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Full Length Research Paper

Impact of Beressa river water quality on the chemical properties of soils along its bank

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Beressa is a major perennial river in the North Shewa Zone of Amhara regional state and it takes the north-west ward to join the Jema River, which form the tributary of the Blue Nile around a place known as Sundo Meskel near the lower side of Abay Bereha. On its natural flow way, the River provides different uses that can be determined in terms of environmental, economical and social values. However, the River is facing an interruption on its potential service especially for irrigation due to its quality deterioration by the discharge of untreated wastes from different sectors in the town of Debre Berhan. Thus, this study was conducted to reveal the impact the river water quality on the chemical properties of the irrigated soils along the river bank. On the bases of their position and extent of water pollution, three different farms were identified and representative soil samples were collected from each for laboratory analysis. All the soils were clay loam in texture with the lowest amounts of pH (6.10), electrical conductivity (EC) (0.10 dS cm⁻¹), organic matter (OM) (3.46%), total N (0.22%), C:N (9.12), available P (30.35 mg kg⁻¹), cation exchange capacity (CEC) (23.75 cmol(+) kg⁻¹), Na (0.11 cmol(+) kg⁻¹), K (0.73 cmol(+) kg⁻¹), Ca (8.25 cmol(+) kg⁻¹), Mg (4.32 cmol(+) kg⁻¹), Cu (1.19 mg kg⁻¹), Zn (2.18 mg kg⁻¹), Cr (1.15 mg kg⁻¹) and Pb (1.11 mg kg⁻¹) at farm 2 (never been irrigated from the River water), and had no detected Cd, Ni, As and Hg. Therefore, in addition to the difference in agronomic management practices, the River water had a direct connection with almost all presences of the concerned chemicals specifically in the soils of irrigated farms. Eventually, conducting pollution remediation studies is as such important in curing the current illness in the Beressa River water and in some instances in the soils under irrigation.

Key words: Water quality, heavy metals, micronutrients, soil chemical compositions.

INTRODUCTION

Unsafe industrial and municipal wastes can introduce hazardous chemicals into the environment which cause ecological imbalance and health problems (Pierzeynski et

al., 2000). These wastes, although useful as a source of nutrients, are also sources of carcinogens and toxic metals (Zhen-Guo et al., 2002). Unwise and poorly practiced

urban and industrial activities can degrade the physical, chemical and biological properties of the soil and in many cases they irreversibly reduce its multi functionality (Blum, 1996). Moreover, undesirable and over use of agricultural chemicals has different effects on fertility and productivity of the soil and quality of fauna and flora in the ecosystem. For example, triclopyr inhibits soil bacteria that transform ammonia into nitrite (Pell et al., 1998). Glyphosate reduces the growth and activity of free-living nitrogen-fixing bacteria in soil (Santos and Flores, 1995) and 2,4-D reduces N fixation by reducing the growth and activity of bacteria that live on the roots of bean plants (Fabra et al., 1997).

Excess entrance of inorganic pollutants into the soil reduces the natural filtering and buffering capacity of the soil (Blum, 1996) and according to Ma and Rao (1997), the function of the soils in the ecosystem is affected. For instance, a polluted soil causes a pressure on sensitive microorganisms and changes their diversity and population size (Zaguralskaya, 1997; Pawlowska and Charvat, 2004). Moreover, pollution reduces the fertility status of a soil which finally affects the quality of food products (McGrath, 1996). According to Sawyer and McCarty (1978), organic pollutants with high chemical oxygen demand (COD) levels comprise a reduced chemical species (Fe, Mn and S) which determine the quality of the soils to support life. Most of the time, atmospheric and aquatic pollutants finally come back to soil and has different effects on plants and animals (Miller and Gardiner, 1998) and make the soil pollution to be more serious than both water and air pollutions; because, once the pollutants are accumulated in the soil, they may require centuries to be removed through leaching, plant uptake, erosion or other means to alleviate (Basta and Tabatabai, 1992).

Beressa is a major perennial River in the North Shewa Zone of Amhara Regional State with a maximum and minimum discharges of 58.78 and 0.40 m³ s⁻¹ in August and January, respectively (MoWR, 1995). The River has a total catchment area of 211 km² and a source on the Qundi highlands at about 30 km east of Debre Berhan town and takes the north-west ward to join the Jema River, which form the tributary of the Blue Nile around a place known as Sundo Meskel near the lower side of Abay Bereha. In its flow of natural way, the River has different purposes that can be determined in terms of environmental, economical and social values. For instance, it is mainly used for irrigated commercial vegetable production during dry season.

However, the River is facing an interruption on its potential service due to unwise and uncontrolled discharge

of liquid and solid wastes from municipality and industries which resulted from ignorance or non-ethical attitude, lack of environmental impact assessment, lack of awareness and absence of control measures. According to Negash et al. (2011), the River has been polluted with oxygen demanding wastes (biological oxygen demand/BOD and chemical oxygen demand/ COD), water soluble inorganic chemicals (acids, salts and heavy metals such as Cd, Cr, Pd, Ni, As and Hg), inorganic plant nutrients (water soluble nutrients and phosphate), organic chemicals (plastics, pesticides), sediment or suspended matter and thermal pollution (using River water for cooling process).

All the aforementioned inconvenient conditions create an opportunity for deterioration of the water quality for various domestic uses and in turn affect the property (physical, chemical and biological) of the soils under irrigation and the plants grown on these soils. Thus, this study was initiated and conducted with a specific objective:

- To reveal the impact of the Beressa River water quality on the chemical properties of soils along its bank.

MATERIALS AND METHODS

Description of the study area

The study was conducted at Tebasie sub-town of Debre Berhan town which is located at 09° 35' 45" to 09° 36' 45" North latitude and from 39° 29' 40" to 39° 31' 30" East longitude and found at 125 km North east of Addis Ababa with an elevation ranging between 2800 and 2845 meters above sea level. The twenty seven (27) years (1985 to 2011) data obtained from the Ethiopian National Meteorological Agency indicates that, the area receives a mean annual rainfall of 927.10 mm and characterized by a unimodal rainfall pattern with a maximum (293.02 mm) and minimum (4.72 mm) peaks in August and December, respectively. The mean monthly maximum and minimum temperature range from 18.3 to 21.8°C and from 2.4 to 8.9°C, respectively.

Site selection, sample collection and preparation

Three different farm sites were selected based on their position and exposure to pollution; one was the Debre Berhan University's Research and Demonstration Field (Farm 2) that has never been irrigated by the Beressa River water, the rest two were the different farms around the Eyerusalem (Farm 1) and Tera (Farm 3) vegetable farms that are located at the upper and down streams of the River on its way through the Tebasie sub-town (Figure 1). These two sites have been under irrigation by the River water especially at the time of dry season for commercial vegetable crop production. Representative soil samples were collected from each

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farm by considering the slope gradient (bottom, medium and upper) and other visual variability (soil colour, farm management and plantation) in a zigzag pattern at a depth of 0 to 20 cm using an auger, with an interval of ten steps and above fifteen spots per single farm. Then, it was air dried on a clean plastic tray at a room temperature for about eight weeks in a dust free atmosphere and mixed properly on a 2 m by 2 m plastic sheet to make a composite sample. The soil samples were ground by using mechanical grinder and were passed through a 2 mm sieve in preparation for laboratory analysis.

Laboratory analysis

The soil pH was determined in H₂O using a 1:2.5 soil to water ratio (Van Reeuwijk, 1993). Electrical conductivity was measured by conductivity meter on saturated soil paste extracts obtained by applying suction (Okalebo et al., 2002). Organic carbon of the soils was determined following the wet digestion method as described by Walkley and Black (1934), while the percentage organic matter (OM) of the soils was determined by multiplying the percent organic carbon value by 1.724. Total N was determined by the micro-kjeldahl digestion, distillation and titration method and the available P was determined using the Olsen extraction method (Olsen et al., 1954).

