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Maize (*Zea mays* L.) nutrient use efficiency as affected by formulated fertilizer with Clinoptilolite Zeolite

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Abstract

Excessive uses of fertilizer can create environmental problems such as soil pollution. This problem could be reduced by amending clinoptilolite zeolite with compound fertilizers. The objective of this study was to evaluate the effect of clinoptilolite zeolite rates in compound fertilizers (N: P: K) on maize nutrients uptake and use efficiency. The following treatments were considered and evaluated: soil alone (T1), 44.6 g 5:3:2 formulated fertilizer (12.83 g compound fertilizer + 31.77 g zeolite) (T2), 44.6 g 5:5:5 formulated fertilizer (18.24 g compound fertilizer + 26.36 g zeolite) (T3), 37.17 g 6:6:6 formulated fertilizer (18.25 g compound fertilizer + 18.92 g zeolite) (T4), 22.30 g 10:10:10 formulated fertilizer (18.24 g compound fertilizer + 4.06 g zeolite) (T5), and 14.87 g 15:15:15 commercial fertilizer (T6). Selected soil chemical properties, as well as, dry weight, nutrients concentrations, uptake and use efficiency were measured. Compound fertilizers with zeolite increased soil pH compared to soil alone (T1) and commercial fertilizer (T6). Application of compound fertilizer did no significantly affect total N and available nitrate in the soil. T6 gave better plant height and dry matter production among treatments. Nitrogen concentrations for all plant parts were similar for all treatments. T6 showed better P concentrations, uptake, and use efficiency. K concentrations in maize plant parts were significantly increased for treatments with zeolite except for roots. T5 and T6 significantly increased K uptake. T6 significantly increased N and P uptake and use efficiency, while T2 significantly increased K use efficiency. Amending N, P, and K fertilizers with higher dosage of clinoptilolite zeolite improved soil chemical properties, nutrient uptake of Masmadu variety. Compound fertilizers amended with clinoptilolite zeolite enhanced K use efficiency of Masmadu maize variety.

Key words: Clinoptilolite zeolite, Compound fertilizers, Nutrient uptake, Nutrient use efficiency, *Zea mays*

Introduction

Maize is being considered the most popular cereal crop after wheat and rice (FAO, 2006). Macronutrient and micronutrient fertilizers play important role as soil conditioner (Hattenschwiler et al., 2000). Agriculture production is usually affected by the fertilizer type applied to plants. Mineral fertilizers are alternative sources of nutrient supplement to supply sufficient nutrients in soil as well as to promote better plant productivity. However, inadequate application of fertilizers leads to its excessive consumption. Low management of fertilizers in agriculture may further cause environmental pollution. The increasing demand for environmental friendly fertilizers is encouraging in crop cultivation at the same time can preserve environmental quality. Natural mineral based material such as ash and rock phosphate can be used in agriculture and horticulture to reduce excessive fertilizer use.

Clinoptilolite zeolite, as a soil conditioner, can be considered in agricultural production. According to Polat et al. (2004), clinoptilolite can be used to improve fertilizer nutrient use efficiency. Zeolite has high cation exchange capacity (CEC) which can hold nutrient release from fertilizers slowly. Nitrogen, P and K in soil can also increase through zeolite application (Abdi et al., 2006).

Normally, the most common used fertilizers among farmers are straight fertilizers, such as urea, triple superphosphate (TSP) and muriate of potash (MOP). Both of AN and Egypt rock phosphate (ERP) are alternative sources of N and P to improve plant development. On the other hand, there is scanty information on the effects of N: P: K

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fertilizers obtained from AN, ERP, and MOP amended with clinoptilolite zeolite on the plant growth and nutrient use. The objective of the study was to determine maize nutrients uptake and use efficiency considering N: P: K formulated compound fertilizers with different rate of clinoptilolite zeolite *Zea mays* L. growth. The ratios used were based those commonly found in the fertilizer industry.

