

Interactive Use of Biochar and Chemical Fertilizer on Soil Nutrients (NPK), Soil Water Retention and Biological Nitrogen Fixation by Mash Bean

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Abstract

Loss of soil fertility, reduction in soil productivity and water scarcity is the major limitation of rain fed area of Pakistan. Applications of biochar on low fertile and degraded soil enhance soil fertility, nutrients uptake and water retention thus improves soil productivity. Field study was conducted to examine the effect of biochar on biological nitrogen fixation (BNF) by mash bean (*Vigna mungo*. L), soil nutrients availability and soil water retention. Biochar was applied at 0, 0.25 and 0.5 t ha⁻¹ along with and without chemical fertilizer (20, 50, 50 kg ha⁻¹ NPK) with four replications. Crop was harvested at maturity and soil samples were collected from each experimental plot before sowing and after harvesting and was analyzed for soil E_c, soil pH, total nitrogen, phosphorus, potassium, soil infiltration rate, soil aggregate stability, soil water retention and cation exchange capacity (CEC). Biological nitrogen fixation was determined by xylem-sap method and xylem sap was extracted at pod filling stage. Soil treated with biochar @ 0.5 t ha⁻¹+chemical fertilizer (NPK 20, 50, 50 kg ha⁻¹ respectively) showed maximum pH (7.78) and soil electrical conductivity (0.67 ds m⁻¹). Application of biochar and chemical fertilizer to soil (0.5 t ha⁻¹+NPK 20,50,50 kg ha⁻¹) increases total N from 3.9 mg kg⁻¹ to 18 mg kg⁻¹, Phosphorus from 4 mg kg⁻¹ to 18.5 mg kg⁻¹, potassium from 98 mg kg⁻¹ to 143 mg kg⁻¹ and soil CEC from 6.6 Cmolc kg⁻¹ to 11.2 Cmolc kg⁻¹. Biochar @ 0.5 t ha⁻¹ stabilized soil aggregates (34%) and improves soil infiltration rates (164 mm h⁻¹) without impacting any significant effect on soil water retention. Biochar applied @ 0.5 t ha⁻¹ along with chemical fertilizer (NPK 20, 50, 50 kg ha⁻¹ respectively) showed maximum increase in BNF (24 kg N ha⁻¹), biomass yield (2.7 t ha⁻¹) and grain yield (1.8 t ha⁻¹). The study concluded that biochar application (0.5 t ha⁻¹) along with chemical fertilizer increase availability of nutrients (NPK), soil pH and E_c where as sole application of biochar (0.5 t ha⁻¹) promoted aggregation and infiltration rate. The significant increase was observed in case of BNF (40%), grain yield (77%) and biomass yield (64%) of mash bean. It is recommended that biochar application to soil along with chemical fertilizer improve soil productivity and BNF by mash bean.

Keyword:

Biochar; Water retention; Biological nitrogen fixation; Soil aggregates

Introduction

The major problem of increasing rapid global human population is decreasing food reserve due to climate change [1]. In Pakistan, most of the cultivated land (23%) depends upon rainfall. In Punjab 20% of cultivated land depends upon rainfall [2]. In semi-arid area high temperature and drier climatic condition led to major problem of soil degradation and infertility [3]. To solve these problems, use of biochar is proven alternative which hold soil nutrients [1,4].

Whereas in fast pyrolysis, heating of biomass can be done at 400-700°C under anaerobic environment [5]. The physico-chemical properties like pore size, structure and pH of biochar depends upon the characteristics of feedstock and the condition of pyrolysis. Temperature of pyrolysis determines the carbon contents and chemical structure of biochar [6,7].

Biochar is chemically composed of four components i.e., carbon, ash, volatile matter and moisture. Biochar addition sometime reduce the availability of nitrogen in tropics soil [8] that correlates with C:N

ratio of biochar and catalyze the reduction of N₂O to N₂ and reduce the emission of greenhouse gases.

