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The effect of biochar on soil organic matter, total N in soil and plant, nodules, grain yield and biomass of mung bean

Shadman Khan*, Muhammad Ismail, Muhammad Ibrar, Jawad ul Haq and Zeeshan Ali
Department of Soil and Environmental Sciences, The University of Agriculture Peshawar,
Khyber Pakhtunkhwa, Pakistan
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Abstract

A field experiment was performed at Research Farm of the University of Agriculture Peshawar, Pakistan to evaluate the effect of biochar on soil and plant nitrogen and yielding parameters of mung bean. The experiment was performed in randomize complete block design with split plot arrangement with four replications. Area of each experimental unit was 10.5 m^2 and was applied with biochar at the rate of 0, 20, and 40 t ha^{-1} along with full and half levels of P and K i-e., (90 kg P, 60 kg K ha^{-1} and 45 kg P, 30 kg K ha^{-1}). Nitrogen was applied to all the experimental units uniformly @ 25 kg N ha^{-1}. The data showed that all of the analyzed parameters were significantly influenced with various biochar levels except fresh and dry weight of nodules. With full and half dose of P and K application, soil total N and soil organic matter were found significant with an increase of 16% and 7% as compared to half dose. With application of various levels of biochar, a significant increase was recorded in most of the parameters. Data regarding Soil N and soil O.M were found significantly enhanced at 40 t ha^{-1} with values of 0.15% and 2.64% which were 200% and 94% higher as compared to 0 t ha^{-1} biochar applications. Other parameters like 1000 grain weight, biological yield (fresh and dry), plant N and number of nodules were significantly affected with 20 t ha^{-1} biochar application which were increased by 20 %, 33%, 21% and 21% as compared to control. Combined application of P&K and biochar significantly affected soil total nitrogen i-e., 0.16% at (full×40 t ha^{-1}) and nodulation number i-e., 36 at (half×20 t ha^{-1}). It was concluded that biochar application @ 20 t ha^{-1} along with half levels of P and K, proved the best treatments combination for most of the plant parameters and hence they are recommended.

Keywords: Soil nitrogen (total), SOM (soil organic matter), grain yield, biological yield, plant nitrogen, nodulation

Introduction

Biochar is a charcoal form of carbon which is produced by the process of pyrolysis from dead organic materials such as straw, wood, kitchen waste etc. Burning of organic materials in the absence of oxygen stores more energy as compared to burning in open environment (Njenga *et al*., 2016). Besides this, biochar is a very important form of organic matter which consists of high amount of carbon and its application helps in improving the fertility and productivity status of a low productive land (Scholz *et al*., 2014; Cernansky, 2015). Its effect on crop yield have been reported from slightly negative to very positive depending on soil, type of biochar and climate (Liu *et al*., 2013). Jeffery *et al*. (2017) concluded that with the addition of biochar in tropical agro climate improves 25% of the crop yield as compared to temperate agro climate which leads to negative effect.

Soil organic matter can be improved by the application FYM, poultry manure, crop residues, compost etc. but one of the good sources for increasing the fertility of soil is biochar, which draws the attention of many scientists around the globe. Biochar is a resistant organic matter that is being used by scientists as a source of organic matter (Lehman *et al*., 2003). There is a similarity among the biochar and organic matter (Wolf *et al*., 2008), however the carbon content in biochar is more as compared to other organic matters and hence became useful to be used in leguminous crops (Rahim *et al*., 2019). Biochar has drawn the attention of many researchers to improve degraded soil, because it improves the physical, chemical and biological properties of soil (Chan *et al*., 2008).

Biochar is produced from the pyrolysis of plant litters (leaves, stem, etc.), crop, and animal residues. It is an organic product produced in the absence of oxygen in a closed system (Zheng *et al*., 2010). Organic carbon

*Email: shadmankhan@aup.edu.pk

concentration is high in fine grained charcoal and is resistant to decomposition. The structure less soil can be conserved by applying biochar (Lehman and Rondon, 2006). The leaching of nutrients absorbed by biochar in soil and contamination of ground water can be minimized with its application (Yu *et al*., 2009).

