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Effect of biochar on physico-chemical properties of acidic soil

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Abstract

A field experiment was conducted at farmer's field in Byrasandra village of Shidlaghatta, Chikkaballapura to study the effect of biochar on chemical properties in acidic soil during *Kharif* 2017. The field trial included seven treatments with three replications. The results revealed that application of Recommended dose of fertilizers + 125 per cent of biochar equivalent of carbon in FYM recorded higher primary, secondary and micronutrient status in soil and increased pH, EC, organic carbon and significantly decreased Exchangeable Al. The study clearly showed that in acidic soils, application of Recommended dose of fertilizers + 125 per cent of biochar equivalent of FYM is more beneficial in reducing soil acidity and bulk density.

Keywords: acidic soil, pH, EC, exchangeable Al, biochar, FYM

Introduction

The world's population is continuously rising and the current projections indicate that the population is likely to increase from 6.9 billion people at present to 9.1 billion by 2050. As a result world food demand will surge and it is projected that food production will increase by 70 per cent in the world and 100 per cent in the developing countries. But intensive cultivation and application of ammonical fertilizers, causing soil acidity and degradation. Soil acidity is a condition where Hydrogen (H^+) and aluminum (Al^{3+}) ion are dominance in the soil exchangeable complex causes acidity which limits crop yield. Soil acidity is particularly prevalent in the humid tropics and subtropics. Out of 328 m ha of geographical area of India, nearly 145m ha is cultivated and a rough estimate indicated that 48 m ha of soil is acidic in nature of which 25 m ha shows pH below 5.5, while about 23 m ha has pH between 5.6 and 6.5. Out of the 19.2 m ha of geographical area in Karnataka, nearly 9.6 m ha (50 per cent of the total area) is acidic in nature. Ananthanarayana (1996) [1] reported that in Karnataka, acid soils are spread in the districts of Dakshina Kannada (72%), Uttara Kannada (65%), Kodagu (40%), Chickmagalur (39%), Shimoga (33%), Hassan (20%), Mysore (15%), Mandya (12%), Bangalore (10%) and Belgaum (10%).

In the recent years, the environmentalists and agricultural scientists have realized that continued and unbalanced use of fertilizers led to degradation of soil health there by it causes environmental pollution and affect the soil biological activity. Thus, increasing awareness is being created on the use of biochar and organic resources to sustain the soil fertility and productivity.

Biochar is a carbon rich source, fine-grained and highly porous substance used as an amendment in acid soil. Because biochar could be attributed to high surface area that increases the cation exchange capacity (CEC) of the soil. It is alkalinity in nature and have the presence of high exchangeable bases. Yuan *et al.* (2011) [26, 27] revealed that alkalinity of biochar was a key factor affecting their liming potential, and the greater alkalinity of biochars led to greater reductions in soil acidity. The incorporation of biochars decreased soil exchangeable acidity and increased soil exchangeable base cations and base saturation, thus improving soil fertility. As the soil pH increases, the soluble and exchangeable Al^{3+} precipitates as insoluble hydroxyl Al-species (Ritchie 1994) [21]. Apart from the increase in soil pH, the incorporation of biochars can release their base cations into the acidic soil which can participate in exchange reactions and replace the exchangeable Al^{3+} and H^+ on the soil surface and decrease the soil exchangeable acidity (Warnock *et al.*, 2007, Chan *et al.*, 2008; Yuan *et al.*, 2011) [25, 4, 26, 27].

The thermal conversion of biomass (pyrolysis) in a low or no oxygen environment produces high carbonaceous biochar material or charcoal with unique characteristics (Gaskin *et al.* 2008)^[7].

The biochar has been found to have a great impact on soil fertility and increase in crop yield without causing any deleterious hazards on soil. The objective of this study was to evaluate the effect of biochar on selected chemical properties of acidic soil such as soil pH, EC, exchangeable Al and nutrient status.

