste; Biochar; growth; Soil properties; uptake.

## 1. Introduction

Any human activity such as agriculture, may create some wastes. which can be formed during the agricultural production and/or after crop harvesting such as banana trees residues. Some agricultural wastes are a real wealth and need transforming into economic products. On the other hand, they may contain toxic organic and inorganic materials and some harmful microbial species that could have a negative impact on the environment and pose serious health risks to humans. (Kauldhar and Yadav, 2018; Maji *et al.*, 2020; Prasad *et al.*, 2020 ; Taher and Nasr, 2020). Banana trees residues in Qena governorate represents an ongoing environmental problem. The recycling of banana trees residues and reusing it as biochar, as way to managed and benefit of these wastes (Bhushan *et al.*, 2019). Biochar is a solid material is a carbon-rich resulting from the thermochemical combustion of biomass in a low-oxygen environment (IBI, 2015). The addition of this material resulting in enhancing the physiochemical properties of soil, raising water retention capacity, enhancement of nutrient availability, reduction of nutrient leaching, enhancing soil microbial activity and enhancing plant growth (Warnock *et al.*, 2007; Novak *et al.*, 2009; Waters *et al.*, 2011; Alburquerque *et al.*, 2013; Reverchon *et al.*, 2014). Results showed that, biochar can be used to improve the soil physical and chemical properties such as (bulk density, porosity, infiltration rate, moisture content, increases water holding capacity, N, P, K,

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Mg, Ca, and CEC (Adekiya *et al.,* 2020). High adsorptive nature, porosity of biochar, increase in total soil organic carbon contents and provision of habitat to microorganisms are the possible mechanisms behind these improvements in soil physical properties by biochar application (Aslam *et al.,* 2014). Biochar raised soil pH from 5.7 to 6.3 and enhanced the carbon buildup 4.4 t $ha^{-1}$ (Pandian *et al.,* 2016). Biochar could retain N - fertilizers and then release them when needed via a cation exchange process (Hale *et al.,* 2013). Several mechanisms have been proposed to explain the apparent N retention and reduction in N leaching in biochar-treated soils. These include cation or anion exchange reactions and adsorption of NH3 or organic N on biochar (Clough *et al.,* 2013). The addition of biochar to soil leads to increase of the soil pH, soil organic matter, soil bulk density, total nitrogen, available phosphorus and available potassium contents of soil (Syuhada *et al.,* 2016; Timilsina *et al.,* 2017; Mierzwa-Hersztek *et al.,* 2019). Biochar has the potential to improve physical as well as chemical soil properties, due to biochar properties related to surface area and porosity, carbon content, nutrient content and cation exchange capacity (CEC) (Carvalho, 2015). increased of total soil nitrogen, soil phosphorus and soil potassium, due to the addition of biochar to soils (Biederman and Harpole, 2013). Additionally, it was discovered that growing spring wheat with maize biochar changed the morphological properties of the plant by boosting shoot biomass and thickening root systems. On the other hand, numerous researches have demonstrated that biochar has little effect or a detrimental effect on the growth characteristics of plants (Schmidt *et al.,* 2014; Reibe *et al.,* 2015). There is a point at which biochar is deleterious to plant growth; increasing the biochar rate caused a considerable reduction in plant height. It was discovered that biochar had an adverse impact on flowering and plant growth. The way that cultivars responded to different biochar rates also differed. Additionally, biochar rates had no effect on the development or flowering of other varieties of plants (Regmi, 2022). According to the crop and kind of biochar, biochar has been discovered to have a variety of effects on plant development and yield, including positive, neutral, and negative effects (Kavitha *et al.,* 2018). This study aims to evaluate the effect of banana waste Biochar at different ratios on soil properties and plant growth and to determine the threshold rates at which banana waste biochar can be added to soil without having detrimental effects.

