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Improving Nutrient Recovery of *Zea Mays* L. Using Paddy Husk Compost and Clinoptilolite Zeolite

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Abstract: Co-application of inorganic fertilizers and paddy husk compost at different rates amended with clinoptilolite zeolite using maize as a test crop were tested in a pot study to determine their effects on: (i) selected soil chemical properties and (ii) nutrients recovery of maize. A pot study was carried out for 45 days (tasselling stage). The treatments evaluated were: Soil only (T0), 7.40 g urea + 5 g TSP + 3.80 g MOP (T1), 7.40 g urea + 5 g TSP + 3.80 g MOP + 192 g zeolite + 192 g compost (T2), 5.55 g urea + 3.75 g TSP + 2.85 g MOP + 192 g zeolite + 385 g compost (T3), 3.70 g urea + 2.50 g TSP + 1.90 g MOP + 192 g zeolite + 577 g compost (T4) and 3.70 g urea + 2.50 g TSP + 1.90 g MOP + 577 g compost (T5). Co-application of inorganic fertilizers with paddy husk compost and clinoptilolite zeolite improved soil total N, exchangeable Ca, Mg, K, available P, and recovery of P and K. Soil chemical properties and productivity of maize can be improved by adopting co-application of inorganic fertilizers with paddy husk compost and clinoptilolite zeolite.

Key words: chemical fertilizers, organic amendment, nutrients availability, nutrients efficacy

1. Introduction

Highly weathered soils (Oxisols and Ultisols) in the humid tropics are low in nutrients holding capacity because most of the minerals with significant negative charges are lost through weathering leaving behind very low charged crystalline minerals in the soils [1]. Modern agriculture depends on the use of inorganic fertilizers to improve crop production. Synthetic fertilizers, in particular are able to increase crop yield because they add nutrients to soils [2]. Inorganic fertilizers for instance, are important inputs in agriculture as they increase crop yield especially in systems where soil resources are deficient in nutrients and the main goal is to increase crop productivity [3]. However, over-reliance on the use of inorganic fertilizers practice which degrades soil quality decreases soil productivity and crop yield over time [4, 5]. Nutrient run-off *via* leaching from agricultural fields degrades aquatic and terrestrial ecosystems and also the quality of groundwater [6-8]. Various approaches had been carried out on the use of available and renewable resources of plant nutrients to complement and supplement inorganic fertilizers. As a result, efforts had been put in place to evaluate the feasibility and efficacy of organic residues, not only to enhance soil productivity but also to promote efficient use of inorganic fertilizers [9].

The effects of compost application on soil properties in the short and long term are well documented. Composts can be used to enhance soil productivity by

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providing organic matter and biological cycle of nutrients which are crucial to the success of managing acid soils. The use of composts in agriculture does not only enhance retention of nutrients in inorganic fertilizers but they also supply nutrients to crops besides supporting rapid nutrients cycling (through microbial biomass) [10]. Compost derived from co-composting paddy husk and chicken slurry is one of the appropriate organic amendments for managing agricultural wastes generated in the rice milling and poultry industries [11]. Co-application of composts and inorganic fertilizers is considered a more environment-friendly way of achieving sustainable agriculture as this approach increases nutrients availability and crop yield [12-15]. It is important to note that sole application of organic amendments such as composts does not support the entire growth and development of most crops because these organic amendments are generally low in plant nutrients [16]. Therefore, including clinoptilolite zeolite in nutrients availability management in soils is essential as this approach ensures retention of crop nutrients from being leached.

Clinoptilolite zeolite has a three-dimensional crystal lattice, with loosely bound cations, capable of hydrating and dehydrating without altering the crystal structure [17]. The shape, dimensions, and linkage of clinoptilolite zeolite pores and voids are the special features of the clinoptilolite zeolite materials [18]. According to Mumpton (1999) [18], the pores and interconnected voids of clinoptilolite zeolite are occupied by cations and water molecules. This mineral has large open channels in the crystal structure that provides void space for adsorption and exchange of cations [14 15]. For example, clinoptilolite zeolite had been used to improve plant growth, yield of *Zea mays* L., and fertilizer use efficiency because of the unique properties of clinoptilolite zeolite [14, 15, 19, 20]. Although the use of clinoptilolite zeolite improves soil quality and crop productivity, there is dearth of information on the use of optimum rates of inorganic fertilizers and paddy husk compost with clinoptilolite zeolite as an additive to improve soil chemical properties and productivity of crops cultivated on highly weathered acid soils. To this end, we hypothesized that amending inorganic fertilizers with paddy husk compost and clinoptilolite zeolite will improve soil chemical properties, nutrients uptake, and recovery of *Zea mays* L. cultivation on acid soils. Thus, a pot study was carried out to determine the effects of amending inorganic fertilizers with paddy husk compost and clinoptilolite zeolite on: (i) soil total N, exchangeable Ca, Mg, K, NH_4^+, available NO_3^-, available P, total organic C, and organic matter, and (ii) N, P, and K uptake and recovery of *Zea mays* L.

