CHICKEN LITTER BIOCHAR IMPROVES PHOSPHORUS AVAILABILITY IN ACID SOILS

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ABSTRACT

Phosphorus deficiency in tropical acid soils such as Ultisols and Oxisols is a distinct problem because of their characteristically high contents of aluminium (Al) and iron (Fe). Abundance of Al and Fe tend to bind with soluble inorganic P. Organic amendments such as chicken litter biochar can be used to mitigate P fixation. The objective of this study was to determine the optimum amount of chicken litter biochar that could be used to improve P availability of tropical acid soils. An incubation study was carried out for 20, 40, and 60 days with varying rates of chicken litter biochar and 50% Triple Superphosphate (TSP). Selected soil physico-chemical properties before and after incubation were determined using standard procedures. Amending acid soil with chicken litter biochar increased soil pH, total P, available P, and CEC and it also reduced exchangeable acidity, exchangeable Al3+, and exchangeable H+. However, the use of 60% and 90% of 5 t ha-1 chicken litter biochar with 50% TSP of the existing recommendation were more pronounced on soil P availability. This is because chicken litter biochar has large surface area and this creates a pool of negative charges in acid soils to fix Al instead of P. The findings in this study suggest that chicken litter biochar can positively alter soil chemical properties in a way that enhances P availability.

Key words: Organic amendments, waste management, soil productivity, phosphorus fixation, soil liming.

INTRODUCTION

Phosphorus deficiency in tropical acid soils such as Ultisols and Oxisols is a distinct problem because of their characteristically high contents of Al and Fe. Abundance of Al and Fe tend to bind with soluble inorganic P (Adnan et al. 2003). Phosphorus is mostly accessible to plants at soil pH of between slightly acidic to neutral (6 to 7), whereby in acidic soils, P is fixed due to the presence of active forms of Al and Fe oxides and hydroxide whereas, in alkaline soils, P is fixed by Ca and Mn (Mn) (Havlin et al. 1999). As a solution to this problem, farmers tend to apply large amount of P fertilizers to saturate the capacity of P sorption and to ensure there is adequate P available for plant uptake (Rahman et al. 2014). Excessive application of P fertilizers is not only uneconomical, but it also has adverse effect on the environment. This inappropriate practice can cause eutrophication of water bodies as P can lost through soil erosion (Zhou and Zhu, 2003) and leaching (Ruban, 1999). In view of this, studies have been conducted to improve P availability using lime. However, liming is an expensive approach as it is not practical for farmers to apply higher rates of lime. Furthermore, over-liming causes calcium-phosphate formation (Myers and De Pauw, 1995), a reaction which also causes P to be fixed (unavailable).

Therefore, there is a need to find another alternative which is more sustainable and environmental friendly to mitigate the high P-fixing capacity of acid soils. The application of organic amendments has been reported to enhance P availability in tropical acid soils (Audrey et al., 2018; Ahmed et al. 2006b; Palanivell et al. 2013a, b). This is because these organic amendments have higher affinity for Al and Fe. To ameliorate P fixation in acid soils, biochar can be used as an organic amendment to reduce P sorption sites. Biochar is a product of thermal degradation of organic materials in the absence of oxygen (pyrolysis) (Lehmann and Joseph, 2009). Most biochars are neutral to basic in pH and because of this, they increase soil pH (Sohi et al. 2010). Amending tropical acid soils with biochars does not only improve soil total P, available P, organic P, and inorganic fractions of P (soluble-P, Al-P, Fe-P, redundant soluble-P, and Ca-P) but they also change the activity or availability of Al and Fe ions to decrease P sorption in soil. (Ch'ng et al. 2014a). The objective of this study was to determine the optimum amount of chicken litter biochar that could improve P availability of tropical acid soils.

