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Research article

Effects of incubation period and Christmas Island rock phosphate with different rate of rice straw compost on phosphorus availability in acid soil

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Abstract: Phosphorus (P) availability is limited in tropical acid soil due to fixation of soluble inorganic P by aluminium (Al) and iron (Fe). Liming is one of the common ways to overcome this problem. However, this practice is not economical. The aim of this study was to evaluate the effects of laboratory incubation period and different rates of rice straw compost on the soil P availability. During the incubation study, Christmas Island rock phosphate (CIRP) fertilizer was amended with different rates of rice straw compost (5, 10, 15, and 20 t ha^{-1}). Treatments were incubated in the laboratory for 30, 60, and 90 days. Application of rice straw compost with CIRP significantly increased soil available P at 30, 60, and 90 days of incubation, respectively. This implies rice straw compost plays an important role on soil P availability by decreasing the P adsorption due to the competing adsorption sites by organic anion and dissolving the mineral associated P by low-molecular-weight organic acids. Besides, rice straw compost also increased the soil pH, and, at the same time, reduced exchangeable acidity, exchangeable Al and Fe. As the soil pH increased, the compost effectively fixed the Al and Fe in the soil instead of P, thus increasing the P availability in the soil. However, there was no significant increase/loss of available P when the incubation time increases under treatments with rice straw compost. This implies the effectiveness of rice straw compost in minimizing the loss of P due to P fixation in soil and slow microbially mediated mineralization of soil organic P to inorganic P as incubation time increases. The findings suggest that the application of rice straw compost altered soil chemical properties in a way that enhanced the availability of P in the Rengam acidic soil.

Keywords: rice straw compost; Christmas Island rock phosphate; soil phosphorus availability; incubation periods, Rengam series acidic soil

1. Introduction

Phosphorus (P) is one of the important soil macronutrients that is required by plants for optimum growth. It is responsible for cell division and protein synthesis in plants [1,11,17]. Soil available P in the tropics especially Malaysia is relatively low because of P fixation by aluminium (Al) and iron (Fe) which leads to low in yield production in agriculture. Generally, adsorption of P by plants is poor due to fixation by Al and Fe, and adsorption of P by clay minerals [2]. Hence, liming is one of the common ways to overcome this problem. However, Thomas et al. [3] pointed that liming only overcome the acid soils' symptom rather than the main chemistry aspect behind it. Thus, this practice is not economical and not environment-friendly.

Rice straw is an abundant agricultural by product which has a great potential for use in compost production [28]. These rice straws are usually being disposed through open burning but burning of these wastes brings negative effects to the natural environment. Burning causes haze and air pollution [4,5], thus it is an unsustainable waste management practice [6]. For this reason, composting is a green technology that can convert agriculture wastes such as rice straw into value added materials for sustainable farming. According to Lu et al. [7] and Zeng et al. [8], composting is able to produce an organic amendment that can be used for soil remediation, improving the soil condition and fertility.

Application of compost as a soil amendment is eco-friendly and could be effective in reducing P fixation problem [4]. Therefore, through composting, one is able to produce an economical and high quality organic amendment with a large surface area filled with negative charges to minimize P fixation in tropical acid soils. Besides, Ohno and Amirbahman [9] and Ohno et al. [10] concluded that organic amendments application improved soil fertility especially P via increasing the soil pH to near neutral, thus increasing the P availability in the tropics.

Many researches have been done in order to discover effective techniques to improve P availability by using either inorganic or organic phosphate in order to conserve or improve soil P. However, there is a little information on the use of compost with a large surface area and high degree of negative charges which could minimize P fixation in tropical acid soils. This is possible due to the fact that organic amendment with large surface of negative charges has high affinity for Al and Fe. Hence, P will become readily available for efficient plants uptake. Therefore, the aim of this study was to evaluate the effect of application of compost produced from rice straw and goat manure slurry on improving P availability in tropical acid soil via laboratory incubation study.