## 2. Materials and methods

### *2.1. Pot Experiments*

Three pot experiments during three successive growth seasons were carried out in the screen greenhouse in Agricultural Experimental Farm, Faculty of Agriculture, South Valley University, Qena, Egypt. (Winter 2021/2022 followed by summer 2022 and winter of 2022/2023). The study aims t**o** evaluate the effects of Banana trees residues biochar at a level of 0 as control treatment, 0.5, 1, 2 and 5% on the soil characteristic, N, P and K availability, growth, N, P and K uptake of different crop plants. Barley (*Hordeum vulgare L.*) (Giza 121 variety) plants were grown in the first and third seasons in winter (2021/2022 and 2022/2023, respectively) and sorghum (Sorghum Vulgar) (cv. Dorado) plants were grown in the second season in the summer (2022). The soil used in this experiment was taken from the surface layer (0–20 cm) of a farm that is an agricultural experimental farm administered by South Valley University's college of agriculture. Plastic pots measuring 40 cm in height and 35 cm in diameter were used in the completely randomized design (CRD) of the pot experiment. Eight kilograms of earth were used to fill each container. Some of the physical and chemical characteristics of an experimental soil sample that was taken from the experimental farm are listed in Table 1.

### *2.2. Biochar derived from Banana trees residues*

Banana tree waste was collected from farms located nearby the city of Qena and the surrounding areas. The waste was cut into small pieces. then, the raw materials were oven dried (70°C) and converted into Biochar through slow pyrolysis using a furnace at temperatures of 400◦C for 4 hours. Biochar samples were crushed and ground to pass through a 2-mm sieve for chemical analysis. Some characteristics of Banana trees residues biochar are present in Table 2.

**Table 1.** Physical and chemical properties of the soil used in this experiment.

| Sand % | Silt % | Clay % | Texture | pH (1:2.5) | EC (1:5) (dS $m^{-1}$) | $CaCO_3$ (%) | Organic Matter (%) | Total N (%) | Available P (mg/ kg) | Availabl e K (mg /kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| 81 | 11 | 8 | Sandy | 8.07 | 0.55 | 9.88 | 0.95 | 0.033 | 7.14 | 208 |

**Table 2.** Some characteristics of Banana trees residues biochar

| pH (1:20) | EC (1:20) (dS/m) | Organic matter (%) | Organic carbon (%) | Total N (%) | C/N ratio | Total P (%) | Total K (%) |
|---|---|---|---|---|---|---|---|
| 8.87 | 4.23 | 67.39 | 39.08 | 1.65 | 23.69 | 0.89 | 3.73 |

***2.3. Biochar treatments***

Biochar was used at four levels of 0% (0 g $pot^{-1}$) as a control treatment, 0.5% (20 g $pot^{-1}$), 1% (40 g $pot^{-1}$), 2 % (80 g $pot^{-1}$) and 5 % (200g $pot^{-1}$). The examined amendment was applied to the soil in each pot, together with superphosphate (15.5% $P_2O_5$) at a rate of 476.19 $kgha^{-1}$ (2.4 g $pot^{-1}$). Then each pot received 12 seeds of the Giza 121 variety of barley (*Hordeum vulgare* L.). After administering all treatments, all pots were immediately watered, and after germination, all pots were thinned to 6 plants. In addition, two dosages of 866.32 kg ha-1 (4.3 g $pot^{-1}$) of ammonium nitrate (33.5% N) were sprayed. The first dose was administered two weeks after planting, and the second one four weeks later. For the second season of sorghum planting, the same pots from the first season were used without any more biochar being added. Ten sorghum (Sorghum Vulgar) (cv. Dorado) seeds were put in each pot, and following germination, the plants were trimmed to six. Every pot received direct irrigation. At the time of planting, superphosphate fertiliser (which contains 15.5% $P_2O_5$) was added at a rate of 476 ha-1 (2.4 g $pot^{-1}$). Moreover, 721.14 ha-1 (3.6 g $pot^{-1}$) of ammonium nitrate 33.5% were added, applied in two dosages. The first dose was administered two weeks after planting, and the second one four weeks later. Additionally, for the third season of growing barley, the identical pots used for the first and second seasons were used without any additional biochar. Each pot contained ten barley seeds, which were then trimmed to produce six plants per pot. This season, barley plants were grown using all the same agricultural techniques that were employed in the first season.

