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RESEARCH ARTICLE

EFFECT OF BIOCHAR ON NUTRITIONAL STATUS OF SOIL.

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Abstract

Biochar is the carbonaceous material produced by the pyrolysis of organic material (plant/animal) which can be used for long term storage of C and as soil conditioner. The steady decrease in fertility by continuous cultivation practices is compensated by the addition of fertilizers but decrease in SOC is a serious issue. Only biochar can slow or reverse this trend. Three types of biochar viz :- pine needle biochar, poultry biochar and bagasse biochar were prepared at 500ºC. The experimental study include 6 treatment : T1 - control, T2 - Pine needle biochar treatment, T3 - Poultry biochar treatment, T4 - Bagasse biochar treatment, T5 - Mixed biochar treatment and T6 - urea treatment. The effect of biochar on chemical properties were determined and it was found that biochar significantly increased the SOC, SOM, total N, available P, available K, exchangeable cations - Ca^{2+}, Mg^{2+} and Na^{+}. Micronutrients Fe and Mn increases while Zn decreases and Cu concentration was not significantly affected. The data was analyzed by applying Tukey HSD test of post hoc treatment in SPSS 16.00 Software package. Thus the study indicates that biochar can be used as a reclamation for acidic soil, increases nutrient retention, decreases need of chemical fertilizers and can be regarded as best environment friendly soil conditioner.

Introduction:-

The continuous cultivation practices of soil causes a steady decrease in the soil organic carbon (SOC) content and fertility. This steady decrease in fertility is compensated by addition of fertilizers but decrease in organic content is a more permanent problem. Low soil organic matter (SOM) content in soils resulting from high temperatures and rainfall are responsible for the low available water capacity and weak structure of many agricultural soils (Piccolo *et al*., 1996). In the past, organic amendments and polymers such as polyacrylamides (PAM) were used to improve soil physico-chemical properties and protect soils from erosion (Busscher *et al*., 2011). The depletion of SOM and high cost of PAM application are also serious problems to overcome. It is the need of hour to intensify agricultural crop production in order to feed current global population (Thornton *et al*., 2014). The field management, crop selection and solid fertilization practices will need to be modified in order to reduce crop production risks (Bozzola and Swanson, 2014; Smith *et al*., 2014; Wood *et al*., 2014). The soil nutrient pools need to become closed loop cycles simultaneously balancing source and sink of nutrients (Oktem, 2008). To cope up with above issues a new approach i.e. biochar is introduced in the agriculture field of science and technology. Biochar is the porous carbonaceous solid produced by thermo-chemical conversion of organic materials in an oxygen deficient atmosphere which has physico-chemical properties suitable for the safe and long term storage of carbon in the environment and potentially soil improvement (Shackley *et al*., 2010; Sohi *et al*., 2010). Biochar is commonly defined as charred organic matter produced with an intention of its application to soil for C- sequestration and for the improvement of soil properties (Lehmann and Joseph, 2009). At high temperature biochar usually becomes more alkaline as compared to lower temperature (Mukherjee *et al*., 2011). The ability of biochar to store carbon and improve fertility will depend on its physico-chemical properties which later depends on pyrolysis process and choice of feedstock (Lattao *et al*., 2014; Mašek *et al*., 2013; Zhao *et al*., 2013). The choice of feedstock varies from wood material, crop residue, switchgrass, organic waste, chicken litter to dairy manure, green waste and waste water sludge (Chan *et al*., 2008; Demirbas, 2004; Dias *et al*., 2010; Hossain *et al*., 2010; Ogawa and Okimori. 2010; Trompowsky *et al*., 2005; Yuan *et al*., 2011). Biochar physical and chemical properties influence the emergence and growth of crops in different ways (Rogovska *et al*., 2012; Solaiman *et al*., 2011). During conversion of biomass to biochar, about 50% of the original carbon is retained in the biochar which offers considerable opportunity for creating C sink (Lehmann, 2007). The recalcitrant nature of biochar suggests the presence of few components in biochar that would contribute to immobilization however biochar may adsorb organic molecules that have higher C:N from soil solution and increase mineralization (Gundale and Deluca, 2007). Biochar created from grasses and manures (including poultry litter) appear to possess higher nutrient contents than other feedstock. The observed effects on soil fertility have been explained mainly by a ph increase in acid soils (Van Zwieten *et al*., 2010a) or improved nutrient retention through cation adsorption (Liang *et al*., 2006). Biochar as a soil amendment can improve soil quality by increasing SOM, pH, CEC and holding nutrients in soil (Zheng *et al*., 2010). Increased retention of N with biochar addition is also observed (Ding *et al*., 2010; Laird *et al*., 2010; Lehmann *et al*., 2003; Major *et al*., 2009).