2. Materials and methods

2.1. Soil sampling and characterization

The experiment was carried out at University Malaysia Kelantan Jeli Campus, Malaysia. Soil samples were sampled at 0−40 cm from a grassland which has not been cultivated since 2007. The sampling area was 50 m × 50 m from which soil samples were randomly taken. This soil type

(Rengam Series, *Typic Paleudult*) was selected because it is commonly cultivated with different crops in Malaysia although the soil is characterized by high P-fixing due to high Al and Fe contents [4]. They were bulked, air dried, crushed and sieved to pass through a 2 mm sieve for characterization purpose. Prior to the commencement of laboratory incubation study, soil samples were analyzed for soil bulk density using a core-ring method [11]. Soil texture was determined by the hydrometer method [12]. Soil pH and electrical conductivity (EC) were determined in a 1:2.5 soil-water ratio using a digital pH meter and EC meter [13]. Total organic matter was determined by using loss-on-ignition (LOI) as described by Chefetz et al. [14] and the soil total C was derived from the total organic matter using a conversion factor of 0.58 [11]. Soil available P was extracted by using the Mehlich No. 1 double acid [15,11] and the concentration of soil available P was determined by the molybdenum blue method [16] using UV-spectrophotometer at 882 nm. Exchangeable cations (K, Ca, Mg, Fe, and Zn) were extracted by using Mehlich No.1 double acid and the contents of exchangeable cations were determined using Atomic Absorption Spectrometer (AAS) [11]. Soil exchangeable acidity and exchangeable Al were extracted using KCl and determined by titration method [17].

2.2. Compost characterization

The rice straw compost used in this study was produced by composting rice straw and goat manure slurry in our previous study [18]. The rice straw compost was analyzed for pH, EC, total organic matter and total C by using the aforementioned procedures in Section 2.1. Total N, P, K, Ca, Mg, Na, Zn and Fe contents in the compost were extracted by using dry ashing method as described by Cottenie [19]. The concentrations of total cations were eventually determined by AAS while the molybdenum blue method was used to determine the concentration of total P. The C/N and C/P ratios of rice straw compost were calculated using the respective total C, N and P content.

2.3. Laboratory incubation study

During the laboratory incubation study, 300 g of air-dried soil were weighed and added into beakers. Rice straw compost was applied at the rates of 5, 10, 15, and 20 t ha^{-1}. The moisture content of the soil-compost mixture was maintained at 60% field capacity throughout the incubation period by adding distilled water when necessary. The beakers were sealed with parafilm to prevent moisture loss and perforated with two holes to ensure good aeration [20]. The list of treatments was as follows:

i. T0: 300 g soil only,
ii. T1: 300 g soil + 200 kg ha^{-1} CIRP,
iii. T2: 300 g soil + 200 kg ha^{-1} CIRP + 5 t ha^{-1} rice straw compost,
iv. T3: 300 g soil + 200 kg ha^{-1} CIRP + 10 t ha^{-1} rice straw compost,
v. T4: 300 g soil + 200 kg ha^{-1} CIRP + 15 t ha^{-1} rice straw compost,
vi. T5: 300 g soil + 200 kg ha^{-1} CIRP + 20 t ha^{-1} rice straw compost.

Christmas Island rock phosphate (CIRP) was the source of P fertilizer and there was no application of N and K fertilizers in this study. The CIRP was applied at 60 kg P_2O_5 ha^{-1} (200 kg of CIRP ha^{-1}) and rice straw compost was applied at the rates of 5, 10, 15, and 20 t ha^{-1}. These rates were based on the standard recommendation for maize (*Zea mays* L.) cultivation [21]. During the laboratory incubation study, the rates were scaled down according to the volume of the soil in beaker. Treatments were incubated in the laboratory at ambient temperature for 30, 60, and 90 days. At the end of 30, 60 and 90 days of incubation (DAI), soil samples were sampled destructively and analyzed for pH, EC, total organic matter, total C, available P, exchangeable acidity, exchangeable Al, exchangeable K, exchangeable Ca, Mg, and extractable Fe as per the standard methods.

2.4. Statistics analysis

The laboratory incubation study was conducted in a factorial completely randomized design with two factors, namely rate of rice straw compost (5, 10, 15, and 20 t ha^{-1}) and time of incubation (30 days, 60 days, and 90 days). Statistical analysis for all the data was performed using SPSS software version 24.0 (SPSS Inc, US). The effects of different rates of rice straw compost additions on all the replicated measurement were tested via one-way analysis of variance (ANOVA). Significant differences among treatment means were separated using the Tukey's HSD test. All result was considered significant at $P \leq 0.05$.

