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BIOCHAR AND COMPOST INFLUENCE THE PHOSPHORUS AVAILABILITY, NUTRIENTS UPTAKE, AND GROWTH OF MAIZE (*Zea mays* L.) IN TROPICAL ACID SOIL

Huck Ywih Ch'ng[1], Osumanu Haruna Ahmed[1,2,3*] and Nik Muhamad Ab. Majid[3]

[1]Department of Crop Science, Faculty of Agriculture and Food Sciences, [2]Borneo Eco-Science Research Centre, Universiti Putra Malaysia Bintulu Sarawak Campus, 97008 Bintulu, Sarawak, Malaysia; [3]Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, Serdang, 43400 Selangor, Malaysia
[*]Corresponding author's e-mail: osumanu@upm.edu.my

Most soils in the tropics are acidic, highly weathered, less fertile, and fix phosphorus. Organic amendments such as compost and biochar can be used to increase the nutrients availability in these soils. Thus, the objectives of this study were to (i) improve soil phosphorus availability using biochar and compost produced using chicken litter and pineapple leaves as feedstock, respectively and (ii) determine if the use of biochar, and compost could improve nitrogen, phosphorus, potassium, calcium, and magnesium uptake and dry matter production of *Zea mays* L. cultivated in tropical acid soil. An incubation study was carried out for 90 days. The treatments evaluated were soil only (T0), 300 g soil + 8.24 g ERP (T1), 300 g soil + 8.24 g ERP + 28.8 g biochar (T2), 300 g soil + 8.24 g ERP + 14.4 g compost (T3), and 300 g soil + 8.24 g ERP + 14.4 g compost + 28.8 g biochar (T4). Pot experiment was carried out using maize hybrid F1 as test crop. The treatments evaluated were 7 kg soil only (unfertilized condition) (T0), 7 kg soil + recommended NPK (5 g urea + 8.24 g ERP + 2.58 g MOP (T1), 7 kg soil + 5 g Urea + 8.24 g ERP + 2.58 g MOP + 769 g biochar (T2), 7 kg soil + 5 g Urea + 8.24 g ERP + 2.58 g MOP + 385 g compost (T3), and 7 kg soil + 5 g Urea + 8.24 g ERP + 2.58 g MOP + 385 g compost + 769 g biochar (T4). The organic amendments increased availability of nitrogen, potassium, calcium, and magnesium in the soil. They also increased soil pH to near neutral such that the soil's exchangeable aluminium and extractable iron which fix soil phosphorus were significantly reduced. As a result, phosphorus availability (total phosphorus, available phosphorus, inorganic phosphorus fractions, and organic phosphorus) in the soil was increased. The organic amendments also improved *Zea mays* L. nutrient uptake and dry matter production. The findings of this study suggest that the organic amendments can be used to ameliorate phosphorus fixation of acid soils to improve crop production on these soils.
Keywords: Phosphorus fixation, chicken litter biochar, pineapple leaves compost, nutrient uptake, dry matter production

INTRODUCTION

Most soils of the tropics (predominantly Ultisols and Oxisols) are acidic due to high weathering and high rainfall that results into loss of basic cations. In such soils, acidic cations such as Al and Fe predominate, and depending on soil pH, they can fix the applied inorganic phosphorus (P) (Adnan *et al.,* 2003). Phosphorus is generally available to crops at soil pH of between slightly acidic to neutral (6 to 7). Below this range P is fixed due to active forms of Al and Fe oxides and hydroxides, while at higher pH (>7), P becomes less available due to precipitation with calcium. Therefore, in acidic soils, application of regular P fertilizers such as phosphate rocks are required to saturate Al and Fe ions so as to maintain an adequate supply of plant-available P (Rahman *et al.,* 2014). However, this approach has not been successful because it is not economical. The practice is also not environmental friendly as excessive or unbalanced use of fertilizers causes eutrophication and ammonia volatilization.

In order to mitigate soil P fixation, organic amendments are currently being used to restore the fertility of problem soils (for example, Ultisols and Oxisols). Organic amendments additions have been used in the tropics to improve soil chemical properties and nutrients bioavailability especially P *via* minimizing P sorption sites (Ohno and Amirbahma, 2010; Ohno *et al.,* 2007). Organic amendments have the ability to enhance soil fertility and crop productivity, soil water retention, and carbon sequestration (Galinato *et al.,* 2011). Besides, several studies have shown that addition of green manures and animal wastes to acid soils improve soil fertility (Berek *et al.,* 1995; Hue, 1992). Biochar and compost could act in a similar manner like organic amendments used in the studies mentioned previously. Biochar and compost could be used to improve soil chemical properties and minimize P fixation in acid soils because these organic amendments have high affinity for Al and Fe (Ch'ng *et al.,* 2014; Yu *et al.,* 2013). Their affinity enables long term chelation of Al and Fe instead of P in particular. In addition, biochar and compost are alkaline in nature and may increase soil pH (Yan *et al.,* 1996; Haynes and Swift, 1993). The additional benefits are high porosity, high specific surface area and surface functional groups which can sorb the Al and Fe thus minimizing P fixation (Iyamuremye and Dick, 1996; Violante and Gianfreda, 1993). Hence, P and basic cations will become readily and timely available for crop use. In addition, biochar and compost will release essential nutrients into soils.

