International Journal of the Physical Sciences Vol. 5(15), pp. 2393-2401, 18 November, 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 ©2010 Academic Journals

Full Length Research Paper

Use of zeolite in maize (*Zea mays*) cultivation on nitrogen, potassium and phosphorus uptake and use efficiency

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Accepted 05 November, 2010

Concerns about unbalanced use of fertilizers leading to environmental pollution have been globally expressed. As a result, studies on how to use efficient methods to reduce nutrient applications at the same time increasing or maintaining crop yield, reducing nutrient losses and improving nutrient use efficiency are imperative. Nutrient loss due to leaching, volatilization and fixation upon fertilizer application to soils may be reduced through the use of slow-release fertilizers. A pot study was conducted to investigate if the use of inorganic fertilizers together with zeolite will improve nitrogen (N), phosphorus (P) and potassium (K) uptake and efficiency in maize *(Zea mays)* cultivation on Nyalau series (Typic Paleudalts). Maize hybrid no. 5 variety was used as test crop. Treatments evaluated were: (i) Unfertilized condition (T1), (ii) normal N, P and K application (7.4 g urea + 11.3 g Christmas Island rock phosphate (CIRP) + 3.8 g muriate of potash (MOP)) (T2), (iii) 135 g zeolite + 5.92 g urea+9.0 g CIRP + 3.0 g MOP (T3), (iv) 270 g zeolite + 4.44 g urea + 6.8 g CIRP + 2.3 g MOP (T4), (v) 405 g zeolite+3.0 g urea+4.5 g CIRP+1.5 g MOP (T5) and (vi) 540 g zeolite + 1.5 g urea + 2.3 g CIRP + 0.8 g MOP (T6). The effect of T2, T3, T4, T5 and T6 on soil N, P and Mg at harvest was not significantly different compared with T1. However, treatments with zeolite significantly increased K and Ca contents of soil compared to T1. Irrespective of treatment, dry matter production was not different. However, nutrient concentrations determined in plant tissues were clearly affected by the addition of zeolite. N, P and K uptake varied significantly but T6 significantly affected N, P and K use efficiency. The use of inorganic fertilizers mixed with zeolite remarkably increased N, P and K uptake, and their use efficiency in leaves, stem and roots. The use of zeolite could be beneficial with respect to nutrient retention in soil and their use efficiency.

Key words: Zeolite, inorganic fertilizers, nutrient uptake, nutrient use efficiency, *Zea mays.*

INTRODUCTION

In recent times, concerns about unbalanced use of fertilizers leading to environmental pollution have been globally expressed. As a result, studies on how to use efficient methods to reduce nutrient applications at the same time increasing or maintaining crop yield, reducing nutrient losses and improving nutrient use efficiency are imperative (Oosterhuis and Howard, 2008). For instance, sustainable nutrient use efficiency could be attained by agronomic practices which take into account timely synchronization of nutrient application with plant roots development, or use of slow-release fertilizers, and foliar feeding (Matson et al., 1997; Oosterhuis and Howard, 2008). One of the merits of this approach of efficient

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Table 1. Treatments evaluated on hybrid no. 5 variety used as test crop.

Treatment	Zeolite (g)	Urea (g)	CIRP (g)	MOP (g)
T1	0	0.00	0.0	0.0
T2	0	7.40	11.3	3.8
T3	135	5.92	9.0	3.0
T4	270	4.44	6.8	2.3
T5	405	3.00	4.5	1.5
T6	540	1.50	2.3	0.8

synchronization of soil nutrient application with good root system development for nutrient uptake is that it ensures reduction of erosion and nutrient loss through leaching (Jagadeeswaran et al., 2005; Perez-Caballero et al., 2008; Glisic and Milosevic, 2008). In this regard, inclusion of zeolites in fertilizers management for agriculture is essential as besides serving as soil conditioner (including soil fertility improvement), zeolites have the potential to increase crop yield (Valente et al., 1982; Noori et al., 2006).

