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Role of Bio Char on the Amelioration of Soil Acidity

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ABSTRACT

Biochar is being evaluated globally as a means to improve soil fertility, ecosystemservices and sequester carbon. The review was made to understand the role of biochar in amelioration of soil acidity by studying influence of its addition on soil properties and crop productivity. The results of the studies indicated that application of biochar increased soil pH, CEC, available P and organic carbon and significantly increased crop yield. For instance, using biochar at 12 t ha^{-1}, 8 tha^{-1} and lime at 2 t ha^{-1} gave grain yield of 2.67, 1.98 and 2.45 t ha^{-1}, respectively, of teff compared to grain yield of 1.44 t ha^{-1} from treatments with no lime or biochar. Biochar combined with NP fertilizers also increased yield significantly as compared to plots that received fertilizer or lime alone; suggesting that biochar improved fertilizer use efficiency. Therefore, the impact and cost of mineral fertilizers as well as their associated risks on the environmental safety is becoming unaffordable. To alleviate these problems, integrating mineral fertilizers with easily available and an environmental friendly soil amendment, such as biochar is of paramount importance towards meeting our goal of increasing agricultural production and ensuring food security.

Keywords: Biochar; Acid soil; Soil properties; Crop yield

INTRODUCTION

Biochar is a fine grained highly porous charcoal (carbon) that can be formed as a result of the pyrolysis of biomass in a complete or absence of oxygen and it is different from other charcoals for intended use as a soil amendment [1,2]. Biochar is a material produced from organic matter under high temperature and low oxygen conditions. In recent years, scientific attention has been focused on its effect on soil amendment and ecological restoration. The pyrolytic process converts biomass acids into the bio-oil component and the alkalinity is inherited by the solid biochar [3]. Inorganic carbonates and organic anions are alkaline components in biochar [4-6]. When biochar is produced at different temperatures, their alkalinity increases with increasing charring temperature [7]. The pyrolytic process converts biomass acids into the bio-oil component and the alkalinity is inherited by the solid biochar [8]. Inorganic carbonates and organic anions are alkaline components in biochar [9,10]. When biochar is produced at different temperatures, their alkalinity increases with increasing charring temperature [11,12].

The thermal conversion of biomass (pyrolysis) in a low or no oxygen environment produces high carbonaceous biochar material or charcoal with unique characteristics [13]. Biochars are highly recalcitrant with carbon sequestration benefit [14] and can influence soil pH [15]. It was observed that application of biochars to acidic soil increases its sorption capacity for nutrients [16] and reduces the exchangeable acidity [17]. Higher pyrolytic temperature (>400°C) was observed to produce biochars with alkaline pH [18,19]. 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 analyze their composition and liming potential.

The alkaline substances in biochar are more easily released into the soil compared with its feed stock when biochar samples are incubated with the soil [20]. The liming effect of biochar on acidic Ultisols had been confirmed [21-25]. It is indicated that theapplication of biochar can increase the pH in highly weathered tropical soil [26]. The alkalinity of biochars was a key factor affecting their liming potential [27]. When biochar with higher pH value was applied to the soil, the amended soil generally became less acidic [28]. The ameliorating effects of biochar on soil pH clearly increased with increasing biochar application rates [29]. The improvement of crop growth from biochar amendment of a typical Ultisol may result from an increase of pH and cation exchange capacity (CEC) [30].

There are many soil amendment technologies to improve soil properties such as chemical fertilizers, organic fertilizers and lime. The potential of biochar as a soil amendment in agricultural fields is a recently recognized and yet it is underutilized technology. Biochar, (also commonly known as charcoal or agrichar) is defined as a carbon(C) rich product derived from the pyrolysis of organic material at relatively low temperatures (<700°C) [31]. It stores

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carbon for long time, ameliorates degraded soils and reduces soil acidity for better crop production [32]. It improves crop yield when applied as a soil amendment [33]. Biochar application improves crop productivity through enhancing water holding capacity, cation exchange capacity(CEC), adsorption of plant nutrients and creates suitable condition for soil micro-organisms [34,35].

