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Co-application of triple super phosphate and chicken litter biochar improves phosphorus availability of mineral tropical acid soils to reduce water pollution

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ABSTRACT

Although organic amendments could increase P use efficiency, unbalanced use of organic amendments and P fertilizers in farming systems is uneconomical and environmental unfriendly. This study explored if the right combination of chicken litter biochar (CLB) and triple superphosphate (TSP) could improve soil P availability to minimize P losses through leaching to prevent ground water and other water bodies' contamination through for example eutrophication (Algae bloom). Rates of 75%, 50%, and 25% of 5 t ha^{-1} chicken litter biochar and 75%, 50%, and 25% of 130 kg ha^{-1} (existing TSP recommendation for *Zea mays*, L.), respectively were evaluated in a leaching study using standard procedures. Results revealed that CLB treatments minimized P leaching compared with the treatment without CLB. This resulted in significant improvement in available P. This was possible because CLB improved soil pH, P, K, Ca, Mg, and Na besides reducing P fixation by Al and Fe ions. Leaching of available P following application of chicken litter biochar only occurred within the first 10 d after which the leaching significantly reduced. This finding further suggests that if the availability P is not in synchrony with optimum crop uptake in agricultural systems, available P could be lost from the soil profile to contaminate or pollute water bodies. Chicken litter biochar can be used to improve P availability but it is not an excellent organic amendment to sorb P for a long period.

Keywords: Organic amendments; Eutrophication; Phosphorus fertilizers; Nutrient loss; Water quality

1. Introduction

Mitigation of eutrophication of water bodies is becoming a global challenge partly because of excessive use of P and N fertilizers in agriculture. Orthophosphates (P ions) are essential macronutrients which when they are taken up by plants as soluble inorganic P, they are able to regulate protein synthesis [1]. However, in most tropical mineral acid soils such as Ultisols and Oxisols, available P is low. Moreover, the low available P of these soils are fixed by Al and Fe ions (especially when the soil pH is less than 5). This chemical reaction makes P unavailable for crop use and this compels farmers to use more P fertilizers such as rock phosphates and triple superphosphate (TSP) to saturate Al and Fe ions. This practice is neither economically viable nor environmental friendly. For example, excessive use of P fertilizers particularly TSP which is relatively soluble in water could cause P ions to leach or diffuse into the rivers, streams, underground water, and other freshwater

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bodies [2] to cause eutrophication [3]. Phosphorus in water bodies causes rapid growth of algae to negatively affect biological oxygen demand or dissolved oxygen. Aquatic ecosystems are affected most by eutrophication because it causes reduction of oxygen leading to death of algae. Afterwards, the dead algae decompose to change the aquatic ecosystems [2].

One of the promising interventions to ensure balanced use of P fertilizers is to explore if the right amount of organic amendments such as biochars, composts, vermicomposts, charcoals, among others could be used to timely sorb P to improve P fertilizers use efficiency agriculture. This is essential because the fact that organic amendments have the potential to increase P use efficiency does not necessarily suggest they will not be over-used in farming systems. If they are not properly used in the tropics in particular where rainfall is high, the organic amendments and P will not only be lost through surface runoff, erosion, but they will also be leached down the soil profile to contaminate underground water and other water bodies [4]. Thus, there is a need to determine the right amount of soil organic amendments such as chicken litter biochar (CLB) to be used in conjunction P fertilizers such as TSP to minimize P losses in agricultural farming systems.

The use of organic amendments has proven to increase soil availability P [5–7] and plant nutrient uptake [8–10]. Ch'ng et al. [11] reported that amending tropical acid soils with biochar increased soil P fractions besides reducing soil exchangeable acidity, Fe, and Al ions. Although Coelho et al. [12] used chicken litter biochar to improve P availability of TSP, their study did not attempt to optimize chicken litter biochar and TSP as these materials were not varied. This present study focused on using different amounts of CLB and TSP to improve P availability. To date, there is dearth of information on the effects of different rates of CLB and TSP on leaching of available P into for example, fresh water bodies. It is therefore hypothesized the use of right amounts of CLB and TSP will improve soil P availability to minimize P leaching. The objective of this study was to determine if the right amounts of CLB and TSP could improve mineral acid soils' P availability to reduce loss of P through leaching.

2. Experiment

2.1. Soil sampling and preparation

The soil (Nyalau Series, *Typic Paleudults*) which was used in this study was taken from an uncultivated secondary forest at Universiti Putra Malaysia Bintulu Sarawak Campus, Bintulu, Sarawak, Malaysia. Although this soil is high in Al and Fe, it is one of the most cultivated soils in Sarawak, Malaysia. The soil samples were taken at 0–20 cm using a shovel. Thereafter, they were air dried, ground, and sieved to pass a 2 mm after which they were bulked. A 7 kg of soil (based on bulk density method) was taken for each treatment with three replications.

2.2. Leaching experiment set-up

Treatments evaluated in this present study are summarized in Table 1. The recommended rate of P fertilizer used was 60 kg P_2O_5 ha^{-1} (130 kg ha^{-1} TSP) and scaled down to per plant from the standard fertilizer recommendation by the Malaysian Agriculture Research and Development Institute (1993). The CLB rate was 5 t ha^{-1} and it was also scaled to per plant. These rates (Table 1) were mixed thoroughly with the soil samples. Afterwards, the mixed soil and CLB were transferred into a pot (864.33 cm^3). The treatments were arranged in a Completely Randomized Design (CRD) at the Research Centre of Universiti Putra Malaysia Bintulu Sarawak Campus, Bintulu, Sarawak, Malaysia. Based on the soil's field capacity, the mixed soil and CLB was moistened with distilled water to 60% moisture content after which the different rates of TSP (Table 1) were surface applied. A 1,600 mL distilled water was applied to the pots (Table 1) after which leachates were collected at a 3-d interval. Volume of the distilled water used was based on rainy days in 30 d from a 10 y rainfall data recorded by Bintulu Meteorological Department, Bintulu, Sarawak, Malaysia.

2.3. Leachates analysis

Leachates were collected and analyzed every 3 d for pH using pH meter [13]. Available P was determined using Spectrophotometery after blue colour was developed using the Blue Method [14]. Available K, Ca, Mg, Na, and Fe were determined using Atomic Absorption Spectrometer (AAnalyst 800, Perkin Elmer Instruments, Norwalk, CT).

2.4. Soil chemical properties analysis after leaching study

At 30 d of the leaching study, soil samples were collected and air-dried. Thereafter, soil pH in water and KCl were determined in a 1:2.5 (soil: distilled water KCl) using a digital pH meter [15]. Soil total C was calculated as 58% of soil organic matter. Soil organic matter was determined using loss of weight on ignition method [16]. Soil cation exchange capacity (CEC) was determined using leaching method [17] followed by steam distillation [18]. Exchangeable cations

Table 1
Soil weight, chicken litter biochar and triple superphosphate rates for leaching study

Treatments	Soil	Biochar rate	Fertilizers		
	($kg\ pot^{-1}$)	($g\ pot^{-1}$)	N	P	K
T1		–	–	–	–
T2	7	–	–	4.8	–
T3	7	180	–	–	–
T4	7	135	–	3.6	–
T5	7	90	–	3.6	–
T6	7	45	–	3.6	–
T7	7	135	–	2.4	–
T8	7	90	–	2.4	–
T9	7	45	–	2.4	–
T10	7	135	–	1.2	–
T11	7	90	–	1.2	–
T12	7	45	–	1.2	–

were extracted with 1 M NH_4OAc, pH seven using the leaching method [19] after which they were determined using Atomic Absorption Spectrometery (AAnalyst 800, Perkin Elmer Instruments, Norwalk, CT). Total N was determined using Kjeldhal method [20] and inorganic N (NO_3^- and NH_4^+) were determined using [21]. Soil total P was extracted using aqua regia method (Bernas, 1968) whereas soil available P was extracted using Mehlich No.1 Double Acid method [22]. Soluble P was extracted using deionized water. Afterwards, total P, available P, and water soluble P were determined using UV Spectrophotometer after blue colour was developed using the Blue Method [23]. Soil exchangeable acidity, H^+, and Al^{3+} were determined using acid-base titration method [24].

2.5. Statistical analysis

Analysis of variance (ANOVA) was used to test treatment effects whereas treatments means were compared using Tukey's test. Statistical Analysis Software version 9.3 was used for the statistical analysis [25].

3. Findings

3.1. Different rates of chicken litter biochar and triple superphosphate on selected chemical properties of soil leachate

On day three of the leaching study, pH of the leachates ranged between 4.09 and 6.08 (Fig. 1). The leachate of T3 (treatment with the highest amount of CLB) demonstrated the highest pH. With the exception of T1, T2, and T6 (day 6 and day 9), pH of the leachate of the other treatments ranged from 4.2 to 5.3 and 4.16 to 6.07 (Fig. 1). The increase in pH was possible because of the decomposition of CLB with time to release base cations such as K, Ca, Mg, and Na [26]. Although there was pH fluctuation with increasing time, pH of the leachate of T10 was the highest (day 12 to day 30) compared with that of T2 which was consistently lower during the leaching study because T10 had the highest amounts of CLB and TSP. The leachate pH of T2 was lower because dissolution of TSP causes soil acidity (pH of the TSP ranges between one and three).