Biochar addition to soil improve its bulk density, water content, infiltration rate, soil temperature and chemical properties like soil pH, soil CEC and soil EC that help to improve plant growth. Biochar application to soil has no significant effect on soil water retention, soil hydraulic properties and soil aggregate stability. Biochar retain soil moisture and minimize soil irrigation cost. Its application improves potential of soil to retain water and make it available to crops during hot dry period. Biochar has a very high surface area about 100 m² gm⁻¹. This high surface area helps to adsorb more water molecule when more water is available and release it back to soil solution when there is shortage of water. Biochar applications to soil also have significant effect on soil drainage system in clayey and sandy soil.

Biochar has great potential for the exchange of NH₄⁺ with in the soil solution that helps in the nodulation and N-fixation and improves the availability of nitrogen to plants [9]. Addition of biochar to soil can increase the nitrogen fixation derived from the common bean (*Phaseolus vulgaris*) and this increase in N-fixation also increase the yield of crops [10]. In comparison with grasses, legumes performed better in low nitrogen soil with biochar [11].

The addition of biochar to soil increase the biological nitrogen fixation due to the improved availability of some nutrients like boron,

molybdenum, potassium, calcium and phosphorus [10]. Keeping in view the importance of biochar study was conducted to check the effect of biochar with and without chemical fertilizer on biological nitrogen fixation by mash bean on soil water retention.

Materials and Methods

Field experiment was performed at university research farm Koont located at village Koont on Rawalpindi-Chakwal road. Biochar used in experiment was produced locally design air tight vessel. The vessels were consisting of two metal barrels which were 60 cm wide and 90 cm height. The biomass was stocked at barrel as tight as possible and the barrel was ignited by using natural gas. The produced charcoal was left to cool for one hour thus converting 50% biomass to biochar. This local design biochar had a capacity to produce 5 kg biochar per hour. For field study, biochar was ground to pass through 2 mm sieve. Soil pH (8.8) and soil EC (1.78 ds m⁻¹) were determined by 1:1 w/v ratio of biochar and distilled water with standard electrode. Biochar also had 58% C, 0.24% N, 0.92% P and 2.91% K. Biochar was applied at the rate of 0, 0.25 and 0.5 t ha⁻¹ without and with chemical fertilizer (NPK 25, 50, 50 kg ha⁻¹ respectively) with four replications. Mash bean was used as a test crop. The soil samples were collected after harvesting crop, air dried at room temperature and pass through 2 mm sieve for further analysis. Soil pH and soil EC were determined at ratio 1:2.5 soil and distilled water. Combustion method and walkley and black method were used for determination of organic C, total N was by Kjeldahl method, P was determined by Olsen's P method and available K, method used by Rhodes [12] CEC by ammonium acetate method and particle size distribution by hydrometer method. Wet sieving apparatus was used for the aggregate stability. Soil water or moisture retention curve was determined by applying potential of 0.1, 1, 5, 10 and 15 bar through pressure membrane apparatus and soil infiltration rate by double infiltrometer method.

Assessment of BNF

Xylem Solute Technique was used for estimation of biological nitrogen fixation. By vacuum extraction method sap was collected at pod filling stage and was stored at freezer at -15°C. Concentration of ureide, nitrate and amino-N were determined to calculate the relative abundance of ureide (RUN %) and % Pfix (proportion of plant N derived from N₂-fixation).

Parameters	pH	EC dsm ⁻¹	N mgkg ⁻¹	P mgkg ⁻¹	K mgkg ⁻¹	Sand %	Silt %	Clay%	Soil texture	TOC %
Soil	7.6	0.31	3.9	4	98	56	22.8	21.2	Sandy clay loam	1.3
Biochar	8.8	1.78	0.24%	2.50%	-	-	-	-	-	58

Table 1: Basic characterization of soil and Biochar.