Biochar can be produced from different plant materials including wood chip and wood pellets, tree bark, crop residues, grasses, organic wastes (distillers' grain, bagasse, olive waste) [36]. Except olive waste, all sources are found in Ethiopia. Fine grained parts of commercial charcoal which cannot be used or sold could be used as biochar [37] reported an estimate of 30 to 40 % by weight of charcoal production.

The physical and chemical characteristics of any amendment determine its effectiveness as liming agent[38]. 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 [39,40]. The liming effect of any amendment can be determined by studying soil indices such as soil pH and exchangeable acidity [41]. Liming potential of a material can also be predicted by its properties such as calcium carbonate equivalence and ash alkalinity [42,43]. Little information is available on the liming potential of biochars produced from various pyrolytic processes using different biomass feedstocks and their associated reaction mechanisms to reduce soil acidity. It was hypothesized that biochars produced from microwave pyrolysis using corn stover and switchgrass had a permanent ameliorating effect on chemical properties of acidic soil. The ameliorating effect of biochars on acidic soil was assumed to be consistent with their composition and properties which depend on biomass feedstock type and pyrolytic conditions.

Today, in many countries bio-char has widely been accepted and given great attention not only due to its contribution in lowering climate change but also as a desirable soil conditioning material that can enhance fertility and reduce the need for expensive fertilizers and agro-chemicals. Thus, improving the soil quality through increased biomass use efficiency without causing too much environmental pollution would ensure food security in the country. Thus, this review was taken up with the following objectives in mind.

OBJECTIVE

To understand suitability of biochar as an amendment for acid soils

To study the effect of biochar addition on soil properties related to soil acidity

To evaluate the influence of biochar addition on growth and yield of crops

Importance of Biochar

Biochar has agronomic as well as environmental impact for it is a good soil amendment. Evidence shows that the application of biochar can play a significant role in improving soil organic carbon [44], water holding capacity [15-16], soil aeration, increased soil base saturation, nutrient retention and availability and reducing nutrient leaching [45], enhancing plant growth and productivity, reducing greenhouse gas emission and increasing carbon sequestration [46]. Carbon sequestration in soil is favored for improving soil quality and achieving sustainable use of natural resources [47]. It improves water holding capacity and aggregate stability, CEC and soil pH [48].

Biochar is obtained from the pyrolysis or thermal decomposition of surplus and readily accessible biomass which has been proved to be an effective means of carbon sequestration and immobilization of organic contaminants in soil [49]. The use of biochar for remediation is not a new concept, it has been found in areas of the fertile Amazon Basin. The *terra preta*soils of the region received large amounts of charred organic debris from the former inhabitants. Thus, carbon stocks have remained in the soil present day, thousands of years after abandonment providing a historical basis for the benefits of biochar for sequestration and fertility [50].

Biochar application in soils has gained much attention as a climate change mitigation strategy, as it can sequestrate carbon [34-36]. As well as improve soil properties such as nutrient availability, pH value, water-holding capacity and bulk density [51,52], but it has no consistent effects on soil infiltration rates, CEC, and crop yields [53]. The previous results presented various effects of biochar on soil because the properties of biochar derived from different feedstock and conditions were various [54]. The biochar shows different effects when applied to different types of soil [55]. In addition, plants response in different way under different types of biochar application or different application dose. A review of previous research showed a huge range of biochar application rates (0.5–135 t/ha of biochar) as well as a huge range of plant responses (229% to 324%) [56]. Hence, different biochar should be developed for different soils and plants.

Rice husk and wood sawdust are the main feedstock used to produce bio-oil by fluidized-bed reactors or other fast pyrolysis systems in China [28]. Abundant biochar produced during the process of fast pyrolysis as by-product. Cao and Pawlowski evaluated the fast pyrolysis systems by life cycle assessment and reported that fast pyrolysis could be credited with a potential of not only producing considerable net energy but also reducing greenhouse gas emissions [29]. In this context, the objective of this research is to investigate the possible application of biochar in acidic soil improvement by assessing the effects of biochar derived from rice husk and wood sawdust by fast pyrolysis on the properties of acidic soil and radish growth.