Phosphorus concentrations of T1 with increasing time of leaching were similar and these P concentrations were lower than other treatments (Fig. 2). Tropical acid mineral soils especially Oxisols and Ultisols are characterized by low pH, low CEC, and high contents of Al and Fe hydroxides and because of this, P deficiency is common in the aforementioned soils due to strong sorption of phosphate ($PO4^{3-}$) to oxide surfaces in soils and the formation of insoluble Fe and Al phosphates [27]. This further supports the lower total P concentration observed after 30 d of leaching (Fig. 2) because soils with low CEC are unable to effectively hold cations and this causes considerable leaching of nutrients [28] especially when Al and Fe ions are high to replace more cations such as K, Ca, Mg, Na, among others.

The cumulative amounts of P and total P leached during the 30 d of the leaching study are presented in Figs. 2 and 3. Leachate of T2 (recommended fertilization) was consistently higher in P (Fig. 2) because this treatment had no CLB to temporary sorb P from being leached. According to Verheijen et al. [29], pores and functional groups of biochars enable them to temporary sorb nutrients. Furthermore, the solubility of TSP is higher compared with Egypt, China, and Christmas Island Rock Phosphates. It was observed that P was higher during the last 9 d of leaching that is, the first 21 d of the leaching study (Fig. 2) suggesting that during high rainfall, P will be leached if it is not well managed. According to [30], nutrients and water retained by biochars slowly become available to plants as biochars decompose. This suggests that the CLB used in this present study may not permanently retain nutrients but will rather reduce rapid leaching of nutrients from the soil profile. The total amounts of P leached under T2 and T10 were similar but lower than that of T11 (Fig. 3) because T10 had the highest rates of CLB and TSP and they might have released their water soluble P during the 30 d of the leaching study [31].

The cumulative amounts of K and Na leached during the 30 d of the leaching study are shown in Figs. 4 and 6 whereas

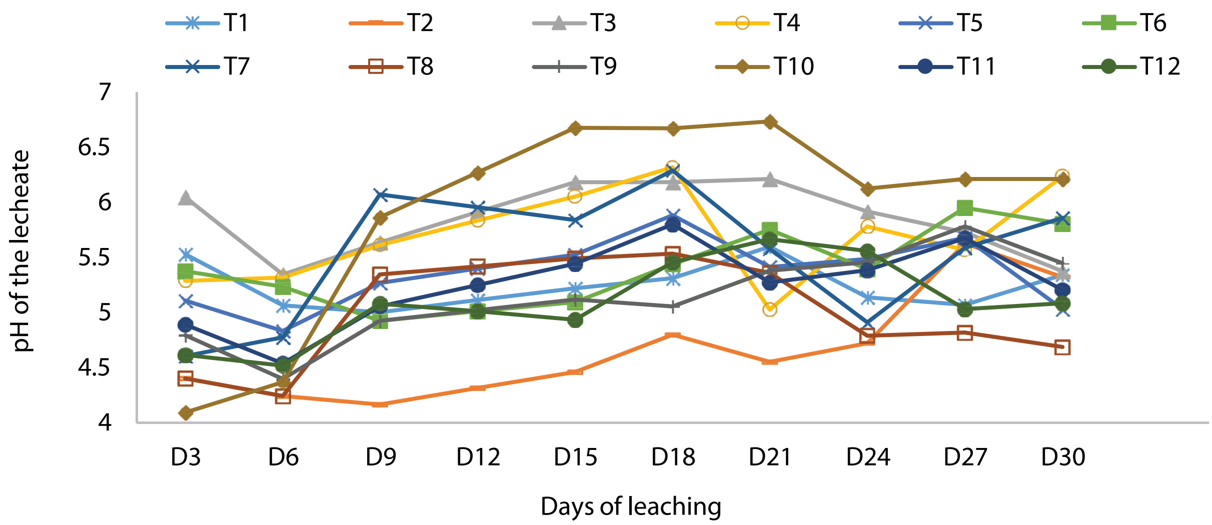

Fig. 1. Different rates of chicken litter biochar and triple superphosphate on leachate pH during 30 d of soil leaching.

the total amounts of these cations at 30 d of leaching are summarized in Figs. 5 and 7. The cumulative concentrations of K and Na of T1 and T2 (Figs. 4 and 6) and total amounts of K and Na (Figs. 5 and 7) were lower compared with the treatments with CLB because of the inherent contents of these cations in the CLB (Ch'ng et al., 2014). Among the soils with CLB, K and Na concentrations in the leachates of T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12 increased significantly

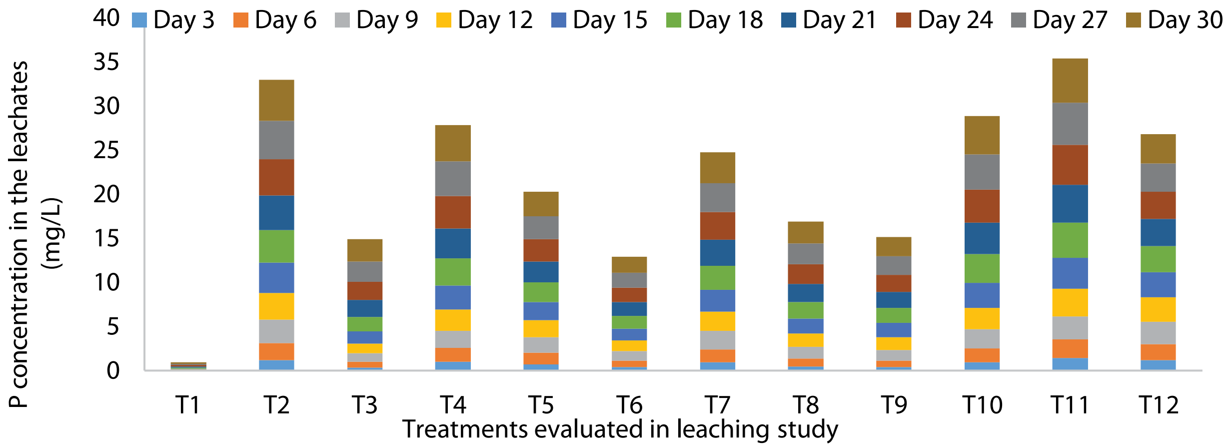

Fig. 2. Different rates of chicken litter biochar and triple superphosphate on cumulative phosphorus in leachate during 30 d of leaching.

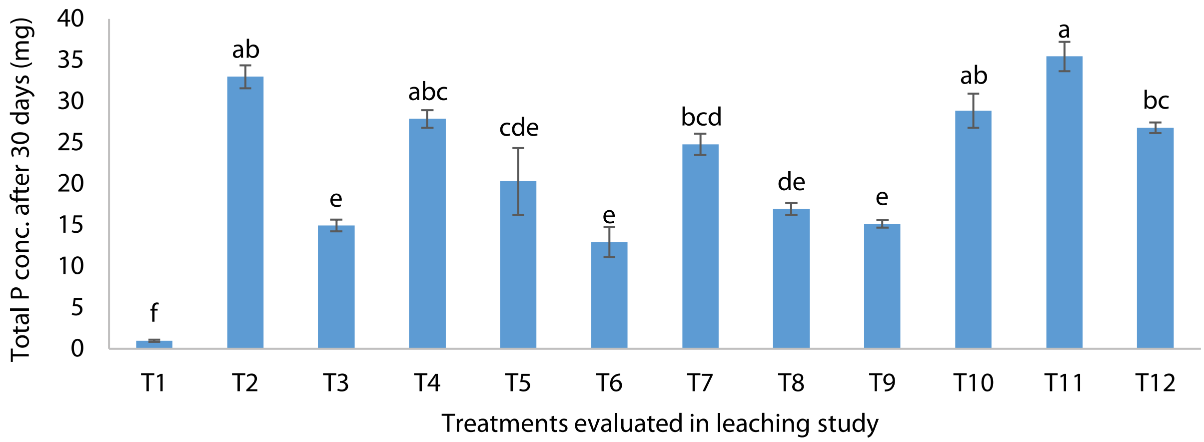

Fig. 3. Different rates of chicken litter biochar and triple superphosphate on total amounts of phosphorus in leachates at 30 d of leaching.

