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The Role of Biochar on Acid Soil Reclamation and Yield of Teff (*Eragrostis tef* [Zucc] Trotter) in Northwestern Ethiopia

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Abstract

The study was conducted to investigate the effect of biochar on soil properties and teff yield at Koga watershed, West Gojam Zone, Amhara National Regional State, Ethiopia. Five rates of amendments including three rates of biochar (4, 8, 12 t ha^{-1}), one rate of lime (2 t ha^{-1}) and no amendment were combined in a factorial design with full, half and zero rates of the recommended N & P fertilizer rates. A randomized complete block design with three replications was used. Composite soil samples were taken from the experimental sites using soil auger at 0-20 cm soil depth before treatment application; and treatment based soil sampling was made after harvest. Soil pH, organic carbon, CEC, total N and available P were analyzed using standard laboratory procedures. Grain yield and biomass data were also collected and analyzed. Results of the study indicated that application of biochar increased soil pH, CEC, available P and organic carbon and significantly increased yield. Using 12 t ha^{-1}, 8 t ha^{-1} biochar, and 2 t ha^{-1} lime rates of biochar, 2.67, 1.98 and 2.45 t ha^{-1}, respectively teff grain yield was harvested while the lowest grain yield (1.44 t ha^{-1}) was found from treatment with no lime or biochar. Biochar combined with NP fertilizers increased yield significantly compared to plots that received fertilizer or lime alone; suggesting that biochar improved fertilizer use efficiency.

Keywords: biochar, acid soil, Koga watershed, soil properties, crop yield

1. Introduction

Teff (*Eragrostis tef* [Zuuc]**)** is one of the stable food crops in Ethiopia. Teff covers 2.73 and 1.00 million ha of land with an average productivity of 1.28 and 1.31 t ha^{-1} in Ethiopia and Amhara Region, respectively (CSA, 2012). The productivity of teff is strongly affected by soil fertility, acidity and water logging (Wakene & Yifru, 2013). Therefore, increasing productivity of this crop could be achieved by ameliorating the soil conditions and improving the fertility of soils. Leaching of nutrients from agricultural soils depletes soil fertility and accelerates soil acidification that aggravates crop yield reduction. Nutrient leaching varies substantially with rainfall intensity and soil properties (Juo & Manu, 1996). In Ethiopia 40.9% of the soil is acidic; out of which 27.7 % is moderately to weakly acidic (pH of 5.5 - 6.7) and 13.2 % is strongly to moderately acidic (pH< 5.5) (Mesfin Abebe, 2007).

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) (Lehmann & Joseph, 2009). It stores carbon for long time, ameliorates degraded soils and reduces soil acidity for better crop production (IBI, 2012). It improves crop yield when applied as a soil amendment (Major et al., 2010). 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 (Glaser et al., 2002; Sohi et al., 2009; Lehmann et al., 2011).

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) (Yaman, 2004). 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. Lehman and Rondon (2006) reported an estimate of 30 to 40 % by weight of charcoal production

with barbeques system in Colombia is a waste. The wastage varies depending on the charring method, the feedstock type, the environmental conditions, and on post charring management of the charcoal. The fraction of waste from charcoal lies between 10 and 15% (Lehmann & Rondon, 2006).

According to FAO (2011), charcoal production in Ethiopia is estimated to be 3.92 million tonnes. From the production of this, if a minimum of 4% of the charcoal is non-marketable, 156,800 tonnes of biochar can be obtained. According to Mecha District Office of Agriculture, 880 tonnes of charcoal were exported by commercial traders from the district between December 2012-March 2013 (personal communication). It is assumed that more than this could be consumed and sold in the nearest cities like Bahr Dar, Merawi and others. Therefore, 3520-7040 tonnes year^{-1} charcoal production is estimated in Mecha district alone and with 4% non-marketable parts of it, 141-282 tonnes year^{-1} waste char can be used as a biochar to ameliorate the acidic soils of the district.

