Bulgarian Journal of Agricultural Science, 23 (No 3) 2017, 418–428
Agricultural Academy

ENHANCING NUTRIENTS USE EFFICIENCY AND GRAIN YIELD OF *ZEA MAYS* L. CULTIVATED ON A TROPICAL ACID SOIL USING PADDY HUSK COMPOST AND CLINOPTILOLITE ZEOLITE

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Abstract

Latifah, O., O. H. Ahmed and N. M. A. Majid, 2017. Enhancing nutrients use efficiency and grain yield of *Zea mays* L. cultivated on a tropical acid soil using paddy husk compost and clinoptilolite zeolite. *Bulg. J. Agric. Sci.*, 23 (3): 418–428

With the ever increasing food demand coupled with environmental pollution due to unbalanced use of chemical fertilizers, there is a need to mitigate nutrients use efficiency to improve crop productivity. A field study was carried out from April 2014 to August 2014 on Nyalau Series (*Typic Tualemkuts*) to determine the effects of chemical fertilizers, compost, and clinoptilolite zeolite on: (i) selected soil chemical availability, nutrients uptake and use efficiency and (ii) grain yield of *Zea mays* L. The field study was conducted for 72 days for two consecutive planting cycles of *Zea mays* L. The use of chemical fertilizers, compost, and clinoptilolite zeolite improved nutrients use efficiency and grain yield of *Zea mays* L. because of nutrients released from compost and retention of exchangeable cations on the exchange sites of clinoptilolite zeolite. The use of chemical fertilizers, compost, and clinoptilolite zeolite does not only improved timely uptake of nitrogen, phosphorus, potassium, calcium, magnesium, and sodium in the aboveground biomass of *Zea mays* L. but also affects the higher grain yield of *Zea mays* L. compared with chemical fertilizers only. Application of chemical fertilizers, compost, and clinoptilolite zeolite can improve nutrients availability, uptake and use efficiency, so was grain yield of *Zea mays* L.

Key words: compost; nutrient use efficiency; zeolite; maize yield
Abbreviations: Ca – calcium, K – potassium, P – phosphorus, Mg – magnesium, Na – sodium, NH_4^+ – ammonium, NO_3^- – nitrate

Introduction

Nutrients deficiency is one of the most yield limiting nutrients and it represents one of the major costs in crop production (Stevens et al., 2005). However, excessive amounts and inappropriate application methods lead to low nutrients efficiency and high fertilizer losses through runoff, leaching, denitrification, and volatilization resulting in a series of environmental problems (Richter and Roelcke, 2000; Zhu et al., 2000). Thus, efficient nutrients utilization should be im-

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proved in agriculture for environmental and economic reasons (Delin et al., 2008; Stevens et al., 2005). Coordination between soil nutrients supply and crop demand is the one of the key to improve nutrients use efficiency (Fageria and Baligar, 2005).

Cropping in tropical acid soils is another problem because tropical acid soils are highly weathered as they exist under tropical environment with high rainfall and temperature throughout the year results in leaching of plant nutrients and accumulation of sesquioxides (Anda et al., 2008). Soils become acidic due to the parent material being acidic and naturally low in the basic cations such as ammonium, potassium, calcium, magnesium, and sodium or due to leaching of these elements by excess rains (Shamsuddin and Daud, 2011). According to Shamshuddin and Daud (2011), most of the Ultisols and Oxisols in the tropics is lacking in organic matter which can supply essential crop nutrients as well as improve soil structures. To reverse this impact, composts can be applied as a direct source of nutrients in conjunction with chemical fertilizers because of high organic matter of the composts (typically > 40%) that affect soils fertility due to the effects of organic matter on soil biota as well as their physico-chemical characteristics (Raviv, 2005). Synchronizing soil nutrients availability through combine application of chemical fertilizers and compost with crop requirements is expected to improve nutrients and reduce their losses through leaching beyond the crop rooting depth or gaseous emissions.

Composts are widely used as soil amendments due to humified organic matter that have lasting effects of the organic matter on soil. Organic matter of the composts contains large amounts of carbon, which results in many complex types of structures and chemical properties (Sanchez-Monedero et al., 2002). Organic matter reacts in the soil like a tiny spongy solid with a large amount of negative charge which reacts strongly with smaller organic molecules such as root exudates (Raviv, 2005). The use of composts in agriculture has been reported to increase crops yield and also improve soil physical and chemical properties (Mylavarapu and Zinati, 2009). Gil et al. (2007) reported the increase pH of acid soils and organic matter content due to composts application. In this study, compost derived from agricultural wastes such as paddy husk and chicken slurry was used to obtain high nutrients use efficiency value that is more nutrients available for crop uptake and less leaching or loss. Compost application is not only a component of waste management, but it also decreases the required amount of conventional fertilizers (Ros et al., 2006). The use of composts can improve soil structure and nutrients supply to crops and thus reduce the input of mineral fertilizers. In this study, compost derived from co-composting of paddy husk and chicken slurry is an approach to make beneficial use of agricultural wastes to supply nutrients for crop and to reduce environment pollution from the indiscriminate disposal of these wastes.

Nutrients use efficiency can also be achieved through the use of clinoptilolite zeolite because of the unique physical and chemical properties of clinoptilolite zeolite coupled with their abundance in sedimentary deposits and in rocks derived from volcanic parent materials have made them useful in many agricultural applications (Ramesh et al., 2010). Clinoptilolite zeolite is a hydrated aluminosilicate of alkali and alkaline earth metals consist of infinite three-dimensional crystal structure, a polyedric shape, and a great open cavity (Dakovic et al., 2007). Clinoptilolite zeolite is widely used in cultivating different crops such as cereals, forage, vegetables, vine, and fruit crops due to their exceptionally high ion-exchange capacity (Butorac et al., 2002). Based on this rationale, it was hypothesized that the use of different rates of chemical fertilizers and different rates of organic fertilizers (compost) amended with clinoptilolite zeolite could improve nutrients uptake and use efficiency and grain yield of *Zea mays* L. cultivated on tropical acid soil. Thus, a field study was carried out for two cropping cycles of *Zea mays* L. as a test crop to determine the effects of different rates of chemical fertilizers and paddy husk compost amended with clinoptilolite zeolite on nutrients uptake and use efficiency as well as grain yield of *Zea mays* L. cultivated on a tropical acid soil.