Material and methods

The study was conducted during *kharif* season 2017 at farmers field in Byrasandra village of Chikkaballapura district located at Eastern Dry Zone of Karnataka. During crop growth period, a total rainfall of 358.2 mm was received from September to December. Maximum temperature ranged from 27.2 °C to 34.5 °C and minimum temperature ranged from 19.0 °C to 20.5 °C. The experiment was laid out in a randomized complete block design (RCBD) with seven treatment combination replicated thrice. The treatments were T₁: NPK + ZnSO₄ alone, T₂: NPK + ZnSO₄ + FYM (POP), T₃: NPK + ZnSO₄ + 25% of biochar equivalent of FYM, T₄: NPK + ZnSO₄ + 50% of biochar equivalent of FYM, T₅: NPK + ZnSO₄ + 75% of biochar equivalent of FYM, T₆: NPK + ZnSO₄ + 100% of biochar equivalent of FYM, T₇: NPK + ZnSO₄ + 125% of biochar equivalent of FYM. The recommended dose of fertilizers were applied at 100, 50, 50 and 20 kg of N, P₂O₅, K₂O and ZnSO₄ per hectares, respectively and farmyard manure was applied at 10 tons per hectares. The application of Biochar was based on the carbon equivalent of FYM.

The representative biochar sample was obtained from locally available wood biochar (*Prosopis juliflora*). The wood biochar was ground to pass through 2 mm sieve and analyzed for different physical and chemical parameters and results are presented in Table 1. The initial physical and chemical properties of experimental site were analyzed and are represented in Table 2. The soil of the experimental site was acidic in soil reaction (pH of 5.46) with organic carbon content of 5.30 g kg⁻¹ and exchangeable Al 1.19 cmol (p⁺) kg⁻¹. The available nutrient status of soil were low in available N (250.84 kg ha⁻¹), medium in available P₂O₅ (26.32 kg ha⁻¹) and medium in available K₂O (174.13 kg ha⁻¹) status.

Soil samples collected from each plot were air dried, passed through 2 mm sized sieve and analyzed for physical and chemical properties by adopting standard chemical analytical methods. Soil pH was determined by method potentiometry (Jackson, 1973)^[15], Electrical conductivity (dS m⁻¹) was determined by method conductometry (Jackson, 1973)^[15], Organic carbon (g kg⁻¹) by wet oxidation method (Walkley and Black, 1934) Exchangeable Al (cmol (p⁺) kg⁻¹) was determined by the method (Yuan, 1959)^[28], and Micronutrients were determined by DTPA extraction method (Lindsay and Norvell, 1978)^[19].

Statistical analysis: Experimental data obtained were subjected to statistical analysis adopting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984)^[10]. The level of significance used in 'F' test was given at 5 per cent. Critical difference (CD) values are given in the Table at 5 per cent level of significance, wherever the 'F' test was found significant at 5 per cent level

Results and discussion

Effect of biochar on physical properties of acidic soil

Bulk density

The data pertaining to effect of biochar application on bulk density of soil is presented in Table 3. The bulk density (1.40 Mg m⁻³) of soil was significantly recorded higher in T₁ which received 100 per cent NPK + ZnSO₄ without the application of biochar. While significantly lower BD (1.28 Mg m⁻³) was observed in the treatment T₇ which received 100 per cent NPK + ZnSO₄ + 125 % of biochar equivalent of FYM followed by T₆ (1.31 Mg m⁻³) and T₅ (1.35 Mg m⁻³) received 100 per cent NPK + ZnSO₄ + 100 per cent of biochar equivalent of FYM and 100 per cent NPK + ZnSO₄ + 75 per cent of biochar equivalent of FYM, respectively.

Table 1: Physical and chemical characteristics of Biochar

P[-Parameters	Value
pH	10.12
EC (dS m ⁻¹)	2.92
Maximum water holding capacity (%)	62
Bulk density (Mg m ⁻³)	0.48
Total carbon (%)	74.50
Nitrogen (%)	0.24
Phosphorus (%)	0.13
Potassium (%)	1.38
Calcium (%)	2.32
Magnesium (%)	0.46
Sulphur (%)	0.08
Iron (ppm)	432.60
Manganese (ppm)	514.27
Zinc (ppm)	22.80
Copper (ppm)	33.20

Table 2: Initial physico-chemical properties of the soil of the experimental site

