

***In vitro* availability of macro nutrients in various North Indian soils by application of biochar**

ABSTRACT

The use of organic amendments is popular these days therefore we conducted a study on biochar in various North Indian region soils under pot culture to evaluate the changes in soil characteristics. Four types of soils taken for 75 days during *Kharif* and *Rabi* season were studied, out of which Soil-1 is slightly acidic while Soil-2 to Soil-4 are alkaline. The soil samples were collected thrice at the interval of 25 days using standard procedures and analyzed for various macronutrients (pH, EC, OC, N, P, and K) essential for plants in the laboratory. The change in status of available NPK in soils and other soil properties like pH, electrical conductivity (EC), and organic carbon (OC) content due to inoculation of biochar was assessed. Results reveal that all treatments having biochar leads to an increase in the content of available N, P, and K together with OC. There recorded a slight elevation in EC initially at 25th DAI due to its inoculation. The pH during the initial period had reduced but later on rise as the number of DAI increased.

Key words: Electrical Conductivity (EC), Organic Carbon (OC), biochar, days after inoculation (DAI)

1. INTRODUCTION

Recent agricultural advent needs various organic products which can enhance productivity and provide sustainability to the farming system while yet cost-effective. Considering all these grounds in mind we had explored the historical products used by our ancestors for the betterment of agricultural production. Biochar is one of those products which for a long time had been used as a major component of the fertile *Terra Preta* i.e. dark earth, of the Amazon Basin. It can sequester large quantities of carbon in the soil for a long time thereby sustaining the productivity of ancient agroforestry of the Amazon vegetation.

Now the day's farmers are taking interest in using it as a source of long-term carbon which can sustain in crop fields. Biochar can be defined as a carbon enriched, fine-grained,

porous by-product of slow pyrolysis, it is formed when organic material (feedstock) is thermally decomposed at low to moderate temperatures during a long heating period under a limited supply of oxygen (Sohi et al., 2010). The feedstock for its preparation may have crop residues of any type, organic wastes, dairy manure, sewage, sludge, etc. First time in 2013 in Europe, the Swiss Federal Ministry of Agriculture approved the use of certified biochar for agriculture.

Generally, biochar can increase soil electrical conductivity by 124.6 % (Oguntunde et al. 2004). It can also increase the soil pH and organic carbon content of soils. The elements like K, Ca, Na, and Mg together with carbon, nitrogen, and hydrogen are generally found in biochar (Zhang et al. 2015). The amounts of the extractable nutrient elements in soil (e.g., Na, K, Ca, and Mg) could be increased after the application of biochar. These available nutrients can enhance soil chemical properties thereby increasing soil fertility.

The application of inorganic fertilizers in the soil, air and water pollution gets enhanced. These chemicals also possess a threat to human or livestock health and contaminate groundwater and the environment. Indian farmers mostly depend on these fertilizers to inculcate available nutrients (N, P, and K) into soils. The overuse of these chemical imbalances the organic carbon in agricultural land, destruct soil's physical characteristics, and accumulate toxic chemicals in water bodies. Therefore, there is a need among farmers, for organic source to supply available nutrients into the soil. Hence, impact of soil application of biochar, a promising organic amendment, on soil fertility parameters was assessed in present research work.

2. MATERIAL AND METHODS

2.1. Site Description and Soil Sampling

The *in vitro* pot analysis was done on four different soil samples in Department of Soil Science and Agricultural Chemistry, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut. The soil samples collected from various locations for analysis having their description in **Table 1**. Each pot was filled with half kilogram soil. The soils were then inoculated with biochar @ 1.25 g pot⁻¹. At the interval of 5 to 7 days according to the requirement of the pots watering was done up to 60% of maximum water holding capacity. During the experiment the soil samples were collected thrice from each experimental pot at the interval of 25 days (25, 50 and 75) during both the seasons (*Kharif* and *Rabi*) for year 2019-2020. The samples taken were cleaned by removing gravels and stones and then processed. The

samples were air dried and grinded with wooden roller, separately. Each sample was then passed through 2mm sieve. All the samples of the soil were stored in labeled polythene bags for conducting laboratory analysis.

