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Effect of Different Source and Rates of Biochar Application on Selected Physic-Chemical Properties of Acidic Soil in Western Ethiopia

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Abstract: Soil acidity is the serious problem in the western Ethiopia. Therefore the aim of this experiment was to study the effect of different source and rates of biochar application on the selected physic chemical properties of acidic soil. The experiment involved factorial combinations of three sources biochar (maize, sesame and soybean) and five rates of biochar (0, 2, 4, 6, 8 and 10 t ha^{-1}) laid out in randomized complete block design with three replications. Soil samples were collected at a depth of 0–15 cm and the selected physic chemical properties of acidic soil were analyzed by standard laboratory procedure. The result indicated that the maximum mean of soil moisture (4.3) was recorded at 8 t ha^{-1} of soybean biochar and all soil treated biochar were sandy clay textural class except at sesame source at 10 t ha^{-1} results sandy loam. They also maximum Electrical conductivity (0.087), soil pH $_{(H2O)}$ (6.81), organic carbon (2.96%), organic matter (5.10), total nitrogen (0.25%), Available K^+ (23.17) Available P (13.96), calcium (8.19) and base saturation percentage (79.53) were recorded from sesame source with 10 tha^{-1} rates but the maximum cation exchange capacity (27.18) and potassium (2.38) where recorded at from maize source at 6 t ha^{-1}rates of biochar while the maximum magnesium and sodium where recorded from the sesame source at 8t ha^{-1} rates. The result indicates that the sesame source of biochar application with the rates of 10 t ha^{-1} were significantly improved the physical and chemical properties of acidic soil but additional research work were needed regarding to integrated management of soil acidity is different location and different Agro-ecology.

Keywords: Biochar, Different Feedstock, Physic-chemical and Acidic Soil

1. Introduction

Acid soils make up approximately 30% of the world's total land area and more than 50% of the world's potentially arable lands, particularly in the tropics and subtropics [30-32]. Aluminum toxicity is serious problem which increase the soil acidity and occurred when pH in water is less than 5.0 [26, 28]. The increasing trend of soil acidity and exchangeable Al^{3+} in arable and abandoned lands are attributed to intensive cultivation and continuous use of acid forming inorganic fertilizers [1], loss or reduction in the availability of certain plant nutrients (such as P, Ca, Mg, and Mo), increase in the solubility of toxic metals such as Al and Mn, which may influence root growth and nutrient and water uptake, and a change in microbial populations and activities [27, 1].

In Ethiopia acidification occurs simultaneously with other conditions including eroded topsoil and depleted organic matter, depleted nutrients, and alternating drought stress and high rainfall [25]. In high rainfall areas, excessive rainfall coupled with unfavorable temperature and precipitation is high enough to leach appreciable amounts of exchangeable basic cations [21, 29]. Its severity is extremely variable due to the effects of parent materials, land form, vegetation and climate pattern [2].

Soil acidity contains toxic levels of aluminum and manganese and characterized by deficiency of essential plant nutrients and when the soil pH decreases over time due to high rainfall, traditional farming system [34]. The optimum soil pH depends on nutrient cycling, soil microbial activity, and soil structure. Soil acidity affects root development, leading to reduced nutrient and water uptake and deficiency in essential plant nutrients, such as K, Ca, and Mg [1].

In moving from central (West Shoa) to western Ethiopia (West wollega), the degree of soil acidity was measured in terms of acid saturation percentage is increased (ASP>60). In western and eastern wollega zones, the large proportions exchangeable acidity was due to exchangeable Aluminum. The acidity problem in east and west wellega zone of oromia region is critical [1, 29].

According to [2], practices of exceptional deforestation, overgrazing and intensive cultivation of soils with low inputs over many years were the most causes of soil acidity, low soil quality and soil fertility in Western Oromia. The same authors opined that soil acidity problem that occurred particularly in eastern and western zones of Oromia was very critical and deserved immediate intervention to amend the soils for crop production. Also smallholder farmers in different districts in East and West Wollega zones have reported yield stagnation and even yield decline of crops and lack of response to application of urea and diammonium phosphate fertilizers because of soil acidity, which needs different amendments to improve soil fertility and acidity problems [1].