***2.4. Plant sampling***

For each season, the plants were completely removed from each pot after 60 days from planting, and the plant's height and root length were recorded. The plants were then washed with deionized water, allowed to dry naturally for three days, and then oven-dried for 48 hours at 70 °C. All pots' plant samples were saved for later chemical examination. Additionally, soil samples from each pot were taken following harvest, air-dried, crushed with a wooden roller, sieved to pass through a 2 mm sieve, and stored for analysis.

***2.5. Soil and biochar analyses***

The soil texture was determined by the hydrometer method (Gee and Or, 2002). Soil pH was determined in soil: deionized water (1:2.5 w/v) after one hour of shaking. Total soluble salts in the soil extract (1:5 w/v) was measured by the electrical conductivity Jackson, (1973). Soil organic carbon content was measured by dichromate oxidation (Walkley and Black, 1934). The soil organic carbon content was determined according to the modified Walkely and Black method (USDA, 1996). calcium carbonate content of the soil samples was estimated by a Collins calcimeter according to Jackson (1973) and USDA (1996). the available phosphorus in the soil samples was extracted by 0.5 M $NaHCO_3$ at pH 8.5 according to Olsen *et al.* (1954) and spectrophotometerically determined according to Jackson (1973). The available K in the soil samples was extracted with 1 N ammonium acetate at pH 7.0 and determined using the flame photometer (Jackson, 1973). The total N of the soil samples were estimated using the microkjeldahl method as described by Jackson (1973). The pH and EC of the Biochar was measured using a biochar to deionized water mass ratio of 1:20 and measurement with a pH meter after one hour of shaking according to (Teutscherova et al.2018). The organic matter content of biochar by weight loss on ignition at 550˚C for 4h as recommended by (Møller et al., 2000). The total organic carbon (TOC) was determined based on the average organic matter containment of 58% total carbon Nelson and Sommers (1996) according to the following procedure. *(TOC)= (O.M × 58/100).* A sample of 0.2 g of biochar digested by a 20: 5 mixture of concentrated $H_2SO_4$ to $H_2O_2$ (Agiza et al. 1985 and Lowther, 1980) and determined of the total of N, P and K in digested samples using by the same way as in the soil samples according to (Jackson, 1973).

### 2.6. Plant analysis

According to Agiza et al. (1985 and Lowther, 1980), a sample of 0.2 g of dried plant material was digested using a 20:5 ratio of concentrated $H_2SO_4$ to $H_2O_2$, and then nitrogen, phosphorus, and potassium were measured in the digested samples using the techniques outlined for the soil analysis in Jackson (1973).

### 2.7. Calculation of N, P and K uptake

Total N, P and K uptake by plant was calculated according to (Dobermann, 2005; Farrag and Bakr, 2021) as follow: *N, P or K uptake (mg pot$^{-1}$) = concentration of N, P or K (mg kg$^{-1}$) in plant dry matter × dry matter (g pot$^{-1}$) /1000.*

### 2.8. Statistical analyses

The least significant difference (L.S.D.) at 5% was used to compare the differences between the means of the various treatments. Using MSTAT-C, all data were examined. (Russell, 1994).

## 3. Results and discussion

Successive effects of application banana waste biochar on the properties change of the sandy soils, nutrient availability, plant growth, nutrient uptake by the plants during three subsequent growth seasons were discussed throw the next results.

### 3.1. Soil properties

Table 3 shown that, the changes in pH, salinity (EC), organic matter (OM%) content and calcium carbonate (CaCO3%) content as well as the changes in total N, Available P and Available K contents in soil after application of banana waste biochar during three successive growth seasons.

#### 3.1.1. Soil pH

The results in Table 3 revealed that, after the first season, all treatments with application banana waste biochar increased the soil pH compared to the control treatment, the increased is significantly with biochar application rate 2 and 5% compared to control and other treatments. highest soil pH values of 9.16, 8.40, 8.02 and 7.85 were found with biochar application rate 5%, 2%, 1% and 0.5% treatments. respectively compared to control treatment was recorded pH value (7.76). Additionally, increases in soil pH were observed with most treatments in the second season following the harvest of sorghum plants as opposed to those in the first season. giving pH values of 9.28, 8.5, 8.13, and 8.12 with biochar application rate 5%, 2%, 1% and 0.5% treatments, respectively. In contrast, following the third season of Barley plant growth, the soil pH values of most treatments started to decline compared to those of the first and second season giving pH values of 8.63, 8.32, 8.07 with biochar application rate 5%, 2% and 1% treatments, respectively. While, we found increases in soil pH were recorded after the third season with biochar application rate 0.5 % and control treatments giving pH values 8.34 and 8.29 respectively.