Table 1: Description of various soil samples taken for analysis			
Sr. No.	Sample No.	Place of Collection of Soil sample	Rhizospheric soil
1.	Soil-1	Krishi Vigyan Kendra (KVK), Distt. Champawat (Uttarakhand)	Field
2.	Soil-2	Horticultural Research Centre, SVPUAT, Meerut (U.P.)	Field
3.	Soil-3	College of Agriculture, SVPUAT, Meerut (U.P.)	Field
4.	Soil-4	Krishi Vigyan Kendra (KVK), Bulandshar (U.P.)	Field

2.2. Material

The treatment material biochar used in this study is made up of sugarcane bagasse and rice residue at the temperature around 300° to 350°C, having pH 9.2, Electrical Conductivity (EC) 12.5 , Total Organic Carbon (TOC) 54.17%, Total Nitrogen 9234 ppm, Total Phosphorus 3190 ppm and Total Potassium 6542 ppm.

2.3. Chemical Analysis and Experimental Design

The analytical work was carried out in the laboratory of Department of Soil Science, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, (U.P) India for soil pH, EC, Organic Carbon and available macronutrients (N, P and K) by using standard protocols. The pH was determined with combined glass electrode pH meter in soil water suspension method (Jackson, 1973). Electrical conductivity was with the help of EC meter soil water suspension method (Jackson, 1973). Organic carbon determination was done by wet oxidation method by Walkely and Black, 1934. Available nitrogen analysis was done using oxidative

hydrolysis through alkaline permanganate (KMnO_4) as outlined by **Subbiah and Asija, (1956)**. The available phosphorus estimation for soils was done using Olsen's Reagent (**Olsen et al., 1954**) using Spectrophotometer. Finally, available K soil determination was done by neutral ammonium acetate extractant, (**Hanway and Heidel, 1952**) using Flame photometer.

Experimental design used for this study is Completely Randomized Design (CRD) because it is a pot culture experiment. Statistical Analysis was worked out using OPSTAT software.

3. RESULTS AND DISCUSSION

The analysis about the effect of biochar was done on four different location soils. The description about the initial soil properties can be observed in **Table 2**.

Sr. No.	Soil Parameters	Soil-1	Soil-2	Soil-3	Soil-4
1.	pH	5.60	7.13	7.45	7.23
2.	EC (dS m^{-1})	0.45	0.32	0.34	0.30
3.	Organic Carbon (g kg^{-1})	8.6	2.7	3.0	2.6
4.	Available N (kg ha^{-1})	224.35	197.01	190.65	195.14
5.	Available P (ppm)	9.5	9.15	8.24	8.94
6.	Available K (kg ha^{-1})	181.84	170.67	175.89	220.34

The initial parameter to be analyzed for any soil must be its pH because it tells about the type of soil chemical environment and possible reaction going on in the soil. The change in soil

pH values of biochar added soils (T_2) from the control T_1 during *Kharif* and *Rabi* season can be observed in **Table 3.1a and 3.1b**. In every season for each soil, there recorded significant increase in pH value due to biochar addition. Also, there is a significant increase in pH value recorded as the number of Days After Inoculation (DAI) increases. The highest increase in pH from T_1 to T_2 during *Kharif* season for Soil-1 to Soil-4 is 36.98%, 9.74%, 7.25% and 9.79%. During *Rabi* season percentage increase in pH for Soil-1 to Soil-4 is 36.23%, 10.81%, 8.22% and 13.33%. The decrease in exchangeable Al^{3+} and exchangeable acidity while increasing exchangeable base content due to addition of biochar leads to an increase in pH of soil samples (Zhao *et al.*, 2015). Chan *et al.*, 2007, Laird *et al.*, 2010, Abbruzzini *et al.*, 2017 and Bista *et al.*, 2019 reported a considerable increase in pH values (around 1 pH unit) by biochar inclusion. There recorded a decrease in pH of the soil at 25th DAI in T_2 samples is might be due to the production of organic acids (Panda *et al.*, 2017) during both seasons (*Kharif* and *Rabi*). The highest increase in pH during both seasons was recorded for Soil-1 which is acidic because of liming effect produced by biochar incorporation in that acid soil (Nguyen *et al.*, 2017).

Soil EC represents the amount of salts present in the soil. The change in EC during both crop seasons can be observed in **Table 3.2a and 3.2b**. The increase in EC was observed at 25th DAI for T_2 due to higher EC value of biochar. EC values increases significantly with the addition of biochar in all soils (Mukharjee *et al.*, 2020; Chintala *et al.*, 2013), it is due to the release of weakly bound nutrients (cations and anions) into the soil solution, which are available for plant uptake (Glaser *et al.* 2001; Gundale & DeLuca 2007; Chan *et al.* 2008).

