Effects of Biochar on Phosphorus Sorption and Desorption in Acidic and Calcareous Soils

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Abstract

Awareness of Phosphorus (P) fates when applying biochar to soil is required. Because, P retention and releasing mechanisms provide vital indication for the effective management of P to boost crop production and sustain soil. This study was conducted to evaluate the effects of coffee husk biochar (CHB) produced at two temperatures (350 and 500^{0}C) and applied at a rates of (0, 5, 10 and 15t/ha) on phosphorus sorption and desorption in two soils with different P sorption capacities Fe and Al dominated strongly acid (pH=5.08) and Ca dominated alkaline calcareous soil (pH=7.85). Composite air dried, ground and sieved (2mm) soil samples were mixed with biochar and a 2 months incubation experiment was conducted at ambient temperature. In addition, P sorption characteristics of soils amended with biochar and in combination with and without mineral KH_2PO_4 fertilizer were determined. The results showed significant effects ($p<0.05$) on selected soil chemical properties by increasing soil pH and reduced exchangeable acidity, exchangeable aluminum, and exchangeable iron in a way that increased the availability of P from 4.52 to 23.21mg/kg (83%) in acidic soil after 2months of incubation and when CHB500^{0}C was applied at a rate of 15t/ha and from 8.2 to 27.4mg/kg (70%) in calcareous soil when CHB350^{0}C was applied at a rate of 15t/ha. Application of highly alkaline biochars to calcareous soil significantly increased the sorption of P and decreased the availability of P by higher biochar application rates. We concluded that CHB500^{0}C and applied at 15t/ha is promising to potentially increase soil P availability in acidic soil and decreased in calcareous soil but, increased in calcareous soil when CHB350 and applied at 15t/ha. Moreover, further researches at field scale are needed to evaluate the effect of biochar on availability and fates of phosphorous in acidic and calcareous soil.

Keywords: desorption, sorption, acidic soil, calcareous soil

Introduction

Biochar is produced by thermal decomposition of organic material under limited supply of oxygen (O_2) and at relatively low temperature (<700°C) (Lehmann and Joseph, 2009). Addition of biochar into soils has reportedly enhanced P bioavailability and plant growth (Lehmann et al., 2003; DeLuca et al., 2009). Biochar application to soils has also increased the extractable P within the soil solution regardless of the temperature used for biochar production. The mechanisms underlying the altered P availability with biochar application to soil remain poorly understood (Lehmann, 2007). DeLuca et al., 2009 reviewed a number of possible mechanisms by which biochar may directly or indirectly influence the components of the P cycle. Biochar contains a large amount of P; thus, direct release of soluble P may be necessary to enhance P availability, especially for short-term uses (Chan et al., 2007; Atkinson et al., 2010). In addition, biochar application reduces soil acidity and subsequently alters P complexing with metals (Al^{3+}, Fe^{3+} and Ca^{2+}), which is important for determining P availability by P sorption and desorption reactions in soils (Wang et al., 2012). Biochar can also directly adsorb cations such as Al^{3+}, Fe^{3+} and Ca^{2+}, resulting in delayed P adsorption or precipitation in soil. Sorption of organic molecules on biochar surfaces can reduce their ability to chelate Al^{3+}, Fe^{3+}, and Ca^{2+} in soil. The direct or indirect influence of biochar on the P cycle in soil has rarely been reported, especially P sorption and desorption after biochar addition to soils (Nelson et al., 2011; Sohi et al., 2009).

The nature of interactions between the biochar and soil, as well as the mechanism of the increase in P availability, must be elucidated (Atkinson et al., 2010). If biochar is to be used as a soil amendment, it is necessary to evaluate its influence on the bioavailability of nutrients such as P in soil. P 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 $CaCO_3$ content (Afif et al., 1993). The impact of these properties on P retention and release depends on soil acidity or alkalinity. The recovery of P by plants from applied fertilizer is limited in acidic and calcareous 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 (Lindsay, 2001; Sample et al., 1980). The high base status and pH of calcareous soils make P sparingly soluble due to formation of metal complexes such as Ca-

P and Mg-P (Amer et al., 1985; Marschner, 1995). So, understanding of P retention and release mechanisms provides vital information for the effective management of P to enhance crop production and sustain soil. Sorption is one of the commonly used mechanisms to describe P retention in soil (McBride , 1994; Villapando and Graetz, 2001). In some studies, biochar application enhanced the availability and plant uptake of P due to biochar's high AEC; reduced availability of Al and Fe in soil reduced P fixation (DeLuca et al., 2009; Novak et al., 2009).Effects of biochar on phosphorous sorption and desorption in acidic and calcareous soils have been studied by a number of researchers. However, effect of coffe husk biochar produced at different charring temperatures is not studied. Therefore, this study was conducted to evaluate the effects of coffee husk biochar produced at two temperatures (350 and 500^{0}C) and applied at different rates on phosphorus sorption and desorption in two soils with different P sorption capacities Fe and Al dominated strongly acid and Ca dominated alkaline calcareous soil.