Materials and Methods

Experimental site descriptions

A field study was carried out at the Share Farm of Universiti Putra Malaysia Bintulu Sarawak Campus, Malaysia (latitude 3° 30´N, longitude 113°09´E). The study area is a humid tropic with yearly average of low and high temperatures of 23°C and 34°C, respectively. The annual precipitation of the area is 2,200 mm (Sarawak Meteorological Department, 2014). There were three blocks (arranged in randomized complete block design) and the plot size within each block was 3 m (length) x 2.5 m (breadth). The planting distance of *Zea mays* L. of Thai Super Sweet hybrid F1 (test crop) was 60 cm within plants and 60 cm between rows whereas the distance between plots was arranged in 1 m. There were 12 plants in each plot.

Soil physico-chemical characterization

Soil samples were taken at 0 – 20 cm depth (using auger) from all plots prior to application of treatments and planting of *Zea mays* L. Soil samples were air dried and ground to pass a 2.0 mm sieve for initial characterization. Soil texture, field capacity, and bulk density were determined using the method described by Tan (2005). 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 (Tan, 2005) followed by the molybdenum blue method (Murphy and Riley 1962). Exchangeable Ca, Mg, K, and Na were extracted using the leaching method (Tan, 2005) after which their contents were determined using Atomic Absorption Spectrophotometry (Analyst 800, Perkin Elmer, Norwalk, USA). Soil CEC was determined using the leaching method (Tan, 2005) followed by steam distillation. The method of Keeney and Nelson (1982) was used to extract exchangeable NH_4^+ and available NO_3^- after which their concentrations were determined using steam distillation.

The soil was characterized as sandy clay loam, Nyalau Series (*Typic Tualemkuts*) with a bulk density of 1.12 g m^{-3}. These physical properties are consistent with those reported in Soil Survey Staff (2014). The selected chemical properties of the soil are summarized in Table 1. The Nyalau Series is classified according to the Malaysian Soil Taxonomy as a member of the coarse-loamy, siliceous, isohyperthermic, red-yellow to yellow family of over sedimentary rocks. They are classified as soils having a deep well drained argillic horizon with a low base saturation (Paramananthan, 2000).

Table 1
Selected chemical properties of Nyalau Series

Property	Value obtained	Standard data range
CEC ($cmol_c$ kg^{-1})	9.32	5.89
pH_{water}	4.25	4.7 – 5
Exchangeable calcium	0.82	0.05
Exchangeable magnesium ($cmol_c$ kg^{-1})	0.53	< 0.01
Exchangeable potassium	0.36	< 0.09
Total nitrogen	0.15	0.06
Organic matter	5.51	†nd
Total organic carbon (%)	3.20	1.30
Total phosphorus	0.005	nd
Available phosphorus	2.16	nd
Exchangeable ammonium (mg kg^{-1})	12.35	nd
Available nitrate	2.12	nd

Standard data range as reported by Paramanathan (2000); nd is not determined

Chemical characteristics of compost derived from paddy husk and chicken manure

The standard procedures used to characterize the compost used in this study are reported in our previous paper (Latifah et al., 2015). The chemical properties of the compost produced by co-composting paddy husk and chicken manure (Table 2) were extracted from our previous paper (Latifah et al., 2015). Humic acid, ash, NH_4^+, NO_3^-, P, Ca, Mg, and K contents of the compost are relatively high (Table 2). The lower contents of Cu, Fe, Mn, Zn, and microbial population of the compost suggest that the compost is stable, mature, and not toxic (Latifah et al., 2015). The chemical properties of the humic acids extracted from the compost are typical of humic acids (Table 3).

Table 2
Selected physico-chemical properties of compost by co-composting paddy husk and chicken slurry

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 (mg kg^{-1})	15 350 (± 1.45)
Potassium	27 720 (± 0.88)
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 (Latifah et al. 2015). Values 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 acid extracted from 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 represent standard error of the mean

Chemical properties of clinoptilolite zeolite

The clinoptilolite zeolite used in this study was in powder form (sieved to pass 250 mm). Total N of the clinoptilolite zeolite was determined using Kjeldahl method (Bremner, 1965). The exchangeable NH_4^+ and available NO_3^- of the clinoptilolite zeolite were determined using the method described by Keeney and Nelson (1982). The pH of the clinoptilolite zeolite was determined in a ratio of 1:2 (clinoptilolite zeolite:distilled water suspension) using a pH meter. The CEC of the clinoptilolite zeolite was determined using the CsCl method (Ming and Dixon, 1986). The CsCl method was used to avoid underestimation of the 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) 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. The CEC of the clinoptilolite zeolite was lower than the value obtained from the supplier of clinoptilolite zeolite, however the value obtained in this study is within the standard range (Table 4). Ming and Dixon (1986) reported the range of clinoptilolite zeolite CEC as 100 – 300 $cmol_c\ kg^{-1}$. This range depends on the amount of $A1^{3+}$ that replaces Si^{4+} in the clinoptilolite zeolite structure (Ming and Dixon, 1986). The pH, total N, Ca, Mg, and K of the clinoptilolite zeolite were lower than those obtained from the supplier of this mineral (Table 4).

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

S.E. is standard error of the mean which included in parenthesis. Data were obtained from Luxurious Empire Sdn. Bhd., Kulai Jaya, Malaysia. Values in parenthesis represent standard error of the mean. nd is not determine

Field study

A field study was carried out from 10th April 2014 to 21st June 2014 for the first planting cycle and 25th June to 27th August 2014 for the second planting cycle of *Zea mays* L. The experimental plots were arranged in randomized complete block design (RCBD) with three blocks. *Zea mays* L. of Thai Super Sweet hybrid F1 variety was used as the test crop. Different rates of chemical fertilizers and compost amended with clinoptilolite zeolite were tested on *Zea mays* L. until kernels were well-filled (72 days after planting) in both of the first and second planting cycles.

