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Effect of Coconut Shell Biochar on Physical, Chemical Properties and Available Major Nutrient Status of Acidic Soil

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The effect of coconut shell biochar addition on the physical and chemical properties of acidic soil such as soil bulk density, maximum water holding capacity, pH, electrical conductivity (EC), available major nutrients were investigated in a field experiment with soybean. This study was conducted by application of coconut shell biochar in combination with recommended Lime. The coconut shell biochar was applied at three rates (5, 7.5 and 10 t ha^{-1}) and lime (calcium carbonate) was applied at two rates (100% and 50% recommendation) to acidic soil. Amendment type, application rate, and their interaction had significant effects ($p < 0.05$) on soil bulk density, maximum water holding capacity, pH, EC, and available major nutrients after the harvest of soybean Application of coconut shell biochar at 10 t ha^{-1} in combination with 50% recommended lime had shown a relatively higher improvement in soil physical and chemical properties after the harvest of soybean.

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1. INTRODUCTION

"Hydrogen (H^+) and aluminium (Al^{3+}) ion dominance in the soil exchangeable complex causes acidity which limits crop yield and utilization of many essential nutrients by plants" [1]. "Liming to remediate these acidic soils has a longer history than the use of any other forms of soil amendments. Liming has shown the synergistic interaction with applied nutrients (through fertilizers) and increased the nutrient uptake by plants" [1]. "Liming results in changes in the physical and chemical properties of soil that improve conditions for plant growth and development. There has been increased interest on alternative liming agents with multiple benefits such as pyrolytic biochars which can be used to improve soil physical, chemical and biological properties and to store carbon (C) in the soil" [2].

"The thermal conversion of biomass (pyrolysis) in a low or no oxygen environment produces high carbonaceous biochar material or charcoal with unique characteristics" [3]. "Biochars are highly recalcitrant with carbon sequestration benefit" [4] and can influence soil pH ([1]It was observed that application of biochars to acidic soil can increase its sorption capacity for nutrients [5] and reduces the exchangeable acidity [6]. Higher pyrolytic temperature (>400°C) was observed to produce biochars with alkaline pH [7,8]. "Several studies have already observed the beneficial effects of biochar on soil quality and fertility parameters. Before applying these biochars to acidic soils as amendment, it will be necessary to analyse their composition and liming potential" [8]. The physical and chemical characteristics of any amendment determine its effectiveness as soil conditioner.

The ameliorating ability of biochars can be varied due to differences in their physical and chemical properties. These biochar properties are influenced by pyrolytic parameters and feedstock type. The objective of this study was to determine the coconut shell biochar induced changes on selected physical properties such as bulk density and maximum water holding capacity and chemical properties of acidic soil such as soil pH, electrical conductivity, organic carbon, available major and micro nutrients status of soil after the harvest of soybean.

2. MATERIALS AND METHODS

A Field experiment was conducted in AICRP on sunflower unit, ZARS, UAS, GKVK Bangalore ($13^0$04'37.7"N 77034'04.2"E) during Kharif 2019 with a test crop soybean. The recommended dose of fertilizer (25:62.5:25 N, P_2O_5 and K_2O) applied as basal dose with recommended spacing of 30×10 cm. Randomized complete block design was used with 9 treatment and 3 replication. Table 1 provides the initial physical and chemical properties of soil from experimental area. There are various grades of biochar available and the locally produced coconut shell biochar has been used in the present investigation. The coconut shell biochar was developed at a comparatively higher temperature (around 600°C) in limited oxygen supply and it was purchased for the cost of Rs. 2 per kg from company Kalpatharu products, Tiptur, Tumkur district, Karnataka. The physical and chemical properties of coconut shell biochar is given in Table 1 and the Following are the treatment combinations used in the present study.