Impacts of biochar on soil

Biochar has substantial potential for soil improvement because of its unique physical, chemical, and biological properties and their interactions with soil and plant communities. If used as a soil amendment, biochar could mitigate the possible negative impacts of forest biomass removal operations. However, uncertainties surround the potential short-and long-term effects of intentional biochar application in many regions and ecosystems, namely temperate forests, as most evidence comes from agricultural systems. While additions have largely been neutral or positive [57], there exists potential for negative impacts. This demonstrates the need for a comprehensive understanding of biochar's origin, production, and functional properties several soil benefits arise from the physical properties of biochar. The highly porous nature of biochar results from retaining the cell wall structure of the biomass feedstock. A wide range of pore sizes within the biochar results in a large surface area and a low bulk density. Biochar incorporation can alter soil physical properties such as structure, pore size distribution and density, with implications for soil aeration, water holding capacity, plant growth, and soil workability [58]. Evidence suggests that biochar application into soil may increase the overall net soil surface area consequently, may improve soil water and nutrient retention [19], and soil aeration, particularly in fine-textured soils [20]. Biochar has a bulk density much lower than that of mineral soils (~0.3 Mg m-3 for biochar compared to typical soil bulk density of 1.3 Mg m-3); therefore, application of biochar can reduce the overall total bulk density of the soil which is generally desirable for most plant growth. Increased surface area, porosity, and lower bulk density in mineral soil with biochar can alter water retention, aggregation, and decrease soil erosion. Biochar feedstocks and pyrolysis conditions largely determine the resulting carbonate concentrations, making some biochar a better liming agent than others. Concentrations of carbonates can vary from 0.5 to 33% depending on starting conditions [31].

Hardwood charcoals are reported to have substantial carbonate concentrations and prove more effective in reducing soil acidity, therefore having a larger influence on soil fertility [59]. The liming of acidic soils decreases Al saturation, while increasing cation exchange capacity and base saturation. Biochar properties may enhance soil microbial communities and create microenvironments that encourage microbial colonization. Biochar pores and its high internal surface area, and increased ability to adsorb OM provide a suitable habitat to support soil microbiota that catalyze processes that reduce N loss and increase nutrient availability for plants [19]. The pores are suggested to serve as a refuge by protecting microbes from predation and desiccation while the organic matter adsorbed to biochar provides C energy and mineral nutrient requirements [17]. In temperate ecosystems with wildfire-produced charcoal, N mineralization and nitrification are enhanced by creating favorable microenvironments that enhance colonization by microbes [10-12]. If microbial activity is able to oxidize biochar, we need to know which microbes can achieve this, the mechanism by which it occurs, and under what conditions and at what rate this will take place.

BIOCHAR COMPOSITION

Biochar is produced from biomass and is predominantly composed of recalcitrant organic C with contents of plant micro and macro nutrients retained from the starting feedstock. We know from research on wildfire occurrence and the development of Anthrosols in the Amazon that charcoal can remain in the soil for hundreds to thousands of years[28]. Consequently, biochar can rapidly increase the recalcitrant soil C fraction of soil. The C in biochar is held in aromatic form which is resistant to decomposition when added as a soil amendment making it a C sequestration tool. However, composition varies by feedstock type and conditions of pyrolysis [52].

The organic carbon, total N and the available P contents of biochar were high. Exchangeable K, Ca, and Mg concentrations of the biochars were medium to high. However, higher carbon and total N content than sugarcane bagasse biochar, but the contents of exchangeable cations and CEC in sugarcane bagasse biochar were higher than in coffee husk biochar **(Table 1).** Both boichars contained plant nutrients in addition to its action as soil conditioners. However, it is better to apply biochar together with additional nutrients to enhance its function (Steiner et al., 2008). Other studies indicated that biochar has been shown to retain nutrients against leaching [56-58], potentially improving the efficiency of nutrients applied alongside biochar [59]. The chemical properties of biochar vary based on the type of feedstock used for charring, the charring environment (e.g. temperature, air) and additions during pyrolysis process [60]. The source of biochar material strongly affects the content and availability of nutrients in the soil after amendment. The soil chemical properties after amendment will strongly be affected by source of biochar applied.

Table 1: Effect of biochar and lime on soil chemical properties.

