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Amending Christmas Island Rock Phosphate with Mixture of Sugarcane and Soybean Bagasse Compost to Improve Soil Phosphorous Availability and Phosphorus Uptake in Maize (*Zea mays L.*) Cultivated in Tropics

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Abstract

In tropical acid soils, phosphorus (P) is often limited because the soluble form of inorganic P in the soil is fixed by aluminium (Al) and iron (Fe), thus reduces the P availability in the soil. Liming and excess application of phosphate fertilizers are the common practices to mitigate this problem. However, these practices are not economically viable and environment-friendly. Therefore, this study aimed to (i) characterize the soil samples, and mixture of sugarcane and soybean bagasse compost used in this study; and (ii) determine the soil P availability, P uptake, and dry matter production of Zea mays L. upon amending Christmas Island rock phosphate with mixture of sugarcane and soy bean bagasse compost. A pot experiment was conducted in a net house at Universiti Malaysia Kelantan Jeli Campus. Maize (hybrid sweet corn 801 variety) was used as a test crop. Treatments with compost showed significant increase in the soil pH, and significant reduction of exchangeable Al and Fe in the soils compared to treatments with soil only and soil applied with chemical fertilizers only. There was also significant increase in the P uptake and dry matter production (leaves, stems, and roots) of Zea mays L. in treatments applied with compost. This was due to reduction of soil exchangeable Al and Fe concentrations as a result of an increase in soil pH, thus reduced the Al toxicity in the maize root zone, and increased the P availability in the soil. As a conclusion, compost derived from mixture of sugarcane and soybean bagasse increased soil pH to near neutral such that the soil's exchangeable Al and Fe which normally fix soil P were reduced. As a result, P availability in the soil increased. Additionally, the organic amendment also improved Zea mays L. dry matter production and P uptake in tropical acid soil.

Keywords: *Soil phosphorus fixation, Sugarcane and soybean bagasse compost, Hybrid sweet corn 801 variety, Phosphorus uptake, Dry matter production, Christmas Island rock phosphate*

Introduction

Phosphorus (P) is one of the most essential macronutrient that is needed by plant. It is the 4th abundant nutrient in plant tissues and also an essential component of adenosine triphosphate (ATP) [1]. Adenosine triphosphate involves in most biochemical process in plant such as energy transfer, extraction of nutrient of the soil, development of cell and reproductive structures of plant, and also play essential role in DNA formation. Therefore, insufficient amount of P supply may lead to several deficiency symptoms in plants such stunted plant growth, development of purple or reddish discoloration and reducing in crop yield [2]. However, too much supply of P sometimes may be detrimental to the plant and the environment. The losses of P from soils with high P content by runoff or leaching may lead freshwater contamination, if the run-off water carried away to the nearby water resources. As the level of P increases in water, the condition triggers and favors the development algae bloom. This condition is known as eutrophication. The algae bloom will produce a layer on the water surface that prevents the oxygen to penetrate the water. This situation causes the depletion of oxygen in the water thus cause death to aquatic animals and plants [3].

In tropical soils, P is the most limiting nutrient due to the challenge in P management. The most problem arise due to P fixation that reduces the P availability in the soil. Phosphorus fixation occurs due to sorption and desorption process in the soil. This process occurs due to the large amount of sesquioxide elements such as Al and Fe in the soil that chelate P tightly thus inhibit the P for plant uptake. This process usually occur in the soil with low pH as it contain more cations such as , and which favor the strong binding with P ions [4]. The most common methods of resolving this problem are by continuous supplying the P fertilizer into the soil and lime the soil to increase the soil pH. However, continuous liming and over-fertilization are not economically viable and environment-friendly [3].

In recent times, many studies have focused on applying organic materials to improve and amend the soil fertility problem [5,6,7]. The organic materials that are commonly being used are animal wastes and green manures. Organic materials help to improve soil P recovery by minimizing the sorption site and improving the soil chemical properties in natural way. Besides, the usage of organic materials also help to balance the nutrient supply in plant and keep the plant healthy thus increase the dry mass production. In addition, applying compost also may help to solve soil problem such as acidic soil and leaching [5,6,7]. Compost is a product of utilized wastes that can be added to the soil as soil improver. Based on several studies conducted, the applications of compost are able to solve the problem regarding P deficiency by supplying organic matter to the soil [8]. The organic matter content being supplied may increase the P availability in four ways: a) forming complexes with the organic P which increases the uptake by plant, b) displacing the P loss by sorption, c) producing humus that may coat Al and Fe oxide which involve as main factors in P sorption and d) supplying the P through the mineralization process. In addition, compost is alkaline in nature. Supplying alkaline medium to the acidic soil will increase the soil pH to between 6 and 7, which is ideal for soil P to become available [9].

