

Article

Soil Fertility, N₂ Fixation and Yield of Chickpea as Influenced by Long-Term Biochar Application Under Mung–Chickpea Cropping System

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Abstract: A research study was established at the research farm of the University of Agriculture, Peshawar during winter 2018–2019. Commercial biochars were given to the experimental site from 2014 to summer 2018 and received 0.95, 130 and 60 tons ha⁻¹ of biochar by various treatments viz., (Biochar₁) BC₁, (Biochar₂) BC₂, (Biochar₃) BC₃ and (Biochar₄) BC₄, respectively. This piece of work was conducted within the same study to find the long-term influence of biochar on the fertility of the soil, fixation of N₂, as well as the yield of chickpea under a mung–chickpea cropping system. A split plot arrangement was carried out by RCBD (Randomized Complete Block Design) to evaluate the study. Twenty-five kilograms of N ha⁻¹ were given as a starter dosage to every plot. Phosphorous and potassium were applied at two levels (half (45:30 kg ha⁻¹) and full (90:60 kg ha⁻¹) recommended doses) to each of the four biochar treatments. The chickpea crop parameters measured were the numbers and masses of the nodules, N₂ fixation and grain yield. Soil parameters recorded were Soil Organic Matter (SOM), total N and mineral N. The aforementioned soil parameters were recorded after harvesting. The results showed that nodulation in chickpea, grain yield and nutrient uptake were significantly enhanced by phosphorous and potassium mineral fertilizers. The application of biochar 95 tons ha⁻¹ significantly enhanced number of nodules i-e (122), however statistically similar response in terms of nodules number was also noted with treatment of 130 tons ha⁻¹. The results further revealed a significant difference in terms of organic matter (OM) (%) between the half and full mineral fertilizer treatments. With the application of 130 tons ha⁻¹ of biochar, the OM enhanced

from 1.67% in the control treatment, to 2.59%. However, total and mineral nitrogen were not statistically enhanced by the mineral fertilizer treatment. With regard to biochar treatments, total and mineral N enhanced when compared with the control treatment. The highest total N of 0.082% and mineral nitrogen of 73 mg kg⁻¹ in the soil were recorded at 130 tons ha⁻¹ of biochar, while the lowest total N (0.049%) and mineral nitrogen (54 mg kg⁻¹) in the soil were recorded in the control treatment. The collaborative influence of mineral fertilizers and biochars was found to be generally non-significant for most of the soil and plant parameters. It could be concluded that the aforementioned parameters were greater for treatments receiving biochar at 95 tons or more per hectare over the last several years, and that the combination of lower doses of mineral fertilizers further improved the performance of biochar.

Keywords: mineral N₂; total nitrogen; N₂ fixation; soil organic matter; grain yield.

1. Introduction

Chickpea (*Cicer arietinum* L.) is an important pulse legume crop of Pakistan. It is used as food and feed for animals and people of Pakistan. Chickpea areas grown in Pakistan cover about 1 million hectares and are mostly cultivated in arid conditions. Chickpea is also used in crop rotations for sustaining soil fertility. The roots of chickpea bear nodules in which symbiotic bacteria (e.g., rhizobia) convert atmospheric nitrogen to plant-available forms, which subsequently increases crop yields. In addition, the nodulated roots contribute a substantial amount of N to the soil [1,2].

After common beans, the crop that is mostly used for their edible grains is chickpea (*Phaseolus vulgaris* L.). The Food and Agriculture Organization [3] states that chickpea is considered as the most grown crop in the tropical, subtropical and temperate regions of the world, and more than 50 countries of the world are involved in the cultivation of chickpea. Chickpea can grow well in low fertile and high temperature areas due to its ability to proliferate root habitats that extract water from the lower profile of soil; this property enables the crop to tolerate drought [4]. The chickpea productivity that is decreased could be due to the combined action of water stress condition and a low availability of phosphorous for a long time, especially in dry conditions [4]. Madzivhandila et al. [5] reported that, chickpea yields reduced to 56% due to the restricted water availability to the roots, along with poor P availability in the dry winter conditions of Thohoyandou. Therefore, P fertilizer is strongly recommended for obtaining the maximum yield of chickpea crops in water stress condition.

Soil condition, nutrient availability, organic matter decomposition and microbial population increased with the application of biochar. According to Downie et al. [6] and Zwieten et al. [7], nitrogen fertilizer efficiency increased with biochar. Gaskin et al. [8] also observed that the increase in crop productivity and improvement in soil fertility was due to the application of biochar. It is claimed that the increase in crop yields, microbial activities and leaching of nutrients from soil can be reduced by the use of biochar, because of its holding capacity and very fine texture [9–11].