Soil fertility and plant nutrition are two closely related subjects that emphasize the forms and availability of nutrients in soils. Soil fertility affects the movement and uptake of nutrients by roots, and utilization of nutrients within plants (Foth and Ellis, 1997). Degradation of soil fertility that relates to changes in different land uses is mainly due to decline in soil organic matter (Smith *et al.,* 2000). McDonald et al. (2002) reported that land clearing and subsequent planting and cropping caused significant reduction in soil organic carbon, total N, exchangeable K, Ca, and Mg, and available P.

To this end, the objectives of this study were to improve soil phosphorus availability using biochar and compost produced from chicken litter and pineapple leaves as feedstock, respectively, and determine if the use of biochar, and compost could improve nitrogen, phosphorus, potassium, calcium, and magnesium uptake and dry matter production of *Zea mays* L. cultivation on a tropical acid soil.

MATERIALS AND METHODS

***Soil sampling*:** Soil at Universiti Putra Malaysia Bintulu Sarawak Campus which has not been cultivated since 2001 was sampled at 0-20 cm. The sampling area was 50 m x 50 m from which 20 soil samples were randomly taken. This soil type (Bekenu Series, *Typic Paleudults*) was selected because it is commonly cultivated with different crops in Malaysia although the soil is characterized by high P-fixing due to high Al and Fe contents. The soil samples were air-dried, ground, and sieved to pass through a 2 mm (for incubation study) and 5 mm (for pot experiment) sieves, respectively. Afterwards, the soil samples were bulked.

***Analyses of soil and organic amendments*:** Before the incubation and pot experiments were carried out, the soil samples were analysed for pH and electrical conductivity (EC) using pH meter and EC meter (Peech, 1965). Soil texture was determined using the hydrometer method (Bouyoucus, 1962). Total organic matter (OM) and total carbon (C) were determined using the combustion method (Chefetz *et al.,* 1996). Total N was determined using the micro-Kjeldahl method (Bremner and Lees, 1949). Total P and available P were extracted using the method described by Tan (2003) after which the blue method (Murphy and Riley, 1962) was used to determine them. Afterwards, C/N and C/P ratios were calculated. Potassium, Ca, Mg, Na, and Fe were determined using the ammonium acetate method and then determined using an Atomic Absorption Spectrophotometer (AAS) (Schollenberger and Dreibelbis, 1945). Exchangeable acidity and Al was determined titrimetrically using 0.01 M NaOH and 0.01 M HCl after extracted by 1 M KCl, respectively as described by Anderson and Ingram (1993). The pH, EC, total OM, total C, total N, P, K, Ca, Mg, Na, Zn, Cu, Fe, and Al of the commercial biochar were obtained from the chemical analysis data sheet provided by the company. The biochar was produced under pyrolysis at a constant temperature of 550 ^{o}C for 20 minutes. The system is a continuous-flow pyrolysis system and converts virtually all the retained carbon in a fixed form with extremely low CO_2 emissions. Compost produced from our previous study (Ch'ng *et al.,* 2013) were analysed for pH, EC, total OM, total C, and total N using the methods previously cited. The single dry ashing method (Cottenie, 1980) was used to extract P, K, Ca, Mg, Na, Zn, Cu, Fe, and Al in the compost. The filtrates were analyzed for K, Ca, Mg, Na, Zn, Cu, Fe, and Al using Atomic Absorption Spectrophotometer (AAS) whereas P was determined using the blue method (Murphy and Riley, 1962).

***Incubation study*:** An incubation study was carried out for 90 days at Universiti Putra Malaysia Bintulu Sarawak Campus. From the bulked 2 mm soil sample, 300 g of the soil were taken for each treatment into 500 mL beaker and each treatment was replicated three times. To understand the selected soil chemical properties and particularly P availability after application of biochar and compost, only Egypt Rock Phosphate (ERP) was added without N and K fertilizers in this incubation study. The rates of the ERP, pineapple leaves compost, and commercial biochar (produced from chicken litter) used in the incubation study were 60 kg P_2O_5 ha^{-1}, 10 t ha^{-1}, and 20 t ha^{-1}, respectively. These rates were based on the standard recommendation for maize (*Zea mays* L.) cultivation (Malaysia Agricultural Research and Development Institute (MARDI), 1993; Zhang *et al.,* 2012; John *et al.,* 2013). The organic amendments requirements were scaled down to per 500-mL beaker. The soil, ERP, biochar, and compost were thoroughly mixed. Beakers with the treatments were sealed with parafilm. The parafilm was perforated to ensure good aeration. The treatments evaluated were:

i. Soil only (T0),
ii. 300 g soil + 8.24 g ERP (T1),
iii. 300 g soil + 8.24 g ERP + 28.8 g biochar (T2),
iv. 300 g soil + 8.24 g ERP + 14.4 g compost (T3), and
v. 300 g soil + 8.24 g ERP + 14.4 g compost + 28.8 g biochar (T4).

The treatments were arranged in a factorial completely randomized design. The samples were incubated for 30 days, 60 days, and 90 days at 27^{o}C, respectively. Each treatment had three replications (that is, 15 samples for 30 days of incubation, 15 samples for 60 days of incubation, and 15 samples for 90 days of incubation). The soil samples were maintained at 60% water holding capacity throughout the incubation period.