Biochar resistance to microbial decomposition and slow release of nutrients from it make it beneficial for plants for a long term (Steiner *et al*., 2007). It rehabilitates the degraded soil and makes it workable for agriculture use (Verheijen *et al*., 2010). A combination of NPK fertilizer and biochar shows a good yield response on Amazonian and semi-arid regions of Australia (Ogawa, 2006).

With the application of different levels of biochar, soil pH, total N, and SOM can be adjusted (Zhang *et al*., 1998). The nitrogen use efficiency (NUE) can also be increase by adding biochar to soil (Lehman *et al*., 2003). The bacterial biomass and its composition in soil can be enhanced with biochar (Steiner *et al*., 2004). The effectiveness of biochar is evident from many studies inhibiting nitrogen loss from leaching and volatilization (Zhou and Lee, 2011). The result showed that biochar had effective response in protecting nutrient losses in calcareous soil, when used in optimum amount that is 10 t ha^{-1} (Zhou *et al*., 2011). It is more efficient in retaining organic nitrogen compound than nitrate compound (Zhou *et al*., 2011). According to Chen Xinxiang's (2014) increasing biochar content in the soil reduces the leaching of both ammonium (NH_4-N) and nitrate (NO_3-N). Rondon *et al*. (2007) as biochar enhances the carbon status soil which lead to enhancement in micro-organisms density, and ultimately their ability to fix nitrogen in soil also enhances (Kateyal *et al*., 2001). Biochar improves soil fertility and reduces N losses (Lal, 2009, Joseph *et al*., 2013).

Among the macro nutrients, nitrogen plays a key role in the metabolic processes of plant /crops, but Pakistani soils are deficient in nitrogen content (Tejada *et al*., 2009). For overcoming deficiency, nitrogen is applied from external sources (fertilizers, manures, and biochar). Nitrogen fertilizers alter soil fertility and productivity (grain yield 43-68%, biomass 25-42%) of the crops by decreasing N deficiency in soil (Yang *et al*., 2015). Biochar incorporation as well as interactive effect of biochar and mineral fertilizers improve the plant growth, production and physio-chemical properties of the soil (Khan *et al*., 2009).

Biochar has the ability to increase cation exchange capacity, nutrients holding capacity, water holding capacity and structural stability besides neutralizing the soil pH. With application of higher amount of biochar, the soil organic matter status increased. It is inversely proportional to the costs of total fertilizers and retention power of soil (Lehmann *et al*., 2007; Glaser *et al*., 2002), increases the total surface area of soil (Chan *et al.,* 2007) and the use of commercial fertilizers with biochar helps in changing the properties of soil such as water retention, aeration, plant growth and also increases its yield and yield components under different cropping system (Yamato *et al.,* 2006).

In order to obtain higher yield, plants are required to supplement with optimum amount of Phosphorus. Most of the soils are deficient in phosphorus and cause reduction in yield (Chen *et al*., 1994). Phosphorous is not a volatile substance and during the process of pyrolysis it will remain in biochar and its concentration will also increase due to the reduction in mass as mentioned by Hossain *et al*. (2010) and Bridle and Pritchard (2004). Sorption mechanism is commonly used for P retention description (MacDowell *et al*., 2001; Villapando *et al*., 2001). In some studies, it was suggested that biochar having high anion exchange capacity enhanced the availability of P in soil and reduced the availability of Al and Fe in soil to reduce P fixation (Deluca *et al*., 2009; Novak *et al*., 2009). After Nitrogen, it is the second limiting factor of crop production. Phosphorus is involved in most of the physiological processes such as photosynthesis, cell division, metabolic activities and is also an important nutrient for the production of energy rich phosphate. Phosphorus is one of the important nutrients that store energy obtained from photosynthesis in the form of ADP and ATP in plant for instant and future use in order to grow and develop (Ayub *et al*., 2002). Phosphorus is also considered to be a component of most genetic material (chromosomes) and thus helps in hereditary transfer of traits to offspring (Blevins, 1999 and Havlin, *et al*., 1999).