Biochar helps in the adsorption of anions and cations when applied through chemical fertilizers, and thus reduces its leaching [12]. Biochar particles behave like clay particles, which retain the nutrients and immobile water within microspores and increase metric potential. The nutrients that dissolve in immobile water will be kept near to the surface of the soil and be available for the plants [13]. Schulz et al. [14] concluded that reasonable amounts of nutrients are released by biochars when used as soil amendments. Biochar produced from the field stock at a high temperature is usually low in nutrients. To overcome these problems, we had to use a mixed organic amendment with the biochar.

The most important nutrient required for the higher growth of a plant is nitrogen. It gives a dark green color and vigorous growth to the plant [15]. Among the primary nutrients, nitrogen and phosphorous effectively increase the growth and yield of crops when applied at a proper rate [16]. The NUE (nitrogen use efficiency) can also be enhanced by applying biochar to soil [17]. With an increase in biochar application, microbial biomass will also be increased [18]. The fixation of nitrogen

in legumes by rhizobia, colonization of mycorrhiza and the organisms that help in the development of plant growth in rhizosphere are increased due to the biochar amendments [19–21]. The enzyme nitrogenase possesses a central position in fixating nitrogen by symbiotic (nodules) or free-living micro-organisms; with the application of biochar, the number of nodules could be improved, which can positively affect the nitrogen production and its sustainability in the agroecosystem. However, the mechanism by which the soil micro-organism benefits from biochar was vague until now [22]. Biochars increased the holding capacity in soil, which made water available for a longer period of time to the plants [23].

Modern agriculture changes its old features rapidly with the evolution of the technological era, to produce food in such an amount that fulfills the needs of the emerging population with lower environmental risk. Lehmann et al. [24,25] stated that there potential environmental risk caused by the emission of carbon from soil and the extensive use of synthetic fertilizers [26,27]. To achieve the goal of the sustainable production of crops, biochar has been reported as extremely important. Therefore, to assess the effect of biochar on the yield and N₂ fixation of chickpea, the study was designed with the following specific objectives: (I) to assess the long-term effects of biochar and PK (phosphorus and potassium) mineral fertilizer application on nodulation, N₂ fixation and chickpea yields; (II) to study the response of soil fertility parameters (organic matter, total nitrogen, mineral nitrogen) to a long-term application of biochar and PK under the mungbean–chickpea cropping system; (III) to formulate the recommendation of biochars for sustainable crop production and improved soil fertility.

2. Materials and Methods

The experiment was conducted to investigate the long-term effect of biochar on soil properties and yield of chickpea under the mung–chickpea cropping system. The present research was conducted on such a site that was established in 2014, at a new developmental research farm of the University of Agriculture, Peshawar. The pre-sowing soil analysis of the experimental soil showed that the soil under study was silty clay loam in texture, strongly calcareous (16.5% CaCO₃) and alkaline in reaction (pH 7.8), and had no sign of salinity (EC (electrical conductivity) 0.15 dS m⁻¹). The soil under study was low in organic matter (0.79%), deficient in nitrogen (0.08%), marginal in P (5.75 mg kg⁻¹) but adequate in K (125 mg kg⁻¹). Biochar was applied in different doses each summer and winter season from winter 2014 to summer 2018. The four treatments were included in this study. Those treatments had received biochar doses as shown in Table 1.

Table 1. Table shows treatment combinations.

Treatments	Biochar t ha ⁻¹	P ₂ O ₅ kg ha ⁻¹	K ₂ O kg ha ⁻¹
BC ₁	0	90	60
BC ₁		45	30
BC ₂	95	90	60
BC ₂		45	30
BC ₃	130	90	60
BC ₃		45	30
BC ₄	60	90	60
BC ₄		45	30

The design followed while conducting this experiment was RCBD, which was arranged in split plot arrangements and replicated four times. The main plot receiving biochar was further split into two halves; half received half of the recommended P and K, while the other half received full doses of the recommended P and K from SSP (single super phosphate) and SOP (sulphate of potash) sources. A starter dose of N at 25 kg ha⁻¹ was applied to all treatment plots from an area source. All the mineral fertilizers added to the field after the preparation of plots and before the sowing of seeds. A composite soil sample was taken before and after the harvest of chickpea in order to assess the important soil properties. The chickpea variety was Karak-3 and was seeded in rows with a 30 cm distance between two rows, and 25 kg ha⁻¹ seed rate was followed for sowing. All NPK (nitrogen, phosphorus, potassium) fertilizers were applied after a seed bed preparation and before the sowing

of chickpea. All the needed cultural practices such as weeding, irrigation, hoeing, etc., were performed as per the common procedure of the area.