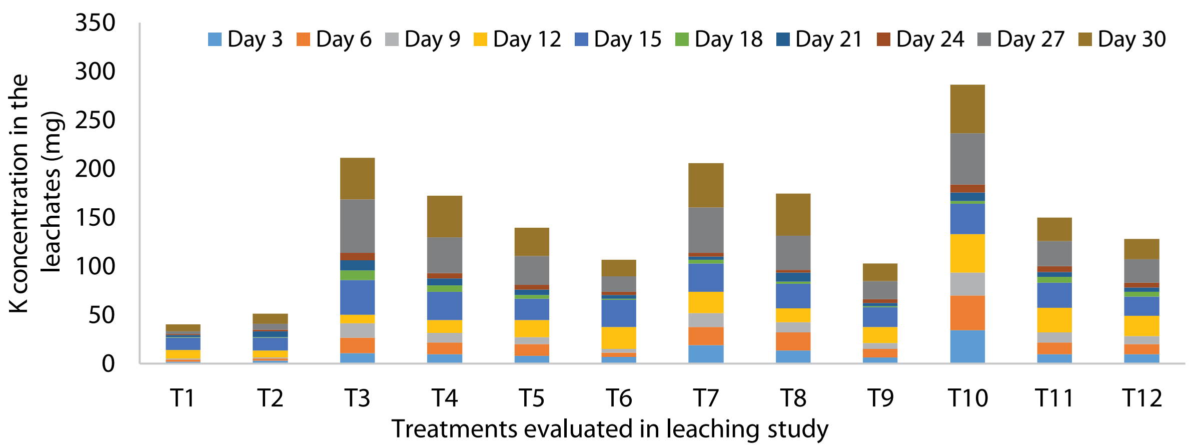

Fig. 4. Different rates of chicken litter biochar and triple superphosphate on potassium in leachates during 30 d of leaching.

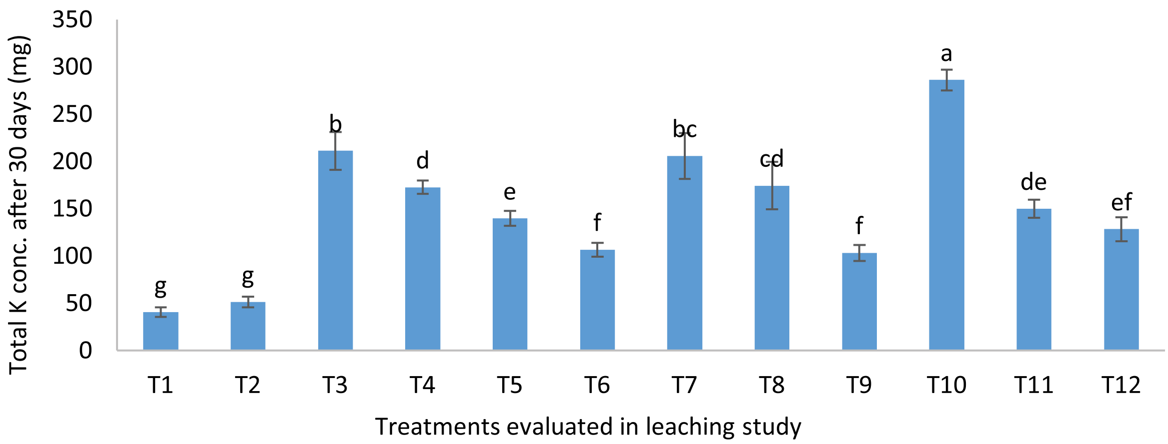

Fig. 5. Different rates of chicken litter biochar and triple superphosphate on total potassium in leachates at 30 d of leaching.

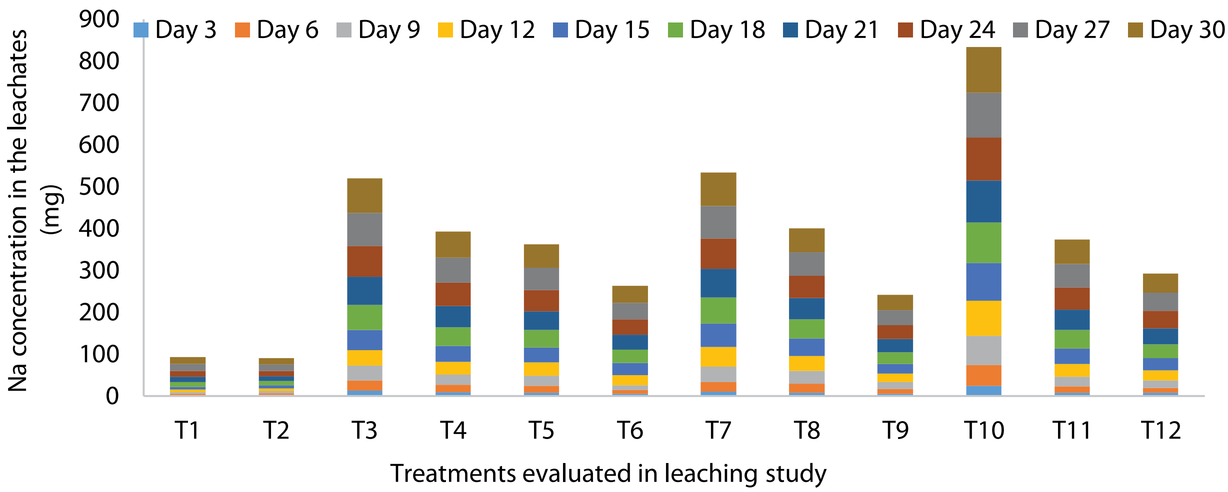

Fig. 6. Different rates of chicken litter biochar and triple superphosphate on sodium in leachates during 30 d of leaching.

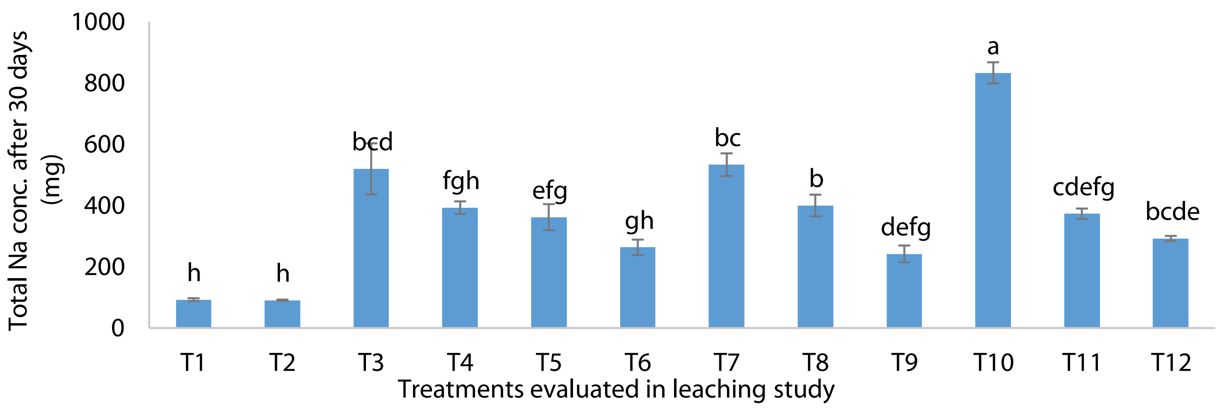

Fig. 7. Different rates of chicken litter biochar and triple superphosphate on total sodium in leachates at 30 d of leaching.

on day 27 after which they decreased until day 30 because of decomposition of the CLB (Figs. 4 and 6). Among the treatments with CLB, K and Na concentrations of T10 were significantly higher than those of T3, T4, T5, T6, T7, T8, T9, T11, and T12 (Figs. 5 and 7). This observation suggests that even with the highest amounts of CLB and TSP of T10, the nutrients could not be retained in the soil.

The cumulative amounts of Ca and Mg leached during the 30 d of the leaching study are demonstrated in Figs. 8 and 10 whereas the total amounts of these cations during the period of this study are summarized in Figs. 9 and 11. The cumulative concentrations of Ca and Mg of T10 (Figs. 8 and 10) and total amounts of Ca and Mg of T10 (Figs. 9 and 11) were significantly higher because of their contents in CLB of T10. The Ca and Mg of CLB might have increased the soil's Ca and Mg contents to cause leaching of Ca and Mg because the soil exchange complexes might have been saturated with these base cations. The TSP of T10 also contributed

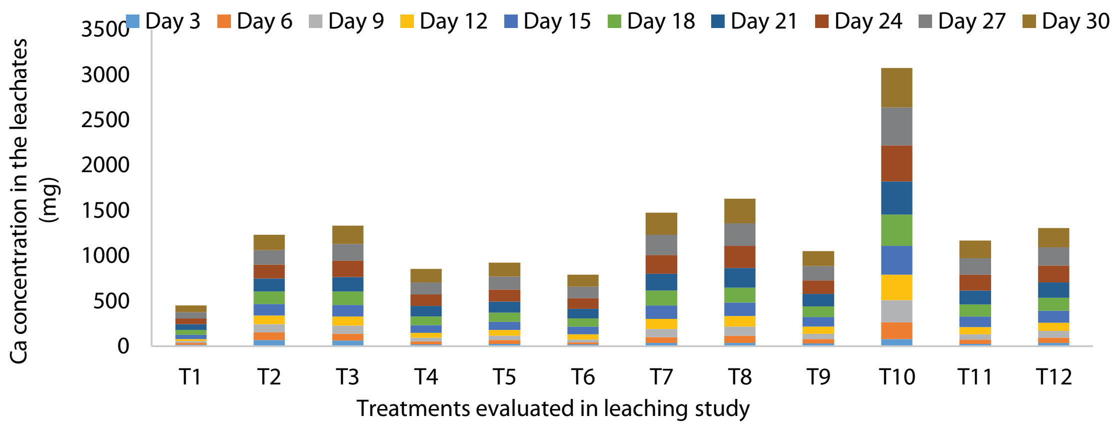

Fig. 8. Different rates of chicken litter biochar and triple superphosphate on calcium in leachates during 30 d of leaching.