Organic carbon (OC) is the most important parameter pertaining to soil health. It is the carbon component of Soil Organic Matter (SOM). The immobilization of OC till 25th DAI for biochar treatment T_2 was recorded then a decrease in OC content for each soil from 25th to 75th DAI takes place in each season. The maximum increase in SOC value of T_2 treatment from control during *Kharif* for Soil-1 is 14 g kg⁻¹, Soil-2 and Soil-3 is 8 g kg⁻¹, while for Soil-4 is 8.1 g kg⁻¹ respectively. In *Rabi* season the maximum increase in T_2 from control in Soil-1 is 13.2 g kg⁻¹, Soil-2 is 7.8 g kg⁻¹, Soil-3 is 7.9 g kg⁻¹ and Soil-4 is 8 g kg⁻¹ respectively. The changes occurred due to biochar inoculation on OC can be seen in **Table 3.3a and 3.3b**. Laird *et al.* (2010) elucidate that biochar amended soils significantly increased soil organic C content. Liu *et al.*, 2016 reported that the pot studies showed the highest increases in SOC response to biochar

amendment. Most of the studies confirmed that the biochar carbon recalcitrance enhances SOC storage in soils (Zhang *et al.*, 2015).

The out-turn of T₂ on soil available nitrogen (N) content during both the seasons is presented in Table 3.4a and 3.4b. The addition of biochar in T₂ leads to increase in value of available N in *Kharif* and *Rabi* from control at 75th DAI. The incremental values for *Kharif* from control in Soil-1 to Soil-4 is 14.80%, 15.44%, 12.56% and 7.60% respectively. The increased values during *Rabi* for N at 75th DAI for Soil-1 to Soil-4 is 9.54%, 11.82%, 10.84% and 4.86%. The rise in the content of N is because of the higher mineralization rate of biochar that happens due to readily decomposable organic carbon present into it (Luo *et al.*, 2011; Zimmerman *et al.*, 2011; Singh *et al.*, 2012) and also the priming effect on biochar within 90 days of its application into the soil that leads to higher N availability into soil (Luo *et al.*, 2011; Zimmerman *et al.*, 2011). The initial decrease in the value of N upto 25th DAI happened due to immobilization of N as biochar contains acid hydrolysable N (e.g. amino sugars, amino acids) which can be readily used by soil microbes (Bruun *et al.*, 2011; Zhang *et al.*, 2012). Khan *et al.*, 2019 reported the rise in content of N by the application of biochar in onion crop. The increased in nitrate nitrogen content is mainly due to increased transformation of NH⁴⁺ to NO³⁻ (Nelissen *et al.*, 2012) or due to enhanced activity of nitrifying bacteria in the soil (Kameyama *et al.*, 2012).

Available P content of the soils clearly represents the plant available form of phosphorus in soil. The significant increase in content of available P in T₂ for both the seasons at 25th DAI can be seen in Table 3.5a and 3.5b. The utmost increase in value for T₂ during *Kharif* season for soils (Soil-1 to Soil-4) is 24.12 ppm, 32.83 ppm, 34.13 ppm and 9.36 ppm. While for *Rabi* the maximum rise for soils (Soil-1 to Soil-4) is 22.98 ppm, 32.05 ppm, 32.75 ppm and 35.72 ppm. The increase in P due to soil biochar inoculation is also reported by Zhu *et al.*, 2014. Diversity of soils and variable environmental state promotes the available P content due to biochar application (Gao *et al.*, 2019). The increase in P availability also happens in acid soils due to application of high pH biochar which is rich in neutral metal oxides (Ca and Mg oxides) and it is due to its liming effect in soils (Steiner *et al.* 2007; Yuan *et al.* 2011). Various P species are found in biochar, out of which the soluble P form can be released into the soils that leads to increase in soil available P pool (Zhai *et al.*, 2015; Fei *et al.*, 2019; Troy *et al.*, 2014; Pratiwi

et al., 2016). Biochar is slow P discharging source which replenishes the soil reliably and continuously with liable P (Zheng et al., 2012; Qian et al., 2013; Yang et al., 2021) and also it has been proved that biochar also activates soil endogenous P.