3. Results and discussion

3.1. Characteristics of soil and rice straw compost

The selected physico-chemical properties of Rengam soil series (*Typic Paleudult*, clayey, kaolinitic, isohyperthermic) soil used in the present study are shown in Table 1. The texture of the soil used in the laboratory incubation study was a sandy clay loam with a bulk density of 1.03 g m^{-3}. Generally, the soil was acidic (pH of 5.19) and had low concentration of available P (0.81 ppm). The soil also showed relatively high concentrations of Al and Fe due to low soil pH (Table 1).

The pH of rice straw compost was 7.55. The C/N and C/P ratios of rice straw compost were 19.92 and 125.38, respectively (Table 2). These ratios suggest net mineralization of the organic amendments [22]. The rice straw compost also contained relatively high concentration of exchangeable cations especially K (8.71%), Ca (0.55%), Mg (0.345) and Na (10.6%) (Table 2).

Table 1. Selected physico-chemical properties of Rengam series soil.

Property	Value obtained
Bulk density (g cm^{-3})	1.03
Soil texture	Sand: 75%
	Clay: 24%
	Silt: 1%
	≥Sandy clay loam
	(*Typic Paleudult*, clayey, kaolinitic, isohyperthermic)
pH (Water)	5.19
Total organic matter (%)	3.36
Total C (%)	1.95
Available P (ppm)	0.81
Exchangeable acidity ($cmol_c$ kg^{-1})	0.57
Exchangeable Al ($cmol_c$ kg^{-1})	1.23
Exchangeable K (ppm)	180.16
Exchangeable Ca (ppm)	959.2
Exchangeable Mg (ppm)	1774.13
Exchangeable Fe (ppm)	186.44
Exchangeable Zn (ppm)	0.85

Table 2. Selected chemical properties of rice straw compost.

Property	Rice straw compost
pH	7.55
Electrical conductivity (dS m^{-1})	1.53
Total organic matter (%)	73.53
Total C (%)	42.63
Total N (%)	2.14
Total P (%)	0.34
C/N ratio	19.92
C/P ratio	125.38
Total K (%)	8.71
Total Ca (%)	0.55
Total Mg (%)	0.345
Total Na (%)	10.60
Total Zn (µg/g)	54.20
Total Cu (µg/g)	8
Total Fe (µg/g)	1362.40

Table 3. Mean square values of analysis of variance (ANOVA) to evaluate the effects of the treatments, days of incubation, and interaction between treatments and days of incubation on the soil pH, EC, total organic matter, total C, exchangeable acidity, exchangeable Al, available P, exchangeable K, exchangeable Ca, exchangeable Mg, and exchangeable Fe.

Source of Variations	df	Mean square										
		pH	EC	Total organic matter	Total C	Exchangeable acidity	Exchangeable Al	Available P	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Exchangeable Fe
Treatments	5	2.973*	0.031*	90.039*	30.274*	0.601*	1.850*	12.769*	186,569,111.700*	377,272.723*	20,373,522.570*	23,832.500*
DAI	2	0.148*	0.042*	0.363	0.124	0.001	0.055	0.017	293,584,014.980*	490,717.392*	312,616.880	1,283.606
Treatments* DAI	10	0.086*	0.004*	0.068	0.023	0.006	0.013	0.015	41,080,682.420*	44,396.210*	390,669.161	886.443
Error	36											

Note: 1. *indicates significant at P ≤ 0.05, implies the particular factor (treatments, days of incubation, and interaction between treatments with days of incubation) significantly affect the variables (pH,EC, total organic matter, total C, exchangeable acidity, exchangeable Al, available P, exchangeable K, exchangeable Ca, exchangeable Mg, and exchangeable Fe) tested in this study.

2. DAI indicates days of incubation.

Table 4. Mean square values of analysis of variance (ANOVA) to evaluate the effects of treatments on the soil pH, EC, total organic matter, total C, exchangeable acidity, exchangeable Al, available P, exchangeable K, exchangeable Ca, exchangeable Mg, and exchangeable Fe during 30 DAI, 60 DAI, and 90 DAI .

