

Research Article

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Effect of Christmas Island rock phosphate and rice straw compost application on soil phosphorus availability and maize (*Zea mays* L.) growth in a tropical acid soil of Kelantan, Malaysia<https://doi.org/10.1515/opag-2020-0015>

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Abstract: Phosphorus (P) fixation is very common in Malaysian acid soils due to the fixation of soluble inorganic P by Al and Fe under acidic soil pH conditions. Farmers tend to perform lots of liming and apply excess amount of P fertilizers in order to saturate the Al and Fe in the soil so that the plants are able to absorb the remaining P. Excessive liming and application of P fertilizers are not only not economical but also not environmentally friendly. Compost with a large surface area and pool of negative charges could be used to reduce P fixation in acidic soil. Hence, this study was carried out to assess the effect of amending Christmas Island rock phosphate (CIRP) with rice straw (RS) compost in improving soil P availability, nutrient uptake, and dry matter production of maize cultivated on a Malaysian tropical acid soil. A pot experiment was carried out in this study with the use of maize (F1 hybrid sweet corn 801) as a test crop. The chemical properties of soils applied with RS compost were significantly improved ($P \leq 0.05$) compared to treatments without RS compost. As the soil pH increased, there was significant reduction in exchangeable acidity, Al and Fe in soil due to exchangeable Al and Fe were fixed with negatively charged functional groups of RS compost's surfaces, thus increased the P availability and exchangeable cations in the soil applied with RS compost. There was also significantly higher N, P, and K uptake in leaf, stem, and root of maize in the treatments applied with RS compost. Application of CIRP with RS compost was found to increase the soil P availability, maize nutrient uptake, and dry matter

production at the end of the pot experiment. An application rate of 15–20 t ha⁻¹ of RS compost together with 130 kg ha⁻¹ urea, 200 kg ha⁻¹ CIRP, and 67 kg ha⁻¹ muriate of potash is recommended to improve the soil NPK contents and growth of *Zea mays* in acidic soil.

Keywords: F1 hybrid sweet corn 801, Malaysia, organic amendment, phosphorus fixation, pot experiment, compost

1 Introduction

Phosphorus (P) is a vital soil nutrient for optimum plant growth and development (Kahura et al. 2018). Generally, soil at a pH range of 6–7 has a maximum P availability for crop uptake (Price 2006). However, most of the tropical acid soils have low P availability. This happens because the soluble inorganic P is fixed by Al and Fe in acid soil (Ch'ng et al. 2014, 2019; Rahman et al. 2014).

Many studies were carried out in order to develop an effective technique to improve P availability. The most common methods used by the farmers are application of large amount of lime in order to raise the soil pH and also application of large quantities of inorganic P fertilizers such as triple superphosphate (TSP) in order to saturate the Al and Fe ions to overcome P deficiency in the soils (Rahman et al. 2014; Ch'ng et al. 2015). However, these practices are not economical and not environmentally friendly because over liming leads to precipitation of P ions with calcium (Ca) as calcium phosphate, which is not available for plant uptake (Ch'ng et al. 2019). Besides, excessive or unbalanced application of P fertilizer is not economical too and will cause water pollution such as eutrophication (Ayoola and Makinde 2009; Petrus et al. 2010).

In recent decades, compost application is one of the major interesting research subjects due to increasing awareness of waste management (Petrus et al. 2010; Choy et al. 2015). Therefore, the abundance of agricultural waste such as rice straw (RS) in paddy industry can

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be effectively transformed and converted into organic fertilizer via the composting process. Through composting, a better nutrient balance output can be produced, relatively cost-saving, and able to serve as an alternative to produce a stable end product.