Materials and Methods

A pot study was conducted in a greenhouse located at Universiti Putra Malaysia Bintulu Campus Sarawak, Malaysia. The fertilizers were surface applied following the Malaysian Agricultural Research and Development Institute (MARDI) recommendation for Masmadu variety (60 kg ha^{-1} N; 60 kg ha^{-1} P_2O_5; 40 kg ha^{-1} K_2O) (MARDI, 1990). The fertilizer application was scaled down to per pot basis as follows:

i. T1 : soil only
ii. T2 : 44.6 g 5:3:2 formulated fertilizer (12.83 g compound fertilizer + 31.77 g zeolite)
iii. T3 : 44.6 g 5:5:5 formulated fertilizer (18.24 g compound fertilizer + 26.36 g zeolite)
iv. T4 : 37.17 g 6:6:6 formulated fertilizer (18.25 g compound fertilizer + 18.92 g zeolite)
v. T5 : 22.30 g 10:10:10 formulated fertilizer (18.24 g compound fertilizer + 4.06 g zeolite)
vi. T6 : 14.87 g 15:15:15 commercial fertilizer

These fertilizers were surface applied in split form at 9 days after planting (DAP) and 27 DAP. Plants were monitored until 65 DAP before harvest. The harvested plants were partitioned into leaves, stems and roots. The washed plant parts with distilled water were oven dried at 60 °C until constant weight. After harvesting, soil samples were randomly taken from the pots and crushed. The pH, total and available N, P, and K were analysed in crushed soil samples. Total N, P and K were analysed in plant samples to determine their nutrient uptake. Soil pH was determined in a ratio of 1:2.5 soils: distilled water suspension and 1 M KCl using a glass electrode (Peech, 1965). Total N of the soil and plant parts were determined by the Kjeldahl method, as described by Bremner (1965). Total P and cations in the soil were extracted by the Aqua Regia method. Soil available P and exchangeable cations were extracted using the double acid method (Tan, 2005). Nutrients in plant samples were extracted using the single dry ashing method (Cottenie, 1980). Total and available P was determined following Murphy and Riley (1962), while total and exchangeable cations (K, Ca, and Mg) were determined using atomic absorption spectrometer (AAS). Exchangeable NH4+ and available NO3- were determined using Keeney and Nelson (1982) method. Fertilizer nutrient use efficiency (NUE) was calculated according to following formula (Pomares-Gracia and Pratt, 1987):

$$\% \text{ NUE} = (\text{TNF} - \text{TNU}) \div \text{RFA} \times 100$$

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 experimental design was a completely randomized design with three replications. Analysis of variance was used to test treatment effects while means of treatments were compared using Duncan's New Multiple Range Test (DNMRT) (SAS, 2008).

Results and Discussion

The selected physical and chemical properties of Bekenu series after planting are presented in Table 1. It was found that soil pH, total P and K, exchangeable K+ and available P displayed differences between unfertilized (T1) and fertilized (T2, T3, T4, T5, and T6) treatments. The pH in both water and KCl for soil alone (T1) and the commercial fertilizer (T6) were found to be acidic when compared to treatments with clinoptilolite zeolite. Zeolite also changed the soil pH (to neutral) when it was applied with fertilizers (Polat et al., 2004). The pH in the treatments with more zeolite kept alkaline. These findings remained consistent with other researchers (Noori et al., 2006; Perez-Caballero et al., 2008; Ahmed et al., 2010). Both total N and available NO3- did not show any difference between treatments, however, soil exchangeable NH4+ showed differences among treatments after planting. The increase in NH4+ eventually resulted of the sorption in the zeolite lattice when greater dosages of zeolite were applied (Ippolito et al., 2011). According to Mumpton (1999), application of clinoptilolite zeolite could improve the amount of P in the soils due to the presence of P in the form of P2O5. This reaction takes place through ion exchange processes (Lai and Eberl, 1986; Chesworth et al., 1987; Van Straaten, 2002). Additionally, exchangeable K+ in the soil was higher for treatments with zeolite, relatively to both commercial fertilizer (T6) and soil alone (T1) treatments. Treatments having higher amounts of zeolite showed higher K+ in the soil because zeolite has the potential to absorb K+ from chemical fertilizers, hence reducing K leaching (Hershey et al., 1980; Carolino et al., 1998).