Sugarcane bagasse is one of agriculture source of wastes which are produced in large quantity in Malaysia aside from oil palm and pineapple wastes. Sugarcane bagasse is the most abundant wastes product produces by sugar industry (Food and Agriculture Organization of The United Nation (FAO) [10]. This residue is commonly being produced after the extraction of sugar solution from the sugarcane. In soy bean production sector, the large quantity of wastes also being generated due to the high production of soy bean beverage in Malaysia. Impropriate way of wastes disposal may lead to high environmental risk such as air and water pollution to the environment [11]. Therefore, converting these wastes into value added product has been seen as beneficial way to conserve the environment. Therefore, composting the mixture of sugarcane bagasse and soil bean bagasse is a way that can help to sustain the environment by utilizing wastes into a good use as well as solving the P-fixation in acid soils could be novel.

Although there are a lot of studies focusing on the supplying organic material such as animal manure, green manure, and compost as soil remedies to reduce the soil problem especially the P fixation in tropical acid soil, there is a dearth information on the use of mixture of sugarcane and soybean bagasse compost with large surface area and high negative change to minimize P fixation in soils. This process can fundamentally enable ions term chelation of Al and Fe by compost instead of P. This process is possible because functional groups such as carboxyl and phenols of humic substances such as humic acid, fulvic acid and humin in the compost surface are known to be negatively charged in alkaline condition which will chelate the Al and Fe. This is so because the functional groups have high affinity for Al and Fe. Hence, P will become readily available for plant.

Therefore, this study aimed to: 1) characterize the soil samples and mixture of sugarcane and soy bean bagasse compost used in this study; and 2) determine the soil P availability, P uptake and dry matter production of *Zea mays* L. by amending Christmas Island rock phosphate with mixture of sugarcane and soy bean bagasse compost.

MATERIALS AND METHODS

Soil and Compost Characterization

Prior to the pot experiment, soil samples (Rengam Series, *Typic Paleudult*) from uncultivated land were collected at 0-20 cm using a soil auger. The sampling area was 50 m x 50 m. The soil were air-dried, ground and sieve to pass through a 2-mm and 5-mm sieve, respectively for laboratory analysis and pot experiment. Coring method was used to determine the soil bulk density [12]. The soil samples were analysed for pH and electrical conductivity (EC) using pH meter and EC meter [13]. Soil texture was determined using the hydrometer method [14]. Soil total N, total organic matter, and total C were determined using a CHNS analyser (TruSpec Micro Elemental Analyser (NCHS), LECO, USA). Soil total P was extracted using aqua regia extractant while available P was extracted by Mehlich No.1 double acid [15] after which the molybdenum blue method was used to determine the total P and available P contents [16]. Afterwards, C/N and C/P ratios were calculated. Soil exchangeable K, Ca, Mg, Na, and Fe were extracted using the Ammonium Acetate method after which K, Ca, Mg, Na, Cu, Zn, and Fe were determined using an Atomic Absorption Spectrophotometer (AAS) (PerkinElmer Pin AAcle 900F, USA) [17]. Exchangeable acidity and Al were determined titrimetrically using 0.01 M NaOH and 0.01 M HCl after being extracted by 1 M KCl, respectively as described by Rowell [18].

The mixture of sugarcane and soy bean bagasse compost used in this study was commercially produced and purchased. The compost was analysed for pH and EC [13], total organic matter, total C, and total N using a CHNS analyser (TruSpec Micro Elemental Analyser (NCHS), LECO, USA). Dry ashing method [19] was used to extract P and K from the compost. The extracts were analysed for K using AAS (PerkinElmer Pin AAcle 900F, USA) whereas P was determined using the molybdenum blue method [16]. C/N and C/P ratios of the compost were calculated using the total C, N, and P determined.