Amendment	OC (%)	Total N (%)
2 t ha^{-1} lime	1.91	0.19
12 t ha^{-1} biochar	1.84	0.18
8 t ha^{-1} biochar	1.77	0.18
4 t ha^{-1} biochar	1.70	0.17
No Amendment	1.66	0.17

EFFECTS OF BIOCHAR ADDITION ON SOIL PROPERTIES RELATED TO SOIL ACIDITY

Soil pH and Exchangeable Acidity

According to soil analysis result before application of treatments, exchangeable Al was trace, and the exchangeable acidity value was 0.60 cmol$_c$kg^{-1}. also It reported that exchangeable acidity of the area lies between 0.78-0.60 cmol$_c$kg^{-1}. Post-harvest soil analysis results showed that application of biochar and lime showed relative reduction on exchangeable acidity. Addition of biochar from lower rate to higher rates produced a reduction trend of exchangeable acidity. Incorporation of 12 t ha^{-1} biochar gave the lowest exchangeable acidity (0.39 cmol$_c$ kg^{-1}) followed by 2 t ha^{-1} lime (0.44 cmol$_c$ kg^{-1}), whereas the highest exchangeable acidity was (0.60 cmol$_c$ kg^{-1}) from the control plots **(Figure 1).** Lowering of exchangeable acidity and a rise in pH can provide a wide range of benefits in terms of soil quality, notably by chemically improving the availability of plant nutrients, and in some cases by reducing the availability of detrimental elements such as Al [14].

Soil available P

Soil available P increased after application of biochar and lime. As biochar rates increased, availability of P also increased. It increased from 12.75 ppm without amendment to 18.92 and 17.50 ppm after application of 12 t ha-1biochar and 2 t ha-1 lime, respectively **(Figure 2).** Soil analysis result showed that application of fertilizer increased available P and 14.70, 16.35 and 17.30 ppm were found on the application of 0, 23/30 and 46/60 (N/P2O5) kg ha-1,respectively. Accordingly, application of biochar and lime with fertilizer and without fertilizer showed different values on available P. As the rate of biochar and the rate of fertilizer increased, the P value also increased. This could be due to the synergetic effect of biochar and the fertilizer. As biochar is added to the soil, the pH of acidics oil is raised and the amount of fixed P could be reduced.

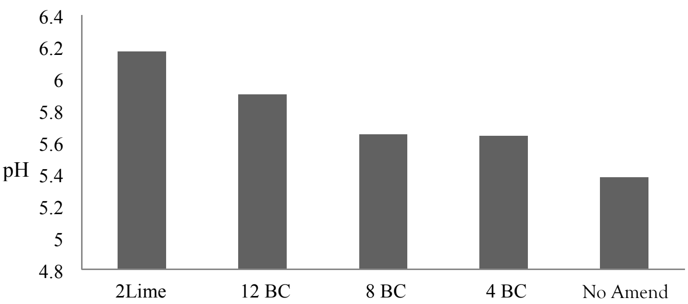

Figure 1: Effect of biochar and lime on soil sources pH.

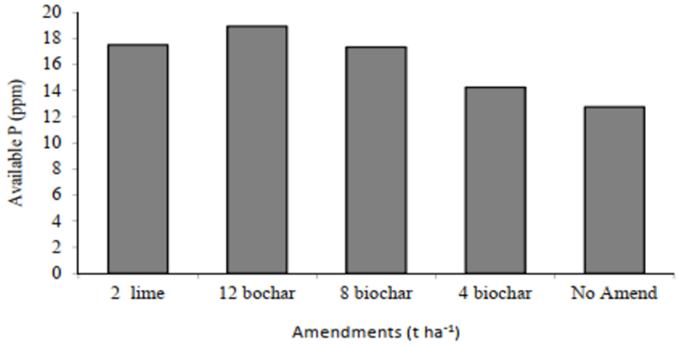

Figure 2: Effects of Biochar and lime on variable phosphorus.

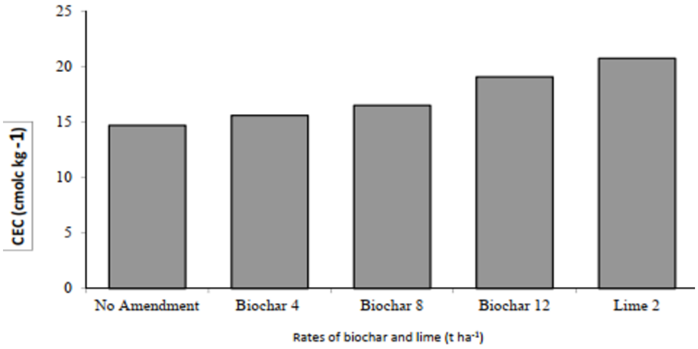

Figure 3: CEC as influenced by biochar and lime application.