Roots, stems and leaves dry weight in all treatments also revealed significant changes (Table 2; Figure 1). In the roots, T1 which is soil alone had the lowest dry matter production compared to the fertilized treatments. T5 and T6 gave similar roots dry weight values, while, T4 developed the highest roots dry weight. T1, T2, T3, and T5 showed no significant difference on stem dry weight. With the exception of T4 and T6, the remaining treatments had no significant effects on leaves dry weight. Overall, Figure 1 shows that the total of dry weight for T1, T2, T3 were significantly lower than those of T4, T5, and T6.

Nutrient accumulation in the maize roots, stems, and leaves were inconsistently affected by the rates of zeolite in the fertilizers (Table 3). In roots, there was no significant difference in N content regardless of treatment. Except for T6 (commercial fertilizer), both P and Mg concentrations in roots showed no statistical differences between treatments. However, there was significant variations between treatments for K in roots at 65 DAP. Potassium concentration in roots for T1 was lower than those of the fertilized treatments. However, K concentrations for fertilized treatments (T3, T4, T5, and T6) were not different except for T2. Calcium concentrations in roots were significantly different for T1 and T6 but no difference for treatments with clinoptilolite zeolite. Amending compound fertilizers with clinoptilolite zeolite affected N, K, Ca, and Mg concentrations in stems. Total N in stems increased with higher amounts of clinoptilolite zeolite (T2). Nitrogen concentration in stems statistically differed between soil alone and fertilized treatments. Similar effects on P accumulation as in roots were found in both in stems and leaves. A phosphorus concentration in both stems and leaves for T1 and those treatments with (T2, T3, T4, and T5) zeolite did not show differences except for T6. Both K and Mg contents in stems were higher for treatments with zeolite compared to T1 and T6. However, Ca concentrations were not statistically different for T1, T2, and T3. In the leaves, treatments showed no significant difference for N and Ca contents. Nevertheless, clinoptilolite zeolite in the compound fertilizers inconsistently affected K and Mg.

Table 1. Selected physico-chemical properties of Bekenu series after planting.

Physico-chemical properties	Treatments					
	T1	T2	T3	T4	T5	T6
pH (water)	4.42^{b}	4.90^{a}	4.76^{a}	4.86^{a}	4.80^{a}	4.23^{b}
pH (KCl)	3.71^{b}	3.99^{a}	4.07^{a}	4.03^{a}	4.05^{a}	3.62^{b}
Total N (%)	0.042^{b}	0.098^{a}	0.084^{ab}	0.098^{a}	0.098^{a}	0.098^{a}
Total P (mg kg^{-1})	82.93^{f}	2504^{d}	3639^{b}	4456^{a}	3493^{c}	264^{e}
Available P (mg kg^{-1})	1.96^{f}	204.8^{d}	577.6^{b}	540.7^{c}	647.2^{a}	58.5^{e}
Total K (mg kg^{-1})	69.1^{c}	1904.7^{a}	1961.1^{a}	1826.4^{a}	536.1^{b}	125.4^{c}
Exchangeable K^+ (mg kg^{-1})	12.57^{e}	316.67^{c}	479.00^{a}	395.80^{b}	182.17^{d}	45.27^{e}
Exchangeable NH_4^+ (%)	0.002^{c}	0.008^{a}	0.006^{ab}	0.004^{bc}	0.003^{bc}	0.008^{a}
Available NO_3^- (%)	0.001^{a}	0.002^{a}	0.001^{a}	0.001^{a}	0.001^{a}	0.001^{a}

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

Table 2. Dry weight (in g) of roots, stems, and leaves of maize (var. Masmadu) at 65 days after planting.

Treatments	Roots	Stems	Leaves
T1	11.14^{d}	7.20^{b}	10.83^{c}
T2	13.74^{bc}	7.54^{b}	10.82^{c}
T3	12.32^{cd}	7.36^{b}	10.57^{c}
T4	16.18^{a}	10.58^{ab}	13.26^{b}
T5	15.68^{ab}	8.94^{b}	11.82^{bc}
T6	14.47^{ab}	13.39^{a}	16.80^{a}

Means with difference alphabets in row indicate significant difference between treatments by DNMRT's test at P ≤ 0.05.