2.1 Treatments Details

Chart 1. The experiment comprised of 9 treatments

Treatments	Details
T_1	Absolute control
T_2	Package of Practice (Recommended NPK + FYM)
T_3	Recommended NPK + Biochar @ 5 t ha^{-1}
T_4	Recommended NPK + Biochar @ 7.5 t ha^{-1}
T_5	Recommended NPK + Biochar @ 10 t ha^{-1}
T_6	Package of Practice (Recommended NPK + FYM) + 100% Lime Recommendation
T_7	Recommended NPK + Biochar @ 5 t ha^{-1} + 50% Lime Recommendation
T_8	Recommended NPK + Biochar @ 7.5 t ha^{-1} + 50% Lime Recommendation
T_9	Recommended NPK + Biochar @ 10 t ha^{-1} + 50% Lime Recommendation

Note: Farm Yard Manure 6.25 t ha^{-1}; Recommended Lime 3.0 t ha^{-1} ; NPK Provided through Urea, Diammanium Phosphate and Muriate of potash

Table 1. Initial physico-chemical properties of the soil of experimental area and coconut shell biochar

Parameters	Soil	Coconut shell biochars (% by weight)
Sand (% by Weight)	68.83	-----------
Silt (% by Weight)	17.86	-
Clay (% by Weight)	13.29	-
Soil textural class	Sandy loam	-
Bulk density (Mg m^{-3})	1.39	0.73
Maximum water holding capacity (%)	34.13	68.54
pH	5.16	9.6
Electrical conductivity (d S m^{-1})	0.097	1.78
Organic carbon	0.51 %	77.50 %
Nitrogen	262.71 kg ha^{-1}	0.27%
Phosphorus	26.82 kg ha^{-1}	0.15%
Potassium	136.4 kg ha^{-1}	0.84%
Exchangeable Calcium	2.16 c mol (p+) kg^{-1}	0.22%
Exchangeable Magnesium	1.35 c mol (p+) kg^{-1}	0.13%
Sulphur	9.30 mg kg^{-1}	0.02%
Iron (mg kg^{-1})	11.12	423.06
Zinc (mg kg^{-1})	2.02	25.80
Manganese (mg kg^{-1})	6.01	273.26
Copper (mg kg^{-1})	0.55	31.20

2.2 Collection of Soil Samples and Methodology for Soil Analysis

Soil samples at a plough layer depth (0-15 cm depth) were obtained from each of the experimental site's twenty-seven plots after the crop's harvest. The samples obtained were dried in shade, rendered with a pestle and motor to ground, passed through 2 mm sieve, and placed in polythene bags. The soil samples that were initially obtained are examined for different physical and chemical characteristics using standard techniques after soybean harvest.

2.3 Statistical Analysis of Data

The comparative study of experimentally collected results was carried out by implementing Fisher's system of measurement of variance as described by Gomez and Gomez (1984). The significance level ($p<0.05$) used in the 'F' evaluation was offered at 5%. Critical difference (CD) values are presented at a significance level of 5% in the table, wherever the 'F' measure was found to be relevant at 5%.

3. RESULTS AND DISCUSSION

3.1 Bulk Density (Mg m^{-3}) and Maximum Water Holding Capacity (%) of Soil after the Harvest of Soybean

Table 2 presents the data pertaining to the effect of biochar application on soil bulk density and maximum water holding capacity. Significantly ($p<0.05$) lower BD (1.27 Mg m^{-3}) and higher water holding capacity (42.02%) was observed in T9 (Recommended NPK + biochar @ 10 t ha^{-1} + 50% Lime Recommendation), followed by T5 (bulk density of 1.28 Mg m^{-3} and water holding capacity of 41.94%) receiving Recommended NPK + biochar @ 10 t ha^{-1}. The higher value of bulk density (1.39 Mg m^{-3}) and lower values of the soil's water holding capacity (34.70%) were observed in the treatment T1 which was absolute control.

Biochar application (Table 2) has had a significant ($p<0.05$) influence on the physical properties of soil viz., bulk density and maximum water holding capacity and recorded lower bulk density and higher maximum water holding capacity values over the rest of treatments. This may be attributed to the high carbon content in the biochar, which in the formation of stable soil aggregates serves as cementing materials. [9] Gundale and Deluca revealed biochars has a large density that is much lower than that of mineral soils and therefore biochar application can reduce the overall density of the soil. The biochar application reduced the bulk density by 12 to 25% and the water holding capacity was increased compared to zero application at all biochar application rates [10-12].

3.2 pH and Electrical Conductivity (dS m^{-1}) of Soil after the Harvest of Soybean

The data in Table 3 showed that after harvesting the soybean, there was a substantial difference in soil pH and Electrical Conductivity condition. pH and EC of the soil increased with increasing rate of biochar and combination with lime has slight increase than biochar alone. Significantly ($p<0.05$) higher pH (6.27) and EC (0.20dS m^{-1}) was reported in treatment receiving Recommended NPK + Biochar @ 10 t ha^{-1} + 50% Lime Recommendation (T9) and was on par with T8 (pH 6.18 and EC 0.19dS m^{-1}) receiving Recommended NPK + Biochar @ 7.5 t ha^{-1} + 50% Lime Recommendation when compared to treatment T2 which received package of practice (Recommended NPK + FYM).

