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ORIGINAL PAPER

INFLUENCE OF POULTRY LITTER CHAR ON PHOSPHORUS AVAILABILITY AND GROWTH PERFORMANCE OF CORN (*Zea mays* L.) IN DEGRADED SOIL

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Abstract

Biochar created from poultry litter is a way to produce a value- added soil amendment that is lighter and less expensive to transport out of manure nutrient excess areas but its effects on nutrient availability are less known. A pot experiment was conducted: 1) To evaluate the phosphorus availability and growth performance of corn applied with poultry litter char grown in degraded soil. 2) To determine the optimum rate of poultry litter char as amendment for corn in degraded soil. There were four treatments with four rates of PLC application (T1-0g kg^{-1} soil; T2-200g kg^{-1} soil, T3 - 400g kg^{-1} soil and T4 - 60g PLC kg^{-1} soil). Each treatment was replicated four times and arranged in Randomized Complete Block Design (RCBD). Corn plants were used as test crop for nutrient availability. Planting was done after 10 days of incubation of soil and poultry litter char mixture for reaction. Plants were harvested 30 days after planting for soil and tissue analysis. Results revealed that addition of poultry litter char enhances phosphorus availability and better growth performance. Generally, addition of increasing rates (20-60g kg^{-1} soil) of PLC resulted in consistent increase on weekly plant height, pH_{H2O}, %OC, and extractable P of soil after harvest. On the other hand, similar increasing trend was observed in the soil extractable P within 10 days of incubation before planting. Tissue P concentration and dry matter yield were increased after addition of increasing rates of PLC. However, there were no significant differences observed between the rates of PLC.

Keywords: Poultry litter char, Phosphorus, Corn, degraded soil

INTRODUCTION

Soil fertility can be maintained and improved by using either organic or inorganic fertilizers. Unfortunately, application of inorganic fertilizers is often unaffordable for upland farmers and the rising cost is coupled with their inability to condition the soil(Mando et al., 2005). In addition, continuous use of inorganic fertilizers are adversely affecting soil chemical, biological and physical properties causing nutrient imbalance (Adeleye et al., 2010) forcing them to use organic fertilizer as a source of nutrients (Craswell and Lefroy, 2001) and directed attention to organic manures in recent time. However, effectiveness of organic fertilizers in reclaiming and improving the fertility and productivity of degraded upland varies also with quality and quantity of organic material applied. Moreover, one of the most abundant organic wastes is the animal manure, which has higher nutrient content than crop residues. Therefore, poultry litter can be one of a valuable source of rich nutrients (Roeper et al., 2005) due to its considerable amount of organic matter. This is a mixture of excreta, feed, feathers, and bedding material (Nahm, 2005). Although the nutrient content of poultry litter is variable, it is rich in nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and micronutrients (Mitchel and Tu, 2005; Tewolde et al. 2005). Recently, the use of poultry litter is considered as popular practice in crop cultivation among some farmers in the Philippines. However, this animal manure produces in the country with an average of about 57 M tons annually (PCAARRD, 2006).Consequently, this figure which has likely increased in recent years, imply that substantial source of poultry litter is available in the country, especially in the urban centres which addresses to the problem of waste disposal. Therefore, an alternative practice could be conversion of poultry litter to biochar by pyrolysis as a safer, effective and more stable compound (Glaser et al.,2002) instead of the ordinary degradable organic manures. It is because carbonized material is higher in available P by up to 5 times compared to the original waste (Shinogi et al., 2003; Tagoe et al., 2008).Although, beneficial effects of biochar as a soil amendment in terms of increased crop yield and improved soil quality have been reported but the responses have been very variable (Chan et al. 2007). Such like, biochars from plant materials are often low in nutrient content, particularly N, compared with other organic fertilizers (Chan et al. 2007;Lehmann et al. 2003). With this, Shinogi (2004) reported that biochars produced from animal origins may have higher nutrient content due to the generally higher nutrient content of animal wastes than plant wastes.

