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IMPROVING SOIL PHOSPHORUS AVAILABILITY FOLLOWING APPLICATION OF EGYPT ROCK PHOSPHATE AND CHICKEN LITTER BIOCHAR

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ABSTRACT

Biochar has high concentrations of organic carbon, high porosity and surface area, improvement in soil physical properties including soil structure and water holding capacity. Chicken litter biochar had been used to improve soil phosphorus (P) availability for maize production but limited information on optimum rates of biochar and Egypt Rock Phosphate (ERP) to increase P availability. This research determined the rate of biochar and Egypt Rock Phosphate (ERP) that could increase soil P retention and availability. A laboratory study on P retention by different rates of biochar was evaluated in a leaching study for 30 days where the leachates were collected at three-day interval. Selected soil chemical properties before and after incubation were determined using standard procedures. The total P, pH, K, Mg, total C and P, exchangeable P, and water-soluble P, of the soils with biochar significantly higher than recommended fertilization practice. Around 75% biochar of 10 t ha-1 with 50% and 25% ERP of the existing recommendation showed significant retention and nutrients availability.

Keywords: Biochar, Egypt rock phosphate, Phosphorus availability

INTRODUCTION

Poor crop growth on highly weathered acid soils partly relates to low pH, aluminium (Al) toxicity, low organic matter, and leaching of P from the soil profile (Asap et al., 2018; Ch'ng et

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al., 2016b). Leaching of P due to high rainfall contributes to pollution of fresh bodies (eutrophication) (Carpenter, 1998). Moreover, leaching of nutrients from agricultural soils reduces soil productivity, speeds up soil acidification, lessens crop yield, and it also increases cost of crop production. Complications of nutrient leaching differ greatly with both rainfall intensity and soil properties. Ancient Amerindian farmers resolved this difficulty by combining huge amounts of biochar with manure, bones, and other organic residues into soils to transform native Oxisols into Anthrosoils (Glaser et al., 2001). In recent times, to minimize losses of nutrient leaching, various methods including water table management (Drury et al., 2001), bio-reactors and engineered marshes (Christianson et al., 2009), and cover crops have been employed (Askegaard et al., 2011; Sattell et al., 1999). Nevertheless, these methods have not been successful in mitigating P leaching in particular due to weathered soils being poor in anion exchange capacity (AEC) (Ulen et al., 2012).

To meet plant P requirements, approximately 15 million tons of P fertilizer was used worldwide (Wang et al., 2012), out of which only a fraction (5–30%) of P applied is used by crops (Veneklaas et al., 2012). The applied ortho-phosphate in substantial amount is frequently lost in the aqueous environment via runoff or leaching. Phosphorus loss through runoff is approximately 79% (Zhuan-xi et al., 2009; Liang et al., 2006). Majority of P fertilizers are from mined rock phosphate, a non-renewable resource, and supplies of rock phosphate will be depleted by the end of this century as the worldwide demand for P will increases over the next 50 years (Zhang et al., 2016). Predominantly leached is orthophosphate, a reactive negatively charge P (Wang et al., 2012; Ulen et al., 2012) because highly weathered soils lack positively charged exchange sites. Thus, the loss of this form of P is more pronounce because the electrostatic repulsion of the negative charge sites on the soil colloid surfaces and the orthophosphate. This increases the rapid movements of the orthophosphate into the soil water (Wang et al., 2012). Amending tropical soils with biochar increases soil pH (Asap et al., 2018; Ch'ng et al., 2016; Mikan et al., 1996), water holding capacity (Karhu et al., 2011), reduce bulk density (Case et al., 2012), and it as well increases soil cation exchange capacity and anion exchange capacity (Ch'ng et al., 2016; Mao et al., 2012).

Functional groups of biochar include hydroxyl, carbonyl, carboxylate, hydrogen (H), and ether (Mao et al., 2012; Cheng et al., 2008) have effect on the electrical charges, dipole, and H-bond of the biochar with water and solutes. Addition of biochar to soil also reduces phosphate leaching (Knowles et al., 2011; Laird et al., 2010) due to the AEC of biochar. The objective of this study was to determine the rate of biochar and Egypt Rock Phosphate (ERP) that could increase soil P retention and availability.

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MATERIALS AND METHODS

Initial characterization of soil sample

Typic *Paleudults* (Nyalau Series) was collected at Universiti Putra Malaysia, Bintulu Sarawak Campus, Malaysia, at a depth of 0 to 25 cm. The soil was air dried after which it was sieved to pass a 2 mm sieve for selected chemical properties of the soil before and after the 30 days of leaching study. Soil pH in water and KCl were determined in a 1:2.5 (soil: distilled water) suspension using a digital pH meter (Peech et al., 1965). Soil total carbon was determined as 58% of the total loss of weight on ignition (Cheftez et al., 1996). Soil total P was extracted using aqua regia method (Bernas, 1968) whereas soil available P was extracted using Mehlich No.1 Double Acid method (Mehlich, 1953) and soil soluble P was extracted using deionized water. Thereafter, total P, available P, and water soluble P was determined using Spectrophotometer after blue colour was develop using the Blue Method (Murphy and Riley, 1962).

Leaching study

A laboratory study on P retention by different rates of biochar was evaluated. A 500 mL plastic container was filled with 300 g of air dried soil after thoroughly mixed with chicken litter biochar (Table 1). The three replicates of each treatment were arranged in a well-ventilated room at Universiti Putra Malaysia, Bintulu Sarawak Campus in a Complete Randomized Design (CRD). The soil mixture was moistened to 60% of moisture content based on the soil field capacity after which different rates of ERP (Table 1) were surface applied. Distilled water of 463 mL was sprayed to every container after which the leachates were collected at three-day interval. Treatments evaluated are summarized in Table 1. The recommended rate of P fertilizer used was 60 kg P2O5 ha^{-1} (130 kg ha^{-1} ERP) and scaled down to per plant basis from the standard fertilizer recommendation by Malaysian Agriculture Research and Development Institute (1995). The biochar rate was 10 t ha^{-1} and scaled down to per plant basis.

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Table 1: Chicken litter biochar and Egypt rock phosphate rates for leaching study

Application treatment	Soil	Biochar rate	ERP rates
			P
	g container^{-1}	……………….………………	g plant^{-1}……………………..
T1	300	0	0
T2	300	0	7.71
T3	300	360	0
T4	300	270	5.79
T5	300	270	3.86
T6	300	270	1.93
T7	300	180	5.79
T8	300	180	3.86
T9	300	180	1.93
T10	300	90	5.79
T11	300	90	3.86
T12	300	90	1.93

Leachates analysis for leaching study

Leachates were collected and analysed every 3 days for pH using pH meter (Peech et al., 1965). Available P was determined using Spectrophotometer after blue colour was developed using the Blue Method (Murphy and Riley, 1962). Available K, Ca, and Mg were determined using

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Atomic Absorption Spectrometer (AAnalyst 800, Perkin Elmer Instruments, Norwalk, CT).