MATERIALS AND METHODS

The soil (Nyalau Series, *Typic Paleudults*) 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 Malaysia. The soil samples were taken at 0-20 cm using shovel and thereafter, they were air dried, ground, and sieved to pass a 2 mm. A 300 g of soil was taken for each treatment. The weight of the soil was derived base on the bulk density method. The chicken litter biochar and triple superphosphate (TSP) rates used in this study are summarized in Table 1. The soil, chicken litter biochar, and TSP were thoroughly mixed after which the mixture was incubated in a transparent polypropylene container of 800 cm^3 volume. The treatments were arranged in a Complete Randomized Design (CRD) with three replicates at the Research Centre of Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia. The mixture was moistened to 60% of moisture content based on the soil field capacity after which the TSP rates in Table 1 were surface applied. The lids of the polypropylene containers were perforated to allow good aeration. When necessary, the soil moisture content was maintained using distilled water. The incubated soil was sampled using destructive sampling at 20, 40, and 60 days of incubation. The recommended rate of P fertilizer used was 60 kg P_2O_5 ha^{-1} (130 kg ha^{-1} TSP) and scaled to per plant basis from the standard fertilizer recommendation by Malaysian Agriculture Research and Development Institute (1995). The chicken litter biochar rate was 5 t ha^{-1} but it was scaled to per plant basis. The treatments which were evaluated in this present study are presented in Table 1.

Table 1. Treatments evaluated in incubation study for twenty, forty, and sixty days of incubation

Treatment	Soil (g)	Biochar (g)	TSP (g)
T1	300	-	-
T2	300	7.70	-
T3	300	-	2.4
T4	300	2.31	2.4
T5	300	4.62	2.4
T6	300	6.93	2.4

Before and after the incubation study, the soil samples were characterized for physico-chemical properties. Soil pH in water and KCl were determined in a 1:2.5 (soil: distilled water/KCl) using a digital pH meter (Peech et al., 1965). Soil total carbon was calculated as 58% of the organic matter determine using loss of weight on ignition method (Chefetz et al., 1996). The soil cation exchange capacity (CEC) was determined using the leaching method (Cottenie, 1980) followed by steam distillation (Bremner, 1965). 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). Soil total P and available P were determined using Spectrophotometer after blue colour was develop (Murphy and Riley, 1962). Soil exchangeable acidity, H^+, and Al^{3+} were determined using acid-base titration method (Rowell, 1994). Analysis of variance (ANOVA) was used to test treatment effects whereas treatments means were compared using Tukey's Test. Statistical Analysis Software version 9.4 was used for the statistical analysis (SAS, 2013).

RESULTS AND DISCUSSION

The selected chemical properties of the soil used in this present study are presented in Table 2. These properties are typical of a mineral acid soils of Malaysia (Paramananthan, 2000). The chemical properties of the chicken litter biochar were also within the range reported by the BlackEarth Company in North of Bendigo Victoria, Australia (Table 3).

Table 2. Selected chemical properties of Bekenu Series before incubation study

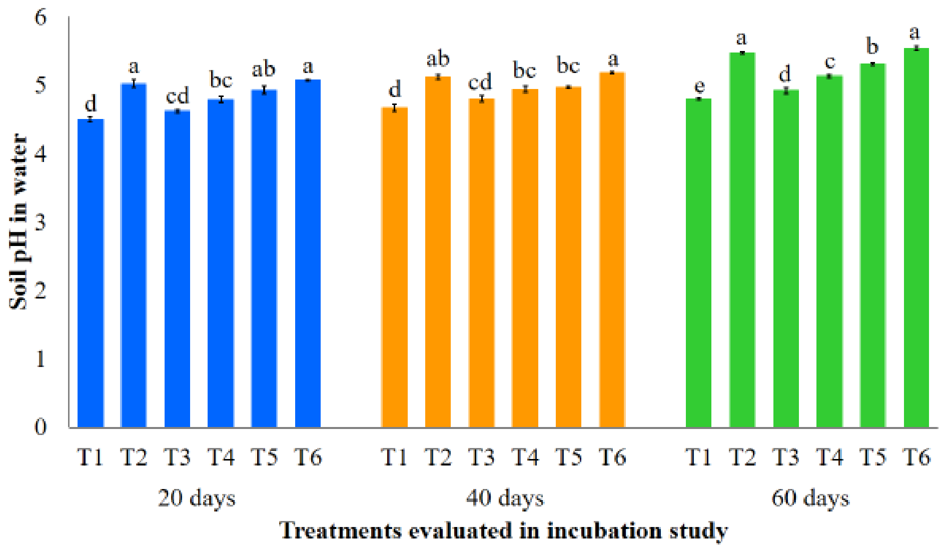
Properties	Value Obtained
pH in water	4.58
pH in KCl	4.30
Total organic carbon (%)	2.68
CEC (cmol kg^{-1})	5.52
Total P (mg kg^{-1})	81.00
Exchangeable acidity (cmol kg^{-1})	0.88
Exchangeable Al (cmol kg^{-1})	0.73
Exchangeable H (cmol kg^{-1})	0.15