2.1. Data on Crop (Chickpea)

2.1.1. Number and Mass of Nodules

At the flowering stage of the chickpea crops, four plants were carefully uprooted and washed, and the nodules were counted and detached from the roots. The freshly detached nodules were weighed on a top balance and then kept in an oven at 40 °C for three days. After three days, the nodules were weighed again and the readings were recorded.

2.1.2. N₂ Fixation in Chickpea

The nitrogen difference method was used for measuring N₂ fixation, in accordance with the formula given below [28].

$$\text{Total Nitrogen fixed } \left(\frac{\text{kg}}{\text{ha}}\right) = \text{Total N in legumes } \left(\frac{\text{kg}}{\text{ha}}\right) - \text{Total in reference } \left(\frac{\text{kg}}{\text{ha}}\right) \quad (1)$$

2.1.3. Grain Yield (kg ha⁻¹)

In order to obtain the grain yield, the central two rows at the maturity stage were harvested with the help of a sickle and allowed to be dried. After drying, the plant was threshed and cleaned, and the grain weight was recorded.

2.1.4. Total P and K Uptake

For the determination of P and K uptake by the plants, first the concentration of P and K was measured in the plants and then converted to uptake by the following formula:

$$\text{P and K uptake } \left(\frac{\text{kg}}{\text{ha}}\right) = \text{P and K conc in crop biomass } (\%) \times \text{crop biomass yield } \left(\frac{\text{kg}}{\text{ha}}\right) \quad (2)$$

2.2. Data on Soil

2.2.1. SOM (Soil Organic Matter)

For analyzing the soil organic matter content, the Walkley–Black, Nelson and Sommar procedure was followed [29]. 1 g of soil was mixed with 10 mL of 0.5 N K₂Cr₂O₇ and 20 mL of concentrated H₂SO₄. The mixture was then left for 30 min and allowed to react completely. This step was followed by the addition of 200 mL of distilled water and then filtration. Afterward, the filtrate was titrated with 0.5 N Fe₂SO₄·7H₂O until reaching a dark brown color, indicating the end point. The following formula was used for the determination of soil organic carbon:

$$\% \text{OM} = \frac{\{(\text{mL of K}_2\text{Cr}_2\text{O}_7 \times \text{N}) - (\text{mL of FeSO}_4 \times 7\text{H}_2\text{O} \times \text{N})\}}{\text{Weight of soil}} \times 0.69 \quad (3)$$

2.2.2. Total N

For the measurement of total N concentration in the soil, the Kjeldhal process was followed as mentioned by Bremner [30]. 0.2 g of air-dried sample was digested with 3 mL of concentrated H₂SO₄ in the presence of 1.1g of digestion mixture covering CuSO₄, K₂SO₄ and Se on a heating mantle for about 1 h. Digestion was followed by distillation with 10 mL of 10 M NaOH, which was performed after transferring the digested material into a distillation flask. Finally, the distillate was collected in 5 mL of boric acid mixed with indicator solution and then titrated with 0.01 M of HCL.

$$\text{Total N (\%)} = \frac{(\text{sample} - \text{blank}) \times N \text{ of HCl} \times \text{meq of N} \times \text{dilution}}{\text{g weight of plant or soil sample} \times \text{ml taken for distillation}} \times 100 \quad (4)$$

2.2.3. Mineral Nitrogen

For assessing the mineral N concentration of the soil, 10 g of soil was taken in a plastic bottle along with 50 mL of KCl. The bottles were shaken in a mechanical shaker for 45 minutes, and then filtered via 42 Whatman filter paper. The aliquot solution obtained was further analyzed by a steam distillation technique in which MgO and Devarda's alloy were used, and then the distillate was titrated against HCl [31].

2.2.4. Statistical Analysis

The data obtained was subject to statistical analysis using the appropriate statistical package. Differences among treatments were determined using an LSD (least significant differences) test at a 1 or 5% level of significance [32].