At 30 days, 60 days, and 90 days of incubation (DAI), the soil samples were air-dried and analyzed for pH, exchangeable acidity, exchangeable Al, Ca, and Fe, respectively. To understand the mechanisms responsible for P sorption after application of biochar and compost, inorganic P retained by Al, Fe, and Ca were fractionated after the soil samples were incubated. All of the incubated soil samples were analyzed for P fractions using Kuo (1996) procedure. The P fractions were sequentially extracted on the basis of their relative solubility.

***Pot experiment*:** A pot experiment was conducted in a net house at Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia. The test crop used in this study was maize (*Zea mays* L.) hybrid F1. Pots measuring 22 cm (height) x 30 cm (width) were filled with seven kg of soil (from the 5 mm bulked soil sample). Since pot experiment involves cultivation of *Zea mays* L., N, P, and K fertilizers were applied for optimum growth of the test crop. Urea (46% N), ERP (28% P_2O_5), and Muriate of Potash (MOP) (60% K_2O) were applied at 60 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, and 40 kg K_2O ha^{-1}. These rates were based on the recommendation of MARDI (1993). The fertilizers were applied in two equal splits at 10 and 28 days after sowing (DAS). The compost and biochar were applied at rates of 10 t ha^{-1} and 20 t ha^{-1}, respectively. These rates were based on the standard recommendation for maize (*Zea mays* L.) cultivation (Zhang *et al.,* 2012; John *et al.,* 2013). The treatments evaluated were:

i. 7 kg soil only (unfertilized condition) (T0),
ii. 7 kg soil + recommended N, P, and K (5 g urea + 8.24 g ERP + 2.58 g MOP (T1),
iii. 7 kg soil + 5 g Urea + 8.24 g ERP + 2.58 g MOP + 769 g biochar (T2),
iv. 7 kg soil + 5 g Urea + 8.24 g ERP + 2.58 g MOP + 385 g compost (T3), and
v. 7 kg soil + 5 g Urea + 8.24 g ERP + 2.58 g MOP + 385 g compost + 769 g biochar (T4).

The soil, urea, ERP, MOP, compost, and biochar were thoroughly mixed. Maize seeds were soaked in water for 24 hours before sowing. This was done to ensure good germination and plant establishment. The sowing depth was 4 cm. The seeds were sown in planting holes (1 seed per hole) after which the holes were partially covered with loose soil. Five seeds were sown per pot and they were thinned to two at seven days after sowing (DAS). The pot experiment was conducted in a completely randomized design with three replications. The soil moisture was maintained at 70% field capacity throughout the pot experiment. The plants were monitored for 48 days. At tasseling stage (48 DAS), the plants were harvested and partitioned into leaves, stems, and roots. The plant parts were oven dried at 60°C until constant weight were attained after which their dry weight were determined using a digital balance.

At tasseling (48 DAS), soil samples were collected, air-dried, crushed, and sieved to pass through a 2 mm sieve. Afterwards, the soil samples were analyzed for pH, exchangeable acidity, exchangeable Al, total N, total P, available P, and cations (K, Ca, Mg, and Fe) using the methods cited previously. To understand the mechanisms responsible for P sorption after application of biochar and compost, P fractions fixed by Al, Fe, and Ca were fractionated (Kuo, 1996). The single dry ashing method (Cottenie, 1980) was used to extract P, K, Ca, and Mg in the plant tissues (roots, leaves, and stems). The filtrates were analyzed for K, Ca, and Mg using AAS. Phosphorus was determined using the blue method (Murphy and Riley, 1962). Total N was determined using the micro-Kjeldahl method (Bremner and Lees, 1949). The concentrations of N, P, K, Ca, and Mg in roots, leaves, and stems were multiplied by the respective dry weight of the plant parts to obtain the amounts of N, P, K, Ca, and Mg taken up by the maize plants.

***Statistical analysis*:** The incubation study was a factorial completely randomized design with two factors, namely organic amendments (biochar and compost) and time of incubation (30 days, 60 days, and 90 days). There were three replications for the factorial experiment. The pot experiment was conducted in a completely randomized design with three replications. Analysis of variance was used to detect treatment effects while Tukey's HSD test was used to compare treatment means at $P \leq 0.05$. The Statistical Analysis System (SAS) version 9.2 was used for the aforementioned statistical analysis.

RESULTS

***Characteristics of soil and organic amendments*:** The selected physico-chemical properties of Bekenu Series (*Typic Paleudults*) are shown in Table 1. The soil is characterised by the coarse loamy red yellow podzolic group that developed from sandstone that have a texture class (fine-earth fraction) of coarse sand, sand, fine sand, loamy coarse sand, loamy sand, or loamy fine sand throughout a layer extending from the mineral soil surface to the top of an argillic horizon (Soil Survey Staff, 2014). The pH, EC, C, N, P, K, Ca, Zn, Al, and Cu of the biochar were higher but the Mg and Na of the biochar were lower than those of the compost (Table 2).

***Incubation study*:** Days of incubation significantly affected soil pH, exchangeable acidity, exchangeable Al, extractable Fe, and exchangeable Ca (Table 3). Selected soil chemical properties as affected by treatments are summarized in Table 4.

Table 1. Selected physico-chemical properties of Bekenu Series soil.