Table 3. Selected chemical properties of chicken litter biochar

Properties		Chicken little biochar
pH in water		8.5
pH in KCl		7.83
Total Carbon		63.7
Total N	(%)	2.8
Total P	(%)	2.6
Total K	(%)	3.9
Total Ca	(%)	5.9
CEC (cmol kg^{-1} biochar)		80.5
Total Mg	(g kg^{-1} biochar)	15.2
Total Na	(g kg^{-1} biochar)	19.5
Total Fe	(g kg^{-1} biochar)	2.7
Total Al	(g kg^{-1} biochar)	0.0006

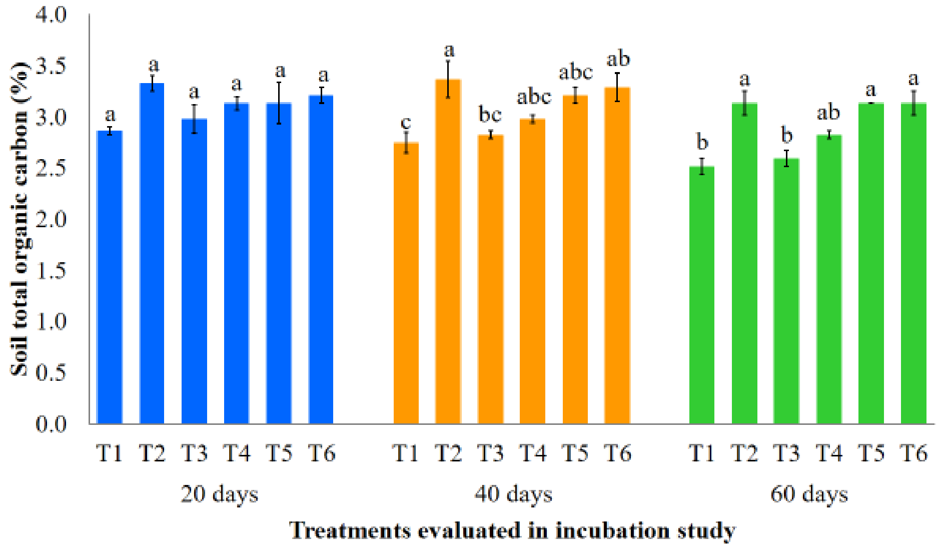
The interaction between treatments and incubation time significantly affected soil pH in water (Figure 1). The treatments with chicken litter biochar (T2, T4, T5 and T6) significantly increased soil pH in water compared with the treatments without chicken litter biochar (T1). At 20, 40 and 60 days of incubation, T2 and T6 recorded the highest pH value followed by T5, T4 and T3. There was no significant difference between T2 and T6. T1 showed the lowest pH.

Figure 1. Treatments on soil pH in water after 20, 40, and 60 days of incubation. Means with different letter(s) within the same incubation period indicate significant difference between treatments by Tukey's HSD test at $p \leq 0.05$, i.e., a > b > c. Bars represent the mean values ± SE



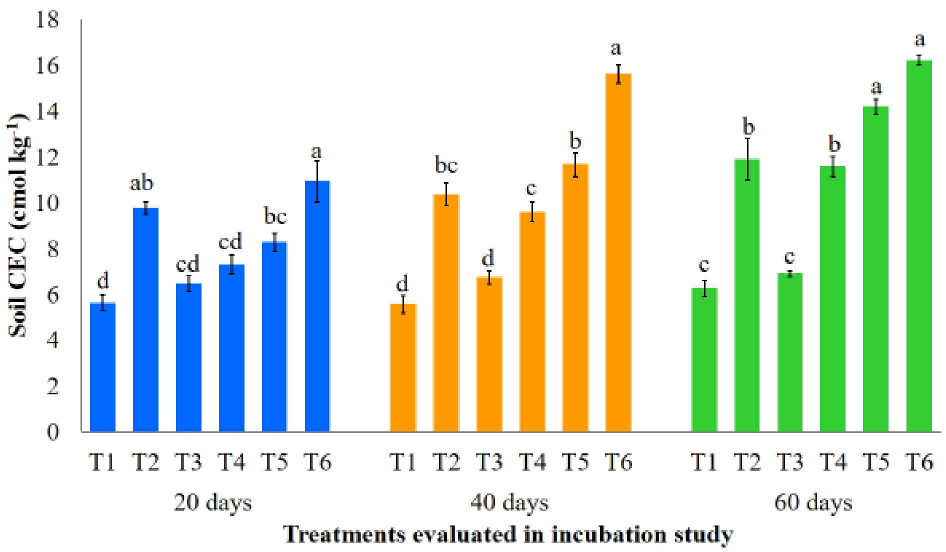
Treatments and incubation time significantly affected soil total carbon (Figure 2) although there was no consistent trend. At 20 days of incubation, the treatments showed no significant effects on soil total carbon but at 60 days of incubation, the effects of T5 and T6 were significantly higher than those of the treatments without the chicken litter biochar.