Soil management by biochar increases nutrient availability, pH, CEC, crop yields and decreases risk of crop failure as well as opens new possibilities for cropping of high-value crops (Edmunds, 2012; Major et al., 2010; Lehman and Rondon, 2006). Despite the high potentials of biochar in Ethiopia, only very limited information exists. Therefore, this study was carried out to investigate the effect of biochar on selected soil chemical properties and teff yield.

2. Material and Methods

2.1 Description of the Study Area

The study was carried out at Koga watershed. Koga is situated in Mecha District, West Gojam Zone of Amhara National Regional state, Ethiopia. Mecha district, where the study site is located lies between 11°10′ N to 11°25′ N latitude and 37°02′ E to 37°17′ E longitude at an altitude ranging from 1900 to 3200 masl. The mean annual rainfall at Merawi town is 1589 mm and mean temperature is 16-20°C (Nigusssie & Yared, 2010). Nitisol is the dominant soil type in the study area (Yihenew, 2002) and it is moderately acidic (Yihenew, 2002; Birru et al., 2013). The command area of Koga irrigation scheme is 7,000 ha (Figure 1).

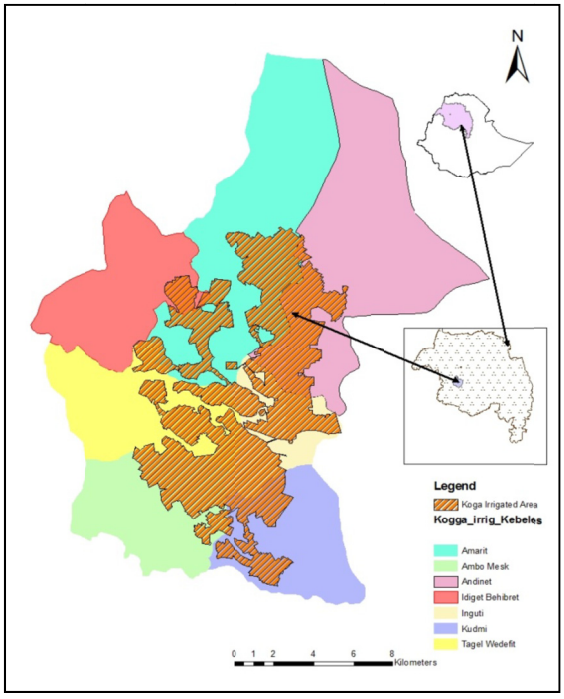

Figure 1. Koga Irrigation command area in the Koga watershed

2.2 Experimental Setup

The field experiment was carried out in 2012 using 15 treatments. Three rates of biochar (4, 8, 12 t ha^{-1}), one rate of lime (2 t ha^{-1}) and a control treatment (without biochar and lime) were combined in a factorial arrangement with three rates of chemical N and P fertilizer rates (0, ½ and full recommended). The recommended fertilizer rates for the specified crop at the study area are 40 kg ha^{-1} N and 60 kg ha^{-1} P_2O_5 that is equivalent to 36 kg Urea and 130 kg

DAP. A randomized complete block design (RCBD) with three replications was used. A recently released variety of teff (*Kuncho*) with the seed rate of 25 kg ha^{-1} was used as a test crop.

Eucalyptus char from commercial sellers at Merawi town was collected and the bigger sized were crushed and fine grained in order to distribute them uniformly and increase the surface area of the char for better soil-char contact (Figure 2). Lime produced from Dejen lime mill enterprise was used. Biochar and lime were broadcasted and incorporated to the soil at time of planting. DAP fertilizer was applied at planting while urea at tillering.

Figure 2. The state of charcoal before (left) and after (right) crashed

2.3 Soil Sampling

Prior to planting and before application of biochar and lime, composite soil samples were taken from the experimental sites using soil auger in 0-20 cm soil depth. At harvesting, soil samples from each treatment were taken and independently analyzed. Soil samples were air dried under shade, grounded by mortar & pestle and sieved to pass through 2 mm mesh.