Pot Experiment Set Up and Experimental Design

A pot experiment was conducted in a net house at Universiti Malaysia Kelantan Jeli Campus. A total of 21 pots were filled with 7 kg of soil which have been sieved with 5-mm sieve. The test crop used in this pot experiment was *Zea mays* L (hybrid sweet corn 801 variety). As the cultivation of *Zea mays* L. was done in this pot experiment, each of the pots were supplied with N, P and K fertilizer to ensure the optimum growth of the plants. The fertilizers that were being applied are Urea (46% N), CIRP (30% P_2O_5) and Muriate of Potash (MOP) (60% K_2O) and each of them were being applied at 60 kg N ha^{-1} (130 kg Urea ha^{-1}), 60 kg P_2O_5 ha^{-1} (200 kg CIRP ha^{-1}) and 40 kg K_2O ha^{-1} (67 kg MOP ha^{-1}) rate based on the recommendation by Malaysia Agricultural Research and Development Institute (MARDI). However, the percentages of CIRP application amounts were different based on the listed in Table 1. The fertilizers were applied in two equal splits i.e., at 10 and 28 days after sowing (DAS). The mixture of sugarcane and soybean bagasse compost was applied at the rates of 10 t ha^{-1}. The experimental design of this study was completely randomized design (CRD) with 3 times replication. The pot experiment was stopped when the maize plants achieved tasseling stage, which is on 55 DAS.

Table 1. *List of treatments evaluated in the pot experiment.*

Treatment	Description
T0	Soil only
T1	Soil + 100% CIRP + 100% Urea + 100% MOP
T2	Soil + 100% CIRP + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost
T3	Soil + 75% CIRP + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost
T4	Soil + 50% CIRP + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost
T5	Soil + 25% CIRP + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost
T6	Soil + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost

Soil and Plant Tissue Analysis after Pot Experiment

The soil samples were collected during the tasselling stage, which is on 55 DAS. The soil samples were collected, air-dried, crushed and sieved using 2-mm sieve. After that, the soil samples were analysed for pH, soil EC, soil total

C, soil available P, soil exchangeable Al, and soil exchangeable acidity using the same procedure described previously in section 2.1. During 55 DAS, the plants in the pot experiment were harvested and partitioned into leaves, stem and root and separated at 55 DAS for plant tissues analysis. For plant tissue analysis, single dry ashing method was used in order to extract total the P in the plant tissues (roots, stems, and leaves) [15].

The procedure was similar to the aforementioned procedures in previous section. The concentration of P in roots, stems and leaves were multiplied by respective dry weight to obtain the amount of P uptake by maize plants.

Data Analyses

Statistical analysis of data such as analysis of variance (ANOVA) and comparisons of means was performed using SAS program version 9.2. The Analysis of Variance (ANOVA) was used to detect the treatment effects while the comparison of means was carried out using Tukey's HSD tests at $P < 0.05$.

Results and Discussion

Characterization of Soil Samples and Compost

The selected physico-chemical properties of Rengam series (*Typic Paleudult*) are presented in Table 2. The soil was a sandy loam and had a low pH of 4.8. The soil showed relatively high concentrations of Al and Fe due to low soil pH. The C/N and C/P ratios of the soil were 72.5 and 290.55, respectively. The high C/N and C/P ratio suggests the possibility of N and P immobilization in the soil. The total organic matter, C and N in the soil were relatively low due to the high percentage of sand which caused little capacity to hold these nutrients. Low soil available P could be attributed to the high concentration of Al and Fe in the soil.

The selected chemical properties of mixture of sugarcane and soybean bagasse compost are presented in Table 3. The C/N and C/P ratios of the compost were 7.44 and 22.82, respectively. These ratios suggest net mineralization of the organic amendments.

The near neutral pH of the compost (6.34) are particularly useful because they can raise the soil pH which is an important contribution to improve soil quality. The significant concentrations of EC present in the compost were correlated with the presence of K and Na.

Table 2. *Selected physico-chemical properties of Rengam.*

Property	Value Obtained
Bulk density (g cm^{-3})	0.98
Soil texture	Sand: 69.5% Silt: 13.5% Clay: 17% Sandy loam
pH (Water) Electrical conductivity (EC) (dS m^{-1})	4.80 0.03
Total organic matter (%)	1.36
Total C (%)	0.80
Total N (%)	0.08
Total P (ppm)	115.30
Available P (ppm)	4.20
C/N ratio	72.50
C/P ratio	290.50
CEC (cmol kg^{-1})	4.50
Exchangeable acidity (cmol kg^{-1})	9.00
Exchangeable Al (cmol kg^{-1})	0.20
Exchangeable K (ppm)	3,975.00
Exchangeable Ca (ppm)	34.98
Exchangeable Mg (ppm)	14.83
Exchangeable Na (ppm)	8.08
Exchangeable Cu (ppm)	0.03
Exchangeable Zn (ppm)	2.18
Extractable Fe (ppm)	60.17