Utilization of zeolites in agriculture is possible because of their special cation exchange properties, molecular sieving and adsorption (Mumpton, 1999; Glisic and Milosevic, 2008; Hecl and Toth, 2009). It is believed that because zeolites have the ability to lose and gain water reversibly, without the change of crystal structure, they could be used as fertilizers, stabilizers and chelators (Kapetanios and Loizidou, 1992; Perez-Caballero et al., 2008). As an example, a study has shown that zeolites enable both inorganic and organic fertilizers to slowly release their nutrients (Perez-Caballero et al., 2008). However, there is dearth of information on the right amount of zeolites to be used with for instance inorganic and organic fertilizers. In this study, it was expected that the right proportion of inorganic fertilizers and zeolite will improve nutrient uptake and use efficiency of corn on Typic Paleudalts (Nyalau series) soils. Although, nutrient uptake and use efficiency of corn seems to be dependent on soil fertility, the effect of zeolite on the slow release of nitrogen (N), phosphorus (P) and potassium (K) is yet to be investigated. The objective of this study was to investigate if the use of inorganic fertilizers together with zeolite will improve N, P and K uptake and use efficiency in maize cultivation on an acid soil.

MATERIALS AND METHODS

A pot study was conducted in a rain shelter at University Putra Malaysia Bintulu Campus of Sarawak, Malaysia. The experimental design was randomized complete block design with three replications. The test crop in this study was super sweet corn hybrid number 5 variety. The selected variety was tested with the treatments summarized in Table 1.

The amounts of urea, Christmas Island Rock Phosphate (CIRP) and Muriate of Potash (MOP) used were based on the standard recommendation for the test crop (Hybrid number 5 variety). It must be noted that the rates used in this study were a scale down of the standard fertilizer recommendation for the test crop. Soil in pots was mixed with clinoptilolite zeolite according to the treatments in Table 1. Inorganic fertilizer was prepared by first weighing the 3 materials for treatments T2 to T6 separately into plastic vials, tightly closed and shaken on an orbital shaker at 150 rpm for 30 min for uniform mix.

The soil used was coarse loamy, siliceous, isohyperthermic, red-yellow to yellow Typic Paleudalts (Nyalau series) (Paramanathan, 2000). Based on the soil's bulk density, plastic pots measuring 22 cm (height) × 30 cm (diameter) were filled with soil samples until the bulk density of the soil was attained. Each pot was filled with 9 kg soil (air-dried, crushed and sieved to pass a 2 mm sieve). For good plant establishment, the maize seeds were soaked in water for 24 h prior to planting. The depth of the planting holes was 4 cm. Seeds were sown directly in each planting hole. The planting holes were partially covered with loose soil from the surface to allow quick emergence of the seeds. There were five seeds per pot and they were thinned to three at 7 days after seeding (DAS). Soil moisture was maintained at field capacity.

A fertilizer rate of 60 N kg/ha, 60 P kg/ha and 40 K kg/ha for the maize was followed, MARDI (Malaysia Agriculture Research Development Institute) recommendation and applied in two equal splits at 10 and 28 DAS. The fertilizers used were urea (46% N), CIRP (30% P_2O_5) and MOP (60% K_2O).

Prior to the commencement of the experiment, soil samples were analyzed for bulk density (Tan, 2005), soil texture (Bouyoucos, 1962), pH in water and 1 M KCl (Peech, 1965), total N (Bremmer, 1965), exchangeable K, Mg and Ca (Tan, 2005), P, and cation exchange capacity (CEC) (Cottenie, 1980). The bulk density of the Nyalau series was 0.956 g/cm^3 and was typical of this soil series. Standard procedures were used to determine the selected chemical properties of zeolite, CIRP, MOP and urea. The pH of the urea, zeolite, CIRP and MOP was determined in a 1:2.5 soil: distilled water suspension and/or 1 N KCl using a glass electrode. The CEC of the zeolite was determined by the CsCl method of Ming and Dixon (1986).

The plants were monitored for 60 days. At tasseling (60 DAS), the plants were harvested and partitioned into leaves, roots and stems. Standard procedures were used to dry these parts for dry weight determination. At tasseling (60 DAS), soil samples were taken and analyzed for N, P, K, Ca, Mg, organic matter, pH, and CEC as previously outlined. Nitrogen concentration in the selected plant parts was determined by the Kjeldahl ((Bremmer, 1965) while the single dry ashing method (Cottenie, 1980) was adopted for the extraction of P, K, Ca, and Mg in the plant tissues. The filtrates were analyzed for K, Ca, and Mg by Atomic absorption spectrophotometry (AAS) and UV-spectrometer for P. The concentrations of N, P and K in the plant parts multiplied by their dry matter gave the amount of N, P and K taken up by the plant parts. Nitrogen, P, and K use efficiency were calculated using the

Table 2. Selected physico-chemical properties of Nyalau series and zeolite before planting.