Materials and Methods

Description of the soil sampling area

Acidic and calcareous soils were selected from composite surface (0–30 cm) samples from two different locations. Acidic soil was collected from Dedesa(Yembero) area in Southwest Ethiopia. The soil of the study area is dominated by Nitosol according to soil classification systems by FAO (FAO, 2006). It is strongly acid with (pH=5.08). The location is found between 7^{o}50'-8^{o}10' N latitude and 36^{o}30'-36^{o}45'E longitude. The altitude of the area is about 2260 meter above sea level). The mean annual minimum and maximum temperatures are 13^{0}C and 28^{0}C respectively and the mean minimum and maximum annual rainfalls are 1800 and 2200 mm respectively. The calcareous with (pH=7.85) soil was collected from Boset(Nura Era), in the Eastern parts of Ethiopia. The soil of the area is dominated by calcareous soil. Boset is one of the Woredas of Eastern Shewa found in Oromia Regional State, Ethiopia, located; 8^{o}40'N latitude and 39^o 30' E longitude and has an altitude of about 1500 meter above sea level. The mean annual maximum and minimum temperatures are 24^{0}C and 30^{0}C respectively, and the mean maximum and minimum annual rainfalls are 800 mm and 1200 mm respectively.

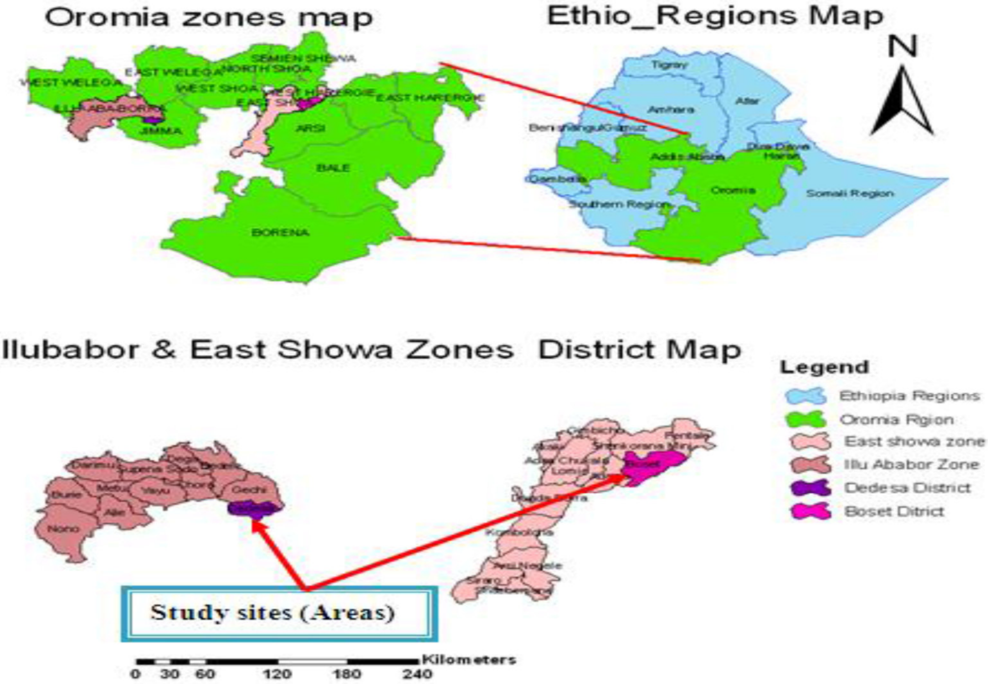

Figure 1: Map of the study area

Soil and Biochar Materials

The top 0 – 30 cm composite soil samples were collected. The collected soil samples were air-dried, crushed by using mortar and pestle and then passed through a 2 mm square-mesh sieve. Biochar from coffee husk was prepared in Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) by using a pyrolysis unit at two different temperatures (350, 500^{0}C) and 3 hrs of residence time. The resulting biochar materials were grounded and sieved through a 0.25mm square-mesh sieve.