Source of Variations	df	Mean square										
		pH	EC	Total organic matter	Total C	Exchangeable acidity	Exchangeable Al	Available P	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Exchangeable Fe
30 DAI	5	0.583*	0.002*	27.842*	9.359*	0.137*	0.817*	4.269*	1,126,762.048*	243,394.468*	6,461,683.849*	12,748.750*
60 DAI	5	0.854*	0.013*	32.149*	10.815*	0.226*	0.495*	4.114*	163,825,084.600*	63,744.827	7,797,016.756*	6,845.361*
90 DAI	5	1.709*	0.024*	30.183*	10.154*	0.250*	0.564*	4.415*	103,778,629.900*	158,925.848*	6,896,160.292*	6,011.276*

Note: 1. *indicates significant at $P \leq 0.05$, implies the variables (pH, EC, total organic matter, total C, exchangeable acidity, exchangeable Al, available P, exchangeable K, exchangeable Ca, exchangeable Mg, and exchangeable Fe) tested in this study exerted significant difference between the treatments (T0, T1, T2, T3, T4, and T5) during 30 DAI, 60 DAI, and 90 DAI, respectively.

2. DAI indicates days of incubation.

Table 5. Mean square values of analysis of variance (ANOVA) to evaluate the treatment effects on soil pH, EC, total organic matter, total C, exchangeable acidity, exchangeable Al, available P, exchangeable K, exchangeable Ca, exchangeable Mg, and exchangeable Fe as incubation period increases.

Source of Variations	df	Mean square										
		pH	EC	Total organic matter	Total C	Exchangeable acidity	Exchangeable Al	Available P	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Exchangeable Fe
T0	2	0.390*	0.001	0.046	0.015	0.011	0.089	0.006	1,210,664.658*	19,076.338	123.110	703.680
T1	2	0.182*	0.004*	0.001	0.000	0.012	0.020	0.008	1,725,188.853	32,366.458*	20,833.404	440.718
T2	2	0.000	0.019	0.162	0.055	0.006*	0.009	0.017	24,539,328.440*	178,813.670*	296,352.871	384.736*
T3	2	0.002	0.009*	0.312	0.104	0.000	0.003	0.044*	61,682,568.020*	45,521.831	318,495.058	896.646
T4	2	0.002	0.014*	0.096	0.033	0.001	0.000	0.013	119,100,427.20*	365,028.924*	1,107,870.240	1,845.302
T5	2	0.001	0.014*	0.084	0.029	0.002	0.000	0.002	290,729,249.80*	71,891.218	522,288.000	1,444.740

Note: 1. *indicates significant at $P \leq 0.05$, implies the variables (pH, EC, total organic matter, total C, exchangeable acidity, exchangeable Al, available P, exchangeable K, exchangeable Ca, exchangeable Mg, and exchangeable Fe) tested in this study exerted significant difference between the treatments (T0, T1, T2, T3, T4, and T5) when the incubation period increases from 30 DAI until 90 DAI. 2. DAI indicates days of incubation.

Table 6. Effects of amending rice straw compost with CIRP on selected soil chemical properties and soil available P in Rengam acidic soil under 30 DAI, 60 DAI, and 90 DAI.

