Nutrient availability in acidic soil added with composted paddy husk amendment

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Abstract

Organic amendments such as composted paddy husk can improve the fertility of tropical acid soil through replenishment of cations, reduction of phosphorus and potassium fixation, increase soil total carbon and nutrients availability. The objective of this study was to determine the effect of incubation period on soil quality and availability of major nutrients in composted paddy husk treated using different ligninolytic microbes isolated from termite guts. Each treatment of soil with various compost mixtures was incubated for 30, 60, and 90 days before harvested. The physico-chemical properties of the incubated soils were determined using standard procedures. Results indicated that soil pH, electrical conductivity, total nitrogen and phosphorus, available phosphorus, exchangeable potassium, magnesium, and calcium interacted positively to incubation time and treatments. Thus, the application of composted paddy husk improved soil carbon content, reduced soil acidity, and increased the availability of essential plant nutrients.

Keywords: *incubation period, ligninolytic microbes, paddy husk compost, soil fertility, termite gut*

1. Introduction

Plant nutrient availability and use efficiency are poor in acid soils due to the availability of heavy metals such as aluminium (Al) and iron (Fe) ions as affected by high weathering and rainfall [5]. Soil acidity increased with the removal of basic cations through leaching, plant uptake and harvest [11]. Application of acid forming chemicals namely ammonium compounds, phosphate fertilizers, and microbial production of organic acids further increases soil acidity [30]. The presence of hydrogen (H) and Al ions resulted in complex interactions among soil physical, chemical, and biological properties. Chemicals such as Al toxicity, calcium (Ca^{2+}), magnesium (Mg^{2+}), and phosphorus (P) deficiencies can affect the availability of nutrients required for normal plant growth. Furthermore, such constraints affect soil exchangeable capacity whereby soil acidity increases with increasing agricultural activities. Meanwhile, as biological activities decline, soil aggregation becomes poorer, and availability of nutrients to plants can also be affected [11]. Acidic soils are usually low in Ca^{2+} and Mg^{2+}, while under extreme conditions, the supply of these nutrients can be deficient for plants [15].

Studies have shown that the application of soil organic amendments can ameliorate soil acidity due to the liming properties of organic amendments. Compost applied to soil can replenish lost cations thus reduced soil acidity. The buffering capacity of organic amendments leads to the formation of complexes with Al and Fe thereby increasing plant nutrients availability [25]. Organic amendments also contain some phenolic and humic-like material that increase soil pH, and nutrient availability [25]. In addition, the introduction of organic amendments to tropical acid soils increases soil microbial activities which in turn increase the decomposition of soil organic matter thus increasing nutrient mineralization and nutrient availability [12].

Application of organic amendments to tropical acid soils influences the concentration of plant nutrient availability. Interactions between tropical acid soil and organic amendments are affected by factors such as soil moisture, temperature, micro-organisms, existing soil macro and micronutrients, heavy metals, and time of interaction. Organic materials from different sources interact differently to soil physical and chemical properties [11]. Studies regarding the interaction of organic amendments such as biochar and compost from animal wastes are abundant [6, 11]. Recently, rice husk has been used a source of compost to improve the soil properties and plant growth. Since Malaysia is a rice production country, wastes like paddy husk can be found in abundance and cheap. Applying paddy husk as soil organic amendment helps to reduce agricultural waste in an environment-friendly manner. In addition, dusk compost of paddy husk has been found to be beneficial in lowering cowpea susceptibility against Cowpea Mottle Virus [1]. Co-composting of paddy husk with clinoptolite zeolite and urea showed similar capability in promoting germination and growth of crop similar to those sown in peat-based growing medium [16]. Furthermore, paddy husk compost also improved soil quality and yield of tomato in both greenhouse and open field [10].

Paddy husk contains high amount of polysaccharides (cellulose, hemicellulose and lignin). Degradation of paddy husk using lignocellulolytic microbial is ideal in speeding up the degradation process and improving nutrient contents of the paddy husk compost. Badar and Qureshi (2014) [2], found that amendment of paddy husk compost added with beta-glucan, chitin and cellulose degrading microbes (*Trichoderma hamatum*, *Rhizobium* spp. and *Bradyrhizobium* spp.) helped in improving total carbohydrate and protein contents of soil after 15 days of incubation. The application of the compost led to the improvement of sunflower plants growth. Modifying of black (typic *Haplustalf*) and red (typic *Rhodustalf*) soils with paddy husk degenerated with lignocellulolytic fungus *Aspergillus* spp. along with supplementation of recommended fertilizer doses have also improved yield and quality of the blackgram crop and became an alternative for organic chicken manure [37]. Although a number of studies suggested a positive impact of using paddy husk compost on the plant growth, studies concerning how organic amendments from paddy husk compost interact and affect soil chemical and physical properties of tropical acid soil is limited. In light of this, the present study aims to determine the effect of incubation period on soil quality and availability of major plant nutrients in composted paddy husk treated using different lignocellulosic microbes isolated from termite gut.