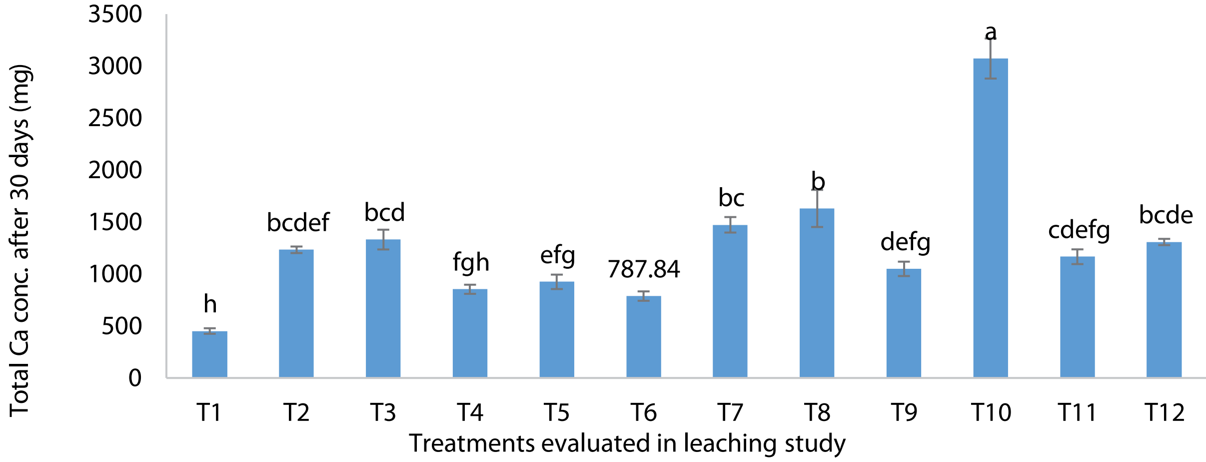

Fig. 9. Different rates of chicken litter biochar and triple superphosphate on total calcium in leachates at 30 d of leaching.

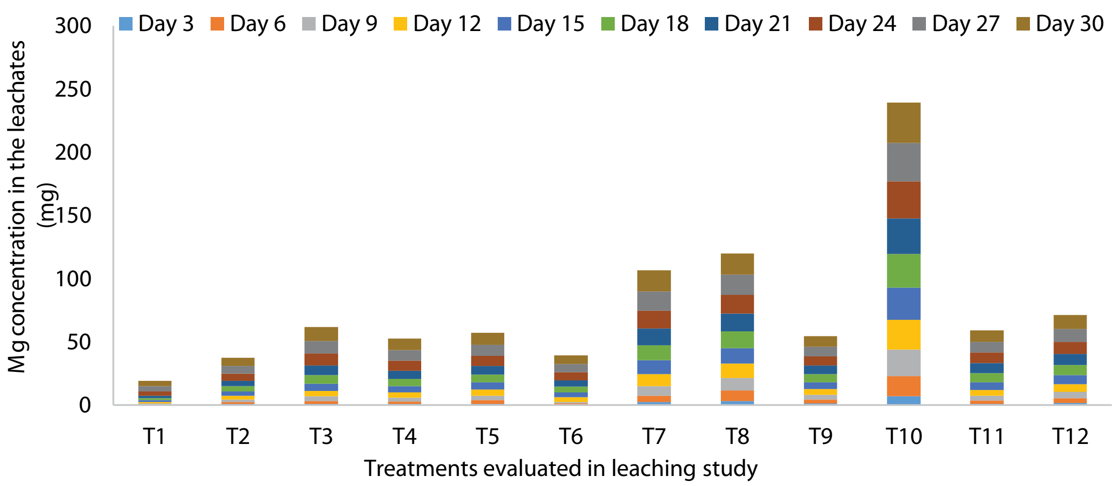

Fig. 10. Different rates of chicken litter biochar and triple superphosphate on magnesium in leachates during 30 d of leaching.

to the higher content Ca in the soil because TSP contains approximately 15% Ca. Furthermore, Ca and Mg are high in water soluble TSP [32].

Leached Fe from T7 was similar to those of T5, T8, T9, T10, T11, and T12 but significantly higher than those of T1, T2, T3, T4, and T6 (Figs. 12 and 13). Although tropical acid soils are high in Al and Fe to fix P as Al-P and Fe-P [33], the leached Fe from T1 and T2 were lower because Al-P and Fe-P minerals in acid soils of the tropics are insoluble in soil solution and this resulted in the reduction of Fe. Also,

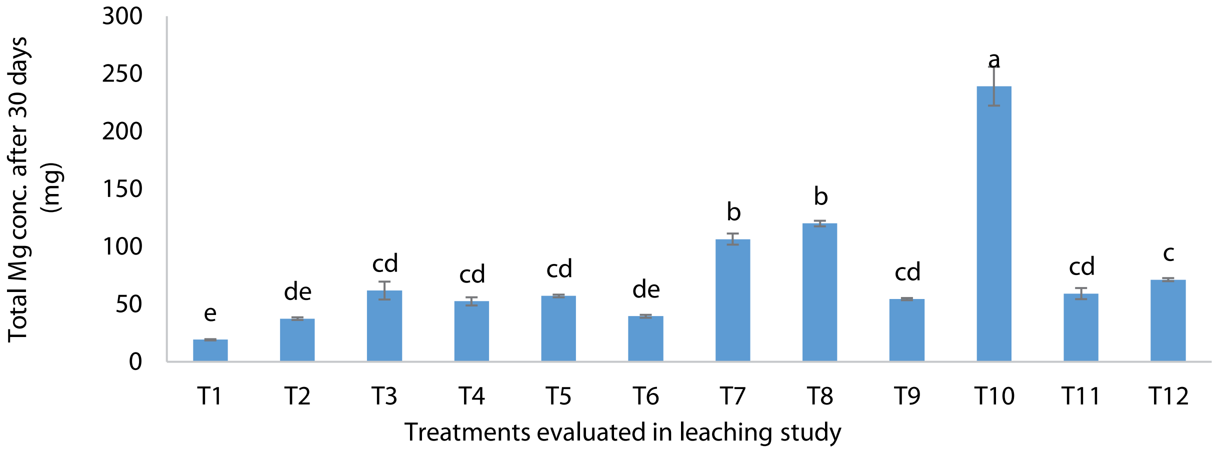

Fig. 11. Different rates of chicken litter biochar and triple superphosphate on total magnesium in leachates at 30 d of leaching.

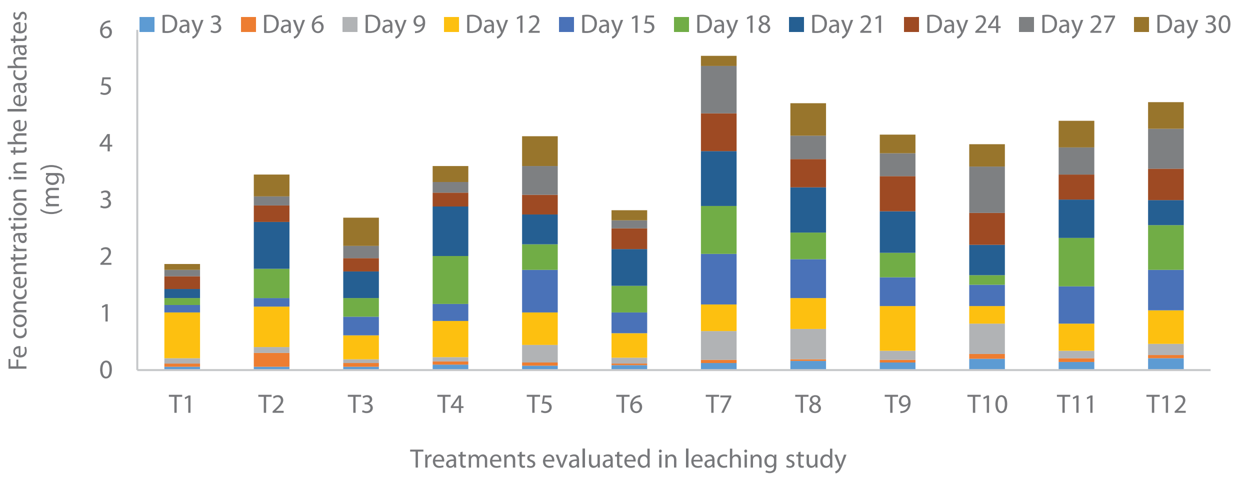

Fig. 12. Different rates of chicken litter biochar and triple superphosphate on iron in leachates during 30 d of leaching.