Cation exchange capacity (CEC) was determined at soil pH level of 7 after displacement by using 1 N ammonium acetate method in which it was, thereafter, estimated titrimetrically by distillation of ammonium that was displaced by sodium (Chapman, 1965). The exchangeable bases (Ca, Mg, Na and K) in the soil were determined from the leachate of 1 molar ammonium acetate (NH₄OAc) solution at pH 7. Exchangeable Ca and Mg were determined by atomic absorption spectrophotometer, while K and Na were read using flame photometer (Rowell, 1994). Percent base saturation was calculated as the ratio of the sum of the base forming cations (Ca, Mg, Na and K) to the CEC of the soil and multiplied by 100.

As described by Lindsay and Norvell (1978), extractable micronutrients (Fe, Mn, Zn and Cu) and heavy metals (Cd, Cr, Pb, As, Ni and Hg) contents were extracted from the soil samples with DTPA and aqua regia digestion, respectively, and all were quantified by flame atomic absorption spectrometry (AAS). Moreover, soil particle size distribution was determined by the Bouyoucos hydrometer method after destroying the OM using hydrogen peroxide (H₂O₂) and dispersing the soil with sodium hexametaphosphate (NaPO₃) (Bouyoucos, 1962).

RESULTS AND DISCUSSION

The soil textural class of all farms was clay loam with relatively high silt (35.0%), sand (39.0%) and clay (35.0%) compositions at Farms 1, 2 and 3 (Figure 1), respectively (Table 1). According to Rans (1991), soil texture is a stable characteristic that influences the physical and chemical properties of the soils depending on the nature and amounts of clay and organic matter. Having a similar texture implied that the quality of the Beressa River water had nothing to do with the textural class of the soils. However, the River might have a concern on the distribution of particle size at the soil surface; because the farms along the bank had a relatively higher amount of easily transported finer soil

particles (clay and silt) that probably modify the textural class through a time. The texture of a soil may be modified due to the removal of finer particles by erosion; leaching and mixing up of surface plus sub-surface soils during mechanical tillage and other management practice (Wakene, 2001).

The soil pH values were 6.66, 6.10 and 6.76 at farms 1, 2 and 3 (Figure 1), respectively (Table 1) that was found as neutral (6.6 to 7.3) and slightly acidic (6.1 to 6.5) (Bruce and Rayment, 1982). The two concerned farms would have a connection with the river through irrigation, due to its slightly alkaline pH (Awgchew et al., 2015). Irrespective of their nutrient adsorption, solubility and exchanging differences, soils having a pH value between 5.5 and 8 are considered as ideal for plant growth (Gazey and Davies, 2009).

The electrical conductivity of saturated extracts (ECe) values of the soils at farms 1, 2 and 3 were 1.21, 0.86 and 1.46 dS m⁻¹, respectively (Table 1) that found under a non saline (< 2 dS m⁻¹) range (USSLS, 1954). Eventhough the river water had no effect of salinity, it was possible to say that the river had some relation with the irrigated soils; because as indicated by Awgchew et al. (2015), there was a detectable amount of salinity in the water near the irrigated farms that directly brought a relatively higher ECe values for the irrigated soils than non-irrigated one and also from the irrigated farms, Farm 1 (Figure 1) had the lower salinity.

The amounts of organic matter (OM) in the soils of Farms 1, 2 and 3 (Figure 1) were 5.44, 3.46 and 4.39%, respectively (Table 1) that were under very high (> 5.15%) and high (3 to 5.15%) ranges (Charman and Roper, 2007). Generally, the irrigated soils had higher amount of OM than the non-irrigated but the Beressa River had no negative concern on the OM content of the irrigated farms; because according to Awgchew et al. (2015), the concentrations of oxygen demanding organic pollutants (COD and BOD) in the water taken from the sites near farm 1 were very low.

The amounts of total nitrogen (TN) were 0.31, 0.22 and 0.27% in the soils of Farm 1, 2 and 3 (Figure 1), respectively (Table 1) and were under high (0.25 to 0.50%) and medium (0.15 to 0.25%) ranges (Bruce and Rayment, 1982). Moreover, the C:N of these farms were 10.18, 9.12 and 9.43 accordingly that found under low (10 to 15) and very low (< 10) ranges (Newey, 2006) with a fairly good (8:1 to 15:1) level of C: N (Prasad and Power, 1997). In addition to the differences in the type, source, amount and rate of applying OM and N containing fertilizers, the Beressa River water might contribute a little for the TN content of the irrigated soils; because, there were significant amount of ammonia and nitrate in the water samples near Farms 1 and 3 (Awgchew et al., 2015).

The amounts of available P were 46.86, 30.35 and 40.05 mg kg⁻¹ in the soils of Farms 1, 2 and 3 (Figure 1),

Table 1. Composition of essential nutrients and heavy metals in irrigated and non-irrigated soils.

Parameter	Farm 1	Farm 2	Farm 3
Particle size distribution (%)			
Clay	31.0	28.0	35.0
Silt	35.0	33.0	32.0
Sand	34.0	39.0	33.0
Texture class	Clay loam	Clay loam	Clay loam
pH (1:2.5 soil to water)	6.66	6.10	6.76
E _{Ce} (dS m ⁻¹)	1.21	0.86	1.46
Organic matter (%)	5.44	3.46	4.39
Total N (%)	0.31	0.22	0.27
Available P (mg kg ⁻¹)	46.86	30.35	40.05
CEC (cmol(+) kg ⁻¹)	42.40	23.75	30.51
Exchangeable bases (cmol(+) kg⁻¹)			
Sodium	0.35	0.11	0.36
Potassium	2.06	0.73	1.60
Calcium	12.74	8.25	10.33
Magnesium	7.29	4.32	6.94
Extractable micronutrients (mg kg⁻¹)			
Iron	75.75	89.56	69.59
Manganese	11.68	15.83	13.63
Copper	1.60	1.19	1.30
Zinc	2.37	2.28	2.55
Total heavy metals (mg kg⁻¹)			
Cadmium	ND	ND	ND
Chromium	19.01	1.15	21.36
Lead	25.81	1.11	22.13
Nickel	ND	ND	1.25
Arsenic	1.81	ND	2.01
Mercury	ND	ND	0.24

ND = Not Detected,

respectively (Table 1) and were found under very high (> 25 mg kg⁻¹) range (Holford and Cullis, 1985). Nevertheless, the Beressa River water might have a connection with the detected amounts of available P in the irrigated soils; because, relatively the higher detections were in the irrigated soils (Farm 1 and 3) and phosphate was one of the pollutants in the river (Negash et al., 2011; Awgchew et al 2015). However, the differences could arise either from the current P status (indigenous/native P) in the soil and/or from the previous P fertilizer application (residual P) (Indiati, 2000) or from the variations in vegetation cover, biomass production and nutrient cycling (Solomon et al., 2002). Moreover, the physico-chemical properties (the nature and amount of soil mineral, soil pH, cation and anion effects, reaction

time and temperature) of soils were reported to influence the availability and adsorption of P in the soil (Landon, 1991; Tisdale et al., 1993).