2. Materials and methods

2.1 Source of compost materials

Raw paddy husk was obtained from a rice mill in Dalat, Sarawak, Malaysia. Microbes of different species were isolated from termite (*Coptotermes curvignathus*) gut obtained from the collection of Microbiology Laboratory, Faculty of Agricultural Science and Forestry, Universiti Putra Malaysia Bintulu Sarawak Campus (UPMKB) Malaysia. Chicken feeds, organic fertilizer and molasses were purchased from a local market. Leguminous leaves and chicken manure were obtained from the Share Farm of UPMKB, Malaysia.

2.2 Soil Sampling and Preparation

The soil of Nyalau Series (Typic *Paleudults*) used in this study was obtained from an uncultivated secondary forest within the compound of UPMKB, Sarawak, Malaysia. Although acidic, this soil is mostly used for cultivation in Sarawak. Soil samples were taken at 0 to 25 cm depth using manual shovel and transported to the research centre to be air dried, ground, and sieved through a 2 mm mesh. Exactly 400 grams of soil was taken for each treatment with nine replications made based on the bulk density.

2.3 Experiment Setup

An incubation experiment was carried out for 90 days beginning September 5th, 2018 to December 4th, 2018 at the Horticulture Unit of University Agriculture Park Division, Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia (3°12'31.0" N, 113°04'42.0 °E). Paddy husk was composted using three different ligninolytic microbes isolated from termite gut and the compost was later used as soil organic amendments. The three microbe strains have been identified as *Bacillus toyonensis* strain BCT-7112 (CH2), *Bacillus cereus* strain JCM2152 (CH5) and *Bacillus thuringiensis* NBRC101235 (CH9).

Summary of the treatments are as listed in Table 1. Treatment 9 with paddy husk and chicken manure (as source of microbes) was included as it is a common practice by local farmers to process compost. This treatment was included to compare the common decomposition practice with those with microbes isolated from the termite gut. Meanwhile, T10 (organic fertilizer) was a positive control in this study. Treatments were thoroughly mixed and incubated in a transparent polypropylene container of 800 cm^3 in volume. Each treatment was represented by three samples which was replicated three times and arranged in a completely randomized design (CRD). The mixture was moistened to 60% of field capacity. The lids of the polypropylene containers were perforated for aeration. The soil moisture content was monitored and maintained at 60% throughout the composting period using Extech MO57 Pinless Moisture Meter. The incubated soil was sampled using destructive sampling at 30, 60, and 90 days of incubation by sampling three replicates at each sampling stage. According to recommendation by the Malaysian Agriculture Research and Development Institute (MARDI), the rates of N, P, K fertilizers for *Zea mays* L. are 60 kg N/ha,60 kg P_2O_5/ha and 60 kg K_2O/ha [23]. The amount was scaled down accordingly to per plant basis whereas the rates of compost used were based on 15 t ha^{-1} rate and which was also scaled down to per plant basis.

Table 1: Treatments applied for incubation study

Treatments	Soil	Amount of compost used	Compost type
		------- g -------	
T0	400	-nil-	Negative control
T1	400	27	Paddy husk compost without microbe
T2	400	27	Paddy husk compost with microbe CH2
T3	400	27	Paddy husk compost with microbe CH5
T4	400	27	Paddy husk compost with microbe CH9
T5	400	27	Paddy husk compost with mix microbe CH2 + CH5
T6	400	27	Paddy husk compost with mix microbe CH5 + CH9
T7	400	27	Paddy husk compost with mix microbe CH2+ CH9
T8	400	27	Paddy husk compost with mix microbe CH2 + CH5 + CH9
T9	400	27	Paddy Husk compost with chicken manure
T10	400	27	Organic fertilizer
T11	400	-nil-	Standard fertilizer

Note: NIL (*) indicates Not in list

2.4 Characterization of Soil before and after Incubation Study

Soil samples were characterized for physical and chemical properties before and after the incubation period. Soil pH in water was determined in a 1:2.5 (soil: distilled water) ratio using a digital pH meter (Eutech instruments) [29]. Electrical conductivity (EC) of the compost was determined using an Electrical Conductivity Meter (Mettler Toledo SevenEasy[TM] Conductivity Meter S30, New Zealand). Soil total carbon was calculated as 58% of the organic matter determined using loss of weight from the ignition method [7]. Exchangeable cations were extracted with 1 M NH_4OAc, pH 7.0 using the leaching method by Cottenie (1980) [9], and determined using the Atomic Absorption Spectrometer (AAnalyst 800, Perkin Elmer Instruments, Norwalk, CT). Total N was determined using Kjeldahl method [34]. Soil total P was extracted using the aqua regia method [3] and soil available P was extracted using Mehlich No.1 Double Acid method [21]. Total P and available P were determined using the UV Spectrometer (Lambda 25 uv/vis spectrometer Perkin Elmer) after the blue colour developed [24].

2.5 Statistical Analysis

Analysis of variance (ANOVA) was used to test treatment effects whereas treatment means were compared using Tukey's Test. The Statistical Analysis Software suite version 9.4 was used for the statistical analysis (SAS, 2013).