Physico-chemical properties	Values
pH (in water)	4.68
pH (in KCl)	3.47
CEC (cmol (+)/kg) soil	8.6
Bulk density (g/cm^3)	0.955
Texture	Sandy clay loam
Clay (%)	24.1
Silt (%)	23.3
Sand (%)	52.6
Total N (%)	0.14
Available P (mg/kg) soil	trace
Exchangeable K^+ (mg/kg) soil	959.74
Exchangeable Ca^{2+} (mg/kg) soil	476.543
Exchangeable Mg^{2+} (mg/kg) soil	86.771

Table 3. Physico-chemical properties of Nyalau series after planting.

Physico-chemical properties	Treatment					
	T1	T2	T3	T4	T5	T6
pH (water)	4.61^a	4.90^{ab}	5.13^{bc}	5.25^c	5.22^{bc}	5.05^{bc}
pH (KCl)	3.67^a	3.86^b	3.89^b	3.92^b	3.82^{ab}	3.76^{ab}
CEC	8.82^a	10.16^{ab}	11.94^{bc}	10.38^{ab}	15.17^d	14.48^{cd}
Total N (%)	0.14^{ab}	0.13^{ab}	0.11^b	0.16^a	0.13^{ab}	0.15^a
Available P (mg/kg)	Trace^b	66.56^{ab}	102.72^{ab}	140.34^a	27.48^{ab}	65.99^{ab}
Exchangeable K^+ (mg/kg)	52.70^a	264.50^a	272.20^a	660.40^b	1057.00^c	1054.90^c
Exchangeable Ca^{2+} (mg/kg)	506.36^a	640.93^b	850.71^c	1012.84^d	1185.29^e	1295.31^f
Exchangeable Mg^{2+} (mg/kg)	102.51^a	107.96^a	84.87^a	87.64^a	89.73^a	106.11^a

Means with different alphabets in column indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

subtraction method stated below (Pomares-Gracia and Pratt, 1987).

% FE = (TNF – TNU) ÷ RFA x 100

Where, TNF = total nutrient uptake of fertilized plants (T2, T3, T4, T5 and T6), TNU = total nutrient uptake of unfertilized plants (T1), RFA = rate of fertilizer nutrient applied.

The data were analyzed statistically by analysis of variance to detect treatment effect. Means of treatments was compared using Duncan's Multiple Range Test DMRT). The statistical software used was Statistical Analysis System (SAS) version 9.1.

RESULTS AND DISCUSSION

The selected physico-chemical properties of Nyalau series are presented in Table 2. The soil pH (water and KCl) and CEC before planting were 4.68, 3.47 and 8.6 cmol kg^{-1}, respectively. Regardless of treatment, soil texture, CEC, bulk density, pH, total N and exchangeable K, Mg and Ca, were typical of Nyalau series (Paramanathan, 2000). The soil pH (water and KCl) and CEC of zeolite were 6.84, 5.48 and 105 cmol kg^{-1}, respectively and they were also consistent with those reported in the literature (He et al., 2002; Ahmed et al., 2008).

The soil pH, CEC, total N, available P, exchangeable K, Ca and Mg after harvest under fertilized and unfertilized conditions are presented in Table 3. At harvest, the CEC and pH (water and KCl) for the treatment without fertilizer (T1) were 8.82 cmol (+)/kg, 4.613 and 3.665, respectively, while these variables were significantly affected by T3, T4, T5 and T6. This finding is consistent with some studies who also reported that addition of zeolite usually increases soil pH (Noori et al., 2006; Perez-Caballero et al., 2008). Zeolites are known for not being acidic but marginally alkaline and this is one of the reasons why when they are used with fertilizers they help to buffer soil pH, thus reducing the need for liming

Table 4. Dry weight (DW), N, P, K, Ca, and Mg concentrations in leaves, roots, and stems of maize hybrid no.5 variety.