Statistical analysis

Analysis of variance (ANOVA) was used to test treatment effects whereas treatments means were compared using Tukey's Test and Statistical Analysis Software version 9.4 was used for the statistical analysis (SAS, 2011).

RESULTS AND DISCUSSION

Initial Physico-Chemical Properties of Soil and Chicken Litter Biochar Used

The physico-chemical properties of the soil used in this study (Table 2) were within the range reported by Soil Survey Staff (2014) and Paramananthan in 2000 for Nyalau series (Typic Paleudult). The pH values, C, P, K, Ca, Al, and Mg contents of the chicken litter biochar were also within the range reported by the Black Earth Company in North of Bendigo Victoria, Australia (Table 3).

Table 2: Selected physical and chemical properties of Nyalau series

Property	Current study	Range* (0-36 cm)
pH in H_2O	4.43	4.6-4.9
pH in KCl	3.83	
Bulk density (Mg m^{-3})	1.16	NA
Total organic carbon (%)	1.43	0.57-2.51
Organic matter (%)	2.44	NA
Available P (mg kg^{-1})	4.85	NA
---------- (cmol (+) kg^{-1}) ----------		
Total acidity	0.86	NA
Exchangeable H^+	0.22	NA
Exchangeable Al^{3+}	0.64	NA

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Exchangeable K	0.22	NA
Exchangeable Ca	1.04	NA
Exchangeable Mg	2.25	NA
---------- (%) ----------		
Sand (%)	71.04	72-76
Silt (%)	14.58	8-9
Clay (%)	14.38	16-19
Texture (USDA)	Sandy loam	Sandy loam

Note: NA: not available; *subjected to the soil development, range as found in Paramananthan (2000)

Table 3: Selected chemical properties of chicken litter biochar

Property	**Chicken litter biochar**
pH	9.54
EC (mS cm^{-1})	3.50
Moisture (%)	46.08
CEC (cmol (+) kg^{-1})	59.27
Molarity (M)	nd
---------- (%) ----------	
Organic matter	71.67
Total organic carbon	41.57

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Total N	2.39
Total P	4.52
Total K	6.05
Total Ca	4.80
Total Mg	1.77
Total Na	1.75
Total Fe	0.49
--- ($mg\ kg^{-1}$) ---	
Total Zn	772
Total Mn	1479
Total Cu	264

Note: nd: not determined

The pH of leachate over 30 days of leaching

The pH of the leachate of all treatments ranged between 4.7 to 8.4 on day 3 and the order was T3 > T4 > T8 > T5 > T7 > T9 > T6 > T10 > T12 > T11 > T1 > T2. The highest pH was in T3 (100% chicken litter biochar) which was due to the liming effect of the biochar. T2 showed the lowest effect on day 3 compared with T1 because the ERP used have reacted with the soluble Al and Fe to reduce production of H+ through the hydrolysis of Al and Fe (Ch'ng et al., 2014b, 2014c; Jiao et al., 2007). From day 6 to day 30, the pH of T2 was higher than in T1 but the pH of T2 lower than with biochar (T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12). The pH of the treatments with chicken litter biochar (T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12) fluctuated within a range of 6.9 to 8.3 but generally higher than those without the organic amendment (T1 and T2) due to the base cations of the biochar, besides, the ability of this organic amendment to impede Al^{3+} and Fe^{2+} hydrolysis to release H^+. This observation is consistent with the findings of Ch'ng et al. (2016) and Asap et al. (2018). The increase in soil pH was also due to the rapid proton (H^+) exchange between the soil and the added organic amendments (Tang et al., 2007).

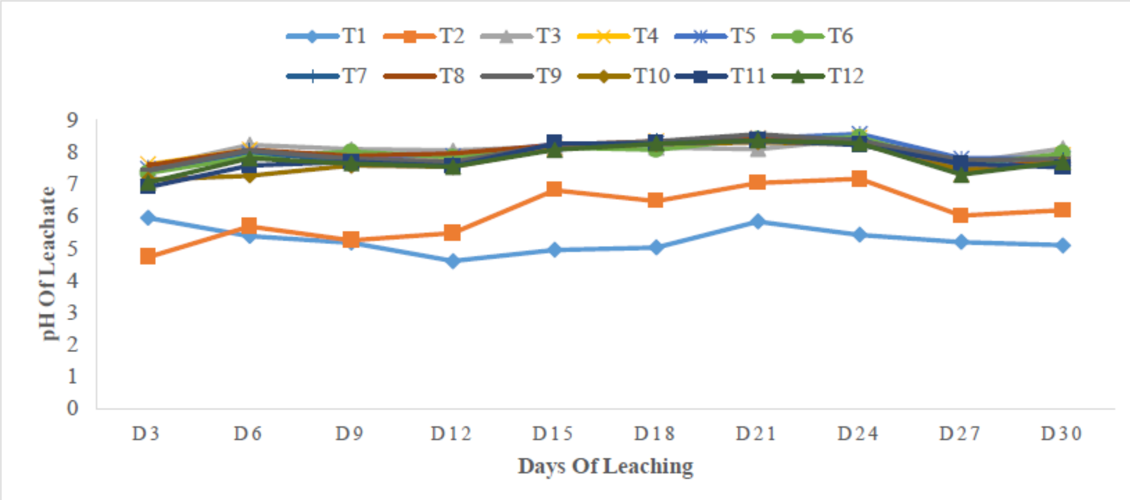

Fig 1: Effects of treatments with and without chicken litter biochar on leachate pH over 30 days of leaching

Availability of phosphorus in leachate over 30 days of leaching

The soil P concentrations of T1 and T2 were constant throughout the leaching period because tropical soils are low in P due to Al and Fe fixation (Ch'ng et al., 2016b). The soil P concentrations of T3, T4, T5, T6, T7, T8, T9, T10, T11, and were T12 were higher on the first day of leaching (day 3) with T3 having the highest concentration after which the P concentration increased in T3, T4, T5, T6, T7, T8, and T9 on day 6 but decreased gradually from day 9 to day 18. Treatment with 25% of 10t ha^{-1} biochar (T10, T11 and T12) showed slightly higher P concentration compared with the treatments without biochar (T1 and T2) but lower than those with 100% of 10t ha^{-1} (T1), 75% of 10t ha^{-1} (T4, T5 and T6) and 50% of 10t ha^{-1} (T7, T8 and T9).

The P concentrations of T10, T11 and T12 showed a consistent trend right from day 3 to day 30. The treatments with 25% of 10 t ha^{-1} biochar (T10, T11 and T12) showed more P in the leachate than in T2 and T1, indicating the P contribution of the biochar but with co-application with ERP, the P higher than that of the normal practice (T2). Treatment 3 release of P was substantial on day 3 but decreased gradually compared with the treatments with 50% of 10 t ha^{-1} biochar (T7, T8 and T9) but higher than those with 25% of 10 t ha^{-1} biochar (T10, T11 and T12) on day 18. Treatment 3 showed significant increase in P on day 21 higher than other treatments, after which there was a decrease until day 27. On day 30, the P of T3 was higher than those of T1, T2, T4, T5, T6, T7, T8, T9, T10, and T12 due to the slow release of nutrients from the biochar as T3 had 360g (10 t ha^{-1} or 100% biochar applied) of biochar (Table 1). For this, the biochar application

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significantly increased P retention of the soil (Novak et al., 2009a). Generally, the soils with biochar showed the higher amount of P concentration in the leachate compared with the normal practice (T2) despite the biochar having some substantial amount of P coupled with the applied P. 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 (Xu et al., 2013; Atkinson et al., 2010).