The values of cation exchange capacity (CEC) (42.40, 23.75 and 30.51 cmol(+) kg⁻¹) and percentage base saturation (PBS) (52.93, 56.46 and 63.03%) were recorded at Farms 1, 2 and 3, respectively (Table 1). According to Metson (1961), the CEC were under very high (> 40 cmol(+) kg⁻¹), moderate (12 to 25 cmol(+) kg⁻¹) and high (25 to 40 cmol(+) kg⁻¹) ranges while the PBS were under moderate (40 to 60%) and high (60 to 82%) ranges. Generally, CEC is derived from the clay and OM fractions (Landon, 1991) and can be affected by the different soil management practices such as cultivation, fertilization and irrigation (Gao and Chang, 1996). This

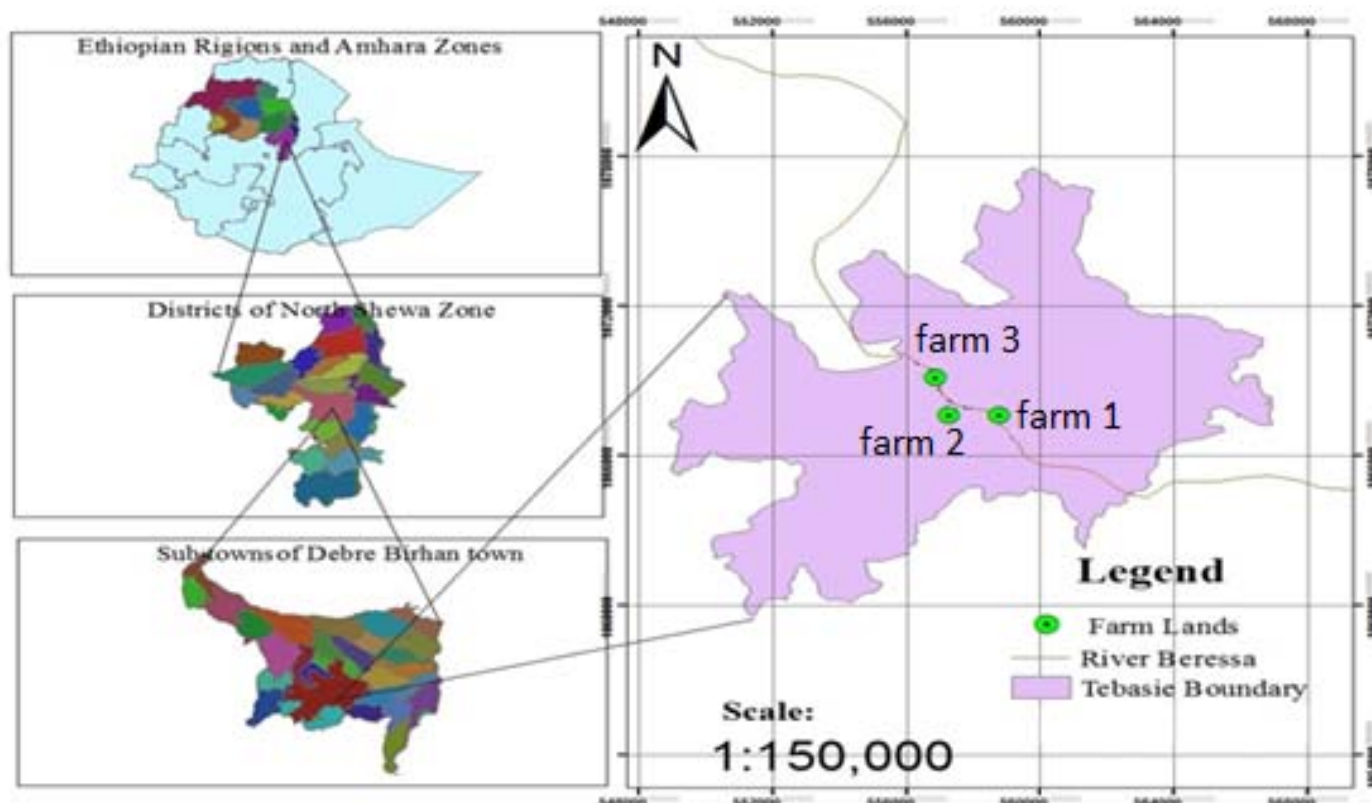


Figure 1. Location map of the study area.

means, the River water might act indirectly on the CEC of the Farm 1 and 3 soils, irrigated, (Figure 1) through irrigation that led to redistribution of finer soil particles and increasing of OM level. The contents of Na were 0.35, 0.11 and 0.36 $\text{cmol}(+) \text{kg}^{-1}$ in the soils of Farms 1, 2 and 3, respectively (Table 1) and were in moderate (0.3 to 0.7 $\text{cmol}(+) \text{kg}^{-1}$) and low (0.1 to 0.3 $\text{cmol}(+) \text{kg}^{-1}$) ranges (Metson, 1961). Even though, the concentration of Na in the Beressa River was below the maximum permissible limit, there was a significant amount in the water near the two irrigated farms, Farms 1 and 3, (Figure 1) (Awgchew et al., 2015) that could have a direct concern with the relatively raised levels in soils upon irrigation.

The lowest (0.73 $\text{cmol}(+) \text{kg}^{-1}$) K content was recorded in the soils of Farm 2 while the highest (2.06 $\text{cmol}(+) \text{kg}^{-1}$) at Farm 1 (Table 1). In addition to the difference in the amount and extent of ash application, previous plantation and farm management practices, the river water might have a connection with the raised amounts in the irrigated soils (Farm 1 and 3, Figure 1); because the concentration of K in the water near the two irrigated farms was a little below its maximum permissible limit (Awgchew et al., 2015). However, all the soils had no

problem of K shortage and were under very high ($> 2 \text{ cmol}(+) \text{kg}^{-1}$) and high (0.7 to 2 $\text{cmol}(+) \text{kg}^{-1}$) ranges (Metson, 1961).

The amounts of Ca and Mg were 12.74, 8.25 and 10.33 $\text{cmol}(+) \text{kg}^{-1}$ and 7.29, 4.32 and 6.94 $\text{cmol}(+) \text{kg}^{-1}$ in the soils of Farms 1, 2 and 3 (Figure 1), respectively (Table 1) at which the Ca found under the range of moderate (5 to 10 $\text{cmol}(+) \text{kg}^{-1}$) and high (10 to 20 $\text{cmol}(+) \text{kg}^{-1}$) while the Mg under high (3 to 8 $\text{cmol}(+) \text{kg}^{-1}$) range (Metson, 1961). The higher presence of these two elements in the soils of the two irrigated farms (Farms 1 and 3, Figure 1) was possibly due to the River water; because there were a significant amount of Ca and Mg in the water near the irrigated farms (Awgchew et al., 2015) and even upon repeated irrigation, their bicarbonate from the river water might precipitate and concentrate them in the soil solution as carbonate.

The highest amounts of Fe (89.56 mg kg^{-1}) and Mn (15.83 mg kg^{-1}) were recorded in the soils of the non-irrigated farm (Table 1). But, they were under high (5.1 to 250 mg kg^{-1}) Fe and medium (10 to 20 mg kg^{-1}) ranges Mn, respectively (Jones, 2003). The River could have no concern with the detected amounts of Fe and Mn in the soils of the irrigated farms (Farms 1 and 3, Figure 1);

because there was no detection of Fe and Mn in the Beressa River water near these farms (Awgchew et al 2015).

The lowest Cu (1.19 mg kg^{-1}) and Zn (1.11 mg kg^{-1}) concentrations were detected in the soils of Farm 2 (Table 1) at which the Cu was under low (0.3 to 2.5 mg kg^{-1}) while the Zn under high (1.1 to 10 mg kg^{-1}) ranges (Jones, 2003). The river water had connection with the amounts of Cu and Zn in the soils of the irrigated farms (Figure 1); because there was a considerable amount of Cu and Zn in the river water near the two irrigated farms (Awgchew et al., 2015) and also the solubility of most micronutrients like Cu, Zn, Mn and Fe is strongly dependent on the soil reaction (Zovoko and Romic, 2011) and form toxic concentrations that hinder plant growth (Miller and Donahue, 1995). Moreover, differences in soil temperature, wetting and drying, tillage practices, redox process, liming and organic matter maintenance can affect the availability of micronutrients in the soil (Fisseha, 1996).

Cadmium was not detected in the soils of all farms (Table 1) and neither in the water around the two irrigated farms (Farms 1 and 3, Figure 1) (Awgchew et al., 2015) implying that there was no worry of Cd. On the other hand, the two higher (19.01 and 21.36 mg kg^{-1}) amounts of Cr were recorded in the soils of Farms 1 and 3, respectively (Table 1). But, all the soils of each farm were below the maximum tolerable limit of 100 mg kg^{-1} (USEPA, 1995). This means, the river might be a source of Cr in the irrigated farms; because there was a detected concentration in the water near these farms (Awgchew et al., 2015; Negash et al., 2011).