Methodology:-

Biochar Preparation:-

In this study four types of biochar were prepared - pine needle biochar, poultry biochar (made from chicken manure), bagasse biochar and mixed biochar. The mixed biochar was prepared from the combination of three feedstock in equal proportion- pine needle, chicken manure and sugarcane derived bagasse. The feedstock were grinded using a grinder. Later the samples were dried at 105ºC in an oven for 24 hours to remove surface moisture. The feedstock was then pyrolysed at 500ºC under the recommendation of Lehmann *et al*. (2003) in a muffle furnace. After pyrolysis the sample was cooled, crushed and sieved with 2mm mesh.

Soil Sampling:-

The soil used for experimental study was collected from Botanical Garden of Government Post Graduate College Rishikesh. The soil was collected 10-20cm below the top soil layer. The soil was air-dried for 24 hrs and then sieved through a 2 mm mesh to remove plant debris, stones and other unwanted matter prior to potting. 10% (w/w) biochar was applied according to big biochar experiment of IBI. The texture of soil was loamy sand. The chemical properties of soil used for experiment is given in table 1.

Description of experimental site:-

The study was conducted under natural conditions from june 2014 to october 2014 and june 2015 to october 2015 at botanical garden of Government P. G College Rishikesh geographically located in the foothils of the himalayas in northern india at 30.103368ºN 78.294754ºE having average elevation of 372 mts. According to Köppen- Geiger climatic classification system, its climate is humid subtropical.

Experimental Plot:-

The study was a two year study in consecutive years to confirm the results. After applying biochar to soil the plants were grown in soil and after four months when harvesting is done the untreated and biochar treated soils were subjected to chemical analysis there were total 6 treatments given below :-

T1 - Control.
T2 - Pine needle biochar treatment.
T3 - Poultry biochar treatment.
T4 - Bagasse biochar treatment.
T5 - Mixed biochar treatment.
T6 - Chemical fertilizer treatment i.e urea treatment.

Laboratory Analysis:-

The soil samples before biochar treatment and after biochar treatment were subjected to chemical analysis. The pH and EC was measured by using a pH meter and electrical conductivity meter in a 1.2.5 soil : water ratio. Soil organic carbon was determined by Walkey- Black method and total N by Kjeldahl method (Van Reewijk, 1992). O.M can be obtained by multiplying O.C by 1.72. The available potassium and available phosphorus was determined by ammonium acetate method(Hanway and Heidel, 1952**)** and olsen method (1954) respectively. The Na was determined using ammonium acetate method. The exchangeable cations Ca^{2+} and Mg^{2+} were determined using

EDTA titration method (Cheng and Bray, 1951) and Na^+ by Hanway and Heidel (1952). The micronutrients Fe, Mn, Zn and Cu were determined using DTPA micronutrient extraction method (Lindsay and Norvell, 1978). S was determined using Chensen and Yien (1951) method. CEC was determined at soil pH 7 after displacement by using 1N ammonium acetate method in which it was, thereafter estimated tetrimetrically by distillation of ammonium that was displaced by sodium (FAO, 1990; Rhoades and Polemio, 1977). Bicarbonate were determined by titration with H_2SO_4 while silver nitrate was used to determine chloride (Jackson, 1962). Chloride was analyzed by following the methodology of Jackson (1962).

Statistical analysis of data:-

One way analysis of variance (ANOVA) was performed to assess the significance difference in soil parameters between different treatments using the general linear model (GLM). For comparison of means in order to assess their performance regarding various treatments Tukey HSD test was applied at p= 0.05 using SPSS 16.00 software package.

Results and discussion:-

The chemical properties of soil used for experiment are given in Table-1. The effect of biochar on chemical properties of soil in 2014 are given in Table 2 (i) and 2(ii) and the effect of biochar on chemical properties of soil in 2015 are given in Table 3 (i) and 3(ii).