Treatment	pH	Electrical conductivity (EC)	Total organic matter	Total C	Available P	Exchangeable acidity	Exchangeable Al	Exchangeable K	Exchangeable Ca	Exchangeable Mg	Exchangeable Fe
		$dS\ m^{-1}$	%		ppm	$cmol\ kg^{-1}$		ppm			
30 DAI											
T0	5.17±0.006c	0.084±0.006d	4.97±0.037b	2.63 ± 0.019b	0.61 ± 0.093d	0.73 ± 0.007a	1.52 ± 0.035a	221.73 ± 13.964d	1119.73 ± 52.340c	1258.67 ± 84.359d	252.80 ± 10.043a
T1	5.86±0.022b	0.095±0.000c	6.06 ± 0.376b	3.21±0.199b	1.17±0.087d	0.573±0.007b	1.27±0.064b	245.87±0.933cd	1152.67±45.690bc	1469.33±130.667d	283.73±3.654a
T2	6.22±0.040a	0.125±0.002b	11.33±1.947a	6.01±1.032a	2.31±0.121c	0.33±0.18c	0.65±0.018c	755.33±65.075bc	1568.40±67.419ab	2666.67±134.191cd	183.73±3.654b
T3	6.21±0.032a	0.136±0.003a	11.53±2.278a	6.11±1.208a	2.84±0.072bc	0.27±0.013cd	0.53±0.007cd	1023.87±50.006b	1447.47±165.712abc	3191.87±133.758bc	140.53±19.637b
T4	6.26±0.153a	0.136±0.002a	11.07±0.926a	5.87±0.491a	3.38±0.183ab	0.24±0.009de	0.36±0.080de	1591.87±146.943a	1845.73±49.813a	4477.33±461.767ab	137.33±13.397b
T5	6.32±0.044a	0.144±0.002a	11.53±1.397a	6.11±0.740a	3.55±0.163a	0.19±0.027e	0.21±0.013e	1589.33±203.097a	1646.53±111.812a	4752.00±551.536a	132.80±13.742b
60DAI											
T0	4.96±0.003c	0.093±0.003b	4.88±0.105c	2.83±0.061c	0.69±0.003f	0.80±0.151a	1.19±0.214a	1090.67±314.43d	1001.33±55.561a	1266.67±20.177d	226.35±4.544ab
T1	5.89±0.003b	0.120±0.012b	6.10±0.064bc	3.54±0.037bc	1.27±0.003e	0.69±0.027a	1.11±0.044a	1453.33±506.819d	1009.47±50.964a	1351.33±191.403d	261.63±9.097a
T2	6.24±0.003a	0.227±0.017a	11.67±1.768a	6.77±1.025a	2.38±0.015d	0.28±0.007b	0.58±0.156b	4605.33±636.885cd	1093.07±63.587a	2042.67±223.503cd	169.07±2.677bc
T3	6.25±0.035a	0.233±0.020a	12.17±1.650a	7.06±0.957a	2.89±0.003c	0.25±0.009b	0.51±0.055b	7648.00±125.73bc	1275.6±53.249a	2766.67±39.350bc	167.33±6.492bc
T4	6.3±0.100a	0.250±0.029a	11.40±0.643ab	6.61±0.373ab	3.41±0.003b	0.22±0.009b	0.35±0.012b	11400.00±2124.760b	1223.33±55.206a	3605.33±573.887b	139.73±24.551c
T5	6.34±0.026a	0.223±0.007a	11.83±1.105a	6.86±0.641a	3.58±0.019a	0.15±0.018b	0.20±0.009b	20628.00±529.714a	1351.2±190.447a	5508.00±248.269a	150.13±26.789c
90DAI											
T0	4.47±0.067c	0.053±0.020b	4.72±0.123d	2.74±0.072d	0.60±0.041d	0.85±0.064a	1.25±0.087a	1458.93±210.190d	968.00±10.377c	1271.33±433.492c	252.95±16.664a
T1	5.45±0.131b	0.167±0.023ab	6.08±0.0536c	3.53±0.031c	1.21±0.060c	0.68±0.053a	1.15±0.100a	1644.40±461.460d	950.73±9.033c	1512.27±97.249bc	264.07±19.744a
T2	6.23±0.170a	0.283±0.069a	11.22±0.331b	6.51±0.192ab	2.46±0.108b	0.24±0.009b	0.55±0.018b	6344.00±846.993c	1234.00±43.471b	2288.93±542.915bc	161.45±4.149b
T3	6.26±0.055a	0.230±0.010a	11.96±0.030a	6.93±0.017a	2.66±0.051b	0.26±0.009b	0.47±0.145b	9700.00±696.440bc	1208.67±47.250bc	2551.60±233.691bc	172.85±8.555b
T4	6.31±0.090a	0.260±0.006a	11.12±0.160b	6.45±0.093b	3.51±0.211a	0.24±0.020b	0.35±0.021b	13348.00±732.779ab	1261.60±58.407b	3308.13±203.018b	181.44±21.694b
T5	6.3±0.021a	0.280±0.010a	11.55±0.135ab	6.70±0.078ab	3.60±0.081a	0.14±0.003b	0.21±0.044b	15453.33±1400.020a	1579.33±104.085a	5436.00±614.769a	176.39±8.782b

Note: Mean values within column with different letter(s) indicate significant difference between treatments by Tukey's HSD test at $P \leq 0.05$. Columns represent the mean values ± SE. DAI indicates days after incubation.