3. Results and discussion

The result showed that there was significant effect of incubation time on soil pH as depicted in Table 2. A significant increase in soil pH was detected when the compost was incubated for 30 days in comparison to those incubated for 60 and 90 days (Figure 1). Higher pH was due to the release of the humic acid content from the paddy husk compost [5]. This finding aligned to that reported by Njoku et al. (2017) [27], where rice husk compost increased exchangeable bases such as K^+, Mg^+ and Ca^{2+} which also affecting the pH of the soil. A significant decrease in soil pH was observed during 60 and 90 days as continual weathering of the parental soil triggered the release of more acid elements such as Al and Fe which are dissociated to increase in pH [35]. Furthermore, the application of organic matter led to an increase in microbial activity, leading to production of more hydrogen ions and increased acidity [26]. The release of organic acids from the rice husk compost also contributed to significant drop in soil pH at days 60 and 90.

Table 2: Mean square values of analysis of variance (ANOVA) to evaluate the effects of treatments and incubation time on soil pH, EC, total C, total N, total P, available P, exchangeable K, exchangeable Mg, and exchangeable Ca

Source of variations	**Degree of Freedom**	pH	EC	Total C	Total N	Total P	Available P	K	Mg	Ca
Time	2	42.51*	117425.60*	0.15	0.0004*	568099.78*	3789.38*	9.58*	14.52*	0.002*
Treatments	11	1.14*	55945.26*	6.60*	0.0011*	150214.11*	4053.90*	3.80*	2.48*	0.041*
Time*Treatments	22	0.50*	2749.71*	0.09	0.0001*	21767.20*	309.77*	0.47*	1.15*	0.002*
Error	53									

Note: Asterisks (*) indicates significant at $P \leq 0.05$

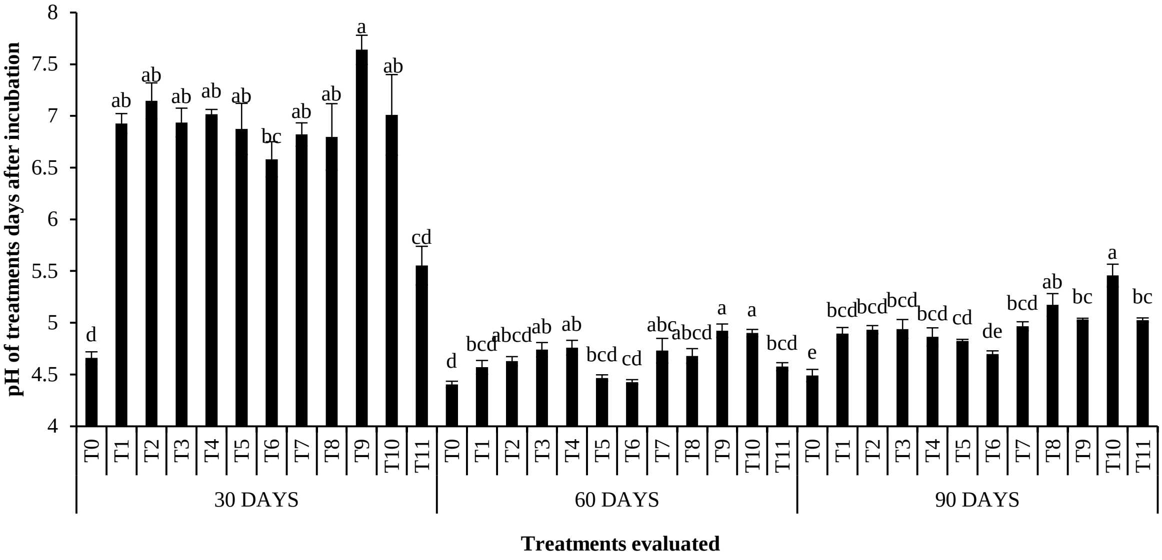

Fig. 1: pH of soil incubated at 30, 60 and 90 days. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

Adding compost as amendment into the soil also influence soil pH (Table 2). As indicated in Figure 1, soil amended with composted paddy husk (T1, T2, T4, T5, T6, T7, T8, and T9) and T10 increases soil pH when compared to T0 and T11 without any compost. This concurred to a previous study using pineapple leaves as compost [6]. In addition, the interaction between incubation time and incubated treatments further significantly contributed to higher pH as seen during the first 30 days of incubation (Table 2). As mentioned previously, the increase in pH was mainly due to the composting effect of organic matter [14] in T2, T3, T4, T5, T6, T7, T8, T9, and T10 as opposed to treatments T0 and T11 without any application of organic matter. Soil amended with paddy husk compost, with and without microbe, failed to show any significant difference in pH when compared to soil amended with organic fertilizer and chicken manure.