Physicochemical properties of biochar and experimental soil samples

The surface area of biochar was estimated according to Sears's method for silica-based materials (Sears, 1981**)**. This can be obtained by agitating 1.5g of each of the produced sample in 100ml of diluted hydrochloric acid (pH

3). Then a 30g of sodium chloride was added with stirring and the volume was made up to 150ml 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) of biochar were measured in distilled water at 1:10 biochar to water mass ratio after shaking for 30 min, pH and EC of the soil were determined in water suspension at 1:2.5 soil: liquid ratio (w/v) potentiometrically using a glass-calomel combination electrode(ASTM, 2009; Van Reewijk, 1992). Soil organic carbon content was determined by the Walkley-Black wet digestion method 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) (Chintala et al., 2013; Black, 1965; Walkley, 1934) whereas biochar Organic carbon was determined by using dry digestion method. Available phosphorous (P) of biochar and calcareous soil was determined by using the Olsen extraction method(Shaheen et al., 2009) whereas, available P of soil acidic was determined by using 1M HCl and 1M NH4F solutions as an extractant by BrayII method(Van Reewijk, 1992). Total P was determining by spectrophotometer after digested by concentrated sulfuric acid and 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. Cation exchange capacity and exchangeable bases (Ca, Mg, K and Na) were determined after extracting the samples by (1N NH_4OAc) at pH 7. Ex. Fe and Al were 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 of acidic soil was determined by titration method after 1N KCl solution at pH 7 used to leach exchangeable hydrogen and aluminum ion from soil sample (Gaskin et al., 2008). The particle size distribution (texture), of the soil sample was determined by the Boycouos hydrometric method(Van Reewijk, 1992) 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^oC to constant weights.

Laboratory Incubation experiments

The effect of different levels of the biochar produced at different temperatures on sorption and desorption of phosphorous was examined through a laboratory incubation experiment. One kilogram 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, and 2.732, 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 (≈100 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.

Phosphorous (P) sorption experiments

A 0.5g soil incubated with biochar samples were placed in 50mL screw cap centrifuge tubes and added 20 mL of standard solutions at various P concentrations (0, 20, 40, 60, 80, 100, and 120mgPL-1). The standard P solutions were prepared by dissolving KH_2PO_4 in 0.01MKCl at pH 7. Two drops of chloroform were added to retard microbial activity. The samples were shaken on a reciprocal shaker at 200 rpm for 24hrs. After equilibrium, the samples were centrifuged at 3500rpm for 15 min, filtered through a 0.45-mm membrane filter, and the P in the supernatant was determined on UV-630 Spectrophotometer using ascorbic acid molybdenum blue method (Murphy and Riley, 1962). The amount of P sorbed by the soil was calculated as the difference between the P added and the P remaining in the solution at equilibrium, according to the Langmuir equation as follows:

$$S = \frac{K_L S_m C}{1 + K_L C}$$

Where C is the concentration of P remaining in solution after the 24 h equilibrium (mg L^{-1}), S is the total amount of P sorbed (mg kg^{-1}), Sm is the sorption maximum (mg kg^{-1}), KL is a constant related to the binding strength (Lair et al., 2009). After removing the supernatants of the sorption experiment, each tube was weighed to estimate the volume of the residual solution and account for P entrapped in that solution. Then the residuals were mixed with 20 ml of 0.01 M KCl solution for P desorption. The tubes were shaken for 24 h, centrifuged and the supernatants were determined for P content. The desorption process was repeated 3 times and the amount of P remaining in the soil was determined each time.

Effects of biochar application on phosphorus availability

Available P (bicarbonate extractable P) for Calcareous soil was determined in samples used for the sorption batch study by using 0.5 M sodium bicarbonate ($NaHCO_3$) and 1M HCl/1M NH_4F solution for acidic soil as an extractant. Samples from sorption batch study were washed a few times with isobutyl alcohol and then extracted with 50 mL of 0.5 M $NaHCO_3$ for calcareous soil and 1M HCl/1M NH_4F acidic soil at a 1:50 ratio. Centrifuge tubes with sample and extractant were shaken for 30 min on a horizontal shaker (Shaheen et al., 2009). After shaking, the samples were centrifuged for 5 min and the clear supernatant solutions were collected to analyze bicarbonate extractable P (available P) and 1M HCl/1M NH4F using colorimetric method as described above.

Statistical data analysis

Data analysis was done using SAS version 9.3. Analysis of variance (ANOVA) namely biochar material produced by two different pyrolysis temperatures and four application rates were performed to see the significance of differences on soil physico-chemical properties, P sorption and availability P and among each treatment, using the General Linear Model (GLM) procedure of SAS 9.3. Means separation was done using Least Significant Difference (LSD) after the treatments were found significant at $p<0.05$.

Results and Discussion

Selected physicochemical properties of the experimental soils and biochar

Physicochemical properties of the experimental soils and biochar are shown in (Table 1). The texture of both acidic and calcareous soils was clay loam. The acidic soil had lower available P, total P, and higher exchangeable Fe and Al. Calcareous soil had significantly higher clay content and CEC. Total nitrogen and organic matter content were also significantly different between acidic and calcareous soils which higher in acidic than calcareous soil.