Materials and Methods

The experiment was conducted at the Research Farm of the Agriculture University Peshawar. Three doses of biochar (0, 20 and 40 t ha^{-1}) were applied to the field before the sowing of mung bean variety (Ramzan 92). Design followed for conducting this research was randomized complete block design with split plot arrangement replicated four times. Each plot was divided into two halves. One half received half recommended dose of P and K i.e., (45 and 60 kg ha^{-1}) and the other half received full recommended dose of P and K i.e., (45 and 30 kg ha^{-1}). Nitrogen was applied as starter dose at 25 kg ha^{-1} to each plot. Wood biochar which is commercially available was used in this experiment, while phosphorous from SSP, potassium from SOP, and nitrogen from Urea were applied.

Treatment	Biochar t ha^{-1}	P kg ha^{-1}	K kg ha^{-1}
T1	0	90	60
	0	45	30
T2	20	90	60
	20	45	30
T3	40	90	60
	40	45	30

The soil was collected from the depth of 0-15 cm after the harvest of crop in order to analyze soil OM and total nitrogen. The plants were harvested, air dried and then brought to laboratory (laboratory of Soil and Environmental Sciences) for analysis. For determining OM in soil, the Walkley-Black procedure (Nelson and Sommers, 1996) was used. Total nitrogen was determined by following Bremner (1996) by Kjeldal method. For nodulation, four plants from each plot during the flowering stage, were uprooted by using spade. The roots were washed, nodules were detached and counted besides having their fresh and dry weights. For the biomass and grain yield, each plot of mung bean was harvested at full maturity from $1m^2$ area, its fresh weight was recorded after air-drying while after complete drying collected grains from it. And a representative sample taken for determining total N using Bremner (1996) procedure.

Results and Discussion

In Table 1 and Figure 1a, 1b, the data revealed that highest organic matter content of 2.64% was obtained from treatment receiving biochar at 40 t ha^{-1} (T_3). The lowest organic matter of 1.3% was obtained from treatment receiving biochar 0 t ha^{-1} (T_1). With application of various levels of biochar, there was an increasing trend followed by organic matter in soil as obvious from the table 1, which showed an increase of 94% as compared to control when the highest level of biochar i-e., 40 t ha^{-1} was applied. Similar was the results for soil total nitrogen which was also enhanced as the levels of biochar increased. The highest soil total nitrogen (0.15%) was found at 40 t ha^{-1} which was 200 % higher as compared to control. There was an increasing influence on soil total nitrogen when 40 t ha^{-1} biochar and full levels of P and K were applied. The biological nitrogen fixation is the function of bacteria found in nodules of

Table 1: Biochar effects on soil organic matter and total nitrogen

Effect of PK	Organic Matter %	Total N %
½ PK	1.97 B	0.094 B
Full PK	2.11 A	0.109 A
Significance	**	***
Effect of Biochar		
T_1 (0 t ha^{-1})	1.36 C	0.05 C
T_2 (20 t ha^{-1})	2.12 B	0.09 B
T_3 (40 t ha^{-1})	2.64 A	0.15 A
Significance	***	***
Interaction		
Biochar*PK	**ns**	***

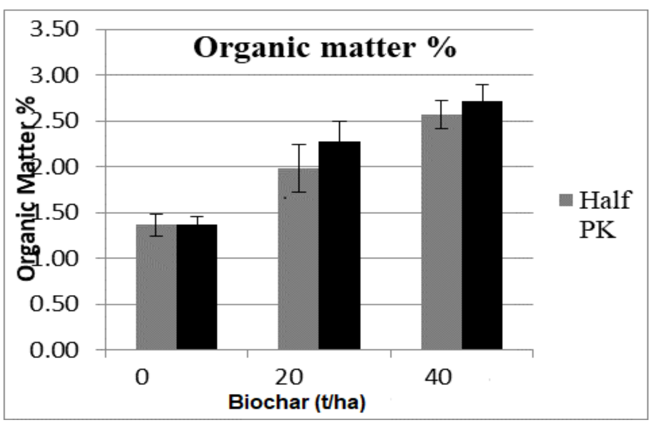

Figure 1a: Graphical representation soil organic matter affected by different treatments of biochar