The increase in soil pH after the first season due to biochar application was generally attributed to biochar residues which contain carbonates of alkali and alkaline earth metals, heavy metals, silica, organic and inorganic nitrogen and phosphates, also pH increased with higher rates of biochar application (Raison, 1979; Timilsina *et al.*, 2017). The increase in soil pH after the second season was generally attributed to, the high percentage of calcium carbonate in the soil used, and with decomposition and oxidation of organic compounds in biochar and production of inorganic and organic acids and $CO_2$ produced from the activity of microorganisms as well as root exudates this encourages the dissolution of calcium carbonate, this leads to the pH value increasing as a result of the released carbonate and bicarbonate anions. (Farrag and Bakr, 2021; Farrag and Bakr, 2023). Reductions in the soil pH that occurred in the third season after the first and second seasons may be attributed to the progress of decomposition and oxidation of biochar organic compounds in the soil. In addition to increase of activity of soil microorganisms producing $CO_2$ and the root exudates. This helps produce of inorganic and organic acids. as well as getting rid of a large part of the carbonate in the soil during the first and second season. These results are consistent with those of (Abo-baker, 2017; Barka *et al.*, 2018).

**Table 3.** Effect of different rates of Banana Waste Biochar application on pH, salinity (EC), organic matter (OM%) and calcium carbonate (CaCO3%) as well as the total N, available P and available K in the soil during three successive growth seasons.

| Biochar levels | PH (1:2.5) | EC dS/m | O.M (%) | $CaCO_3$ (%) | Total N (%) | Available p (mg/kg) | Available K(mg/kg) |
|---|---|---|---|---|---|---|---|
| Season 1 | | | | | | | |
| Control (0%) | 7.76c | 0.95bc | 0.25d | 9.39a | 0.12d | 15.21d | 277.30b |
| 0.5% | 7.85c | 1.15b | 0.75c | 9.58a | 0.26cd | 39.83c | 431.00b |
| 1% | 8.02c | 0.70c | 0.89c | 9.29a | 0.40c | 50.57bc | 431.00b |
| 2% | 8.40b | 1.83a | 1.58b | 9.33a | 0.56b | 63.59ab | 606.40b |
| 5% | 9.16a | 2.13a | 3.12a | 9.26a | 1.52a | 77.88a | 1757.71a |
| Season 2 | | | | | | | |
| Control (0%) | 8.15bc | 1.37a | 0.15d | 9.24a | 0.08d | 22.45c | 162.10d |
| 0.5% | 8.12bc | 1.45a | 0.70c | 9.16a | 0.37c | 66.59b | 446.71cd |
| 1% | 8.13bc | 1.28a | 0.82c | 8.34ab | 0.44c | 81.21b | 510.31c |
| 2% | 8.50b | 1.17a | 1.44b | 7.27b | 0.77b | 85.74b | 1348.2b |
| 5% | 9.28a | 1.55a | 3.01a | 6.92b | 1.45a | 109.05a | 2591.61a |
| Season 3 | | | | | | | |
| Control (0%) | 8.29bc | 0.47bc | 0.28d | 8.12a | 0.14d | 20.92c | 229.11c |
| 0.5% | 8.34b | 0.35c | 0.54cd | 7.38ab | 0.34c | 40.22ab | 261.71c |
| 1% | 8.07c | 0.66b | 0.68c | 7.54ab | 0.33c | 46.13ab | 277.81c |
| 2% | 8.32b | 0.67b | 1.35b | 6.98b | 0.71b | 48.33b | 660.70b |
| 5% | 8.63a | 1.46a | 2.74a | 5.64c | 1.34a | 65.52a | 1824.20a |