The treatments evaluated in the field study during the two planting cycles were:

T0 Soil only (Control)

Standard fertilization

U1: 0.13 t ha^{-1} urea + 0.10 t ha^{-1} TSP + 0.07 t ha^{-1} MOP

Standard fertilization + clinoptilolite zeolite

U1Z: 0.13 t ha^{-1} urea + 0.10 t ha^{-1} TSP + 0.07 t ha^{-1} MOP + 5 t ha^{-1} clinoptilolite zeolite

25% reduction from standard fertilization + Paddy husk compost + clinoptilolite zeolite

U2C1Z: 0.09 t ha^{-1} kg urea + 0.07 t ha^{-1} TSP + 0.05 t ha^{-1} MOP + 5 t ha^{-1} compost + 5 t ha^{-1} clinoptilolite zeolite

50% reduction from standard fertilization + Paddy husk compost + clinoptilolite zeolite

U3C2Z: 0.04 t ha^{-1} urea + 0.03 t ha^{-1} TSP + 0.02 t ha^{-1} MOP + 10 t ha^{-1} compost + 5 t ha^{-1} clinoptilolite zeolite

The rates of the chemical fertilizers (MARDI, 1993), compost (John et al., 2013), and clinoptilolite zeolite (Najafinezhad et al., 2014) used were based on the standard fertilizer recommendation for *Zea mays* L. cultivation. The N, P, and K requirements of the test crop are 60 kg N, 60 kg P_2O_5, and 40 kg K_2O (130 kg ha^{-1} urea: 130 kg ha^{-1} Triple Super Phosphate: 67 kg ha^{-1} Muriate of Potash), respectively (MARDI, 1993). These fertilizers were applied based on per plant and their rates were 7.40 g of urea, 5 g of TSP, and 3.80 g of MOP. The amounts of the chemical fertilizers in U2C1Z and U3C2Z were reduced by 25% and 50%, respectively of the standard recommendation (U1) to complement the use of compost based on 10 and 15 tonnes ha^{-1} (John et al., 2013) in U2C1Z and U3C2Z, respectively. The amount of the clinoptilolite zeolite used to enhance retention of nutrients released from the chemical fertilizers and compost was based on 5 tonnes ha^{-1} (Najafinezhad et al., 2014). A day before planting, the compost and clinoptilolite zeolite were mixed in planting holes. This application was carried during the first planting cycle only, whereas, the chemical fertilizers (equal amount) were applied twice that is, 10 and 28 days after planting in both of the first and second planting cycles. Soil only (T0) without addition of fertilizers was used to calculate nutrients use efficiency which is defined as the amount of fertilizer taken up and used by crops versus the amount of fertilizer lost (Nielson, 2006).

At harvest (72 days after planting), soil samples were analysed for CEC, pH, exchangeable Ca, Mg, K, and Na, available P, and total N using standard methods previously outlined. The *Zea mays* L. cobs were harvested at kernel development stage (72 days after planting) and their fresh cob weight was recorded to determine the total yield of each treatment. Grain count was determined by selecting five cobs from each treatment. Belowground biomass (root) was not assessed but aboveground biomass (stem and leaves) was sampled at the upper 0.1 m in both of the first and second planting cycles. The aboveground biomass of *Zea mays* L. was harvested and partitioned into stem and leaves. These parts were oven dried until constant weight was attained. Afterwards, the dry weight of the plant parts was determined using a digital balance. Each plant part was ground and analyzed for total N, P, K, Ca, Mg, and Na uptake and use efficiency.

Dry ashing method (Tan, 2005) was used to extract P, K, Ca, Mg, and Na in plant parts. The extract of total K, Ca, Mg, and Na were analysed using AAS, whereas total P was determined using the molybdenum blue method (Murphy and Riley, 1962). Total N was determined using Kjeldahl method (Bremner, 1965). Nitrogen, P, K, Ca, Mg, and Na uptake by *Zea mays* L. were estimated by multiplying the dry weight of the plant parts with their N, P, K, Ca, Mg, and Na concentrations.

Statistical analysis

Data were statistically analysed using analysis of variance (ANOVA) and means separation were compared using Tukey's test at $P \leq 0.05$. Statistical Analysis System (SAS Version 9.2) was used for the statistical analysis.

Results and Discussion

Soil CEC and pH at seventy two days after planting (first and second cycles)

The treatments with paddy husk compost and clinoptilolite zeolite (U1Z, U2C1Z, and U3C2Z) significantly increased soil CEC compared with T0 and U1 (without paddy husk compost and clinoptilolite zeolite) regardless of planting cycle (Table 5) because of the CEC of the paddy husk compost (176 $cmol_c$ kg^{-1}) and clinoptilolite zeolite (100.33 $cmol_c kg^{-1}$) (Tables 2 and 4). The retention of NH_4^+, K^+, Ca^{2+}, Mg^{2+}, and Na^+ in U2C1Z and U3C2Z was due to the high negative charges due to functional groups of humic and fulvic acids such as carboxyl and phenolic of the organic matter in the composts (Pedra et al., 2008). The humic and fulvic acids of the paddy husk compost also contributed to the increase in the soil CEC of U2C1Z and U3C2Z. The functional groups of humic and fulvic acids in composts bind positively charged multivalent ions such as NH_4^+, K^+, Ca^{2+}, Mg^{2+}, and Na^+ to improve the availability of these cations (Kaur et al., 2008; García-Gil, 2000). In addition, the higher soil CEC in U1Z, U2C1Z, and U3C2Z was because of the negatively charged aluminosilicates in the pores of clinoptilolite zeolite which are responsible for the CEC of the clinoptilolite zeolite. Lebedynets et al. (2004) reported that the negatively charged aluminosilicate systems in the pores of the clinoptilolite zeolite have high affinity for NH_4^+, K^+, Ca^{2+}, Mg^{2+}, and Na^+.

Table 5
Soil cation exchange capacity and pH at 72 days after planting of *Zea mays* L.