2.4 Soil Analysis

The soil pH was determined using glass electrode pH meter in 1:2.5 soil to water ratio in volume and exchangeable acidity (Al^{+3} and H^{+}) were extracted with KCl solutions (Sahlemedihn & Taye, 2000). Total nitrogen analysis was done using the Kjeldahl method (Jackson, 1958). Available phosphorus was determined by Bray II method (Bray & Kurth 1945). Cation exchange capacity (CEC) was determined using the ammonium replacement method. Soil Organic Carbon (SOC) was determined following the wet digestion method used by Walkley and Black (Van Reeuwijk, 1992) and organic carbon was converted to organic matter by multiplying with a coefficient of 1.724.

2.5 Agronomic Data Collection and Interpretation

Crop data, including dry biomass and grain yield were collected. Analysis of variance (ANOVA) for yield and yield data were conducted using SAS 9.2 version (SAS, 2008). In conditions where ANOVA is significant, the treatment means were compared using Duncan's multiple range test (DMRT).

3. Result and Discussion

3.1 Effect of Biochar on Soil Properties

3.1.1 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}. Birru et al. (2013) also 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 3). 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 (Brady & Weil, 2008).

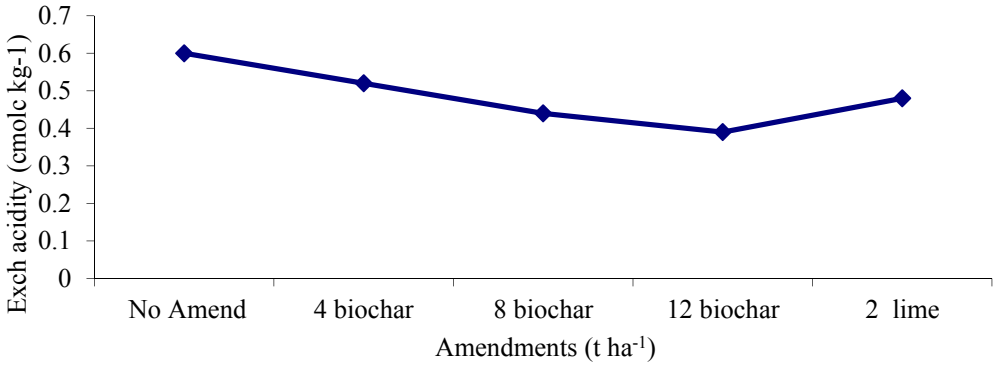

Figure 3. Effect of biochar on exchangeable acidity

Despite the long term potential impacts are to be seen, application of biochar and lime raised the soil pH substantially in one season. The higher pH values (6.17 and 5.9) were obtained on application of 2 t ha^{-1} lime and 12 t ha^{-1} biochar, respectively, whereas the lowest pH (5.38) was found on the control plot (Figure 4). Within one season pH increased by 0.79 and 0.52 units by application of 2 t ha^{-1} lime and 12 t ha^{-1} biochar, respectively from the control. Application of biochar at rates of 8 and 4 t ha^{-1} also showed 0.31 and 0.29 unit increment, respectively on soil pH from the same. It was apparent that the biochar applied in this study had a pH value of 8.43, which is basic in reaction. The alkalinity of most biochar can be beneficial to acidic soils, acting as a liming agent to increase pH, and decrease exchangeable Al (Chan et al., 2007, 2008; Major et al., 2010).