The seasonal effect of biochar treatment T₂ on soil available potassium (K) content during *Kharif* and *Rabi* season is presented in Table 3.6a and 3.6b. In *Kharif*, addition of biochar in T₂ leads to increase in value of available K from control upto 75th DAI in Soil-1 to Soil-4 is 55.34%, 47.78%, 45.16% and 14.53%. In *Rabi* due to the addition of biochar in T₂ leads to increase in value of available K from control upto 75th DAI in Soil-1 to Soil-4 is 55.37%, 49.02%, 46.64% and 15.15% respectively. There are various reasons for increase in content of K in soils due to biochar addition. The biochar contain various carbonates and oxides of potassium which can be solubilized into soil solution therefore increases content of available K in soil (Gaskin et al. 2010; Glaser, Lehmann, and Zech 2002; Joseph et al. 2010; Abu Zied Amin, 2016). At the time of preparation of biochar the potassium ions don't volatilize in its burning process hence remains as free nutrient cation (Abu Zied Amin, 2016). Another reason may be increase in number of K solubilizing microbes and relative abundance of other bacteria, this also promotes solubilized K in soils (Xia, et al., 2022). The Potassium (K) in various organic residues like biochar exists in inorganic forms and after its application to soil it sets free the easily soluble and exchangeable fractions of K.

CONCLUSION

In modern agriculture, nutrient management is the most crucial factors affecting plant growth, yield, and quality performances. The results of this study represents that the application of organic fertilizer like biochar enhanced basic soil physicochemical properties as well as improve soil health. Additionally, the inoculation of this factor into acid soils is helpful in bringing pH to its neutral range that promotes the availability of major nutrients especially available P. The increase in organic carbon under all soils upgrades soil health and increases soil microbial reserve, therefore causes overall soil development. The other macro nutrients also display the positive growth in all soils and availability of all these nutrients got enhanced by inoculation of biochar factor into the soil. Overall biochar is useful because of its long residence time in soil which makes it a slow and constant supply source for soil nutrients. The research must be undertaken to discover more positive effects of biochar on soil nutrient properties.

Exploring more about this component can help us to slowly integrate organic more into our farming system and can prevent environmental problems posed due to inorganic fertilization.

REFERENCE

Abbruzzini TF, Moreira MZ, de Camargo PB, Conz RF, Cerri CE. Increasing rates of biochar application to soil induce stronger negative priming effect on soil organic carbon decomposition. *Agricultural Research*. 2017 Dec;6(4):389-98.

Abu Zied Amin AE. Impact of corn cob biochar on potassium status and wheat growth in a calcareous sandy soil. *Communications in Soil Science and Plant Analysis*. 2016 Sep 24;47(17):2026-33.

Bista P, Ghimire R, Machado S, Pritchett L. Biochar effects on soil properties and wheat biomass vary with fertility management. *Agronomy*. 2019 Oct 10;9(10):623.

Bruun EW, Müller-Stöver D, Ambus P, Hauggaard-Nielsen H. Application of biochar to soil and N₂O emissions: potential effects of blending fast-pyrolysis biochar with anaerobically digested slurry. *European Journal of Soil Science*. 2011 Aug;62(4):581-9.

Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S. Agronomic values of greenwaste biochar as a soil amendment. *Soil Research*. 2007 Dec 7;45(8):629-34.

Chintala R, Schumacher TE, McDonald LM, Clay DE, Malo DD, Papiernik SK, Clay SA, Julson JL. Phosphorus sorption and availability from biochars and soil/Biochar mixtures. *CLEAN–Soil, Air, Water*. 2014 May;42(5):626-34.

Fei YH, Zhao D, Cao Y, Huot H, Tang YT, Zhang H, Xiao T. Phosphorus Retention and Release by Sludge-Derived Hydrochar for Potential Use as a Soil Amendment. *Journal of Environmental Quality*. 2019 Mar;48(2):502-9.

Gao S, DeLuca TH, Cleveland CC. Biochar additions alter phosphorus and nitrogen availability in agricultural ecosystems: A meta-analysis. *Science of the Total Environment*. 2019 Mar 1;654:463-72.

Gaskin JW, Speir RA, Harris K, Das KC, Lee RD, Morris LA, Fisher DS. Effect of peanut hull and pine chip biochar on soil nutrients, corn nutrient status, and yield. *Agronomy journal*. 2010 Mar;102(2):623-33.