Mitigation of soil acidity is a key for improving soil health and crop production in the country. The most important to reclaim soil acidity was application of biochar [3]. Biochar is a carbon (C) rich product produced from the organic (waste) material relatively at the same or different temperatures and burned with little oxygen (gasification process) and no exposure to oxygen (pyrolysis) [33, 11]. It stores carbon for long time to improve soil fertility and optimized soil pH [9]. It can also improve crop biomass N_2 fixation and enhances the efficacy of N fertilizers [23] but the biochar capacity to neutralize the soil acidity was depend on the biomass selection on which the biochar was prepared.

In our country in general and in East Wollega, Western Ethiopia in particular, only little information is available on the liming potential of biochar to neutralize the soil acidity. Therefore this study was carried out to determine the effect of different source and rates of biochar application on the selected physic chemical properties of acidic soil in Western Ethiopia particularly in East Wollega zone Guto Gidaa District.

2. Material and Methods

2.1. Description of the Study Site

The study was carried out at Guto Gidda woreda, Eastern Wollega zone, which is located in western parts of our country of Oromia National Regional State. It is located 375 km from Addis Ababa. The study area is located on 8°11’52 and 10°94’44 North latitude and 36°97’51 and 37°11’52 East longitude, and the altitude of 1500-1700masl.

2.2. Experimental Materials and Experimental Design

The experimental materials used for this experiment was different source of Biochar (sesame source, soybean source and maize source of biochar). The experiment was laid out in Randomized Complete Block Design (RCBD) in a factorial arrangement, with three replications which consisted three different source (maize, sesame and soybean source) and six rates of biochar (Control (0), 2, 4, 6, 8, and 10 tons ha^{-1}).

2.3. Experimental Procedure

Experimental materials (Maize stalk, sesame stalk and soybean residue) were collected from farmer’s field during the off season (after the crop harvested during the off season/January/2018) and experimental material was dried for the biochar preparation through gasification process as well as the soil were collected from acidic soil of the experimental site of the wollega university and three kilogram (3 kg) of the soil sample were incorporated to the plastic pot prepared for the experiment. The diameter of plastic pot was 30 cm and 35 cm height with the area of 0.105 m^2 and soil were incorporated with biochar and incubated for three month for the selected physic chemical properties of the soil.

2.4. Soil Sampling

The selected physic chemical properties of the acidic soil incubated (treated) with biochar were analyzed using the standard soil laboratory procedure and equipment. The soil samples were collected from each plastic pot they also 500 g composite sample were taken from the experimental soil to analysis the selected physical and chemical properties of the acidic soil.

2.5. Soil Analysis

a) Particle size distribution (soil texture) was analyzed by modified Bouyoucos hydrometer method [5].
b) Soil pH was measured using a glass combination pH meter in 1:2.5 soils to solution ratio of H_2O and 1 N KCl.
c) Soil organic carbon was determined by the wet oxidation method as described by [22].
d) Total Nitrogen and CEC was performed by the Kjeldahl method [13].
e) Exchangeable Cations (Ca, Mg, K and Na) using distillation and back titration with 0.1 N H_2SO_4.
f) Available Phosphorus Content was measured after Bray II [6].
g) The soil percent base saturation (PBS) was calculated from sum the basic exchangeable cations (Ca, Mg, K and Na) as the percentage of CEC.

2.6. Data Analysis

Data Analysis was done by using the mean comparison of the treatments.