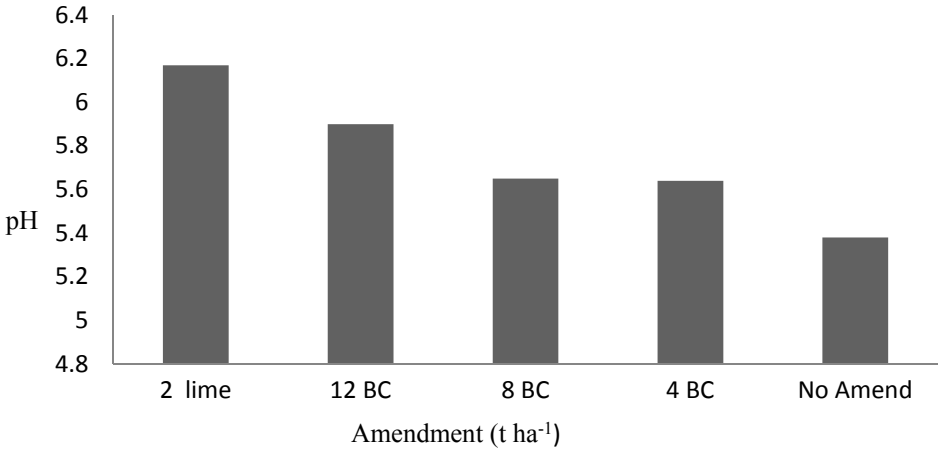

Figure 4. Effect of biochar and lime on soil pH

Depending on the sources of biochar used, basic cations such as Ca, K, Mg, and silicon (Si) can form alkaline oxides or carbonates during the pyrolysis process. Following the release of these oxides into the environment, they can react with the H^+ and Al^{3+}, raise the soil pH, and decrease exchangeable acidity (Novak et al., 2009). The finding of this study is in line with several authors (Chan et al., 2007; Granatstein et al., 2009; Liard et al., 2010; Rodriguez et al., 2009; Yamato et al., 2006) who measured the rises in soil pH by applying biochar to soil. Granatstein et al. (2009) noted that soil pH increased from 7.1 to 8.1 when 39 t ha^{-1} biochar was added to a sandy soil. Liard et al. (2010) also reported that pH increased up to one pH unit after application of biochar. Application of 37 t ha^{-1} wood bark biochar raised the pH by 1.0 to 1.5 units (Yamato et al., 2006). Similarly, Rodriguez et al. (2009) found an increase in soil pH by nearly 2 units due to addition of biochar. Chan et al. (2007) in their pot experiment found that the pH increased by 1.22 from the control by application of 100 t ha^{-1} in the absence of N fertilizer and the corresponding increase was 0.61 units in the presence of N fertilizer. They related the reduction of pH was accompanied by significant reduction in exchangeable Al by >50% at the higher rates of biochar application (50 and 100 t ha^{-1}).

3.1.2 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^{-1} biochar and 2 t ha^{-1} lime, respectively (Figure 5). 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/P_2O_5) 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 acidic soil is raised and the amount of fixed P could be reduced. Consequently the applied P could not be reacting with Al and Fe and precipitated as $AlPO_4$ and $FePO_4$. 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. Van Zwieten et al. (2010) 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. The lime (as carbonates) in the biochar decreased the availability of Al to below detection limit. Achalu et al. (2012) 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 (Tisdale et al., 2002). According to Griffith (2006) and Tisdale et al. (2002), 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. Miller and Donahue (1997) also indicated that phosphorus is most available near pH 6.5 for mineral soils. Tisdale et al. (2002) 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 $H_2PO_4^-$ which is more readily absorbed by the plant than HPO_4^{2-} and occur at pH values above 7.0 (Tisdale et al., 2002).