Increasing incubation period generally showed significant decreased in pH and the value remain similar until 90 days. At 60 days of incubation, T2, T3, T4, T7, T8 were able to retain high soil pH, similar to T9 (soil + chicken manure) and T10 (soil + organic fertilizer). Interestingly, T8 (paddy husk treated with CH2, CH5 and CH9 bacteria) was still able to maintain highest soil pH after 90 days of incubation, similar to T10. However, the pH values obtained were slightly lower than those reported by Trupiano et al. (2017) [38], on composts added with soil-beneficial bacteria (range pH6 to 7) and fungi (pH5.5 to 8) for optimal growth condition. However, the soil pH of paddy husk compost (with and without microbial treatment) is within this optimal growth values when incubated for 30 days thus can be used as an alternative to usual compost of chicken manure and organic fertilizer, aside from pineapple leaves and water hyacinth composts [6, 13].

Soil EC is an important indicator of soil health as it is related to the soil nutrient availability, soil texture and available water capacity. Soil EC affects crop yields, crop suitability and activity of soil microorganisms. Incubation time significantly affected soil EC (Table 2) but increased in soil EC was greater after 30-days of incubation, in comparison to 60 and 90 days incubation period with nearly similar results. Meanwhile, soil EC for T0 was always significantly lower when compared to other treatments for all incubation periods (Figure 2).

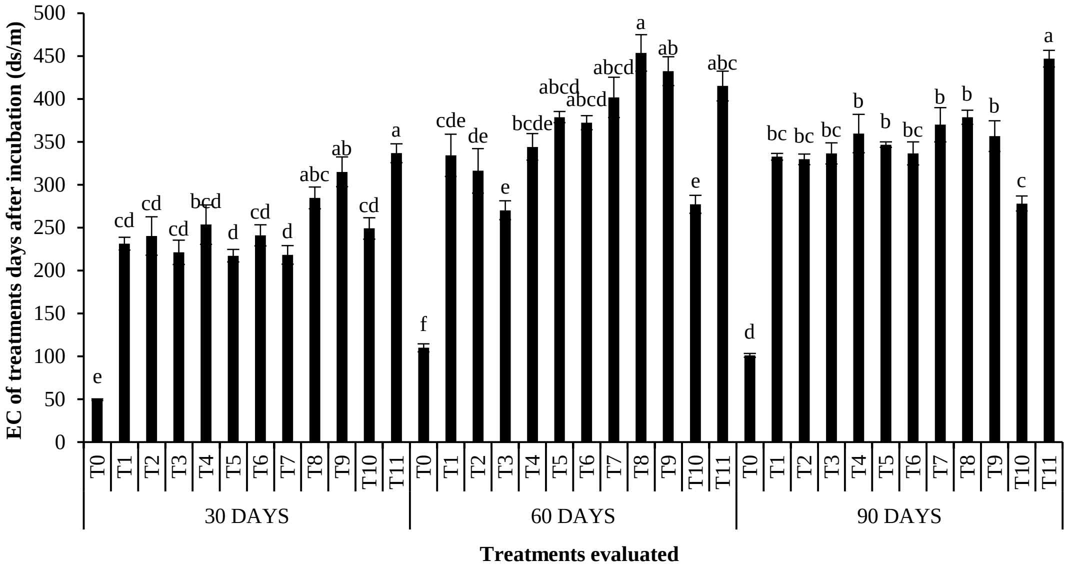

Fig. 2: Electrical conductivity of soils incubated at 30, 60 and 90 days. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

The results also indicated that soil alone contributed a small amount of salt (T0) as compared to treatments of rice husk compost, organic and chemical fertilizers (Figure 2). However, this findings contradicted previous study where vegetable waste, bone meal, saw dust and slaughter house waste was used as compost mixture [11]. Interestingly, T8 was able to increase soil EC like that of T9 and T11 (positive control). This showed that T8 (paddy husk with CH2, CH5 and CH9 microbes) may has the same capability to increase soil EC similar to organic chicken manure and higher than T1 which was without any microbe. At 90 days of incubation, all treatments with paddy husk were still able to increase soil EC but not as high as T11 (positive control). This result suggested that soil treated with paddy husk composts can increase soil EC at the same level of T11 up to a period of two months. However, the addition of paddy husk with and without lignocellulolytic microbe generally failed to show any significant difference in soil EC at 60 and 90 days of incubation.

Other studies have reported that excess salts in soils can hinder plant growth due to soil-water imbalance [32]. In the present study, high soil EC showed that the ratio of soil and compost used may have contributed to the compost increasing plant nutrients availability. Under field conditions, where the volume of soil is greater, the value of soil EC based on applied compost can decline appreciably. Recent studies have shown that levels of salt can also increase due to cropping system, irrigation, and adopted land management practices [39]. Measurement of soil EC does not provide a direct measurement of specific ions or nutrient element in the soil [8]. However, it has been proven that soil EC correlates to the concentration of nitrates, potassium, sodium, chloride, sulphate, and ammonia [8]. In some acid soils, determination of soil EC is a convenient and economical method to estimate the amount of N available for plant growth [20].