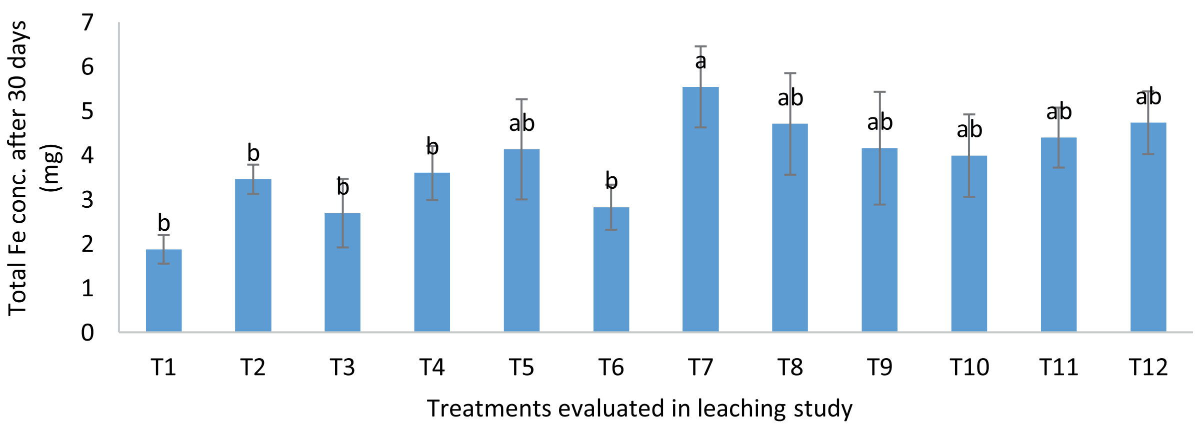

Fig. 13. Different rates of chicken litter biochar and triple superphosphate on total iron in leachates at 30 d of leaching.

the amending tropical acid soil with CLB increased base cations such as Ca, Mg, and K which in turn increased soil pH to minimize formation of insoluble Fe-P minerals [33]. Moreover, the CLB used in this present study has higher affinity for Fe and Al and during the leaching study, the tiny organic particles which absorb the Fe were leached thus, resulting in the increase of Fe in the leachates of the treatments with CLB.

3.2. Different amounts of chicken litter biochar and phosphorus fertilizer on soil total carbon and pH of soil at 30 d of leaching

Soil total carbon of T3 was similar to those of T4, T6, T7, and T10 but significantly higher than those of T1, T2, T5, T8, T9, T11, and T12 (Fig. 14). Soil total C of T4, T6, T7, and T10 were similar but significantly higher than those of T1, T2, and T9 (Fig. 14). Generally, soil total carbon of T1 and T2 were similar but lower than those with chicken litter biochar (Fig. 14).

The soil pH in water and KCl of T1 and T2 at 30 d of leaching were lower than those with biochar (T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12) (Figs. 15 and 16) because tropical mineral acid soils inherently have significant amounts of Al and Fe hydrous oxides (Figs. 15 and 16). These findings are comparable to those reported by [34,35]. Furthermore, leaching of base cations such as Ca, Mg, K, and Na during the 30 d of the leaching experiment might have increased the acidity of the soils with the treatments without chicken litter biochar. The reaction is through exchange of the base cations with for example excessive H^+ produced during Fe^{3+} and Fe^{2+} hydrolysis. Hydrolysis of Al^{3+} and Fe^{2+} ions result in production of many hydrogen ions [36]. Among the treatments with chicken litter biochar, the acidity (in water) of the soils with T3 and T7 were not significantly different from those of T4, T5, T8, T11, and T12 but lower than those T6, T9, and T10 because of the differences in the amount of base cations leached within the 30 d of the leaching study [36]. In addition, the treatments with higher amounts of chicken litter biochar demonstrated lower acidity because of the increased contents of phenolic and humic-like materials. The negatively charged complexes of these humic substances are able to attract or neutralize H^+ [37,38], suggesting that 50% of 5 t ha^{-1} of chicken litter biochar could be used to reduce soil acidity.

3.3. Different amounts of chicken litter biochar and phosphorus fertilizer on soil phosphorus at 30 d of leaching

Available P of T1 was significantly lower than those of T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12 (Fig. 17). However, total P and water soluble P of T1, T2, T6, T8, T9, and T12 at 30 d of leaching were similar but significantly lower than those of T3, T4, T7, T10, and T11 (Figs. 17 and 19). This was due to insufficient positively charged exchange

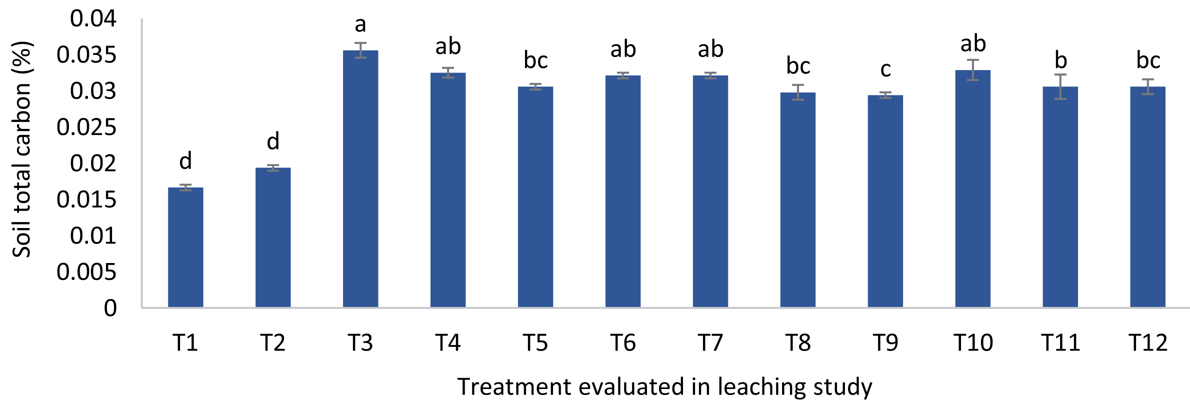

Fig. 14. Different rates of chicken litter biochar and triple superphosphate on soil total carbon at 30 d of leaching.

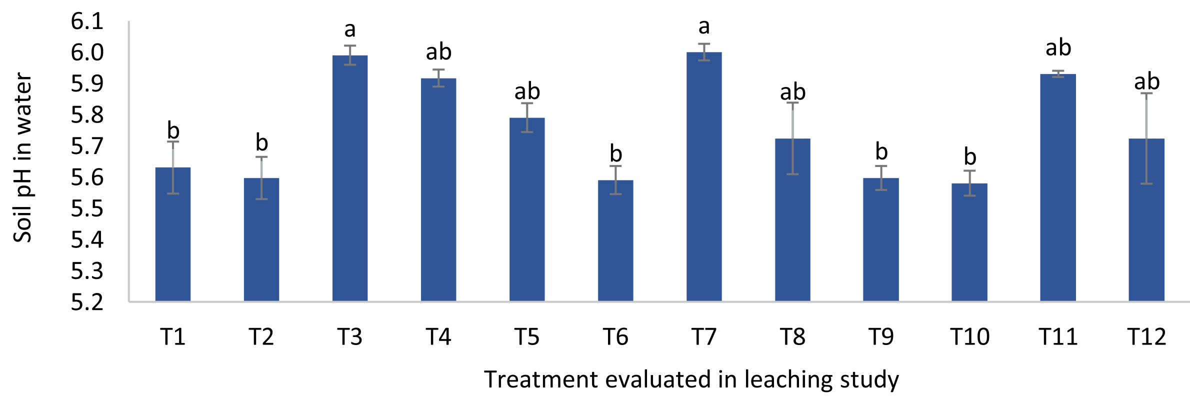

Fig. 15. Different rates of chicken litter biochar and triple superphosphate on soil pH in water at 30 d of leaching.

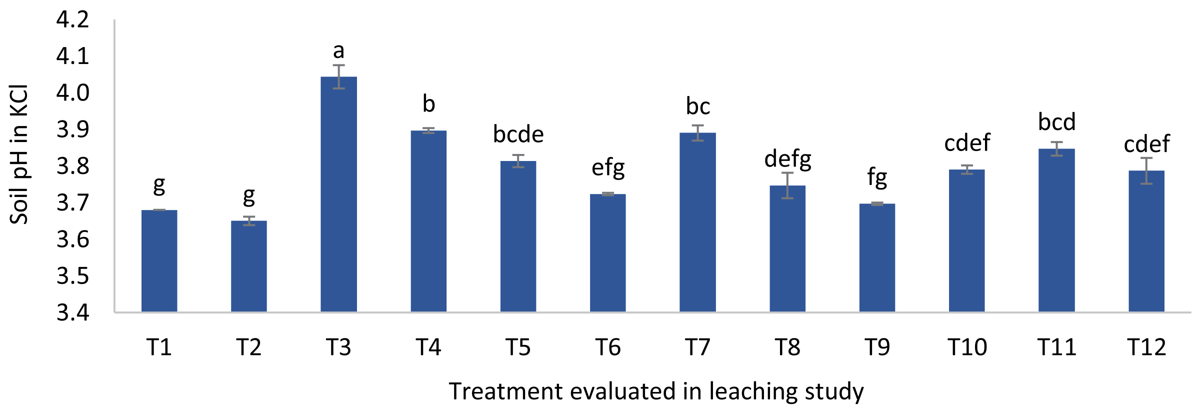

Fig. 16. Different rates of chicken litter biochar and triple superphosphate on soil pH in potassium chloride at 30 d of leaching.