2. Materials and Methods

2.1 Soil Selected Physical and Chemical Properties

The soil used in pot study was Bekenu Series (*Typic Paleudults*) and it was collected at 0-20 cm depth from an uncultivated area at Universiti Putra Malaysia Bintulu Campus Sarawak, Malaysia. The soil was air dried and ground to pass a 2 mm sieve for initial characterization and pot experiment. Soil texture, field capacity, and bulk density were determined using the method described by Tan (2005) [21]. The pH of the soil was determined in a ratio of 1:2 (soil: distilled water suspension) using a pH meter. The soil total C, N, and organic matter were determined using Leco CHNS Analyzer (LECO Truspec Micro Elemental Analyzer CHNS, New York). Soil available P was extracted using the double acid method [21] followed by the molybdenum blue method [22]. Exchangeable cations were extracted using the leaching method [21] and thereafter, their contents were determined using Atomic Absorption Spectrophotometry (Analyst 800, Perkin Elmer, Norwalk, USA). Soil CEC was determined using the leaching followed by steam distillation [21]. The method of Keeney and Nelson (1982) [23] was used to extract exchangeable NH_4^+ and available NO_3^- after which their concentrations were determined using steam distillation.

The texture of the soil was sandy loam with a bulk density of 1.51 g cm^{-3}, fine loamy, siliceous, isohyperthermic, with a colour of red-yellow to yellow. It has an argillic horizon with fine sandy clay loam textures. The structure is generally weak medium to coarse sub angular blocky. It is friable in nature [24]. These physical properties are consistent with those reported in Soil Survey Staff (2014) [25]. The selected chemical properties of the soil are summarized in Table 1. The soil pH, total N, and total C are also consistent with those reported for Bekenu series by Paramanathan (2000) [24] whereas exchangeable Ca, Mg, and K are higher than those reported by Paramanathan (2000) [24].

Table 1 Selected chemical properties of Bekenu Series (*Typic Paleudults*).

Property	Value obtained (Mean ± S.E.)	Standard data range
CEC ($cmol_c$ kg^{-1})	7.43 (± 0.15)	8.0-24
pH_{water}	4.66 (± 0.10)	4.60
Exchangeable calcium ($cmol_c$ kg^{-1})	1.41 (± 0.05)	0.01
Exchangeable magnesium ($cmol_c$ kg^{-1})	1.53 (± 0.05)	0.21
Exchangeable potassium ($cmol_c$ kg^{-1})	0.60 (± 0.02)	0.19
Total Nitrogen (%)	0.15 (± 0.01)	0.04-0.17
Organic matter (%)	2.06 (± 0.10)	nd
Total carbon (%)	1.20 (± 0.60)	0.57-2.51
Available phosphorus (mg kg^{-1})	4.16 (± 0.13)	nd
Exchangeable ammonium (mg kg^{-1})	19.85 (± 0.68)	nd
Available nitrate (mg kg^{-1})	5.16 (± 0.09)	nd

Standard data range reported by Paramanathan (2000) [24]; nd: not determined. Values in parenthesis represent standard error of the mean.

2.2 Chemical Characteristics of Paddy Husk Compost

The standard procedures used to characterize the paddy husk compost and their chemical properties are reported in our previous paper [11]. Humic acid, ash, NH_4^+, NO_3^-, P, Ca, Mg, and K contents of the paddy husk compost are relatively high (Table 2). The lower contents of Cu, Fe, Mn, Zn, and microbial population of the paddy husk compost suggest that the compost is stable, mature, and not toxic [11]. The chemical properties of the humic acids extracted from the paddy husk compost and reference values [26] are given in Table 3.

2.3 Chemical Properties of Clinoptilolite Zeolite

The clinoptilolite zeolite used in this study was in powder form. Total N of the clinoptilolite zeolite was determined using Kjeldahl method [27]. The pH, exchangeable NH_4^+, and available NO_3^- of the clinoptilolite zeolite were determined using the method described previously [23, 28]. The CEC of the clinoptilolite zeolite was determined using the CsCl method [17]. The CsCl method was used to avoid underestimation of CEC of the clinoptilolite zeolite as this method does not lead to entrapment of NH_4^+ in the channels of the clinoptilolite zeolite. The exchangeable K, Ca, and Mg contents of the clinoptilolite zeolite were extracted using the method of Ming and Dixon (1986) [17] and their contents determined using Atomic Absorption Spectrophotometry (Analyst 800, Perkin Elmer, Norwalk, USA). The chemical properties of the clinoptilolite zeolite used in this study are summarized in Table 4.