3. Results and Discussion

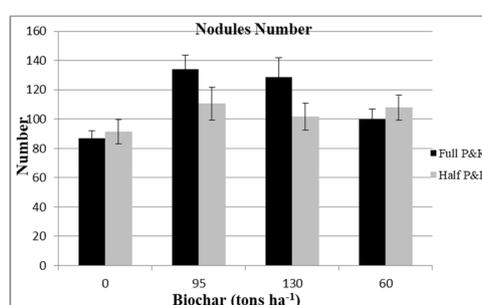
3.1. Number and Mass of Nodules

Table 2 shows the data regarding nodules numbers of chickpea, as influenced by application of biochar in mung-bean cropping system. According to the data, it was concluded that the application of mineral fertilizers (PK) and biochar significantly enhanced the number of nodules. The interaction between biochar and mineral fertilizers (PK) also significantly affected the number of nodules per plant. With the amendments of mineral fertilizers, the maximum number of 112 nodules per plant was recorded for the fully applied mineral fertilizers (PK), with respect to the half-applied mineral fertilizers (PK) as shown in Figure 1a. In the case of biochar treatment, the nodules were significantly influenced by the amendments of biochar. The highest number of nodules per plant was 122, recorded in the BC₂ treatment, receiving 95 tons ha⁻¹ of biochar over the last five years, which was statistically similar to the BC₃ treatment, which received 130 tons ha⁻¹ of biochar over the last five years. The lowest number of nodules per plant of 89 was recorded in the BC₁ control treatment, which received no biochar in any season. The combination of biochar and PK treatments also significantly affected the number of nodules. Our results were similar to those of Ma et al. [33], who recorded that the number of nodules were linearly enhanced with the amendments of biochar in irrigated conditions. The fresh and dry weights of the nodules affected by the long-term applications of biochar and mineral fertilizers (PK) are given in Table 2. There was no effect of mineral fertilizers (PK) on the fresh and dry weights of the nodules, while the maximum fresh and dry weights of 8.87 g and 1.6 g per plant were recorded for the half-applied mineral fertilizers (PK), with respect to the fully applied mineral fertilizers (PK) as stated in Figure 1b and c. In the case of the biochar treatment, the weights of the nodules were significantly affected, and the highest fresh and dry weights of 9.82 g and 1.90 g per plant were observed in treatment BC₃, which received 130 tons ha⁻¹ of biochar over the last five years, which was similar to BC₂ (90 tons biochar ha⁻¹) and BC₄ (60 tons biochar ha⁻¹). The lowest fresh and dry weights of 6.29 g and 1.10 g per plant were measured in the BC₁ control treatment, receiving no biochar in any season. The data showed that the biochar and mineral fertilizers (PK) affected the weight of the nodules in same pattern. Only the combined effect of mineral fertilizers (PK) and biochar for the dry weights of the nodules was statistically not significant. Hiama et al. [34,35] concluded that the number and mass of nodules and fixation of nitrogen was significantly enhanced with the application of biochar. From another point of view, it was suggested that more availability of Mo at the rhizosphere plant roots was attributed to absorbing more Mo, which enhanced the BNF (biological nitrogen fixation) and yields of soybeans and common beans [36,37].

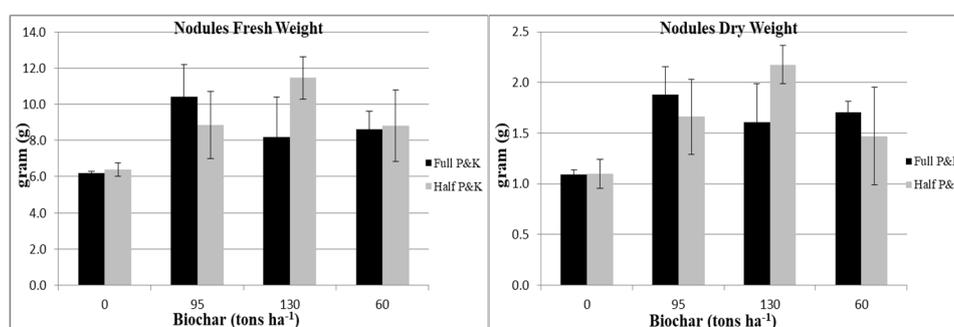
Table 2. Number of chickpea nodules and their masses, as influenced by two levels of mineral fertilizers and four levels of biochar.

PK Treatments	No. of Nodules	Fresh weight (g)	Dry weight (g)
Half PK	103 b	8.87 a	1.6 a
Full PK	112 a	8.35 a	1.57 a
Significance	**	NS	NS
Biochar Treatments			
BC ₁ (0 t ha ⁻¹)	89 c	6.29 b	1.10 c
BC ₂ (95 t ha ⁻¹)	122 a	9.62 a	1.77 ab
BC ₃ (130 t ha ⁻¹)	115 a	9.82 a	1.90 a
BC ₄ (60 t ha ⁻¹)	103 b	8.72 a	1.60 b
Significance	***	***	**
Interaction			
Biochar*PK	***	***	NS

BC, NS, ** and *** represent biochar, non-significant, significant and highly significant, respectively. The means followed by different letters in each column are significantly different from each other at $\alpha = 0.05$.



(a)



(b)

(c)

Figure 1. (a, b, c). Combined effect of two levels of PK fertilizers and four levels of biochar on nodules number and weight of chickpea nodules. Error bars represent standard error of mean for $n = 4$.