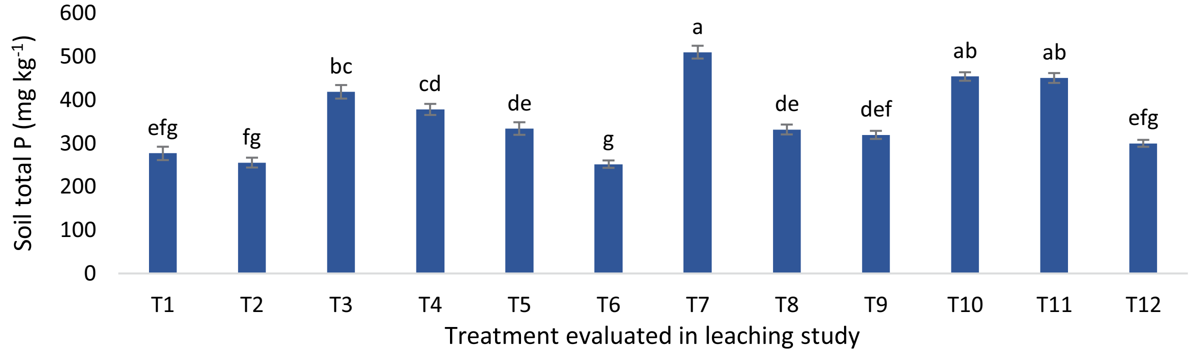

Fig. 17. Different rates of chicken litter biochar and triple superphosphate on soil total phosphorus at 30 d of leaching.

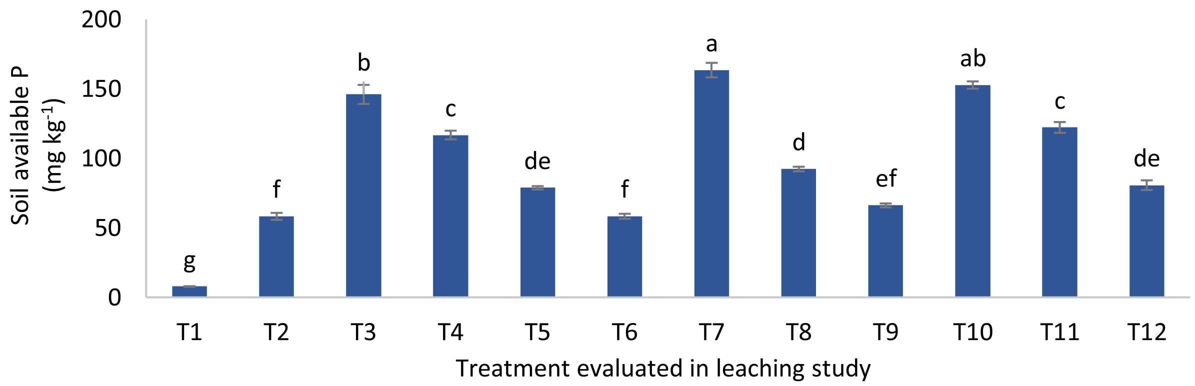

Fig. 18. Different rates of chicken litter biochar and triple superphosphate on soil available phosphorus at 30 d of leaching.

sites (low anion exchange capacity) to impede or minimize P movement in the soil [33]. Moreover, the electrostatic repulsion of the negative charge sites on surfaces of the soil colloid resulted in rapid movements of the orthophosphates because they are negatively charged. This partly explains the higher loss of P in T1 [38]. Available P of T7 and T10 were similar but significantly lower than those of T1, T2, T4, T5, T6, T8, T9, T11, and T12 (Fig. 18) whereas total P and available P of T7 were higher than those of T1, T2, T3, T4, T5, T6, T8, T9, and T12 but similar to T10 (Figs. 17 and 18). Although water soluble P of T3 and T7 were similar, they were higher than those of T1, T2, T4, T5, T6, T8, T9, and T12 (Fig. 19) because of the inherent content of nutrients in the chicken litter biochar apart from this organic amendment's relative ability to sorb.

The chicken litter biochar is more effective in increasing the soil carbon pool [39,40]. This enhances soils to sorb P from excessive leaching. In addition, the resident time of the chicken litter biochar used in this present study cannot be overlooked, it is resistant to oxidation [41] principally because of the chicken litter biochar's pyrolytic C and condensed aromatic structure [33,25]. Although the chicken litter biochar could not effectively reduce leaching of P because of low P sorption [33], soil P at 30 d of leaching was significantly higher than the soils without chicken litter biochar, and this observation confirms the findings of [33]. Moreover, the P leached relative to that retained in the soil after leaching indicates that the chicken litter biochar significantly increased P availability in the soil.

3.4. Chicken litter biochar on total soil acidity, aluminium, iron, and hydrogen ions after 30 d of leaching

Total acidity of T3, T4, T5, T6, T7, T8, T10, T11, and T12 were significantly lower than those of T1 and T2 (Fig. 20). Total acidity of T3 was significantly lower than the other treatments with chicken litter biochar (T4, T5, T6, T7, T8, T9, T10, T11, and T12) (Fig. 20) because of the liming effect of the chicken litter biochar as it has significant amounts of Ca and Mg [33]. In addition, buffering capacity of biochars enables them to form complexes with Al and Fe in acid soils to reduce Al and Fe ions hydrolysis to produce more hydrogen ions [22]. Amending soils with biochar has been reported to increase soil organic matter (OM) (Ch'ng et al., 2014) and it also increases soils' ability to resist their natural tendency to become acidic [41]. Soil exchangeable Al and Fe of T1 and T2 were significantly higher than those of the treatments with chicken litter biochar (T3, T4, T5, T6, T7, T8, T10, T11, and T12) (Figs. 21 and 23). The exchangeable hydrogen ions of T8 and T9 were significantly higher than those of T1, T2, T3, T4, T5, T6, T7, and T10 (Fig. 22) because most tropical mineral acid soils are highly weathered due

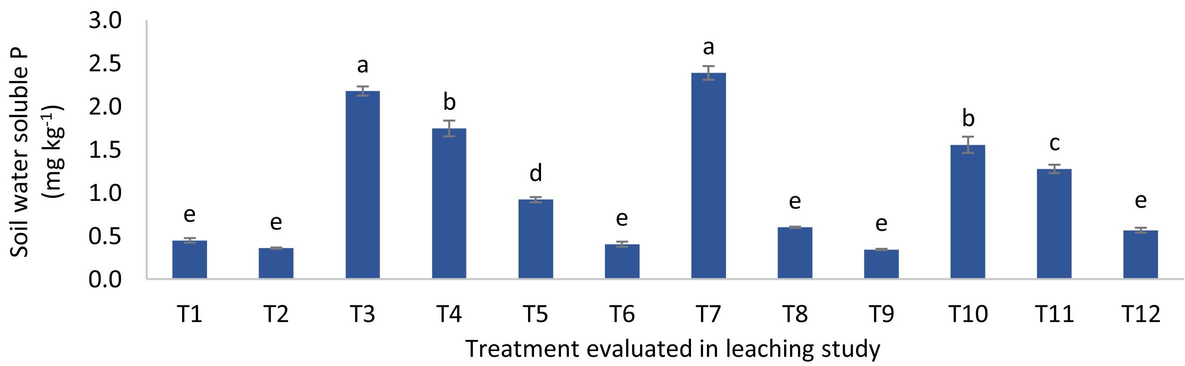

Fig. 19. Different rates of chicken litter biochar and triple superphosphate on soil water soluble phosphorus at 30 d of leaching.

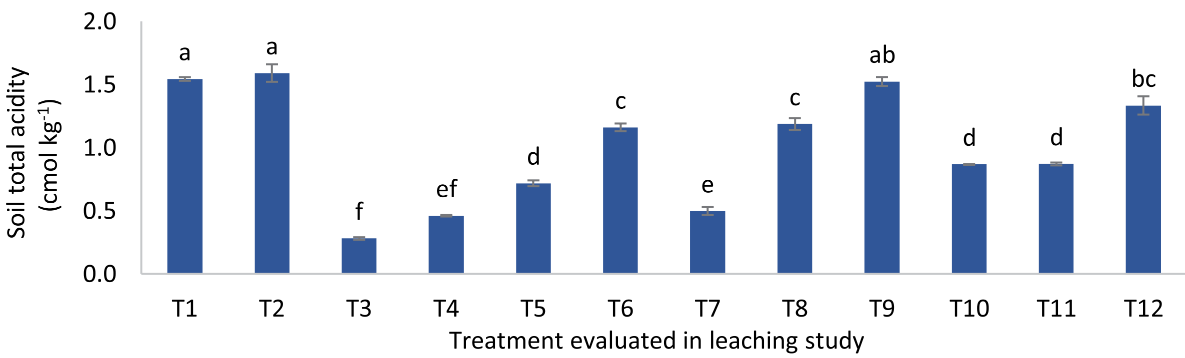

Fig. 20. Different rates of chicken litter biochar and triple superphosphate on soil total acidity at 30 d of leaching.