Treatments	Leaves						Stem						Roots					
	DW	N	P	K	Ca	Mg	DW	N	P	K	Ca	Mg	DW	N	P	K	Ca	Mg
	(g)	(%)					(g)	(%)					(g)	(%)				
T1	6.175^{a}	0.800^{a}	0.063^{a}	1.973^{a}	0.157^{a}	0.170^{abc}	9.546^{a}	0.383^{a}	0.050^{a}	0.723^{c}	0.033^{a}	0.100^{b}	3.787^{a}	0.427^{bc}	0.053^{a}	0.697^{bc}	0.010^{c}	0.093^{ab}
T2	5.857^{a}	1.616^{b}	0.160^{b}	2.570^{a}	0.157^{a}	0.133^{c}	9.124^{a}	0.570^{a}	0.090^{a}	2.673^{a}	0.043^{a}	0.107^{b}	3.269^{a}	0.550^{abc}	0.107^{a}	0.933^{b}	0.040^{a}	0.110^{a}
T3	6.692^{a}	1.823^{b}	0.110^{a}	2.750^{a}	0.463^{a}	0.143^{bc}	10.918^{a}	1.147^{b}	0.080^{a}	2.720^{a}	0.047^{a}	0.153^{a}	4.345^{a}	0.213^{c}	0.097^{a}	0.740^{bc}	0.027^{b}	0.103^{ab}
T4	6.458^{a}	1.447^{ab}	0.090^{a}	2.607^{a}	0.200^{a}	0.150^{bc}	9.234^{a}	0.883^{ab}	0.073^{a}	2.303^{a}	0.033^{a}	0.123^{ab}	4.002^{a}	0.787^{ab}	0.073^{a}	1.293^{a}	0.023^{bc}	0.090^{ab}
T5	6.819^{a}	1.223^{ab}	0.077^{a}	2.736^{a}	0.287^{a}	0.190^{ab}	9.816^{a}	0.460^{a}	0.050^{a}	1.953^{ab}	0.047^{a}	0.117^{ab}	3.812^{a}	0.647^{ab}	0.073^{a}	0.747^{bc}	0.023^{bc}	0.080^{ab}
T6	7.391^{a}	0.830^{a}	0.070^{a}	2.793^{a}	0.277^{a}	0.203^{a}	14.657^{a}	0.523^{a}	0.063^{a}	1.263^{bc}	0.043^{a}	0.087^{b}	4.486^{a}	0.850^{a}	0.113^{a}	0.430^{c}	0.017^{bc}	0.070^{b}

Means with different alphabets in row indicate significant difference between treatments by Duncan's test at $P \leq 0.05$.

(Mumpton, 1999). The significant effect of T3, T4, T5 and T6 on CEC could be due to the addition of zeolite (Table 2). This observation was comparable with those reported by other authors (He et al., 2002; Huang and Petrovic, 1994).

Irrespective of treatment, the soil total N and exchangeable Mg at harvest were not significantly different (Table 3). It should be noted that T4 and T6 (treatments with higher amounts of zeolite) showed the highest soil N content, which was approximately 0.16%. Except for T4, the effect of T2, T3, T5 and T6 on soil available P content was not significant compared with T1. Soil exchangeable K and Ca contents of all the treatments with fertilizer significantly increased compared to T1. Treatments with zeolite marginally increased soil N compared to T1, because zeolite has the capacity to reduce nitrate and ammonium from leaching (Perez-Caballero et al., 2008). Treatments with zeolite improved P, K and Ca concentrations in the soil because the zeolite also has the ability to adsorp these nutrients from the fertilizers used as well as reducing leaching in the soil. Increase in soil pH due to zeolite application may have also contributed to these nutrients availability in the soil.

The dry weight (DW) and N, P, K, Ca, and Mg concentrations of maize hybrid 5 leaves, roots and stems under unfertilized and fertilized conditions are presented in Table 4. Irrespective of treatment, the test crop dry matter production (leaves, stems and roots) was not statistically different. Except for T6, N concentration in leaves differed significantly compared with T1. In the case of stem, N concentration except for T3 (highest concentration of 1.823%), the other treatments showed no significant difference compared to T1. Nitrogen concentration in roots was statistically similar to that of T2. However, plants of T6 accumulated the highest N concentration in plant tissues compared to T1. The differences in P and Ca concentrations in leaves, stems and roots for all the treatments were not statistically significant. Comparatively, leaves and stems tissues had the highest P and Ca concentrations for T2 and T3, respectively. Potassium contents in leaves and roots were not significant and the opposite was true for K content in stems. Except for stems where the effect of T3 was significant, there was no significant difference in Mg content in all of the plant tissues.