Therefore, utilizing poultry litter as a pyrolysis feedstock which clearly show result in higher nutrient value (both N and P) than those produced from plant materials (Chan et al., 2008). It also has advantages over typically used plant derived material because it is a by-product of another industry and in some regions is considered a waste material with little or no value. They also revealed that application of poulty litter biochars significantly changed all the chemical parameters of the soil- increased CEC, pH, total N, total C, Colwell P, exchangeable cations (Ca, Mg, Na, and K), and effective cation exchange capacity but decreased exchangeable Al (Chan et al., 2008).In view of the anticipated increase in the supply of biochar in the future, utilizing this byproduct as a means for improving the retention and releasing capacity for nutrients like phosphorus warrants an investigation.There is little information on whether there would be greater benefit of poultry litter char on the availability on P and plant growth. Therefore, the study was conducted to evaluate the P availability and growth performance of corn applied with poultry litter char grown in degraded soil and determines the optimum rate of poultry litter char as amendment for corn in degraded soils.

MATERIALS AND METHODS

Soil Sampling, Collection, and Analyses

Bulk samples of degraded upland soils from a depth of 0-20 cm were collected randomly from the agricultural farm in Sitio Batuan, Linao, Inopacan, Leyte.The bulk soil samples were air-dried, pulverized and passed through a 4 mm sieve. Subsamples were then subsequently taken for initial chemical analyses and the rest will be prepared for bagging. The subsamples for initial chemical properties were passed through a 2 mm and 0.425 mm sieve for the following analyses:

Soil pH. This was analyzed by potentiometric method using 1:5 soil-diluent ratio – distilled water (pH_{H20}) (PCAARRD, 1980).

Organic carbon (OC). This was determined using the modified Walkley-Black method (Nelson and Sommers, 1982).

Extractable P. This was determined through Olsen extraction method (Olsen and Sommers, 1982). The amount of P in the extract was quantified by the ascorbic-molybdate method (Murphy and Riley, 1962).

Poultry Litter Char Processing

Charring was done using a Top Lit Updraft Double Barrel processing method (Quayle, 2010) with minor modifications. Sub-samples of air-dried poultry litter were placed into a tin can measuring 35 cm in height x 20 cm diameter (the carbonization chamber) at about ¾ height of the can. The carbonization chamber was tightly covered and placed in a drum measuring 80 cm in height x 40 cm diameter (the combustion chamber) with three holes (measuring 5 cm diameter) at its lower side. Three small cans measuring 5.8 cm height x 5.2 cm diameter were placed under the carbonization chamber to facilitate airflow. After the set-up of the poultry litter and combustion chamber, the combustion chamber was filled with rice hull and wood chips at 3:1 ratio which acted as the combustion fuel to achieve an even burn. After a few minutes, a tin lid with a chimney (measuring 62 cm height x 8 cm diameter) was placed on top center of the drum to achieve a sufficient draft for a clean burn. During the 4 hours period of charring, temperature of about (500 ^{0}C and above) was monitored every 10 minutes using a thermometer attached to the external wall of the combustion chamber. After the poultry litter converted into char, the combustion and carbonization chambers were allowed to cool overnight at room temperature (28^{0}C) and removed from the carbonization chamber; weighed and placed in a sealed polyethylene bags ready for chemical analysis and incubation. After charring, poultry litter char (PLC) was ground and passed through to a 2 mm sieve. The sieved PLC wasalso analyzed for pH, % OC and extractable P following the same method mentioned above.

Soil and Poultry Litter Analysis

Table1. Chemical properties of soil and poultry litter char before incubation and planting

Chemical properties	Soil	Poultry litter char
pH water (1: 2.5)	4.39	10.36
Organic C (%)	2.62	27.31
Extractable P (mg kg^{-1})	0.74	728.39

Experimental Design

Pot experiment was carried out in a modified shed house with plastic film roofing at the Department of Agronomy and Soil Science (DASS) Experimental Area, Visayas State University (VSU), Visca, Baybay City, Leyte. There were four treatments and four levels of poultry litter char (20, 40 and 60 g kg^{-1} soil) application.The treatments were replicated four times and laid out in Randomized Complete Block Design.

Treatments:
T_1 – 0g Poultry Litter Char kg^{-1} soil
T_2 – 20g Poultry Litter Char kg^{-1} soil
T_3 – 40g Poultry Litter Char kg^{-1} soil
T_4 – 60g Poultry Litter Char kg^{-1} soil

Pot Preparation, Bagging and Poultry Litter Char Application

Sixteen pots were prepared and used in the experiment. Each pot was filled with 1.25 kg of non-sterilized soil on oven dry weight basis. Prior to bagging, poultry litter char was mixed to the soil in each pot based on the treatments. Each pot was watered up to 50% field capacity and incubated for 10 days before planting. After incubation, subsamples were also collected in each pot. These were air-dried and used for phosphorus availability determination.