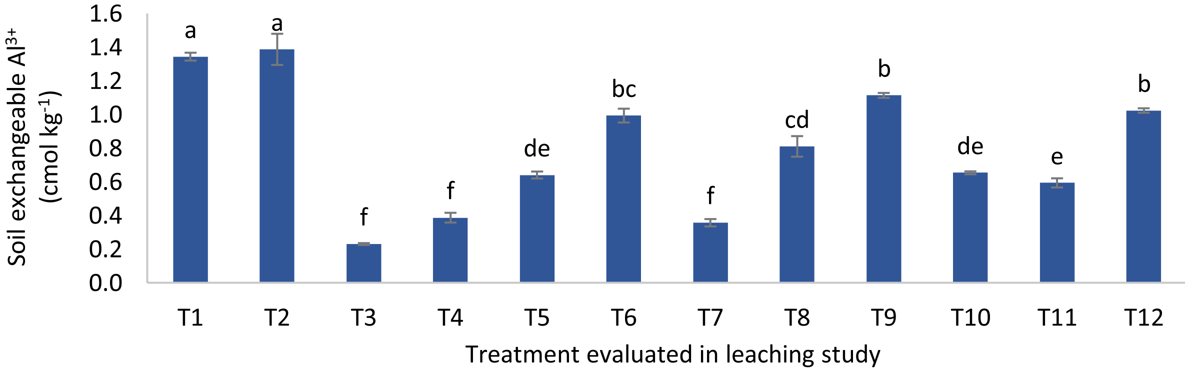

Fig. 21. Different rates of chicken litter biochar and triple superphosphate on soil exchangeable aluminium at 30 d of leaching.

to high temperature and rainfall besides the fact that such soils such as Ultisols and Oxisols are high in Fe^{2+} and H^{+} ions. Also, the soils with chicken litter biochar were lower in H^{+} and Al^{3+} because of the higher affinity of the chicken litter biochar for the Al and H ions.

In general, total acidity, exchangeable Al, and exchangeable Fe of the soils with chicken litter biochar decreased with increasing amount of this organic amendments (Figs. 20, 21, and 23). The soils with 25% chicken litter biochar (T6, T9, and T12) demonstrated higher total acidity, exchangeable Al, and exchangeable Fe than those with 75% (T4, T7, and T10) and 100% (T3) (Figs. 20, 21, and 23) and this was due to the increased content of phenolic, humic-like, and affinity of the chicken litter biochar for Al and Fe because the increasing the amount of this organic amendment caused significant reduction of Al and Fe in the soil. This reaction also caused reduction of the soil total acidity.

3.5. Different amounts of chicken litter biochar and phosphorus fertilizer on soil total nitrogen, cation exchange capacity, and cations at 30 d of leaching

Total N of all of the treatments were similar (Fig. 24). The total K, Ca, Mg, Na, and CEC of T1 and T2 were significantly lower than those with chicken litter biochar (T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12) (Figs. 25–29) because the nutrients which dissolved in the pore water near the soil surface were retained by the chicken litter biochar to reduce cation mobility.

Total K, Ca, Mg, Na, and CEC of the soils with chicken litter biochar (T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12) (Figs. 25–29) were similar in spite of the different amounts of the organic amendment used because the functional groups of the chicken litter biochar such as hydroxyl, carbonyl, carboxylate, hydrogen, and ether influenced the electrical charges, dipole, and H-bond of the biochar with water and solutes. The carboxylate, ether, and hydroxyl functional groups primarily affected the CEC of the chicken litter biochar because of the negative charges of this organic amendment. This resulted in the increased contents of the cations of in the soils with chicken litter biochar (T3, T4, T5, T6, T7, T8, T9, T10, T11, and T12) than in the soils the without chicken litter (T1 and T2).

4. Conclusion

Although organic amendments could increase P use efficiency, unbalanced use of organic amendments and P fertilizers in farming systems is uneconomical and environmental unfriendly. This study explored if the right combination of chicken litter biochar (CLB) and triple superphosphate (TSP) could improve soil P availability to minimize P losses through

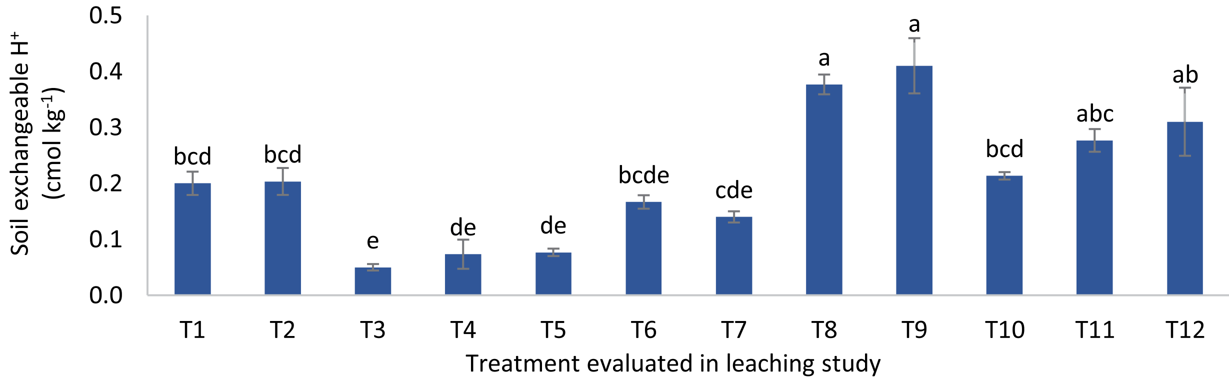

Fig. 22. Different rates of chicken litter biochar and triple superphosphate on soil exchangeable hydrogen at 30 d of leaching.

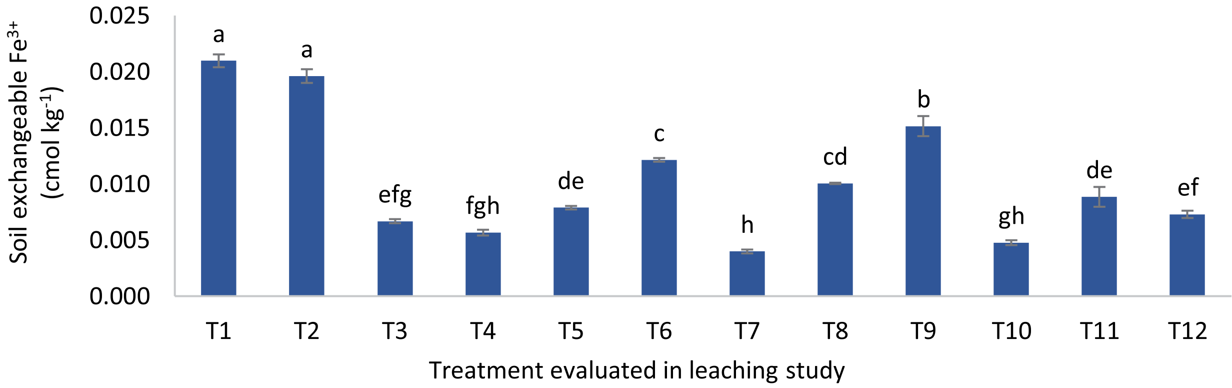

Fig. 23. Different rates of chicken litter biochar and triple superphosphate on soil exchangeable iron at 30 d of leaching.

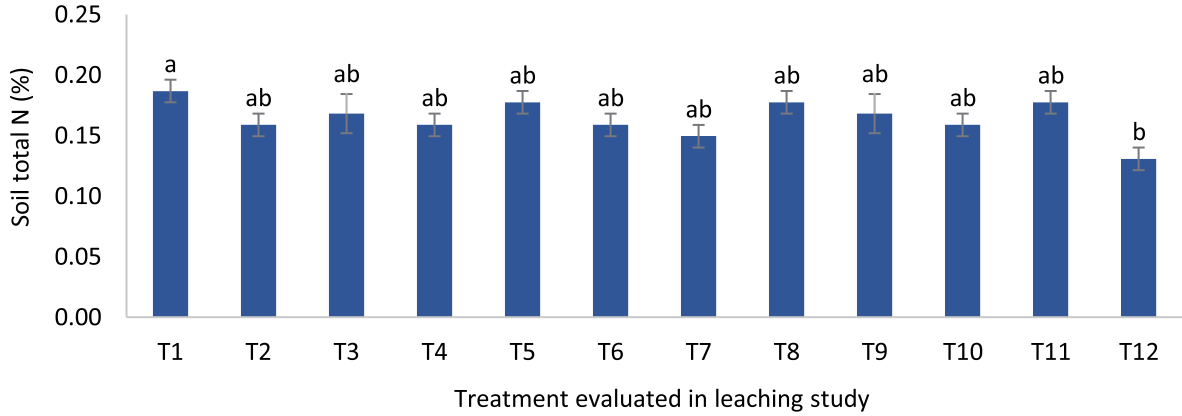

Fig. 24. Different rates of chicken litter biochar and triple superphosphate on soil total nitrogen at 30 d of leaching.