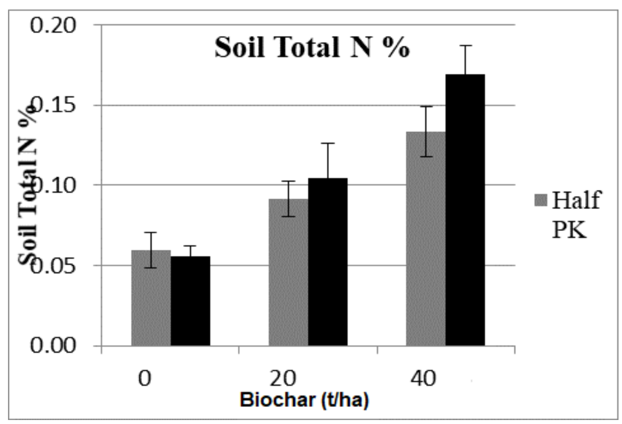

Figure 1b: Graphical representation soil total N affected by different treatments of biochar

leguminous crops and as the application of biochar provide enough carbon for optimum growth of these bacteria, hence the soil total nitrogen and organic matter were improved in line with the findings of Partey *et al*. (2014) and Nelson *et al*. (2011) who reported improved soil nutritional status with combined application of biochar and mineral nutrients.

Table 2: Biochar effects on 1000 grain weight and biomass (fresh and dry weight) of mung bean

Effect of PK	1000 grain weight (g m^{-2})	Fresh weight (kg m^{-2})	Dry weight (kg m^{-2})
½ PK	38.8 A	1.09 A	0.37 A
Full PK	38.1 A	1.05 A	0.36 A
Significance	**ns**	**ns**	**ns**
Effect of Biochar			
T_1 (0 t ha^{-1})	35.33 C	0.92 C	0.33 B
T_2 (20 t ha^{-1})	42.37 A	1.22 A	0.41 A
T_3 (40 t ha^{-1})	37.69 B	1.06 B	0.35 AB
Significance	***	***	**
Interaction			
Biochar*PK	**ns**	**ns**	**ns**

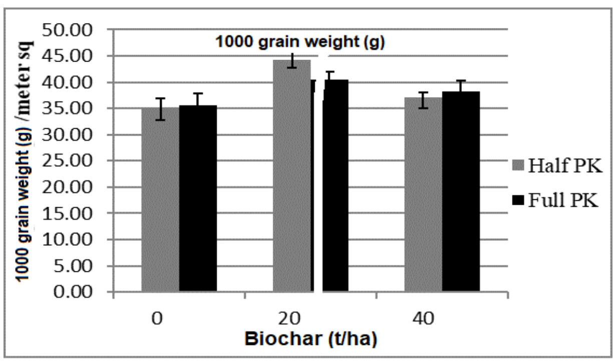

Figure 2a: Graphical representation of 1000 grain weight affected by different treatments of biochar

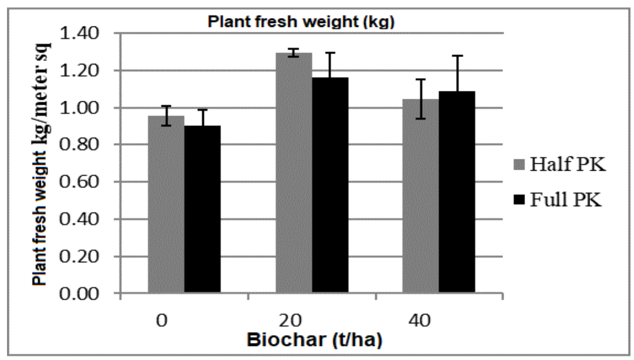

Figure 2b: Graphical representation of fresh weight of mung bean affected by different treatments of biochar