However, there is a dearth of information on the use of compost produced from agricultural wastes with a large surface area and a high degree of negative charges which could reduce P fixation in order to increase the soil P availability, improve plants' nutrient uptake, and plants' dry matter production cultivated on a tropical acid soil. The process of applying compost to tropical acid soils will fundamentally allow temporary chelation of Al and Fe instead of P. This is possible because of functional groups such as carboxyls and phenols in humic substances such as humic acids, fulvic acids, and humin contained in the compost are known to be negatively charged in alkaline conditions, thus will chelate the positively charged Al and Fe. These functional groups have high bonding for Al and Fe; thus P will become readily available for plant uptake (Ch'ng et al. 2019). Hence, this study was carried out to assess the effect of amending Christmas Island rock phosphate (CIRP) with RS compost in improving soil P availability, nutrient uptake, and dry matter production of maize cultivated on Malaysian tropical acid soil.

2 Materials and methods

2.1 Soil sampling and characterisation

Soil samples were sampled at 0–40 cm from an uncultivated land in Agro Techno Park of the Universiti Malaysia Kelantan Jeli Campus, Malaysia (5.6955 latitude and 101.8389 longitudes) which has not been cultivated since 2007. According to the meteorological data obtained from the Kelantan Meteorological Service Department in 2019, Kelantan in general receives relatively moderate annual rainfall. The mean annual rainfall is about 2,993 mm and the mean daily temperature recorded is 27°C. The mean monthly relative humidity of the area is usually above 80%. The sampling area was 50 m × 50 m from which soil samples were randomly taken. This soil was a Rengam Series (Typic Paleudult), and it is commonly being used to cultivate different crops in Kelantan, Malaysia, although the soil is characterized by high P-fixing due to high Al and Fe contents (Ch'ng et al. 2019). The soils were bulked, air

dried, crushed, and sieved to pass through a 2 mm sieve for characterisation and a 5 mm sieve for pot experiment.

Before the commencement of pot experiment, soil samples were characterized. Soil bulk density was determined by using a core-ring method (Tan 2005). A hydrometer was used to determine the soil texture (Bouyoucos 1962). A digital pH and electrical conductivity (EC) meter was used to determine the soil pH and EC in a 1:2.5 soil–water ratio (Peech 1965). The loss-on-ignition method as described by Chefetz et al. (1996) was used to estimate the soil total organic matter, and the soil total C was derived from the total organic matter by using a conversion factor of 0.58 (Tan 2005). Soil total N was determined by using the Kjeldahl method (Tan 2005). Mehlich No. 1 double acid was used to extract the soil available P (Mehlich 1953; Tan 2005) and the estimation of soil available P concentration was done via the molybdenum blue method (Murphy and Riley 1962) by using an 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 an atomic absorption spectrometer (AAS) (Tan 2005). Soil exchangeable acidity and exchangeable Al were extracted using KCl and estimated by the titration method (Rowell 1994).

2.2 RS compost characterization

The RS compost used in this study was produced by composting RS and goat manure slurry as reported in the previous study (Sanusi et al. 2018a). The RS 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 the dry ashing method as described by Cottenie (1980). 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 RS compost were calculated using the respective total C, N, and P contents.

2.3 Pot experiment

The pot experiment was conducted in a netted house located at the Universiti Malaysia Kelantan Jeli Campus, Malaysia.

Table 1: Selected physicochemical properties of soil

Property	Value obtained	Property	Value obtained
Bulk density (g cm^{-3})	1.03	Available P (mg kg^{-1})	0.81
Soil texture	Sand: 75%	Exchangeable acidity (cmol kg^{-1})	0.57
	Clay: 24%	Exchangeable Al (cmol kg^{-1})	1.23
	Silt: 1% (sandy clay loam)	Exchangeable K (mg kg^{-1})	180.16
pH (water)	5.19	Exchangeable Ca (mg kg^{-1})	959.2
Total organic matter (%)	3.36	Exchangeable Mg (mg kg^{-1})	1,774.13
Total C (%)	1.95	Exchangeable Fe (mg kg^{-1})	186.44
Total N (%)	0.03	Exchangeable Zn (mg kg^{-1})	0.85

The test crop used in this study was F1 hybrid sweet corn 801 variety. Pots (22 cm height, 30 cm width, and 30 cm diameter) were filled with 7 kg of soil (from the 5 mm bulked soil sample). The selected physicochemical properties of Rengam series soil (typic paleudult, clayey, kaolinitic, and isohyperthermic) used in this study are shown in Table 1. The texture of the soil 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 a low concentration of available P (0.81 mg kg^{-1}). The soil also showed relatively high concentrations of Al and Fe due to low soil pH (Table 1).