### *3.1.2. Soil salinity (EC)*

The amount of salts in the soil is measured by the electrical conductivity (EC) of the soil extract, which is a crucial sign of the soil's health. The data in Table 3 show that, after the first season Increasing the added amount of banana biochar resulted in increases in the soil EC. The highest EC values of 2.13 and 1.83 dS $m^{-1}$ were found with biochar application rate 5% and 2% treatments. respectively, compared to control treatment was recorded EC value (0.95 dS $m^{-1}$). It can be due to high content of soluble salts in biochar. Additionally, the degradation of biochar over time affects increases the amount of soil salts that dissolve. (Farrag and Bakr, 2021). Generally, after the third season, all treatments the soil EC reached the lowest values. The soil EC values after the third season were 1.46, 0.67, 0.66 and 0.35 dS $m^{-1}$ for 5%, 2%, 1% and 0.5% biochar treatments, respectively. Can be attributed to, produce some organic and inorganic acids result of an activity of soil microorganisms during the decomposition of organic compounds in biochar, as well as root exudates, this facilitates the irrigation water's faster removal of soluble salts. (Abo-baker, 2017; Farrag and Bakr, 2021; Farrag and Bakr, 2023).

#### ***3.1.3. Soil organic matter (OM) content***

Compared to the control treatment, the use of biochar dramatically improved the soils' organic matter content. (Table 3) the soil organic matter content after the first season reached 3.12, 1.58, 0.89 and 0.75% for 5%, 2%, 1% and 0.5 biochar treatments, respectively, higher than the organic matter content in control (0.25%). on the other hand, after the second season, these treatments in the same sort showed decrease in the value of organic matter of 3.01, 1.44, 0.82 and 0.70 % respectively, compared to the first season. in addition, After the third season, the value of organic matter continued to decline of 2.74, 1.35, 0.68 and 0.35 % were found with in the Same previous treatments respectively, compared to the first and second season. the increase in soil organic matter was caused by a rise in organic carbon as biochar application rates rose. Van Zwieten *et al.* (2010) and Timilsina *et al.* (2017) reported that, high organic carbon in soil treated with biochar. Moreover, decreased the soil organic matter content after the second and third season compared to the first season. This may be due to use of organic matter as a carbon source by microorganism. Rashid *et al.* (2004) and Abo-baker (2017) reported that, the soil's organic matter content serves as a carbon source for the majority of microorganism strains.

#### ***3.1.4. Soil calcium carbonate ($CaCO_3$) content***

The data in Table 3 show that, After the first season, there was no significant effect of adding biochar at different rates on the percentage of calcium carbonate in the soil compared to the control treatment. After the second season decrease in the $CaCO_3$ content was from 9.58, 9.29, 9.33 and 9.26% in the soil after the first season to 9.16, 8.34, 7.27 and 6.92 % in the soil amended with 0.5%, 1, 2 and 5% biochar respectively. In addition, due to the tested treatments, the decline in soil $CaCO_3$ content persisted after the third season, they recorded % $CaCO_3$ values of 7.38, 7.54, 6.98 and 5.64% In the same previous treatments, respectively. After the second and third seasons, the decreased in the calcium carbonate percentage in the soil with the increase in the rate of added biochar, also 2 and 5% biochar treatments resulted in significant decreases in the soil $CaCO_3$ content compared with the other treatments and control. Numerous studies show that the decomposition rate of biochar is substantially slower than that of plant litter. (Rumpel *et al.*, 2006; Lehmann *et al.*, 2009; Major *et al.*, 2010). with the decrease in the decomposition rate of biochar during the first season, the treatments had no significant effect on the percentage of calcium carbonate in the soil. after the second and third seasons, the effect of biochar on the decreased soil $CaCO_3$ level is mostly ascribed to the enhanced microbial activity during the biochar's slow decomposition that results in the production of $CO_2$ and organic acids. These organic acids aid in the soil's calcium carbonate's dissolution. These outcomes support the reported findings Abo-baker (2017) and Farrag and Bakr (2021).