Parameters	Value
Sand (%)	61.55
Silt (%)	21.5
Clay (%)	16.8
Textural class	Sandy loam
Bulk density (g cc ⁻¹)	1.41
Maximum water holding capacity (%)	34
Soil pH	5.46
Electrical conductivity (dS m ⁻¹)	0.098
Organic carbon (g kg ⁻¹)	5.30
Available N (kg ha ⁻¹)	250.84
Available P ₂ O ₅ (kg ha ⁻¹)	26.32
Available K ₂ O (kg ha ⁻¹)	174.13
Available S (ppm)	15.82
Exchangeable Ca (cmol (p+) kg ⁻¹)	2.24
Exchangeable Mg (cmol (p+) kg ⁻¹)	1.78
DTPA Zn (ppm)	1.50
DTPA Fe (ppm)	12.18
DTPA Cu (ppm)	0.84
DTPA Mn (ppm)	30.94
Available B (ppm)	0.38
Exchangeable Al (cmol (p+) kg ⁻¹)	1.19

Maximum water holding capacity

The data pertaining to effect of varied levels of biochar application on maximum water holding capacity of soil is presented in Table 3. The application of 100 per cent NPK + ZnSO₄ + 125 per cent of biochar equivalent of FYM recorded

significantly maximum water holding capacity (42.23 %) in soil followed by application of 100 per cent NPK + ZnSO₄ + 100 per cent of biochar equivalent of FYM (40.50 %). The lower water holding capacity of soil (34.07 %) was observed in the treatment that received 100 per cent NPK + ZnSO₄ (control).

The physical properties of soil viz., bulk density and maximum water holding capacity were significantly influenced by biochar application. Among the different treatments, the treatment which received 100 per cent NPK + ZnSO₄ + 125 per cent of biochar equivalent of FYM recorded lower bulk density and maximum water holding capacity over the rest of the treatments. This could be attributed to total

carbon content in the biochar which acts as cementing materials in forming stable soil aggregates. It has been reported that the porous structure of biochar can influence its impact on soil water holding capacity and adsorption capacity (Ogawa and okiomori 2010) [20]. Similar results were reported by Emmanuel *et al.* (2010) [6] and Gundale and DeLuca (2006) [11]. Hseu *et al.* (2014) [14] stated that biochar application reduced the bulk density by 12 to 25 per cent and the penetration resistance by 57 to 92 per cent after incubation, of compared with the control. Besides, porosity and aggregate size increased by 16 to 22 per cent and by 0.59 to 0.94 mm, respectively.

Table 3: Effect of biochar application on bulk density (BD) and maximum water holding capacity (MWHC) of post harvested soil in finger millet under the field condition

Treatment details	BD (g cc ⁻¹)	MWHC (%)
T ₁ : NPK + ZnSO ₄ alone	1.40	34.07
T ₂ : NPK + ZnSO ₄ + FYM (POP)	1.33	38.41
T ₃ : NPK + ZnSO ₄ + 25% of biochar equivalent of FYM	1.39	35.62
T ₄ : NPK + ZnSO ₄ + 50% of biochar equivalent of FYM	1.37	35.12
T ₅ : NPK + ZnSO ₄ + 75% of biochar equivalent of FYM	1.35	36.75
T ₆ : NPK + ZnSO ₄ + 100% of biochar equivalent of FYM	1.31	40.50
T ₇ : NPK + ZnSO ₄ + 125% of biochar equivalent of FYM	1.28	42.23
S.E.M±	0.01	0.24
CD@ (5%)	0.02	0.75

Effect of biochar on chemical parameters of acidic soil Soil pH

The data in Table 4 revealed that there was significant difference among different treatments with respect to soil pH after harvest of finger millet crop. The soil pH (6.44) was significantly increased by application of 100 per cent RDF + ZnSO₄ + 125 per cent of biochar equivalent of FYM as compared to application of 100 per cent NPK + ZnSO₄ + FYM. The lowest soil pH was recorded in the plot which received chemical fertilizers alone in treatment T₂.

The increase in pH of soil over control is due to application of biochar could be attributed to high surface area that increases the cation exchange capacity (CEC) of the soil. It is also due to alkalinity nature of biochar and the presence of high exchangeable bases. Similar results were noticed by Chintala *et al.* (2014) [5], Anteneh *et al.* (2014) [2], Hass *et al.* (2012) [13] and Yuan *et al.* (2011) [26, 27].