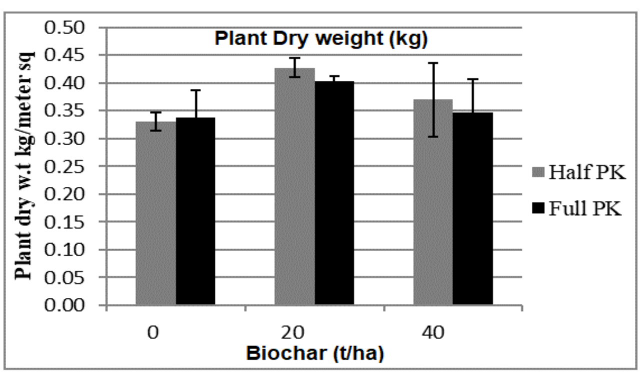

Figure 2c: Graphical representation of dry weight of mung bean affected by different treatments of biochar

In Table 2 and Figure 2a, 2b, 2c, the effect on 1000 grain weight, fresh and dry biomass was observed with application of two levels of P and K and also various levels of biochar. It is obvious from the table that with application of P and K either full or half didn't influence the 1000 grain weight and biomass. However, the effect of biochar on grain weight and biomass were found enhanced at 20 t ha^{-1} with recorded values of 42.3g (1000 grain weight), 1.22 kg fresh and 0.41 kg dry biomass. There was an increment of 20% observed in thousand grain weight, 33% increment in fresh biomass and 24% increment in dry biomass with application of 20 t ha^{-1} biochar application as compared to control. The interactive effect of biochar and mineral fertilizer (P&K) on 1000 grain weight and biomass (both fresh and dry) were found non-significant. Biomass increment is a function of nitrogen, and hence nitrogen is mostly available when microbial activities are optimum so accordingly enhancement in biomass and 1000 grain weight was observed. The present results are in conformity with those of (Agegnehu *et al*., 2015; Gul and Whalen 2016: Nawab *et al*., 2018).

In Table 3 and Figure 3a, 3b, 3c, the data regarding nodule number in mung bean were found significantly enhanced with application of biochar; however, the influence on dry and fresh weight of nodules were found non-significant with all the three levels of biochar. The effect of full and half P&K application had no increment in nodule number and its weight. As regards the number of nodules, there was an increase of 21% observed with the application of 20 t ha^{-1} biochar as compared to control (28). The interactive effect of biochar and P&K was found significant in terms of nodule number only with highest number of nodules i-e., 36 at 20 t ha^{-1} and half levels of P and K. The weight of nodules showed no significant increase when combined application of biochar and mineral fertilizers were applied. The nitrogen concentration in soil increased with levels of mineral fertilizer and thus nodules didn't perform properly at high N concentration in soil, so at 20 t ha^{-1} biochar the condition was too much conducive for nodules to increase in number and performed well as suggested by several other researchers (Rondon *et al.*, 2007; Tagoe *et al.*, 2008; George *et al.*, 2012; Mia *et al.*, 2014).

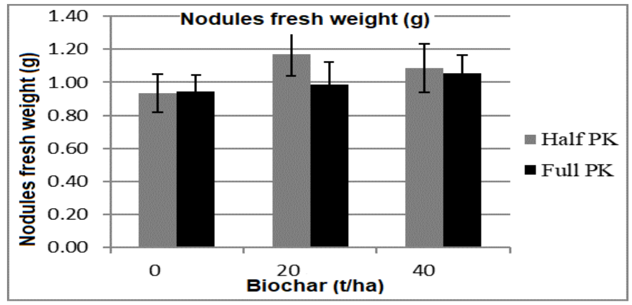

Figure 3b: Graphical representation of nodules fresh weight affected by different treatments of biochar

Table 3: Biochar effects on nodules number and there fresh and dry weight

Effect of PK	No. of Nodules	Fresh weight (g)	Dry weight (g)
½ PK	31.5 A	1.06 A	0.21 A
Full PK	31.5 A	0.09 A	0.21 A
Significance	**ns**	**ns**	**ns**
Effect of Biochar			
T_1 (0 t ha^{-1})	28 B	0.94 A	0.20 A
T_2 (20 t ha^{-1})	34 A	1.07 A	0.22 A
T_3 (40 t ha^{-1})	32 A	1.06 A	0.22 A
Significance	***	**ns**	**ns**
Interaction			
Biochar*PK	***	**ns**	**ns**