#### ***3.1.5. Total N, Available P and Available K contents in soil***

Table 3 shows the impact of applied biochar on the total soil nitrogen, available phosphorus, and available potassium. After the first season, we found the lowest values of total nitrogen, available P and available K contents, was recorded in the soil treated with 0.5, 1, 2 and 5% biochar giving total N values of 0.26, 0.40, 0.56 and 1.52 % and available P values of 39.83, 50.57, 63.59, 77.88 mg/kg and available K values of 413, 435, 606.40 and 1757.71 mg/kg, respectively, compared to the control treatment its giving the total soil nitrogen, available phosphorus and available potassium 0.12% , 15.21 mg/kg and 277.30 mg/kg respectively. Moreover, After the second season, show increase of total nitrogen, available P and available K contents in soil compared to first season. After the second season in the soil treated with 0.5, 1, 2 and 5% biochar giving the total N values of 0.37, 0.44, 0.77 and 1.45% and available P values of 66.59, 81.21, 85.74 and 109.05 mg/kg and available K values of 446.71, 510.31, 1348.20 and 2591.61 mg/kg, respectively. in addition, after the third season, there was a decrease in the total nitrogen, available P and available K contents in soil compared to the second season, after the third season in the soil treated with 0.5, 1, 2 and 5% biochar were giving total N values of 34, 0.33, 0.71 and1.34 % and available P values of 40.22, 46.13, 48.33 and 65.52 mg/kg and available K values of 261.74, 277.81, 660.70 and 1824.20mg/kg, respectively.

biochar has a significantly slower rate of decomposition than plant litter, so, with slower rate of decomposition and increased microbial activity with biochar addition (Rumpel *et al.,* 2006; Lehmann *et al.,* 2009; Major *et al.,* 2010; Gomez *et al.*, 2014). This could be the reason for the low concentration of nutrients in the soil after the first season as a result of the low rate of release of nutrients from biochar and use by microorganisms. on the other hand, after the second season, increased of biochar mineralization may be responsible for increasing the availability of plant nutrients in the soil (Sanchez *et al.,* 2008, Aboukila *et al.,* 2018). While A decrease in the total nitrogen, available P and available K contents in the soil after the third season, they may be related to depletion of the nutrient through its uptake by growing plants and its use by microorganisms. Also, from the results in the Table 3 we conclude that, the soil content of total nitrogen, available P and available K increased with increased rate of biochar, could be due to the positive effect of biochar to improve the soil physical and chemical properties due to biochar properties related to surface area and porosity, carbon content, nutrient content and cation exchange capacity (CEC) (Carvalho, 2015). Biederman and Harpole (2013) found that, increased of total soil nitrogen, soil phosphorus and soil potassium, due to the addition of biochar to soils.

### 3.2. Effect of banana biochar on the growth of plants

#### 3.2.1. Plant height, Root length and Dry matter yield of plants

Table (4) showed that, treatments with applying biochar rate 0.5 and 1% increased of the height of plants, root length and dry matter yield compared to control treatment and the treatments with applying biochar rate at 2 and 5% after the successive three seasons. The highest plants height after first season were for applying biochar rate 0.5 and 1% which recorded 22.51 and 23.11 cm respectively, the same treatments give the highest plants height after the second season which recorded 66.75 and 46.15 cm respectively, also after the third season the same treatments give the highest plants height which recorded 22.33 and 18.67 cm. In addition, from the data in table 4 show that, the same treatments give the highest plants root length and dry matter yield compared to other treatments. Generally, application of banana biochar at rates 2 and 5% gave significant decreased in the height of plants, root length and dry matter yield compared to control and application of banana biochar at rates 0.5 and 1%. After the third season, application of banana biochar at rate 5% give the lowest the height of plants, root length and dry matter yield compared to other treatments. The data show that, applying banana biochar under low rate have positive effect on height of plants, root length and dry matter yield, my be attributed to impact of biochar on soil properties such as nutrient availability, water-holding capacity, as well as improved soil structure and drainage which hold key roles in sustaining soil health (Rondon *et al.,* 2007; Warnock *et al.,* 2007; Steiner *et al.,* 2008). Which is reflected on the improvement of plant growth. However, using banana biochar at a high rate has a detrimental impact on plant height, root length, and dry matter output. This may be because high biochar levels have detrimental effects on soil properties, such as pH and salinity increases, which are detrimental to plant growth. Kavitha *et al.* (2018) found that Depending on the crop and the type of biochar, biochar has been found to have both favourable and unfavourable impacts on plant development and yield. In addition, in another study by Furtado *et al.* (2016) found that, biochar reduced the growth of sunflowers.