Electrical conductivity (EC)

The data on electrical conductivity (EC) in Table 4 showed that there was significant difference among the different treatments with respect to soil EC after harvest of finger millet. The EC (0.19 dS m⁻¹) was significantly higher in treatment imposed of 100 per cent NPK + ZnSO₄ + 125 per cent of biochar equivalent of FYM as compared to control which received 100 percent NPK + ZnSO₄ alone (0.10 dS m⁻¹

¹). Further, there was a gradual increase in EC with increasing levels of biochar. It might be due to the salt concentration and exchangeable cations in wood biochar which can increase the EC of soil. Significant increase in EC with varied levels of biochar application was also reported by Chintala *et al.* (2014) [5], Glaser *et al.* (2000) [8], Gundale and De luca (2007) and Chan *et al.* (2008) [4].

Soil organic carbon

The organic carbon content of soil after harvest of finger millet ranged from 5.40 to 6.40 g kg⁻¹ (Table 4). Numerically higher organic carbon (6.40 g kg⁻¹) was recorded in the plot which received 100 per cent NPK + ZnSO₄ + 125 per cent of biochar equivalent of FYM as compared to plot which received 100 per cent NPK + ZnSO₄ + FYM (5.80 g kg⁻¹). The lower value was recorded in plot which received only 100 per cent NPK + ZnSO₄ alone (5.40 g kg⁻¹).

Application of biochar along with chemical fertilizers increased the organic carbon content in soil as compared to application of chemical fertilizers alone. It may be due to rich source of carbon which contributed higher carbon content in the soil. Similar findings of high organic carbon in soils with the application of biochar also reported by Lehmann (2007b) [17] and Solomon *et al.* (2007), Hass *et al.* (2012) [13], Anteneh *et al.* (2014) [2] and Warnock *et al.* (2007) [25].

Table 4: Effect of biochar application on pH, EC and organic carbon status of post harvested soil in finger millet under the field condition

Treatment details	pH	EC (dS m ⁻¹)	OC (g kg ⁻¹)	Exchangeable Al (cmol (p+) kg ⁻¹)
T ₁ : NPK + ZnSO ₄ alone	5.47	0.10	5.40	1.20
T ₂ : NPK + ZnSO ₄ + FYM (POP)	5.33	0.13	5.80	1.16
T ₃ : NPK + ZnSO ₄ + 25% of biochar equivalent of FYM	5.57	0.11	5.50	1.10
T ₄ : NPK + ZnSO ₄ + 50% of biochar equivalent of FYM	5.69	0.14	5.67	1.09
T ₅ : NPK + ZnSO ₄ + 75% of biochar equivalent of FYM	6.12	0.15	5.97	1.00
T ₆ : NPK + ZnSO ₄ + 100% of biochar equivalent of FYM	6.36	0.18	6.20	0.98
T ₇ : NPK + ZnSO ₄ + 125% of biochar equivalent of FYM	6.44	0.19	6.40	0.96
S.E.M±	0.08	0.01	0.06	0.01
CD@ (5%)	0.26	0.02	0.19	0.02

Exchangeable aluminum

The results indicated in table 4 showed that there was significant decrease in exchangeable aluminum in biochar plots compared. Among the treatments, the lowest exchangeable aluminum of $0.96 \text{ cmol (p}^+) \text{ kg}^{-1}$ was recorded in the plot treated with 100 per cent recommended inorganic fertilizers + ZnSO_4 + 125% of biochar equivalent of FYM. It may be due to the contribution of exchangeable basic cations of soil which improved the base saturation and thus improved soil acidity. Yuan and Xu. (2011)^[26, 27] revealed that greater alkalinity of biochar led to greater reductions in soil acidity and aluminum toxicity.

DTPA extractable iron

The iron content of post harvest soil did not show any significant difference due to different levels of biochar application. However, the numerically lower value of Fe (7.91 mg kg^{-1}) was observed in T_7 received 100 per cent NPK + ZnSO_4 + 125 per cent of biochar equivalent of FYM, followed by T_5 (8.06 mg kg^{-1}) and T_6 (8.04 mg kg^{-1}) received 100 per cent NPK + ZnSO_4 + 75 per cent of biochar equivalent of FYM and 100 per cent NPK + ZnSO_4 + 100 per cent of biochar equivalent of FYM. The highest value of Fe

(12.65 mg kg^{-1}) was found in control which received 100 per cent of NPK + ZnSO_4 alone (T_1).