Planting, Thinning, Care and Management

Three corn seeds were sown per pot. After emergence, plants were watered whenever necessary. Thinning was done also by removing the other two plants and leaving one plant per pot. Weeds in each pot were removed manually immediately after the emergence of weeds and insects were also removed by handpicking.

Harvesting

Corn plants were harvested 30days after planting. Plants in each pot were uprooted carefully as well as the soils adhering to the roots. The shoots and roots were washed with tap water, and rinsed with distilled water. Using paper-towel, the plant samples were blot-dried. The roots and shoots were weighed using a top loading balance. The different plant parts were air-dried for two days and oven dried for three days or until constant weight was obtained in a forced draft oven set at 70^0C. Soil samples also in each pot were air-dried and set aside for chemical analysis after harvest as mentioned above.

Plant Parameters Gathered

Plant height (cm) was determined by measuring the height of corn from the soil surface up to the tip of the longest leaf in weekly basis until harvest (30DAP).
Dry matter yield (g $plant^{-1}$) was obtained by weighing the shoot and roots after oven drying at 70^0C for three days until obtaining the constant weight. Dry weight of shoots and roots were combined to obtain the total dry matter yield per plant.

Plant Tissue Analysis

The oven-dried shoot and root samples were weighed in a top loading balance and ground to a particle size of <1mm using the Willey MillGrinder and placed in paper bags until used for analysis. These were used for Total

P (plant P uptake) determination using Olsen Method at the Australian Centre for Agricultural Research (ACIAR) Forestry Laboratory.

Data Analysis

Statistical analysis was done using Cropstat version 7.20. The main effects of levels of poultry litter char on P availability and plant growth of corn were analysed using the Analysis of Variance (ANOVA). The treatment means were also compared using Fischer Protected Least Significant Difference (FPLSD) at 5% level of significance.

RESULTS AND DISCUSSION

General Observation

Three days after sowing, 100 % seed germination was observed. At one week after seedling emergence, corn plants applied with 20g, 40g, and 60g PLC showed bigger stem and longer than the control. On the second week after planting, purple and bronze to yellow discoloration along the edges of older leaves were observed especially on plants without PLC amendment, an indicator of P and K deficiency. In addition, yellowing of leaves (chlorosis) in all the treatments were observed indicates nitrogen deficiency. This observation could be attributed to the slow nutrient releasing capacity of the organic fertilizer and also due to the low nutrient content of the soil used. However, plants recovered three weeks after seedling emergence.

Chemical Properties of soil and poultry litter char before planting

The initial soil analysis in Table 1 showed that the soil used was moderately acidic (pH - 4.39), had low amount of organic carbon (2.62%), and low extractable P (0.74 mg kg^{-1}).According to PCARRD (1978), organic matter of 2.00% or an equivalent of 1.16% OC is considered low. The low P content on the other hand, could partly explain the observed purplish coloration of older leaves in some plants particularly in pots without PLC amendment. In contrast, the initial analyses of poultry litter charcontained high pH (10.36), high percent organic carbon (27.31%) and high extractable P (728.39 mg kg^{-1}). Earlier studies had shown that poultry litter char has alkaline nature (pH 9-13) and high organic C content (15 -16%) (Chan et al., 2008). In addition,earlier research had also noted that nutrient content in biochar ranged from 2.7 to 480g total P kg^{-1} soil and172 and 905g total C kg^{-1} soil (Lehmann et al., 2003). This nutrient content of poultry litter char could be a good source enhances nutrient availability and plant growth.