Property	Value Obtained
Bulk density (g cm^{-3})	1.23
Soil texture	Sand: 67.5% Silt: 15.5% Clay: 17.0% Sandy loam
pH (Water)	4.56
Total organic matter (%)	7.20
Total carbon (%)	4.18
Total N (%)	0.18
Total P (ppm)	132.30
Available P (ppm)	4.50
C/N ratio	23.20
C/P ratio	321.54
Cation exchange capacity ($cmol_c$ kg^{-1})	5.10
Exchangeable acidity ($cmol_c$ kg^{-1})	1.16
Exchangeable Al ($cmol_c$ kg^{-1})	0.84
Exchangeable K (ppm)	1.16
Exchangeable Ca (ppm)	470.30
Exchangeable Mg (ppm)	553.00
Extractable Fe (ppm)	2300.00

Table 2. Selected chemical properties of chicken litter biochar and pineapple leaves residues compost.

Property	Pineapple leaves compost	Chicken litter biochar
pH	7.89	8.50
EC (dS m^{-1})	6.90	15.50
Total carbon (%)	45.80	63.70
Total N (%)	2.30	2.80
Total P (%)	0.46	2.60
C/N ratio	19.91	22.75
C/P ratio	99.56	24.50
Total K (%)	2.67	3.90
Total Ca (%)	0.40	5.90
Total Mg (g kg^{-1})	6365.00	15.20
Total Na (g kg^{-1})	1143.00	19.50
Total Zn (mg kg^{-1})	119.00	856.00
Total Cu (mg kg^{-1})	47.20	167.00
Total Fe (mg kg^{-1})	5062.00	5.60
Total Al (mg kg^{-1})	1.50	0.60

At 30 DAI, 60 DAI, and 90 DAI, the organic amendments (T2, T3, and T4) significantly increased soil pH, reduced exchangeable acidity, exchangeable Al, and extractable Fe compared with the non-organic amendments (T0 and T1) (Table 4). However, the organic amendments (T2, T3, and T4) increased exchangeable Ca in the soil compared with the non-organic amendments (T0 and T1) (Table 4). There were significant differences in the soil total P and available P at 30 DAI, 60 DAI, and 90 DAI (Table 5). All of the organic amendments (T2, T3, and T4) increased total and available P concentrations compared with the non-organic amendments (T0 and T1) at 30 DAI, 60 DAI, and 90 DAI (Table 6). The organic amendments (T2, T3, and T4) also increased Al-P, Fe-P, redundant soluble P, and Ca-P compared with the non-organic amendments (T0 and T1) (Table 6).

***Pot experiment*:** The soil pH, exchangeable acidity, exchangeable Al, total N, exchangeable K, Ca, Mg, and extractable Fe at the end of the pot experiment are shown in Table 7. The pH of the soils with organic amendments (T2, T3, and T4) increased significantly compared with those without the organic amendments (T0 and T1). Increase in the soil pH is consistent with that of the incubation study. At 48 DAS, T2, T3, and T4 reduced exchangeable acidity, exchangeable Al, and extractable Fe compared with T0 and T1 (Table 3). Soil exchangeable Al was negligible in the soils treated with the organic amendments (T2, T3, and T4) at 48 DAS (Table 7). Besides, significant increase in soil total N, exchangeable K, Ca, and Mg concentrations were also observed in T2, T3, and T4 compared with the treatments without the organic amendments (T0 and T1) (Table 7). Treatments with the organic amendments (T2, T3, and T4) increased total P and available P concentrations compared with the non-organic amendments (T0 and T1) (Table 8). This observation is consistent with the findings in incubation study. There were also significant differences in soil P fractions at 48 DAS. The organic amendments also increased Al-P, Fe-P, redundant soluble-P, and Ca-P compared with the non-organic amendments (T0 and T1) (Table 8). This finding collaborates that of our incubation study in Section 3.2.

The dry weight and N, P, K, Ca, and Mg concentrations of the maize hybrid F1 leaves, stems, and roots are presented in Table 9. There were significant differences in the dry matter production (leaves, stems, and roots) of the test crop. The N,

Table 3. Mean square values of analysis of variance (ANOVA) to evaluate the effects of treatments and incubation time on soil pH, exchangeable acidity, exchangeable Al, exchangeable Fe, and exchangeable Ca.

Source of variations	Degree of freedom	Mean square				
		pH	Exchangeable acidity	Exchangeable Al	Exchangeable Fe	Exchangeable Ca
Treatments	4	8.36*	0.95*	0.08*	0.36*	290.14*
Time	2	0.58*	0.01*	0.01*	2.22*	5.49*
Treatments*Time	8	0.07*	0.01*	0.01*	0.34*	1.56*
Error	30					

Note: * indicates significant at $p \leq 0.05$.

Table 4. Effect of treatments and incubation time on soil pH, exchangeable acidity, exchangeable Al, extractable Fe, and exchangeable Ca. Columns represent the mean values ± SE.