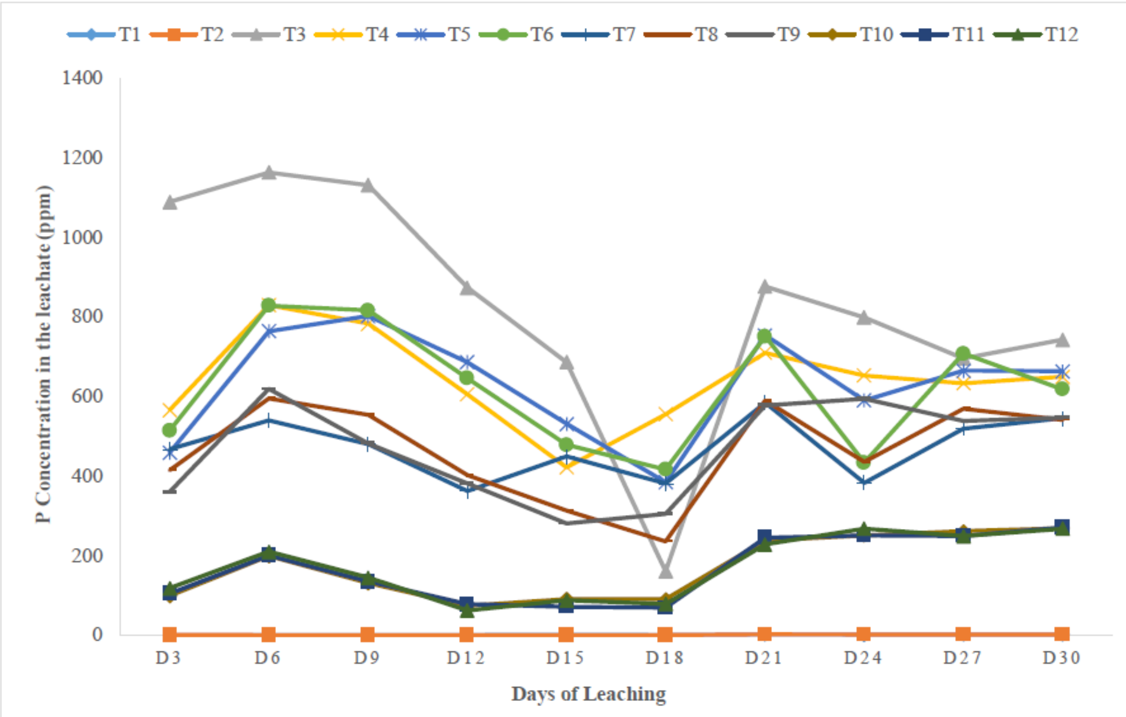

Fig. 2: Effects of treatments with and without chicken litter biochar on leachate P availability over 30 days of leaching

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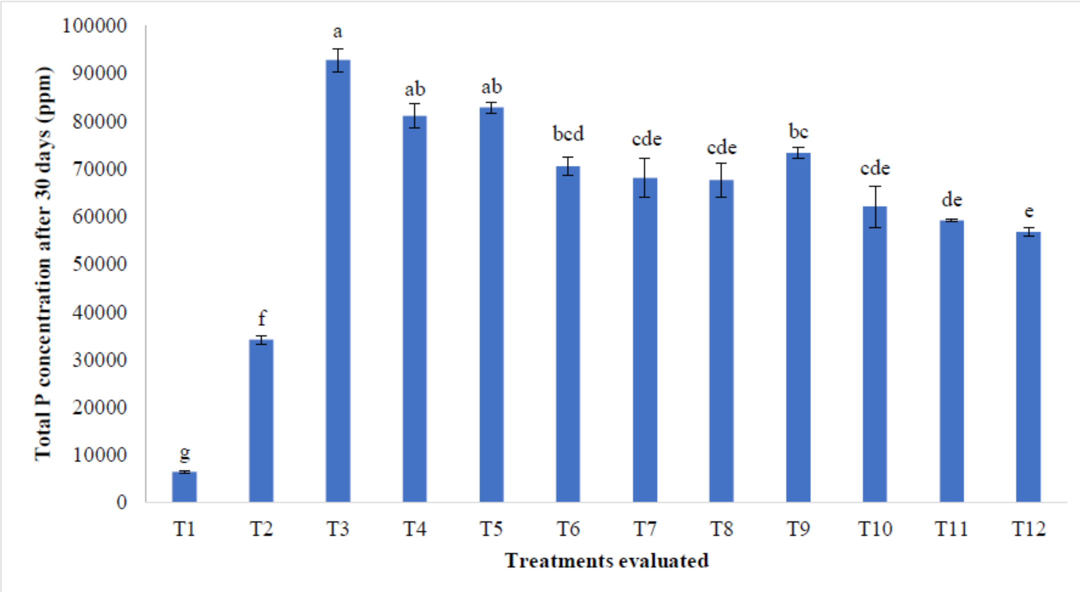

Fig. 3: Effects of treatments with and without chicken litter biochar on leachate total P availability after 30 days of leaching

Base cations of soil after 30 days of leaching

Irrespective of treatment, K in the leachate increased from day 3 to day 9 with those of T1 and T2 having the lowest K concentration because of the K content in the chicken litter biochar in T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12. The K concentrations in the leachate of all of the treatments decreased from day 12 to day 21 (Figure 4) after which increases in K concentrations of T4, T5, T7, and T11 occurred on day 21 but there was a decrease on day 27. For T3, T6, T9 and T8, there was an increase in K concentration of leachate on day 27 because the chicken litter biochar might have acted as a slow release fertilizer thereby releasing more K into the soil (Figure 4). The Ca concentrations in the leachate of the chicken litter biochar treatments were similar (Figure 5). The Mg content in the leachate of the biochar treatments were higher than T1 and T2 on day 3 and the order was T4 > T7 > T8 > T5 > T10 > T6 > T9 > T3 > T11 > T12 > T2> T1. Thereafter, there was a rapid decrease from day 9 to 30.