Effect of biochar addition of soil chemical properties

Effect of biochar along with and without chemical fertilizer are shown in Table 2. Soil chemical (pH, ECe, CEC) and soil physical properties (aggregate stability, infiltration rate) changes by addition of biochar to soil. Application of biochar with and without chemical fertilizer significantly (p<0.05) increase soil pH from 7.6 to 7.6 to 7.9 this increase in pH is due to the alkaline nature of biochar Zhang et al. [16]. Uzoma et al. [17] also reported the same results where application

Following formula was used to calculate RUN % and Pfix.

$$\text{RUN (\%)} = [4 \times \text{ureide} / (4 \times \text{ureide} + \text{nitrate} + \text{amino-N})] \times 100$$

After calculating RUN%, the proportion of plant N derived from N₂-fixation (%Pfix) was estimated.

$$\%P\text{fix} = 1.6 (\%RUN - 15.9) \text{ for plants during pod fill}$$

The legume N was derived from the measure of biomass accumulation and tissue N content as follows:

$$\text{Crop N (kg ha}^{-1}\text{)} = \text{Legume dry matter (kg ha}^{-1}\text{)} \times (\%N)$$

The amount of nitrogen fixed by legume can be regulated by two factors, the amount of N accumulated during growth, and the production of that N derived from symbiotic N₂-fixation.

$$\text{Amount of N}_2\text{-fixed (kg ha}^{-1}\text{)} = \%P\text{fix} \times \text{Crop N (kg ha}^{-1}\text{)} \times 1.5 \text{ [13].}$$

Statistical analysis

Randomized complete block design (RCBD) was used for this experiment. The data collected was analyzed statistically in RCBD and means were compared at 5% level of significance [14].

Results and Discussion

Basic characteristics of soil and biochar investigated

Basic characteristics of soil and biochar are shown in Table 1. The basic soil characteristics were analyzed before the application of biochar to soil. Soil pH was 7.68 while soil ECe was 0.31 ds m⁻¹. Due to high soil pH soil was alkaline and there was no problem of salinity in soil because soil ECe is less than 4 ds m⁻¹. Rainfed area is considered normal when soil ECe is 0.2 to 2 ds m⁻¹ [15]. Soil texture is sandy clay loam with sand 56%, silt 22.8% and clay 21.2%. Soil pH increased upto 7.8 after application of biochar whereas soil electrical conductivity remained same i.e. 0.31 ds m⁻¹. Soil total organic carbon, N and P are 1.3%, 3.9 mg kg⁻¹, 4 mg kg⁻¹ and K 98 mg kg⁻¹ respectively. Biochar has pH 8.8 and ECe 1.78 ds m⁻¹. Biochar contain 0.24% P, K 2.5% and 0.92% N.

of cow manure biochar increase soil pH from 6.4 to 8. Like pH, BC +NPK also significantly increase (p<0.05) soil EC from 0.366 to 0.76 ds m⁻¹. It was observed that chemical characterization of biochar had high variation in EC values vary from 0.39 to 4.18 ds m⁻¹ [18].

In case of CEC biochar along with chemical fertilizer increases (6.6 to 11.2 Cmolc kg⁻¹). Biochar is a porous and have high surface charge and also have charged organic material, due to these characteristic biochar additions to soil increase soil CEC [19]. Same results also

suggested by Jien et al. [20] that it's to soil improved soil chemical properties as soil CEC increases from 7.41 to 10.8 Cmolc kg⁻¹.