Treatments	pH	Exchangeable Acidity	Exchangeable Al	Extractable Fe	Exchangeable Ca
		cmol kg^{-1}			
30 DAI					
T0	5.09 ± 0.5e	0.67 ± 0.05a	0.22 ± 0.05a	0.3 ± 0.1d	0.03 ± 0.01d
T1	6.19 ± 0.3d	0.12 ± 0.03b	0.04 ± 0.02b	1.34 ± 0.2b	12.74 ± 0.3c
T2	6.86 ± 0.2c	0.07 ± 0.02c	Trace	0.33 ± 0.1d	14.88 ± 0.2a
T3	6.96 ± 0.3b	0.11 ± 0.04b	Trace	1.48 ± 0.3a	13.33 ± 0.2b
T4	7.31 ± 0.2a	0.07 ± 0.02c	Trace	0.48 ± 0.1c	12.16 ± 0.3c
60 DAI					
T0	4.29 ± 0.5e	0.9 ± 0.1a	0.22 ± 0.05a	0.26 ± 0.1a	0.03 ± 0.01d
T1	5.84 ± 0.3d	0.09 ± 0.02b	0.02 ± 0.02b	0.10 ± 0.03c	13.83 ± 0.3a
T2	6.55 ± 0.2c	0.08 ± 0.01b	Trace	0.04 ± 0.01d	13.07 ± 0.2a
T3	6.74 ± 0.2b	0.1 ± 0.04b	Trace	0.16 ± 0.02b	12.60 ± 0.3b
T4	7.01 ± 0.2a	0.09 ± 0.02b	Trace	0.04 ± 0.01d	11.88 ± 0.3c
90 DAI					
T0	4.33 ± 0.5e	0.89 ± 0.10a	0.22 ± 0.05a	0.25 ± 0.1a	0.03 ± 0.01d
T1	5.89 ± 0.3d	0.11 ± 0.04b	0.04 ± 0.02b	0.09 ± 0.02c	12.76 ± 0.2a
T2	6.65 ± 0.3c	0.08 ± 0.02b	Trace	0.04 ± 0.01d	11.66 ± 0.3b
T3	6.87 ± 0.2b	0.09 ± 0.03b	Trace	0.15 ± 0.02b	12.07 ± 0.3a
T4	6.94 ± 0.2a	0.09 ± 0.02b	Trace	0.04 ± 0.02d	10.72 ± 0.3c

Means within column with different letter(s) indicate significant difference between treatments by Tukey's test at p≤0.05.

Table 5. Mean square values of analysis of variance (ANOVA) to evaluate the effects of treatments and incubation time on soil P fractions.

Source of variations	Degree of freedom	Mean square						
		Total P	Available P	Al-P	Fe-P	Redundant soluble-P	Ca-P	Total Organic P
Treatments	4	33462070*	1215840*	9066456.5*	5046776.9*	565310.4*	2408900.8*	24865887*
Time	2	134471*	6108.4*	1230.7*	1636.9*	3533.1*	20986.2*	16308.1*
Treat. x Time	8	49023*	625.6*	5129.6*	228.6*	1874.8*	16526.8*	2516.3*
Error	30							

* indicates significant at p≤0.05.

Table 6. Effect of treatments and incubation time on soil total P, available P, Al-P, Fe-P, redundant soluble-P, Ca-P, and total organic P. Columns represent the mean values ± SE.

Treatments	Total P	Available P	Al-P	Fe-P	Redundant soluble-P	Ca-P	Total organic P
30 DAI							
T0	132.2±18e	37.2±2e	33±4e	22.9±3e	7.58±0.2e	15.3±1.5e	52.88±10e
T1	7668.2±30d	2147.1±50d	1844.9±30d	1378±40d	459.3±20d	918.7±50d	3067.3±20d
T2	10094.6±130b	2826.5±40b	2349.5±36b	1752.4±40b	584.1±30b	1168.3±60b	4240.1±150b
T3	7948.2±100c	2225.5±50c	1913.3±34c	1427.5±40c	475.8±30c	951.7±50c	3179.3±200c
T4	10290.5±150a	2881.2±50a	2476.1±48a	1846.6±40a	614.6±30a	1232±10a	4120.5±160a
60 DAI							
T0	133.2±30e	37.3±3e	31±5e	23.3±3e	7.8±0.2e	15.5±1.5e	53.3±10e
T1	7750.5±40d	2170.2±50d	1856.9±45d	1392.7±40d	462.2±20d	930.5±40d	3100.5±20d
T2	10164.6±125b	2847±20b	2352.8±40b	1765±43b	586.3±30b	1178±60b	4269.1±170b
T3	8002.4±150c	2241±20c	1920.3±46c	1440.2±35c	472±30c	958.12±60c	3201.1±150c
T4	10340.5±140a	2895.3±50a	2476±40a	1858.8±35a	616.4±30a	1240±10a	4136.2±140a
90 DAI							
T0	134.2±33e	37.4±3e	31.3±5e	23.5±4e	7.84±0.2e	16±1.5e	96.5±13e
T1	7798.2±35d	2183.5±60d	1868.5±30d	1402±35d	466.3±20d	934.3±40d	2264.9±20d
T2	10224.6±125b	2866.7±40b	2366.7±35b	1775±37b	590.1±30b	1185±70b	3211.8±170b
T3	8018.2±120c	2245.1±40c	1920±32c	1440.1±37c	479.8±40c	960±50c	2787.6±230c
T4	10444.5±130a	2924.5±60a	2500.7±38a	1875.5±30a	623.4±40a	1252±10a	3637±200a

Means within column with different letter(s) indicate significant difference between treatments by Tukey's test at p≤0.05.