Consequently, the applied P could not be reacting with Aland Fe and precipitated as AlPO4 and FePO4. Available P increment in the soil system may be due to application of the readily available P as DAP fertilizer. This result indicates that the availability of the applied P fertilizer couldsupported by the application of biochar and lime. It is observed significant increasedbread wheat growth averaging about 2.5-fold more than the control when paper mill biochar with fertilizer wasapplied to an acidic highly weathered soil. The lime (as carbonates) in the biochar decreased the availability of Alto below detection limit. It is also reported that application of lime could increase availability of P. This was due to lime could increase available P which was fixed by Al and Fe an increase of available P on application of biochar could happen due to two reasons: the first one is that liming effect of biochar on acid soil that precipitates Al and Fe as Fe (OH)3 and Al (OH)3, thus increases availability of phosphorus in the soil system [61]. According to Griffith and Tisdale, under acid conditions, phosphorus is precipitated as Fe or Al phosphates. Maximum availability of phosphorus generally occurs in a pH range of 6.0 to 7.0. It is also indicated that phosphorus is most available nearpH 6.5 for mineral soils. Tisdale also discussed that P availability is at maximum in the pH range 5.5-6.0. Maintaining a soil pH in this range also favors the presence of H2PO4– which is more readily absorbed by the plant than HPO42- and occur at pH values above 7.0 [62].

Available P increment in the soil system may be due to application of the readily available P as DAP fertilizer. This result indicates that the availability of the applied P fertilizer could be supported by the application of biochar and lime. It is observed significant increased bread wheat growth averaging about 2.5-fold more than the control when paper mill biochar with fertilizer was applied to an acidic highly weathered soil [63]. The lime (as carbonates) similar to the biochar decreased the availability of Al to below detection limit. The application of lime could increase availability of P. This was due to lime could increase available P which otherwise could be fixed by Al and Fe.

Cation Exchange Capacity (CEC)

The soil analysis result showed that incorporation of biochar and lime increased CEC of the soil. High CEC values(20.73 and 19.05 cmolc kg-1) were found on plots treated with 2 t ha-1 of lime and 12 t ha-1 of biochar, respectively, whereas the lowest CEC (14.69 cmolc kg-1) was found in the control plots (**Figure 3**). Generally, all biochar treatments showed higher CEC than the control one. Application of 4, 8 and 12 t ha-1 of biochar gave 6.13%,11.25% and 29.68% CEC increment, respectively over the control. The increase in CEC could have resulted from the inherent characteristics of the biochar, since biochar has high surface area that has exposed negative charges. Itis highly porous, contains variable charge, and hence improves surface sorption capacity when added to the soil [15]. Edmundsalso mentioned that biochar has high CEC. Glaser discussedthat after weathering, oxidation occurs that results in the formation of carboxylic groups on the edges of the aromatic carbon, which results in greater CEC.

The benefit of lime to enhance CEC was reported [1]. They discussed that liming of acidic soil have positive effect on CEC. The direct relationships between pH, exchangeable Ca and CEC with the increase of the lime rates is attributed to the applied lime which enhances the concentration of Ca^{2+} and thereby increases the soil pH due to the replacement of H^+ and Al^{3+} from the soil solution and soil exchange complex by Ca^{2+}. The direct relationship of CEC with soil pH may be attributed to the presence of pH dependent negative charges which can increase with increasing soil pH due to applied lime.

Organic Carbon and Total Nitrogen

Based on the soil analysis result, higher organic carbon (1.91% and 1.84) were found on 2 t ha^{-1} lime and 12 tha^{-1} biochar, respectively whereas the lowest content (1.66%) was found from control plots (**Table 1**). The soil analysis data revealed that soil organic carbon increased by biochar application. Similarly, It is reported that due to application of lime soil organic carbon was increased. This is due to the raise of soil pH in short period of time that favors soil microbes to decompose crop residues.