Treatments	CEC ($cmol_c$ kg^{-1})	pH
	Mean (S.E.)	
	First planting cycle of *Zea mays* L.	
T0	7.92^d (0.32)	4.25^c (0.14)
T1	18.02^c (0.42)	5.68^b (0.08)
T2	22.55^b (0.66)	6.22^a (0.14)
T3	26.70^a (0.10)	6.53^a (0.04)
T4	24.61^{ab} (0.08)	6.57^a (0.07)
	Second planting cycle of *Zea mays* L.	
T0	7.35^c (0.13)	4.10^c (0.08)
U1	17.42^b (0.25)	5.54^b (0.14)
U1Z	24.11^a (0.34)	6.31^a (0.14)
U2C1Z	25.37^a (0.17)	6.45^a (0.12)
U3C2Z	24.51^a (0.31)	6.26^a (0.02)

S.E. is standard error of the mean which included in parenthesis. Different letters within a column indicate significant difference between means using Tukey's test at $P \leq 0.05$

The higher pH of the paddy husk compost (Table 2) and clinoptilolite zeolite due to basic cations such as Ca, Mg, K, and Na (Tables 2 and 4) contributed to the significant increase in soil pH of the plots with U1Z, U2C1Z, and U3C2Z compared with T0 and U1 (Table 5). This observation is consistent with our previous soil incubation and leaching experiments in which paddy husk compost and clinoptilolite zeolite decreased soil acidity (Latifah et al., 2015).

Soil available nitrogen, phosphorus, exchangeable calcium, magnesium, potassium, and sodium (first and second planting cycles)

Soil available N, P, Ca, Mg, K, and Na were significantly higher in treatments with chemical fertilizers, paddy husk compost, and clinoptilolite zeolite (U1Z, U2C1Z, and U3C2Z) compared with no fertilizers (T0) and chemical fertilizers only (U1) (Table 6) in both of the two planting cycles because of the organic matter content of the paddy husk compost (Table 2). John et al. (2013) opined that high organic matter content of composts does not only enhance absorption of nutrients by growing

Table 6
Soil selected chemical properties at 72 days of *Zea mays* L. planting (two planting cycles)

Treatment	N	Ca	Mg	K	Na	P
	($mg\,kg^{-1}$) Mean (S.E.)					
First planting cycle of *Zea mays* L						
T0	1220^{d} (±5.77)	26.24^{d} (±0.49)	11.88^{c} (±0.41)	2.90^{e} (±0.08)	75.66^{c} (± 1.76)	245.66^{e} (±5.45)
U1	2754^{c} (±9.88)	709.67^{c} (±5.60)	1110^{b} (±5.29)	1241^{d} (±2.30)	814^{b} (± 3.46)	1070.66^{d} (±4.05)
U1Z	5744^{b} (±10.12)	832^{b} (±4.40)	1329^{a} (±1.88)	1655.33^{c} (±1.76)	933.66^{a} (± 2.40)	1232.66^{c} (±2.96)
U2C1Z	5887^{a} (±11.15)	872.16^{a} (±1.13)	1338.23^{a} (±3.56)	1819.53^{a} (±1.53)	882.95^{a} (± 6.73)	1417^{a} (±3.60)
U3C2Z	5724^{b} (±11.15)	841.56^{b} (±5.70)	1335.23^{a} (±2.08)	1771.43^{b} (±3.93)	869.71^{a} (± 1.79)	1312^{b} (±0.57)
Second planting cycle of *Zea mays* L.						
T0	988^{c} (±2.15)	24^{d} (±1.50)	9.40^{d} (±0.45)	2.06^{d} (±0.21)	57.74^{d} (± 1.29)	185^{d} (±5.85)
U1	1219^{b} (±6.15)	724.96^{c} (±9.65)	1004.97^{c} (±1.34)	1208^{c} (±7.61)	717^{c} (± 1.44)	1004.33^{c} (±6.83)
U1Z	3874^{a} (±6.99)	850.86^{a} (±1.86)	1350.87^{a} (±1.86)	1537.53^{b} (±13.69)	844.24^{a} (± 2.40)	1388.67^{b} (±5.20)
U2C1Z	3899^{a} (±8.02)	822.93^{b} (±0.89)	1321.57^{b} (±1.01)	1321.57^{b} (±1.01)	762.19^{b} (± 2.49)	1383.67^{a} (±4.91)
U3C2Z	3914^{a} (±9.10)	817.90^{c} (±0.85)	1337.57^{a} (±5.80)	1724.87^{a} (±2.58)	742.95^{b} (± 1.80)	1329.33^{a} (±1.45)

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

crops but it also affects the level of nutrients in soils. Humic acids are also important in retaining soil available N and P, as well as exchangeable Ca, Mg, K, and Na because they increases soil cation and anion exchange capacity (Kulikova et al., 2005).

The large open channels in the crystal structure of the clinoptilolite zeolite is responsible for retention of soil exchangeable Ca, Mg, K, and Na in U1Z, U2C1Z, and U3C2Z as these open channels provide a large void space for sorption and exchange of Ca, Mg, K, and Na (Ramesh et al., 2010). Increase in soil available N and P, exchangeable Ca, Mg, K, and Na is also related to clinoptilolite zeolite because the clinoptilolite zeolite sorbed these nutrients, thus preventing them for being lost for example leaching. According to Abdi et al. (2006), natural zeolites have been extensively used to improve soil exchangeable NH_4^+, Ca, Mg, K, P, and Na in sandy and clay poor soils because of their sorption capacity.

Dry weight of aboveground biomass of *Zea mays* L. at seventy two days after planting (first and second planting cycles)

The dry weight of the aboveground biomass of *Zea mays* L. significantly higher in the plots with U1Z, U2C1Z, and U3C2Z compared with T0 and U1 (Figure 1) because of the availability of N, P, K, Ca, Mg, and Na in the plots of the former treatments (U1Z, U2C1Z, and U3C2Z) compared with the latter treatments (T0 and U1). This finding suggests the combined effect of chemical fertilizers, paddy husk compost, and clinoptilolite zeolite more beneficial than the use of chemical fertilizers only. The higher dry production in U2C1Z and U3C2Z was partly due to the residual effects of the paddy husk compost in these treatments. Mineralization and better availability of P, K, Ca, Mg, and Na from the paddy husk compost in U2C1Z and U3C2Z contributed to the increase in the *Zea mays* L. dry matter production (Amanuallah and Khalil, 2010). The clinoptilolite zeolite in U1Z, U2C1Z, and U3C2Z also affected the availability of N, Ca, Mg, K, and Na because the tiny pores in the clinoptilolite zeolite framework are large enough for NH_4^+, Ca^{2+}, Mg^{2+}, K^+, and Na^+ to be held on the cation-exchange sites of this mineral (Petrovic, 1990). As a results, NH_4^+, Ca^{2+}, Mg^{2+}, K^+, and Na^+ were released slowly and taken up by *Zea mays* L. similar to the way a slow-release fertilizer works. According to He et al. (2002), increase in dry weight of crops under co-application of chemical fertilizers and clinoptilolite zeolite was because clinoptilolite zeolite served as a control release fertilizer.