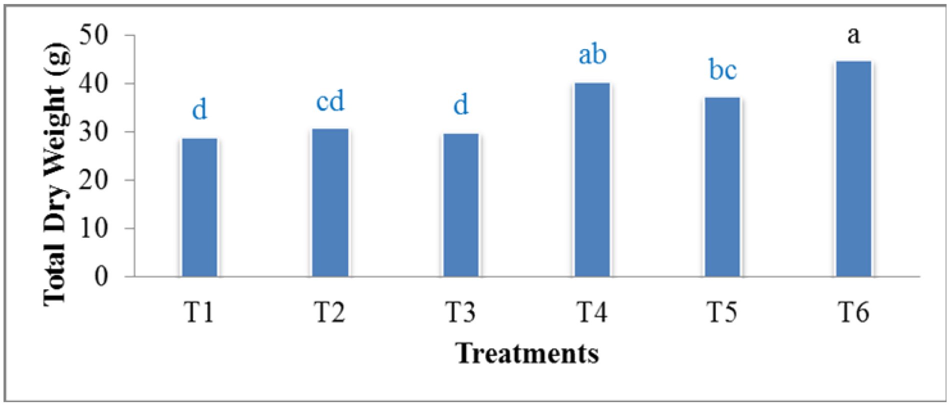

Figure 1. Effect of treatments on total dry weight of maize (var. Masmadu) at 65 days after planting.
Means with difference alphabets indicate significant difference between treatments by DNMRT's test at $P \leq 0.05$.

Table 3. Nitrogen, P, K, Ca, and Mg concentrations in roots, stems, and leaves of maize (var. Masmadu) at 65 days after planting.

Treatments	Element concentration (%)				
	N	P	K	Ca	Mg
Roots					
T1	0.738[a]	0.090[b]	0.266[c]	0.010[b]	0.050[b]
T2	0.972[a]	0.084[b]	0.814[b]	0.019[ab]	0.073[b]
T3	0.822[a]	0.095[b]	1.311[a]	0.015[ab]	0.065[b]
T4	1.074[a]	0.098[b]	1.120[ab]	0.018[ab]	0.064[b]
T5	1.158[a]	0.091[b]	1.340[a]	0.010[ab]	0.057[b]
T6	1.224[a]	0.312[a]	0.989[ab]	0.022[a]	0.105[a]
Stems					
T1	0.560[b]	0.062[b]	0.352[c]	0.065[a]	0.166[ab]
T2	1.140[a]	0.078[b]	3.042[ab]	0.065[a]	0.212[a]
T3	1.074[ab]	0.100[b]	4.491[a]	0.060[a]	0.202[a]
T4	0.934[ab]	0.092[b]	4.248[a]	0.053[ab]	0.228[a]
T5	1.074[ab]	0.069[b]	3.937[ab]	0.041[cb]	0.146[ab]
T6	1.392[a]	0.314[a]	1.564[bc]	0.029[c]	0.100[b]
Leaves					
T1	0.831[a]	0.090[b]	0.806[c]	0.078[a]	0.193[a]
T2	1.307[a]	0.092[b]	1.495[b]	0.058[a]	0.160[ab]
T3	1.233[a]	0.086[b]	2.092[ab]	0.097[a]	0.142[b]
T4	1.261[a]	0.089[b]	1.681[b]	0.070[a]	0.137[b]
T5	1.373[a]	0.080[b]	2.364[a]	0.033[a]	0.172[ab]
T6	1.606[a]	0.431[a]	1.686[b]	0.038[a]	0.069[c]