**Table 4.** Effect of different rates of Banana Waste Biochar application on plant height, root length, dry matter yield (g/pot), N, P and K concentration and the uptake of N,P and K (mg pot$^{-1}$) by plants during three successive growth seasons.

| Biochar levels | Plant height (cm) | Root length (cm) | Dry matter g pot$^{-1}$ | plant nutrient concentration (%) N | P | K | plant nutrient uptake(mg/pot) N | P | K |
|---|---|---|---|---|---|---|---|---|---|
| Season 1 | | | | | | | | | |
| Control (0%) | 21.67a | 6.70b | 7.42a | 1.34ab | 0.11b | 0.55b | 90.54b | 7.28b | 36.66b |
| 0.5% | 23.11a | 7.65ab | 9.56a | 1.32b | 0.16b | 0.76b | 101.27b | 12.02b | 58.48a |
| 1% | 22.51a | 8.78a | 7.98a | 1.63ab | 0.31ab | 0.77b | 143.08a | 27.79a | 67.85a |
| 2% | 17.33b | 3.13c | 3.16b | 1.58ab | 0.36ab | 0.81b | 49.58c | 11.31b | 25.35b |
| 5% | 16.51b | 2.06c | 1.70b | 2.13a | 0.51a | 1.51a | 43.92c | 10.50b | 31.19b |
| Season 2 | | | | | | | | | |
| Control (0%) | 33.95bc | 8.49bc | 11.32bc | 1.58abc | 2.49b | 1.53a | 173.42bc | 277.61c | 176.09c |
| 0.5% | 66.75a | 22.69a | 30.25a | 1.47bc | 2.13b | 1.78a | 445.01a | 642.41a | 538.82a |
| 1% | 46.15b | 11.54b | 15.38b | 1.43c | 2.61b | 1.65a | 220.10b | 391.95bc | 255.04b |
| 2% | 28.15cd | 7.04cd | 9.38cd | 1.87a | 3.95a | 1.67a | 174.52bc | 457.58ab | 155.97c |
| 5% | 19.51d | 4.88d | 6.5d | 1.73ab | 4.47a | 2.04a | 112.32c | 290.15c | 132.81c |
| Season 3 | | | | | | | | | |
| Control (0%) | 20.00b | 8.49b | 8.49ab | 1.55bc | 1.56c | 1.39c | 131.51bc | 130.02b | 117.74b |
| 0.5% | 22.33a | 11.39a | 10.92a | 1.50c | 1.61c | 1.61b | 170.79ab | 183.43b | 182.86a |
| 1% | 18.67bc | 10.98a | 10.31a | 1.61abc | 2.34b | 1.49bc | 177.54a | 253.59a | 164.10a |
| 2% | 17.67c | 6.40c | 9.73a | 1.85ab | 2.63b | 1.49bc | 118.42cd | 168.46b | 95.68bc |
| 5% | 10.01d | 4.30d | 5.97b | 1.91a | 3.99a | 1.80a | 82.12d | 171.00b | 77.59c |

### *3.2.2. N, P and K content in plants*

N, P and K percent in plants after during three successive seasons showed response to the different doses of banana biochar application. Generally, increase in the amounts of N, P and K -percent in plants with increase rate of banana biochar application The highest values of N, P and K in plants after during three successive seasons were recorded for banana biochar at the level of 2 and 5%. it may be attributed to, the direct nutrient addition by biochar and improved nutrient retention result in higher nutrient availability for plants (Lehmann *et al.,* 2003a). On other hand, the increase values of N, P and K in plants may be attributed to, may be caused to a concentration impact caused by decrease in the plant dray matter in biochar treatments at the level of 2 and 5% compared to other treatments.