Regardless of plant portion (leaves, stem and roots), T2, T3, T4, T5 and T6 significantly improved N, P and K uptake compared with T1 (Figures 1 to 9). Among these treatments (except for T2 in terms of N uptake in leaves), T3 and T6 improved N, P and K uptake in leaves and stems while the effect of T1 resulted in the lowest uptake. Nitrogen and P uptake in roots was highest for T6, but the opposite was true for K uptake, where T4 showed the highest uptake. Low N and P uptake in roots was recorded for T3 and T1, respectively.

The influence of treatments on N, P and K use efficiency in leaves, stem and roots are shown in Table 5. T6 showed the best N, P and K use efficiency in plant tissues, except for N use efficiency in leaves and K use efficiency in roots, where T3 and T4 were the best. From Table 5, it is obvious that application of chemical fertilization alone (T2) resulted in lower nutrient use efficiency compared with treatments with using zeolite. Furthermore, low P use efficiency in leaves (0.028%) and roots (0.011%) was recorded for T4 (0.028%). Nitrogen and K use efficiency in roots was negative for T3 and T6, respectively. In terms of overall nutrient use efficiency of maize hybrid 5 variety, T6 improved N, P and K use efficiency significantly (Table 6). The general lack of significant difference in nutrient concentrations in the plant tissues irrespective of zeolite dose (Table 3) could be attributed to dilution effect (Mengel and Kirkby, 1996). In soil-plant system,

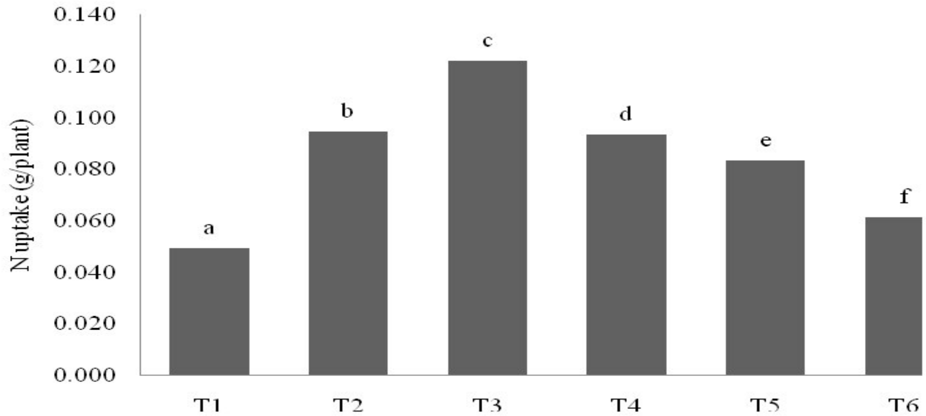

Figure 1. Effect of treatments on N uptake in leaves of maize hybrid number 5 variety. Means with different alphabets indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

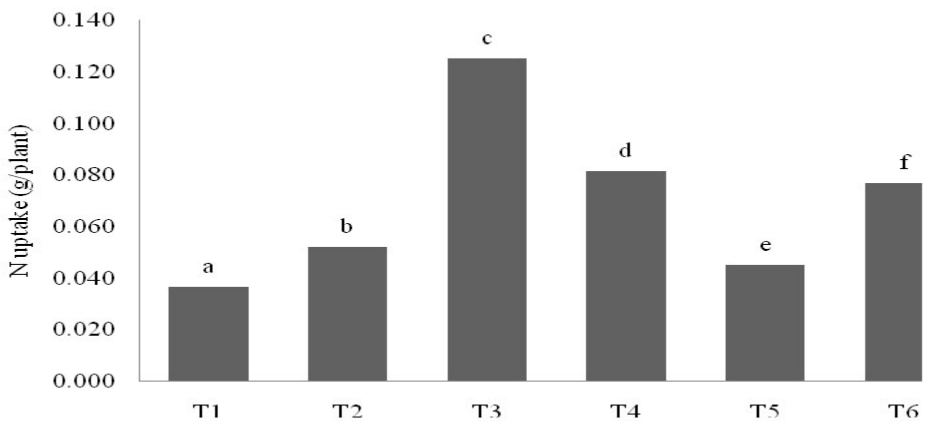

Figure 2. Effect of treatments on N uptake in stem of maize hybrid number 5 variety. Means with different alphabets indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