3.2. N₂ Fixation in Chickpea

The data regarding the fixation of nitrogen in chickpea as affected by the long-term biochar application under the mung–chickpea cropping arrangement are shown in Table 3. Nitrogen fixation was not significantly affected by the application of mineral fertilizers (PK), but the maximum N₂ fixation of 46.25 kg ha⁻¹ was recorded by the fully applied mineral fertilizers (PK) with respect to the half-applied (PK) mineral fertilizers as show in Figure 2. While the fixation of nitrogen was significantly enhanced by the amendments of biochar and the higher N₂ fixation of 72.50 kg ha⁻¹ was observed in treatment BC₃ (130 tons ha⁻¹ of biochar) and a minimum N₂ fixation of 17.75 kg ha⁻¹ was recorded in control treatment BC₁, the N₂ fixation was not significantly affected by the combined application of biochar and PK mineral fertilizers. Our results were similar with the results reported

by Mete et al. [35] They revealed that biochar influenced the bio-chemical and physical property of soils, and also enhanced the nitrogen fixation ability of plants.

Table 3. Nitrogen fixation in chickpea as influenced by two levels of PK fertilizers and four levels of biochar.

PK Treatments	N ₂ Fixed kg ha ⁻¹
Half PK	42.25 a
Full PK	46.25 a
Significance	NS
Biochar Treatments	
BC ₁ (0 t ha ⁻¹)	17.75 d
BC ₂ (95 t ha ⁻¹)	56.75 b
BC ₃ (130 t ha ⁻¹)	72.50 a
BC ₄ (60 t ha ⁻¹)	35.50 b
Significance	**
Interaction	
Biochar*PK	NS

BC, NS and ** represent biochar, non-significant and significant, respectively. The means followed by different letters in each column are significantly different from each other at $\alpha = 0.05$.

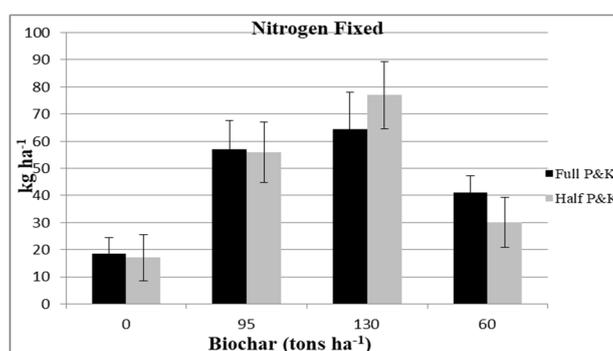


Figure 2. Combined effect of two levels of PK fertilizers and four treatments of biochar on nitrogen fixation in chickpea. Error bars represent standard error of mean for $n = 4$.

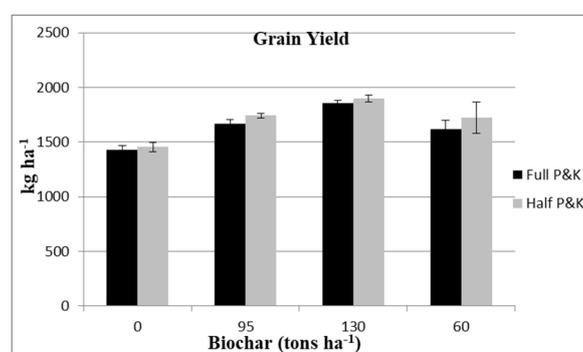
3.3. Grain Yield of Chickpea (kg ha⁻¹)

The grain yields of chickpea as influenced by the long-term amendment of biochar and mineral fertilizers (PK) are given in Table 4. The application of mineral fertilizers significantly influenced the grain yield of chickpea. The highest grain yield of 1703 kg ha⁻¹ was obtained at a half PK rate, compared with 1642 kg ha⁻¹ recorded for the full PK rate as shown in Figure 3. In the case of biochar treatment, treatment BC₃ received 130 tons ha⁻¹ of biochar over the last 5 years; given the highest grain yield of 1876 kg ha⁻¹, the minimum grain yield of 1442 kg ha⁻¹ was measured in the control treatment, receiving 0 tons ha⁻¹ of biochar in any season (BC₁). The combined effect of biochar and mineral fertilizers (PK) on the grain yield of chickpea was statistically not significant. Qian et al. [38] concluded that the grain yield and biomass of soybean were influenced by the combined application of mineral fertilizers and biochar. Azeem et al. [39] revealed that the amendments of sugarcane-bagasse biochar, with fertilizer and alone, in dry, low fertile soil significantly influenced the biomass and grain yields of both wheat and mash bean during the experimental period. YAO et al. [40] revealed that the quality of green pepper and its productivity was enhanced by the application of biochar to soil when compared with synthetic fertilizers. Mete et al. [35] concluded that the integrated use of biochar and PK fertilizers significantly increased the grain yield and fresh biomass of soybean. Usman et al. [41] stated that the yield and plant growth of tomato was significantly influenced by biochar incorporated with tree residues.