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

Incorporation of clinoptilolite zeolite in compound fertilizers significantly affected N, P, and K uptake in the roots, stems, and leaves (Table 4). Except for T3, N uptake in both maize roots and leaves were improved for treatments with clinoptilolite zeolite, relatively to T1. T2 caused higher uptake of N in stems compared to treatments with lower amounts of clinoptilolite zeolite. This finding is comparable to that of Ahmed et al. (2010) who also reported that zeolite amended with inorganic fertilizers enhanced uptake of N in maize. Uptake of P was also significantly affected. Unlike N uptake, P uptake in roots was higher with lower amount of zeolite. In stems, only T6 increased P uptake. Uptake of K in roots and stems were higher in treatments with zeolite, relatively to T1 and T6. However, uptake of K in leaves had similar effect as found for P uptake in roots. Total uptake of N showed no differences after application of different amounts of clinoptilolite zeolite (Figure 2). However, N uptake showed difference between soils alone, treatments with zeolite and commercial fertilizer. In the N and P uptake were also higher for the commercial fertilizer relatively to the treatments with clinoptilolite zeolite (Figures 2, 3). In terms of total nutrient uptake, T6 caused higher N and P uptake (Figures 2 and 3) and not for K uptake (Figure 4). T6 caused better N use efficiency in roots, and stems (Table 5). Nitrogen use efficiency for treatments with zeolite (T2, T4) was similar to that of the commercial fertilizer (T6). Phosphorus use efficiency in roots, stems and leaves for T6 was better than the other treatments (Table 5). Contrary to P, higher amount of zeolite caused significant increase in K use efficiency in roots, stems, and leaves relatively to the commercial fertilizer. For total N, P, and K use efficiency, T6 proved to have an higher ranking for N and P, while T2 was better for K (Figures 5, 6, and 7). This observation can be comparable to the report of Gul et al. (2005), concerning to the use of zeolite to reduce the leaching of K. The heights of unfertilized and fertilized plants were inconsistent as shown in Figure 8, but the application of the commercial fertilizer caused better height compared to other treatments.

Table 4. Nitrogen, P, and K uptake in roots, stems, and leaves of maize (var. Masmadu) at 65 days after planting.

Treatments	N	P	K
	Uptake (mg plant^{-1})		
Roots			
T1	62.83^{c}	9.085^{d}	28.54^{d}
T2	144.0^{b}	10.40^{d}	110.6^{c}
T3	74.67^{c}	12.10^{c}	183.1^{ab}
T4	116.4^{b}	13.55^{bc}	214.2^{a}
T5	120.6^{b}	14.60^{b}	166.6^{ab}
T6	192.7^{a}	46.15^{a}	150.9^{bc}
Stems			
T1	29.95^{d}	4.50^{b}	25.35^{d}
T2	98..98^{b}	5.23^{bc}	216^{b}
T3	68.75^{c}	5.97^{b}	309^{a}
T4	71.73^{c}	6.00^{b}	300^{ab}
T5	63.73^{c}	5.33^{bc}	290^{b}
T6	180.6^{a}	38.0^{a}	202^{c}
Leaves			
T1	95.96^{c}	8.35^{b}	86.97^{e}
T2	181^{b}	9.92^{b}	183^{d}
T3	104^{c}	9.05^{b}	217^{cd}
T4	170^{b}	9.74^{b}	236^{bc}
T5	175^{b}	9.36^{b}	269^{b}
T6	271^{a}	71.8^{a}	306^{a}

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

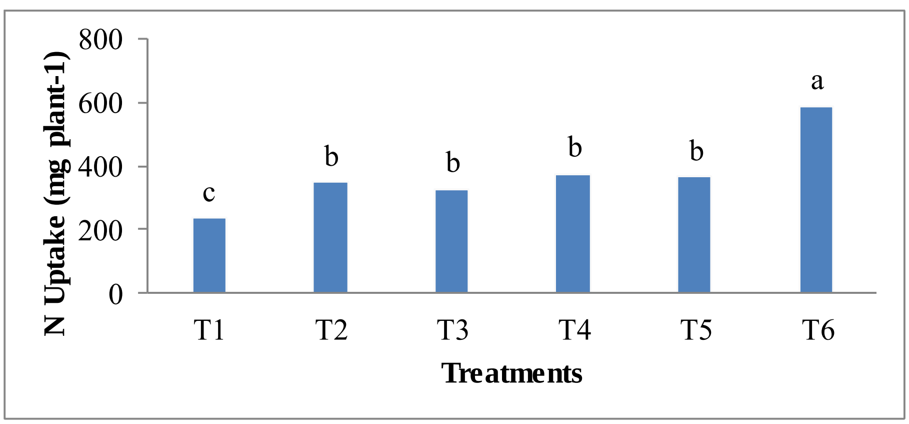

Figure 2. Effect of treatments on N uptake of maize (var. Masmadu) at 65 days after planting.
Means with difference alphabets indicate significant difference between treatments by DNMRT's test at $P \leq 0.05$.