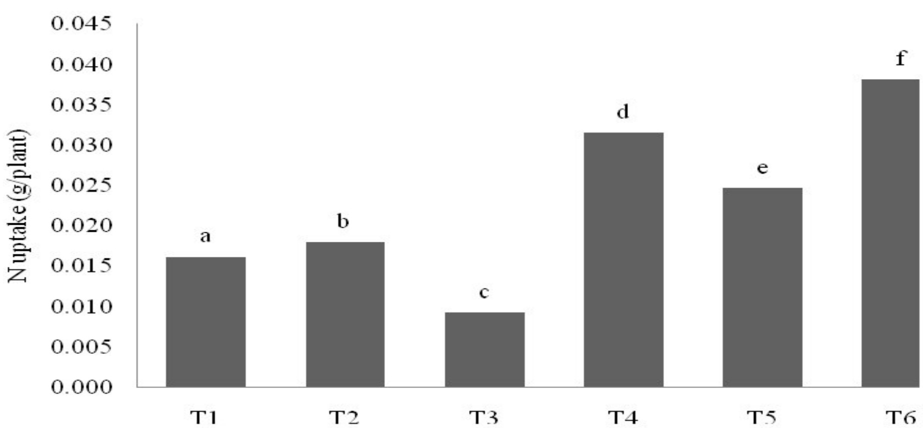

Figure 3. Effect of treatments on N uptake in roots of maize hybrid number 5 variety.Means with different alphabets indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

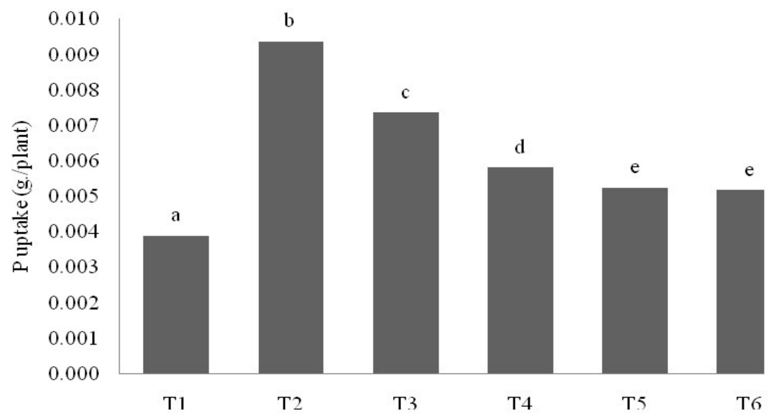

Figure 4. Effect of treatments on P uptake in leaves of maize hybrid number 5 variety. Means with different alphabets indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

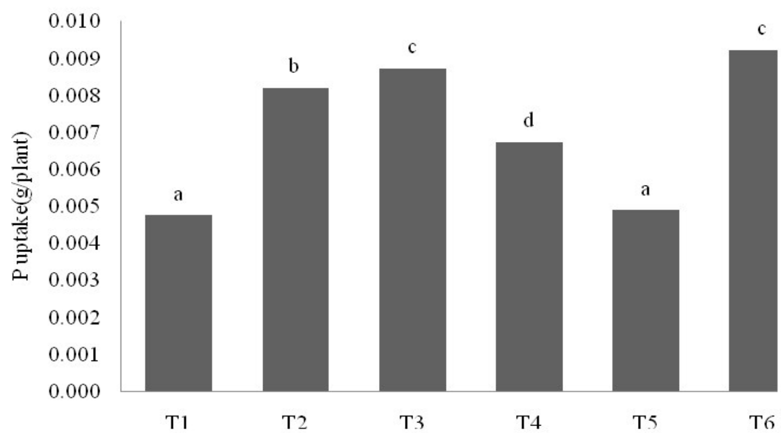

Figure 5. Effect of treatments on P uptake in stem of maize hybrid number 5 variety. Means with different alphabets indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