Table 4. Biomass and grain yield of chickpea as influenced by two levels of PK fertilizers and four levels of biochar.

PK Treatments	Grain Yield (kg ha ⁻¹)
Half PK	1703 a
Full PK	1642 b
Significance	***
Biochar Treatments	
BC ₁ (0 t ha ⁻¹)	1442 c
BC ₂ (95 t ha ⁻¹)	1704 b
BC ₃ (130 t ha ⁻¹)	1876 a
BC ₄ (60 t ha ⁻¹)	1668 b
Significance	***
Interaction	
Biochar*PK	NS

BC, NS and *** represent biochar, non-significant and highly significant, respectively. The means followed by different letters in each column are significantly different from each other at $\alpha = 0.05$.

**Figure 3.** Combined effect of two levels of PK fertilizers and four levels of biochar on biomass and grain yield of chickpea. Error bars represent standard error of mean for $n = 4$.

3.4. P and K Uptake in Chickpea Plant (kg ha⁻¹)

The uptake of phosphorous in chickpea as affected by the long-term biochar application under the mung–chickpea cropping arrangement is shown in Table 5. In the case of mineral fertilizer treatment, the maximum P uptake of 14.77 kg ha⁻¹ was recorded for the full PK rate as compared with 13.87 kg ha⁻¹ for the half PK rate (Figure 4). In the case of biochar treatment, the uptake of P in chickpea was enhanced significantly and it was observed that with the increasing rate of biochar P uptake was also influenced. The highest uptake of P was 20.75 kg ha⁻¹, measured in the biochar rate (BC₃), which received 130 tons ha⁻¹ of biochar over the last five years, and the minimum of 9.86 kg ha⁻¹ was measured in BC₁ (0 tons ha⁻¹ of biochar), which received no biochar in any season, which was statistically similar to BC₄ (60 tons ha⁻¹ of biochar). The interaction between mineral fertilizers and biochar was not significant for the uptake of P in chickpea. The data obtained on the uptake of potassium in chickpea as affected by the long-term application of biochar under the mung–chickpea cropping arrangement are shown in Table 5. According to the data, it was concluded that there was no effect of mineral fertilizers (PK) on the uptake of K, while the amendments of biochar positively affected the uptake of potassium. The combined effect of mineral fertilizers and biochar on the uptake of K was not significant. With the application of the mineral fertilizer (PK) at the full rate, the maximum K uptake of 120 kg ha⁻¹ was achieved in comparison with the half mineral fertilizer (PK) rate of 111 kg ha⁻¹ (Figure 4). The K uptake was linearly impacted by the amendments of biochar. The maximum K uptake of 155.4 kg ha⁻¹ was recorded in treatment BC₃, which received 130 tons ha⁻¹ of biochar over the last five years, which was statistically similar to treatment BC₂, which received 90 tons ha⁻¹ of biochar. The minimum of 83.6 kg ha⁻¹ was recorded in the BC₁ control treatment, which received no biochar in any season (0 tons ha⁻¹ of biochar), and it was similar to BC₄ (60 tons ha⁻¹ of

biochar). Our results were similar to the findings of Oram et al. [42], who recorded that the potassium uptake was enhanced with the application of biochar and organic amendments. Sharpley [43] reported that commercial fertilizers and biochars increased the uptake of phosphorous. Nigusse et al. [44] revealed that biochars increased the efficiency of P and K in lettuce.

Table 5. P and K uptake of chickpea receiving two levels of PK and four levels of biochar.

PK Treatments	P Uptake (kg ha ⁻¹)	K Uptake (kg ha ⁻¹)
Half PK	13.87 a	111.3 a
Full PK	14.77 a	120.7 a
Significance	NS	NS
Biochar Treatments		
BC ₁ (0 t ha ⁻¹)	9.86 c	83.6 b
BC ₂ (95 t ha ⁻¹)	16.27 b	134.0 a
BC ₃ (130 t ha ⁻¹)	20.75 a	155.4 a
BC ₄ (60 t ha ⁻¹)	10.39 c	91.1 b
Significance	***	**
Interaction		
Biochar*PK	NS	NS

BC, NS, ** and *** represent biochar, non-significant, significant and highly significant, respectively. The means followed by different letters in each column are significantly different from each other at $\alpha = 0.05$.