Table 3. *Selected chemical properties of mixture of sugarcane and soybean bagasse compost.*

Property	Value Obtained
pH (Water) EC (dS m^{-1})	6.34 0.12
Total organic matter (%)	28.72
Total C (%)	16.66
Total N (%)	2.24
Total P (%)	0.73
Total K (%)	0.42
C/N ratio	7.44
C/P ratio	22.82

Effect of Treatments on Selected Soil Chemical Properties and Soil P Availability after Pot Experiment

The selected chemical properties of soil after the pot experiment are shown in Table 4. Treatments treated with mixture of chemical fertilizer with compost (T2, T3, T4, T5, and T6) showed significant increase in soil pH and EC compared to the soil only (T0) and soil with chemical fertilizer only (T1) (Table 4). This was due to the initial pH of the compost and basic cations such as K, Ca, Mg, and Na of the compost. The rapid proton (H^+) exchange between the soil and the organic amendments used in this study also contributed to the increase of the soil pH [20,21]. The increase in the soil pH also relates to further decomposition of the organic amendments and this might have further solubilised the inherent K, Ca, Mg, and Na contents of the organic amendments to the soil, thus the increases in soil pH. Formation of phenolic, humic-like materials during the initial decomposition of the organic amendments [22] leads to formation of organic anions which consume protons in the soil, thus causing soil pH to increase [23]. Besides, the release of OH^- due to specific adsorption of humic material and organic acids produced by the biochar and pineapple leaf residues compost onto the hydrous surfaces of Al and Fe oxides by ligand exchange also responsible for the increased in soil pH [24].

At 55 DAS, treatments with mixture of sugarcane and soybean bagasse compost (T2, T3, T4, T5, and T6) reduced exchangeable acidity, exchangeable Al, and exchangeable Fe compared with T0 (soil only) and T1 (soil + 100% CIRP + 100% Urea + 100% MOP) (Table 4). Soil exchangeable Al was significantly lower in the soils with the compost (T2, T3, T4, T5, and T6) (Table 4). The decrease in soil exchangeable acidity, exchangeable Al, and exchangeable Fe (Table 4) partly is related to the increase in soil pH. Several authors have reported increase in soil pH as exchangeable Al decreases [22,25,26]. As the soil pH increased, exchangeable and soluble Al and Fe precipitated as insoluble Al and Fe hydroxides on the negatively charged functional groups of the organic amendments' surfaces. This reaction normally decreases Al and Fe contents in soil [27]. Additionally, the use of compost also resulted in significant increase in soil total C (Table 4). These results are in agreement with those of Meeuwissen [28] and Kaschl et al. [29] who also found positive correlation between the addition of compost and soil total C contents.

Table 4. *Selected chemical properties of soil samples after pot experiment.*

Treatment	Soil pH	Soil EC (dS m^{-1})	Soil exchangeable acidity (cmol kg^{-1})	Soil exchangeable Al (cmol kg^{-1})	Soil exchangeable Fe (ppm)	Soil total C (%)
T0	3.69±0.2c	0.03±0.01b	9.04±0.36d	0.20±0.03d	116.87±5d	0.7±0.10a
T1	3.99±0.1c	0.04±0.01b	8.89±0.35c	0.16±0.02c	96.5±3c	0.90±0.20a
T2	5.25±0.1a	0.12±008a	1.86±0.80a	0.06±0.04a	58.8±3a	1.75±0.20a
T3	5.04±0.1a	0.11±0.02a	1.70±0.22a	0.05±0.02a	64.9±3ab	1.50±0.50a
T4	4.78±0.2b	0.10±0.06a	2.90±0.53b	0.10±0.02b	65.4±4ab	1.30±0.30b
T5	4.86±0.2b	0.09±0.03a	2.85±0.08b	0.10±0.02b	75.6±4b	1.0±0.50b
T6	4.73±0.1b	0.10±0.02a	2.53±0.08b	0.12±0.03b	70.4±5b	1.10±0.45b

Note: Means within column with different letter(s) indicate significant difference between treatments by using

Tukey's HSD test at P ≤ 0.05.

At the end of pot experiment, treatments with mixture of sugarcane and soybean bagasse compost (T2, T3, T4, T5, and T6) increased soil available P concentrations compared with T0 (soil only) and T1 (soil + 100% CIRP + 100% Urea + 100% MOP) (Table 5). As a result of the increase in the soil pH at 55 DAS, the negative charges on the surface area of compost increased, thus the increased affinity for Al and Fe ions instead of P. This led to the increase in the soil available P concentrations. An increase in the soil pH under T2 and T3 (Table 5) generally favors P mobilization and could also stimulate the mineralization of organic P, thus increased the soil available P [30].