2.4 Pot Experiment

A pot experiment was conducted in a net house at Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia using completely randomized design (CRD) with three replications. Size of the pots used was 22 x

28 cm. Each pot was filled with 8 kg soil (based on soil bulk density). Maize (*Zea mays* L.) hybrid F1 variety was used as test crop. The N, P, and K requirement of the test crop were 60 kg N, 60 kg P_2O_5, and 40 kg K_2O (130 kg ha^{-1} urea: 130 kg ha^{-1} TSP: 67 kg ha^{-1} MOP) [29]. The fertilizer requirement was scaled down to per pot basis and this was equivalent to 7.40 g of urea, 5 g of TSP, and 3.80 g of MOP. The volume of water used for each pot was based on field capacity (65%).

Table 2 Selected physico-chemical properties of paddy husk compost.

Property	Value obtained (Mean ± S.E.)
pH value	7.9 (± 0.03)
CEC ($cmol_c$ kg^{-1})	176 (± 3.17)
Humic acid (%)	5.7 (± 0.03)
EC (ds m^{-1})	1.2 (± 0.02)
Total carbon (%)	28.2 (± 0.52)
Organic matter (%)	47 (± 0.55)
Total nitrogen (%)	1.6 (± 0.03)
C/N ratio	17
Ammonium	362 (± 2.92)
Nitrate	172 (± 1.85)
Total phosphorus	1097 (± 0.88)
Calcium	15, 080 (± 0.88)
Magnesium	15, 149 (± 1.85)
Potassium (mg kg^{-1})	27, 150 (± 9.87)
Sodium	14,001 (± 2.48)
Iron	3.6 (± 0.14)
Zinc	11.2 (± 0.17)
Copper	2.4 (± 0.11)
Manganese	2.1(± 0.12)
Ash content (%)	6.4 (±0.29)
Moisture content (%)	44 (±0.71)

Values were obtained from our previous study on co-composting paddy husk and chicken manure [11]. Value in parenthesis represent standard error of the mean. Carbon to N ratio was calculated by dividing the percentage of C with the percentage of N.

Table 3 Selected chemical properties of humic acids extracted from paddy husk compost.

Property	*Value obtained (Mean ± S.E.)	Tan (2003)
E_4/E_6	7.78 (± 0.03)	7-8
Phenolic ($cmol_c$ kg^{-1})	350 (± 5.54)	240-540
Carboxyl ($cmol_c$ kg^{-1})	400 (± 10.68)	150-440
Total acidity ($cmol_c$ kg^{-1})	750 (± 5.03)	500-700

E_4/E_6 (optical density) is the absorbance at two arbitrary selected wavelengths (extinction at 465 and 665 nm). The E_4/E_6 is the value of humic acid that indicate humification level of humic acid and it is widely used as an indicator for evaluating the maturity of compost. Values in parenthesis represents standard error of the mean. *Value obtained from previous [11].

Table 4 Selected chemical properties of clinoptilolite zeolite.

Property	Present study (Mean ± S.E.)	Reference*
pH	6.80 (± 0.03)	8-9
CEC ($cmol_c$ kg^{-1})	100.33 (± 0.35)	160
Total nitrogen (%)	1.18 (± 0.04)	1.36
Calcium	18,400 (± 19.09)	25, 600
Magnesium	11,200 (± 4.48)	15,000
Potassium (mg kg^{-1})	14,850 (± 10.17)	22,600
Ammonium	12.60 (± 0.43)	nd
Nitrate	11.58 (± 0.18)	nd

CEC: Cation exchange capacity; nd: not determine; *Data were obtained from Luxurious Empire Sdn. Bhd., Kulai Jaya, Malaysia. Values in parenthesis represent standard error of the mean.

The treatments evaluated were:

1) Soil only (T0)
2) 7.40 g urea + 5 g TSP + 3.80 g MOP (T1)
3) 7.40 g urea + 5 g TSP + 3.80 g MOP + 192 g zeolite + 192 g compost (T2)
4) 5.55 g urea + 3.75 g TSP + 2.85 g MOP + 192 g zeolite + 385 g compost (T3)
5) 3.70 g urea + 2.50 g TSP + 1.90 g MOP + 192 g zeolite + 577 g compost (T4)
6) 3.70 g urea + 2.50 g TSP + 1.90 g MOP + 577 g compost (T5)

The rates of the clinoptilolite zeolite [30] and paddy husk compost [31] were scaled down from the standard fertilizer recommendation for *Zea mays* L. cultivation. The amounts of the paddy husk compost used were based on 5, 10, and 15 tonnes ha^{-1} and scaled down to per plant basis which were equivalent to 192 g, 385 g, and 577 g of the compost [31]. The amounts of the inorganic fertilizers used in T3 and T4 were reduced by 25 and 50%, respectively and this was based on the amount of paddy husk compost used to compensate the requirement of the test crop. The paddy husk compost and clinoptilolite zeolite were mixed with soil a day before planting. The inorganic fertilizers (equal amount) were applied twice that is, 10 and 28 days after planting. Soil only (T0) without addition of fertilizers was used to calculate nutrient efficiency which is defined as the amount of fertilizer taken up and used by plant versus the amount of fertilizer lost [32].