Table 1. Selected physicochemical properties of the experimental soils and biochar produced from coffee husk at 350 and 500°C (Mean ±SD)

Parameters	Acidic Soil	Calcareous Soil	CHB350	CHB500
Bulk density (gm/cm3)	1.22 ± 0.03	1.15	-	-
Specific surface area(m2/g)	12.09±0.1	15.1±0.02	14.07±0.02	26.2±0.01
pH-H2O (1:2.5)	5.08 ± 0.06	7.85	9.62 ± .06	11.04±0.02
Exch. Acidity(me/100g)	4.5± 0.1	-	-	-
EC (mS/cm) (1:5)	0.03 ± 0.00	0.235	4.29 ± 0.03	6.44 ± 0.13
Exch. Ca (me/100g)	8.08 ± 1.32		50.48 ± 0.68	61.48 ± .81
Exch. Mg (me/100g)	1.20 ± 0.2		6.71 ± 0.11	8.21 ± 0.06
Exch. K (me/100g)	0.8 ± 0.02		1.96 ± 0.27	2.77 ± 0.43
Exch. Na (me/100g)	0.02 ± 0.00	0.188	3.43 ± 0.02	5.15 ± 0.11
Exch. Fe(me/100g)	35.54± 1.12	6.15	-	-
Exch. Al(me/100g)	795.00± 0.23	0.40	-	-
CEC (me/100g)	24.36 ± 1.7	37.14	64.75 ± 0.76	79.23 ± 0.33
Organic Carbon (%)	3.97 ± 0.23	1.853	16.45 ± 1.96	26.91 ± 7.22
Organic Matter (%)	6.85 ± 0.39	3.194	28.35 ± 3.38	46.39 ± 12.45
Nitrogen (%)	0.34 ± 0.02	0.160	1.42 ± 0.17	2.32 ± 0.62
Total P(mg/kg)	19.2± 0.14	12.41	105.25±2.12	149.12±3.45
Available P (mg /kg)	4.52 ± 0.09	9.12	9.79 ± 1.34	13.87 ± 2.16
Texture	Clay loam	Clay loam		
%Sand	29.33 ± 4.16	21.33		
%Clay	30.67 ± 4.16	33.33		
%Silt	40.00 ± 0.00	45.34		

CEC: Cation exchange capacity, CHB350= Coffee husk biochar produced at 350°C, CHB500: Coffee husk biochar produced at 500°C

Coffee husk biochar produced at both temperature (350 and 500^0C) were more alkaline with higher base cation concentration(Tab.1).pH, EC, CEC, available P, and base cation concentration were highest in coffee husk biochar produced at 500°C followed by coffee husk biochar produced at 350°C with highest specific surface area and total nitrogen content. 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 biochar materials (Gaskin et al., 2008). The presence of high calcium carbonate content ($CaCO_3$) in coffee husk biochar determines their utility as liming agents to reduce soil acidity. The liming effect of these biochar may affect the P sorption and availability. Coffee husk biochar produced at 500°C had higher EC values, indicating the existence of water soluble salts. The CEC of coffee husk biochar was also higher which may be due to high negative charge potential of surface functional groups. Available P and total P were also higher in coffee husk biochar produced at 500°C than biochar produced at 350°C. The available P of biochar may influence the sorption and availability of P. Organic carbon and total nitrogen concentrations were high in coffee husk biochar produced at 500°C. This characterization demonstrated the significant effect of different pyrolytic conditions on the composition of biochar produced, which was also observed in previous studies (Novak et al., 2009).

Effect of biochar application on soil pH, exchangeable acidity, exchangeable Aluminum and exchangeable Iron

The pH of acidic soil was significantly increased from 5.08-6.66 after incubation with coffee husk biochar produced at 500^0C and applied at a rate of 15t/ha. The exchangeable acidity was decreased by the incorporation of coffee husk biochar into the acidic soil. CEC, OC, total N, available P, and total P were also increased in the acidic soil after incubation with biochar. Concentration of exchangeable Fe and Al were decreased in acidic soil which may be due to increased precipitation as hydroxides and formation of organo-metallic complexes with the organic ligands released from biochars due to solubility of organic fraction as the soil pH increased due to incorporation of biochars. Coffee husk biochar produced at 500^0C had a stronger effect on exchangeable Fe and Al than coffee husk biochar produced at 350^0C.