The present study also identified that interaction between treatments and incubation time failed to affect soil total carbon (TC) (Table 2). No significant difference was detected in the amount of soil total C incubated for 30, 60, and 90 days which could be due to the high lignin content coupled with slow decomposition of the paddy husk [19]. However, there were significant differences among treatments for TC (Table 2). As seen in Figure 3, soil treated with paddy husk compost (T1, T2, T4, T5, T6, T7, T8, and T9) were significantly higher in TC than those of T0, T10, and T11 (Figure 3). The results also demonstrated no interaction between incubation time and treatments (Table 2).

Application of high amount of organic matter to soils can aid in increasing soil total carbon content [22] as evident in the findings of this study. Organic matter application on tropical acid soils is an important management practice to maintain sustainable agriculture productivity as soil organic matter helps in increasing soil nutrients. Soil organic matter levels increased in cultivated agriculture soils through the application of organic matter such as compost produced from biomass wastes [22].

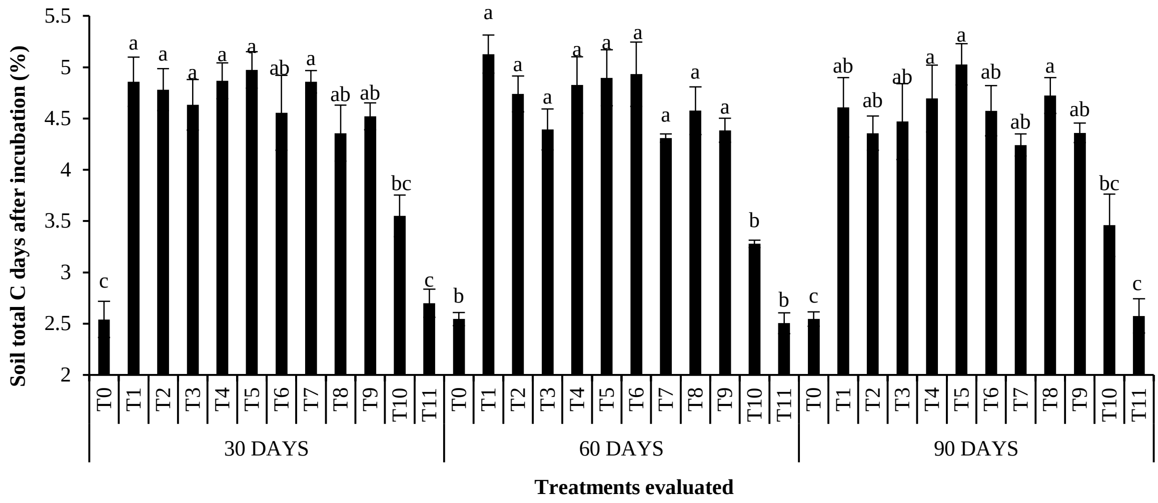

Fig. 3: Soil total carbon of treatments incubated at 30, 60 and 90 days. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

Increase in soil total carbon after paddy husk compost application also raised soil nutrients availability. A significant effect of incubation time on N availability was observed as soil total N was significantly higher at 30 days of incubation compared with 60- and 90-days incubation period. Soil total N in T0, T1, T2, T3 and T4 was found to be significantly lower than those of T5, T6, T7, T8, T9, T10, and T11 (Figure 4). Interactions between incubation time and treatments showed similar patterns where higher soil total N were observed in T5, T6, T7, T8, T9, T10, and T11. The addition of paddy husk compost degraded with combination of lignocellulolytic microbes increased total available N in the soil after 30 days of incubation and maintain the high amount until 90 days. The use of paddy compost released available N as reported in other research using different source of compost [11]. Nevertheless, the total available N can further be improved with the addition of urea in the compost mixture [28].