The amounts of Pb were 25.81 and 22.13 mg kg^{-1} in soils of irrigated farms and 1.11 mg kg^{-1} in the soils of non-irrigated farm (Table 1) at which all the soils were below the maximum tolerable limit of 150 mg kg^{-1} (USEPA, 1995). The Beressa River appeared to have connection with the detected levels of Pb in the irrigated farms (Farm 1 and 3, Figure 1); because it was the one among the pollutant in river water (Awgchew et al., 2015; Negash et al., 2011). Basically, Ni was not detected in the soils of Farms 1 and 2 and was 1.25 mg kg^{-1} at Farm 3 (Table 1) which was below the maximum tolerable limit of 60 mg kg^{-1} (USEPA, 1995). The River water could be a factor for the presence in the soils of Farm 3 (Figure 1); because the amount in the water near this farm was relatively higher (Awgchew et al., 2015; Negash et al., 2011).

In soils of the non-irrigated farm (Farm 2, Figure 1), it was not detected but was 1.81 and 2.01 mg kg^{-1} in the soils of Farms 1 and 3, respectively (Table 1). Additionally, Hg was not detected at Farms 1 and 2 and was 0.24 mg kg^{-1} at Farm 3 (Table 1). However, the detected As and Hg were below their respected maximum tolerable limit of 20 and 1 mg kg^{-1} , respectively (USEPA, 1995). The Beressa River might be blamed for the

presence of As in the soils of Farms 1 and 3 and that of Hg in the soils of Farm 3; because they were detected in the water at the sites around the concerned farms and were reported as pollutants in the river (Awgchew et al., 2015; Negash et al., 2011).

Conclusions

There was a difference in the particle size distribution of the soils; however, all were similar in their textural class, clay loam. The soil of the non-irrigated farm was the lowest in its pH, ECe, OM, total N, C:N, available P, CEC, Na, K, Ca and Mg which were 6.10 , 0.86 dS m^{-1} , 3.46% , 0.22% , 9.12 , 30.35 mg kg^{-1} , $23.75 \text{ cmol}(+) \text{ kg}^{-1}$, $0.11 \text{ cmol}(+) \text{ kg}^{-1}$, $0.73 \text{ cmol}(+) \text{ kg}^{-1}$, $8.25 \text{ cmol}(+) \text{ kg}^{-1}$ and $2.32 \text{ cmol}(+) \text{ kg}^{-1}$, respectively. The higher amounts of Fe (89.56 mg kg^{-1}), Mn (15.83 mg kg^{-1}), Cu (1.60 mg kg^{-1}) and Zn (2.55 mg kg^{-1}) were recorded at Farms 2, 2, 1 and 3, respectively. Generally, Cd was not detected in the soils of all farms, Ni and Hg at Farms 1 and 2 and As only at Farm 2. Moreover, the lowest amounts of Cr (1.15 mg kg^{-1}) and Pb (1.11 mg kg^{-1}) were found in the soils of Farm 2.

The soil textural class of all farms was clay loam with no salinity problem and commonly all the soils had a favourable/conducive pH and essential nutrients content for health functioning of the soils in the ecosystem but heavy metals like Cr, Pb, As and Hg require extra attention to be adjusted or corrected to their safe level.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

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Full Length Research Paper

Improving available phosphorus in acidic soil using biochar

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Understanding of phosphorus (P) retention and release mechanisms provides crucial information for the effective management of phosphorus to enhance crop production and sustain soil. In acidic soil, available phosphorus is fixed by aluminum and iron. To overcome this problem, soils are limed to fix aluminum and iron. But this practice is not economical for small scale farmers and also it is not environmentally friendly. This study was conducted to improve phosphorus availability using biochar produced from coffee husk and corn cob to fix aluminum and iron instead of phosphorus. Acidic soil samples were mixed with biochar applied at the rates of 0, 5, 10 and 15 t ha⁻¹ and incubated in laboratory for 2 months at ambient temperature. The results showed significant effects (p<0.01) on selected soil chemical properties by increasing soil pH and reduced exchangeable acidity, exchangeable aluminum, and exchangeable iron in a way that enhanced the availability of phosphorus. Due to the incorporation of biochar the available P level increased to a level ranging 3.64±0.34 - 23.21±0.07 mg/kg after an incubation period of 2 months and it increased by 84.3% available phosphorus when coffee husk biochar produced at 500°C temperature was applied at a rate of 15t/ha. Moreover, further field researches are needed to evaluate the effect of biochar on availability, the fate and uptake of available P in soil.

Key words: Fixation, biochar, feedstock, acidic soil, pyrolysis temperature.

INTRODUCTION

Phosphorus is an essential macronutrient for plants next to nitrogen. Understanding of phosphorus (P) retention and release mechanisms provides crucial information for the effective management of phosphorus to enhance crop production and sustain soil. Phosphorus undergoes several geo-chemical processes in soil such as

solubilization, complexation, adsorption, and precipitation that determine its mobility and fate. These chemical processes are a complex function of several soil properties including, Al and Fe oxide form and content, the amount and form of silicate clays, and CaCO₃ content. The impact of these properties on P retention and release

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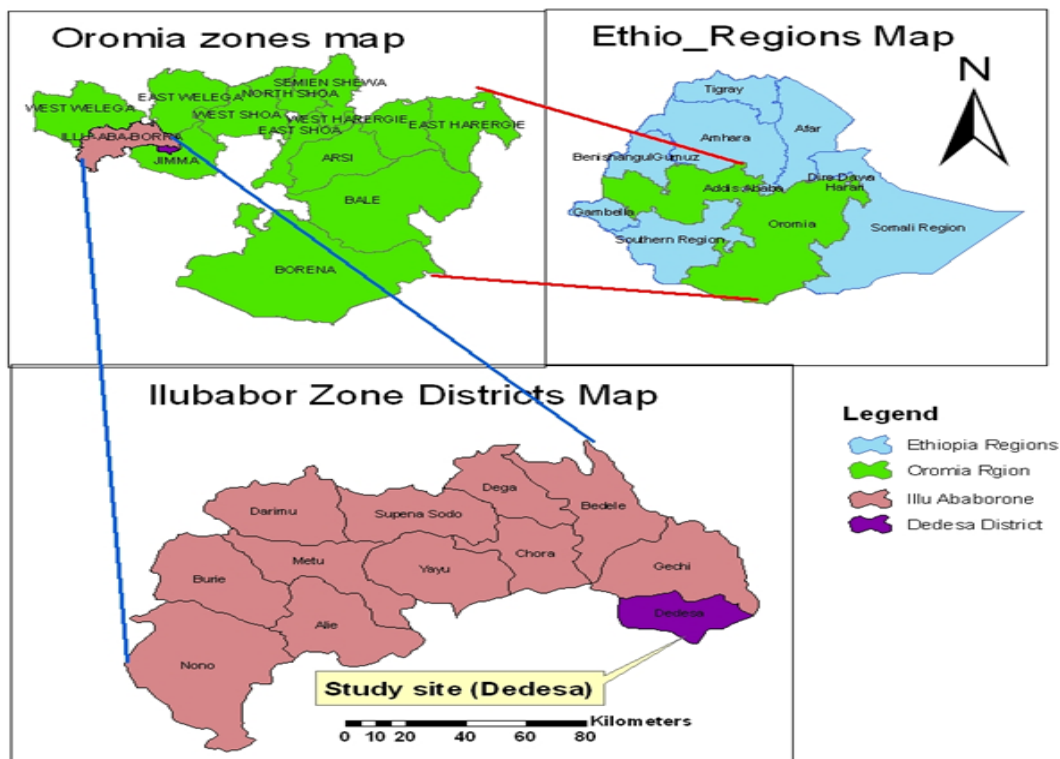


Figure 1. Map of the study area.

depends on soil acidity or alkalinity. The recovery of phosphorus by plants from applied fertilizer is limited in acidic soils due to P fixation. In acidic soils, the P is fixed by high-energy sorption surfaces such as oxides and hydroxides of Fe and Al by formation of insoluble Fe and Al phosphates by ligand exchange and precipitation reactions (Ohno and Amirbahman, 2010). The availability of P is influenced by soil organic matter, pH, and exchangeable and soluble Al and Fe. Phosphorus is generally available to crops at soil pH of 6 to 7. When the soil pH is less than 6, P deficiency increases in most crops. Conventionally, large amounts of lime and inorganic P fertilizers such as phosphate rocks and Triple Superphosphate (TSP) are used to saturate Al and Fe ions. This approach has not been successful because it is not economical for small scale farmers. The practice is also not environmentally friendly. Because, over liming precipitates P ions with Ca as calcium phosphate, whereas excessive use of P fertilizers causes eutrophication. Although there exist some information on P sorption and fixation using organic matter, there is a lack of information on the use of biochar to reduce P fixation. This is because biochar has high affinity for Al and Fe. Their affinity enables long term chelation of Al and Fe by biochar instead of P. Hence P will become readily and timely available for efficient crop use (Ohno et al., 2007). Therefore; the objective of this study was to improve available phosphorus by using biochar produced

from the pyrolysis of coffee husk and corn cob at different charring temperature on acidic soil.