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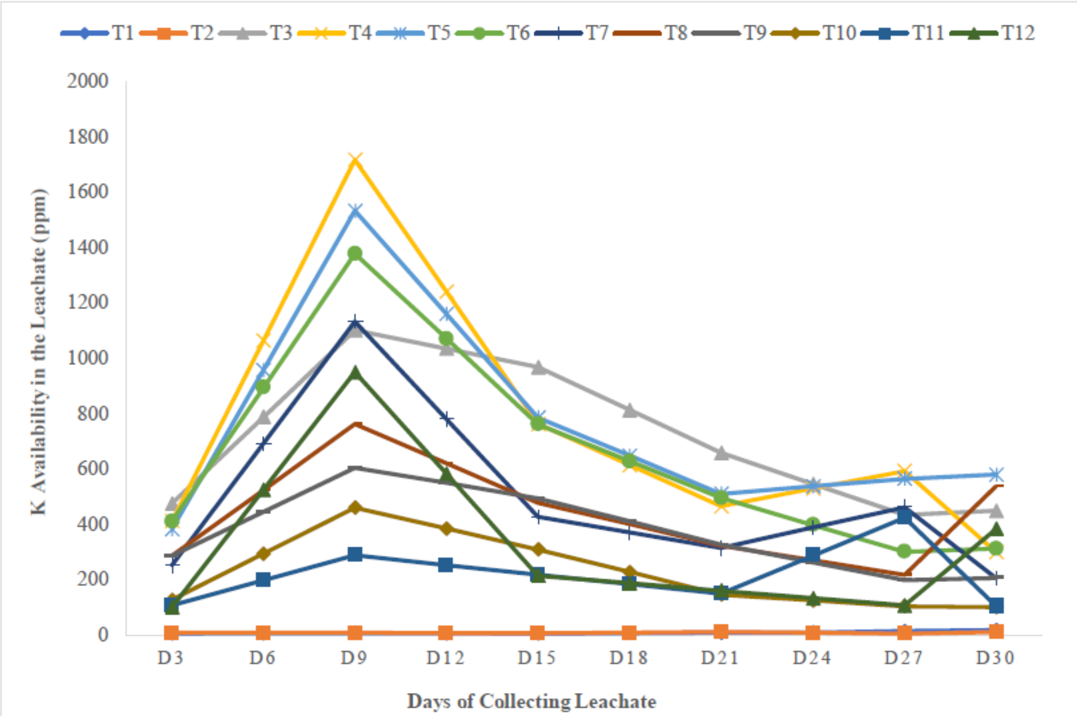

Fig. 4: Effects of treatments with and without chicken litter biochar on leachate K availability over 30 days of leaching

The Ca of T1 increased from day 3 to day 9 after which there was a decline until day 15, afterwards, there was a slight increase until day 30 for both Ca and Mg (Figures 5 and 6). The K, Ca, and Mg concentrations of T1 were lower throughout the leaching period. Treatment 2 showed higher effect on Ca starting from day 3 to day 21, although its effect from day 27 to day 30 showed higher increase (Figure 5). This was due to the high content of Ca in the rock phosphate and retention of Ca in the soil Ca-Pi formation (Ch'ng et al., 2016). The high affinity of biochar for Al^{3+}, Fe^{3+}, and Ca^{2+}, delays P adsorption or precipitation in soils (Xu et al., 2014). The increase in exchangeable Ca and Mg is explained by Ca-induced or Mg-induced P sorption or precipitation causing increase in P sorption after biochar application (Xu et al., 2014). Thus, the increase in P sorption is attributed to the chemistry and retention of Ca rather than the hydrolytic reactions of Al (Xu et al., 2014; Chen et al., 2013; Soil Survey Staff, 2010). The Mg concentrations in T2 showed a similar trend as Ca and Mg were contents lower than those with the chicken litter biochar (Figure 6). Biochar from poultry litter had been reported to have significant amounts of Ca, Mg, K, and P and following the application of this kind of biochar, these nutrients are available to crops (Kambo and Dutta, 2015; Chan et al., 2008).

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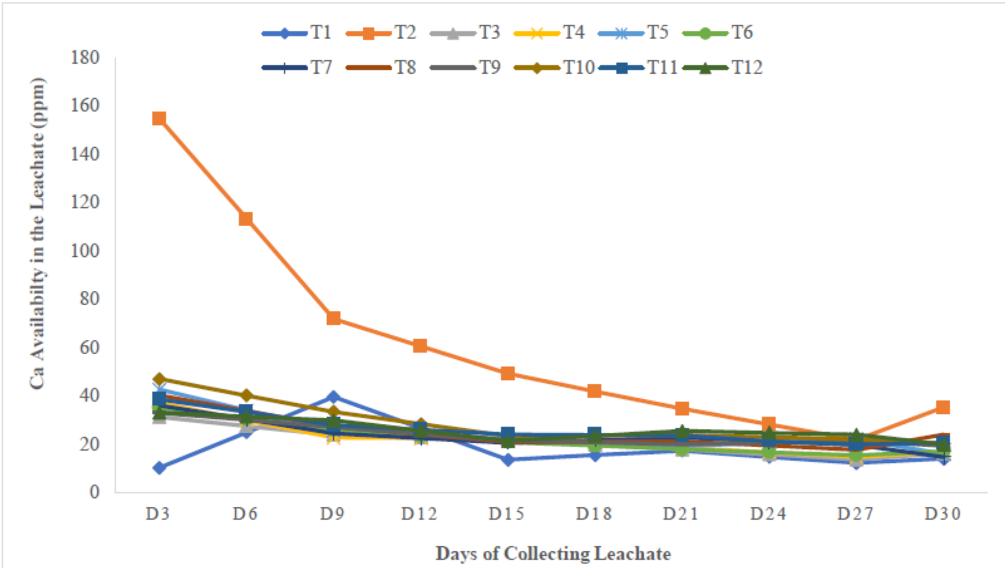

Fig. 5: Effects of treatments with and without chicken litter biochar on leachate Ca availability over 30 days of leaching

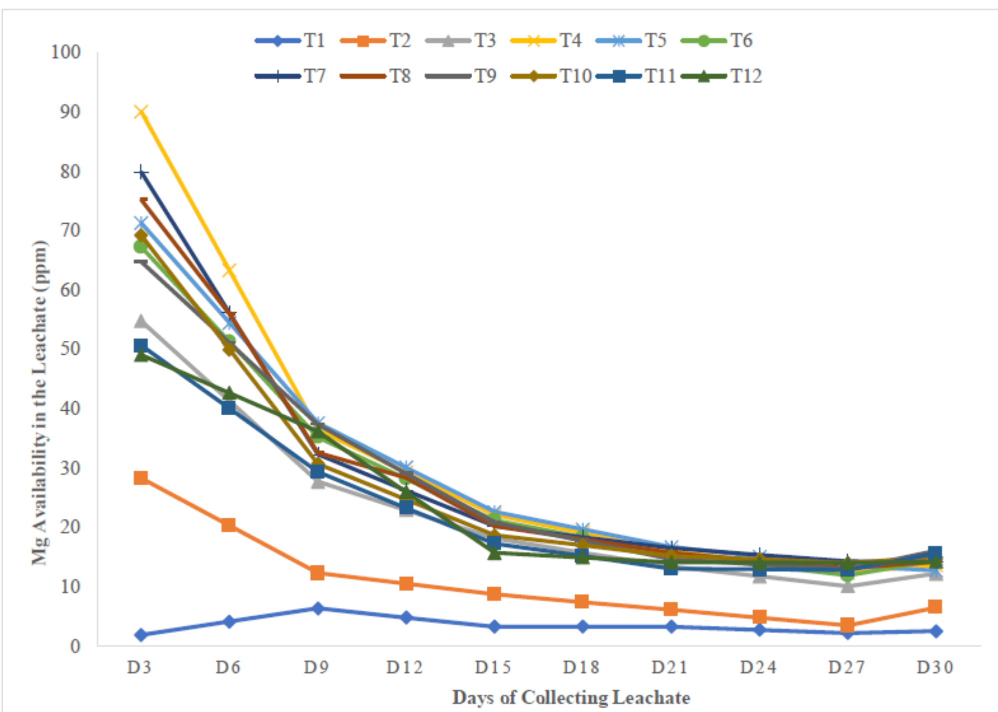

Fig 6: Effects of treatments with and without chicken litter biochar on leachate Mg availability over 30 days of leaching