Glaser B, Haumaier L, Guggenberger G, Zech W. The 'Terra Preta' phenomenon: a model for sustainable agriculture in the humid tropics. *Naturwissenschaften*. 2001 Jan;88(1):37-41.

Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal—a review. *Biology and fertility of soils*. 2002 Jun;35(4):219-30.

Gundale MJ, DeLuca TH. Charcoal effects on soil solution chemistry and growth of *Koeleria macrantha* in the ponderosa pine/Douglas-fir ecosystem. *Biology and Fertility of soils*. 2007 Jan;43(3):303-11.

Hanway JJ, Heidel H. Soil analysis methods as used in Iowa state college soil testing laboratory. *Iowa agriculture*. 1952;57:1-31.

Jackson ML. Soil chemical analysis, pentice hall of India Pvt. Ltd., New Delhi, India. 1973;498:151-4.

Joseph SD, Camps-Arbestain M, Lin Y, Munroe P, Chia CH, Hook J, Van Zwieten L, Kimber S, Cowie A, Singh BP, Lehmann J. An investigation into the reactions of biochar in soil. *Soil Research*. 2010 Sep 28;48(7):501-15.

Kameyama K, Miyamoto T, Shiono T, Shinogi Y. Influence of sugarcane bagasse-derived biochar application on nitrate leaching in calcaric dark red soil. *Journal of environmental quality*. 2012 Jul;41(4):1131-7.

Laird DA, Fleming P, Davis DD, Horton R, Wang B, Karlen DL. Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. *Geoderma*. 2010 Sep 15;158(3-4):443-9.

Liu S, Zhang Y, Zong Y, Hu Z, Wu S, Zhou JI, Jin Y, Zou J. Response of soil carbon dioxide fluxes, soil organic carbon and microbial biomass carbon to biochar amendment: a meta-analysis. *Gcb Bioenergy*. 2016 Mar;8(2):392-406.

Luo Y, Durenkamp M, De Nobili M, Lin Q, Brookes PC. Short term soil priming effects and the mineralisation of biochar following its incorporation to soils of different pH. *Soil Biology and Biochemistry*. 2011 Nov 1;43(11):2304-14.

Mukherjee S, Mavi MS, Singh J, Singh BP. Rice-residue biochar influences phosphorus availability in soil with contrasting P status. *Archives of Agronomy and Soil Science*. 2020 May 11;66(6):778-91.

Nelissen V, Ruyschaert G, Manka'Abusi D, D'Hose T, De Beuf K, Al-Barri B, Cornelis W, Boeckx P. Impact of a woody biochar on properties of a sandy loam soil and spring barley during a two-year field experiment. *European Journal of Agronomy*. 2015 Jan 1;62:65-78.

Nguyen TT, Xu CY, Tahmasbian I, Che R, Xu Z, Zhou X, Wallace HM, Bai SH. Effects of biochar on soil available inorganic nitrogen: a review and meta-analysis. *Geoderma*. 2017 Feb 15;288:79-96.

Oguntunde PG, Fosu M, Ajayi AE, Van De Giesen N. Effects of charcoal production on maize yield, chemical properties and texture of soil. *Biology and Fertility of soils*. 2004 Mar;39(4):295-9.

Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *U.S. Department of Agriculture Circular*. 1954;939.

Panda A, Kumar A, Bajpai RK. Effect of organic resources and Subabul (*Leucaena leucocephala*) biochar on competitive ability of barley crop in acidic soil. *Journal of Pharmacognosy and Phytochemistry*. 2017;6(6):2430-2.

Pratiwi EP, Hillary AK, Fukuda T, Shinogi Y. The effects of rice husk char on ammonium, nitrate and phosphate retention and leaching in loamy soil. *Geoderma*. 2016 Sep 1;277:61-8.

Qian T, Zhang X, Hu J, Jiang H. Effects of environmental conditions on the release of phosphorus from biochar. *Chemosphere*. 2013 Nov 1;93(9):2069-75.

Singh BP, Cowie AL, Smernik RJ. Biochar carbon stability in a clayey soil as a function of feedstock and pyrolysis temperature. *Environmental science & technology*. 2012 Nov 6;46(21):11770-8.

Sohi SP, Krull E, Lopez-Capel E, Bol R. A review of biochar and its use and function in soil. *Advances in agronomy*. 2010 Jan 1;105:47-82.

Steiner C, Teixeira WG, Lehmann J, Nehls T, de Macêdo JL, Blum WE, Zech W. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and soil*. 2007 Feb;291(1):275-90.