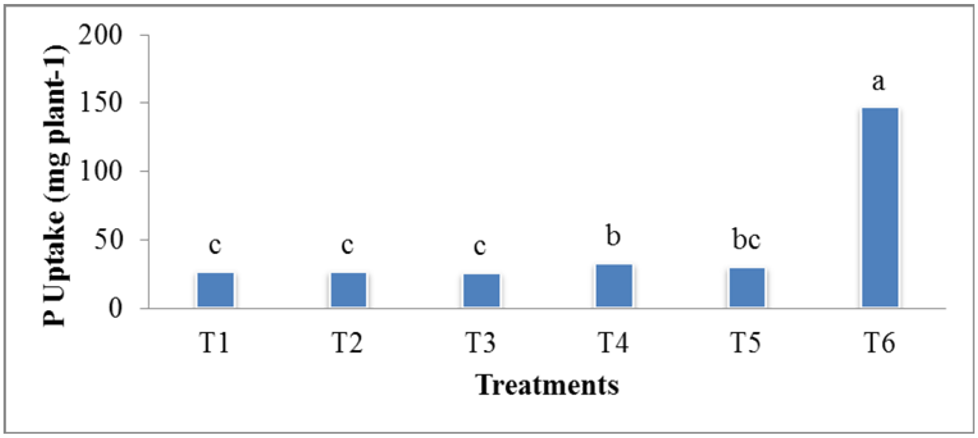

Figure 3. Effect of treatments on P uptake of maize (var. Masmadu) at 65 days after planting.
Means with difference alphabets indicate significant difference between treatments by DNMRT's test at $P \leq 0.05$.

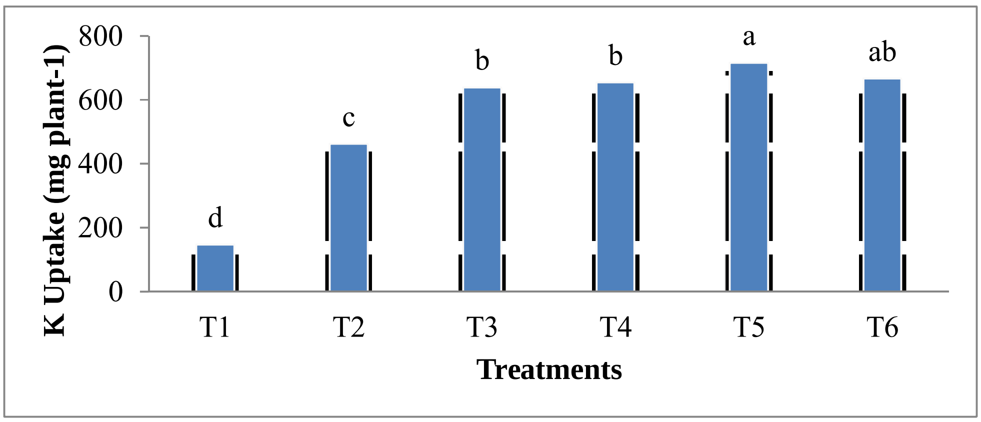

Figure 4. Effect of treatments on K uptake of maize (var. Masmadu) at 65 days after planting.
Means with difference alphabets indicate significant difference between treatments by DNMRT's test at $P \leq 0.05$.

Table 5. Nitrogen, P, and K use efficiency in roots, stems, and leaves of maize (var. Masmadu) at 65 days after planting.