The rise in pH of the treatments over control may be attributed to high surface area and biochar porous nature which increases the soil's cation exchange capacity and the availability of easily exchangeable bases. The basic cations in biochar can be exchanged on soil exchange complex with the exchangeable Al^{3+} and H^{+} and therefore decrease the exchangeable acidity in acidic and neutral soils. Such observations are consistent with [1] Chintala et al. and [13] Anteneh et al. findings. EC's been increasing gradually with increasing rate of biochar to the soil. This may be due to the ameliorating effects of the biochar increased with increase in pyrolysis temperature, which is consistent with changes in EC of biochar. Increased rate of application of biochar increased soil EC. Increased rate of application increased the addition of basic cations and salt concentration and there by recorded higher EC in the present investigation. Significant increase in EC with varied levels of biochar application was often reported by [1] Chintala et al. and [14] Chan et al.

3.3 Soil Organic Carbon (%) of Soil after the Harvest of Soybean

The organic carbon data in Table 3 indicated that there was a significant ($p<0.05$) difference in soil organic carbon content among the various treatments after soybean harvest. Soil organic carbon content after soybean harvest varied from 0.52% to 0.58%. Numerically higher organic carbon value (0.58%) was recorded in T9 with Recommended NPK + Biochar @ 10 t ha^{-1} + 50% Lime Recommendation followed by T5 (0.57%) receiving Recommended NPK + Biochar @ 10 t ha^{-1}. The higher organic carbon levels in biochar treated soils show the recalcitrant organic carbon in biochar which is immune to mineralization and further loses. The soil organic carbon stock named carbon sequestration will then be improved. [4] Lehmann et al. and [15] Solaiman et al. have also reported high organic carbon in soils where biochar is used. The special properties of stable C in biochar and high surface area, high charge per unit area, occurrence of specific functional surface groups and ash content have a beneficial impact on chemical properties of the soil. Application of biochar increase SOC, pH, EC, CEC and exchangeable bases in bio char applied soil [16,13,17].

3.4 Available Major Nutrients (kg ha^{-1}) Status of Soil after the Harvest of Soybean

After the harvest of soybean field, the available major nutrients content in soil differed significantly ($p<0.05$) due to different rates of

Table 2. Effect of coconut shell biochar application on bulk density (Mg m^{-3}) and maximum water holding capacity (%) of soil after the harvest of soybean

Treatments	Bulk density	Maximum water holding capacity
	Mg m^{-3}	%
T1	1.39	34.70
T2	1.37	35.90
T3	1.33	38.87
T4	1.30	40.31
T5	1.28	41.94
T6	1.36	36.11
T7	1.33	39.03
T8	1.29	40.34
T9	1.27	42.02
SEm ±	0.04	0.89
CD @ 5%	0.13	2.68

*Note: *$ZnSO_4$ @12.5 kg ha^{-1} common for all treatments except in absolute control*

Chart 2. Provides the standard methods used for the analysis of soil samples

Parameters	Methods	References
Physical analysis		
Texture	International Pipette method	[15]Piper, 1966
Bulk density (Mg m^{-3})	Keen Raczkowski Cup method	[15]Piper, 1966
MWHC (%)	Keen Raczkowski Cup method	[15]Piper, 1966
Chemical analysis		
pH (1:2.5)	Potentiometry	[10]Jackson, 1973
EC (dS m^{-1})	Conductometry	[10]Jackson, 1973
Organic Carbon (%)	Wet oxidation	[21]Walkley and Black, 1934
Available N (kg ha^{-1})	Alkaline potassium permanganate	[19]Subbiah and Asija, 1956
Available P_2O_5 (kg ha^{-1})	Bray's extraction, Colorimetry	[10]Jackson, 1973
Available K_2O (kg ha^{-1})	Ammonium acetate extraction Flame photometry	[10]Jackson, 1973

Table 3. Effect of coconut shell biochar application on pH, electrical conductivity (dS m^{-1}), organic carbon (%) and major nutrients status of soil after the harvest of soybean