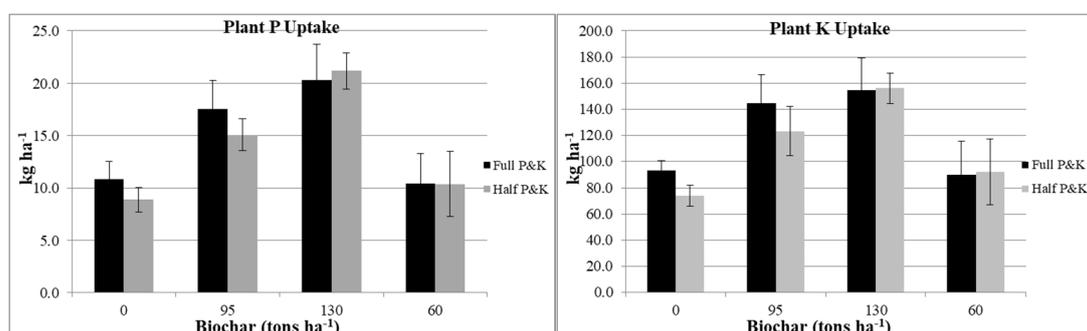


Figure 4. Combined effect of two levels of PK and four levels of biochar on P and K uptake of chickpea. Error bars represent standard error of mean for $n = 4$.

3.5. Soil Organic Matter (%)

Organic matter in soil as affected by the long-term application of biochar under the mung-chickpea cropping system is shown in Table 6. The data showed that soil organic matter was significantly enhanced by biochar treatment as well as by the application of mineral (P and K) fertilizers as shown in Figure 5a. Soil organic matter was not significantly affected by the combined application of mineral fertilizers and biochar. In the case of mineral fertilizer treatment, the soil OM of 2.27% was measured highest for the fully applied mineral fertilizers (PK) in comparison with the half-applied mineral fertilizers (PK). In the case of biochar treatment, the percentage of organic matter was linearly enhanced with the amendments of biochars. The maximum soil OM of 2.59% was measured in BC₃, which received 130 tons ha⁻¹ of biochar over the last five years, which was similar to the BC₂ treatment (95 tons ha⁻¹ of biochar). The lowest organic matter of 1.67% was noted in the control treatment BC₁, which received no biochar in any season. Biochar is a carbon-rich compound [45]. Organic carbon in soil is an important indicator of organic matter in soil [46,47]. The amendments of biochars enhanced the carbon in the soil. Juriga et al. [48,49] stated that the SOM was influenced by the application of biochars.

3.6. Soil Total N (%)

The total N in the soil as affected by the long-term application of biochar under the mung–chickpea cropping arrangement is presented in Table 5. According to the data, it was stated that the total N in the soil was linearly increased with biochar treatment, but not by the use of commercial fertilizers (PK). The combined amendments of biochar and P and K did not affect the total N in the soil. In the case of mineral fertilizer treatment, the total soil N of 0.066% was the maximum recorded by the full application of mineral fertilizers (PK) as shown in Figure 5b, in comparison with half the application of mineral fertilizers (PK), at 0.063% (Table 6). The maximum total nitrogen of 0.082% was recorded in BC₃, which received 130 tons ha⁻¹ of biochar over the last five years, and the minimum soil total nitrogen of 0.049% was obtained in the BC₁ (0 tons biochar ha⁻¹) control treatment. The same findings were concluded by Ali et al. [50], that soil total N was linearly affected by biochar over the long-term application. Total nitrogen was reduced during their first season of research but increased during the second season of research, as well as with the increased dose of biochar from 0 to 50 tons ha⁻¹.

3.7. Soil Mineral N (%)

The data regarding mineral N in soil enhanced by the long-term biochar application under the mung–chickpea cropping system is shown in Table 6. According to the data, it was concluded that the mineral N in soil linearly increased with biochar treatment but not with the use of mineral fertilizers (PK). Soil mineral N was not affected by the combined use of mineral fertilizer and biochar. In the case of mineral fertilizer treatment, the maximum mineral nitrogen of 65 mg kg⁻¹ in soil was recorded for the fully applied mineral fertilizers (PK) as compared with the half-applied mineral fertilizers (PK) as stated in Figure 5c. In the case of biochar treatment, the percentage of mineral nitrogen in soil was linearly influenced by the amendments of biochars. In BC₃ (130 tons ha⁻¹ of biochar), the highest soil mineral nitrogen of 73 mg kg⁻¹ was recorded, and the lowest soil mineral nitrogen of 54 mg kg⁻¹ was recorded in the BC₁ control treatment (0 tons ha⁻¹ of biochar). In our case, mineral nitrogen was high in BC₃ (130 tons ha⁻¹ of biochar) which was due to the high amount of organic matter that was transformed into nitrogen. Total nitrogen had only a positive effect on nitrogen mineralization as showed in (Table 6). Annually, only 1–4% of total nitrogen in soil is transformed into the ammonium and nitrate form of nitrogen, which is available to plant [51]. Dessureault et al. [52] exposed that many researchers concluded that soil OM and total N is the best predictor of available nitrogen.