MATERIALS AND METHODS

Description of the soil sampling area

Soil sample was collected from Dedesa, Southwest Ethiopia. The site is located between 7°50'-8°10' N latitude and 36°30'E to 36°45' E longitude. The altitude of the area is about 2260 m above sea level. The mean annual minimum and maximum temperatures are 13 and 28°C, respectively and the mean minimum and maximum annual rainfalls are 1800 and 2200 mm respectively. The soil of the study area is dominated by Nitosol (World Reference Base, 2006) (Figure 1).

Preparation of biochar

Biochar of coffee husk and corn cob were prepared in Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) by using a pyrolysis unit at two different temperatures (350 and 500°C) and 3 h of residence time. The resulting biochar materials were grounded and sieved through a 0.25 mm -mesh sieve.

Soil sampling, preparation and incubated with biochar

The top 0 to 30 cm soil samples were collected by using auger. The collected soil samples were air-dried, crushed by using mortar and

pestle and then passed through a 2 mm -mesh sieve. The effect of different levels of the biochar produced from different feedstock and different temperatures on available phosphorous was examined through a laboratory incubation experiment. Two hundred fifty grams of air-dried soil (<2 mm) were weighed in different beakers and biochar was added at rates of 0, 5, 10 and 15 t/ha which is equivalent to 0, 1.366, 2.732 and 4.098, g/kg respectively and thoroughly homogenized. The moisture content of the soil-biochar mixture was maintained at field capacity throughout the incubation period, by adding distilled water whenever necessary. Three replicates of each treatment were prepared, randomly placed and incubated in the laboratory at ambient temperature for 2 months. At the end of two months, samples (\approx 50 g) were removed from all the treatments and analyzed for pH, OC, OM, TN and other parameters were also analyzed as per the standard methods. But available P was analyzed by following successive weeks of incubation.

Physicochemical properties of biochar materials

The surface area of biochar was estimated according to Sears's method for silica-based materials (Sears, 1956). This can be obtained by agitating 1.5 g of each of the produced biochar in 100 ml of diluted hydrochloric acid (pH 3). Then a 30 g of sodium chloride was added with stirring and the volume was made up to 150 ml with deionized water. The solution was titrated with 0.10M NaOH and the volume, V, needed to raise the pH from 4 to 9 was then recorded. $S (m^2/g) = 32V-25$, where V is the volume of sodium hydroxide require raising the pH of the sample from 4 to 9 and S is the surface area. pH and electrical conductivity (EC) were measured in distilled water at 1:10 biochar to water mass ratio after shaking for 30 min (ASTM, 2009). Biochar organic carbon content was determined by the Walkley-Black method and total nitrogen (TN) by the Kjeldahl method as cited in Chintala et al., 2013. Available phosphorous (P) was determined by using the Olsen extraction method (Shaheen et al., 2009). Total exchangeable bases were determined after leaching the biochar with ammonium acetate. Concentrations of Ca and Mg in the leachate were determined by atomic absorption spectrometer. K and Na were determined by flame photometer. Cation exchange capacity was determined at soil pH 7 after displacement by using 1N ammonium acetate method, and then estimated titrimetrically by distillation of ammonium that was displaced by sodium (Gaskin et al., 2008).

Physicochemical properties of soil sample and the soil-biochar mixture

The particle size distribution (texture), of the soil sample was determined by the Boycouous hydrometric method after destroying OM using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexametaphosphate ($NaPO_3$)₆. Soil bulk density was determined by the undisturbed core sampling method after drying the soil samples in an oven at 105°C to constant weights. The pH of the soil and soil-biochar mixture was determined in water suspension at 1:2.5 soil/soil-biochar: liquid ratio (w/v) potentiometrically using a glass-calomel combination electrode (Van Reeuwijk, 1992). Electrical conductivity (EC) was measured from a 1:5 (w/v) soil to water ratio after a one hour equilibration time as described by (ASTM, 2009). The Walkley and Black (1934) wet digestion method was used to determine carbon content and, percent OM was obtained by multiplying percent soil OC by a factor of 1.724 following the assumptions that OM is composed of 58% carbon. Total N was analyzed using the Kjeldahl method by oxidizing the OM in (0.1N H_2SO_4) as described in Black (1965). Cation exchange capacity and exchangeable bases (Ca, Mg, K and Na) were determined after extracting the soil samples by (1N NH_4OAc) at pH 7. Ex. Fe was determining by AAS after extracting

by DTPA solution.

Exchangeable Ca and Mg in the extracts were analyzed using atomic absorption spectrometer (AAS), while Na and K were analyzed by flame photometer (Rowell, 1994). Cation exchange capacity was there after estimated titrimetrically by distillation of ammonium that was displaced by sodium from NaCl solution (Chapman, 1965). Exchangeable acidity was determined by titration method after 1N KCl solution at pH 7 used to leach exchangeable hydrogen and aluminum ion from soil sample. Available P was determined by using 1M HCl and 1M NH_4F solutions as an extractant by Bray II method (Van Reeuwijk, 1992). Total P was determining by spectrophotometer after digested by concentrated sulfuric acid. The sample-extractant mixtures were shaken for 30 min on a horizontal shaker (Shaheen et al., 2009), then centrifuged for 10 min at 1500 rpm and filtered by using Whatman no. 42 filter paper. The clear supernatant solutions were collected and analyzed using spectrophotometer at 882 nm. BDL=below detection level, CEC: Cation exchange capacity, CHB350: Coffee husk biochar produced at 350°C, CHB500: Coffee husk biochar at 500°C, CCB350: Corn cob biochar at 350°C, CCB500: Corn cob biochar at 500°C. Selected physicochemical properties of the studied soil and biochar are shown in Table 1. In the Table it indicates that the soil is strongly acidic. This shows that, the soil might possibly be affected by Al toxicity, excessive levels of micronutrients such as Co, Cu, Fe, Mn, Zn and, deficiency of macronutrients such as Ca, K, Mg, S, N, P. The low EC value shows that the soil is non-saline which indicates that the total concentration of the major dissolved inorganic solutes (Na^+ , Mg^{2+} , Ca^{2+} , K^+ , Cl^- , SO_4^{2-} , HCO_3^- , NO_3^- and CO_3^{2-}) in the soil solution is low and this soil acidity can cause limited availability of macronutrients like P and micronutrients Mo which binds to iron and aluminum oxides in acidic soil (Brady and Weil, 2002).