Application of biochar resulted in little differences on total nitrogen. Actually, the study area has low total nitrogen [4]. Intensive cultivation as well as less crop residue management may contribute significant roles for the low level of total nitrogen. Application of biochar has no direct effect on nitrogen content of the soil, but it retains nitrogen from leaching [7]. The review indicated that biochar has a high adsorption capacity of NO_3^- that prevents nitrogen leaching from the top soil. It is concluded that NO_3^- was only weakly adsorbed to biochar, that it could be desorbed by water infiltration[16], and that the net result may be an increase residence time for NO_3^- in the soil. Due to its resistance to decomposition in soil, single applications of biochar can provide beneficial effects over several growing seasons in the field [40-41]. Therefore, biochar does not need to be applied frequently, as is usually the case for manures, compost, and synthetic fertilizers. Beneficial effect of applying biochar to soil is a long lasting [42-45]. Chan reported that plant yield increase in the presence of both biochar and fertilizer is related to nitrogen fertilizer use efficiency. The study on the acidic Highlands of Ethiopia confirmed that there is no contribution of lime on nitrogen that could be due to the absence of N in put to the soil.

YIELD RESPONSE TO APPLICATION OF BIOCHAR, LIME AND MINERAL FERTILIZERS

Significant teff yield variation was obtained by incorporating biochar and lime. The highest rate of biochar (12 t ha^{-1}) resulted in better yield, while application of 2 t ha^{-1} lime resulted in a yield above application of 8 t ha^{-1} biochar and less than 12 t ha^{-1} biochar applications (**Table 2).** In general, biochar and lime applications resulted in a significant yield increase (P<0.01) (**Table 2).** Application of 12 t ha^{-1} biochar and 2 t ha^{-1}lime gave 2.67 and 2.45 t ha^{-1} grain yield, respectively, while the lowest yield (1.44 t ha^{-1}) was obtained from control plots. Incorporation of 12 t ha^{-1} biochar, 2 t ha^{-1} lime, 8 t ha^{-1} and 4 t ha^{-1}biochars had 85.66%, 70.63%, 37.79% and 19.97% yield advantage, respectively over the untreated plots.

Table 2: Effect biochar and lime on grain yield of teff.

Amendment	Dry biomass yield (t ha^{-1})	Grain yield (t ha^{-1})
2 t Lime	15.03 ab	2.452 a
12 t biochar	17.77 a	2.668 a
8 t biochar	13.67 bc	1.980 b
4 t biochar	13.15 bc	1.724 c
No Amend	11.55 c	1.437 d
CV	10.74	10.93
Probability	**	**

** Significant different at (P≤0.01), * significantly different at P≤0.05 and ns denotes for not significantly different at P≥0.05. Means with the same letter in in a column are insignificantly.

Similar to grain yield, significant dry biomass yield variation was obtained by incorporation of biochar and lime. The highest rate of biochar (12 t ha^{-1}) had a better biomass yield response than the lower rates. Application of 2 t ha^{-1} lime resulted in better yield than 8 t ha^{-1} but less than 12 t ha^{-1} biochar **(Table 2).** Application of 12 t ha^{-1} biochar and 2 t ha^{-1}lime gave 17.77 and 15.03 t ha^{-1} teff dry biomass yield, respectively whereas the lowest biomass yield (11.55 t ha^{-1}) was obtained from control treatment **(Table 2).**

The yield and biomass increment by incorporation of biochar in this experiment is similar to other research findings. In tropical soils, above-ground biomass was shown to increase by 189% when 23 t ha^{-1} biochar was added [64]. Edmunds, reported that biochar application rate increased the switch grass biomass yield to 50.6 and 53.2 g pot^{1} in for 17 and 34 t ha^{-1} biochar application rates, respectively, compared to 42.7 g pot^{-1} in the control. It is also reported that biochar treatments produced higher yields and produced remarkably highest number of tubercles. Large volume applications of biochar (30 and 60 t/ha) in the Mediterranean basin was sustained for two consecutive seasons and increased durum wheat biomass and yield to 30% [45].