Table 2: Effect of biochar application on soil pH, exchangeable acidity, exchangeable Aluminum and exchangeable Iron

Soil types	Biochar Materials	Rate of Biochar(t/ha)	pH	Ex. acidity	Ex.Al	Ex. Fe	CEC
			cmol (+)/kg				
AS	Control	0	5.2±0.03	1.9± 0.1	795± 0.4	35.54± 0.1	24.95 ± 1.05
	CHB350	5	6.10±0.07	1.22± 0.1	530± 0.3	29.62± 0.02	34.55 ± 1.09
		10	6.10±0.33	1.19± 0.1	373.5± 0.3	14.8± 0.02	35.46 ± 1.07
		15	6.20±0.01	1.15± 0.2	186.75± 0.3	9.87± 0.02	35.69 ± 1.09
	CHB500	5	6.1±0.15	0.16± 0.04	124.5± 0.01	17.64± 0.03	36.03 ± 1.03
		10	6.3±0.10	0.14± 0.04	62.25± 0.01	5.88± 0.03	37.31 ± 0.86
		15	6.6±0.03	0.11± 0.04	20.75± 0.01	2.96± 0.03	38.46 ± 1.07
	Pv<0.05		<.0001	<.0001	<.0001	<.0001	<.0001
	LSD		0.3821	0.271	0.1911	0.1932	2.80

Where: AS: Acidic soil, CEC: Cation exchange capacity, CHB350= Coffee husk biochar produced at 350°C, CHB500: Coffee husk biochar produced at 500°C

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. 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 Nitrogen (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.

Application of biochar to calcareous soil couldn't increase Olsen P and pH and as compared to application of biochar to acidic soil. In general, the results indicated a decrease in the recovery of added P from the biochar source in spite of the initial increase and pH is slightly increased with statistically no significant. There was no a significant effect due to increasing the rate of both biochar produced at 350 and 500^0C. The results described here show that increasing the incubation time leads to a sharp decrease in the available phosphorus from both biochar produced at 350 and 500^0C. Therefore, it may be concluded that alkaline biochar application had un appreciable and different impact on the availability of P in calcareous soils

Effect of biochar application on availability and sorption of P in soils

Phosphorous availability and its sorption is influenced by soil pH, metal oxides, and carbonate (Harrell and Wang, 2006). Amendment of biochar significantly ($P<0.05$) increased pH of acidic soil, from an initial value of 5.08 to 6.66 after 60 days in the treatment of 15t/ha coffee husk biochar produced at 500^0C. In contrast, the biochar didn't significantly influence the pH of calcareous soil characterized by an initial pH of 7.85-8.4 which was only increased by 0.55 unit, this could be due to buffering capacity of the soil. In this study, the acidic soil showed higher sorption and lower availability of P than calcareous soil due to its low pH (5.08) and larger concentrations of Fe and Al, oxides (Tab. 2), which can fix and reduce P availability in soil solution(Geelhoed et al., 1997). But biochar application decreased P sorption and increased available P in the acidic soil, which might be attributed to increase in the negative surface charge potential. The soil pH also increased during incubation with biochars which may be due to proton consumption reactions, such as ligand exchange between functional groups of biochar with anions of P on aluminol (Al–OH) and ferrol (Fe–OH) surfaces (MacDowell, 2001) and decarboxylation during decomposition of partially burnt organic matter present in biochar(Noble and Zenneck, 1996). Soil pH was increased by 1.58 unit when acidic soil was incubated for 2months with coffee husk biochar and decreased exchangeable acidity (Chintala et al., 2013). Apart from changes to soil pH, the increased solution P may be due to lower concentrations of free Fe, Al, and Mn oxides (Tab. 2) which may transform to Fe, Al, and Mn hydroxides and reduce the availability of high energy sorption sites (Stevenson and Vance, 1989). There was a possibility for P mineralization from biochars into the soil solution during incubation. In acidic soil, application of biochar seemed to increase the ionic strength of solution due to release of soluble nutrients, which may reduce the positive electric potential of soil surface through a screening effect and ultimately reduced the P sorption. Moreover, some of the increase in concentration and availability of P may be attributed to P released from biochar apart from changes to surface properties of acidic soil during incubation.

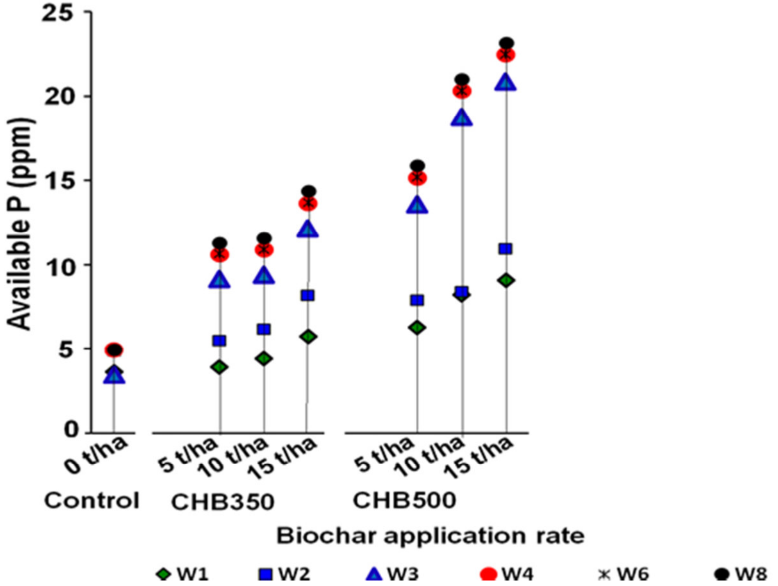

Figure 2. The effect of rate of application and incubation period of CHB350 and CHBC500, on available P in acidic soil