3. Result and Discussion

3.1. Effect of Different Source and Rates of Biochar Application on the Soil Moisture Soil Texture and Textural Class

Data of soil analysis indicated on the Table 1 showed that the application of different source and rates of biochar application on the acidic soil were significance mean difference among the treatments. The maximum soil moisture

(4.3%) was recorded from soybean source at 8 t ha^{-1} rates of application and the minimum soil moisture (1.8%) were recorded from control. Biochar treated acidic soils were significantly different from the control (1.82%). The result indicates that application of biochar can increase the soil moisture which indicates that in high moisture area the soil acidity becomes reduced. According to Eyasu, [25] reports Moisture-stressed areas, acidification can also be caused by continuous application of acid-forming chemical fertilizers and the result were supported by [12].

Table 1. *Effect of different source and rates of biochar application on soil moisture and soil texture of the acidic soil.*

Treatment combination	Physical properties				Textural class
	Soil Moisture	Soil texture			
		Sand	Silt	clay	
Control	1.8	51	19	30	Sandy Clay
Maize*2tha^{-1}	2.1	53	21	26	Sandy Clay
Maize*4tha^{-1}	2.9	51	19	30	Sandy Clay
Maize*6tha^{-1}	2.1	55	17	28	Sandy Clay
Maize*8tha^{-1}	2.5	51	19	30	Sandy Clay
Maize*10tha^{-1}	2.3	55	19	26	Sandy Clay
Sesame*2tha^{-1}	3.2	53	19	28	Sandy Clay
Sesame*4tha^{-1}	2.8	51	21	28	Sandy Clay
Sesame*6tha^{-1}	2.5	51	19	30	Sandy Clay
Sesame*8tha^{-1}	3	53	21	26	Sandy Clay
Sesame*10tha^{-1}	2.9	57	25	18	Sandy loam
Soybean*2tha^{-1}	2	53	21	26	Sandy Clay
Soybean*4tha^{-1}	2.8	53	23	24	Sandy Clay
Soybean*6tha^{-1}	1.9	53	21	26	Sandy Clay
Soybean*8tha^{-1}	4.3	55	23	22	Sandy Clay
Soybean*10tha^{-1}	4.2	55	17	28	Sandy Clay
Mean	2.7	53.1	20.3	26.6	

The application of different source and rates of biochar application on the particle size (soil texture) distribution on the acidic soil shows significant mean difference (Table 1). The highest average clay fractions (51 to 55%) were recorded at soybean source with the 10 t h^{-1} rates of biochar application. The results indicate that biochar application can change the soil texture/ maximum the soil texture percentage were recorded in the clay soils but the application of biochar in different source and rates was non significant in soil textural class (all the soil textural class was sandy clay) except sesame source of biochar applied at the 10 t ha^{-1} rates were sandy loam. The result indicates that application of different source and rates of biochar application on the acidic soil increase the water holding capacity of the soil due to high percentage of the clay particle size/soil texture. This result positive with the result of Sohi [19] which indicates that biochar contains high surface area and porous nature of biochar which increased values of clay particles.

3.2. Effect of Different Source and Rates of Biochar Application on the Electrical Conductivity and Soil pH (H_2O)

The results indicated on the Table 2 showed that application of different source and biochar application on electrical conductivity and soil pH (H_2O) were significance mean difference among the treatment. The highest mean of electrical conductivity 0.087 ms.cm^{-1} were recorded from the sesame source at 10 t ha^{-1} rates of biochar application while minimum electrical conductivity (0.032 ms.cm^{-1}) were recorded from the control. The result indicated that sesame and soybean source of biochar increased electrical conductivity as the rates of biochar application increased but maize source of biochar application increased the electrical conductivity as the rates of biochar application increased except at 8 ton/ha rates of biochar application. This indicates that a low Electrical conductivity level indicates that low nutrients available and high EC levels indicate an excess of nutrients. Therefore the result indicates that biochar made from nutrient rich materials contain high nutrient content which reduce the soil acidity by increasing the soil nutrient, soil moisture and reduce Aluminum toxicity in the soil rather than the other source of biochar application. The results were explained by the finding [6, 18].