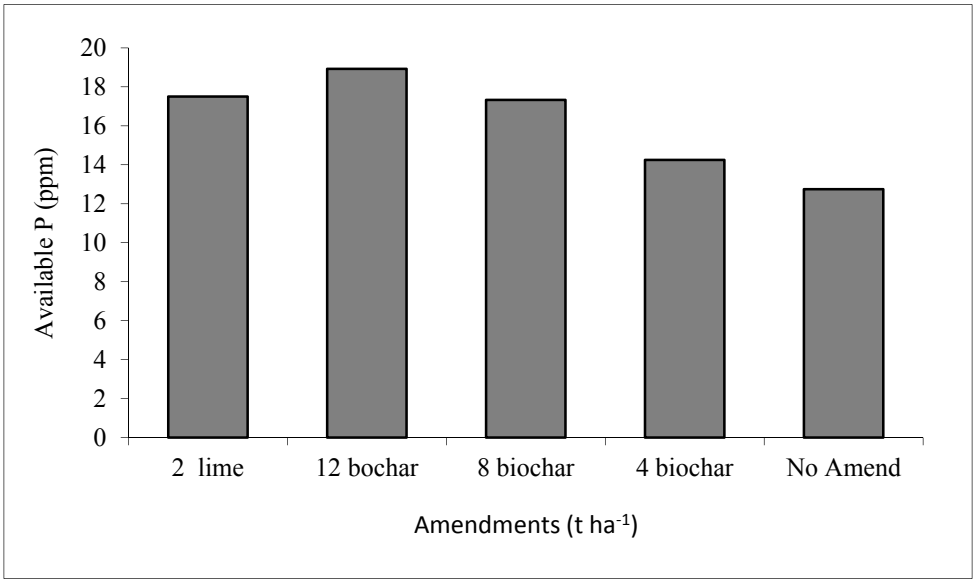

Figure 5. Effect of biochar and lime on available phosphorus

The second reason is the presence of available phosphorus in biochar itself. Deluca et al. (2009) reported that biochar inherently contains a high content of soluble P salts formed during the charring of organic materials. Lehmann and Rondon (2006) reviewed that an increase in availability of phosphorus after application of biochar could be due to the direct nutrient addition by the biochar and changes in soil microbial dynamics. Edmunds (2012) stated that the concentration of Mehlich-I extractable P was significantly increased in all biochar amended soil samples that were 70 to 175 times higher than un-amended soil. Chan et al. (2007) and Lehman et al. (2006) also discussed that application of biochar increased phosphorus concentration. Abebe et al. (2012) also mentioned that the amount of available phosphorous in chromium polluted and unpolluted soils were significantly increased by application of biochar. Collins (2008) as cited in Granatstein et al. (2009) stated that increasing available P in soil

is one of the beneficial effects of liming. For soils that require liming, there is growing evidence that biochar may provide similar benefits of improving soil pH balance.

Soil analysis result showed that application of fertilizer increased available P; 14.70 ppm, 16.35 and 17.30 ppm were found on the application of 0, 23/30 and 46/60 (N/P_2O_5) kg ha^{-1} (Table 1). Accordingly, application of biochar and lime with fertilizer and without fertilizer showed different values on available P. Biochar rates and lime showed higher P at higher rates of fertilizer. As the rate of biochar and the rate of fertilizer increases, the P value also increases.

Table 1. Effect of fertilizer on selected soil chemical properties

Fertilizer N/P_2O_5 (kg ha^{-1})	pH	Total N (%)	Available P (ppm)
0	5.73	0.17	14.70
23/30	5.77	0.18	16.35
46/60	5.75	0.18	17.40

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. Van Zwieten et al. (2010) 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. The lime (as carbonates) similar to the biochar decreased the availability of Al to below detection limit. Achalu et al. (2012) also reported that 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.

3.1.3 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 $cmol_c$ 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 $cmol_c$ kg^{-1}) was found in the control plots (Figure 6). 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. It is highly porous, contains variable charge, and hence improves surface sorption capacity when added to the soil (Glaser et al., 2002). Edmunds (2012) also mentioned that biochar has high CEC. Glaser et al. (2001) discussed that after weathering, oxidation occurs that results in the formation of carboxylic groups on the edges of the aromatic carbon, which results in greater CEC.