Figure 2. Treatments on soil total carbon after 20, 40, and 60 days of incubation. Means with different letter(s) within the same incubation period indicate significant difference between treatments by Tukey's HSD test at p ≤ 0.05, i.e., a > b > c. Bars represent the mean values ± SE



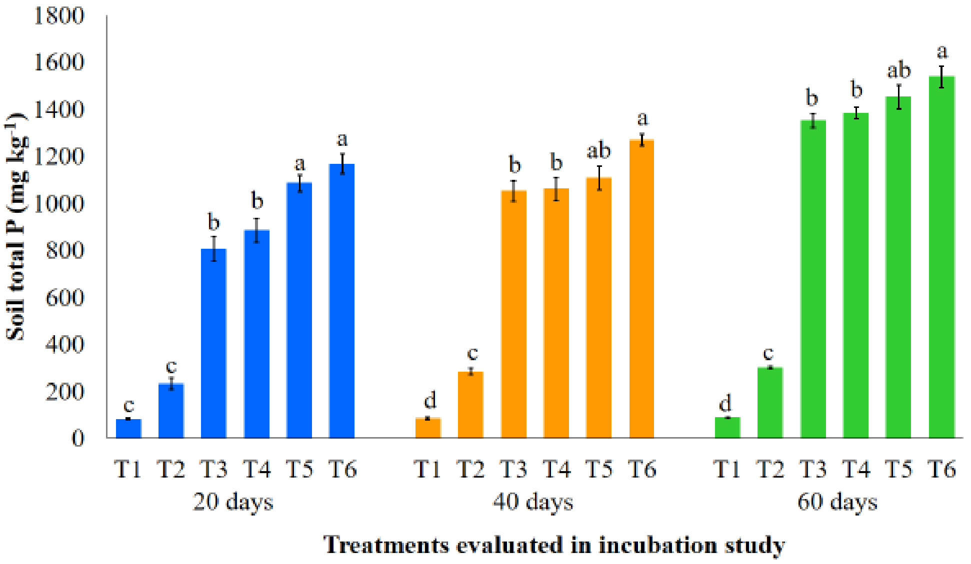
The interaction between time of incubation and treatments significantly affected soil CEC (Figure 3). Throughout the incubation study, soil CEC of the treatments without chicken litter biochar (T1 and T3) were not significantly different. At 40 and 60 days of incubation, T6 showed higher CEC than T2. T5 showed improvement in soil CEC at 60 days of incubation.

Figure 3. Treatments on soil CEC after 20, 40, and 60 days of incubation. Means with different letter(s) within the same incubation period indicate significant difference between treatments by Tukey's HSD test at p ≤ 0.05, i.e., a > b > c. Bars represent the mean values ± SE