Table 5. *Effect of treatments on soil available P after pot experiment.*

Treatment	Soil available P (ppm)
T0	4.00±0.14c
T1	5.20±3.30c
T2	169.90±20.00a
T3	163.92±11.80a
T4	155.63±21.23a
T5	84.00±14.22b
T6	53.10±10.12b

Note: Means within column with different letter(s) indicate significant difference between treatments by using Tukey's HSD test at P ≤ 0.05.

Dry Mass Production and Total Phosphorus Uptake by Zea Mays L. after Pot Experiment

There were significant differences ($P \leq 0.05$) in leaves, stems, and roots dry weights of maize at the end of pot trial. The treatments with chemical fertilizer and compost (T2, T3, T4, T5, and T6) showed a significant increase in the dry mass production of leaves, stems and roots (Figure 1). This finding is consistent with the results obtained in several studies [6,7,31]. The dry weight of leaves, stems, and roots were not significantly different in T2 (soil + 100% CIRP + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost), T3 (soil + 75% CIRP + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost), T4 (soil + 50% CIRP + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost), T5 (soil + 25% CIRP + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost), and T6 (soil + 100% Urea + 100% MOP + 10 t ha^{-1} mixture of sugarcane and soybean bagasse compost) (Figure 1). The dry weigh of leaves, stems, and roots of T0 (soil only) and T1 (soil + 100% CIRP + 100% Urea + 100% MOP) were significantly lower compared with T2, T3, T4, T5, and T6 (Figure 1). This suggests that the positive effect of combining mixture of sugarcane and soybean bagasse compost and inorganic fertilizers on growth of maize plants.

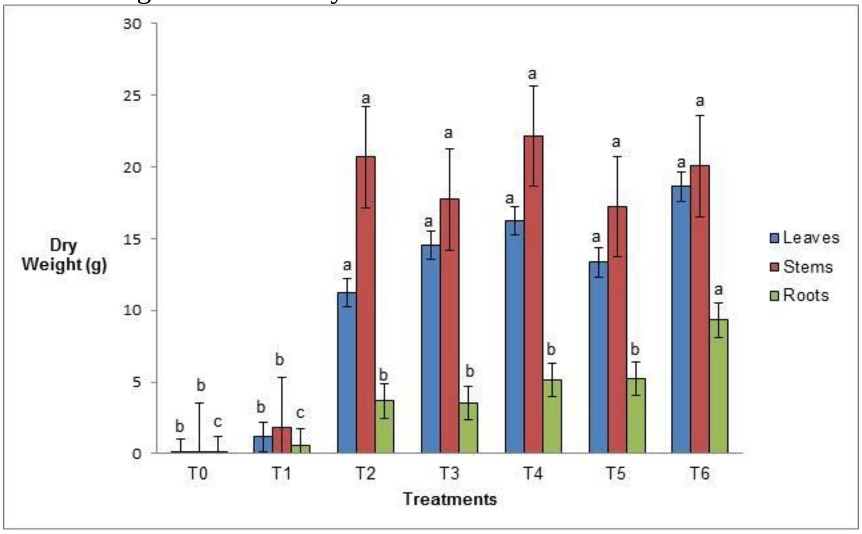

Figure 1. *Effect of treatments on the maize dry weight of leaves, stems, and roots after pot experiment.*

Note: *Means within column with different letter(s) indicate significant difference between treatments by using Tukey's HSD test at* $P \leq 0.05$.