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Effects of chicken litter biochar on soil total carbon and ph after 30 days of leaching

The soil total carbon of T3 was similar to that of T5, but significantly higher than those of T1, T2, T4, T6, T7, T8, T9, T10, T11, and T12 (Figure 7). The addition of chicken litter biochar increases soil carbon pool (Fang et al., 2010; Liang et al., 2006) because of the resistance of biochars to oxidation pyrolytic C (Laird, 2008), and condensed aromatic structure of biochars (Ch'ng et al. 2016b). The soil total carbon of T1 and T2 were statistically similar but lower than in the soils treated with biochar (Figure 7). This is true in tropical soils due to high rainfall with low organic matter (Zhang et al., 2016; Jien and Wang 2000).

The soil pH in water and KCl of the treatments without chicken litter biochar amendment (T1 and T2) after 30 days of leaching, showed higher acidity than those with chicken litter biochar (T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12) (Figures 8 and 9) because of the acidic nature of the soil (Table 2). These results were consistent with those reported by Ch'ng et al. (2016), Wang et al. (2012), and Narambuye and Haynes (2006). Tropical acid soils have high amounts of Al (Figures 11) which when undergo hydrolysis, causes production of H^+ to cause soil acidity. The treatments with chicken litter biochar showed higher soil pH. Treatments T3, T4, T5, T6, T7, T8, and T9 were significantly similar, but lower than those of T10, T11, and T12. The treatments with biochar in relation to soil pH in KCl showed significant differences, where T3, T4, T5, T6 had higher effect than T7, T8, T9, T10, T11, and T12. This was due to the different rates of the chicken litter biochar applied. The initial increase of the soil pH with chicken litter biochar as an amendment is consistent with the initial pH of the chicken litter biochar (Table 3). The high pH buffering capacity of chicken litter biochar clarifies the high pH of the soils (Yuan and Xu, 2012; Lehmann et al. 2011; Yuan and Xu, 2011). This finding suggests that 50% of 10t ha^{-1} of biochar could be used to reduce soil acidity (Figure 8).

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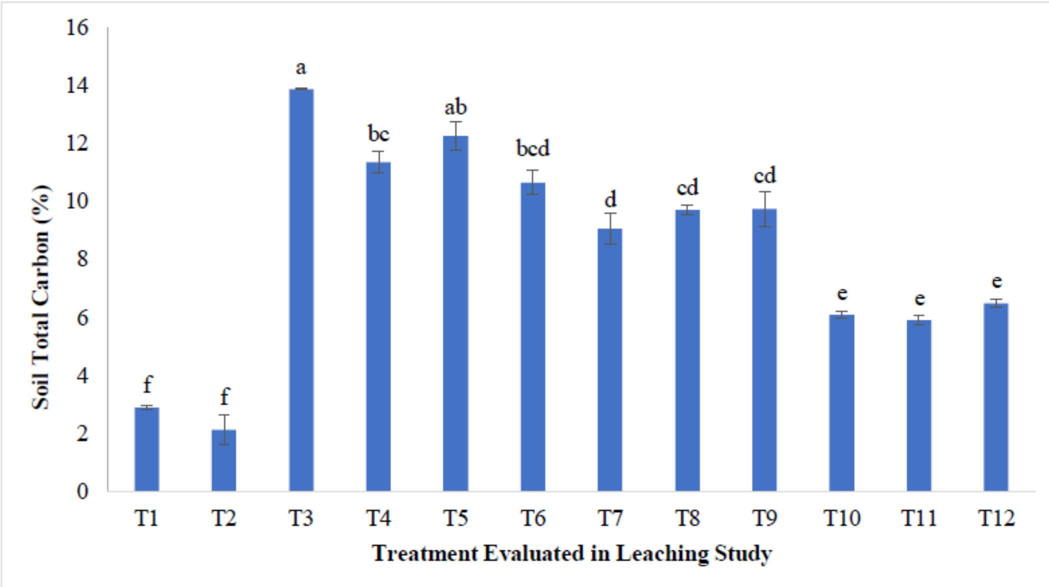

Fig. 7: Effects of treatments with and without chicken litter biochar on total carbon after 30 days of leaching. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at *P* ≤ 0.05. Bars represent the mean values ± SE

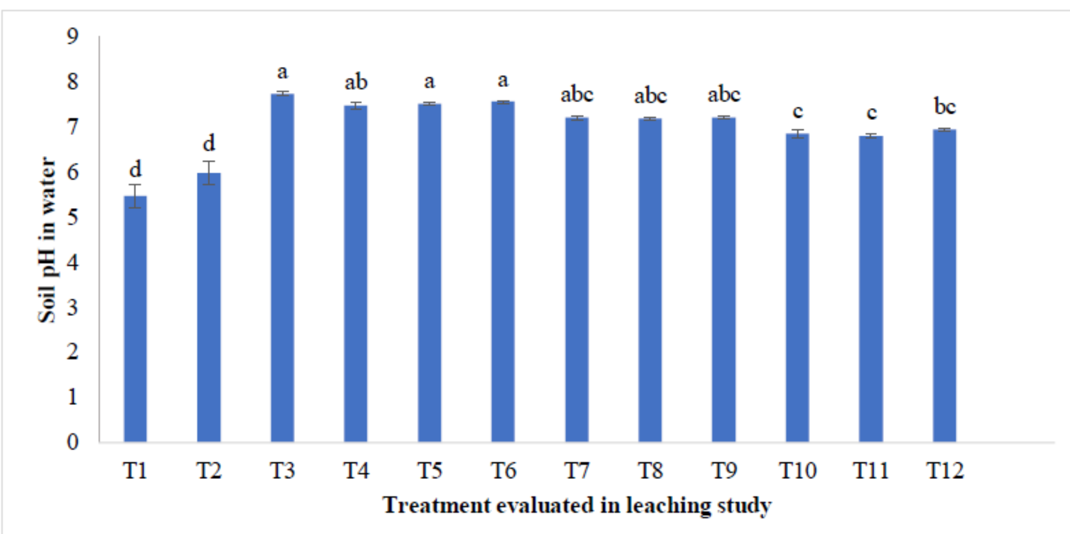

Fig. 8: Effects of treatments with and without chicken litter biochar on soil pH in water after 30 days of leaching. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at *P* ≤ 0.05. Bars represent the mean values ± SE