Table 2. *Effect of different source and rates of biochar application on the mean of soil pH (H_2O) and electrical conductivity of acidic soil.*

Rates of biochar	pH (H_2O)			EC		
	Maize	Sesame	Soybean	Maize	Sesame	Soybean
control	5.73	5.73	5.73	0.032	0.032	0.032
2tha^{-1}	6.08	6.11	6.41	0.042	0.052	0.046
4tha^{-1}	6.11	6.16	6.32	0.054	0.067	0.054
6tha^{-1}	6.33	6.31	6.52	0.069	0.069	0.066
8tha^{-1}	6.31	6.54	6.8	0.058	0.079	0.069
10tha^{-1}	6.28	6.81	6.73	0.071	0.087	0.068

The data indicated (Table 2) that effect of different source and rates of biochar application on the soil pH (H_2O) were significant mean different among the treatments. The highest recorded mean values of the soil pH (6.81) from sesame source applied 10 t ha^{-1} rate and the lowest (5.73 PH_{H2O},) mean values were recorded from the untreated (control) soil. The results indicated that Maize, sesame and soybean source of biochar application on the soil PH_{H2O} were increased as the rates of biochar application increased up to the optimum level. The result showed different source and rates of biochar has the ability to neutralize the acidic soil. Increasing the nutrient availability, soil organic matter and decreases the proportion of Al^{+3} and H^+ ions occupying cation exchange sites, which effectively increases base saturation.

According to Nigussie [18] reports the higher soil pH was recorded due to the ability of biochar amendments to neutralize soil acidity and legume materials have higher ash alkalinity due to the unbalanced uptake of cations and anions, and thus have greater amelioration effects on soil acidity than non-legume materials. The input of ash alkalinity and the mineralization of organic N are two main factors contributing to increased soil pH early in the incubation study, while nitrification of NH_4^+- N would contribute to decreased soil pH later in the incubation; the balance of these reactions determined the final soil pH [24].

3.3. Effect of Different Source and Rates of Biochar Application on Soil Organic Carbon, Organic Matter, Total Nitrogen and CEC of Acidic Soil

Application of different source and rates of biochar application on the acidic soil significantly increased the mean of organic carbon percentage, organic matter percentage, total Nitrogen and Cation exchange capacity of the acidic soil (Table 3). The highest mean of soil organic carbon (2.96%), soil organic matters (5.10%) and maximum total nitrogen (0.255%) were recorded from sesame source with 10 t ha^{-1} rates of biochar but the minimum mean data were also recorded from untreated plot (control). According to Solomon [20] report the application of biochar increases soil organic carbon significantly in the biochar amended soil samples. Additionally, alkaline biochar may increase the pH of acidic soils and subsequently stimulate microbial activity there by further promoting mineralization or decomposition of existing soil organic carbon.

Table 3. *Effect of different source and rates of biochar application on the organic carbon, organic matter, total nitrogen and cation exchange capacity on th eacidic soil.*

Treatment combination	OC%	OM%	TN%	CEC
Control	2.01	3.44	0.12	13.7
Maize*2tha^{-1}	2.52	4.35	0.21	20.66
Maize*4tha^{-1}	2.22	3.83	0.19	24.23
Maize*6tha^{-1}	2.67	4.6	0.23	27.18
Maize*8tha^{-1}	2.29	3.94	0.19	16.44
Maize*10tha^{-1}	2.65	4.57	0.22	16.21
Sesame*2tha^{-1}	2.14	3.69	0.18	25.13
Sesame*4tha^{-1}	2.77	4.78	0.23	18.18
Sesame*6tha^{-1}	2.88	4.97	0.24	23.29
Sesame*8tha^{-1}	2.92	5.04	0.25	22.36
Sesame*10tha^{-1}	2.96	5.1	0.25	16.7
Soybean*2tha^{-1}	2.85	4.91	0.24	18.05
Soybean*4tha^{-1}	2.82	4.86	0.24	17.42
Soybean*6tha^{-1}	2.78	4.79	0.24	24.17
Soybean*8tha^{-1}	2.85	4.92	0.24	16.43
Soybean*10tha^{-1}	2.51	4.33	0.21	26.81
Mean	2.6	4.5	0.22	19.9