Soil	pH	EC dsm ⁻¹	N mgkg ⁻¹	P mgkg ⁻¹	K mgkg ⁻¹	CEC Cmolkg ⁻¹	Infiltration rate mmh ⁻¹	Aggregate stability %
BC 0 t ha ⁻¹	7.6	0.36	3.9	4	98	6.6	140	21.5
BC 0.25 t ha ⁻¹	7.78	0.51	5.07	5.4	120	8.7	155	27.3
BC 0.5 t ha ⁻¹	7.9	0.67	7.5	10	132	11.1	165	34
Recommended NPK	7.62	0.41	8	8	104	7.1	132	23.2
BC+NPK 0.25 t ha ⁻¹ +20,50,50 NPK	7.65	0.54	14	13.4	130	9.5	155	27
BC+NPK 0.5 t ha ⁻¹ +20,50,50 NPK	7.78	0.66	18	18.5	143	11.2	164	31

Table 2: Effect of biochar along with chemical fertilizer on soil properties.

Effect of biochar on N, P, K

Biochar increase soil fertility as by making available nutrients to soil. As its application to soil increase ($p < 0.05$) total N (3.9 to 18 mg kg⁻¹) high concentration of N were found in BC @ 0.5 t ha⁻¹+20,50,50 kg ha⁻¹ NPK as shown in Table 2. Nigussie et al. [21] also reported that there is significantly increase in N by applying biochar at different rate of 5 and 10 t ha⁻¹. Knicker [22] also suggested in his study that addition of biochar to soil significantly change total N of soil but there is no effect of biochar on soil mineral N. Same results also reported by Zhang et al. and Nelson et al. [16,21].

Same like N its application along with chemical fertilizer also have significant effect on P and K. Maximum concentration of soil P (18 mg kg⁻¹) was found in BC 0.5 t ha⁻¹+20,50,50 kg⁻¹ NPK as compared to control. Biochar contain different concentration of P and very little amount of P are soluble in water due to this solubility application of biochar change the concentration of P in soil [23]. Biochar application to soil have tendency to minimize the leaching of P and thus to maintain high concentration of P in soil [24]. Nelson et al. [23] also reported increase in concentration of P with biochar addition in soil and suggested that biochar inhibit P sorption. Potassium was also significantly increase because of the presence of concentration of K in biochar.

Effect on soil physical properties

Like soil chemical properties biochar application to soil also have positive effect on soil physical properties like soil infiltration rate, aggregate stability, soil water content and soil water retention [25].

In case of soil infiltration rate application of biochar at 0.5 t ha⁻¹ without chemical fertilizer significantly increase ($P < 0.05$) soil infiltration rate from 140 mm ha⁻¹ to 165 mm ha⁻¹. Biochar application to soil increase soil porosity and aggregate stability due to increase in soil porosity biochar application to soil increase soil infiltration rate [26]. Dumroese et al. [27] also reported that biochar addition to soil increase soil infiltration rate.

Stable aggregates (34%) were found in soil treated with biochar 0.5 t ha⁻¹ without chemical fertilizer. The increasing rate of biochar to soil increase aggregate stability of soil and due to this increase in aggregates

stability soil becomes less prone to erosion Zhang et al. [28]. Biochar when incorporated to soil it slowly changes to stable humus [29]. It is reported that soil contain humus can increase soil aggregate stability [30,31]. Biochar and charcoal can make a bond through carboxylic and phenolic group with soil minerals significantly increases the aggregate stability of soil [32].

The effect of biochar on soil water retention is shown in Figure 1. It is indicated that biochar applied at 0.5 t ha⁻¹ retained more water but due to the short duration of study there is no significant increase in soil water retention. Biochar addition to soil brings changes in soil hydraulic properties and have significant changes in soil water retention [33] but this study showed that biochar did not significantly change soil water retention as reported by major et al. [34] that biochar had no significant effect on soil moisture retention. Gaskin et al. [35] also reported that application of biochar had no significant effect on soil moisture holding capacity. The mechanism behind the influence of biochar on soil water retention and other physical properties are still poorly understood [36].