Table 7. Effect of treatments on selected soil chemical properties at 48 days after sowing. Columns represent the mean values ± SE.

	pH	Exchangeable Acidity (cmol kg^{-1})	Exchangeable Al (cmol kg^{-1})	Total N (%)	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Extractable Fe
					cmol kg^{-1}			
T0	5.81±0.3e	0.94±0.1a	0.22±0.05a	0.16±0.02d	1.85±0.2e	20.85±0.25e	4.6±0.2e	8.42±0.3a
T1	6.02±0.15d	0.66±0.1b	0.12±0.02b	0.18±0.02c	8.85±0.2d	25.58±0.3d	4.39±0.3d	4.03±0.2b
T2	6.67±0.15b	0.30±0.05d	Trace	0.22±0.03b	38.85±0.3b	35.72±0.15b	9.6±0.4b	2.16±0.2d
T3	6.54±0.1c	0.38±0.1c	Trace	0.2±0.02b	26.17±0.15c	29.7±0.3c	7.16±0.4c	2.82±0.3c
T4	7.07±0.2a	0.28±0.1e	Trace	0.27±0.01a	73.26±0.4a	42.28±0.3a	14.16±0.5a	1.74±0.4e

Means within column with different letter(s) indicate significant difference between treatments by Tukey's test at p≤0.05.

Table 8. Effect of treatments on the soil total P, available P, Al-P, Fe-P, redundant soluble-P, Ca-P, and total organic P at 48 days after sowing. Columns represent the mean values ± SE.

Treatments	Total P	Available P	Al-P	Fe-P	Redundant soluble-P	Ca-P	Total organic P
				ppm			
T0	89.1±5e	1.63±5e	21.4±4e	16±3e	5.36±2e	10.7±1.5e	35.6±10e
T1	7581±30d	2036.1±30d	1819.6±20d	1364.7±30d	454.9±20d	909.8±15d	3032±20d
T2	9823±40b	2419.5±50b	2357.6±25b	1768.2±30b	589.4±30b	1178.8±20b	3929±40b
T3	7795.7±20c	2182.8±30c	1871±30c	1403.2±28c	467.7±30c	935.5±15c	3118.3±40c
T4	9997±50a	2500.3±50a	2399.3±35a	1799.5±30a	599.8±30a	1199.6±10a	3998.8±50a

Means within column with different letter(s) indicate significant difference between treatments by Tukey's test at p≤0.05.

Table 9. Dry weight, N, P, K, Ca, and Mg concentrations in leaves, stems, and roots of maize hybrid F1 at 48 days after sowing.
Columns represent the mean values ± SE.

Treatments	Dry Weight (g)	N	P	K	Ca	Mg
				%		
Leaves						
T0	9.57 ± 1.2f	4.4 ± 0.1a	0.07 ± 0e	0.84 ± 0.02e	0.42 ± 0.06c	0.19 ± 0.03c
T1	10.05 ± 1.5d	3.72 ± 0.1b	0.1 ± 0.02d	1.77 ± 0.04d	0.47 ± 0.05c	0.18 ± 0.03d
T2	22.75 ± 1.6b	3.3 ± 0.12b	0.23 ± 0.02b	2.33 ± 0.05b	0.61 ± 0.04b	0.2 ± 0.02c
T3	21.95 ± 1.8c	3.2 ± 0.15c	0.18 ± 0.02c	1.97 ± 0.05c	0.58 ± 0.06b	0.25 ± 0.04b
T4	24.67 ±2.0a	3.76 ± 0.1d	0.31 ± 0.02a	3.59 ± 0.04a	0.65 ± 0.06a	0.29 ± 0.03a
Stems						
T0	7.88 ± 1.6e	2.44 ± 0.1c	0.14 ± 0.02e	1.58 ± 0.03d	0.30 ± 0.05c	0.24 ± 0.03a
T1	16.18 ± 1.8d	2.65 ± 0.1b	0.20 ± 0.02d	1.71 ± 0.02e	0.38 ± 0.04b	0.15 ± 0.03c
T2	30.8 ± 2b	2.34 ± 0.1d	0.37 ± 0.03b	3.59 ± 0.04b	0.41 ± 0.05b	0.17 ± 0.02b
T3	26.95 ± 2.3c	2.36 ± 0.15d	0.29 ± 0.03c	2.84 ± 0.03c	0.39 ± 0.04b	0.18 ± 0.03b
T4	33.43 ± 2.5a	2.53 ± 0.15a	0.47 ± 0.03a	4.53 ± 0.03a	0.44 ± 0.04a	0.19 ± 0.03b
Roots						
T0	7.68 ± 0.5e	3.03 ± 0.1a	0.05 ± 0.01e	0.14 ± 0.02e	0.26 ± 0.03c	0.07 ± 0.01c
T1	10.2 ± 0.4d	2.47 ± 0.1e	0.12 ± 0.01d	0.19 ± 0.04d	0.42 ± 0.05b	0.08 ± 0.01c
T2	13.02 ± 0.6b	2.56 ± 0.12d	0.23 ± 0.01b	1.96 ± 0.03b	0.56 ± 0.05a	0.25 ± 0.02a
T3	11.9 ± 0.7c	2.73 ± 0.1b	0.2 ± 0.02c	1.17 ± 0.03c	0.52 ± 0.04a	0.14 ± 0.02b
T4	21.93 ± 1a	2.69 ± 0.08c	0.34 ± 0.02a	2.27 ± 0.03a	0.58 ± 0.04a	0.28 ± 0.02a

Means within column with different letter(s) indicate significant difference between treatments by Tukey's test at p≤0.05.

P, K, Ca, and Mg concentrations in leaves, stems, and roots differed significantly (Tables 9). Regardless of plant part (leaves, stem and roots), the treatments with organic amendments (T2, T3, and T4) significantly improved N, P, K, Ca, and Mg uptake compared with the non-organic treatment (T1, chemical fertilizers only) (Figures 1, 2, 3, 4, and 5).