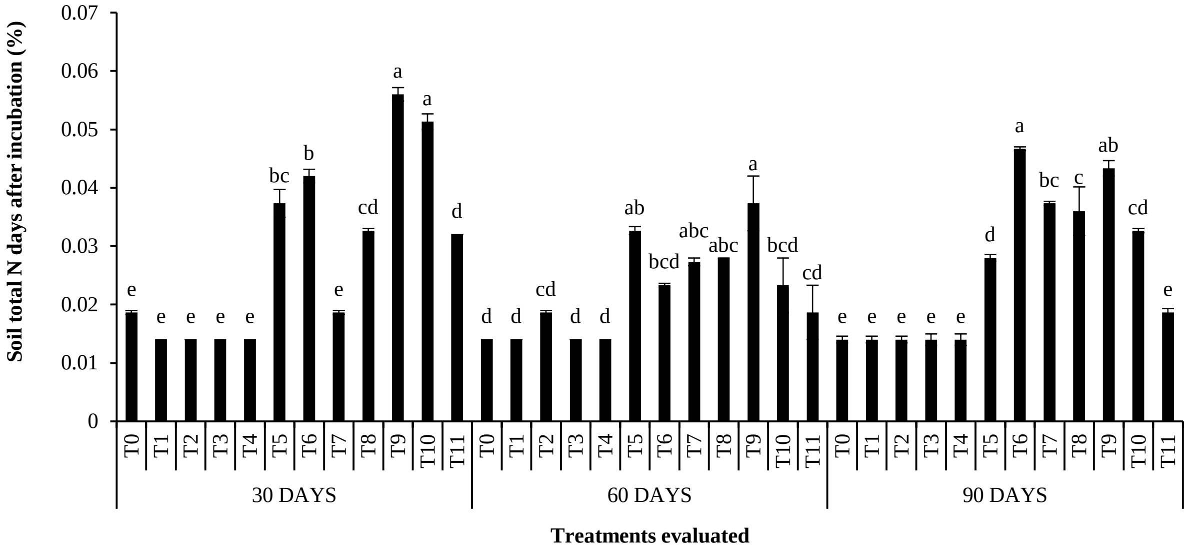

Fig. 4: Soil total nitrogen of treatments incubated at 30, 60 and 90 days. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

Other essential plant nutrients such as soil total P and available P were significantly affected by incubation time (Table 2). Soil total P at 30 days of incubation was lower compared to those of 60 and 90 days whereas available P at 30 days of incubation showed a reverse pattern (Figures 5 and 6). Soil total P in treatments with paddy husk compost (T1, T2, T3 and T4, T5, T6, T7, T8, and T9) were generally higher than T0 and T11 (Figures 5). After 30 days of incubation, the soil total P in T1, T5, T4, T6 contained similar amount of total phosphorus, similar to T9 (paddy husk with chicken manure) and T10 (organic fertilizer). The total phosphorus amount increased after the 60 days incubation period for all treatments but T2 and T6 were not significantly different than T9. Lower soil pH at 30 days incubation period may have impeded the mineralization of organic phosphorus thus causing the accumulation of total phosphorus. This was evident in the present study where the total phosphorus remained high after 90 days of incubation.

The amount of available P in treatments with paddy husk compost (T1, T2, T3 and T4, T5, T6, T7, T8, and T9) were found to be higher than T0, T10, and T11 (Figure 6). The paddy husk mixed with chicken manure led to high soil available P values during all three samplings conducted. Among treatments provided with digested paddy husk, T5 showed highest available P after 30 and 60 days similar to the chicken manure treatment. However, the amount of available P decreased after 90 days of incubation but was still higher than the negative control, organic and standard fertilizer treatments.

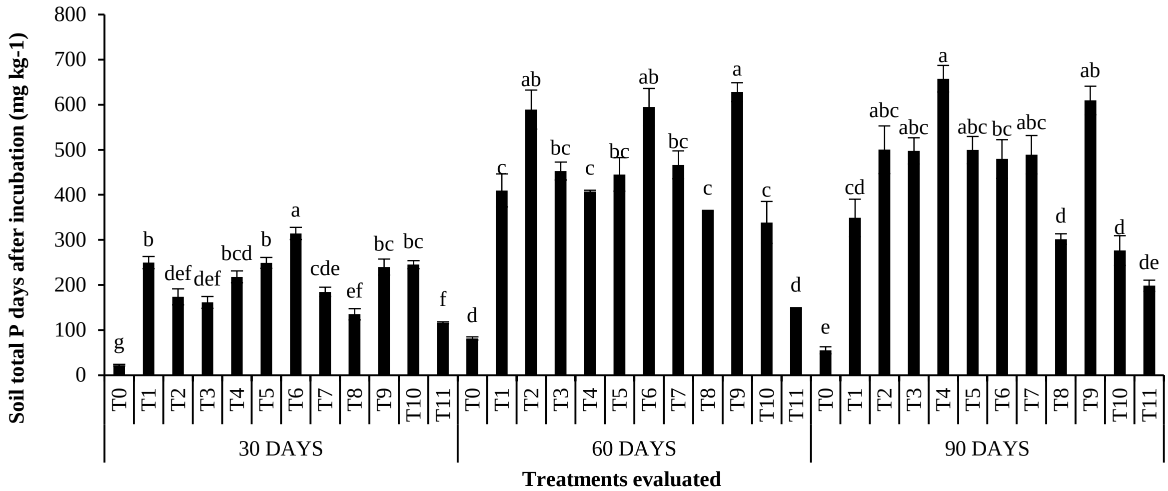

Fig. 5: Soil total phosphorus of treatments incubated at 30, 60 and 90 days. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at *P* ≤ 0.05. Bars represent the mean values ± SE.