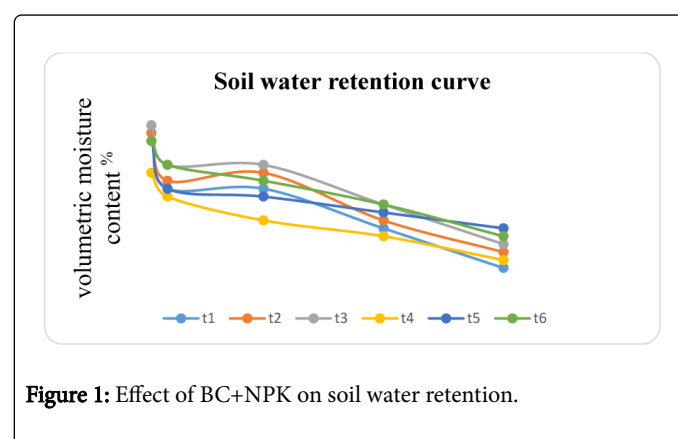


Figure 1: Effect of BC+NPK on soil water retention.

Effect of biochar on crop growth and BNF

Effect of biochar on BNF and crop growth are given in Table 3. It is indicated from the result that biochar application to soil increase BNF significantly. Soil treated with biochar at 0.5 t ha⁻¹+NPK showed

maximum N fixation (24 kg N ha^{-1}) followed by biochar at 0.5 t ha^{-1} without NPK fertilizer. The highest rate of BNF with biochar is due to the availability of soil nutrients like B, Mo, Ca, K and higher pH. Biochar addition to soil increase availability of these nutrients which have good effect on BNF [10]. Evidence of this increase in BNF by biochar is also provided by Nishio and Okano [11] using the Nitrogen difference and acetylene reduction assay methods. Addition of biochar

to soil increase soil pH so, low acidity of soil also contributed to the BNF as by liming. Biochar application to soil increases biological nitrogen fixation but mechanism behind is un clear. There are some possibilities that how biochar increases biological nitrogen fixation. As biochar have high C/N ratio which lower the N availability in soil resulting in N immobilization [8,19].

Soil	pH	EC dsm^{-1}	N mgkg^{-1}	P mgkg^{-1}	K mgkg^{-1}	CEC Cmolkg^{-1}	Infiltration rate mmh^{-1}	Aggregate stability%
BC 0 t ha^{-1}	7.6	0.36	3.9	4	98	6.6	140	21.5
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BC 0.5 t ha^{-1}	7.9	0.67	7.5	10	132	11.1	165	34
Recommended NPK	7.62	0.41	8	8	104	7.1	132	23.2
BC+NPK $0.25 \text{ t ha}^{-1}+20,50,50 \text{ NPK}$	7.65	0.54	14	13.4	130	9.5	155	27
BC+NPK $0.5 \text{ t ha}^{-1}+20,50,50 \text{ NPK}$	7.78	0.66	18	18.5	143	11.2	164	31

Table 3: Effect of Biochar+NPK on Biological N fixation, Biomass and Grain yield.

Biochar application to soil increase biomass yield and also grain yield of mash bean from 1.6 to 2.7 t ha^{-1} and 1.07 to 1.75 t ha^{-1} as given in Table 3. Biochar application to soil increase grain yield and biomass yield of common bean. Biochar application also increases yield of moon bean, cow pea, pea and rice [8,37,38].

Conclusion

The present results of study are based on evaluation of biochar with and without chemical fertilizer with the objectives to improve soil water retention and N_2 -fixation by mash bean under rainfed areas. Biochar applied at higher rate ($0.5 \text{ t ha}^{-1}+\text{NPK}$) resulted better crop yield and maximum biological nitrogen fixation as compare to control. Biochar application without NPK fertilizer to soil improve the soil aggregates and enhanced soil infiltration rate. There is also some significant effect of different doses of biochar+NPK on total nitrogen, potassium and phosphorus. Soil water retention is not significantly affected by biochar because of short duration study. Mash bean yield and biomass are increased 77% and 64% by application of biochar +NPK. It is recommended from the study that biochar application along with NPK increase BNF and grain yield of mash bean.

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