At 45 days after planting (tasseling stage), the *Zea mays* L. plants were harvested. Tassel stage is the maximum growth stage for the plant before it goes to reproductive stage [33]. At 45 days after planting, plants were partitioned into stem, leaf, and root. The root in the soil were removed carefully and washed using tap followed by distilled water. The leaf, stem, and root were oven dried at 60°C until constant weight were attained and their dry weight were determined. Each of the maize plant part was ground and analyzed for total N, P, and K uptake and N, P, and K use efficiency. Total N of the plant tissues was determined by the Kjeldahl method [27]. Potassium of the plant tissues was obtained by digesting the tissues using the dry ashing method [21] after which the extracts were analyzed using AAS. Phosphorus of the plant tissues was extracted using the dry ashing [21] followed by the molybdenum blue method [22]. At 45 days after planting, soil samples were analyzed for soil total N, pH, exchangeable NH_4^+, available NO_3^-, exchangeable cations, and available P using the standard methods as previously outlined [21-23, 27, 28]. Nitrogen, P, and K uptake in leaf, stem, and root were determined by multiplying their concentrations with the dry weight of the plant parts.

Nitrogen, P, and K recovery were determined by the equation described by Dobermann (2005) [32]:

$$\text{Nutrient recovery}\,(\%) = \frac{(\text{Uptake with fertilizer - Uptake without fertilizer}) \times 100}{\text{Total amount of fertilizer that had been applied}}$$

2.5 Experimental Design and Statistical Analysis

The experimental design of the pot study was completely randomized design (CRD) with three replications. Analysis of variance (ANOVA) was used to detect treatment effects whereas Tukey's test was used to compare treatment means at $P \le 0.05$. The Statistical Analysis System version 9.2 was used for the statistical tests.

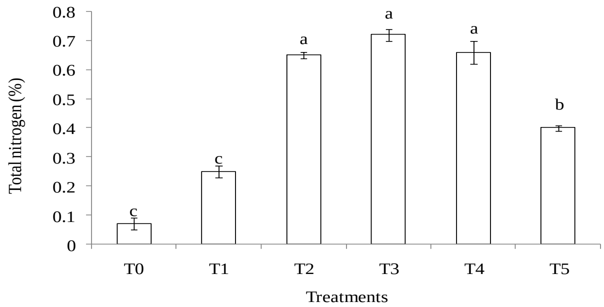
3. Results

3.1 Soil Chemical Properties at forty Five Days After Planting

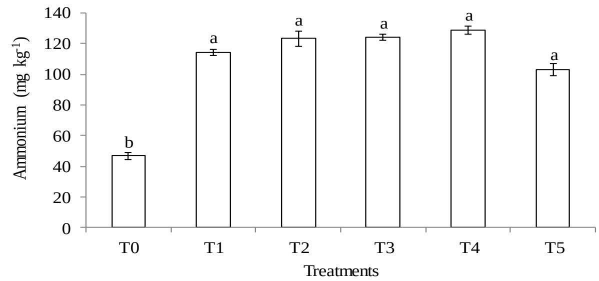
The treatments with paddy husk compost and clinoptilolite zeolite (T2, T3, T4, and T5) had significant effects on soil total N at 45 days after planting compared with that of soil only (T0) and soil with inorganic fertilizers only (T1) (Fig. 1). The soil exchangeable NH_4^+ and available NO_3^- were not affected by the addition of paddy husk compost and clinoptilolite zeolite (Fig. 1). However, soil exchangeable Ca, Mg, K, and available P were significantly improved in the all treatments with paddy husk compost and clinoptilolite zeolite (T2, T3, T4, and T5) compared with the treatment without paddy husk compost and clinoptilolite zeolite (T1) (Table 5). Co-application of inorganic fertilizers with the highest rates of paddy husk compost affected soil pH at 45 days after planting (Fig. 2). The pots with inorganic fertilizers only (T1) and those with inorganic fertilizers, paddy husk compost, and clinoptilolite zeolite (T2, T3, T4, and T5) showed no significant effect on soil total organic C and organic matter (Fig. 3).

3.1 Dry Weight, Nutrient Uptake, and Nutrient Recovery of Zea Mays L.

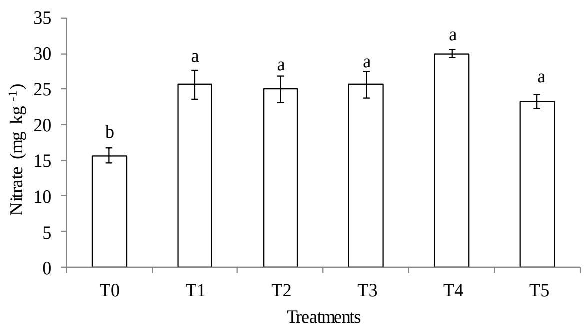
Dry weight of *Zea mays* L. stem were significantly higher in T2, T4, and T5 compared with T1 (Fig. 4a). For leaf, the highest dry weight of *Zea mays* L. was observed in T4 (Fig. 4b), whilst no significant effect was detected for the dry weight of root of T1, T2, T3, T4, and T5 (Fig. 4c). Similar effect on N uptake of *Zea mays* L. was observed in application of inorganic fertilizers only (T1) and co-application of inorganic



(a) Soil total N at 45 days after planting.