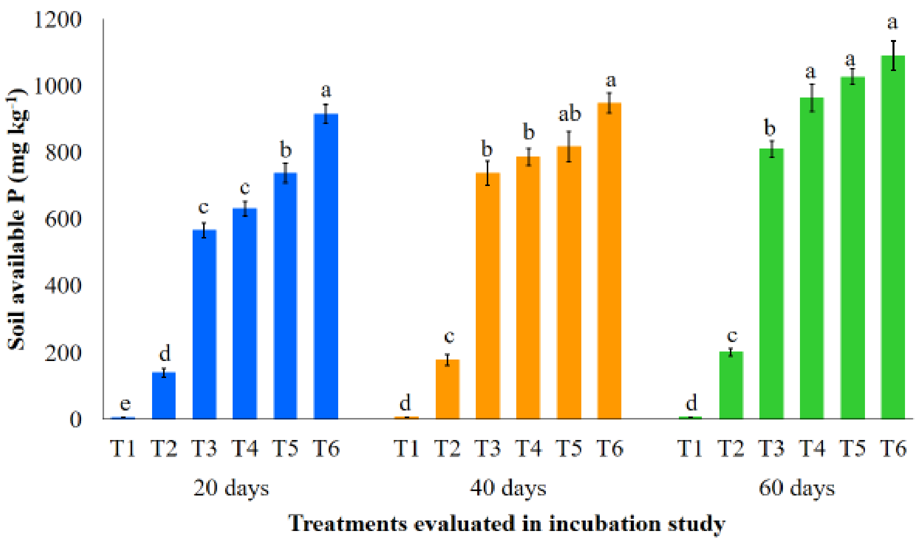
The interaction between treatments and incubation time significantly affected soil total P (Figure 4). T1 and T2 showed the lowest soil total P than those of T3, T4, T5 and T6. The treatment with chicken litter biochar only (T2) showed lower effect on total P than those with chicken litter biochar and TSP (T4, T5 and T6). At 20 days of incubation, the soil total P of T5 and T6 were significantly higher than those of T3 and T4.

Figure 4. Treatments on soil total P after 20, 40, and 60 days of incubation. Means with different letter(s) within the same incubation period indicate significant difference between treatments by Tukey's HSD test at p ≤ 0.05, i.e., a > b > c. Bars represent the mean values ± SE



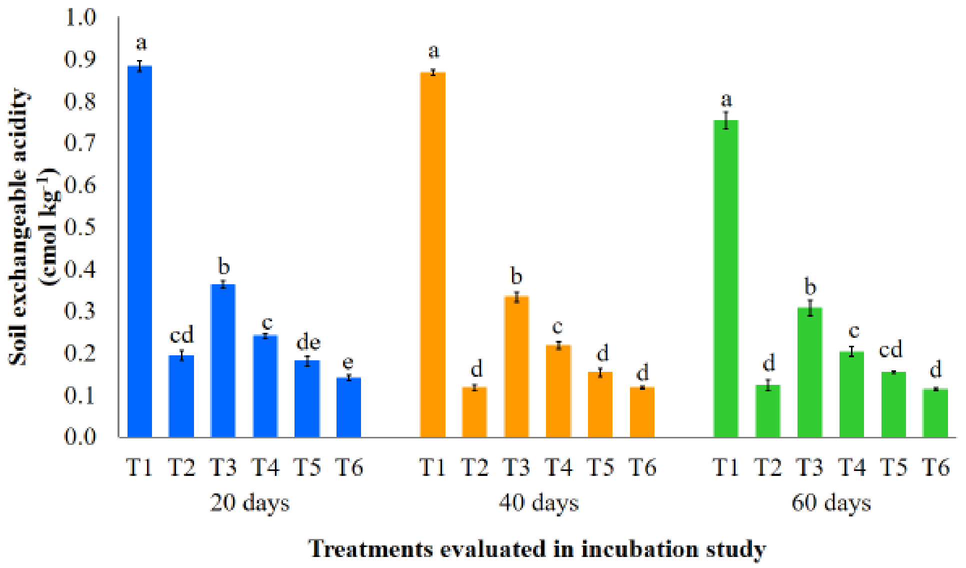
The interaction between treatments and incubation time significantly affected soil available P (Figure 5). T1 and T2 had the lowest effect on soil available P than T3, T4, T5 and T6. The treatment with chicken litter biochar only (T2) showed lower effect on available P compared with the treatments with chicken litter biochar and TSP (T4, T5 and T6). At 20 days of incubation, soil available P of T6 was significantly higher than T5.