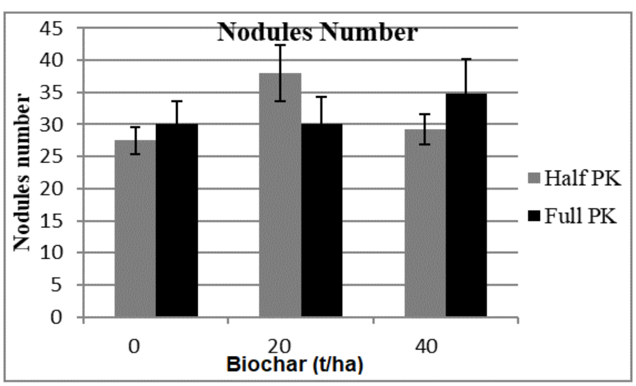

Figure 3a: Graphical representation of nodules number affected by different treatments of biochar

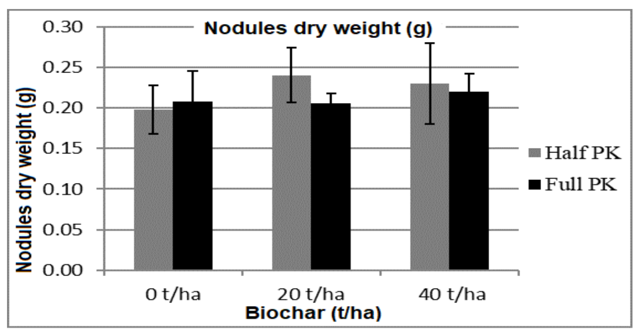

Figure 3c: Graphical representation of nodules dry weight affected by different treatments of biochar

Table 4: Biochar effects on plant total nitrogen %

Effect of PK	Total N %
½ PK	2.49 A
Full PK	2.42 A
Significance	**ns**
Effect of Biochar	
T_1 (0 t ha^{-1})	2.22 B
T_2 (20 t ha^{-1})	2.69 A
T_3 (40 t ha^{-1})	2.45 AB
Significance	***
Interaction	
Biochar*PK	*

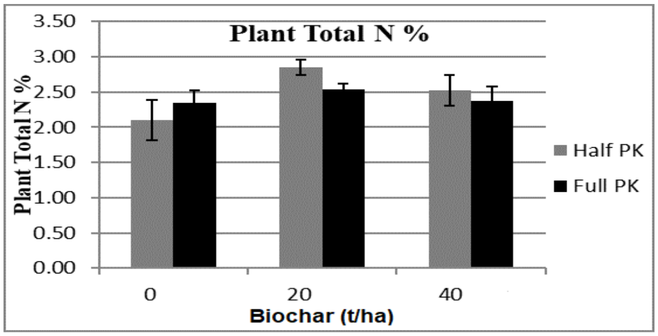

Figure 4: Graphical representation of plant total N affected by different treatments of biochar

In Table 4 and Figure 4, data for plant N revealed that with application of P and K either full or half didn't influence plant N concentration and both levels gave the same results i-e., (2.4%) however the levels of biochar significantly enhanced nitrogen concentration in plant as obvious from the Table 4. The highest plant N concentration was recorded at 20 t ha^{-1} biochar with the value of 2.69% which was 21% higher as compared to control. The interactive effect was also found significant on plant N concentration. The proper functioning of nodules guaranteed the optimum availability of nitrogen to plants and hence N content in plant was enhanced. Similar enhancement in plant N was recorded in a study performed by Widowati and Utomo (2014) and Malhotra *et al*. (2018) which confirm our present results.

Conclusion

In present research, most of the yielding parameters of mung-bean were found enhanced with biochar application along with mineral fertilizers i-e., P and K. Among the levels of biochar, the application of 20 t ha^{-1} was found superior in terms of increasing various yielding parameters like plant biomass, grain yield, nodulation and plant N uptake.

Recommendation

Keeping in view the above results for various yielding parameters of mung bean, the application of 20 t ha^{-1} biochar along with half P&K (45 kg P ha^{-1} and 30 kg K ha^{-1}) is recommended.

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