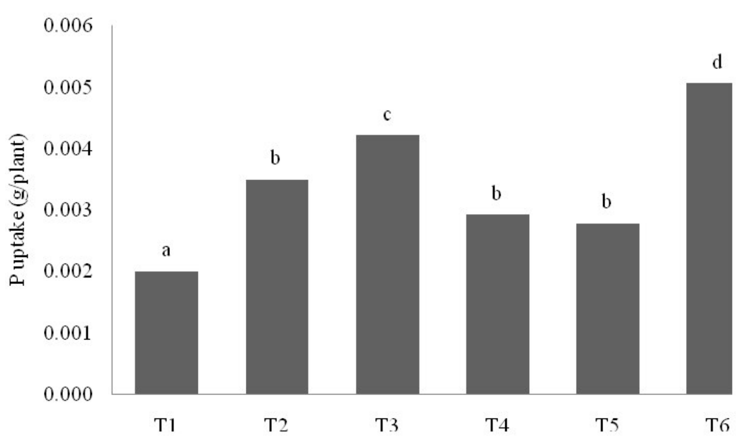

Figure 6. Effect of treatments on P uptake in roots of maize hybrid number 5 variety. Means with different alphabets indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

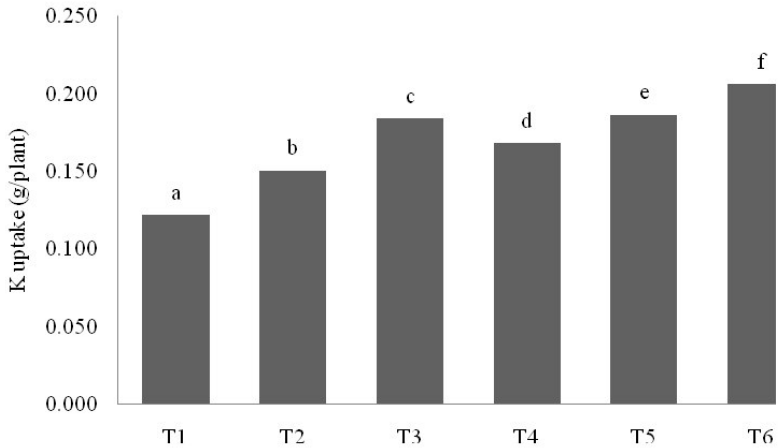

Figure 7. Effect of treatments on K uptake in leaves of maize hybrid number 5 variety. Note: Means with different alphabets indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

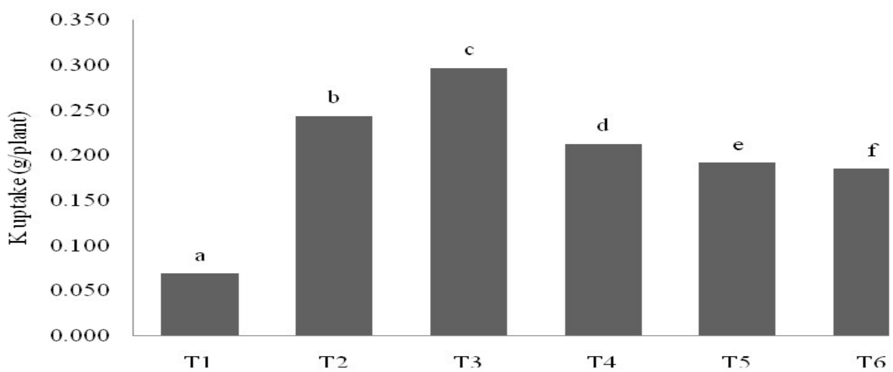

Figure 8. Effect of treatments on K uptake in stem of maize hybrid number 5 variety. Means with different alphabets indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