Subbaiah VV, Asija GK. A rapid procedure for utilization of available nitrogen in soil. *Curr. Sci*. 1956;26:258-60.

Troy SM, Lawlor PG, O'Flynn CJ, Healy MG. The impact of biochar addition on nutrient leaching and soil properties from tillage soil amended with pig manure. *Water, Air, & Soil Pollution*. 2014 Mar;225(3):1-5.

Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science*. 1934 Jan 1;37(1):29-38.

Xia H, Riaz M, Zhang M, Liu B, Li Y, El-Desouki Z, Jiang C. Biochar-N fertilizer interaction increases N utilization efficiency by modifying soil C/N component under N fertilizer deep placement modes. *Chemosphere*. 2022 Jan 1;286:131594.

Yang L, Wu Y, Wang Y, An W, Jin J, Sun K, Wang X. Effects of biochar addition on the abundance, speciation, availability, and leaching loss of soil phosphorus. *Science of the Total Environment*. 2021 Mar 1;758:143657.

Yuan JH, Xu RK. The amelioration effects of low temperature biochar generated from nine crop residues on an acidic Ultisol. *Soil use and management*. 2011 Mar;27(1):110-5.

Zhai L, Cai Ji Z, Liu J, Wang H, Ren T, Gai X, Xi B, Liu H. Short-term effects of maize residue biochar on phosphorus availability in two soils with different phosphorus sorption capacities. *Biology and Fertility of Soils*. 2015 Jan;51(1):113-22.

Zhang A, Liu Y, Pan G, Hussain Q, Li L, Zheng J, Zhang X. Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China Plain. *Plant and soil*. 2012 Feb;351(1):263-75.

Zhang H, Voroney RP, Price GW. Effects of temperature and processing conditions on biochar chemical properties and their influence on soil C and N transformations. *Soil Biology and Biochemistry*. 2015 Apr 1;83:19-28.

Zhang J, Liu J, Liu R. Effects of pyrolysis temperature and heating time on biochar obtained from the pyrolysis of straw and lignosulfonate. *Bioresource Technology*. 2015 Jan 1;176:288-91.

Zhao R, Coles N, Kong Z, Wu J. Effects of aged and fresh biochars on soil acidity under different incubation conditions. *Soil and Tillage Research*. 2015 Mar 1;146:133-8.

Zheng H, Wang Z, Deng X, Zhao J, Luo Y, Novak J, Herbert S, Xing B. Characteristics and nutrient values of biochars produced from giant reed at different temperatures. *Bioresource Technology*. 2013 Feb 1;130:463-71.

Zimmerman AR, Gao B, Ahn MY. Positive and negative carbon mineralization priming effects among a variety of biochar-amended soils. *Soil biology and biochemistry*. 2011 Jun 1;43(6):1169-79.

Table 3.1a: Soil pH (*Kharif*)

Treatment Name	Trt. No.	Soil-1			Soil-2			Soil-3			Soil-4		
		25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days
Control	T₁	5.65	5.6	5.57	7.18	7.20	7.19	7.4	7.42	7.45	7.23	7.21	7.25
Soil + Biochar	T₂	7.41	7.57	7.63	7.70	7.79	7.89	7.84	7.90	7.99	7.78	7.89	7.96
CD		0.68	0.68	0.69	0.19	0.14	0.02	0.22	0.10	0.27	0.38	0.27	0.26
SEm±		0.17	0.17	0.17	0.05	0.04	0.01	0.06	0.03	0.07	0.09	0.07	0.06

Table 3.1b: Soil pH (*Rabi*)

Treatment Name	Trt. No.	Soil-1			Soil-2			Soil-3			Soil-4		
		25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days
Control	T₁	5.68	5.61	5.63	7.22	7.25	7.21	7.43	7.41	7.42	7.23	7.21	7.2
Soil + Biochar	T₂	7.44	7.59	7.67	7.82	7.93	7.99	7.89	7.99	8.03	7.99	8.02	8.16
CD		0.68	0.68	0.69	0.27	0.33	0.23	0.22	0.48	0.48	0.30	0.54	0.44
SEm±		0.17	0.17	0.17	0.07	0.08	0.06	0.05	0.12	0.12	0.07	0.13	0.11

Table 3.4a: Soil Available Nitrogen [kg ha⁻¹] (Kharif)