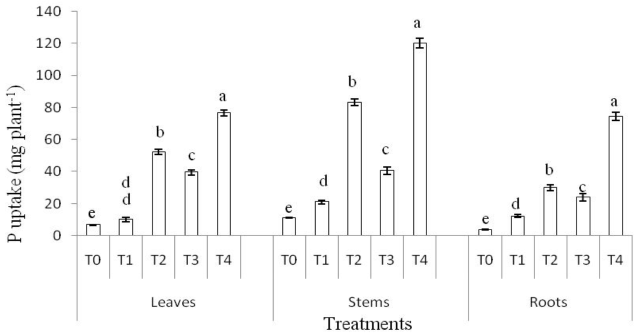

Figure 2. Effect of treatments on P uptake in leaves, stems, and roots of maize hybrid F1. Means within column with different letter(s) indicate significant difference between treatments by Tukey's test at $p \leq 0.05$. Bars represent the mean values ± SE.

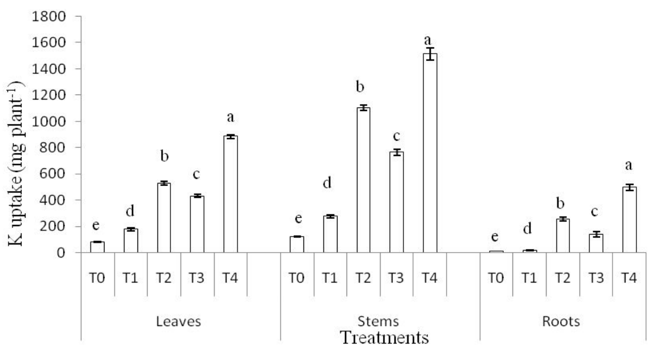

Figure 3. Effect of treatments on K uptake in leaves, stems, and roots of maize hybrid F1. Means within column with different letter(s) indicate significant difference between treatments by Tukey's test at $p \leq 0.05$. Bars represent the mean values ± SE.

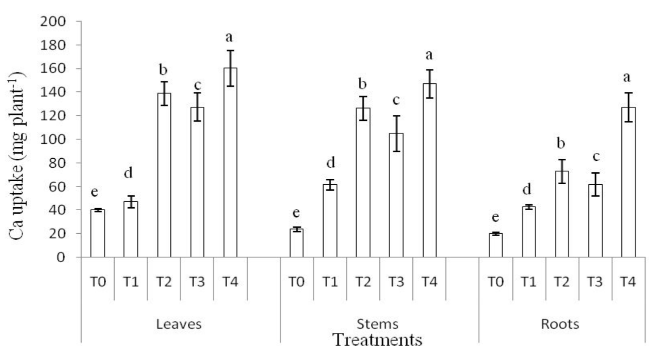

Figure 4. Effect of treatments on Ca uptake in leaves, stems, and roots of maize hybrid F1. Means within column with different letter(s) indicate significant difference between treatments by Tukey's test at $p \leq 0.05$. Bars represent the mean values ± SE.

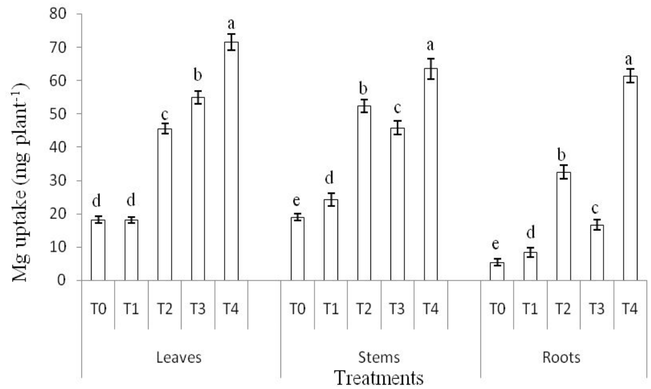

Figure 5. Effect of treatments on Mg uptake in leaves, stems, and roots of maize hybrid F1. Means within column with different letter(s) indicate significant difference between treatments by Tukey's test at $p \leq 0.05$. Bars represent the mean values ± SE.

DISCUSSION

***Effect of treatments and incubation time on soil pH, exchangeable acidity, exchangeable aluminium and iron, and phosphorus availability*:** The C/N ratios of the biochar and compost were 22.75 and 19.91, respectively whereas their C/P ratios were 24.50 and 99.56, respectively (Table 2). These ratios suggest net mineralization of the organic amendments. The increase in soil pH of treatments with organic amendments (T2, T3, and T4) was because of the rapid proton (H^+) exchange between the soil and the organic amendments (Table 3) (Tang *et al.,* 1999; Wong *et al.,* 1998). Several authors have reported increase in soil pH as exchangeable Al decreases (Opala *et al.,* 2012; Narambuye and Haynes, 2006; Noble *et al.,* 1996). Precipitation of exchangeable and soluble Al and Fe as insoluble Al and Fe hydroxides could be one of the causes of the increase in soil pH (Table 4). Precipitation of exchangeable and soluble Al as insoluble Al hydroxide is also evident in the significant reduction of Al through the use of the organic amendments (T2, T3, and T4) in Table 3 (Ritchie, 1994). The organic amendments (T2, T3, and T4) increased exchangeable Ca in the soil compared with the non-organic amendments (T0 and T1) because of the relatively high Ca content in the biochar and compost of T2, T3, and T4.