Plant growth

Biochar is suggested that would be beneficial and potential for plant growth in acid soils where the elements Al becomes the limiting factor of plant growth(Tewolde et al., 2005).Their report suggest also that soil incorporated biochars can enhance plant growth (Asai et al. 2009; Blackwell et al. 2009). In the study, growth was vigorous during 1^{st} week to 3^{rd} week after planting in all treatments (Figure 2). At two to three weeks, maize growth, as measured by plant height, generally reflected the availability of soil P due to increasing addition rate of P containing poultry derived biochar. In contrast, plants in all treatments at two weeks after planting showing nitrogen deficiency (yellowing of leaves). The greatest plant height was observed for addition of 60g kg $soil^{-1}$ PLC (T_4). However, the plant height of treatments with increasing levels of PLC addition were only significantly different ($p < 0.05$) at 1 to 2 weeks after planting, whereas at 3 to 4 weeks the plant height of treatments were not significantly different from the other. Technically, the weekly plant growth of maize from week 1 to week 4 follows an increasing trend in all treatments. Results indicate that increasing levels of PLC addition has significant increased in plant growth.Moreover, analysis of the data showed that the greatest level of PLC (60g kg^{-1}) provided the statistically best growth response compared to the control (Figure 2). Similarly, a study in highly weathered tropical soils stated that charcoal addition significantly increased plant growth (Lehmann and Rondon, 2005.In contrast, application of PHC at 10 g PHC kg^{-1} soil or 20 g kg^{-1}soil did not significantly affect the peanut growth rate (Rollon, 2010).

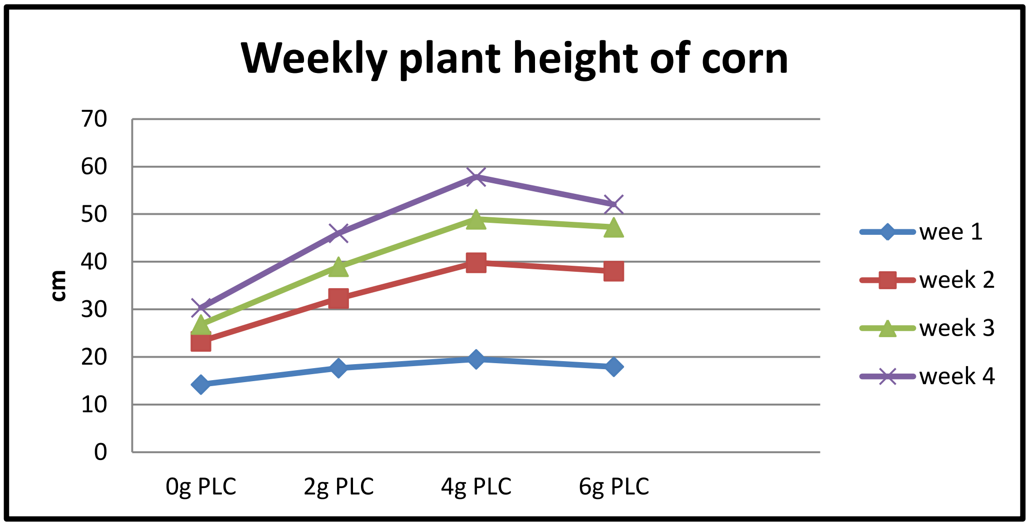

Figure 2. Weekly plant height (cm) of corn as influenced by different levels of poultry litter char.