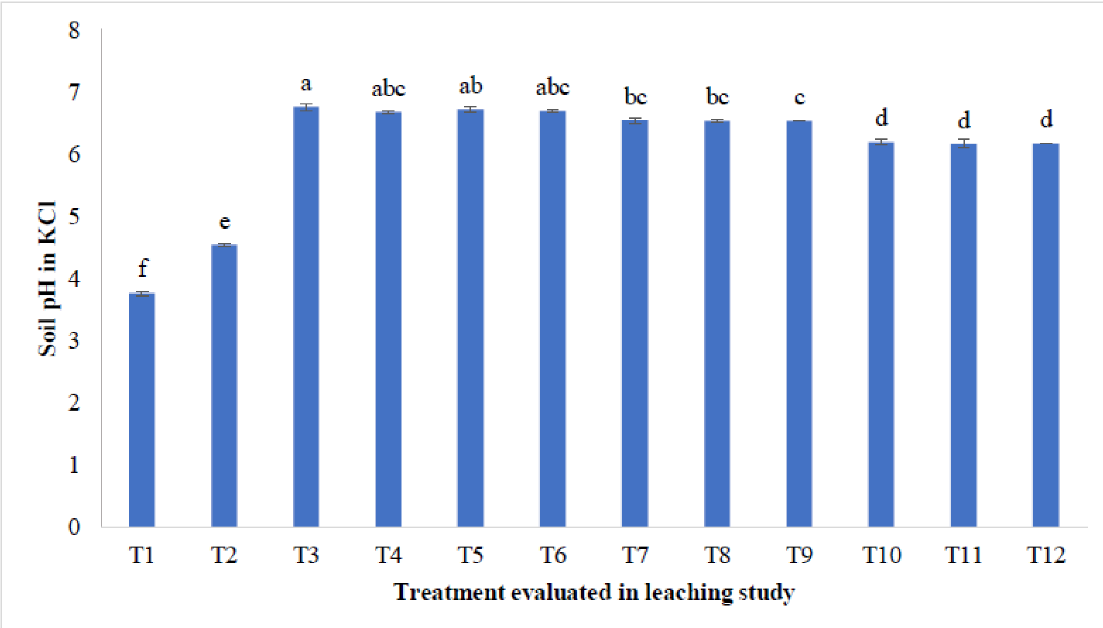

Fig 9: Effects of treatments with and without chicken litter biochar on soil pH in KCl after 30 days of leaching. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE

Effects of chicken litter biochar on total soil acidity, aluminium, and hydrogen ions after 30 days of leaching

Total acidity was significantly lower in T3, T4, T5, T6, T7, T8, T10, T11, and T12 than those of T1 and T2 (Figure 10). Furthermore, the total acidity of the soil amended with biochar were similar (T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12) (Figure 10). The liming effects of biochars especially with Ca and Mg lowered the total acidity of the soils with this organic amendment (Ch'ng et al., 2016). Biochars have the capability of contributing to soil negatively charged surface sites (deprotonation of functional groups) (Jin et al., 2016) and amending soils with chicken litter biochar have described to increase the soil organic matter (OM) (Ch'ng et al., 2016; Tang et al., 2007) and soil organic matter (SOM) content, nutrient holding capacity, nutrient content, elevated pH, and water retention (Scott et al., 2014; Glaser et al., 2002). In addition, biochars improve soils ability to resist rapid change in pH (Asap et al., 2018; Fageria and Baligar, 2008) by controlling soil exchangeable acidity is pH dependent H^+ and Al^{3+} and Fe^{2+} hydrolysis (FAO, 1995). These findings were observed in this study, where the total acidity was lower in the treatments that had higher pH (Figures 8 and Figure 9). The soil exchangeable Al^{3+} and soil exchangeable H^+ of T1 and T2 were significantly higher than those with biochar

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(T3, T4, T5, T6, T7, T8, T10, T11, and T12) (Figures 11 and Figure 12). Besides, the biochar treatments have the ability to form complexes with Al (Ch'ng et al., 2016; Tang et al., 2007). The highly weathered soil used in this study, is known to be high in H^+ and Al^{3+} due to leaching of base cations (Zhang et al., 2016; Gachene and Kimaru, 2003; FAO, 1995).

Overall, the soil total acidity, exchangeable Al^{3+}, and exchangeable H^+ in soils amended with biochar decreased with increasing amount of biochar (Figures 10, Figure 11, and Figure 12). The decrease in exchangeable acidity, exchangeable Al^{3+}, and exchangeable H^+ is related to the increase in soil pH (Figures 8 and Figure 9). With the high pH of the chicken litter biochar, increase in pH was possible (Glaser et al. 2002; Gaskin et al. 2008) partly because of greater quantities of hydrolysed alkali and alkaline salts (Torrent, 1997) and negatively charged surface sites (deprotonation of functional groups) (Ch'ng et al., 2016b), which are able to precipitate exchangeable and soluble Al and Fe ions as insoluble Al and Fe hydroxides on the surfaces of the organic amendment (Ritchie, 1994). In addition as a potential P source, 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 (Xu et al., 2014; Atkinson et al., 2010) which can be adsorb efficiently from solutions (Zeng et al., 2013), this confirms that biochar can retain P from fertilizers as well as being a P enhancer.

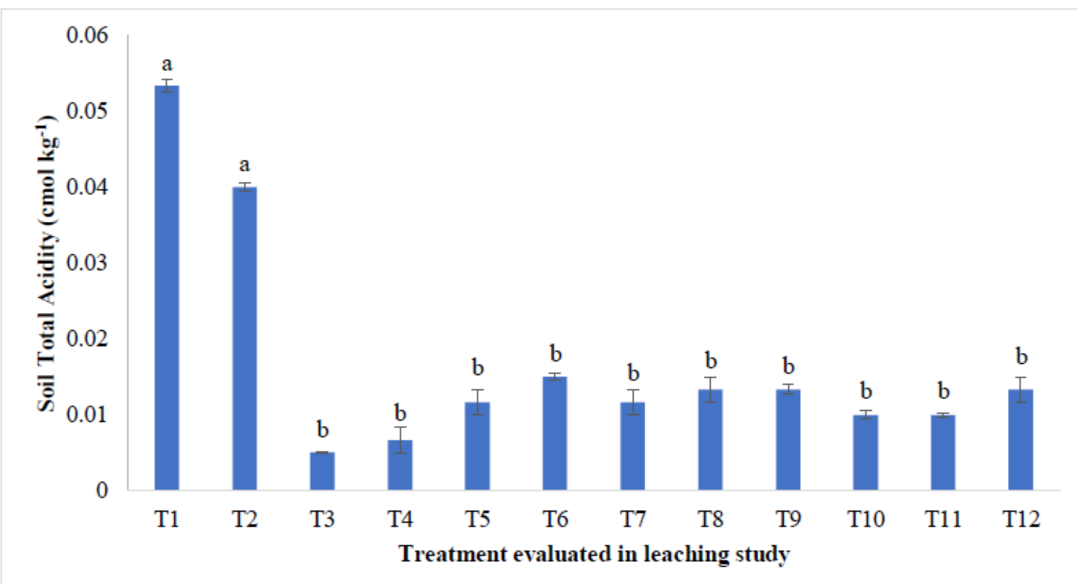

Fig 10: Effects of treatments with and without chicken litter biochar on soil total acidity after 30 days of leaching. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE

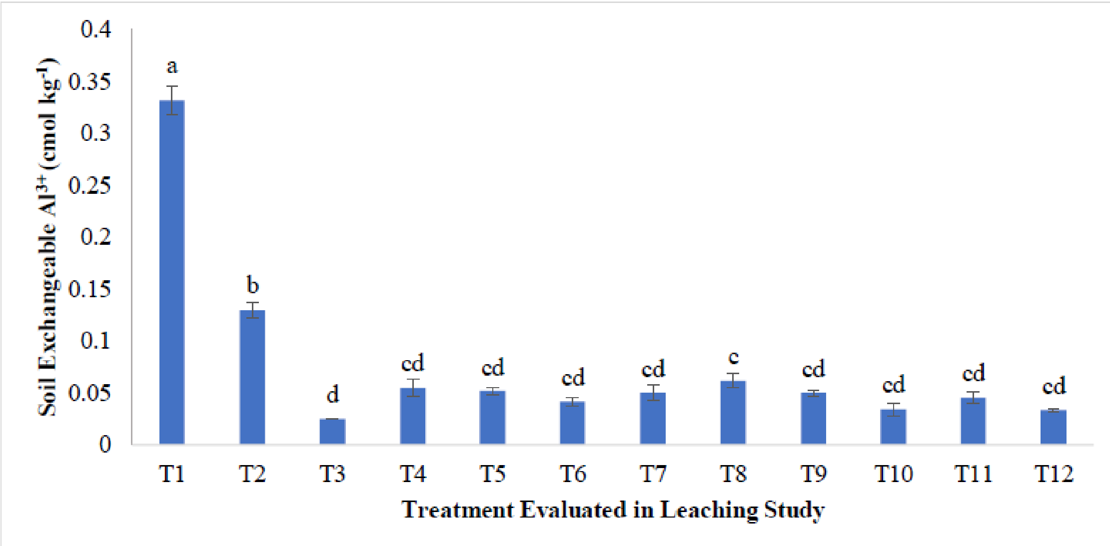

Fig 11: Effects of treatments with and without chicken litter biochar on soil exchangeable Al3+ after 30 days of leaching. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at P ≤ 0.05. Bars represent the mean values ± SE

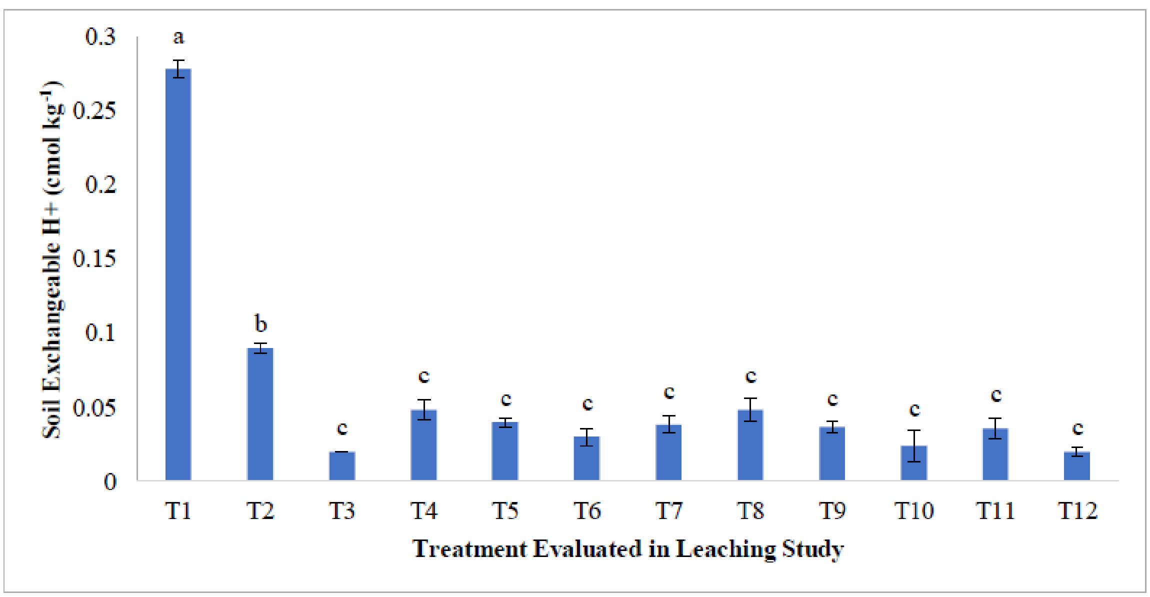

Fig 12: Effects of treatments with and without chicken litter biochar on soil exchangeable H+ after 30 days of leaching. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at *P* ≤ 0.05. Bars represent the mean values ± SE

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Phosphorus retention by chicken litter biochar after 30 days of leaching

Soil total P after 30 days of leaching as affected by T3, T4, T5, T8, T9, T10, T11, and T12 but significantly higher than those of T1, and T2 (Figures 4.13) due to leaching of P from T1 and T2 treatments. This might be due to the lack of positively charged exchange sites for nutrients or aggregate formation in T2 (Asap et al., 2018; Laird et al. 2010a; Liang et al., 2006). Loss of orthophosphate (negatively charged) is also increased by the electrostatic repulsion caused by the negative charge sites on surfaces of the soil colloids (Coelho et al., 2012 and Ulen et al., 2012). This lead to rapid movements of the orthophosphate, increasing its concentrate in the soil solution (Ch'ng et al., 2016 and Coelho et al., 2012). This is reflected in the finding of the leachate in Figure 2. The available P and water soluble P in T1 and T2 were significantly lower than those of T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12 (Figure 14 and Figure 15). This due to T1 and T2 having high P fixation because of high Al^{3+} cations (Figure 11) and lower pH from high H^{+} concentration (Figure 12). Overall, the chicken litter biochar treatments had significant effect on soil total P, available P, and water soluble P value.