According to Zhang [35] reports that the application of biochar considerably increased soil organic carbon and N but decrease bulk density of the soil and the total soluble N, soluble C, available P, sodium, bulk density and exchangeable calcium were considerably improved with the application of biochar [14]. According to Chan and Xu [7], biochar does not contain high levels of nitrogen (N), indirect nutrient value is attributed to its ability to retain nutrients in soil and reduce leaching losses. Biochar applications to the acidic soil will increase NH^4 storage by enhancing cation exchange capacity in soils [8]. The application of different source of biochar to the acidic soil can increase the total nitrogen [15].

The soil analysis on the Table 3 indicated that highest CEC values (27.18 meq/100gm soil) were recorded from maize source at 6 t ha^{-1} rates, where as the lowest CEC (13.709 meq/100 gm) was recorded from the untreated soil (soils) in the acidic soil. The finding shows that ability to hold negatively charged particles of clay and humus. This increase in CEC may be due to increase in organic matter and pH which facilitate the availability of exchangeable cations. According to Glaser [12] reports biochar application to the acidic soil can improves surface sorption capacity when added to the acidic soil due to it is highly porous, contains variable charge.

3.4. Effect of Different Source and Rates of Biochar Application Exchangeable Bases (Ca^{2+}, Mg^{2+} and, K^+)

The result indicated (Table 4) that the effect of different source and rates of biochar application on the acidic soil can improve the cation exchange Bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+). Highest exchangeable calcium (8.19 meq/100gm) was recorded from the sesame source at of 10 tha^{-1} rate. Exchangeable calcium was increased in the biochar treated soil than the untreated soil (5.51 meq/100gm) in acidic soil. The maximum magnesium (4.51meq/100gm) and sodium cation (0.381 meq/100gm) was recorded from the soil treated sesame source at the rate of 8 tha^{-1} biochar application While the maximum potassium cation (2.38 meq/100gm) was recorded from maize source with 6 tha^{-1} rates but biochar treated soil carried the highest magnesium and sodium cation than the untreated soil in the acidic soil.

The results were supported by Lima and Marshall [16] report that the release of Ca^{2+}, K^+ Mg^{2+} and Na^+ ions by biochar increases the EC of soil. The soil acidity decreased due to the result of burning; base ions such as K^+, Ca^{2+}, and Mg^{2+} will cause the ash to be alkaline neutralizing some of the soil acidity. According to Nigussie [18] report that the increase in the exchangeable bases was as a result of the presence of ash in the biochar which helps in the immediate release of mineral nutrients like Ca and K for crop use.

The data revealed on the Table 4 shows that the effects of biochar application on the mean of base saturation were significantly different. The maximum base saturation percentages (79.53%) were recorded from sesame source with 10 ton/ha rates of biochar application. The base saturation percentage of treated soil shows maximum base saturation percentage than the untreated soil (40.63%). The highest values of exchangeable bases at biochar treated soils might be attributed to the presence of ash in the biochar and increasing the base saturation percentage to reduce the aluminum and acid saturation becomes decreased. The ash content of biochar helps for the immediate release of the mineral nutrients like Ca, K and N for crop use [17]. The results of the present study also agree with Chan and Xu [7] who reported the highest exchangeable bases in biochar applied soils.