As can be seen in the table, the coffee husk biochar was more alkaline and has higher base cation concentration relative to that of the corn cob biochar. The pH, EC, CEC, P, and base cation concentration were higher in the coffee husk biochar produced at 500 and 350°C followed by corn cob biochar produced at 500 and 350°C. The high pH values of coffee husk biochar may be due to hydrolysis undergone by carbonates and bicarbonates of base cations such as Ca, Mg, Na, and K, which were present in the feedstock's materials (Gaskin et al., 2008). The EC value of coffee husk biochar was found to be higher than that of corn cob biochar, indicating the existence of more water soluble salts in coffee husk biochar than in corn cob biochar. The CEC of coffee husk biochar was also found to be higher than that of corn cob biochar. This may be due to high negative charge potential of surface functional groups in coffee husk than in corn cob. In general, results of the characterization studies of the biochars are clear demonstrations of the significant difference in the composition of biochar produced from different feed-stocks even when they are pyrolyzed under the same temperature. This fact was also reported in a study carried out by Novak et al., 2009. Available P, organic carbon and total nitrogen were also found to be higher in coffee husk biochar than in that of corn cob biochar. The high carbon, organic matter, total nitrogen and total P content in coffee husk biochar might have enriched the soil with high organic matter.

Statistical data analysis

Data analysis was done using SAS version 9.2. Three way analysis of variance (ANOVA) namely two feedstock biochar materials, two different pyrolysis temperatures and four application rates were performed to see the significance of differences in the effects of the various soil parameters and among each treatment, using the General Linear Model (GLM) procedure of SAS 9.2. Means separation was done using Least Significant Difference (LSD) after the treatments were found significant at $p < 0.05$.

Table 1. Selected physicochemical properties of the studied soil and biochar produced from coffee husk and corn cob at 350°C and 500°C (Mean \pm SD)

Parameters	Soil	CHB350	CHB500	CCB350	CCB500
Bulk density (gm/cm ³)	1.22 \pm 0.03				
Specific surface area(m ² /g)	-	14.07 \pm 0.02	26.2 \pm 0.01	4.46 \pm 0.05	18.14 \pm 0.04
pH-H ₂ O (1:2.5)	5.08 \pm 0.06	9.62 \pm .06	11.04 \pm 0.02	8.154 \pm .01	9.44 \pm 0.03
Exch. Acidity	4.5 \pm 0.1	BDL	BDL	BDL	BDL
EC (mS/cm) (1:5)	0.03 \pm 0.00	4.29 \pm 0.03	6.44 \pm 0.13	0.891 \pm 0.23	1.81 \pm 0.24
Exch. Ca (me/100g)	8.08 \pm 1.32	50.48 \pm 0.68	61.48 \pm 0.81	37.38 \pm 0.56	48.36 \pm 0.06
Exch. Mg (me/100g)	1.20 \pm 0.2	6.71 \pm 0.11	8.21 \pm 0.06	4.93 \pm 0.04	6.43 \pm 0.06
Exch. K (me/100g)	0.8 \pm 0.02	1.96 \pm 0.27	2.77 \pm 0.43	1.711 \pm 0.26	2.16 \pm 0.14
Exch. Na (me/100g)	0.02 \pm 0.00	3.43 \pm 0.02	5.15 \pm 0.11	0.71 \pm 0.18	1.45 \pm 0.19
Exch. Fe	35.54 \pm 1.12	BDL	BDL	BDL	BDL
Exch. Al	795.00 \pm 0.23	BDL	BDL	BDL	BDL
CEC (me/100g)	24.36 \pm 1.7	64.75 \pm 0.76	79.23 \pm 0.33	47.52 \pm 0.66	62.03 \pm 0.80
Organic Carbon (%)	3.97 \pm 0.23	16.45 \pm 1.96	26.91 \pm 7.22	13.98 \pm 2.45	20.57 \pm 1.40
Organic Matter (%)	6.85 \pm 0.39	28.35 \pm 3.38	46.39 \pm 12.45	24.09 \pm 4.23	35.46 \pm 2.41
Nitrogen (%)	0.34 \pm 0.02	1.42 \pm 0.17	2.32 \pm 0.62	1.2 \pm 0.21	1.77 \pm 0.12
Total P	16.2 \pm 0.14	105.25 \pm 2.12	149.12 \pm 3.45	91.92 \pm 1.32	116.22 \pm 2.56
Available P (mg /kg)	4.52 \pm 0.09	9.79 \pm 1.34	13.87 \pm 2.16	8.55 \pm 1.31	10.81 \pm 2.41
Texture	Clay loam				
%Sand	29.33 \pm 4.16				
%Clay	30.67 \pm 4.16				
%Silt	40.00 \pm 0.00				

RESULTS AND DISCUSSION

Effect of biochar application on soil pH, exchangeable acidity, exchangeable aluminum and exchangeable iron

The biochar application significantly affects soil pH compared with the control pH (Table 2). The increase in soil pH was due to the rapid proton (H⁺) exchange between the soil and the biochar (Tang et al., 1999). The reduction in exchangeable acidity, exchangeable Al, and exchangeable Fe relates to the increase in soil pH. Increase in pH resulted in the precipitation of exchangeable and soluble Al and Fe as insoluble Al and Fe hydroxides, thus reducing the concentrations of Al and Fe in the soil solution and also exchangeable acidity (Ritchie, 1994). The increase in the pH of the soil due to the application of biochar was generally attributed to an increase in ash content, because ash residues are generally dominated by carbonates of alkali and alkaline earth metals, phosphates and small amounts of organic and inorganic N (Arocena and Opio, 2003). A study by Khanna et al., 1994, has also revealed that the increase in soil pH due to the application of biochar could be because of the high surface area and porous nature of biochar that subsequently increase the CEC of the soil. But, with an increase in incubation period the pH of the soil-biochar mixture nearly constant and this could be due to buffering capacity of the soil.

Effect of biochar application on OC, OM and TN

The application of different rates of biochar on the acidic soil significantly ($P < 0.01$) increased the mean soil organic carbon (OC), organic matter (OM), total nitrogen (TN) and total phosphorous content (Table 3). The untreated acidic soil had 3.97 \pm 0.23% OC and 6.85 \pm 0.39% OM level before treatment, however, due to the incorporation of biochar the OC level increased to a level ranging 3.8 \pm 0.29 - 5.79% and 6.56 \pm 0.51% - 9.98 \pm 0.07% OM in the first month of incubation period and it increased by 34.37% OC and 34.3% OM. In the control however, the level of OC and OM were found to decrease after an incubation period of 2 months. At the end of the incubation period the control had an OC level of 3.6 \pm 0.29 and 6.56 \pm 0.21% OM, whereas the soil amended with the biochar had levels ranging 3.6 \pm 0.29 to 6.69 \pm 0.04% OC and 6.56 \pm 0.21 to 11.53 \pm 0.41% OM which is increased by 45.6% OC and 43.1% OM. The highest OC and OM levels were recorded in the soil amended with 15t/ha of coffee husk biochar produced at 500°C temperature after 2 month incubation period. There were significant differences in the soil total nitrogen and total P after application of biochar. The highest increase was recorded in the soil amended with 15t/ha of coffee husk biochar produced at 500°C temperature. The observed increase in TN and total P could be due to some amount of decomposition which might have occurred when biochar is added to soil (Liang et al., 2006), which could

Table 2. Effect of biochar application on soil pH, exchangeable acidity, exchangeable aluminum and exchangeable iron.