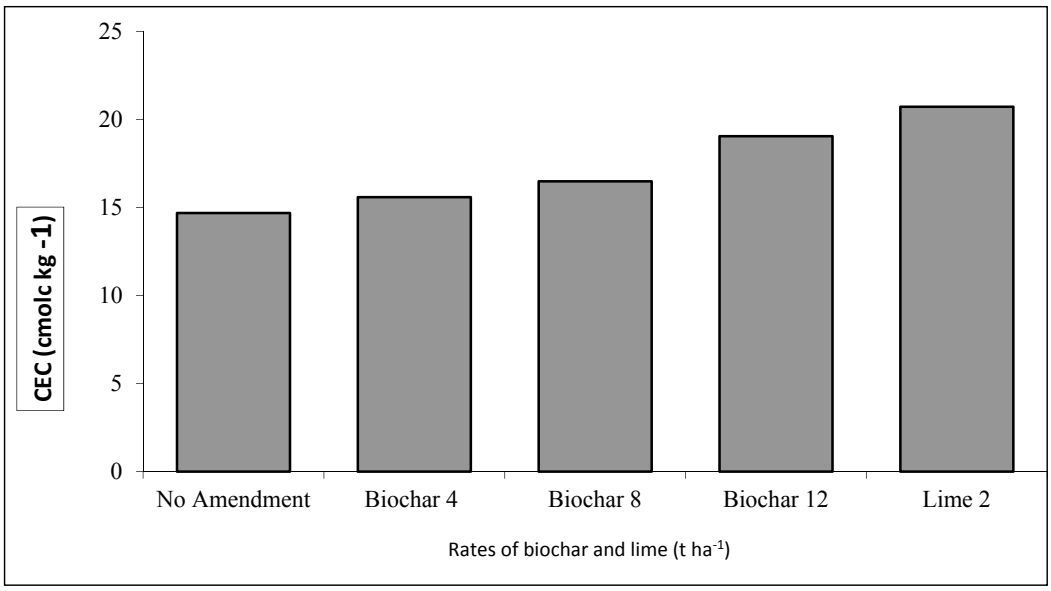

Figure 6. CEC as influenced by biochar and lime application

The benefit of lime to enhance CEC was reported by Achalu Cimdi et al. (2012). 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 dependant negative charges which can increase with increasing soil pH due to applied lime.

3.1.4 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, Achalu chimdi et al. (2012) 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.

Table 2. 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

Application of biochar resulted in little differences on total nitrogen. Actually the study area has low total nitrogen (Birru et al., 2013). 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 (Clough et al., 2013). The review of Clough et al. (2013) indicated that biochar has a high adsorption capacity of NO_3^- that prevents nitrogen leaching from the top soil. Kamayama et al. (2010) concluded that NO_3^- was only weakly adsorbed to biochar, that it could be desorbed by water infiltration, 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 (Steiner et al., 2007; Major et al., 2010). 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 (Lehman, 20003; Major et al., 2010). Chan et al. (2007) reported that plant yield increase in the presence of both biochar and fertilizer is related to nitrogen fertilizer use efficiency. Achalu et al. (2012) 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.

3.2 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 3). In general, biochar and lime applications resulted in a significant yield increase ($P<0.01$) (Table 3). 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.

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 3). 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 3).

Table 3. 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 ($P \leq 0.01$), * significantly different at $P \leq 0.05$ and ns denotes for not significantly different at $P \geq 0.05$. Means with the same letter in in a column are insignificantly.

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 (Major et al., 2010). Edmunds (2012) 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. Lei Dou et al. (2012) 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% (Vaccari et al., 2011).

The effect of biochar might be more pronounced in long year bases. According to Major et al. (2010), 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 soils 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 (Major et al., 2010).

3.3 Interaction Eeffects of Ccombined Application of Biochar, Lime and Chemical Fertilizers on Teff Yield

The interaction of amendments with chemical fertilizer also showed significant effects ($P<0.01$). Maximum grain yield (3.13 t ha^{-1}) was found by application of 12 t ha^{-1} biochar combined with 100% recommended chemical fertilizer (40/60 N/ P_2O_5 kg ha^{-1}) followed by 2.88 t ha^{-1} grain yield by using 2 t ha^{-1} lime combined 100% recommended chemical fertilizer. The lowest grain yield (0.82 t ha^{-1}) was found from control treatment (Table 4). Application of 12 t ha^{-1} biochar without fertilizer was higher than all other treatments except 2 t ha^{-1} lime and 8 t ha^{-1} biochar combined with full rate of fertilizer. Application of biochar and lime as a soil amendment significantly increased yield, even in the absence of fertilizer (Table 4). For instance application of 12 t ha^{-1} biochar and 2 t ha^{-1} lime without fertilizer exceeds full fertilizer rate without amendment in grain yield. Similarly, the lowest rate of biochar (4 t ha^{-1}) with 50% recommended fertilizer had similar yield response with full rate of fertilizer without amendment.