The pH of RS compost was 7.55. The C/N and C/P ratios of RS compost were 19.92 and 125.38, respectively (Table 2). These ratios suggest net mineralization of the organic amendments (Ch'ng *et al.* 2018). The RS 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).

The N, P, and K fertilizers were applied during the pot experiment to ensure the optimum growth of the maize crop.

Table 2: Selected chemical properties of RS compost

Property	RS 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 (%)	10.6
Total Zn ($\mu\text{g g}^{-1}$)	54.2
Total Cu ($\mu\text{g g}^{-1}$)	8
Total Fe ($\mu\text{g g}^{-1}$)	1,362.40

Phosphate fertilizer and CIRP (30% P_2O_5) were used in this pot experiment. Urea (46% N), CIRP (32% P_2O_5), and muriate of potash (MOP) (60% K_2O) were applied at 60 kg N ha^{-1} (130 kg ha^{-1} urea), $60 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ (200 kg ha^{-1} CIRP), and $40 \text{ kg K}_2\text{O ha}^{-1}$ (67 kg ha^{-1} MOP). These rates were based on the recommendation of Malaysia Agricultural Research and Development Institute (1993). Based on the recommendations, the rate was scaled down to 5 g of urea, 7.7 g of CIRP, and 2.58 g of MOP in 7 kg of soil per pot, respectively. The fertilizers were applied in two equal splits at 10 and 28 days after sowing (DAS) by surface application (Petrus *et al.* 2010; Ch'ng *et al.* 2015). The RS compost was applied at the rates of 5 t ha^{-1} , 10 t ha^{-1} , 15 t ha^{-1} , and 20 t ha^{-1} , respectively. These rates follow the standard recommendation for maize (*Zea mays* L.) cultivation reported by John *et al.* (2013).

The soil and RS compost were thoroughly mixed. The maize seeds were soaked in water for 24 h before sowing to ensure a good germination and plant establishment (Ch'ng *et al.* 2015). Then, the seeds were sown in planting holes (1 seed per hole) after which the holes were partially covered with loose soil. Three seeds were sown per pot and later they were thinned to one at 7 DAS. The pot experiment was carried out in a completely randomized design with three replications. The volume of water used for each pot was maintained at 60% field capacity. Plants were checked regularly for possible disease and pest attack during the pot experiment. The plants were monitored up to tasselling stage (60 DAS) before harvest. This is because tasselling stage is the maximum growth stage of the plant before it goes to the productive stage (Susilawati *et al.* 2009). Treatments evaluated in the pot experiment are listed in Table 3.

At tasselling (60 DAS), the plant growth variables of maize plant (plant height, number of leaves per plant, leaf length, leaf width, and root length) for each treatment were measured by using a measuring tape. The soil samples from pots were collected, air dried, crushed, and sieved to pass through a 2 mm sieve. Afterwards, the soil samples were analyzed for pH, EC, exchangeable acidity and Al, total N, total C, available P

Table 3: Description of treatments evaluated in the pot experiment

Treatment	Description
T0	Soil only (serves as a negative control, without any application of urea, CIRP, MOP, and RS compost)
T1	Soil + 130 kg ha ⁻¹ urea + 200 kg ha ⁻¹ CIRP + 67 kg ha ⁻¹ MOP (serves as a positive control, application of chemical fertilizers [urea, CIRP, and MOP] only without any RS compost)
RST2	Soil + 130 kg ha ⁻¹ urea + 200 kg ha ⁻¹ CIRP + 67 kg ha ⁻¹ MOP + 5 t ha ⁻¹ RS compost
RST3	Soil + 130 kg ha ⁻¹ urea + 200 kg ha ⁻¹ CIRP + 67 kg ha ⁻¹ MOP + 10 t ha ⁻¹ RS compost
RST4	Soil + 130 kg ha ⁻¹ urea + 200 kg ha ⁻¹ CIRP + 67 kg ha ⁻¹ MOP + 15 t ha ⁻¹ RS compost
RST5	Soil + 130 kg ha ⁻¹ urea + 200 kg ha ⁻¹ CIRP + 67 kg ha ⁻¹ MOP + 20 t ha ⁻¹ RS compost (application of chemical fertilizers [urea, CIRP, and MOP] with different rates of RS compost to evaluate the potential of RS compost in improving the soil P availability provided by CIRP)