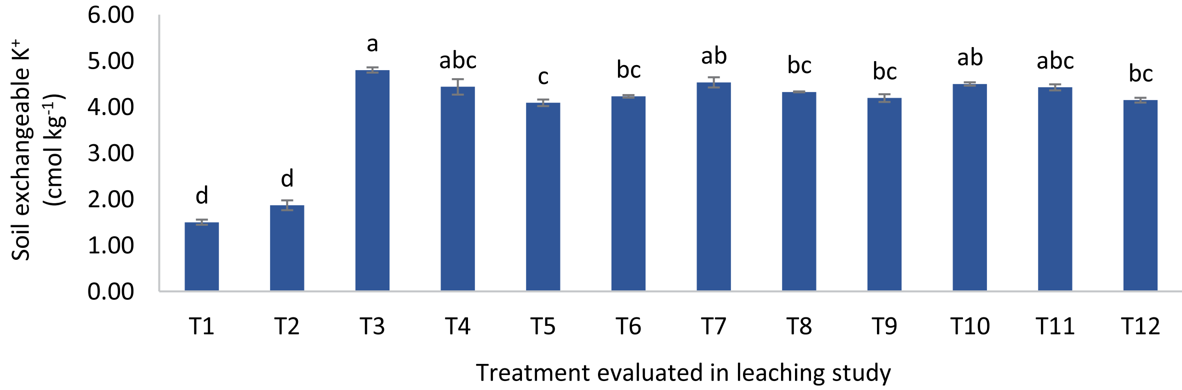

Fig. 25. Different rates of chicken litter biochar and triple superphosphate on soil exchangeable potassium at 30 d of leaching.

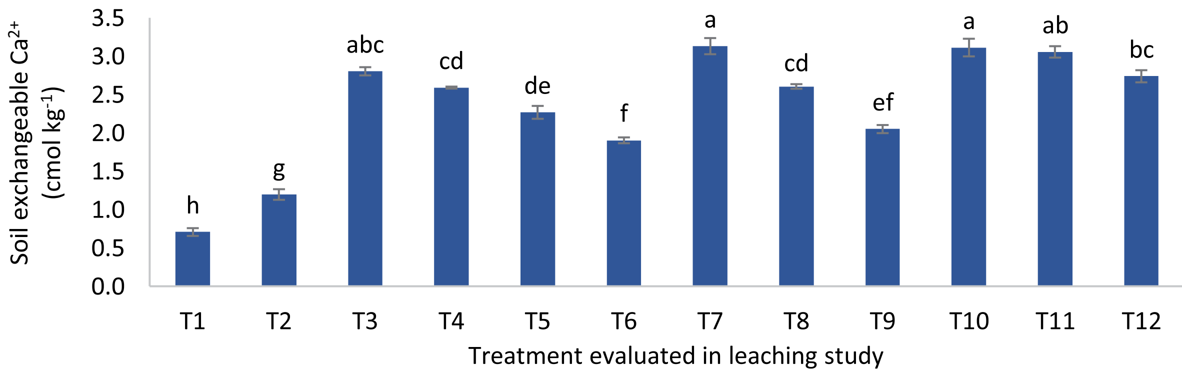

Fig. 26. Different rates of chicken litter biochar and triple superphosphate on soil exchangeable calcium at 30 d of leaching.

leaching. Rates of 75%, 50%, and 25% of 5 t ha^{-1} chicken litter biochar and 75%, 50%, and 25% of 130 kg ha^{-1} (existing TSP recommendation for *Zea mays*, L.), respectively were evaluated in a leaching study using standard procedures. Results revealed that CLB treatments minimized P leaching compared with the treatment without CLB. This resulted in significant improvement in available P. This was possible because CLB improved soil pH, P, K, Ca, Mg, and Na besides reducing P fixation by Al and Fe ions. Leaching of available P following application of chicken litter biochar only occurred within the first 10 d after which the leaching significantly reduced. This finding further suggests that if the availability P is not in synchrony with optimum crop uptake, available P could be lost from the soil profile. Chicken litter biochar can be used to improve P availability but it is not an excellent organic amendment to sorb P for a long period.

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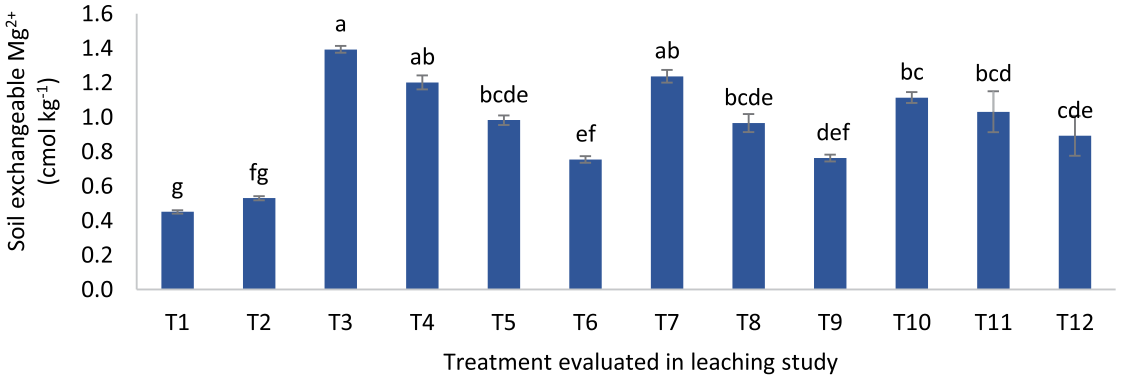

Fig. 27. Different rates of chicken litter biochar and triple superphosphate on soil exchangeable magnesium at 30 d of leaching.

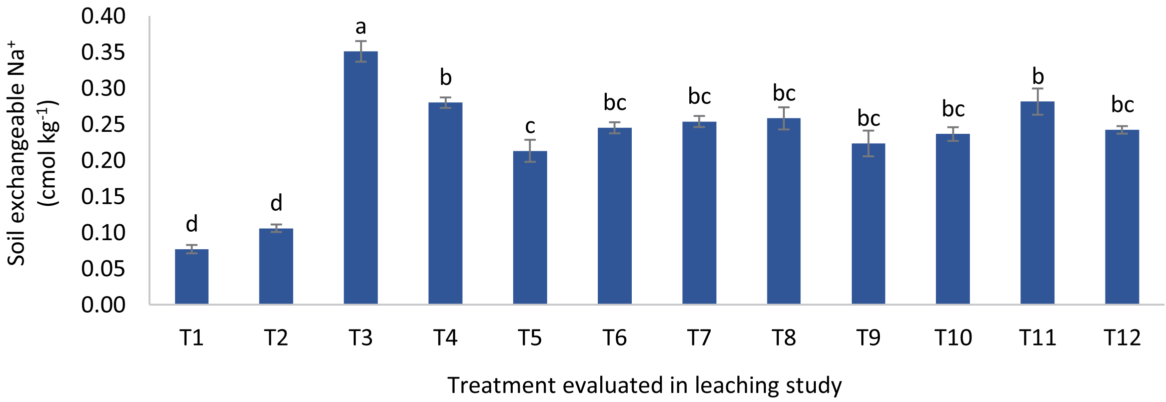

Fig. 28. Different rates of chicken litter biochar and triple superphosphate on soil exchangeable sodium at 30 d of leaching.

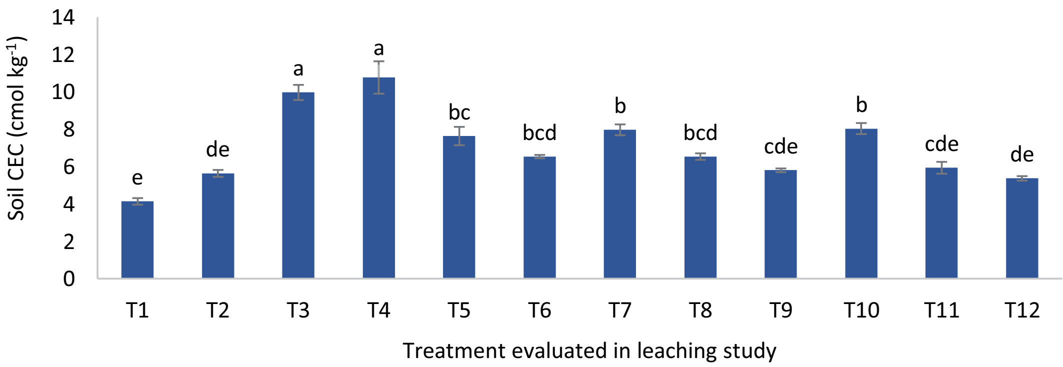

Fig. 29. Different rates of chicken litter biochar and triple superphosphate on soil CEC at 30 d of leaching.

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