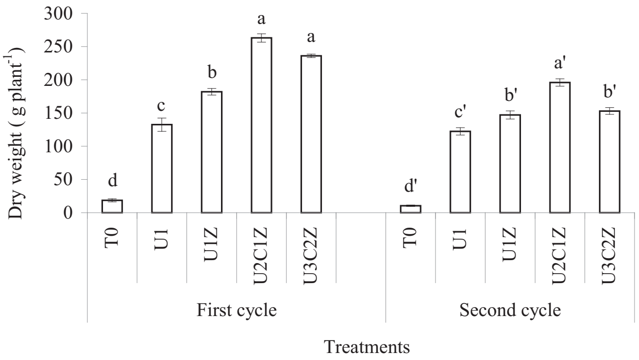

Fig. 1. Effects of treatments (T0, U1, U1Z, U2C1Z, and U3C2Z) on dry weight of *Zea mays* L. aboveground biomass at 72 days after planting for first and second cycles

Means with same letter are not significantly different by Tukey's test at $P \leq 0.05$. Letters without prime represents first cycle and single prime superscript represents second planting cycle

Nitrogen, phosphorus, potassium, calcium, magnesium, and sodium contents and uptake of *Zea mays* L. (first and second planting cycles)

There was no significant effect of U1, U1Z, U2C1Z, and U3C2Z on N concentration irrespective of planting cycle (Table 7). However, higher N uptake (stems and leaves) was observed in U1Z, U2C1Z, and U3C2Z compared with U1 in both of the first and second planting cycles (Table 7 and Figure 2). At 72 days after planting, plots with chemical fertilizers, paddy husk compost, and clinoptilolite zeolite (U1Z, U2C1Z, and U3C2Z) showed higher contents and uptake of P, K, Ca, Mg, and Na compared with the plots with soil alone (T0) and chemical fertilizers alone (U1) (Table 7, Figures 3, 4 and 5). The higher contents and uptake of N, P, K, Ca, Mg, and Na could be due to the timely retention of exchangeable N, Ca, Mg, K, and Na, and available P in soil (Table 6). Increase in soil CEC and availability of N, P, K, Ca, Mg, and Na in the soil with paddy husk compost and clinoptilolite zeolite in the two planting cycles of *Zea mays* L. suggest the residual effect of paddy husk compost and clinoptilolite zeolite treatments (U1Z, U2C1Z, and U3C2Z) as these amendments were applied in the first planting cycle only. According to Ngwira et al. (2013), the build-up of nutrients in soils following application of compost and inorganic fertilizers relates to increase in soil microbial biomass C and activities. Eghball (2002) confirmed that available P content in soils following compost application contributed to P uptake.

Table 7
Effects of treatments on nutrient contents in stems and leaves of *Zea mays* L. (first and second planting cycles)

Treatment	N	Ca	Mg	K	Na	P
	($mg\,kg^{-1}$) Mean (S.E.)					
First planting cycle of *Zea mays* L.						
T0	4213^{c} (±1.99)	6110^{e} (±1.15)	2114^{e} (±2.02)	11023^{d} (±5.78)	1105^{e} (± 2.02)	1046^{e} (±2.90)
U1	12431^{a} (±2.88)	7345^{d} (±2.02)	2392^{d} (±5.13)	19368^{c} (±1.76)	1341^{d} (± 3.48)	1534^{d} (±6.55)
U1Z	11465^{b} (±3.15)	8414^{ab} (±2.02)	2926^{a} (±1.76)	22488^{a} (±1.73)	1615^{a} (± 0.88)	3553^{a} (±6.06)
U2C1Z	12474^{a} (±2.02)	8422^{a} (±5.69)	2819^{b} (±4.61)	21444^{b} (±4.80)	1461^{b} (± 1.45)	3233^{b} (±5.60)
U3C2Z	12287^{a} (±2.15)	8115^{c} (±2.30)	2677^{c} (±3.28)	19975^{b} (±5.69)	1425^{c} (± 1.76)	2358^{c} (±2.08)
Second planting cycle of *Zea mays* L.						
T0	3988^{b} (±2.15)	6103^{d} (±2.18)	2105^{e} (±2.02)	10010^{e} (±1.15)	1005^{d} (± 1.20)	1023^{e} (±5.78)
U1	12453^{a} (±3.88)	7292^{c} (±5.13)	2384^{d} (±1.76)	19345^{d} (±2.02)	1334^{c} (± 1.45)	1467^{d} (±2.72)
U1Z	12446^{a} (±1.15)	8224^{a} (±2.05)	2916^{a} (±0.88)	22414^{a} (±2.02)	1613^{a} (± 2.66)	3448^{a} (±1.73)
U2C1Z	12887^{a} (±1.99)	8219^{a} (±1.15)	2730^{b} (±8.68)	21968^{b} (±5.19)	1432^{b} (± 4.09)	3161^{b} (±12.05)
U3C2Z	12987^{a} (±2.02)	7415^{b} (±2.30)	2560^{c} (±8.96)	19743^{c} (±6.35)	$1421b^{b}$ (± 1.73)	2128^{c} (±2.78)

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

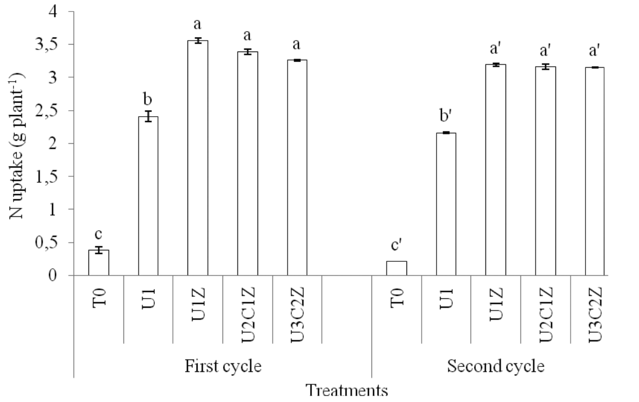

Fig. 2. Effect of treatments (T0, U1, U1Z, U2C1Z, and U3C2Z) on nitrogen uptake of *Zea mays* L. aboveground biomass at 72 days after planting for first and second cycles