The incorporation of biochar to acidic and calcareous soils resulted in a significant effect on availability and sorption of P. Acidic soil amended with biochar significantly increased the available P concentration when coffee husk biochar produced at 500^{0}C applied at a rate of 15t/ha (Fig. 2) and available of P in calcareous soil decreased by an increasing a rate of biochar application and pyrolysis temperatures (Fig.3). However, the two soils (acidic and calcareous) had different responses to addition of P solutions. When the same concentration of P was added to soils, the amount of P sorbed by calcareous soil was significantly higher than by acidic soil. In contrast, amendment of biochar to calcareous soil altered the P sorption compared with the control, although their overall pattern was the same.

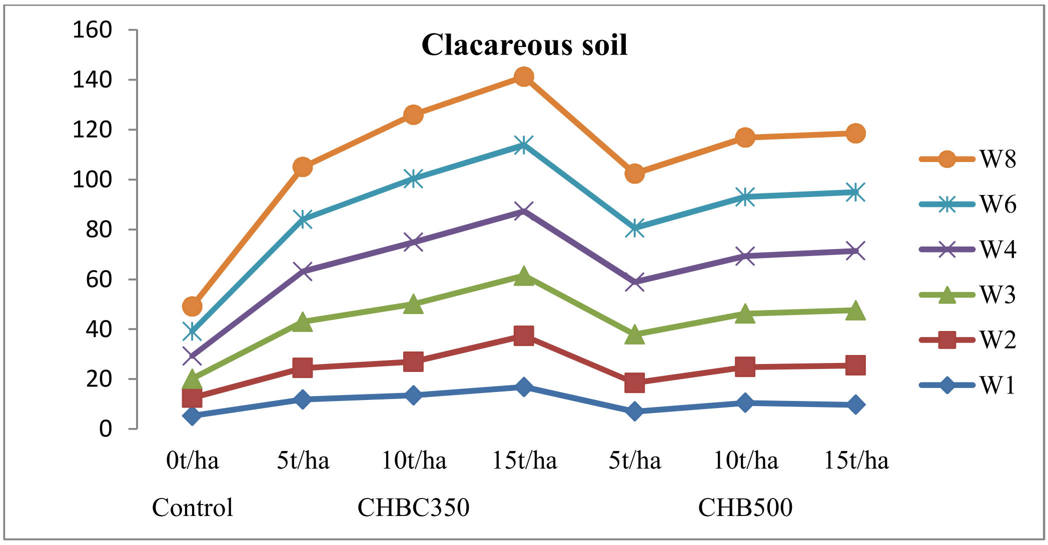

Figure 3. The effect of rate of application and incubation period of CHB350 and CHBC500, on available P in calcareous soil

P sorption significantly increased in the calcareous soil as compared to acidic soil with corresponding application of biochars and concentration of inorganic fertilizer KH_2PO_4 (Fig.4 and 5) which may be due to exchangeable complexes formed by P ions with surface of sorbent at high solution P concentrations to application biochars, which could result higher sorption and lower availability of P.