(b) Soil exchangeable ammonium at 45 days after planting.



(c) Soil to available nitrate at 45 days after planting.

Fig. 1 Soil total N, exchangeable ammonium, and available nitrate at 45 days after planting. Bars with different letters are significantly different at by Tukey's test at *P* ≤ *0.05*.

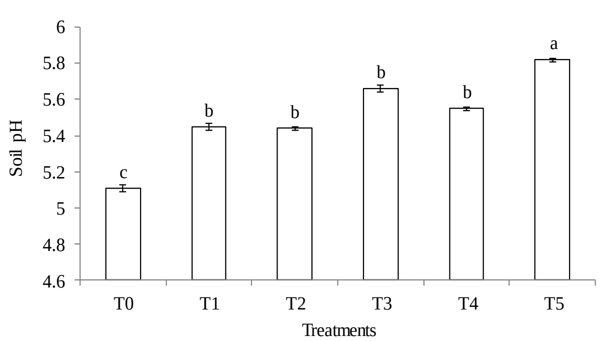
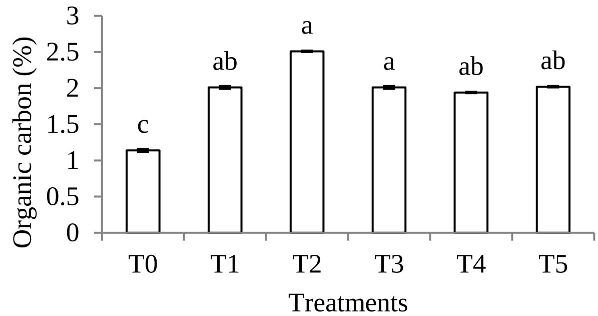
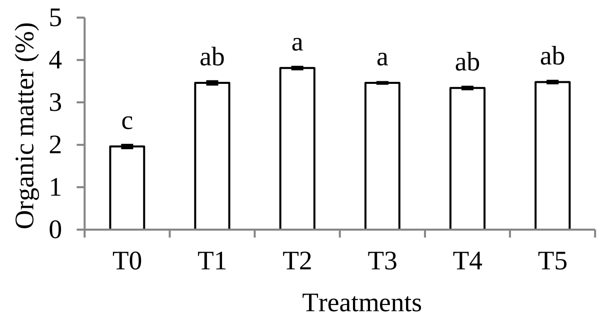


Fig. 2 Soil pH at 45 days after planting. Bars with different letters are significantly different by Tukey's test at *P* ≤ *0.05*.



(a) Soil organic carbon at forty five days after planting.



(b) Soil organic matter at forty five days after planting.

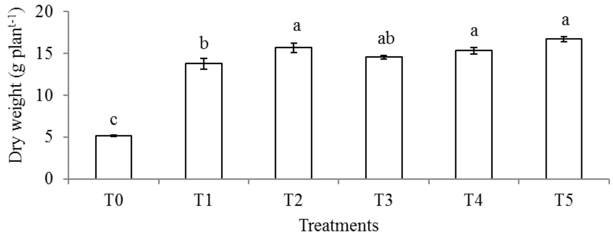
Fig. 3 Soil organic carbon and organic matter at forty five days after planting. Bars with different letters are significantly different by Tukey's test at *P* ≤ *0.05*.

Table 5 Selected soil chemical properties at 45 days after planting maize.

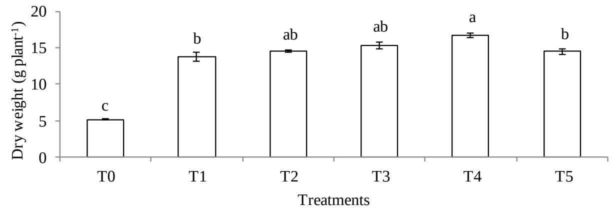
Treatment	Ca	Mg	K	P
	(mg kg^{-1}) Mean	(S.E.)		
T0	1.42^{c} (±0.69)	1.22^{d} (±0.08)	0.79^{d} (±0.08)	3.26^{d} (±0.20)
T1	1079.67^{b} (±3.52)	1329^{c} (±2.88)	2054.3^{c} (±4.80)	1112^{c} (±1.15)
T2	1259^{a} (±3.84)	1482^{a} (±2.02)	2255^{a} (±1.76)	3230^{a} (±2.02)
T3	1288^{a} (±2.08)	1419^{b} (±0.57)	2244^{b} (±8.35)	3219^{a} (±0.88)
T4	1261^{a} (±1.73)	1366^{c} (±1.20)	2297^{a} (±8.41)	2316^{b} (±2.08)
T5	1214^{c} (±2.40)	1394^{c} (±3.38)	2281^{a} (±5.23)	2128^{b} (±2.08)

Means followed by the same letter are not significantly different based on Tukey's test at *P* ≤ *0.05.* S.E. is standard error of the mean which included in parenthesis.