Table 1: Chemical properties of soil.

S.No	Parameter	Soil before experiment
1	pH	6.21 ± 0.70
2	EC (dsm^{-1})	0.48 ± 0.23
3	OC (%)	0.69 ± 0.04
4	OM (%)	1.2 ± 0.3
5	Total N (%)	0.06 ± 0.004
6	Available P (ppm)	3.7 ± 0.41
7	Available K (ppm)	83.35 ± 0.32
8	Ca^{2+} (ppm)	126.24 ± 1.82
9	Mg^{2+} (ppm)	63.10 ± 1.47
10	Na^+ (ppm)	54.21 ± 0.18
11	S (ppm)	78 ± 0.12
12	Fe (ppm)	1.35 ± 0.2
13	Zn (ppm)	1.72 ± 0.43
14	Mn (ppm)	0.49 ± 0.08
15	Cu (ppm)	0.77 ± 0.54
16	HCO^{3-} (ppm)	341 ± 0.5
17	Cl^- (ppm)	275 ± 0.14
18	CEC (Cmol/Kg)	0.31 ± 0.1

Table 2 (i): Effect of biochar incorporation on chemical properties of soil levelled by tukey's HSD test of post-hoc treatment analyzed by SPSS 16.00 software package.

Treatment	pH	EC (dsm^{-1})	O.C (%)	O.M (%)	Total N (%)	Available P (ppm)	Available K (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)
T1	6.47^a	0.51^a	0.74^a	1.30^a	0.64^a	3.60^a	80.77^a	128.21^a	61.67^a
T2	7.83^c	0.59^{bc}	2.24^e	3.84^e	0.19^f	8.90^b	406.00^d	135.11^{bc}	88.25^b
T3	8.23^d	0.63^c	1.73^d	2.98^c	0.15^d	67.77^e	719.67^f	141.62^c	104.67^c
T4	7.87^c	0.57^{bc}	1.57^c	2.67^b	0.13^c	15.3^c	267.33^c	139.57^{bc}	101.11^c
T5	7.85^c	0.58^{bc}	1.74^d	3.16^d	0.16^e	43.5^d	593.53^e	137.65^{bc}	96.34^{bc}
T6	7.17^b	0.53^b	0.83^b	1.43^a	0.74^b	9.33^b	122.00^b	131.71^{bc}	70.21^a

*Figures with same alphabets are statistically at par.

Table 2 (ii): Effect of biochar incorporation on chemical properties of soil levelled by tukey's HSD test of post-hoc treatment analyzed by SPSS 16.00 software package.

Treatment	Na (ppm)	S (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)	HCO^{3-} (ppm)	Cl^- (ppm)	CEC (Cmol/Kg)
T1	51.33^a	89.00^a	1.36^a	1.75^a	0.51^a	0.83^a	346.87^a	280.00^a	0.33^a
T2	54.85^{ab}	94.12^a	2.01^c	0.88^a	0.56^a	0.94^a	351.77^a	315.00^c	1.14^d
T3	70.67^d	98.33^a	3.02^f	1.46^a	0.68^a	0.76^a	415.67^c	332.15^d	1.51^f
T4	57.33^{bc}	117.08^b	2.27^e	1.25^a	0.65^a	$0.^{69a}$	421.67^c	365.00^e	1.28^e
T5	61.45^c	110.15^b	2.17^d	1.74^a	0.66^a	0.71^a	389.20^b	329.12^d	0.83^c
T6	52.00^{ab}	91.14^a	1.74^b	1.52^a	0.59^a	0.84^a	352.63^a	302.40^b	0.42^b

* Figures with same alphabets are statistically at par.

Table 3 (i): Effect of biochar incorporation on chemical properties of soil levelled by tukey's HSD test of post-hoc treatment analyzed by SPSS 16.00 software package.