The increase in the availability of P with increasing days of incubation (Table 6) contradicted the findings of several studies where a decline in available P with increasing time was ascribed to P sorption (Sharply, 1983; Sample *et al.,* 1980). However, the P availability reported in this study is comparable to those reported by Laboski and Lamb (2003), Spychaj-Fabisiak *et al.* (2005), and Opala *et al.* (2012). There were also significant differences in the soil P fractions at 30 DAI, 60 DAI, and 90 DAI (Table 5). This observation is consistent with that of Chang *et al.* (2004) who also observed significant increase in Al-P and Fe-P fractions upon application of organic amendments and inorganic fertilizers. In this study, Al-P was the dominant P fraction. This was followed by Ca-P, Fe-P, and redundant soluble-P. Calcium induced P sorption or precipitation due to the organic amendments used in this study increased the soil Ca-P fraction. The increase in Ca-P fraction could also be associated with the retention of Ca rather than the hydrolytic reaction of Al (Noble *et al.,* 1996). The organic amendments (T2, T3, and T4) increased organic P (P_o) compared with the non-organic amendments (T0 and T1) (Table 6). At 90 DAI, the concentrations of P_o were relatively higher than in 30 DAI and 60 DAI. The increase in P_o with increasing of days of incubation is essential as P_o will eventually mineralize to release P into the soil for crop use.

***Effect of treatments on selected soil chemical properties and phosphorus availability after pot experiment*:** After 48 DAS, the increase in soil pH of treatments with organic amendments (T2, T3, and T4) was partly because of the initial pH of the organic amendments (Table 2). The increase in the soil pH also relates to the rapid proton (H^+) exchange between the soil and the organic amendments used in this study (Tang *et al.,* 1999; Wong et al., 1998). Potassium, Ca, Mg, and Na in the organic amendments may have also contributed to the increase of the soil pH. The decrease in exchangeable acidity and exchangeable Al partly relates to the increase in soil pH (Table 7). The treatments T2, T3, and T4 increased soil total N (Table 7) compared with T0 and T1 because of the stronger affinity of T2, T3, and T4 for nitrate and ammonium (Yazdanpanah *et al.,* 2013). A study by Yao *et al.* (2012) revealed that biochar effectively reduced the contents of nitrate and ammonium in leachates by 34.0% and 34.7%, respectively. It has also been reported that soils that are enriched with compost show similar results (Paulin and Malley, 2008). The inherent contents of K, Ca, and Mg in the organic amendments may have partly contributed to this difference.

There were significant differences in soil total P and available P at 48 DAS (Table 8). As a result of the increase in soil pH from 5.81 to between 6.67 and 7.07 at 48 DAS, the organic acids of the organic amendments may have out competed P for specific adsorption sites on the soil surfaces, hence the increase in the soil total P and available P concentrations (Violante and Gianfreda, 1993). Al-P and Fe-P are available fractions for crops in acidic soils. This is contrary to redundant soluble P which is occluded in acid soils. This process renders redundant soluble-P unavailable for crops. In acid soils, the original superficial loosely bound phosphates (Al and Fe oxides which are available to plants) are re-precipitated into highly crystalline Al-P and Fe-P (not available to crops) but the organic amendments (biochar and compost) were able to fix Al and Fe. This sorption is essential for P availability because sorption reduces Al and Fe oxides in acid soils. The biochar and compost were also able to fix especially Al-P and Fe-P to prevent them from being further precipitated into sorbed P forms. Al-P and Fe-P fractions are biologically labile because increasing soil pH causes dissolution of Al-P and Fe-P to release P.

***Effects of treatments on dry matter production and nutrients uptake by Zea mays L.*:**

Treatments with organic amendments (T2, T3, and T4) used in this study had higher surface area (due to higher contents of COOH, phenolic, alcoholic OH and C=O). The functional groups in the biochar and compost served as exchange sites for the test crop's nutrients (cation exchange capacity). With increase in the cation exchange capacity, nutrients were retained and released timely for optimum uptake by the test crop. This process improved uptake of nutrients in the plants grown with the organic amendments (T2, T3, and T4) compared with the non-organic treatment (T1, chemical fertilizers only) (Figs. 1, 2, 3, 4, and 5). The biochar and compost used in this study also served as bulking agent by improving soil structure, porosity, aeration, and root penetration (Calzolari *et al.,* 2009). This enhanced maize root penetration and aeration in the rhizosphere, thus enabled absorption of water and essential nutrients from soil to improve the *Zea mays*'s growth and development. Lehmann and Rondon (2006) and Uzoma *et al.* (2011) also reported increased nutrient uptake due to addition of organic amendments in the tropical environment.

***Conclusion*:** The results of the present study suggest that the organic amendments can increase availability of N, K, Ca, and Mg in the soil. They can also increase soil pH to near neutral such that the soil's exchangeable Al and extractable Fe which normally fix soil P are reduced. As a result, P availability (total P, available P, inorganic P fractions, and organic P) in the soil increased. Additionally, the organic amendments can also improve *Zea mays* L. nutrient uptake and dry matter production. The findings of this study further suggest that the organic amendments can be used to ameliorate phosphorus fixation of acid soils to improve crop production on these soils.

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