Treatments	pH	Electrical conductivity	Organic carbon	Available nitrogen	Available phosphorus	Available potassium
		dS m^{-1}	**%**	**kg ha^{-1}**	**kg ha^{-1}**	**kg ha^{-1}**
T1	5.18	0.10	0.52	273.01	23.42	139.60
T2	5.20	0.12	0.53	284.46	27.71	148.64
T3	5.37	0.12	0.54	283.30	27.80	149.07
T4	5.54	0.16	0.55	291.21	28.15	151.60
T5	5.75	0.18	0.57	295.67	31.29	152.98
T6	6.02	0.12	0.54	285.60	28.65	149.87
T7	6.12	0.13	0.55	292.98	29.08	152.56
T8	6.18	0.19	0.56	293.82	29.79	151.39
T9	6.27	0.20	0.58	298.89	31.86	153.21
SEm ±	0.14	0.02	0.03	2.53	0.82	1.39
CD @ 5%	0.43	0.06	0.10	7.59	2.44	4.15

*Note: *$ZnSO_4$ @12.5 kg ha^{-1} common for all treatments except in absolute control* biochar application (Table 3). Significantly higher available nitrogen (298.89 kg ha^{-1}), Phosphorus (31.86 kg ha^{-1}) and Potassium (153.21 kg ha^{-1}) was recorded in T9 where Recommended NPK + Biochar @ 10 t ha^{-1} + 50% Lime Recommendation was added compared to package of practice T2 (284.46 kg ha^{-1} Nitrogen, 27.71 kg ha^{-1} Phosphorus and 148.64 kg ha^{-1} Potassium). Nevertheless, T9 was comparable to T5 (295.67 kg ha^{-1} Nitrogen, 31.29 kg ha^{-1} Phosphorus and 152.96 kg ha^{-1} Potassium) obtaining Recommended NPK + Biochar@10 t ha^{-1} and with the increased levels of biochar the available major nutrients content improved.

This might be due to incorporation of biochar in combination with agricultural lime has made nitrogen available to the soil. [4] Lehmann et al. reported that biochar changes soil dynamics of N. The abundance and intensity of organic N mineralization contained in biochar added to soil offers an indicator of biochar's potential as a slow release of N fertilizer stated by [14,12] Chan and Xu and [2] Steiner et al. The high levels of available P found in the biochar [6,18]. Van Zwieten et al. also showed an increase in the available phosphorus in soil after biochar application. The possible cause for improved abundance of P_2O_5 with biochar application in soil may be due to the existence of soluble and exchangeable phosphate in soil pH biochar multiplier and P complexing metals ameliorator (Al^{3+}, Fe^{3+}) driver of microbial development and hurrying P mineralization [19]. Parvage et al. and [16] Hass et al. also reported such an increase in the available content of P_2O_5 with biochar addition. The increased biochar rates in combination with Agricultural lime raised the potassium content in soil which may be attributed to the high K concentration present in the biochar [14,20] Chan et al. Increased potassium is primarily responsible for the immediate beneficial impact of biochar inputs on nutritional abundance [4,21] Lehmann et al. The biochar produces high ash which therefore has more potassium content relative to other main nutrients, so the potassium level improved substantially by adding ash rich biochar to soil.

4. CONCLUSION

In this study, the biochar was a by-products of coconut shell using pyrolysis in an oxygen limited condition unlike previously published studies. With batches of production using comparable feedstock and pyrolytic conditions, the characteristics and reactivity of biochars with soil are highly heterogeneous, making it impossible to generalise study results to all biochar materials. In conclusion, this field study showed how biochars can improve soil physical properties and lessen acidity by raising the pH, EC, and major nutrients that are readily available in the soil. Lime and coconut shell biochar were found to perform significantly better than coconut shell biochar applied alone. Alkalinity, proton consumption/acid neutralisation capacity, and base cation concentration all contribute to biochar's liming potential. These highly carbonaceous biochar materials can be added to acidic soils to improve the chemical properties and increase the bioavailability of vital nutrients for plants. Future studies should assess the practical management (timing and application techniques) and economic viability of biochars in acidic soils. This type of studies at different locations with different feedstocks and pyrolytic process will help to design biochar materials as organic amendments for farmers to reclaim acidic soils and improve soil physical, chemical and biological properties.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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