and exchangeable cations (K, Ca, Mg, Na, and Fe) by using the aforementioned procedures in Section 2.1. Next, the above ground parts of the plants were harvested and partitioned into leaves and stems while the remaining roots in the soil were collected by washing the soil from the root using tap water followed by distilled water (Ch'ng et al. 2019). The plant parts were dried in an oven at 60°C until a constant weight was attained (Lija et al. 2014). The plant parts were ground by using a blender and subsequently total N, P, and K concentrations were determined. The single dry ashing method (Cottenie 1980) was used to extract P and K in the plant tissues (leaf, stem, and root). The filtrates were analyzed for K by using AAS. Meanwhile, P was determined using the molybdenum blue colorimetric method, while total N was determined by using the Kjeldahl method. All nutrients estimated were reported on the elemental percentage basis. The concentrations of N, P, and K in leaf, stem, and root were multiplied by the respective dry weight of the plant parts to obtain the amount of N, P, and K uptake by the maize plants.

$$\text{Uptake} = \text{Concentration} \times \text{Dryweight (g)}$$

2.4 Statistical analysis

Statistical analysis for all the data was performed using SPSS software version 24.0 (SPSS Inc, USA). The effects of different rates of RS compost additions on all the replicated measurements were tested via one-way analysis of variance. Significant differences among treatment means were separated by using Tukey's HSD test. All results were considered significant at $P \leq 0.05$.

Ethical approval: The conducted research is not related to either human or animal use.

3 Results and discussions

3.1 Effects of amending CIRP with RS compost on selected soil chemical properties at 60 DAS

At 60 DAS, the soil pH of the treatments applied with RS compost (RST2, RST3, RST4, and RST5) was significantly increased compared to treatments without RS compost (T0 and T1) (Table 4). This was due to the initial high pH of the RS compost. Highly decomposed RS compost consists of humic and fulvic acids and these acids possessed a carboxyl group which allowed it to consume H⁺ as well as Al (Havlin et al. 2005), thus this might help in increasing the soil pH and decreased the Al concentration. According to Ch'ng et al. (2019), basic cations such as Na, Ca, K, and Mg released from the RS compost might have caused the exchange of protons between the RS compost and the soil, thus increased the soil pH. In addition, the RS compost was high in basic cation contents (K, Ca, Mg, and Na) (Table 2). The release of these cations from the RS compost caused the exchange of protons between the RS and soil, hence increased the soil pH (Ch'ng et al. 2019). Meanwhile, the increase in the soil pH for soil and chemical P fertilizer only (T1) after the pot experiment could be due to the dissolution of Ca and Mg from the applied CIRP which contained high Ca concentration. Similar observation was observed in studies by Ch'ng et al. (2015) and Sanusi et al. (2018b), whereby treatments amended with organic amendments significantly increased soil pH at the end of the pot trial compared with non-organic amendments due to the higher pH of organic inputs.

The soil EC value increased in treatments applied with RS compost (RST2, RST3, RST4, and RST5) compared to treatments without RS compost (T0 and T1)

Table 4: Effects of amending RS compost with CIRP on selected soil chemical properties at 60 DAS of pot experiment