Treatment Name	Trt. No.	Soil-1			Soil-2			Soil-3			Soil-4		
		25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days
Control	T₁	224.68	226.48	225.65	195.73	196.70	199.63	192.27	190.03	191.11	193.06	195.36	196.08
Soil + Biochar	T₂	214.81	246.14	259.05	179.41	220.24	230.45	177.28	198.16	215.11	178.39	206.68	210.99
CD		8.46	10.69	25.21	8.12	21.73	22.36	7.44	3.29	21.16	11.54	10.54	6.38
SEm±		2.10	2.65	6.25	2.01	5.39	5.55	1.84	0.82	5.25	2.86	2.61	1.58

Table 3.4b: Soil Available Nitrogen [kg ha⁻¹] (Rabi)

Treatment Name	Trt. No.	Soil-1			Soil-2			Soil-3			Soil-4		
		25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days
Control	T₁	224.68	223.05	224.17	198.72	196.71	198.68	191.47	190.13	192.09	193.02	194.06	193.53
Soil + Biochar	T₂	215.89	242.44	245.56	180.34	215.48	222.17	178.85	195.17	212.92	179.57	199.75	202.93
CD		8.79	1.95	7.22	9.15	9.89	21.94	5.99	1.57	21.13	9.27	3.98	8.31
SEm±		2.18	0.48	1.79	2.27	2.45	5.44	1.49	0.39	5.24	2.30	0.99	2.06

Table 3.5a: Available P in *Kharif* season (ppm)

Treatment Name	Trt. No.	Soil-1			Soil-2			Soil-3			Soil-4		
		25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days
Control	T₁	9.55	9.51	9.54	9.13	9.16	9.18	8.45	8.43	8.40	9.36	9.31	9.35
Soil + Biochar	T₂	24.12	23.43	22.40	32.83	32.76	32.25	34.13	33.94	32.30	37	36.65	36.18
CD		1.73	1.77	1.66	2.27	2.34	2.19	2.34	2.34	2.23	2.56	2.54	2.51
SEm±		0.43	0.44	0.41	0.56	0.58	0.54	0.58	0.58	0.55	0.63	0.63	0.62

Table 3.5b: Available P in *Rabi* season (ppm)

Treatment Name	Trt. No.	Soil-1			Soil-2			Soil-3			Soil-4		
		25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days
Control	T₁	9.22	9.23	9.24	8.93	8.95	8.90	8.57	8.43	7.44	9.23	9.10	8.99
Soil + Biochar	T₂	22.98	22.74	21.99	32.05	31.99	31.84	32.75	32.22	28.44	35.72	35.22	34.79
CD		1.69	1.68	1.63	2.23	2.23	2.22	2.27	2.23	1.97	2.47	2.44	2.41
SEm±		0.42	0.42	0.41	0.55	0.55	0.55	0.56	0.55	0.49	0.61	0.61	0.60

Table 3.6a: Soil Available Potassium [kg ha⁻¹] (*Kharif*)

Treatment Name	Trt. No.	Soil-1			Soil-2			Soil-3			Soil-4		
		25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days
Control	T ₁	180.29	182.07	182.31	172.43	170.26	171.61	174.77	175.27	175.57	220.24	221.08	222.36
Soil + Biochar	T ₂	275.05	280.33	283.21	249.21	250.8	253.6	248.13	251.2	254.92	250.65	253.85	254.67
CD		23.47	23.76	23.94	21.69	21.65	21.86	21.77	21.94	22.15	24.51	24.70	24.83
SEm±		5.82	5.90	5.94	5.38	5.37	5.42	5.40	5.44	5.49	6.08	6.13	6.16

Table 3.6b: Soil Available Potassium [kg ha⁻¹] (*Rabi*)

Treatment Name	Trt. No.	Soil-1			Soil-2			Soil-3			Soil-4		
		25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days	25 days	50 days	75 days
Control	T ₁	180.4	181.21	182.07	170.61	168.76	169.32	174.27	173.38	172.66	219.08	220.42	219.51
Soil + Biochar	T ₂	275.43	280.01	282.88	248.67	251.2	252.17	249.47	252.61	253.19	249.17	251.23	252.76
CD		23.44	23.71	23.71	21.57	21.60	21.68	21.80	21.91	21.90	24.37	24.55	24.57
SEm±		5.81	5.88	5.88	5.35	5.36	5.38	5.41	5.43	5.43	6.05	6.09	6.09