Table 6. Nitrogen and organic matter of soil receiving two levels of PK and four levels of biochar.

PK Treatments	Organic Matter %	Total N %	Mineral N mg kg ⁻¹
Half PK	2.19 b	0.063 a	63 a
Full PK	2.27 a	0.066 a	65 a
Significance	**	NS	NS
Biochar Treatments			
BC ₁ (0 t ha ⁻¹)	1.67 c	0.049 c	54 c
BC ₂ (95 t ha ⁻¹)	2.42 ab	0.066 b	66 b
BC ₃ (130 t ha ⁻¹)	2.59 a	0.082 a	73 a
BC ₄ (60 t ha ⁻¹)	2.24 b	0.0693 b	62 b
Significance	***	***	***
Interaction			
Biochar*PK	NS	NS	NS

BC, NS, ** and *** represent biochar, non-significant, significant and highly significant, respectively. The means followed by different letters in each column are significantly different from each other at $\alpha = 0.05$.

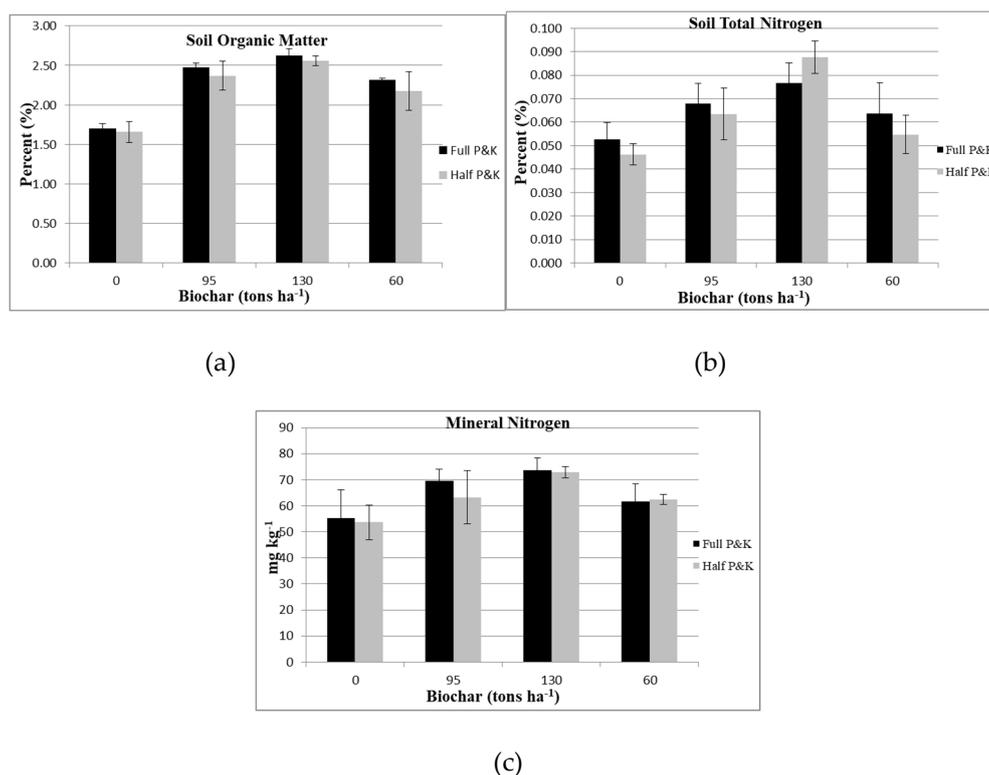


Figure 5(a, b, c). Combined effect of two levels of PK and four levels of biochar on soil fertility. Error bars represent standard error of mean for $n = 4$.

4. Conclusions

The application of 130 tons ha⁻¹ of biochar in combination with half the recommended mineral fertilizers was observed to be the most effective in improving fresh and dry biomass, grain yield and N₂ fixations in chickpea. Soil organic matter significantly increased with the increasing rate of biochars, along with half the recommended mineral fertilizers. Furthermore, the application of half the recommended mineral fertilizers significantly enhanced the numbers and masses of nodules (fresh and dry weights) and N₂ fixation. Therefore, the long-term application of 130 tons ha⁻¹ of biochar, along with half the recommended mineral fertilizer is recommended for enhanced nodulation, N₂ fixation, yield, and NPK nutrition in chickpea under the mung–chickpea cropping system.

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