Means with same letter are not significantly different by Tukey's test at P ≤ 0.05. Letters without prime represents first cycle and single prime superscript represents second planting cycle

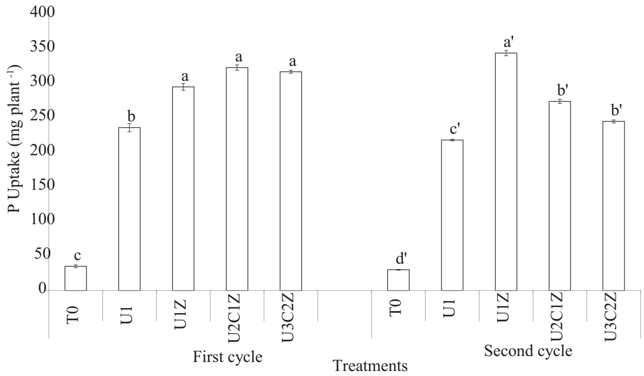

Fig. 3. Effect of treatments (T0, U1, U1Z, U2C1Z, and U3C2Z) on phosphorus uptake of *Zea mays* L. aboveground biomass at 72 days after planting for first and second cycles

Means with same letter are not significantly different by Tukey's test at P ≤ 0.05. Letters without prime represents first cycle and single prime superscript represents second planting cycle

Number of grains per cob and yield of *Zea mays* L. at seventy two days after planting (first and second planting cycles)

The plots with chemical fertilizers, paddy husk compost, and clinoptilolite zeolite (U1Z, U2C1Z, and U3C2Z)) significantly improved the number of grains per cob and cob yield of *Zea mays* L. compared with chemical fertilizers only (U1) irrespective planting cycle (Table 8) because the plots which

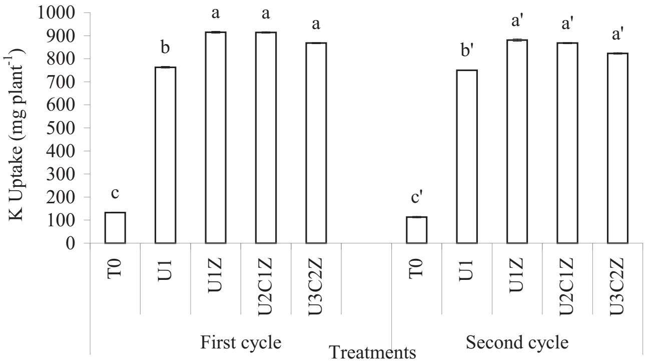

Fig.4. Effect of treatments (T0, U1, U1Z, U2C1Z, and U3C2Z) on potassium uptake of *Zea mays* L. aboveground biomass at 72 days after planting for first and second cycles

Means with same letter are not significantly different by Tukey's test at P ≤ 0.05. Letters without prime represents first cycle and single prime superscript represents second planting cycle

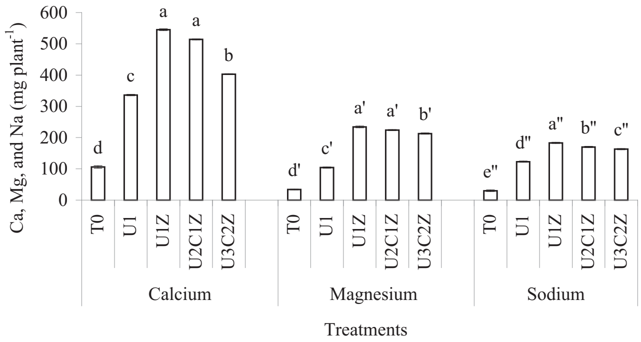

Fig. 5. Effect of treatments (T0, U1, U1Z, U2C1Z, and U3C2Z) on calcium, magnesium, and sodium uptake of *Zea mays* L. aboveground biomass at 72 days after planting for first cycle (above) and second cycle (below)

Means with same letter are not significantly different by Tukey's test at P ≤ 0.05. Letters without prime represents calcium, single prime superscript represents magnesium, and double prime superscript represents sodium

received paddy husk compost and clinoptilolite zeolite improved nutrients availability (Table 6). The availability of N, P, K, Ca, Mg, and Na in the soil contributed to higher N, P, K, Ca, Mg, and Na uptake and use efficiency in the *Zea mays* L. aboveground biomass (Table 7). The availability of these nutrients for timely utilization by the *Zea mays* L. was partly due to the temporary retention of soil exchangeable NH_4^+, Ca, Mg, K, Na, and available P in the plots with U1Z, U2C1Z, and U3C2Z.

Table 8
Effects of treatments on number of grains in cob and grain yield of *Zea mays* L. at 72 days after planting

Treatment	No. of grains in cob	Weight of cobs
	Cob^{-1}	kg $plot^{-1}$
First planting cycle of *Zea mays* L. Mean (S.E.)		
T0	241^{d} (±7.72)	1.46^{c} (±0.17)
U1	568^{c} (±4.40)	4.23^{b} (±0.08)
U1Z	729^{b} (±8.18)	6.40^{b} (±0.40)
U2C1Z	740^{a} (±10.68)	7.13^{a} (±0.17)
U3C2Z	718^{b} (±4.66)	6.96^{a} (±0.06)
Second planting cycle of *Zea mays* L.		
T0	209^{d} (±1.76)	1.13^{c} (±0.17)
U1	555^{c} (±4.05)	4.00^{b} (±0.08)
U1Z	703^{a} (±8.17)	5.86^{a} (±0.40)
U2C1Z	706^{b} ±5.54)	6.36^{a} (±0.21)
U3C2Z	692^{b} (±2.78)	5.06^{a} (±0.08)

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

According to Iqbal et al. (2014) compost gave maximum increase in *Zea mays* L. cob size compared with mineral fertilizers. While Amanuallah and Khalil (2010) opined that such effect was due to better *Zea mays* L. cob development on account of improved supply of N, P, K, Ca, Mg, and Na following compost application. This finding suggests that the use of paddy husk compost and clinoptilolite zeolite in this study is an effective amendment and carrier of crop nutrients such as N, P, K, Ca, Mg, and Na. Bagdasarov et al. (2004) reported that clinoptilolite zeolite serves as stabilizers and regulators of mineral fertilizers besides being source of nutrients such as P, K, Ca, Mg, and Na. As carriers of N and K fertilizers, the clinoptilolite zeolite increase N and K efficacy by decreasing application rates for equal yields to be achieved (Polat et al., 2004) as can be seen in U2C1Z and U3C2Z in this study. This implies that one time application of paddy husk compost and clinoptilolite zeolite could be sufficient to sustain two cropping cycles of *Zea mays* L. but may not be beneficial in long term.