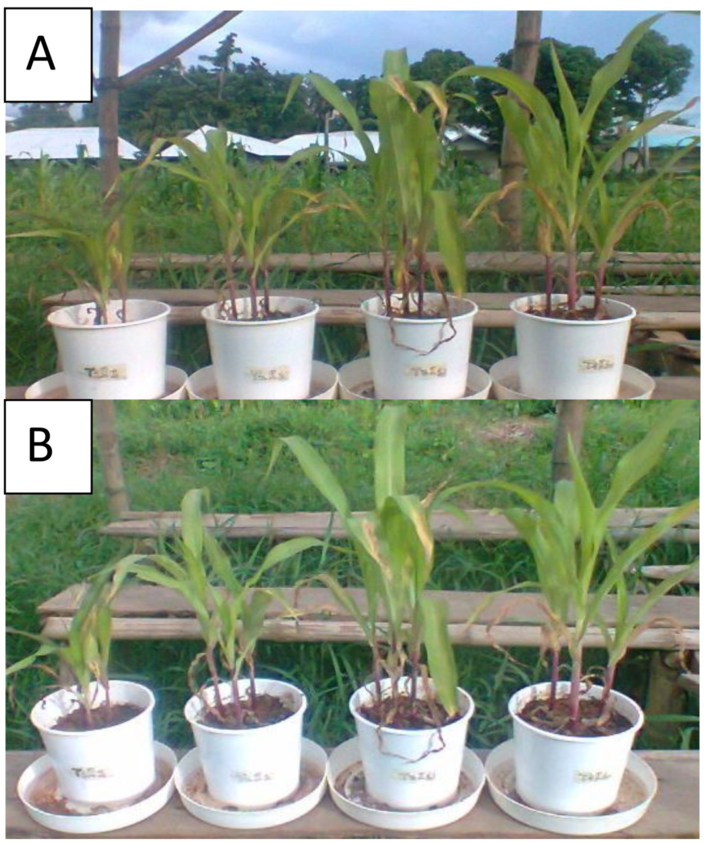

Figure 3. Growth of corn (A)two weeks and (B)three weeks after planting as influenced by different levels of poultry litter char.

pH and percent organic carbon

Soil organic carbon and soil pH is a key factor affecting soil quality. Because of its influence on physical, chemical and biological properties of soils, SOC is crucial in sustaining agricultural productivity and environmental quality (Jha et al., 2010). In the study, addition of increasing levels ofpoultry litter char (20, 40, 60g kg^{-1} soil) significantly increases the pH value of the soil initially from 4.39 to 5.59, 6.53and 6.67, respectively. High significant increasing trends ($p < 0.05$) were observed in all the treatments (T2, T3 and T4). Greatest liming effect was obtained by addition of 60g kg^{-1} PLC (Figure 4). Such liming potential of PLC could be attributed to its high pH (10.36), high Ca content and high percent organic carbon content (27.31%). Similarly, poultry litter biochar with a pH of 9.3 increased the pH of both sandy loam and silt loam soils after addition (Revell et al., 2012).

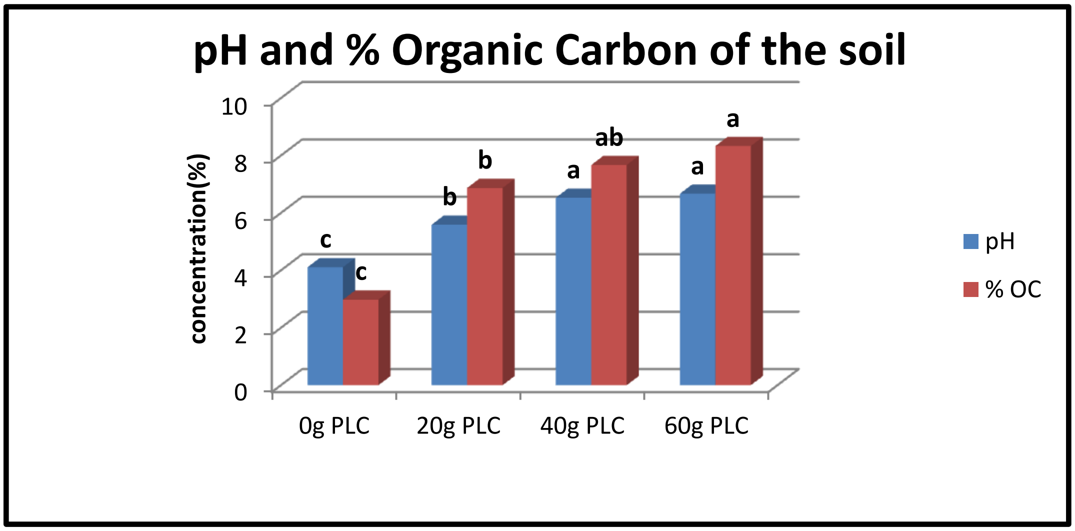

Figure 4. pH and % organic carbon of the soil after harvest as influenced by different levels of poultry litter char.

According to Chan et al (2008) application of poultry litter biochar to acid soil increased soil pH and showed a decreasing trend of exchangeable acid. Moreover, in different study of Uchimiya et al. (2010) they found out that pH increase of soil and water resulting from the application broiler litter-derived biochar that can actually enhance immobilization of heavy metals (e.g. Cu, Cd, Ni, and Pb). A thesis study of Rollon (2010) added also that residual effects of PHC application at rate 10-20 g kg^{-1} soil significantly increase pH (H_2O and $CaCl_2$) of strongly acid soil.Percent organic carbon on the other hand is directly related to the increased in soil pH after PLC addition. It follows similar increasing trend as the pH value increases after addition (Figure 4). The positive change in soil OC can be attributed to OC content (27.31%) of poultry litter char addition. Direct effects of poultry litter char at rates addition 20, 40, 60 g kg^{-1} soil resulted in significant increase in SOC at two weeks to four weeks after planting. Furthermore, addition of 20, 40, 60 g kg^{-1} significantly improved the soil organic carbon from 2.62% to 6.87%, 7.67% and 8.33%, respectively. Enderes (2010) had also shown the positive change in OC and liming benefit of poultry litter char application in strongly acid clay soil.