The effect of biochar might be more pronounced in long year bases. According to [65], application of biochar on maize grain yield had no significant effect in the first year; however, in subsequent years, maize yield increased with increasing biochar rate, and the positive effect of biochar was most prominent in the third year after application. (SARE 2013) also reported that in some soil's biochar additions did not seem to increase yields in the first year. In this report, those plots receiving biochar had a higher yield than those plots received no biochar in subsequent years. A single application of 20 t ha^{-1} biochar resulted in an increase in maize grain yield of 28 to 140% as compared with the control in the 2^{nd} to 4^{th} years after application [38].

PLANT GROWTH EFFECTS WITH BIOCHAR ADDITIONS

Biochar can be used as a soil amendment to improve soil quality and crop productivity in a variety of soils [66]. This has been demonstrated primarily in soils that are highly weathered or degraded through agricultural activities [42-44]. Much of the initial information concerning biochar effects on soil parameters and crop yields has come from studying properties of Amazon Dark Earth Anthrosols to surrounding Oxisols [47]. The soils in this region, known as *terra preta,* were created by pre-Columbian Indians using a slash-and-char method[48].

A combination of biochars ability to raise soil pH [67], improve physical properties such as water holding capacity retain soil nutrients and reduce leaching losseslikely contribute to its ability to increase plant productivity[68].

Biochar can also affect soil nutrient availability indirectly. Amendments of biochar can add chemically active surfaces that modify the dynamics of soil nutrients or facilitate soil reaction, modify physical properties of the soil (*e.g.*reduce soil bulk density, increase porosity, improve water holding capacity; and encourage the formation of mineral and microbial associations with biochar particles [62-65]. Cation exchange capacity increased in all three Inland Northwest soils but only when biochar was mixed with the mineral soil. This result agrees with previous studies, which generally find a rapid CEC response with fully-incorporated biochar amendments [69], compared to those using top-dressing approaches, which fail to produce a strong influence on CEC [70]. We might expect greater cation retention over time due to increased CEC with biochar aging, and biochar movement into the mineral soil. Freshly produced biochar has less ability to retain cations resulting in minimal CEC [40-42], but with time and incorporation in the soil, the surfaces of biochar particles oxidize and interact with soil constituents, resulting in an increase in functional groups and greater surface and negative charge [71], which ultimately leads to increases in CEC. It is possible that topdressing failed to enhance the formation of organo-mineral complexes because a majority of biochar remained on the soil surface over this 30-week study, or that the biochar did not sufficiently oxidize over this time-scale, resulting in minimal change in CEC.

Biochar can indirectly affect nutrient availability by altering soil pH. Since biochar typically has higher pH than soil it can act as a liming agent resulting in an overall increase in soil pH [72]. Higher soil pH increases nutrient availability and decreases the proportion of Al^{+3} and H^{+} ions occupying cation exchange sites, which effectively increases base saturation [73]. The starting pH of the Spodosol was the lowest among the tested soils, with a value of 3.9; whereas biochar had a pH of 6.8. The surface treatment of biochar caused a small increase in soil pH of the Spodosol. The higher pH of the biochar likely explains the increase in the Spodosol pH. The Andisol had an initial pH that was similar to the pH of the biochar, which would explain why there was no change in pH relative to untreated soil following incubation. Although the Mollisol started out with a pH of 4.4, the addition of high pH biochar resulted in no significant change in pH possibly because this soil is more highly buffered [34]. Soil texture may also play a role.

CONCLUSIONS

Understanding the soil resource in an area and adoptions of management options to improve the productivity of soils is necessary for sustainable use. Use of biochar as a soil amendment with mineral fertilizer and other organic amendments has been proved to enhance agricultural productivity significantly by improving soil properties such as soil pH, electrical conductivity, organic carbon, total nitrogen, available phosphorous, CEC and exchangeable cations. Application of biochar results in positive effect on soil physico-chemical properties. In highly degraded soils it may serve as a soil amendment by increasing the soil pH, P availability, CEC and SOC in a sustainable manner. Biochar can enhance crop yield through improving the chemical and biological properties of the soil including organic carbon and other plant nutrients. The application of biochar alone and in combination with fertilizer significantly increases yield. Significant yield increase with combined application of biochar and chemical fertilizer implies that biochar improved fertilizer use efficiency. A long-term experiment for different soil types and crops is critically important to further assess the potentials of biochar in Ethiopian conditions for other ecosystem functions and mitigation of the problem of climate change.

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