Conclusions

Co-application of chemical fertilizers with paddy husk compost and clinoptilolite zeolite improved nutrients use efficiency through temporary retention of soil exchangeable cations on the exchange sites of paddy husk compost and clinoptilolite zeolite thus, increasing grain yield of *Zea mays* L. compared with the use of chemical fertilizers alone. The combination of chemical fertilizers, paddy husk compost, and clinoptilolite zeolite also improved N, P, K, Ca, Mg, and Na concentrations and uptake in stems and leaves of *Zea mays* L. compared with chemical fertilizers alone. The higher retention of soil N, P, K, Ca, Mg, and Na in the two planting cycles of *Zea mays* L. of this present study suggests loading or build-up of these nutrients in the plots with chemical fertilizers, paddy husk compost, and clinoptilolite zeolite hence, increase grain yield of *Zea mays* L. compared with chemical fertilizers only. Through short-term effects on enhances nutrients availability and uptake, improving nutrients use efficiency, and increase grain yield of *Zea mays* L., application of chemical fertilizers, paddy husk compost, and clinoptilolite zeolite have an important role in soil fertility management in the tropic acid soils. Thus, introducing cost effective such as paddy husk compost and clinoptilolite zeolite could improve nutrients use efficiency and availability of crop nutrients while complementing existing nutrient management practices would be a best management practice.

Acknowledgments

The authors gratefully acknowledge the financial support (Exploratory Research Grant Scheme) from the Ministry of Higher Education Malaysia and Universiti Putra Malaysia for the collaborative research.

References

Abdi, G. H., M. Khosh-Khui and S. Eshghi, 2006. Effects of natural zeolite on growth and flowering of strawberry (Fragariaxananassa Duch.). *Intern. J. Agric. Res.*, 1: 384-389.

Amanuallah, M. Z. and S. K. Khalil, 2010: Timing and rate of phosphorus application influence maize phenology, yield and profitability in Northwest Pakistan. *Intern. J. Plant Prod.*, **4** (4): 283-294.

Anda, M., J. Shamshuddin, C. I. Fauziah and S. R. Syed Omar, 2008. Mineralogy and factors controlling charge development of three Oxisols developed from different parent materials. *Geoderma*, 143: 153-167.

Bagdasarov, V. R., A. A. Kazachenko, M. K. Rustambekov, B. G. Uspenskij, V. V. Kuznetsova and E. N. Efremov, 2004. Prolonged-activity nitrogen-zeolite fertilizer, Russia. 2222514 C2 20040127.

Bremner, J. M., 1965. Total nitrogen. In: C. A. Black, D. D. Evans, L. E. Ensminger, J. L. White, F. E. Clark and R. C. Dinauer (Eds.) Method of Soil Analysis, Part 2., *American Society of Agronomy,* Madison, WI, pp. 1149-1178.

Butorac, A., T. Filipan, F. Basic, J. Butorac, M. Mesic and

I. Kisic, 2002. Crop response to the application of special natural amendments based on zeolite tuff. *Rostlinná Výroba*, 48: 118-124.

Daković, A., M. Tomašević-Čanović, E. G. Rottinghaus, S. Matijašević and Z. Sekulić, 2007. Fumonisin B1 adsorption to octadecyldimetylbenzyl ammonium-modified clinoptilolite-rich zeolitic tuff. *Micro. Meso. Mat.,* 105: 285-290.

Delin, S., A. Nyberg, B. Lindén, M. Ferm G. Torstensson and I. Lerenius, 2008. Impact of crop protection on nitrogen utilisation and losses in winter wheat production. *Europ. J. Agron.*, 28: 361-370.

Eghball, B., 2002. Soil properties as influenced by phosphorus- and nitrogen-based manure and compost applications. *Agron. J.,* 94: 128-135.

Fageria, N. K. and V. C. Baligar, 2005. Enhancing nitrogen use efficiency in crop plants. *Adv. Agron.*, 88: 97-185.

Garcia-Gil, J. C., C. Plaza, P. Soler-Rovira and A. Polo, 2000. Long-term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. *Soil Bio. Biochem.,* 32: 1907-1913.

Gil, M. V., M. T. Carballo and L. F. Calvo, 2007. Fertilization of maize with compost from cattle manure supplemented with additional mineral nutrients. *Waste Manag.*, 28: 1432-1440.

He, Z. L., D. V. Calvert, A. K. Alva, Y. C. Li and D. J. Banks, 2002. Clinoptilolite zeolite and cellulose amendments to reduce ammonia volatilization in a calcareous sandy soil. *Plant Soil*, 247: 253-260.

Iqbal, S., H. Z. Khan and M. Yaseen, 2014. Impact of level and source of compost based organic material on the productivity of autumn maize (*Zea mays* L.). *Pak. J. Agric. Sci.,* **51** (1): 41-47.

John, N. M., D. F. Uwah, O. B. Iren and J. F. Akpan, 2013. Changes in maize (*Zea mays* L.) performance and nutrients content with the application of poultry manure, municipal solid waste and ash compost. *J. Agric. Sci.*, 5: 270-272.

Kaur, T., S. S. Brar and N. S. Dhillon, 2008. Soil organic matter dynamics as affected by long-term use of organic and inorganic fertilizers under maize–wheat cropping system. *Nutr.Cycl. Agroecosys.*, 81: 59-69.