3.2. Effects of amending rice straw compost with CIRP and incubation time on selected chemical properties and P availability in Rengam acidic soil

Days of incubation significantly affect soil pH, electrical conductivity, exchangeable K, and exchangeable Ca of the soil (Table 3). At 30 DAI, 60 DAI, and 90 DAI, treatments with rice straw compost (T2, T3, T4, and T5) significantly increased the soil pH and EC compared to treatments without addition of rice straw compost (T0—soil only and T1—soil with CIRP only) (Table 4). The pH of treatments with rice straw compost increased with an increase in the rate of application of the rice straw compost (Table 6). The highest pH was observed in T5 at 30 DAI, 60 DAI, and 90 DAI, ranging from 6.32 to 6.35, while T0 (soil only without addition of CIRP and rice straw compost) had the lowest soil pH (4.47–5.17) at 30 DAI, 60 DAI, and 90 DAI (Table 6). The significant higher soil pH and EC observed in 30 DAI, 60 DAI, and 90 DAI was because of the rapid proton (H^+) ions were absorbed by negative surface charge on organic materials (rice straw compost) (Table 6) [23,24]. Furthermore, the significantly higher soil pH for treatments with rice straw compost (T2, T3, T4, and T5) was due to further decomposition of rice straw compost in the soil during incubation periods and that produce various organic acids and solubilize the inherent of the basic cations such as K, Ca, and Mg of added rice straw compost into the soil. A significant increase in the soil pH was observed in T1 (soil with CIRP only) as incubation period increases which was due to the dissolution of Ca and Mg contained in in CIRP with help of microorganism activity (Table 5) [20]. On the other hand, there was a decrease in the soil pH of T0 (soil only) due to the total organic matter and exchangeable Ca significantly decreased in soil of T0 (soil only) (Table 6), whereas the decreasing of exchangeable acidity at 30 DAI, 60 DAI, and 90 DAI, respectively was due to microorganism activity and no replacement or addition the resource used (Table 6). The soil EC was higher in treatments with rice straw compost (T2, T3, T4, and T5) compared to treatments without addition of rice straw compost (T0 and T1) (Table 6), indicating that rice straw compost had more soluble salts. This was confirmed by the data in Table 2 which shows that rice straw compost had higher concentrations of K, Ca, and Mg.

Table 6 shows that there were significant difference between treatments with rice straw compost and treatment without rice straw compost on total organic matter and total C at 30 DAI, 60 DAI, and 90 DAI. However, there was no significant difference in the total organic matter and total C for treatments with rice straw compost when the incubation time increases (Table 5) due to slow mineralization process that decomposed the rice straw compost [25]. Treatments with rice straw compost (T2, T3, T4, and T5) significantly reduced exchangeable acidity, exchangeable Al, and exchangeable Fe compared with treatments without rice straw compost (T0 and T1) (Table 6). The reduction in exchangeable acidity, exchangeable Al and precipitation of exchangeable and soluble Al and Fe as insoluble Al and Fe hydroxides [4, 22] for treatment with rice straw compost (T2, T3, T4 and T5) were due to the increase in soil pH at 30 DAI, 60 DAI, and 90 DAI, respectively (Table 6). The soil with CIRP alone (T1) was highest in exchangeable Fe at 30 DAI, 60 DAI, and 90 DAI compared to other treatments because the CIRP may had released Fe into the soil [4].