Extractable P before (10d incubation) and after harvest

Phosphorus is important in energy storage and transfer. It influences plant growth by stimulating vigorous root growth which accounts for better utilization of the nutrients. Under strongly acidic condition, the formation of iron (Fe) and aluminum (Al) phosphate minerals results in the reduced solubility of P (Uchimiya, 2010).Results of statistical analysis showed high significant differences ($p < 0.05$) between treatments in terms of extractable P before (10d incubation) and after harvest (Figure 5).Results in extractable P before (10d incubation) planting found that the lowest value obtained in the control (0g kg^{-1} PLC) treatments with a value of 0.79 mg kg^{-1} P on the other hand addition of 60g kg-1 PLC (T4) reached the highest content of extractable P (83.17 mg kg^{-1} P). Whereas treatments (containing 20, 40g kg^{-1} PLC)also gave high value of extractable P such as 41.97 and 53.29 mg kg^{-1}P, respectively. Generally, increasing trend value of extractable P was observed in all the treatments (T1, T2, T3 and T4). The increasing trend of soil extractable P could be due to addition of high phosphorus containing biochar (PLC-728.39 mg kg^{-1}P) that provided benefits of donations adsorption complex for cations and anions needed for plant growth. Similarly, total phosphorus (P) in the biochar was 43 g kg^{-1}, and although almost none of this was water soluble in the pure biochar, the Mehlich 1 P and Olsen P were greatly increased in biochar amended soils (Revell et al., 2012).

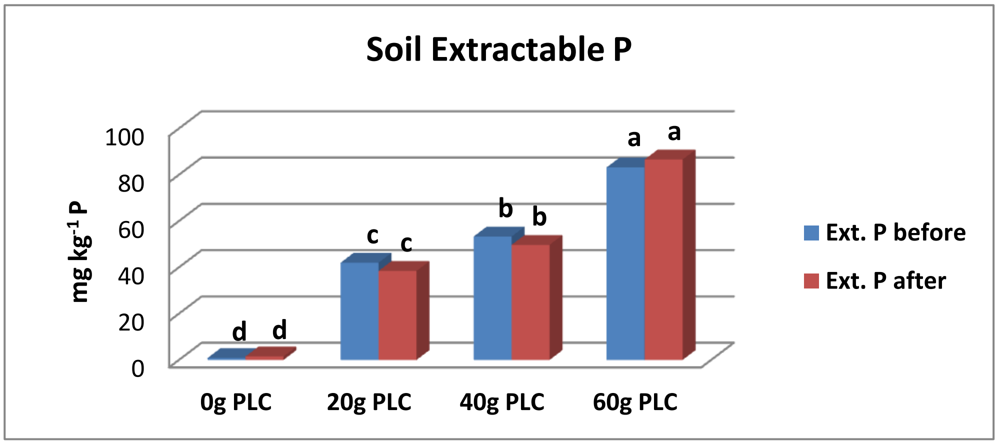

Figure 5. Extractable P (mg kg^{-1}) of soil before (10 days incubation) and after harvest as influenced by different levels of poultry litter char.