Application of 12 t ha^{-1} biochar 2 t ha^{-1} lime and 8 t ha^{-1} biochar combined with full fertilizer gave 282.97%, 227.54 and 227.54% yield advantage over the control plots, respectively. Actually, full and 50% fertilizer rate without biochar and lime gave 128.86% and 98.65% yield advantages, respectively over the control.

This result indicated that, integrated use of biochar and lime with fertilizer boosts grain yield of crop. Similar synergistic effects reported in previous field experiments (Muhamed, 2012; Yamato et al., 2006; Zheng et al., 2010) and greenhouse experiments (Chan et al., 2007; 2008). Muhamed et al. (2012) found higher grain yield (4.19 t ha^{-1}) from plots where biochar was applied in combination with chemical fertilizer. In Western Australia, when using soluble fertilizers at half the recommended rate (30 kilograms per hectare), addition of biochar at 6 tonnes per hectare resulted in a yield increase of 18% (Solaiman et al., 2010 as cited in Sparkes & Stoutjesdijk, 2011). Zheng et al. (2010) reported that biochar as a soil amendment may reduce fertilizer use while maintaining high crop yield. The application of biochar as a soil amendment significantly increased crop yields even in the absence of nitrogen fertilizer (Zheng et al., 2010). Chan et al. (2007) reported a significant increase in the dry matter (DM) production of radish when N fertilizer was used together with biochar in a pot experiment. Their results showed

that in the presence of N fertilizer, there was a 95 to 266 % variation in yield by applying biochar to 100 t ha^{-1}. In a study conducted on the response of DM production of radish using green wastes, the biochar application increased the P concentration. Significant yield increases were only found at biochar application rates greater than 50 t ha^{-1}, and when no N fertilizer was applied. This increase was due to the high concentrations of available P found in the biochar, and because P was no longer limiting (Chan et al., 2007).

Table 4. Effect of biochar combined with chemical fertilizer on yield of Teff

Amendments	Fertilizer Rate N/P_2O_5 (kg ha^{-1})	Grain Yield (t ha^{-1}) +	Dry Biomass Yield (t ha^{-1})
No Amend	0	0.817 ^{h}	9.22 ^{f}
	20/30	1.623 ^{gf}	11.54 ^{def}
	40/60	1.870 ^{ef}	13.89 ^{cde}
4 t ha^{-1} biochar	0	0.959 ^{h}	9.37 ^{f}
	20/30	1.860 ^{f}	14.33 ^{cd}
	40/60	2.354 ^{cde}	15.76 ^{bc}
8 t ha^{-1} biochar	0	1.266 ^{gh}	10.40 ^{ef}
	20/30	1.999 ^{def}	13.59 ^{cde}
	40/60	2.676 ^{abc}	17.03 ^{bc}
12 t ha^{-1} biochar	0	2.413 ^{bcd}	16.15 ^{bc}
	20/30	2.462 ^{bcd}	16.14 ^{bc}
	40/60	3.129 ^{a}	21.04 ^{a}
2 t ha^{-1} Lime	0	2.182 ^{cde}	13.36 ^{cde}
	20/30	2.296 ^{cde}	13.59 ^{cde}
	40/60	2.877 ^{ab}	18.16 ^{ab}
Probability (0.05)		**	**
CV		12.87	12.35

+ = Means with the same letter are not significantly different.

4. Conclusions

Application of biochar resulted in positive effect on soil chemical properties in the study site. 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 teff yield through improving the chemical and biological properties of the soil including organic carbon and other plant nutrients. This result also indicates application of biochar alone and in combination with fertilizer significantly increases yield. Significant yield increase was also achieved by combined application of biochar with chemical fertilizer, implying the role of biochar to improve 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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