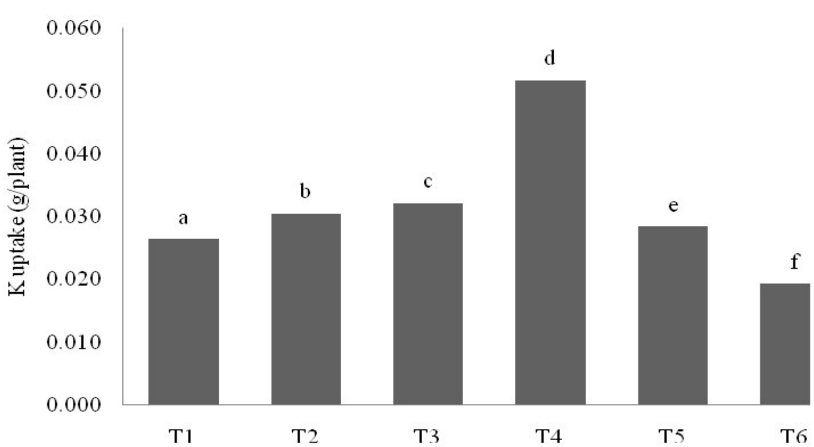

Figure 9. Effect of treatments on K uptake in roots of maize hybrid number 5 variety. Means with different alphabets indicate significant difference between treatments by Duncan's test at P ≤ 0.05.

Table 5. Effects of treatments on N, P and K use efficiency in leaves, stem and roots of maize hybrid number 5 variety.

Treatment	Nutrients (%)		
	N	P	K
	Leaves		
T2	0.612[a]	0.049[a]	0.755[a]
T3	1.226[b]	0.039[b]	2.073[b]
T4	0.992[c]	0.028[c]	2.023[c]
T5	1.133[d]	0.030[d]	4.316[d]
T6	0.796[e]	0.056[e]	10.575[e]
	Stem		
T2	0.209[a]	0.030[a]	4.602[a]
T3	1.498[b]	0.044[b]	7.598[b]
T4	1.013[c]	0.029[c]	6.245[c]
T5	0.286[d]	0.003[d]	8.17[d]
T6	2.673[e]	0.194[e]	14.513[e]
	Roots		
T2	0.024[a]	0.013[a]	0.108[a]
T3	-0.117[b]	0.025[b]	0.192[b]
T4	0.345[c]	0.011[c]	1.102[c]
T5	0.283[d]	0.017[d]	0.139[d]
T6	1.464[e]	0.133[e]	-0.888[e]

Means with different alphabets in column indicate significant difference between treatments by Duncan's test at $P \leq 0.05$.

Table 6. Total N, P and K use efficiency of maize hybrid number 5 variety.

Treatment	Nutrients (%)		
	N	P	K
T2	0.845	0.092	5.465
T3	2.607	0.108	9.863
T4	2.350	0.068	9.37
T5	1.682	0.050	12.625
T6	4.933	0.383	24.200

lack of significant effect on N uptake could be partly due to ammonia volatilization under surface-applied urea (Ferguson, 1984) because significant N loss as ammonia results in low N uptake by plants from soil. The effect of zeolite is more noticeable for K than for N, both in terms of plant tissue and soil nutrient contents. Treatments with zeolite gave best N, P and K uptake in plant tissues, probably because of less leaching of these nutrients. This is because when zeolites are mixed with chemical fertilizers, they help to retain nutrients in root zone and, hence, improving the long term soil quality by enhancing nutrient absorption (Mumpton, 1999). Regardless of treatment, variations in the nutrient uptake by the test crop could be attributed to dry matter production. The N, P and K use efficiency was significantly increased by combination of chemical fertilizer and zeolite (Table 4). The highest N, P and K use efficiency was obtained by adding low dosage of chemical fertilizer and high dose of zeolite (T6) and this positive effect could be that the low dose enabled efficient nutrient retention and availability for timely uptake.

Conclusion

Addition of zeolite affects soil chemistry. In terms of N, P and K uptake in plant tissues, T3 and T6 had significant effect, while irrespective of treatment, dry matter production was similar. Generally, all the treatments with zeolite improved N, P and K uptake and use efficiency in comparison with control treatment. The highest zeolite dose (T6) significantly increased N, P and K use efficiency of maize hybrid number 5 variety. The use of zeolite in maize cultivation on acids soils could be beneficial.

ACKNOWLEDGEMENT

The researchers acknowledge the financial support for this research by University Putra Malaysia, Malaysia.

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