Treatments	pH (water)	EC (dS m ⁻¹)	Total organic matter (%)	Total C	Exchangeable acidity (cmol kg ⁻¹)	Exchangeable Al	Total N (%)	Available P ppm
T0	5.28 ± 0.06d	0.12 ± 0.02d	7.47 ± 0.09c	4.33 ± 0.05b	1.13 ± 0.03a	0.72 ± 0.06b	0.06 ± 0.00c	14.59 ± 0.15f
T1	6.12 ± 0.01c	0.30 ± 0.03c	7.63 ± 0.09c	4.43 ± 0.05b	0.98 ± 0.01a	0.99 ± 0.12a	0.06 ± 0.00c	29.61 ± 0.52e
RST2	6.32 ± 0.01b	0.48 ± 0.04b	9.60 ± 0.23b	4.67 ± 0.91b	0.67 ± 0.07b	0.64 ± 0.06b	0.08 ± 0.00b	62.65 ± 0.13d
RST3	6.46 ± 0.01b	0.59 ± 0.02b	11.07 ± 0.98b	6.42 ± 0.57a	0.46 ± 0.02c	0.42 ± 0.06c	0.08 ± 0.00b	282.73 ± 1.07c
RST4	6.60 ± 0.02a	0.76 ± 0.00a	11.27 ± 1.00b	6.53 ± 0.58a	0.17 ± 0.01d	0.32 ± 0.07c	0.09 ± 0.01b	305.54 ± 0.92b
RST5	6.63 ± 0.03a	0.76 ± 0.01a	13.33 ± 0.24a	7.73 ± 0.14a	0.10 ± 0.01d	0.21 ± 0.04c	0.11 ± 0.00a	370.87 ± 0.56a

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

at 60 DAS (Table 4). This was due to the dissolution of Na from the RS compost (Hamad et al. 2011). Treatments with higher rates of RS compost (RST3, RST4, and RST5) significantly increased the total organic matter in the soil at 60 DAS compared to T0, T1, and RST2 (Table 4). The highest total organic matter in soil after 60 DAS was RST5 (13.33%), and this was due to the highest rate of RS compost application, which in return contributed more to organic matter meanwhile the lowest total organic matter was found for T0 as any organic amendment was not added. With the increase in soil total organic matter, the total C also increased (Table 4).

Exchangeable acidity and Al of soil were affected significantly ($P \leq 0.05$) due to the application of RS compost (Table 4). The soil amended with RS compost reduced the exchangeable acidity and Al level significantly with the increasing rates of RS compost compared to treatments without RS compost amendment (T0 and T1). The significant reduction in exchangeable acidity and Al concentrations in RST2, RST3, RST4, and RST5 was due to the increase in soil pH. In addition, the reduction of exchangeable Al was due to the adsorption of Al by RS compost complexation sites (Fleming et al. 2013). Furthermore, the finding is consistent with the findings of previous study by Ch'ng et al. (2014–2019), in which the organic amendments resulted in lowering of the exchangeable acidity and exchangeable Al level due to increase in soil pH.

The total N in the soil was significantly increased with treatments amended with RS compost at 60 DAS (Table 4). This was due to mineralization of the RS compost (Latifah et al. 2015) and retention of ammonium (NH_4^+) and nitrate (NO_3^-) from being lost through volatilization and leaching. This finding is consistent with the findings of the previous study by Yazdanpanah et al. (2013), who concluded that the increase in total N in soil was due to the fact that treatments with organic amendments had stronger affinity for NH_4^+ and NO_3^- . Besides, the inherent total N in the RS compost also might increase the total N in soil. This observation is also consistent with that of the study of Latifah et al. (2015), who mentioned that organic amendment serves as a source of microorganism to decompose organic N in soil and hence increase the total N in soil.

Soil amended with RS compost and CIRP significantly improved the soil available P compared to control treatment (T0) and treatment with chemical P fertilizer only (T1) (Table 4). Treatment with the highest rate of RS compost application (RST5) showed the highest soil available P due to more inherent P contents in RS compost.