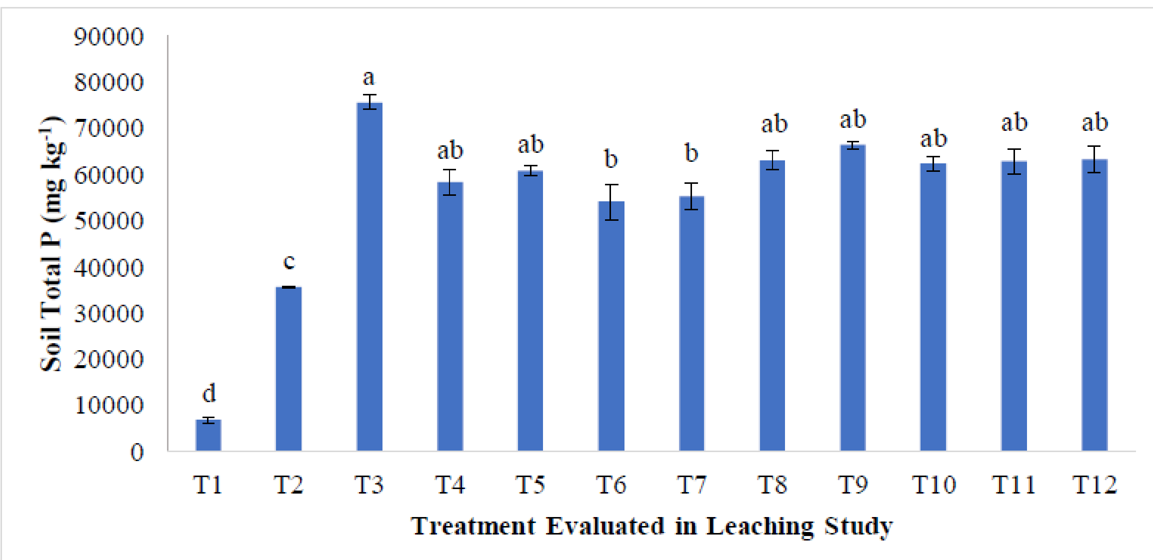

Fig 13: Effects of treatments with and without chicken litter biochar on soil total P after 30 days of leaching. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at *P* ≤ 0.05. Bars represent the mean values ± SE

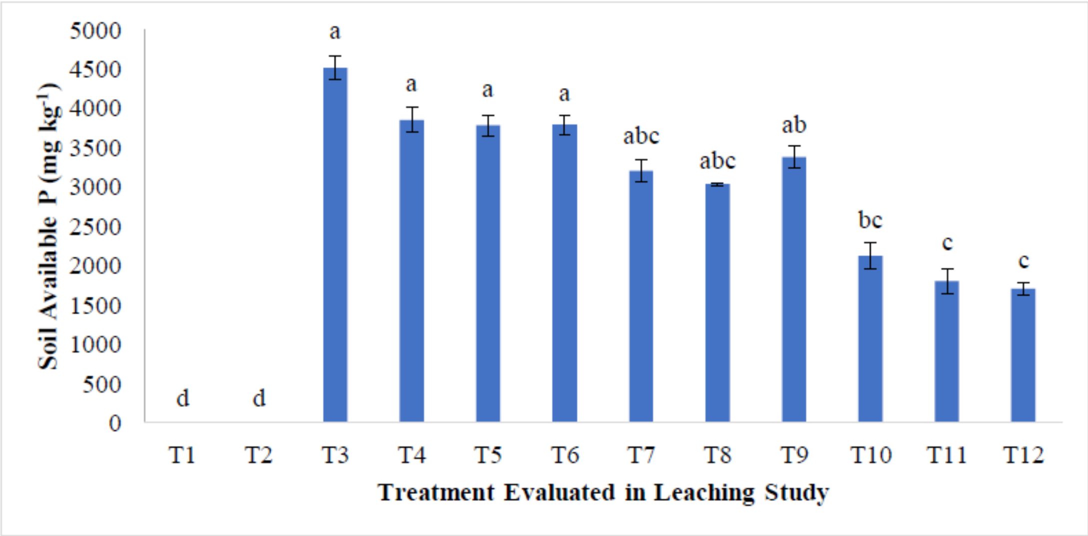

Fig 14: Effects of treatments with and without chicken litter biochar on soil available P after 30 days of leaching. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at *P* ≤ 0.05. Bars represent the mean values ± SE

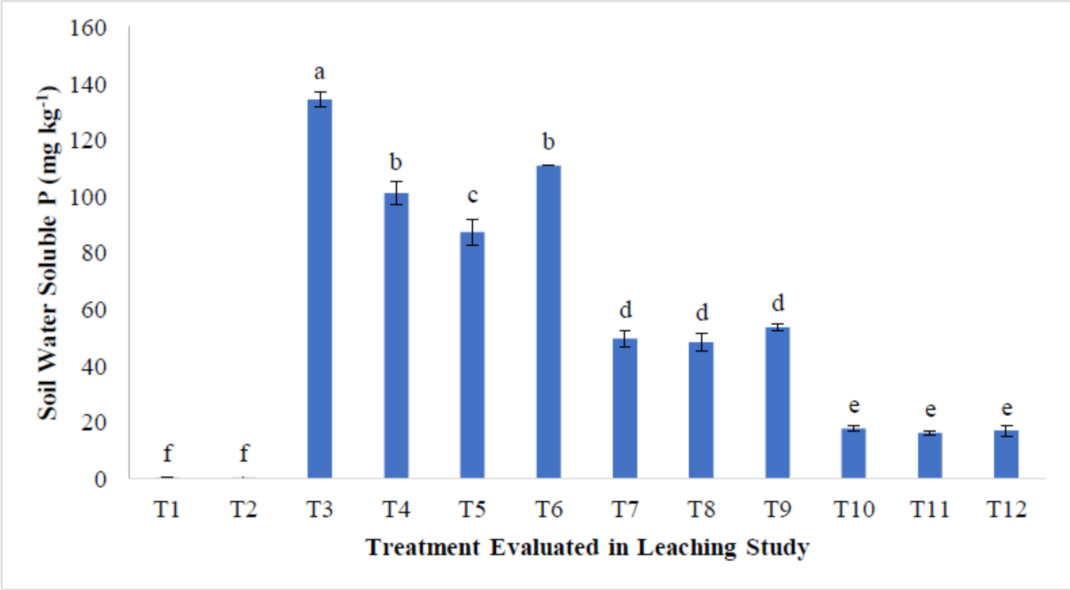

Fig 15: Effects of treatments with and without chicken litter biochar on soil water soluble P after 30 days of leaching. Means between columns with different letter(s) indicate significant difference between treatments by Tukey's HSD test at *P* ≤ 0.05. Bars represent the mean values ± SE

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CONCLUSION

The total P, pH, K, and Mg of leachates with biochar were higher than those of soil only and normal fertilization. This was because of the liming effect and high pH value of chicken litter biochar. The pH, total C and P, exchangeable P, water soluble P, of the soils with biochar after 30 days of leaching were significantly higher than that of normal fertilization. This is because the biochar was able to fix Al and Fe to increase soil pH, thereby reducing the soil total acidity compared with the normal P application. Approximately, 75% biochar of 10 t ha^{-1} with 50% and 25% ERP of the existing recommendation showed significant retention and nutrients availability.

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