Table 6 shows that there were significant difference between treatments with rice straw compost and treatment without rice straw compost on soil available P at 30 DAI, 60 DAI, and 90 DAI, respectively. This implies rice straw compost plays an important role on P availability by decreasing the P adsorption due to the competing adsorption sites by organic anion and dissolving the mineral associated P by low-molecular-weight organic acids [29]. However, there was no significant difference in the soil available P (net increase/loss) when the incubation time increases under treatments with rice straw compost (Table 5). This implies the effectiveness of rice straw compost in minimizing the loss of P due to P fixation in soil. This finding contradicted with study reported by Kahura et al. [26] who were using biochar as organic amendment in which they reported that soil available P decreased with the increase in incubation period due to P fixation in soil. The absence of significant increase of soil available P when the incubation time increases (Table 5) could be due to slow microbially mediated mineralization of soil organic P to inorganic P [20]. That is to say, if the organic P in rice straw compost mineralizes readily, the soil available P will increase rapidly. Treatment with soil only without any CIRP and rice straw compost (T0) had the lowest soil available P relative to other treatments, thus confirming that P was deficient in this soil. Treatment T5 (soil with 200 kg ha^{-1} CIRP and 20 t ha^{-1} rice straw compost) showed the highest soil available P compared to other treatments with rice straw compost (T2, T3, and T4) at 30 DAI, 60 DAI, and 90 DAI (Table 6). This was due to the increase of application rate of rice straw compost which could had increased the soil pH and eventually precipitated the exchangeable and soluble Al and Fe as insoluble Al and Fe hydroxides, thus increasing the soil P availability. Ch'ng et al. [27] concluded that the soil available P increased under treatments applied with poultry manure biochar and pineapple leaves compost because of the efficient retention of P in the soil as a result of chelation of Al and Fe by the biochar and compost. Exchangeable cations (K, Ca, and Mg) of treatments with rice straw compost (T2, T3, T4, and T5) were significantly increased at 30 DAI, 60 DAI, and 90 DAI compared to treatments without rice straw compost (T0 and T1) (Table 6). This was due to high inherent basic cations contents contained in the rice straw compost which might had contributed to the increment in the exchangeable cations content in soil across the incubation periods (Tables 5 and 6). Therefore, high content of basic cations in soil treated with rice straw compost (T2, T3, T4, and T5) reduced the exchangeable acidity of the soil compared to treatments without rice straw compost (T0 and T1).

4. Conclusions

In this study, application of rice straw compost with CIRP was found to increase soil available P at three respective incubation periods in the Rengam acidic soil. This was possible because amending rice straw compost with CIRP increased the soil pH, and, at the same time, they reduced exchangeable acidity, exchangeable Al, and exchangeable Fe. As the soil pH increased, the rice straw compost effectively fixed the Al and Fe in the soil instead of P, thus increasing the available P in the soil. Generally, all the treatments with rice straw compost were observed to significantly improve the chemical properties in the soil compared to treatments without addition of rice straw compost at 30 DAI, 60 DAI, and 90 DAI, respectively. Similar observation was found in soil available P, but there was no significant difference in the soil available P (in terms of soil available P gain/loss) when the incubation time increases under treatments with rice straw compost. The findings suggest that the application of rice straw compost altered soil chemical properties in a way that enhanced the availability of P in the Rengam acidic soil.

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Conflict of interest

All authors declare no conflicts of interest in this paper.