Treatment	pH	EC (dsm^{-1})	O.C (%)	O.M (%)	Total N (%)	Available P (ppm)	Available K (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)
T1	6.67^a	0.51^a	0.80^a	1.37^a	0.06^a	3.67^a	81.30^a	131.33^a	61.33^a
T2	7.86^c	0.60^{bc}	2.24^d	3.84^d	0.19^f	8.73^b	406.33^d	138.22^{bc}	85.12^c
T3	8.17^d	0.63^c	1.74^c	2.89^{bc}	0.15^d	66.67^e	735.67^f	144.00^d	98.33^d
T4	7.95^{cd}	0.62^{bc}	1.55^b	2.69^b	0.13^c	14.63^c	266.33^c	139.62^{cd}	95.25^d
T5	7.88^c	0.61^{bc}	1.77^c	3.13^c	0.16^e	44.27^d	594.97^e	135.6^{abc}	97.10^d
T6	7.17^b	0.56^{ab}	0.87^a	1.53^a	0.07^b	9.37^b	120.73^b	133.67^{ab}	70.67^b

*Figures with same alphabets are statistically at par.

Table 3 (ii): Effect of biochar incorporation on chemical properties of soil levelled by tukey's HSD test of post-hoc treatment analyzed by SPSS 16.00 software package.

TREATMENT	Na (ppm)	S (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)	HCO^{3-} (ppm)	Cl^- (ppm)	CEC (Cmol/Kg)
T1	52.33^a	99.15^a	1.37^a	1.83^b	0.59^a	0.91^a	360.70^a	220.67^a	0.50^a
T2	55.23^a	108.92^b	1.92^{bc}	0.85^a	0.68^{bc}	0.76^a	376.33^b	249.00^b	1.13^d
T3	72.33^c	110.20^{bc}	2.92^d	1.78^b	0.71^c	0.69^a	418.00^d	315.33^c	1.42^f
T4	56.33^a	119.60^c	2.23^c	1.13^a	0.65^{ab}	0.77^a	422.33^d	340.00^d	1.28^e
T5	63.37^b	105.06^{ab}	2.17^c	1.75^b	0.67^{bc}	0.57^a	392.00^c	329.00^{cd}	0.86^c
T6	54.33^a	101.16^{ab}	1.63^{ab}	1.61^b	0.62^{ab}	0.82^a	363.70^a	225.00^a	0.65^b

* Figures with same alphabets are statistically at par.

From the perusal of Table-2(i), 2(ii), 3(i) and 3(ii), it is concluded that application of biochar of different origin showed highly significant results on chemical properties of soil. The results of present study including the effect of biochar on nutritional status of biochar are discussed in the following paragraphs:

Effect of biochar application on pH and EC of soil:-

The effect of biochar application on pH and EC of soil are given in Table-2(i) for 2014 and Table-3(i) for 2015. The statistical analysis revealed a significant increase in pH and EC in biochar amended soil. The highest pH was found in poultry biochar followed by pine needle biochar, bagasse biochar and mixed biochar treated soils. The study of Suppadit *et al*. (2012) also found an increase in pH and EC. An increase in soil pH by increasing biochar application rate might be due to the presence of alkali elements (Ca, Mg and Na) and the presence of -OH ions in biochar (Danish *et al*., 2015). An increase in soil pH following biochar application is frequently reported for across many soil types (Glaser *et al*., 2002; Ameloot *et al*., 2013a; Farrell *et al*., 2013; Masto *et al*., 2013; Stewart *et al*., 2013; Chintala *et al*., 2014b; Xu *et al*., 2014). The results therefore, indicate that biochar could be used as a substitution for lime materials to increase the pH of acidic soils. Similar increase in pH and EC was found by Bhattarai *et al*. (2015).

According to Novak *et al*. (2009) presence of -OH ions in the biochar enhanced its pH and ultimately the soil in which biochar is applied (Bilgic and Caliskin, 2001). Yuan and Xu. (2011) also noted similar type of results on the soil pH when they applied the biochar in their experiment as soil amendment.

Effect of biochar on Soil Organic Carbon (SOC) and Soil Organic Matter (SOM):-
Application of biochar increases SOC significantly. The value of SOC is higher in biochar amended soil than control. In T6 treatment where urea is applied there is no increase in SOC. The high value of O.C in biochar amended soil indicate the recalcitrance of organic C in biochar. SOM follows the similar trend. High O.C in biochar amended soil samples have been reported by Lehmann. Solomon *et al*. (2007) and Liang *et al*. (2006) also revealed the higher O.C and total N at the ancient terra preta compared with adjacent soils. Biochar application increases SOC (Chen *et al*., 2008; Novak *et al*., 2009; Van Zwieten *et al*., 2010).