Table 5: Effects of amending RS compost with CIRP on selected soil exchangeable cations at 60 DAS of pot experiment

Treatments	Exchangeable K	Exchangeable Ca	Exchangeable Mg mg L ⁻¹	Exchangeable Na	Exchangeable Fe
T0	654.25 ± 0.72f	1,013.00 ± 1.00f	2,179.50 ± 0.87f	333.00 ± 0.89f	359.00 ± 0.69b
T1	786.00 ± 0.12e	1,329.00 ± 0.58e	2,728.30 ± 0.89e	693.00 ± 1.13e	524.00 ± 0.72a
RST2	1,255.00 ± 0.55d	1,565.67 ± 0.55d	4,319.33 ± 0.85d	1,089.00 ± 0.50d	358.33 ± 0.35b
RST3	1,526.67 ± 0.67c	1,709.67 ± 0.88c	5,792.00 ± 1.63c	1,134.00 ± 0.35c	220.67 ± 0.44c
RST4	3,672.00 ± 0.58b	2,779.67 ± 0.34b	9,074.67 ± 1.78b	1,766.00 ± 1.73b	204.34 ± 0.65d
RST5	4,479.33 ± 0.41a	3,508.33 ± 0.34a	9,456.00 ± 1.07a	2,352.50 ± 0.06a	148.67 ± 0.34e

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

As a result of the increase in soil pH at 60 DAS, the negative charges on the surface area of RS compost increased, and thus increased the affinity for Al and Fe ions instead of P. This led to the increase in the soil available P concentrations (Ch'ng et al. 2019).

In Table 5, there was a significant increase in exchangeable cations (K, Ca, Mg, and Na) under the treatments applied with RS compost and CIRP (RST2, RST3, RST4, and RST5) compared to treatments without RS compost (T0 and T1). The increase in exchangeable cations was possibly due to the dissolution from the RS compost, and this causes a liming effect in the soils which in turn reduces the concentrations of Al and Fe. Hence, P that were initially bound by the Al and Fe were freed from the soil. The exchangeable Fe of treatments amended with CIRP and at higher rates of RS compost (RST3, RST4, and RST5) significantly lower than RST2 and treatments of without RS compost (T0 and T1) (Table 5). This was due to a very strong affinity of metals for organic complexation sites and the increase in CEC due to the addition of RS compost (Fleming et al. 2013).

On the other hand, T1 had the highest exchangeable Fe due to CIRP released Fe into the soil solution (Ch'ng et al. 2014).

3.2 Effects of amending CIRP with RS compost on maize dry matter production and nutrient uptake

Dry weight of hybrid sweet corn 801 (leaf, stem, and root) affected by the application of RS compost is summarized in Table 6. At 60 DAS, RST4 and RST5 produced the largest dry weight. The root's dry weight measured at 60 DAS increased significantly RST2, RST3, RST4, and RST5 compared to T0 and T1. The increase in dry matter production of maize plant could be due to the increase in number of leaves (Laekemaria and Gidago 2013). The number of leaves increased with the amount of RS compost input which indirectly influenced the increase in maize dry weight.

Table 6: Effects of amending CIRP with RS compost on dry weight of *Zea mays* L. F1 hybrid sweet corn 801 variety at 60 DAS of pot experiment

Treatment	Dry weight of plant (g plant ⁻¹)			
	Leaf	Stem	Root	Total
T0	1.22 ± 0.14d	0.85 ± 0.27c	1.21 ± 0.10b	3.29 ± 0.43c
T1	0.75 ± 0.28d	0.66 ± 0.24c	0.16 ± 0.02c	1.57 ± 0.52c
T2	6.68 ± 0.70c	6.38 ± 1.55b	1.92 ± 0.35b	14.98 ± 1.94b
T3	13.08 ± 0.65b	11.20 ± 1.75a	5.37 ± 1.88a	29.65 ± 2.99b
T4	18.30 ± 0.91a	12.46 ± 2.19a	5.51 ± 2.21a	36.26 ± 3.71a
T5	18.66 ± 3.27a	15.70 ± 6.90a	5.75 ± 2.18a	40.12 ± 11.93a

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

Table 7: Effects of amending CIRP with RS compost on plant nutrients concentrations of *Zea mays* L. F1 hybrid sweet corn 801 variety at 60 DAS of pot experiment