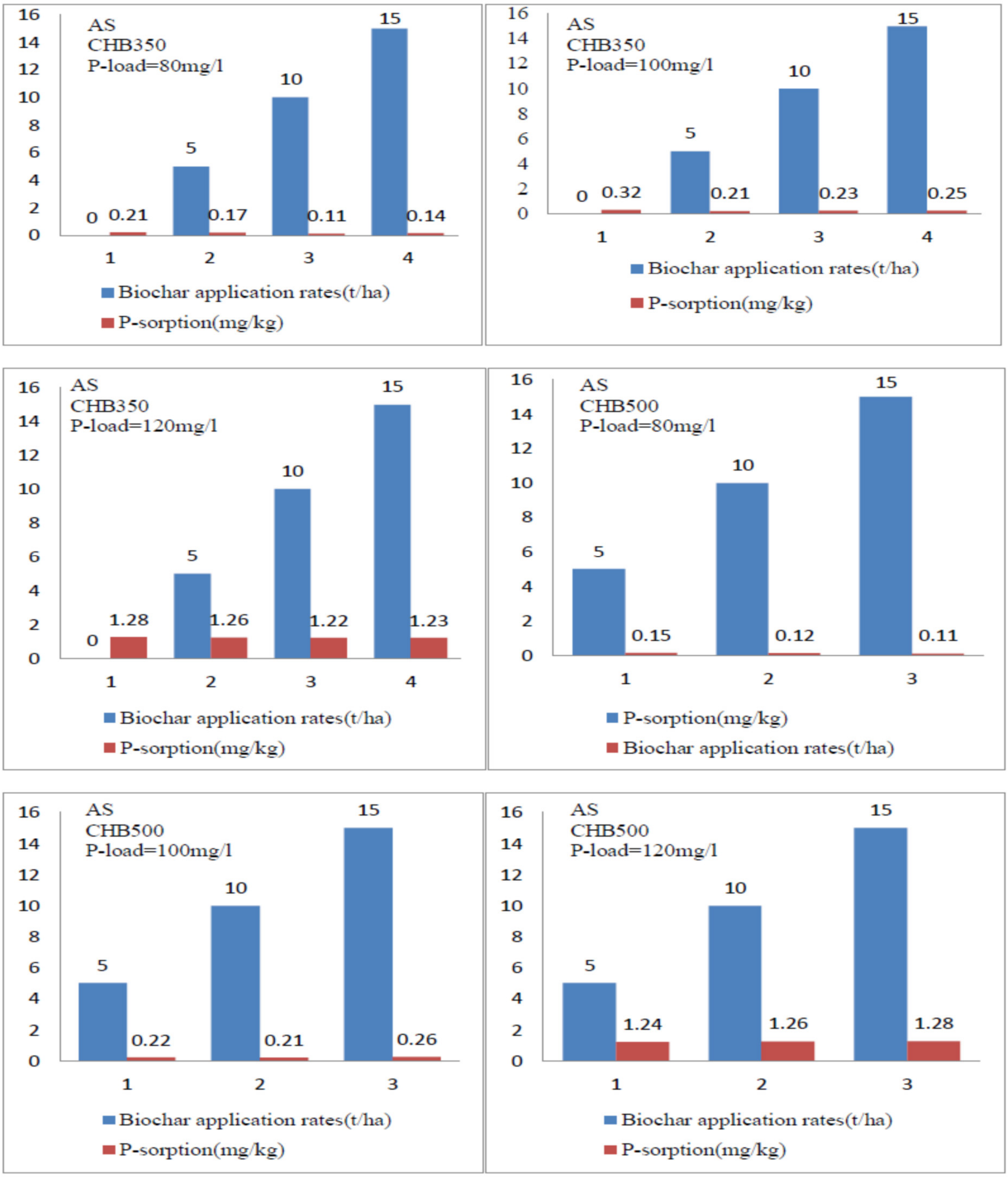

Figure 4. Effect of biochar application rate and different two pyroliyis tempertures (350 and 500^{0}C) on amount of P- sorption in acidic soil (AS) soil at three P loadings of 80,100 and 120mgL-1

This experiment verified that biochars produced from pyrolytic process of biomass feedstock such as coffee husk have high affinity for P. Coffee husk biochar produced at 500^{0}C and applied at 15t/ha had the highest P sorption capacity. The interaction of these coffee husk biochar with soils may cause the changes in their ability to sorb and desorb Phosphorous capacity.