Biochar materials	Rate of Biochar(t/ha)	pH	Exchangeable acidity	Exchangeable Al	Exchangeable Fe
		cmol (+)/kg			
Control	0	5.2±0.03 ^d	1.9± 0.1 ^d	795± 0.4 ^d	35.54± 0.1 ^d
	5	6.10±0.07 ^{abc}	1.22± 0.1 ^{bc}	530± 0.3 ^b	29.62± 0.02 ^b
	10	6.10±0.33 ^{abc}	1.19± 0.1 ^{bc}	373.5± 0.3 ^c	14.8± 0.02 ^c
CHB350	15	6.20±0.01 ^{ab}	1.15± 0.2 ^{bc}	186.75± 0.3 ^e	9.87± 0.02 ^e
	5	6.1±0.15 ^{abc}	0.16± 0.04 ^e	124.5± 0.01 ^f	17.64± 0.03 ^f
	10	6.3±0.10 ^{abc}	0.14± 0.04 ^e	62.25± 0.01 ^g	5.88± 0.03 ^g
CHB500	15	6.6±0.03 ^a	0.11± 0.04 ^a	20.75± 0.01 ^a	2.96± 0.03 ^a
	5	6.1±0.14 ^{bc}	1.34± 0.2 ^{bc}	560± 0.01 ^b	30.12± 0.12 ^b
	10	6.1±0.07 ^{abc}	1.25± 0.2 ^{bc}	395.5± 0.1 ^{bc}	20.08± 0.12 ^{ef}
CCB350	15	6.01±0.09 ^c	1.19± 0.2 ^{bc}	197.75± 0.1 ^e	15.02± 0.12 ^e
	5	6.01±0.19 ^c	0.37± 0.5 ^c	353.3± 0.2 ^c	21.09± 0.11 ^{ef}
	10	6.10±0.01 ^{abc}	0.29± 0.5 ^{ef}	176.6± 0.2 ^{ef}	10.54± 0.11 ^e
CCB500	15	6.14±0.02 ^{abc}	0.19± 0.5 ^e	58.88± 0.2 ^g	5.27± 0.11 ^g
	Pv<0.05	<.0001	<.0001	<.0001	<.0001
	LSD	0.3821	0.271	0.1911	0.1932

LSD: least significant difference, CHB350: Coffee husk biochar at 350°C, CHB500: Coffee husk biochar at 500°C, CCB350: Corn cob biochar at 350°C, CCB500: Corn cob biochar at at 500°C.

Table 3. The effect of biochar application on the soil OC, OM, TN and Total-P.

Biochar materials	Rate of biochar (t/ha)	%OC	%OM	%TN	Total-P
Control	0	3.64 ± 0.29 ^g	6.56 ± 0.21 ^g	0.32 ± 0.03 ^g	96.5 ± 1.3 ^e
	5	6.14 ± 0.06 ^{cd}	10.58 ± 0.37 ^{cd}	0.53 ± 0.016 ^{cd}	136.2 ± 2.6 ^e
	10	6.11 ± 0.04 ^{cd}	10.53 ± 0.37 ^{cd}	0.53 ± 0.0 ^{cd}	271.6 ± 3.25 ^d
CHB350	15	6.18 ± 0.06 ^{cb}	10.65 ± 0.37 ^{cb}	0.53 ± 0.01 ^{cb}	550 ± 4.32 ^b
	5	6.28 ± 0.08 ^{cb}	10.82 ± 0.38 ^{cb}	0.54 ± 0.01 ^{cb}	139.2 ± 3.2 ^e
	10	6.45 ± 0.08 ^{ab}	11.12 ± 0.39 ^{ab}	0.56 ± 0.08 ^{ab}	555 ± 4.50 ^b
CHB500	15	6.69 ± 0.04 ^a	11.53 ± 0.41 ^a	0.58 ± 0.0 ^a	615 ± 4.70 ^a
	5	5.58 ± 0.12 ^f	9.63 ± 0.33 ^f	0.48 ± 0.01 ^f	134.6 ± 3.3 ^e
	10	5.79 ± 0.06 ^{ef}	9.99 ± 0.35 ^{ef}	0.49 ± 0.01 ^{ef}	350 ± 3.60 ^f
CCB350	15	5.86 ± 0.04 ^{d^{ef}}	10.1 ± 0.35 ^{d^{ef}}	0.51 ± 0.0 ^{d^{ef}}	449.5 ± 3.50 ^g
	5	5.98 ± 0.05 ^{cde}	10.32 ± 0.36 ^{cde}	0.52 ± 0.0 ^{cde}	136.2 ± 2.6 ^e
	10	5.98 ± 0.05 ^{cde}	10.32 ± 0.36 ^{cde}	0.52 ± 0.0 ^{cde}	365 ± 4.52 ^{cf}
CCB500	15	6.07 ± 0.04 ^{cde}	10.46 ± 0.37 ^{cde}	0.52 ± 0.0 ^{cde}	469 ± 4.55 ^g
	Pv<0.05	<.0001	<.0001	<.0001	<.0001
	LSD	0.30	0.52	0.026	0.76

OC, Organic carbon, OM, Organic matter; TN, Total nitrogen; LSD, least significant difference.

induce net immobilization of inorganic N and organic P already present in the soil solution.

Effect of biochar application on CEC and exchangeable cations

The effect of biochar addition on CEC and the contents of exchangeable cations in the acidic soil are presented in Table 4. As shown in the Table, CEC and exchangeable

cations were found to increase upon amendment of the acidic soil with coffee husk and corn cob biochar. Statistical assessment of the significance of the observed increases was carried out using ANOVA and, both increases were found to be significant ($P < 0.01$). The untreated acidic soil had 24 me/100 g level before treatment, however, due to the incorporation of biochar the CEC level increased to a level ranging 24.95 ± 1.05 - 38.46 ± 1.07 me/100 g after 2 months of incubation

Table 4. The effect of Biochar application on CEC and exchangeable cations

Biochar materials	Rate of biochar (t/ha)	CEC (me/100 g)	Ca (cmol (+)/kg)	Mg (cmol (+)/kg)	K (cmol (+)/kg)	Na (cmol (+)/kg)
Control	0	24.95 ± 1.05 ^e	12.57 ± 0.82 ^e	1.3 ± 0.11 ^e	0.85 ± 0.04 ^g	0.05 ± 0.0 ^{bc}
	5	34.55 ± 1.09 ^{bcd}	26.94 ± 0.85 ^{bcd}	3.58 ± 0.11 ^{bcd}	1.46 ± 0.03 ^{efg}	0.05 ± 0.0 ^{bc}
	10	35.46 ± 1.07 ^{bcd}	27.65 ± 0.84 ^{bcd}	3.68 ± 0.11 ^{bcd}	1.55 ± 0.03 ^{edf}	0.05 ± 0.0 ^{bc}
CHB350	15	35.69 ± 1.09 ^{abcd}	27.83 ± 0.85 ^{abcd}	3.7 ± 0.11 ^{abcd}	1.99 ± 0.15 ^{bcdde}	0.07 ± 0.0 ^{abc}
	5	36.03 ± 1.03 ^{abcd}	28.1 ± 0.80 ^{abcd}	3.73 ± 0.10 ^{abcd}	2.15 ± 0.19 ^{bcd}	0.05 ± 0.01 ^{bc}
	10	37.31 ± 0.86 ^{ab}	29.09 ± 0.67 ^{ab}	3.87 ± 0.09 ^{ab}	2.96 ± 0.09 ^a	0.06 ± 0.0 ^{abc}
CHB500	15	38.46 ± 1.07 ^a	29.99 ± 0.84 ^a	3.98 ± 0.11 ^a	3.01 ± 0.04 ^a	0.09 ± 0.0 ^a
	5	33.33 ± 0.52 ^d	25.98 ± 0.40 ^d	3.45 ± 0.05 ^d	1.25 ± 0.22 ^{fg}	0.04 ± 0.01 ^c
	10	34.37 ± 1.21 ^{cd}	26.8 ± 0.95 ^{cd}	3.56 ± 0.13 ^{cd}	1.46 ± 0.04 ^{efg}	0.05 ± 0.02 ^{bc}
CCB350	15	35.27 ± 0.46 ^{bcd}	27.5 ± 0.36 ^{bcd}	3.66 ± 0.05 ^{bcd}	1.72 ± 0.29 ^{cdef}	0.08 ± 0.01 ^a
	5	34.7 ± 0.46 ^{bcd}	27.06 ± 0.36 ^{bcd}	3.6 ± 0.05 ^{bcd}	1.85 ± 0.34 ^{bcddef}	0.05 ± 0.02 ^{bc}
	10	35.03 ± 1.15 ^{bcd}	27.32 ± 0.90 ^{bcd}	3.63 ± 0.12 ^{bcd}	2.23 ± 0.27 ^{bc}	0.06 ± 0.01 ^{abc}
CCB500	15	36.99 ± 0.70 ^{abc}	28.84 ± 0.55 ^{abc}	3.83 ± 0.07 ^{abc}	2.5 ± 0.54 ^{ab}	0.07 ± 0.01 ^{ab}
	Pv<0.05	<.0001	<.0001	<.0001	<.0001	<.0001
	LSD	2.80	2.18	0.29	0.68	0.029

CEC, Cations exchange capacity; me, Milliequivalents; cmol, centimol; CHB350, coffee husk biochar at 350°C; CHB500, coffee husk biochar at 500°C; CCB350, corn cob biochar at 350°C; CCB500, corn cob biochar at 500°C; LSD, least significant difference.

period and it increased by 34.13%. The highest increase in CEC was recorded in the soil amended with coffee husk biochar produced at 500°C, applied at a rate of 15t/ha and this increased of CEC results the increment of basic cations. The observed increase in CEC due to the application of biochar could have resulted from the inherent characteristics of biochar feedstock. Biochar has high surface area, is highly porous, possesses organic materials of variable charge that have the potential to increase soil CEC and base saturation when added to soil (Glaser et al., 2002). Available evidences also suggest that, on a mass basis, the intrinsic CEC of biochar is consistently higher than that of whole soil, clays or soil organic matter (Sohi et al., 2009).