Treatment	N (%)	P	K	Ca	Mg
Leaves					
T0	1.35 ± 0.12c	0.10 ± 0.05d	0.62 ± 0.04e	0.08 ± 0.02d	0.04 ± 0.01c
T1	0.61 ± 0.17d	0.26 ± 0.03d	1.28 ± 0.16d	0.15 ± 0.01c	0.01 ± 0.003d
T2	1.40 ± 0.00c	0.48 ± 0.04c	1.87 ± 0.08c	0.18 ± 0.003bc	0.07 ± 0.002b
T3	1.63 ± 0.12c	0.78 ± 0.13c	1.86 ± 0.10c	0.24 ± 0.01ab	0.09 ± 0.003b
T4	2.01 ± 0.09b	2.13 ± 0.41a	2.96 ± 0.17b	0.21 ± 0.01bc	0.12 ± 0.01a
T5	2.75 ± 0.05a	1.26 ± 0.22b	4.17 ± 0.52a	0.28 ± 0.02a	0.15 ± 0.01a
Stem					
T0	0.75 ± 0.05c	0.15 ± 0.02d	0.94 ± 0.24cd	0.10 ± 0.03c	0.02 ± 0.01d
T1	0.65 ± 0.12c	0.08 ± 0.02e	0.29 ± 0.11d	0.03 ± 0.01d	0.01 ± 0.003d
T2	0.84 ± 0.08b	0.32 ± 0.07c	1.45 ± 0.04c	0.15 ± 0.01bc	0.09 ± 0.01c
T3	0.84 ± 0.21b	0.76 ± 0.12b	2.77 ± 0.30b	0.21 ± 0.01ab	0.10 ± 0.01bc
T4	1.31 ± 0.05ab	0.85 ± 0.08b	5.29 ± 0.08a	0.21 ± 0.01ab	0.14 ± 0.01ab
T5	1.68 ± 0.14a	1.80 ± 0.23a	5.70 ± 0.32a	0.23 ± 0.01a	0.15 ± 0.01a
Roots					
T0	0.51 ± 0.12b	0.07 ± 0.02b	1.22 ± 0.18cd	0.15 ± 0.01c	0.04 ± 0.01c
T1	0.33 ± 0.05b	0.04 ± 0.01b	0.62 ± 0.04d	0.08 ± 0.02d	0.01 ± 0.003d
T2	0.65 ± 0.05b	0.23 ± 0.01b	1.87 ± 0.08bc	0.18 ± 0.003bc	0.06 ± 0.002c
T3	1.07 ± 0.05a	0.77 ± 0.03a	1.86 ± 0.10bc	0.28 ± 0.02a	0.10 ± 0.004b
T4	1.17 ± 0.05a	0.69 ± 0.14a	2.21 ± 0.22b	0.20 ± 0.01bc	0.12 ± 0.01b
T5	1.35 ± 0.05a	0.87 ± 0.05a	2.96 ± 0.17a	0.26 ± 0.02ab	0.15 ± 0.01a

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

The effect of treatments on the plant nutrient concentration in F1 hybrid sweet corn 801 variety is presented in Table 7. The concentrations of N, P, and K in plant leaves, stems, and roots were relatively higher in treatments applied with RS compost at 60 DAS (Table 7). The low concentrations could be attributed to the translocation of plant nutrients to the other parts of the plant (Ch'ng *et al.* 2019). The treatments applied with RS compost (RST2, RST3, RST4, and RST5) showed an increase in the N, P, and K uptake for each plant part (leaf, stem, and root) compared to T0 and T1 at 60 DAS (Figure 1). The increase in the concentration of primary nutrients was due to the microbial-mediated mineralization causing an increase in the available nutrients for plant uptake (Osman 2013). According to Liu *et al.* (2018), RS compost can affect total nutrient and plant uptake by increasing the soil pH. Reactive groups on the surface of RS compost such as carboxyl, phenoxyl, as well as hydroxyl react with trace elements (Al and Fe) which formed a stable complex. Altering the metal-blocking capacity caused by the Al and Fe might be useful in reducing the Al and Fe bioavailability (Zhang *et al.* 2017). This would result in the increase in soil pH and caused the release of more available P in the soil for plant

uptake. The T1 had the lowest plant nutrient uptake in plants and this might be due to the drastic immobilization of chemical fertilizer during plant growth (Pan *et al.* 2018). This immobilization will reduce the plant uptake and cause the plant to be stunted growth. Unlike T1, RS compost in RST2, RST3, RST4, and RST5 with slow released properties allowed nutrient retention in soil for plant uptake. This might stimulate the alleviation of significantly immobilization of chemical fertilizer.