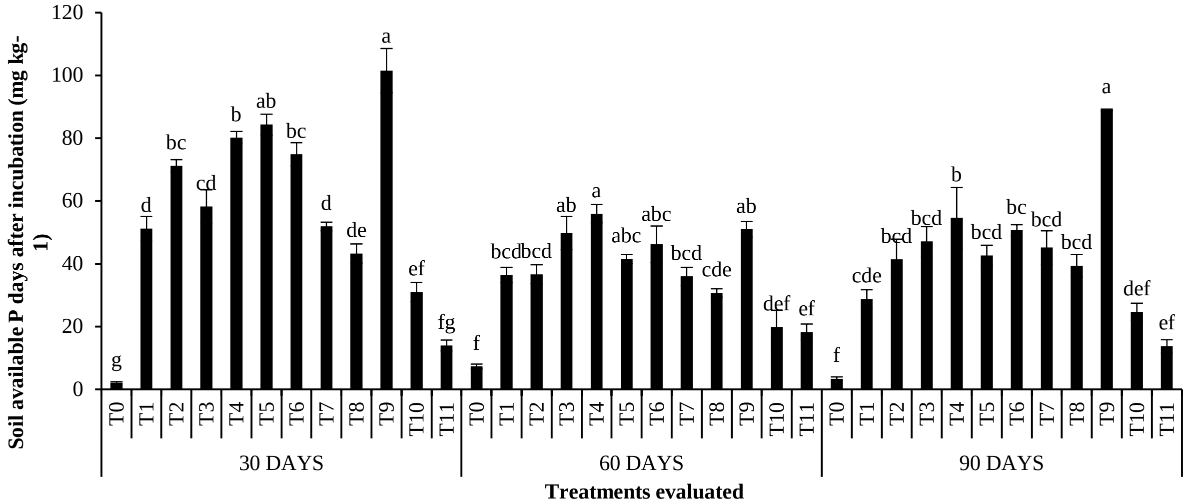

Fig. 6: Soil available phosphorus of treatments incubated at 30, 60 and 90 days. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at *P* ≤ 0.05. Bars represent the mean values ± SE.

Incubation time showed significant effect of soil exchangeable K, Mg and Ca (Table 2). Exchangeable K was significantly higher at 30 days after incubation while exchangeable Mg was higher at 90 days after incubation (Figures 7 and 8). These observations were quite reverse trends to that of exchangeable Ca where T9 and T10 showed significantly higher Ca at 30, 60, and 90 days (Figure 9). The present results were indicative that the soil exchangeable Ca was unaffected by the application of paddy husk compost. No significant difference in soil exchangeable cations was identified between paddy husk with and without microbial degradation treatments.

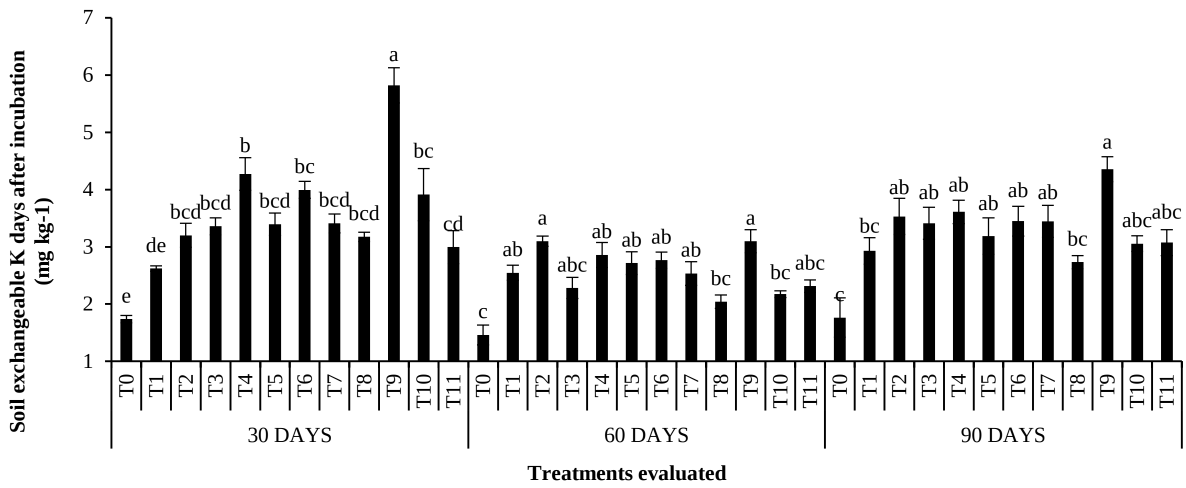

Fig. 7: Soil exchangeable potassium of treatments incubated at 30, 60 and 90 days. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