### *3.2.3. N, P and K uptake of plants*

The uptake of N, P, and K by plants grown in soil modified with the various treatments under study considered to be a sign of how those treatments affect the plant's capacity to utilize the available nutrients in the soil. From the data in Table 4. We observed that, in most cases during three successive seasons, the addition of biochar at levels of 0.5 and 1% led to a significant increase in the amount uptake of nitrogen, phosphorus and potassium, compared to the control and other treatments. The highest uptake values of N, P and K by Barley plants grown in the first season were recorded after application biochar at level 1% which displayed 143.08, 27.79 and 67.85 mg / N, P and K / pot, respectively and biochar at level 0.5% that exhibited 101.27, 12.02 and 58.48 mg N, P and K / pot, respectively. Furthermore, barley plants cultivated in the second winter season displayed higher N, P, and K absorption values than those grown in the first winter season. Additionally, the findings demonstrate that second-winter barley plants absorbed the maximum amounts of N, P, and K. were also obtained with application biochar at level 1% which recorded 177.54, 253.59 and 164.10 mg / N, P and K / pot, respectively. and application biochar at level 0.5% that had 170.79, 183.43 and 182.86 mg N, P and K / pot treatments, respectively. The levels of N, P, and K absorbed by sorghum plants throughout the summer season also exhibited the similar trend as that observed with barley plants during the first and second winter growth seasons. which they were 445.01, 642.41 and 538.82 mg N, P and K/ pot, respectively, for biochar at level 0.5 % and 220.10, 391.95 and 255.04 mg N, P and K / pot, respectively, for biochar at level 1%. On the other hand, in most cases, increasing the levels of biochar to 2 and 5% led to a decrease in the amount of nitrogen, phosphorus and potassium uptake by plants in three successive seasons , compared to biochar treatments at levels 0.5 and 1 % and control treatment.

The crops' positive responses to different forms of biochar could be attributed to the availability of macro- and micronutrients in the soil as a result of the addition of biochar.(Glaser *et al.*, 2002; Lehmann *et al.*, 2003a), in other study Jones *et al* .(2012) found that, Crop N uptake and yields were increased after applicated of biochar ; these effects were linked to higher soil respiration rates and a change in the makeup of the soil's microbial population to favour bacterial decomposers. Increased cation exchange capacity and plant nutrient delivery, a decrease in soil acidity and Al toxicity, and improved fertilizer efficacy due to less nutrient leaching are all advantages of adding biochar to soils (Glaser *et al.*, 2002). However, the appropriate biochar application rate varies depending on the biochar quality, crop species, and soil type. Regardless of the nutrient value, a biochar product should always be taken into consideration in pH and EC to determine the right application rate in soils. also, he found that, the application rate was too high or too low, the effect of biochar amendment on soil health may be shifted from favourable to insignificant or unfavourable, respectively. (Guo, 2020). Gundale and DeLuca (2007) found that, laboratory-produced biochar had a negative effect on plant growth, whereas the same biochar created from wildfires showed a positive effect on plant growth. They speculated that the low-temperature charring method used to create the charcoal in the laboratory may have created toxic compounds that inhibited plant growth. Furthermore, the researchers proposed three possible explanations for the biochar negative results: (i) N immobilization due to the high C/N ratio (>35 in the soils with the highest biochar), (ii) an allelopathic action of hydrocarbons generated from biochar, or (iii) toxic levels of heavy metals (Deenik *et al.*, 2010). Also, Shukla *et al.* (2003) found that, non-judicious application of biochar to soil deteriorates soil quality as well as depresses crop growth.

## 4. Conclusion

The soil's organic matter, pH, EC, total nitrogen, available phosphorus, and available potassium all increased with the application of banana waste biochar, whereas the proportion of calcium carbonate in the soil decreased. the impacts of biochar become more pronounced with application of banana biochar at rates of 2 and 5% compared to using banana waste biochar at low rates (0.5 and 1%). Additionally, compared to the control, using banana waste biochar at low rates (0.5 and 1%) increased plant height, root length, dry matter yield, and N, P, and K uptake by plants. However, application of banana biochar at rates of 2 and 5% resulted in a considerable reduction in plant height, root length, dry matter production, and N, P, and K uptake by plants in comparison to control and banana biochar treatment at rates of 0.5 and 1%. These results highlight the need for more research to determine the immediate and long-term impacts of adding biochar treatments made from banana waste on soil properties and nutrient availability, as well as plant development and nutrient uptake. In-depth research is also required to establish the ideal biochar application rate for banana trash for various soil types and crop types.

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