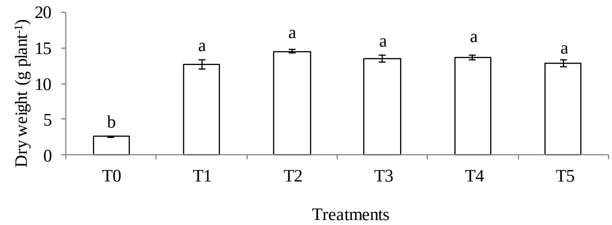
fertilizers, paddy husk compost, and clinoptilolite zeolite (T2, T3, T4, and T5) (Fig. 5a). However, for P and K uptake, the pots with paddy husk compost and clinoptilolite zeolite (T2, T3, and T4) were higher than



(a) Dry weight of stem of *Zea mays* L. at forty five days after planting.



(b) Dry weight of leaf of *Zea mays* L. at forty five days after planting.



(c) Dry weight of root of *Zea mays* L. at forty five days after planting.

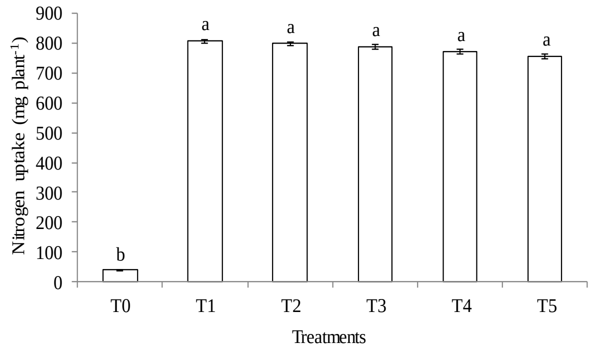
Fig. 4 Dry weight of stems, leaf, and roots of *Zea mays* L. at 45 days after planting. Bars with different letters are significantly different at by Tukey's test at *P ≤ 0.05.*

inorganic fertilizer alone (Fig. 5bc). Treatment 1, T2, T3, T4, and T5 showed similar effect on the N recovery of *Zea mays* L. (Fig. 6a) but T2 significantly improved P recovery of *Zea mays* L. compared with other treatments (Figure 6b). In terms of K recovery, T2, T3, and T4 showed greater effect than the standard recommendation (T1) (Fig. 6c).

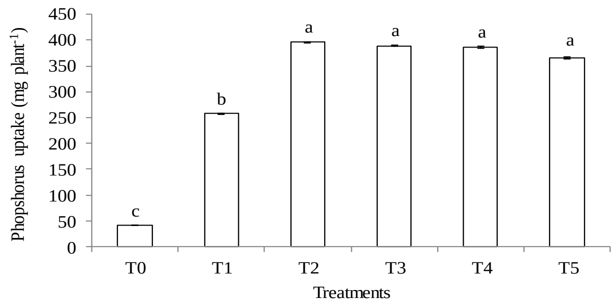
4. Discussion

4.1 Soil Nutrient Availability at Forty Five Days of Planting Maize

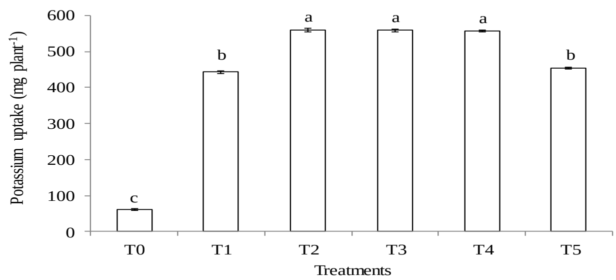
The higher soil total N in the pots with paddy husk compost and clinoptilolite zeolite (T2, T3, and T4) as indicated in Fig. 1a was partly due to the adsorption of NH_4^+ onto the negatively charged sites of the organic matter of the paddy husk compost [34] and clinoptilolite [35]. This is possible because the organic