Figure 5. Treatments on soil available P after 20, 40, and 60 days of incubation. Means with different letter(s) within the same incubation period indicate significant difference between treatments by Tukey's HSD test at p ≤ 0.05, i.e., a > b > c. Bars represent the mean values ± SE



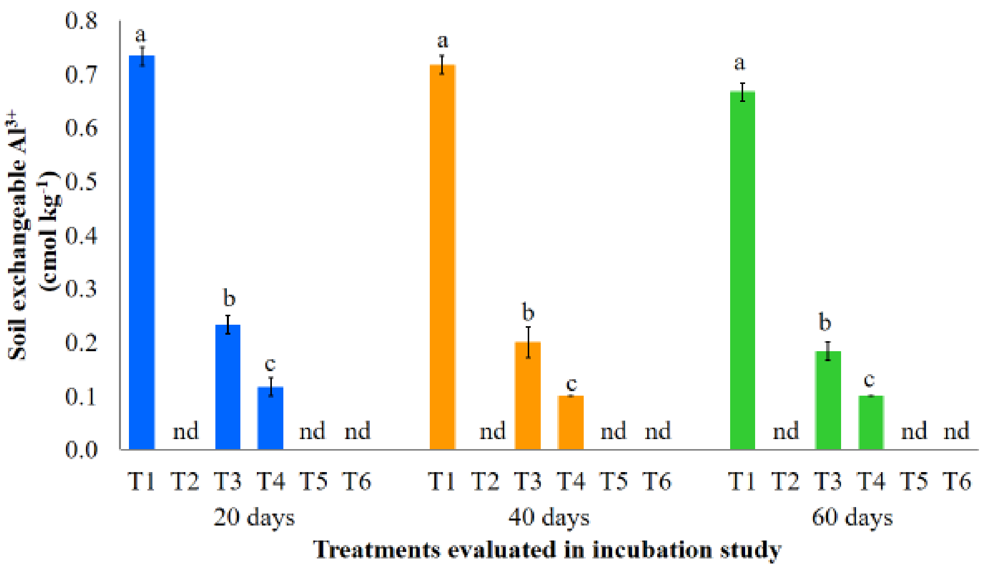
The interaction between time of incubation and treatments significantly affected soil exchangeable acidity (Figure 6). Among the treatments, T1 recorded the highest soil exchangeable acidity. Among the treatments with chicken litter biochar (T3, T4, T5, and T6), T3 showed higher effect on soil exchangeable acidity.

Figure 6. Treatments on soil exchangeable acidity after 20, 40, and 60 days of incubation. Means with different letter(s) within the same incubation period indicate significant difference between treatments by Tukey's HSD test at p ≤ 0.05, i.e., a > b > c. Bars represent the mean values ± SE



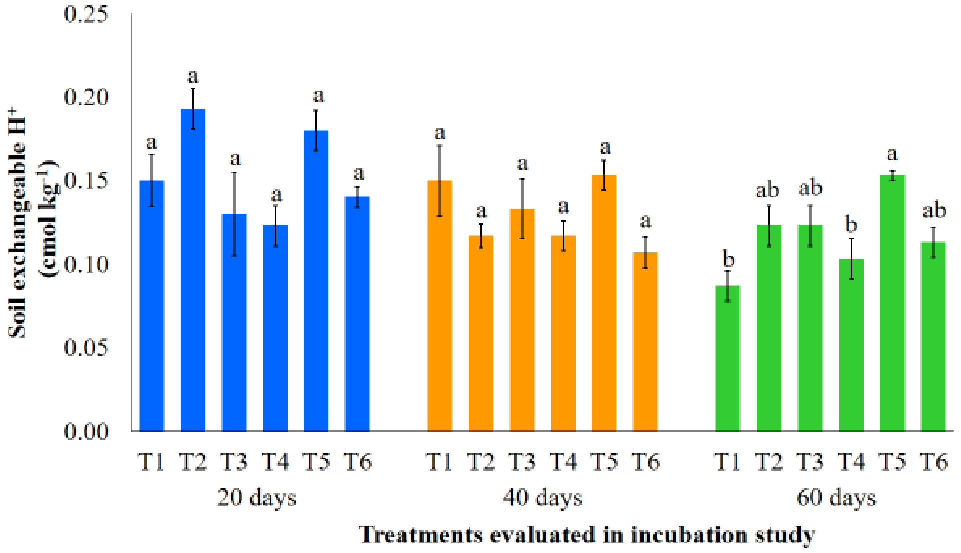
The interaction between time of incubation and treatments significantly affected soil exchangeable aluminium (Figure 7). Soil exchangeable aluminium of T1 was the highest compared with other treatments but T2, T5 and T6 showed negligible amount of soil exchangeable aluminium.

Figure 7. Treatments on soil exchangeable Al^{3+} after 20, 40, and 60 days of incubation. Means with different letter(s) within the same incubation period indicate significant difference between treatments by Tukey's HSD test at p ≤ 0.05, i.e., a > b > c. Bars represent the mean values ± SE



The interaction between time of incubation and treatments affected soil exchangeable hydrogen (Figure 8) with no consistent trend.