References

1. Goundar MS, Morrison RJ, Togamana C (2014) Phosphorus requirements of some selected soil types in the Fiji sugarcane belt. *South Pac J Nat Appl Sci* 32: 1−10.
2. Al Rohily KM, Ghoneim AM, Modaihsh AS, et al. (2013) Phosphorus availability in calcareous soil amend with chemical phosphorus fertilizer, cattle manure compost and sludge manure. *Intern J Soil Sci* 8: 17−24.
3. Thomas BP, Fitzpatrick RW, Merry RH, et al. (2003) Coastal acid sulfate soil management guidelines, Barker Inlet, SA. CSIRO *Land and Water Report* 65.
4. Ch'ng HY, Ahmed OH, Majid NMA (2014) Improving phosphorus availability in an acid soil using organic amendments produced from agroindustrial wastes. *Sci World J* 2014: 1–6.
5. Ahmed OH, Husni MHA, Anuar AR, et al. (2004) A modified way of producing humic acid from composted pineapple leaves. *J Sustain Agric* 25: 129−139.
6. Ch'ng, H Y, Ahmed OH, Kassim S, et al. (2013) Co-composting of pineapple leaves and chicken manure slurry. *Intern J Recycl Org Waste Agric* 2: 1–8.
7. Lu L, Zeng G, Fan C, et al. (2014) Diversity of two-domain laccase-like multicopper oxidase genes in Streptomyces spp.: identification of genes potentially involved in extracellular activities and lignocellulose degradation during composting of agricultural waste. *Appl Environ Microbiol* 80: 3305–3314.
8. Zeng G, Huang D, Huang G, et al. (2007) Composting of lead-contaminated solid waste with inocula of white-rot fungus. *Biores Technol* 98: 320–326.
9. Ohno T, Amirbahman A (2010) Phosphorus availability in boreal forest soils: A geochemical and nutrient uptake modeling approach. *Geoderma* 155: 46–54.
10. Ohno T, Fernandez IJ, Hiradate S, et al. (2007) Effects of soil acidification and forest type on water soluble soil organic matter properties. *Geoderma* 140: 176–187.
11. Tan K (2003) *Soil sampling, preparation and analysis*. New York: Taylor & Francis.
12. Bouyoucos GJ (1962) Hydrometer meter improved for making particle size analysis of soils. *Agron J* 54: 464−465.
13. Peech HM (1965) *Hydrogen-ion activity*. In: Methods of soil analysis, part 2, C.A. Black, D.D. Evans, L.E. Ensminger, J.L. White, F.E Clark, R.C. Dinauer. Madison, WI: Am Soc Agron.
14. Chefetz B, Hatcher PH, Hadar Y, et al. (1996) Chemical and biological characterization of organic matter during composting of municipal solid waste. *J Environ Qual* 25: 776−785.
15. Mehlich A (1953) *Determination of P, Ca, Mg, K, Na and NH4*. Releigh, NC: North Carolina State Univeristy Soil Test Division.
16. Murphy J, Riley JP (1962) A modified single solution method for the determination of phosphate in natural waters. *Anal Chim Act* 27: 31−36.
17. Rowell DL (1994) *Soil science*, methods and applications. Longman Group UK Limited, 86−87.

18. Sanusi S, Ch’ng HY, Suhaimi, O, et al. (2018) Production, characterization and phytotoxicity evaluation of compost from rice straw and goat manure slurry. *Res. J. Appl. Sci.* In press.
19. Cottenie A (1980) Soil testing and plant testing as a basis of fertilizer recommendation. FAO *Soils Bul* 38: 70−73.
20. Ch'ng HY, Ahmed OH, Majid NMA (2016) Minimizing phosphorus sorption and leaching in a tropical acid soil using Egypt rock phosphate with organic amendments. *Philippine Agric Sci* 99: 176−185.
21. John NM, Uwah, DF, Iren OB, et al. (2013) Changes in maize (Zea mays l.) performance and nutrients content with the application of poultry manure, municipal solid waste and ash composts. *J Agric Sci* 5: 270.
22. Ch’ng HY, Ahmed OH, Majid NMA (2014) Biochar and compost influence the phosphorus availability, nutrients uptake, and growth of maize (Zea mays L.) in tropical acid soil. *Pak J Agr Sci* 51: 797–806.
23. Tang C, Sparling GP, McLay CDA, et al. (1999) Effect of short-term legume residue decomposition on soil acidity. *Aust J Soil Res* 37: 561.
24. Wong MTF, Nortcliff S, Swift RS (1998) Method for determining the acid ameliorating capacity of plant residue compost, urban waste compost, farmyard manure, and peat applied to tropical soils. *Commun Soil Sci Plant Analysis* 29: 2927–2937.
25. Vo MH, Wang CH (2015) Effects of manure composts and their combination with inorganic fertilizer on acid soil properties and the growth of muskmelon (Cucumis melo L.). *Compost Sci Util* 23: 117–127.
26. Kahura MW, Hyungi M, Min SK, et al. (2018) Assessing phosphorus availability in a high pH, biochar amended soil under inorganic and organic fertilization. *Ecol Resilient Infrastructure* 5: 11−18.
27. Ch’ng HY, Ahmed OH, Majid NMA (2015) Improving phosphorus availability, nutrient uptake and dry matter production of Zea mays L. on a tropical acid soil using poultry manure biochar and pineapple leaves compost. *Exp Agric* 52: 447–465.
28. Jusoh MLC, Manaf LA, Latiff PA (2013) Composting of rice straw with effective microorganisms (EM) and its influence on compost quality. *Iranian J Environ Health Sci Eng* 10: 17.
29. Huang CY (2000) *Soil science*. Beijing: China Agricultural Press. pp. 32–44.

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