On the other hand, results on extractable P after harvest were observed to have a similar increasing trend as of the extractable P before planting in all the treatments (20, 40, 60g kg^{-1} PLC) with a value from 1.49 to 38.43, 49.7 and 86.59 mg kg^{-1}P, respectively. Extractable soil P was likewise affected by rates of PLC applied. Soils added with 60g kg^{-1} PLC had the highest extractable P in all the treatments (Figure 5).This was expected as PLC had a extractable P of 728.39 mg kg^{-1} soil. In line with this, biochar can alter P availability directly through its anion exchange capacity or by influencing activity/ availability of the cations that interact with P. This can lead to soil oxides of elements such as aluminum and iron being unable to bind with soluble P which has linked with these biochar exchange sites. Phosphorus precipitation on the other hand influences the solubility of P and therefore the amount available to the plant. Similarly, Nelson et al. (2011) found temporary increase in P availability in soil after BC addition and suggested BC induced inhibition of P adsorption pot studies, Chan et al. (2008) reported that poultry litter biochar increased N, P, S, Na, Ca, and Mg concentrations of the radish plants (*Raphanus sativus* variety Long Scarlet) indicating these nutrients are plant available. In addition, phosphorus and K concentrations were high in soil applied with poultry litter biochar [33.6 and 45.6 g kg^{-1}, respectively (Gaskin et al., 2008)]. Moreover, it was found that poultry litter biochar has the highest significant increase in Mehlich 1 extractable P and sodium (Na) concentrations after application to loamy sand (Novak et al., 2009). Based also from the statistical analysis, there were no significant differences in terms with the value comparing the extractable P before and after harvest. Although the value of extractable P after harvest follows the same trend as the value of the extractable P before planting (10d incubation). However, addition of 20g (T2) and 40 g kg^{-1} (T3) PLC were observed decreased in availability of soil P (Figure 5). The decreased could be due to the plant utilization and uptake for plant growth development during vegetative stage. The increased also in the extractable P after harvest with the addition of 60g kg^{-1}PLC could be attributed to high phosphorus content of the PLC readily available for plant uptake.

Plant Total Phosphorus

High plant total phosphorus was observed when increasing addition rates of 20, 40 and 60g kg^{-1} PLC (Table 2). However, they were not statistically different ($p < 0.05$) from the other. High total phosphorus contents were obtained from plant digestion and quantification due to high addition rates of poultry litter char that promoted phosphorus availability for plant uptake. According to Lehmann and Rondon (2005) upon nutrition uptake of P, K, Ca, Zn, and Cu by the plants increased with higher charcoal additions to the control (0g kg^{-1} PLC), biochar amendments (20, 40 and 60g kg^{-1} PLC) increased total P concentration by maize from 990.15 mg kg^{-1} P to 4218.95, 4410.88 and 4328.05 mg kg^{-1} P, respectively.

Table 2. Means of plant total P (mg kg^{-1}) and total dry matter yield (g plant^{-1})after harvest as affected by different levels of poultry litter char.

Treatments	Plant total P (mg kg^{-1})	Dry matter yield (%)
0g PLC kg	990.15b	1.81d
20g PLC kg^{-1} soil	4218.95a	3.75c
40g PHC kg^{-1} soil	4410.88a	6.56b
60g PLC kg^{-1} soil	4328.75a	7.23a
CV (%)	6.11	16.34
0g PLC kg	990.15b	1.81d

Means not sharing letter in common differ significantly at 5% level by duncan's multiple range test.

However, the highest phosphorus content was obtained by the addition of 40g kg^{-1} PLC. This indicates that increasing addition rates of biochar only up to 40g kg^{-1} PLC could already improved availability of soil P and P uptake by maize which in turn improved plant yield. In the study of Rondon et al. (2007) application of biochar to 30 g/kg soil can increase P uptake up to 7 mg/pot on legumes. Additionally, application of 10 and 20 g PHC kg^{-1} soil resulted in higher P uptake value than those without PHC application (Rollon, 2010). The beneficial effect of PHC on P uptake could be due to the additional P supply from PLC.

Dry matter yield

Dry weight of corn plant was significantly affected by increasing rates of biochar addition (Table 2). Addition of 20, 40 and 60g kg^{-1} PLC resulted in higher dry weight (DW) compared to control. Highest dry weight was obtained by addition of PLC (60g kg^{-1}) with a value of 7.23 g plant^{-1}. Dry weight was determined when plants were at four weeks after planting that is why low values were observed. However, an increasing trend between the treatments was indicated.

CONCLUSION

Application of PLC at 20-60 g kg^{-1} soil can enhance phosphorus availability and plant growth of corn grown in degraded soil. The appropriate rate of PLC as soil amendment for corn in degraded soil was not achieved because the study was conducted only for a short period of time (1 month). Such that appropriate rate of PLC application and follow up studies should be conducted for a long period of time to validate its effect on the availability of phosphorus, uptake and growth and yield of corn at maturity stage.

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