Table 4. *Effect of different source and rates of biochar application on Exchangeable bases and base saturation percentage in the acidic soil.*

Treatment combination	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	BSP
Control	5.81	2.24	0.13	1.1	40.63
Maize*2tha^{-1}	5.78	2.64	0.26	1.49	49.27
Maize*4tha^{-1}	6.05	2.87	0.33	1.61	44.94
Maize*6tha^{-1}	6.18	3.88	0.28	2.38	46.89
Maize*8tha^{-1}	5.68	2.42	0.35	2.05	63.96
Maize*10tha^{-1}	5.82	3.55	0.31	2.12	72.86
Sesame*2tha^{-1}	6.2	2.65	0.25	1.46	42.08
Sesame*4tha^{-1}	6.47	3.67	0.25	1.35	64.62
Sesame*6tha^{-1}	6.87	3.31	0.29	2.01	53.64
Sesame*8tha^{-1}	7.13	4.58	0.38	2.05	63.26
Sesame*10tha^{-1}	8.19	2.62	0.2	2.26	79.53
Soybean*2tha^{-1}	6.4	2.85	0.2	1.1	58.51
Soybean*4tha^{-1}	6.51	3.72	0.25	1.34	67.84
Soybean*6tha^{-1}	7.13	4.28	0.32	1.67	55.47
Soybean*8tha^{-1}	6.63	4.01	0.24	1.47	75.24
Soybean*10tha^{-1}	7.35	3.82	0.29	2.22	51.1
Mean	6.51	3.32	0.27	1.73	58.12

Table 5. *Effect of different source and rates of biochar application on Available Potassium and phosphorous in the acidic soil.*

Treatment combination	Available K^{+}	Available P^{+}
Control	2.21	4.73
Maize*2tha^{-1}	13.43	5.96
Maize*4tha^{-1}	14.46	7.76
Maize*6tha^{-1}	22.56	11.98
Maize*8tha^{-1}	19.53	7.6
Maize*10tha^{-1}	22.36	6.24
Sesame*2tha^{-1}	10.12	6.17
Sesame*4tha^{-1}	12.08	7.05
Sesame*6tha^{-1}	16.76	7.97
Sesame*8tha^{-1}	19.83	11
Sesame*10tha^{-1}	23.17	13.96
Soybean*2tha^{-1}	10.4	4.75
Soybean*4tha^{-1}	9.66	6.27
Soybean*6tha^{-1}	10.34	8.66
Soybean*8tha^{-1}	16.36	6.03
Soybean*10tha^{-1}	16.57	12.09
Mean	14.9	8.01

3.5. Effect of Different Source and Rates of Biochar Application Available Phosphorus and Potassium

Available phosphorus and potassium were significantly affected through application of different source and rates of biochar applications on acidic soils (Table 5). The maximum available phosphorus (13.96 ppm) and available potassium (23.172 ppm) were recorded at the combination of sesame source with 10 t ha^{-1} rates of biochar application. In the soil treated biochar were records the maximum available phosphorus and potassium than the soil untreated (4.73ppm and 2.213 ppm respectively). Biochar application increases in available phosphorus due to the presence of phosphorous in the feedstock materials i.e. the sesame source of biochar contain more carbon than the other source of biochar application.

The result were supported Achalu [2] also reported that application of lime could increase availability of Phosphorus. According to Bhattarai [4] reports that biochar application increases the available P in soils and they also increase exchangeable potassium as biochar increases the soil pH, which makes immobile phosphorus available.

4. Conclusion and Recommendation

Biochar application of different source (maize, sesame and soybean) and rates of biochar application can improve the selected physicochemical properties of acidic soil in the areas of western Ethiopia oromia region east wollega zone, wollega university research and demonstration area can neutralize the physic chemical properties of acidic soil. Application of different source and rates of biochar application can improve the acidic soil due to increasing the mean of soil moisture, particle size, electrical conductivity, soil pH, soil organic matter, soil organic carbon, cation exchange capacity, total nitrogen, exchangeable bases Available phosphorus and Potassium and base percentage saturation of the soil due to biochar application have the ability to neutralize the acidic soil. The results indicated that the Sesame source of biochar at 10 t ha^{-1} application rates can neutralize the soil acidity by 15.42 percent rather than the other treatments. All biochar application is not equally improve the selected physic chemical properties of acidic soil therefore the additional research was needed regarding to biochar made from different feedstock materials, quality of biochar preparation, different acidity level of the soil in different location and different Agro-ecology.

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