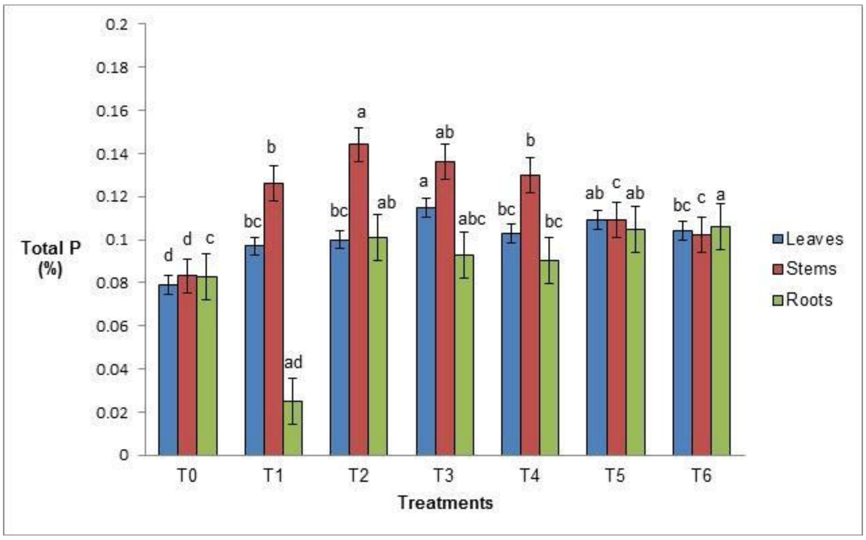

Figure 2. *Effect of treatments on the total P in maize leaves, stems, and roots after pot experiment.*

Note: Means within column with different letter(s) indicate significant difference between treatments by using Tukey's HSD test at $P \leq 0.05$.

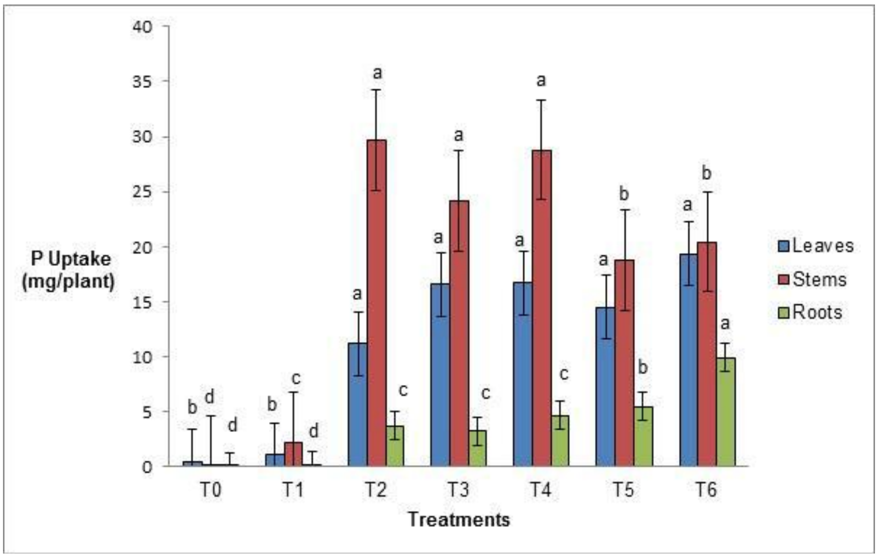

Figure 3. *Effect of treatments on the P uptake in maize leaves, stems, and roots after pot experiment.*

Note: *Means within column with different letter(s) indicate significant difference between treatments by using Tukey's HSD test at* $P \leq 0.05$.

In addition, the treatments with inorganic fertilizer and compost (T2, T3, T4, T5, and T6) also increased the total P concentration in leaves, stems, and roots, and P uptake in maize (Figures 2 and 3). This indicates that there was an increase in the available P in the soil (Table 5). Increasing the soil pH and reduction of exchangeable Al in the soil (Table 4) also contributed to the increase of P uptake. This was due to the improved root growth where Al toxicity was alleviated, thus allowing a greater volume of soil for root elongation and growth. The supply of organic material by compost is said to aid the increase in microorganism efficiency by providing them with suitable condition. The soil microorganism helps in the soil mineralization process by converting organic P into an available form of phosphate namely orthophosphate for plant uptake [2]. Apart from mineralization process, another factor contributed to the increase in plant tissues, total P and P uptake after application of compost in T2, T3, T4, T5, and T6 was the chelation of Al and Fe which released the available P for plant uptake. In acidic soil, most of the P are fixed by Al and Fe which also known as sesquioxides by forming a strong bond between them.

CONCLUSIONS

The results of the present study suggest that amending inorganic fertilizer with mixture of sugarcane and soybean bagasse compost can increase the soil pH to near neutral such that the soil's exchangeable Al and extractable Fe which normally fix soil P are reduced. As a result, P availability in the soil increased. Additionally, the mixture of sugarcane and soybean bagasse compost can also improve the dry matter (leaves, stems, and roots) production of *Zea mays* L., total P content and P uptake in leaves, stems, and roots of *Zea mays* L. cultivated in the tropics.

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CONFLICT OF INTEREST

All authors declare no conflicts of interest in this paper.

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