Effect of biochar on total N:-
The biochar treatments of different origin significantly increases the total N. The biochar application can increase N availability to crops (Chan *et al*., 2008) and therefore high levels of SOC accumulation can enhance N efficiency and increase crop production (Liang *et al*., 2006; Pan *et al*., 2009). Study of Ghoneim *et al*. (2012) also showed an increase in total N.

Effect of biochar on available P and available K:-
The available P and available increases significantly and found higher in poultry biochar treatment. The study of Masulili in 2010 suggested that biochar increases the available P in soils as biochar increases the soil pH, which makes immobile phosphorus available. Poultry manure greatly increases the potassium content of the soil as compared to biochar (Bhattarai *et al*., 2015) and significant increase in exchangeable potassium was recorded by biochar application.

Effect of biochar on exchangeable cations (Ca^{2+}, Mg^{2+} and Na^{+}) and CEC:-
The biochar application significantly increased exchangeable cations (Ca^{2+}, Mg^{2+} and Na^{+}) and CEC. According to Lima and Marshall (2005) the release of Ca, K, Mg and Na ions by biochar increases the EC of soil. They argued that biochar releases these ions in soil solution through ion exchange mechanism (Tyron, 1948). Joseph *et al*. (2010) found that when the volatile matter is removed from the biochar then the rest biomass of biochar contains a sufficient amount of Ca, Mg and inorganic ions in it that become the part of ash contents. Novotny *et al*. (2009) also reported that terra preta soils, which are previously amended by biochar, have higher Ca and Mg contents as compared to the non biochar amended soils. Shenbagavalli and Mahimairaja (2012) reported the presence of Ca and Mg ions in the biochar at sufficient levels that can make biochar a liming agent. According to Amonette and Joseph (2009) Biochar contains significant proportion of Ca, Mg and Na that become the part of soil solution through ion exchange mechanism. Biochar has high surface area, highly porous, variable charge organic material that has the potential to increase soil CEC, surface sorption capacity and base saturation when added to soil (Glasser *et al*., 2002). Because pH increases are related to CEC increases, this benefit can be interrelated to biochars effect on soil pH. Plants which are cultivated in biochar treated soils response better in growth through modifications in soil CEC and nutrients retention (Peng *et al*., 2011).

effect of biochar on micronutrients (Fe, Zn, Mn and Cu):-
Iron and Manganese are associated and largely retained during biochar formation (Amonette and Joseph, 2009). Biochar application increases Fe and Mn while Zn decreases and Cu was not significantly affected. The study carried out by Gaskin *et al*. (2008) suggested that poultry litter biochar had highest amount of Fe where as pine chip biochar has significantly lower Fe. The study conducted by Novak *et al*. (2009) showed that extractable Zn marginally decreases with an increase in the addition of biochar concentration. This demonstrates that the biochar has a high sorption capacity for Zn where as Cu concentration was not significantly affected by biochar addition.

Effect of biochar on Bicarbonate and Chloride ions:-
The effect of biochar on HCO^{3-} and Cl^{-} was significantly higher. According to Yuan *et al* .(2011) the alkaline nature of biochar is developed when the Na, Ca and Mg ions in biochar react with anions. These ions developed liming ability in biochar and make it preferable amendment for soil reclamation. Similar types of results were also note by Novak *et al*., 2009. Chintala *et al*. (2013) noted that Ponderosa pine wood residues biochar had higher bicarbonate

ions that play a vital role in the extraction of soil phosphorus. Similar increase in anions was reported by Danish *et al*. (2015).

Conclusion:-

From the present study it is clear that biochar significantly improved the chemical properties of soil like pH, EC, O.C, O.M, N, P, K. Biochar is more stable than compost and it has a higher capacity to hold nutrients. The chemical fertilizer i.e. urea also improved soil chemical properties but it does not fulfill the aim of C-sequestration and deteriorates the soil health. Biochar can also be suggested for the reclamation of acidic soil and can be incorporate in sandy soil for improving the quality i.e., biochar reduces the acidity of soil which improves the ability of plant to adsorb most nutrients. The bicarbonate ions play major role in phosphorus extraction as well as Ca^{2+} and Mg^{2+} precipitations in soil. The long term effect of biochar on chemical properties of soil need further extensive research to identify the most cost effective and environment friendly management practice for improving soil fertility and enhancing crop production.

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