(a) Nitrogen uptake of *Zea mays* L. at 45 days after planting



(b) Phosphorus uptake of *Zea mays* L. at 45 days after planting

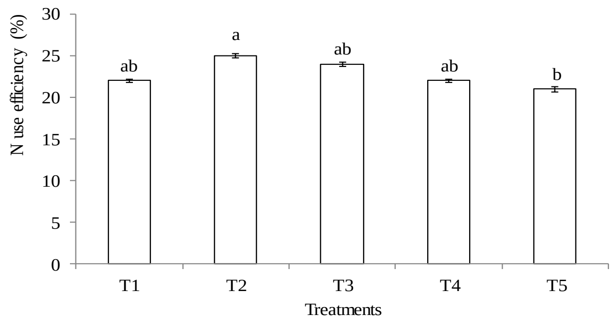


(c) Potassium uptake of *Zea mays* L. at 45 days after planting

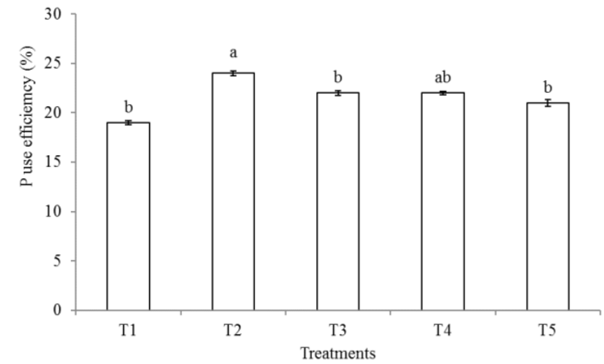
Fig. 5 Nitrogen, phosphorus, and potassium uptake of *Zea mays* L. at 45 days after planting. Bars with different letters are significantly different at by Tukey's test at *P ≤ 0.05.*

matter of the paddy husk compost used in this study was 47% (Table 2) whereas the CEC of the clinoptilolite zeolite was 100 $cmol_c\ kg^{-1}$ (Table 4). According to Siva *et al.* (1999) [36], higher total N following compost application is possible because compost reduces NH_4^+ concentration in soil solution and prevents NH_4^+ from being volatilized through NH_3 volatilization as NH_4^+ is susceptible to NH_3 loss. In terms of N loss, the retention of soil N due to paddy husk compost application is considered as a positive interaction between compost and urea.

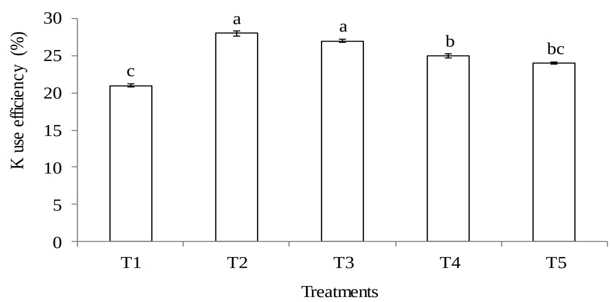
In a related study in which clinoptilolite zeolite was used in a manure-amended soil, Ramesh *et al.* (2011)



(a) Nitrogen recovery of maize plant



(b) Phosphorus recovery of maize plant



(c) Potassium recovery of maize plant

Fig. 6 Nitrogen, phosphorus, and potassium recovery of maize plant. Bars with different letters are significantly different at by Tukey's test at *P* ≤ *0.05.*

[37] reported that inclusion of clinoptilolite zeolite regulated N released and minimized formation of NO_3^-. Latifah *et al.* (2017) [14, 15] also demonstrated the ability of clinoptilolite zeolite to decrease N loss by trapping NH_4^+ through cation exchange. Apart from retaining NH_4^+, clinoptilolite zeolite also minimizes nitrification [35, 38]. Therefore, the lower soil total N due to T1 and T5 could be associated with the absence of clinoptilolite zeolite. At 45 days after planting, the effects of T1, T2, T3, T4, and T5 on soil exchangeable NH_4^+ and available NO_3^- were similar due to the slow release of N in the paddy husk compost (Fig. 1bc). Compared to the similar amount of inorganic N fertilizers added in T1 and T2 with the addition of paddy husk compost in T2, no significant effects on soil exchangeable NH_4^+ and available NO_3^- was because the organic N of the paddy husk compost had to be mineralized before being released into soil system.

The higher retention of soil exchangeable Ca, Mg, K, and available P in the pots with paddy husk compost and clinoptilolite was because the higher CEC of the paddy husk compost and clinoptilolite zeolite might have contributed to the improvement in soil exchangeable Ca, Mg, K, and available P. Because clinoptilolite zeolite has a high selective tendency for K^+, Ca^{2+}, and Mg^{2+}, these cations might have been adsorbed onto its cation exchange sites thus, preventing the cations from being leached [39]. This finding is similar to those of Ahmed *et al*. (2010) [40] and Junrungreang *et al*. (2002) [41] who also reported significant improvement in Ca, Mg, and K following application of clinoptilolite zeolite. The availability of P in the soil with paddy husk compost and clinoptilolite zeolite (T2, T3, T4, and T5) is ascribed to the higher contents of Ca and K of these amendments because of the release of soluble P when Ca^{2+} ions are exchanged with K^+ ions [42]. Furthermore, the content of humic acids in the paddy husk compost (Table 2) might have affected the availability of soil exchangeable Ca, Mg, and K of T2, T3, and T4 because humic acids can serve as buffer, because this process enables Ca, Mg, and K to be soluble in soils [43]. Humic acids which are major components of compost can bind cations because of the high affinity of their carboxylic acid groups for Ca^{2+}, Mg^{2+}, and K^+. In this study, the improvement in soil exchangeable Ca, Mg, K, and available P is related to the functional group of the humic acids of the paddy husk compost (Table 3) as Sahin et al. (2014) [44]

opined that functional groups of humic acids (phenolic and carboxylic) enable percolation of cations in soils and they also act as natural chelate in soils. Sahin *et al.* (2014) [44] also reported that stable complexes of humic acids with ions in soils are associated to the functional groups of humic acids because the high CEC of humic substances enables chelation of cations in soils.