Keeney, D. R. and D. W. Nelson, 1982. Nitrogen-inorganic forms. In: A. G. Page, D. R. Keeney, D. E. Baker, R. H. Miller and J. D Rhoades (Eds), Method of Soil Analysis, part 2. Agron. Monogr. 9, *ASA and SSSA*, Madison, Wisconsin.

Kulikova, N. A., E. V. Stepanova and O. V. Koroleva, 2005. Mitigating activity of humic substances: direct influence on biota. In: I. V. Perminova, K. Hatfield and N. Hertkorn (Eds.), Use of Humic Substances to Remediate Polluted Environments: From Theory to Practice. Chapter 14, *Springer*, Netherlands, ISBN: 978-1-4020-3250-9, pp: 285-309.

Latifah, O. O. H. and N. M. A. Majid, 2015. Compost maturity and nitrogen availability by co-composting of paddy husk and chicken manure amended with clinoptilolite zeolite. *Waste Manag. Res.,* **34** (4): 1-10.

Lebedynets, M., M. Sprynskyy, I. Sakhnyuk, R. Zbytniewski, R. Golembiewski and B. Buszewski, 2004. Adsorption of ammonium ions onto a natural zeolite: transcarpathian clinoptilolite. *Adsorp. Sci. Techn.,* 22: 731-741.

Malaysia Agriculture Research and Development (MARDI), 1993: Jagung Manis Baru (New Sweet Corn): Masmadu, Malaysia Agriculture Research and Development (MARDI), Mardi, Kuala Lumpur.

Ming, D. W. and J. B. Dixon, 1986. Clinoptilolite in South Texas soils. *Soil Sci. Soc. Am. J.*, 50: 1618–1622.

Murphy, J. and R. I. Riley, 1962. A modified single solution method for the determination of phosphate in natural waters. *Analy. Chim. Acta*, 27:31-36.

Mylavarapu, R.S. and G.M. Zinati, 2009. Improvement of soil properties using compost for optimum parsley production in sandy soils. *Sci. Horti.,* 120: 426-430.

Najafinezhad, H., Z. T. Sarvestani, S. A. M. Sanavy and H. Naghavi, 2014. Effect of irrigation regimes and application of barley residue, zeolite, and superabsorbent polymer on forage yield, cadmium, nitrogen and some physiological traits of corn and sorghum. *Intern. J. Biosci.*, 3: 234-245.

Ngwira, A. M., M. Nyirenda and D. Taylor, 2013. Towards sustainable agriculture: an evaluation of compost and inorganic fertilizer on soil nutrient status and productivity of three maize varieties across multiple sites in Malawi. *Agroeco. Sustain. Food Syst.,* **37** (8): 859-881.

Nielsen, R. L., 2006. N loss mechanisms and nitrogen use efficiency. Handout for 2006. Purdue nitrogen management workshop.

http://www.agry.purdue.edu/ext/pubs/2006. Loss Mechanisms. pdf. (retrieved on 2nd February, 2015)

Paramananthan, S., 2000. Soil of Malaysia: Their Characteristics and Identification, Malaysia. Vol. 1, *Academy of Sciences Malaysia*, Kuala Lumpur, Malaysia, ISBN:9839445065, pp.11-125.

Pedra, F., C. Plaza C, J. C. Garcia-Gil and A. Polo, 2008. Effects of municipal waste compost and sewage sludge on proton binding behavior of humic acids from Portuguese sandy and clay loam soils. *Biores. Techn.*, 99: 2141-2147.

Petrovic, A. M., 1990. The potential of natural zeolite as a soil amendment. *Golf Course Manag.*, **58** (11): 92-94.

Polat, E., M. Karaca, H. Demir and A. Naci-Onus, 2004. Use of natural zeolite (clinoptilolite) in agriculture. *J. Fruit Orna. Plant Res.*, 12: 183-189.

Ramesh, K., A. K. Biswas, J. Somasundaram and A. Subba Rao, 2010. Nanoporous zeolites in farming: Current status and issues ahead. *Current Sci.*, **99** (6): 760-765.

Raviv, M., 2005. Production of high quality compost for horticultural. *Hortitechnology*, 15 (1): 52-57.

Richter, J. and M. Roelcke, 2000. The N-cycle as determined by intensive agriculture examples from central Europe and China. *Nutr. Cycl. Agroecosys.*, 57: 33-46.

Ros, M., S. Klammer, B. Knapp, K. Aichberger and H. Insam, 2006. Long term effects of compost amendment of soil on functional and structural diversity and microbial activity. *Soil Use Manag.,* 22: 209-218.

Sanchez-Monedero, M. A., J. Cegarra, D. Garcia and A. Roig, 2002. Chemical and structural evolution of humic acids during organic waste composting. *Biodegradation*, 13: 361-371.

Sarawak Meteorological Department, 2014. Records of Daily Total Rainfall Amount at Bintulu. Malaysian Meteorological Department, *Ministry of Sciences, Technology, and Innovation*, Kuala Lumpur, Malaysia.

Shamshuddin, J. and N. W. Daud, 2011. Classification and management of highly weathered soils in Malaysia for productionof plantation crops. In: E. Burcu and G. Ozkaraova (Eds.) Principles, Application and Assessment in Soil Science. *In Tech Europe*, Rijeka, Croatia, ISBN: 978-953-307-740-6, pp. 75-86.

Soil Survey Staff, 2014. Soil survey of Larimer County, CO, U.S. USDA-NRCS Soil Survey. *U.S. Gov. Print. Office*, Washington, D. C.

Stevens, W. B., R. G. Hoeft and R. L. Mulvaney, 2005. Fate of N15 in a long-term nitrogen rate study: II. Nitrogen uptake efficiency. *Agron. J.*, 97: 1046-1053.

Tan, K. H. 2003. Principles of Soils Chemistry.4th ed, *CRC Press: Taylor & Francis Group*; Boca Raton.

Tan, K. H. 2005: Soil Sampling, Preparation, and Analysis, 2nd edition. *CRC Press*, Boca Raton, Florida, USA.

Zhu, J. G., Y. Han, G. Liu, Y. L. Zhang and X. H. Shao, 2000. Nitrogen in percolation water in paddy fields with a rice/wheat rotation. *Nutr. Cyc. Agroecosys.,* 57: 75-82.

Received February, 12, 2017; accepted for printing May, 2, 2017