Therefore, it is quite logical that soil treated with

biochar had a highest CEC than the corresponding soil. Studies by Agusalin et al. (2010) have also revealed the increase in soil CEC after the application of biochar. Application of CCB500 at a rate of 15 t/ha on the acidic soil was found to increase the levels of exchangeable Ca and Mg significantly ($P < 0.01$) from 12.57 ± 0.82 - 29.99 ± 0.84 and 1.3 ± 0.11 - 3.98 ± 0.11 me/100 g respectively which is increased by 58.08% Ca and 67.3% Mg. Application of CHB500, on the other hand, increased the values of exchangeable K from 0.85 ± 0.04 - 3.01 ± 0.04 me/100 g and Na 0.05 ± 0.0 - 0.09 ± 0.0 me/100 g which is increased exchangeable K by 71.5 and 44.4% Na. The observed increase in exchangeable cations in the biochar treated soils might be attributed to the ash content of the biochar. The ash content of biochar

helps for the immediate release of the concluded mineral nutrients like Ca, Mg, K and Na for crop use (Niemeyer et al., 2005). The increase in soil pH and CEC, that reduce the activity of Fe and Al, could also contribute for the highest values of available phosphorous in soils treated with biochar. Van Zwieten et al. (2010) also reported the increase in available phosphorous after the application of biochar.

Effect of biochar application on available phosphorous

The amount of available phosphorous in acidic soil was also significantly ($P < 0.01$) increased by application of biochar (Figure 2). The untreated

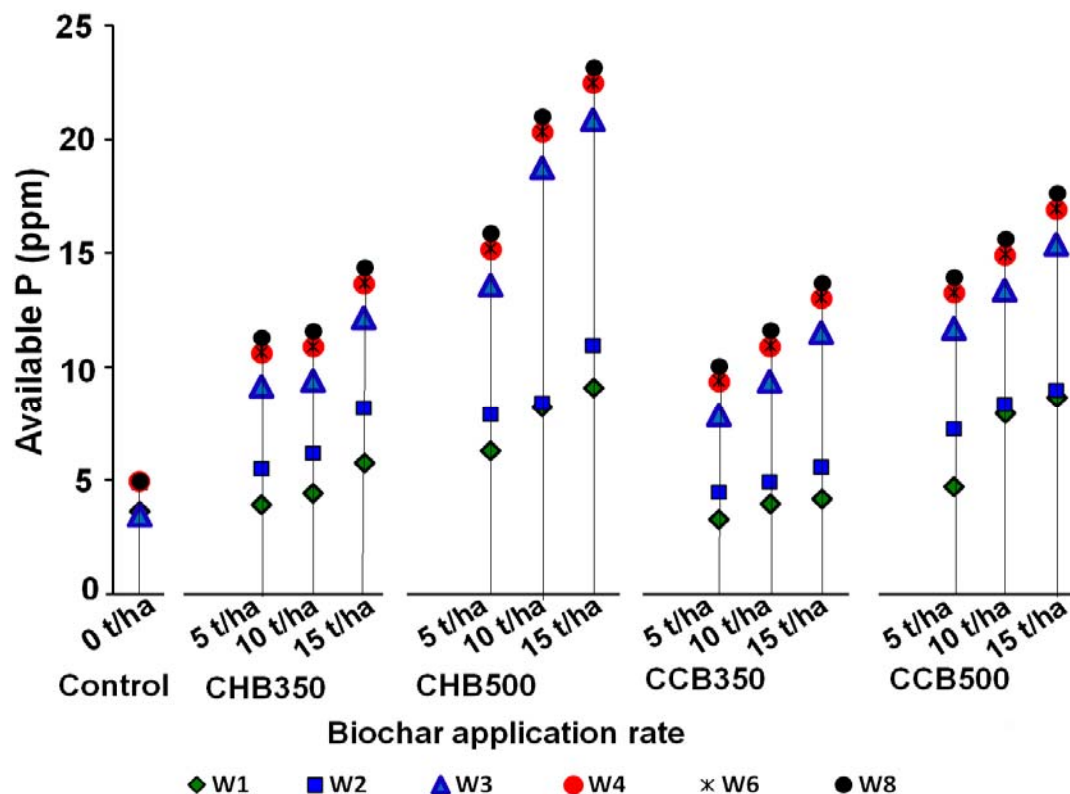


Figure 2. The effect of rate of application and incubation period of CHB350, CHC500, CCB350 and CCB500, on soil available P

acidic soil had 3.64 ± 0.34 mg/kg available phosphorus at first week (W1) of incubation period and 4.99 ± 0.24 mg/kg after an incubation periods of two months. However, due to the incorporation of biochar the available P level increased to a level ranging 3.64 ± 0.34 - 23.21 ± 0.07 mg/kg after an incubation period of 2 months and it increased by 84.3% available phosphorus. The highest values of available phosphorous recorded when coffee husk biochar produced at 500°C temperature was applied at a rate of 15 t/ha after two months of incubation periods and at pH values of 6.6. The observed increase in available phosphorus due to application of biochar could be due to the presence of phosphorous in the coffee husk and corn cob and the increase in the availability of P with time was because of microbially mediated mineralization of soil organic P to form inorganic P (Opala et al., 2012).

Significant differences were observed between soil available P and total levels of successive weeks of incubation of the biochar amended soil, that is, between available P levels of one week incubation and two weeks incubation, or between those of two weeks and three weeks of incubation period etc. (Figure 2). The biochar from both coffee husk and corn cob produced at 350°C and 500°C and applied at different levels on each treatment increased available P levels when compared with the control. The increase in available P with duration

of incubation reported in this study is comparable to those reported by Laboski and Lamb (2003). The observed increase in available P with an increase in the duration of incubation was because of microbially mediated mineralization of soil organic P to form inorganic P.

Conclusion

The influence of coffee husk and corn cob biochar application on the level of available P of an acidic soil has been investigated. Findings of the study showed that, application of the biochar prepared from both feed stocks increased available P. The biochar application has also increased the pH and CEC of the soil. To enhance the bioavailability of P, alkaline biochars can be used on acidic soil and the finding of this study indicated that coffee husk residue biochar produced at 500°C highly increased available P as compared to corn cob reduced at the same temperatures. Corn cob residue biochar had the smallest effect on P availability but it could still improve soil quality parameters and increase available P. The effect of these biochar on soil P was in agreement with their characterization, suggesting that similar biochar evaluations might predict their effect on P availability and

inform recommendations on biochar application to soils. Generally, in this study the application of both coffee husk and corn cob biochar produced at 350 and 500°C increases soil available P in all rating of application as compare to control (soil without application of biochar). Even though both feedstock biochar improved soil available P it is better to use coffee husk biochar produced at 500°C of pyrolyzing temperature applied at a rate of 15 t/ha. Moreover, further field researches are needed to evaluate the effect of biochar on the availability, fate and uptake of available p in soil.

Conflict of Interests

The authors have not declared any conflict of interests.

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