DTPA extractable manganese

The manganese content of post harvest soil did not differ significantly due to application of varied levels of biochar (Table 5). The higher value of Mn (32.02 mg kg^{-1}) was found in treatment T_2 , where 100 per cent NPK + ZnSO_4 + FYM (POP) was applied followed by T_1 (30.69 mg kg^{-1}) where 100 per cent NPK + ZnSO_4 was applied without application of biochar. The lower manganese content (21.06 mg kg^{-1}) was noticed in treatment (T_7) which received 100 per cent of NPK + ZnSO_4 + 125 per cent of biochar equivalent of FYM followed by T_6 (30.69 mg kg^{-1}) received 100 per cent NPK + ZnSO_4 + 100 per cent of biochar equivalent of FYM.

Application of wood biochar reduced Fe and Mn content in soil which might be due to the adsorption and possible immobilization. As pH of soil and micronutrient availability is negatively correlated, immobilization of micronutrient occurs in soil. The decreased trend of metal content with different rate of biochar application was likely a function of increase in total amount of active sites (Kimetu and Lehmann (2010)^[16]).

Table 5: Effect of biochar application DTPA extractable Iron and Manganese status of soil after the harvest

Treatment details	Fe (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Cu (mg kg ⁻¹)
T_1 : NPK + ZnSO_4 alone	12.65	30.69	1.52	0.89
T_2 : NPK + ZnSO_4 + FYM (POP)	11.44	32.02	1.58	0.83
T_3 : NPK + ZnSO_4 + 25% of biochar equivalent of FYM	10.13	28.96	1.52	0.90
T_4 : NPK + ZnSO_4 + 50% of biochar equivalent of FYM	9.13	27.65	1.55	0.88
T_5 : NPK + ZnSO_4 + 75% of biochar equivalent of FYM	8.06	22.03	1.55	0.85
T_6 : NPK + ZnSO_4 + 100% of biochar equivalent of FYM	8.04	21.45	1.59	0.82
T_7 : NPK + ZnSO_4 + 125% of biochar equivalent of FYM	7.91	21.06	1.61	0.79
S.E.M $\pm$	0.15	0.38	0.01	0.01
CD@ (5%)	0.46	1.16	0.02	0.02

DTPA extractable zinc

The DTPA extractable zinc content was found to be significantly varying between the treatments in soil due to the application of different levels of biochar (Table 5). Significantly higher value of available zinc was recorded in T_7 (1.61 mg kg^{-1}) which received 100 per cent NPK + ZnSO_4 + 125 per cent of biochar equivalent of FYM and found on par with T_6 (1.59 mg kg^{-1}) received 100 per cent NPK + ZnSO_4 + 100 per cent of biochar equivalent of FYM. The lower value was recorded in T_1 (1.52 mg kg^{-1}) which received 100 percent NPK + ZnSO_4 alone.

An increase in Zn content in the soil with biochar application. This may be due to water holding capacity of biochar which enhanced mineralization of zinc from organic matter and the release of Zn during decomposition of organic manures and also due to the application of zinc sulphate as a source of zinc. Sharma and Dixit, (1987)^[22] also opined that Increase in the content of zinc might be due to higher availability of the plant nutrients from the soil nutrient reservoir and additional quantity of nutrients supplied through farm yard manure.

DTPA extractable copper

The DTPA extractable copper content was found to be significantly varying between the treatments in soil due to the application of varied levels of biochar (Table 5). Significantly higher value of available copper was recorded in T_7 (0.89 mg kg^{-1}) received 100 per cent NPK + ZnSO_4 + 125 per cent of biochar equivalent of FYM and was on par with T_6 (0.88 mg kg^{-1}) received 100 per cent NPK + ZnSO_4 + 100 per cent of

biochar equivalent of FYM. The lower value of copper was recorded in T_1 (0.79 mg kg^{-1}) which received NPK + ZnSO_4 alone.

A significant increase in copper content of soil by application of biochar could increase the soluble organic carbon; thereby resulting in the mobilization of Cu. Cu is strongly chelated by organic carbon and is less subjected to adsorption process. Beesley and Marmiroli (2011)^[3] also reported dependence of Cu content on soluble C and pH of the soil.

Conclusion

Application of 100 per cent NPK + ZnSO_4 + 125 per cent of biochar equivalent of FYM significantly decreased the bulk density and increased water holding capacity of soil and also increased the nutrient status in acidic soil. Application of biochar significantly decreased soil acidity and improved pH, EC and soil organic carbon content of the soil.

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