The fact that the treatments with the highest paddy husk compost amended with clinoptilolite zeolite (T5) significantly increased soil pH compared with those without paddy husk compost and clinoptilolite zeolite (T0 and T1) suggests that the soil pH was influenced by the quantity of the paddy husk compost (Fig. 2). The effects of T2, T3, and T4 on soil pH (Fig. 2) could be one of the reasons for the similar effect of these treatments on total organic C and organic matter (Fig. 3) as biological activities and transformation of soil organic matter in soils are impeded when pH of soils is below 7. According to Scheffer et al. (1997) [45], low decomposition of organic matter occurs when soil pH ranges between 5.5 and 7.5 because microbial decomposition of organic matter gets impeded within this pH range.

4.2 Dry Weight and Nutrient Uptake and Recovery

The increase in the dry weight of *Zea mays* L. leaf of the soil with paddy husk compost and clinoptilolte zeolite (T4) relates to the functions of humic substances of the paddy husk compost (Fig. 4a). Humic substances temporarily hold soil exchangeable Ca, Mg, K, and available P (Table 5) after which they are released for plant uptake. The higher availability of soil total N (Fig. 1a), soil exchangeable Ca, Mg, K, and available P (Table 5) due to the paddy husk compost and clinoptilolite zeolite application (T4) also explains the increase in the dry weight of *Zea mays* L. leaf and stem compared with T1 (Fig. 4ab). Pots with paddy husk compost and clinoptilolite zeolite (T2, T3, T4, and T5) showed improved uptake of both P and K compared with T1 (Fig. 4bc) because of the high affinity of paddy husk compost and clinoptilolite zeolite for Al^{3+} and Fe^{2+}. This reaction minimizes P fixation by Al^{3+} and Fe^{2+} in highly weathered acid soils [46]. The treatments with paddy husk compost and clinoptilolite zeolite did not only supply Ca, Mg, K, and P (Table 5) but they also reduced exchangeable acidity aside from chelating exchangeable Al and exchangeable Fe ions. In a related study, the use of compost increased soil pH such that Al and Fe were fixed instead of P [47]. The higher uptake of K partly corroborates the high contents of K in the paddy husk compost and clinoptilolite zeolite (Tables 2, 4 and Fig. 5c). According to Millan et al. (2008) [48], clinoptilolite zeolite increases ion-exchange site of soils besides serving as an adsorption sites for small molecules (due to porous structure of clinoptilolite zeolite). This unique feature explains the availability of soil exchangeable K for maize plant uptake (Table 5).

The higher P and K uptake (Fig. 5) and their use efficiency in pots with paddy husk compost was because soil organic matter improves P and K availability in soils (Table 5) and this occurs through solubilization of insoluble forms of phosphate and cations (for example K^+) by organic acids produced during the decomposition of organic matter [49]. Additionally, P and K are either immobilized and used in the synthesis of new microbial tissues or mineralized and released into the soil mineral nutrient pool [50]. However, increased microbial activities may increase nutrients mineralization particularly N. Therefore, the addition of clinoptilolite zeolite in this study enable retention of N in the form of NH_4^+ and NO_3^- to prevent them from loss *via* rapid mineralization, leaching, volatilization, and denitrification [51]. The lowest P and K recovery observed in T1 (inorganic fertilizers only) was because this treatment had no paddy husk compost and clinoptilolite zeolite (Fig. 6bc).

5. Conclusions

Co-application of paddy husk compost and clinoptilolite zeolite with inorganic fertilizers increased soil total N, available P, exchangeable Ca, Mg, and K, and P and K uptake and recovery. Soil chemical properties and productivity of *Zea mays* L. on acid soils can be improved by adopting co-application of paddy husk compost and clinoptilolite zeolite with inorganic fertilizers. The availability of soil total N, available P, exchangeable Ca, Mg, and K from different rates of urea can be enhanced if they are amended with paddy husk compost and clinoptilolite zeolite. Thus, co-application of paddy husk compost and clinoptilolite zeolite with inorganic fertilizers use in agriculture could be a potential cost effective approach for improving soil nutrients availability and crop productivity.

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Conflict of Interest

The authors have declared that no conflict of interests exist.

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