Figure 8. Treatments on soil exchangeable H+ after 20, 40, and 60 days of incubation. Means with different letter(s) within the same incubation period indicate significant difference between treatments by Tukey's HSD test at p ≤ 0.05, i.e., a > b > c. Bars represent the mean values ± SE



The treatments with chicken litter biochar significantly increased soil pH compared with the treatments without chicken litter biochar. The high affinity of the chicken litter biochar for Al ions due to its functional groups (for example, carboxylic and phenolic) suggests that the high negative charges of the chicken litter biochar might have impeded the hydrolysis of Al ions to produce hydrogen ions. Instead, the reaction enabled release of OH- to increase soil pH. The soil pH values observed in this study are consistent with those reported in the literature (Agusalim et al., 2010; Zheng et al., 2010; Nigussie et al., 2012; Zhang et al., 2012). The authors concluded that biochar application can improve soil quality by increasing soil pH.

Although Trupiano et al. (2017) found that application of biochar increased soil total organic carbon content than that in untreated soils, there was no pronounced effect of the chicken litter biochar used in this present study on soil carbon because of the relatively short incubation period (60 days). Cation exchange capacity of the soil increased with application chicken litter biochar (T2, T4, T5 and T6). Mineralization causes a part of the exchangeable cations in the soil to be released from the chicken litter biochar itself as exchangeable cations increased with the increasing biochar rate (Carter et al., 2013). Most cations are highly available at pH of 6.5 to 7.5, thus the increase in soil pH might have increased the soil exchangeable cations (Brady and Weil, 2008). DeLuca et al. (2009) pointed out that chicken litter biochar increases nutrient retention and reduces nutrient loss through leaching. Application of chicken litter biochar to soils which are high in organic matter provides reactive surfaces (within pores and on the biochar surface) to increase the surface sorption ability and base saturation of soils (Chan and Xu, 2009).

The lower soil total P and available P of T1 at 20, 40, and 60 days of incubation than those of T2, T3, T4, T5, and T6 were due to higher P fixation. The soil total P and available P of T2 at 20, 40 and 60 days of incubation were lower than those of T3, T4, T5, and T6 due to the absence of P fertilizer which is the principal source of P in soils. However, the P availability showed increase even without the presence of P fertilizer. Presence of chicken litter biochar causes an upsurge of the negative charges of this organic amendment and this fixes Al instead of P thus, freeing P (Cheng et al. 2008; Ch’ng et al. 2014a). All the treatments amended with chicken litter biochar and TSP showed higher P release at 60 days of incubation than those of 20 days of incubation. This finding is comparable to another study which explained that the trend was directly related to the slow release of nutrients from the chicken litter biochar as chicken litter biochar is recalcitrant to decomposition (Ch’ng et al. 2014a).

The reduction in exchangeable acidity and exchangeable Al partly relates to the increase in soil pH. This finding is also consistent with the findings of several studies which also reported that decrease in exchangeable Al^{3+} was directly related with the improvement of soil pH during decomposition of organic residues in soils (Haynes and Mokolobate, 2001; Narambuye and Haynes, 2006). Application of chicken litter biochar does not only increase soil pH and available P, but it also reduces soil exchangeable acidity and acidic cations (exchangeable Al^{3+} and H^+). The reduction can also be associated to the high total surface area of the organic amendments caused by the higher amount of organic acids with their exchange sites (Vithanage et al., 2017). This also suggests that application of chicken litter biochar is able to reduce Al solubility by replenishing the functional groups of humic substances. The reduction in Al^{3+} further suggests that P fixation by Al is reduced (DeLuca *et al*., 2009; Sika, 2012). It had been reported that in acidic condition, P is precipitated by oxides and hydroxides of Al (variscite and plumbogummite) and Fe (strengite and vivianite) (Hinsinger, 2001).

CONCLUSION

Amending tropical acid soil with 60% and 90% chicken litter biochar of 5 t ha^{-1} with 50% TSP (T5 and T6) improves P availability principally due to reduction of the affinity of aluminium ions for phosphorus ions. Moreover, the chicken litter biochar seems to have the ability to reduce aluminium hydrolysis by minimizing soil exchangeable acidity.

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