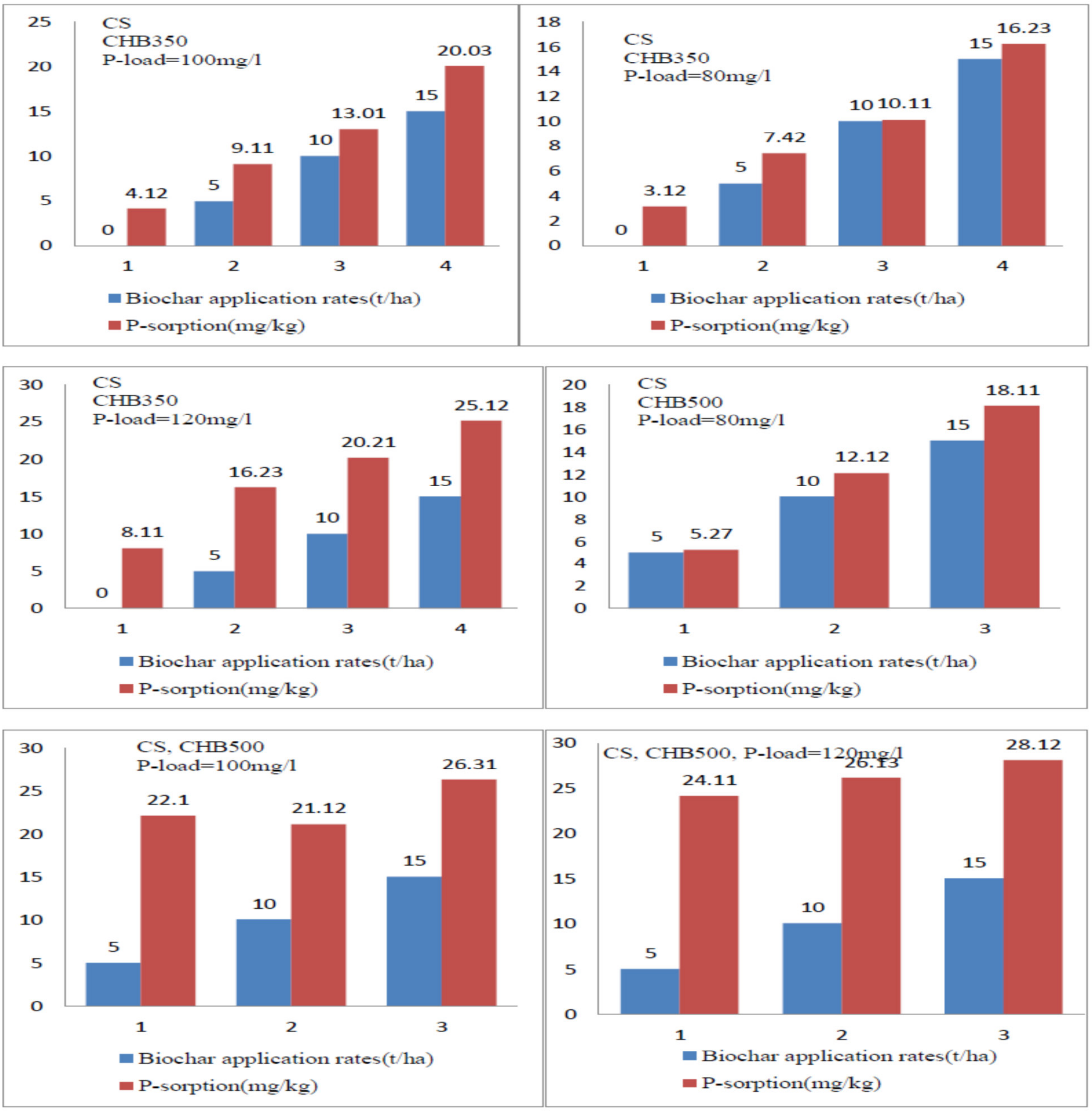

Figure 5. Effects of biochar application rate and two different pyroliyis tempertures(350 and 500^{0}C) on amount of P- sorption in calcareous soil (CS) at three P loadings of 80,100 and 120mgL-1

Application of these biochars significantly decreased the P sorption and increased availability of P in acidic soil, with coffee husk showing the strongest effect in acidic soil than calcareous soil. The extent of the decrease in P sorption and increase in availability in acidic soil was higher with the application of coffee husk biochar produced at 500^{0}C and applied at a rate of 15t/ha. The opposite effect was observed in calcareous soil that biochar amendment, increased P sorption and decreased the availability of P. This effect was larger with the application of coffee husk biochar produced at 500^{0}C and applied at a rate of 15t/ha.

Conclusions

Enhancement of soil Phosphorous by application of biochar is mostly due to high concentrations of P in the ash portion. This study shows the potential of using coffee husk biochar produced at 500^{0}C and applied at rate of 15t/ha enhance P availability in acidic soil which has low available phosphorus and in contrast aggravate P-sorption and decrease P availability in calcareous soil at higher application and pyrolysis temperature. Though, these from these finding further confirmed by field experiments over long term, with consideration of possible adverse effects of coffee husk biochar application at high rates(>15t/ha) to be needed. Application of biochar may be an effective agronomic remedial tool to reduce the P transport from susceptible catchments of a landscape. The incorporation of coffee husk biochar to acidic soil at 15t/ha increased the P concentration, reduced P sorption, and increased bioavailability of P and significantly increased P sorption, especially with alkaline biochars decreased the availability of P in calcareous soil with coffee husk biochar amendment. The effect of these biochars on soil P was aligned with their characterization, suggesting that similar biochar evaluations might predict their effect on P availability and inform recommendations on biochar application to acidic soils and the increase in P sorption was related to the chemical retardation of Ca rather than the hydrolytic reaction of Al and Fe oxides in calcareous soil when biochar applied at higher rate and pyrolysis temperature. Therefore, future investigations should focus on the contributions to P availability of desorbed P from biochar and further researches at field scale are needed to evaluate the effect of biochar on availability and fates of phosphorous in in acidic and calcareous soil.

Acknowledgment

We would like to thank the Capacity building for Scaling up of evidence-based best practices in Agricultural Production in Ethiopia (CASCAPE) project, Jimma University College of Agriculture and Veterinary Medicine Jimma, Ethiopia, for funding this research.

Author's Contributions

All authors involved in the study, helped theoretical and practical development of this research.

Conflict of Interest

All of the authors have read and approved the manuscript and there is no conflict of interest

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