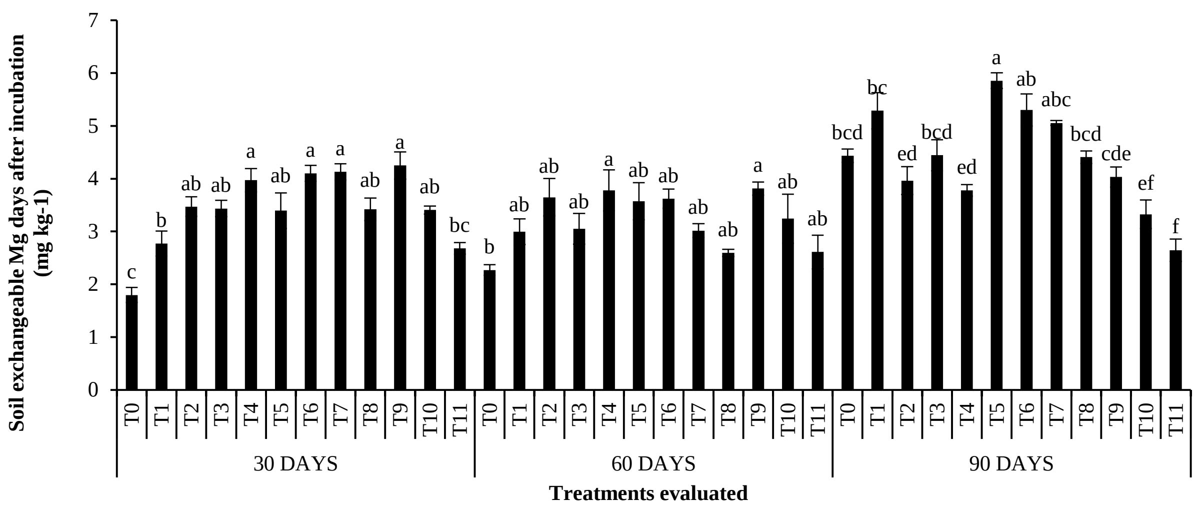

Fig. 8: Soil exchangeable magnesium of treatments incubated at 30, 60 and 90 days. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

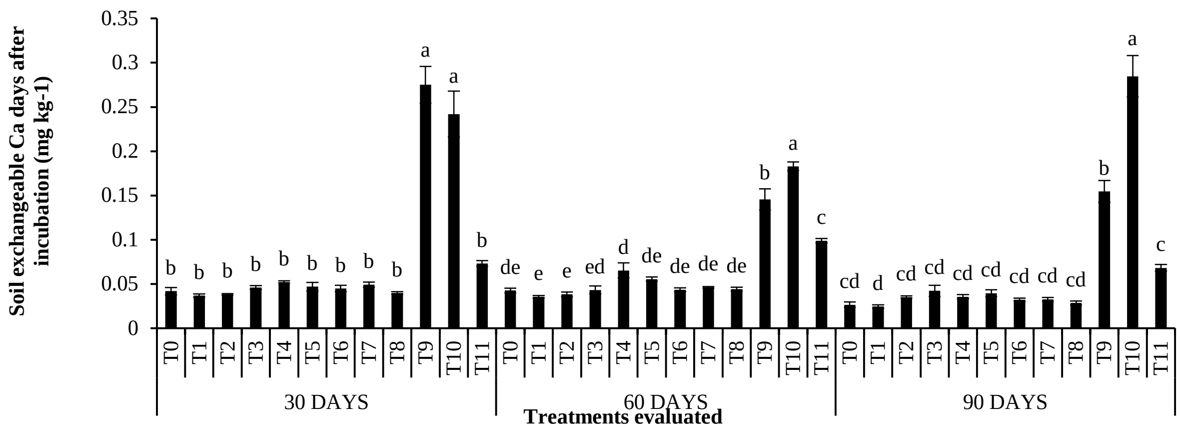

Fig. 9: Soil exchangeable calcium of treatments incubated at 30, 60 and 90 days. Means with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Bars represent the mean values ± SE.

The application of organic compost can enhance sustainable soil management by increasing soil fertility and crop yield. Chemical properties of compost such as C:N ratio, pH and EC depends largely on the type of organic feed stocks and compost processing conditions [18]. An appropriate mixture of organic inputs, humus and nutrient-rich substrates produces a compost rich in macro and micronutrients. Addition of compost to tropical acid soil will not only reduce soil acidity but supply soil with valuable plant nutrients such as N, P, K, Mg, and Ca as well as a variety of essential trace elements [33]. In the present study, soils treated with paddy husk compost (digested with mixture of lignocellulolytic microbe) elevated the concentrations of macro- and micronutrients in comparison to the control. Thus, compost can be used as a substitute for commercial mineral fertilizers in agriculture as reported in sunflower and blackgram [10, 37].

Brown and Cotton (2011) [4], indicated that compost amended soils contain comparable concentrations of plant available nutrients when compared to conventionally fertilized soils. The existence of various binders at different intensity within the organic matrix resulted in partial immobilization of nutrients [36]. Compost gradually releases plant nutrients as opposed to the application of chemical fertilizers [31]. Furthermore, amending tropical acid soil with paddy husk compost can slowdown the leaching process of valuable plant nutrients compared to soluble mineral fertilizers [17].

4. Conclusion

Soil pH, EC, total N and P, available P, exchangeable K, Mg, and Ca interacted positively with incubation time and treatments. Soil pH decreased with incubation period while soil total P and exchangeable Mg showed reverse trends. Soil pH ranged from slightly acidic to neutral within the first 30 days of incubation indicating a high detoxification potential of Al and Fe as result of paddy husk compost application. The application of organic amendments from paddy husk improved soil carbon content, reduced soil acidity, and increased the availability of essential plant nutrients. Thus, paddy husk degraded using mixture of lignocellulolytic bacteria from gut termite compost showed potential to be used as an organic fertilizer to supply sufficient nutrients for agricultural crops.

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