4 Conclusions

In this study, application of CIRP with RS compost was found to increase the soil P availability at the end of the pot experiment. This was possible because amending CIRP with RS compost increased the soil pH, and at the same time, they reduced exchangeable acidity, exchangeable Al, and exchangeable Fe. As the soil pH increases, the RS compost effectively fixed the Al and Fe in the soil instead of P, thus increasing the P availability in the soil. Besides, amending CIRP with RS compost also significantly improved the dry matter production, N,

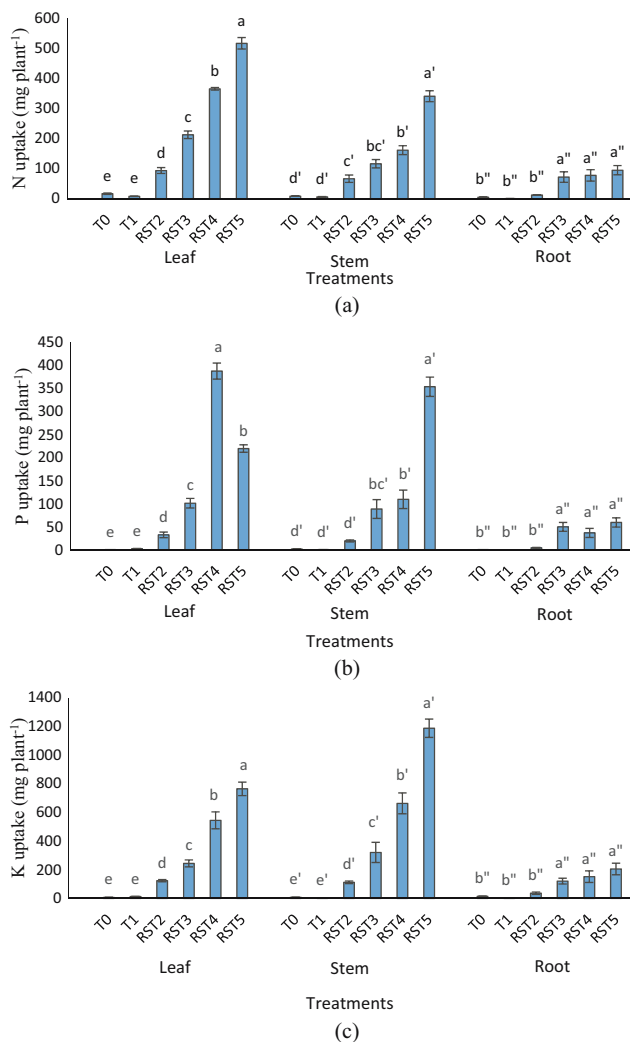


Figure 1: Effect of amending CIRP with RS compost on N, P, and K (a–c) uptake in leaf, stem, and root of *Zea mays* L. Fl hybrid sweet corn 801 variety at 60 DAS of pot experiment. Note: mean values with different letter(s) indicate significance between treatments by Tukey's test at $P \leq 0.05$. Bars represent the mean values \pm SE.

P, and K uptake in leaf, stem, and root of the maize plants compared to treatment with application of chemical fertilizers only. In summary, an application rate of 15–20 t ha⁻¹ of RS compost together with 130 kg ha⁻¹ urea, 200 kg ha⁻¹ CIRP, and 67 kg ha⁻¹ MOP is recommended to improve the soil NPK contents and growth of *Zea mays* in acidic soil. This study will be further evaluated for three cycles of field trials in the upcoming study.

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