Treatments	N Use Efficiency (%)	P Use Efficiency (%)	K Use Efficiency (%)
Roots			
T2	3.640^{b}	0.225^{c}	11.09^{a}
T3	2.718^{b}	0.261^{c}	8.355^{abc}
T4	2.402^{b}	0.374^{bc}	10.04^{ab}
T5	2.592^{b}	0.563^{b}	7.462^{bc}
T6	5.824^{a}	3.782^{a}	6.150^{c}
Stems			
T2	2.697^{b}	0.126^{b}	25.70^{a}
T3	1.544^{c}	0.150^{b}	16.41^{b}
T4	1.475^{c}	0.298^{b}	12.63^{cd}
T5	1.516^{c}	0.059^{b}	14.32^{bc}
T6	6.550^{a}	4.601^{a}	9.894^{d}
Leaves			
T2	4.736^{ab}	0.391^{b}	15.53^{a}
T3	1.292^{c}	0.120^{b}	5.961^{b}
T4	5.110^{ab}	0.142^{b}	8.608^{b}
T5	4.464^{b}	0.049^{b}	9.005^{b}
T6	7.460^{a}	6.588^{a}	11.55^{ab}

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

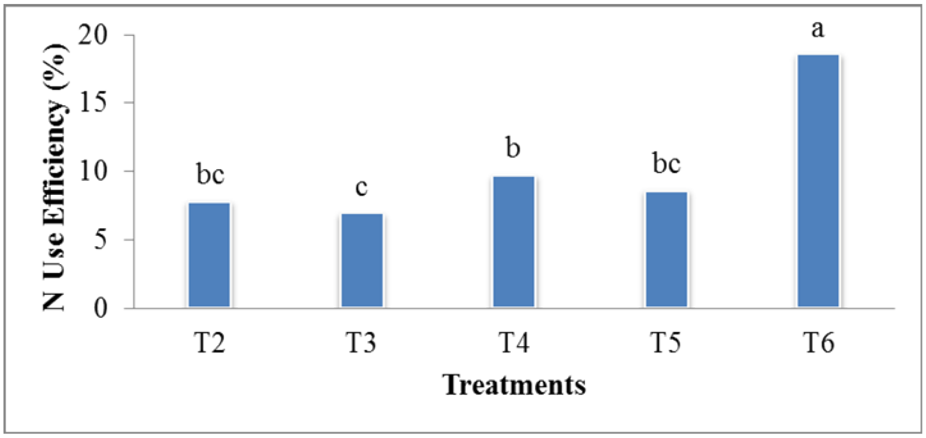

Figure 5. Effect of treatments on N use efficiency of maize (var. Masmadu) at 65 days after planting.
Means with difference alphabets indicate significant difference between treatments by DNMRT's test at $P \leq 0.05$.

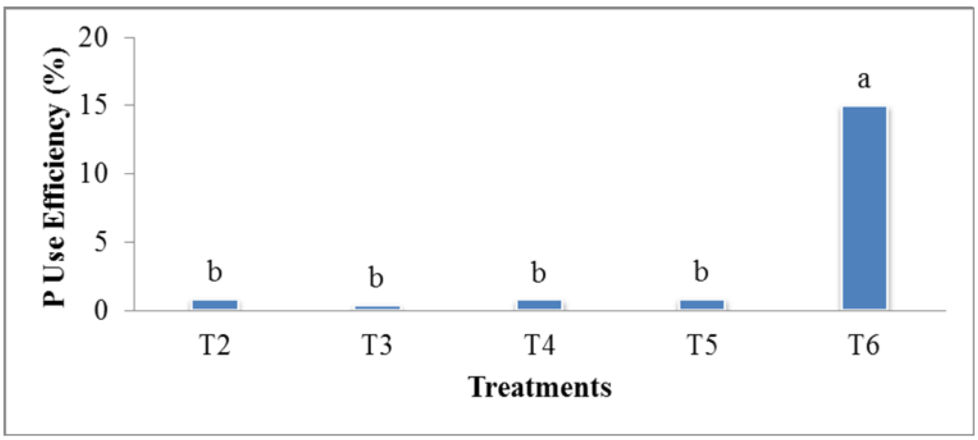

Figure 6. Effect of treatments on P use efficiency of maize (var. Masmadu) at 65 days after planting.
Means with difference alphabets indicate significant difference between treatments by DNMRT's test at $P \leq 0.05$.

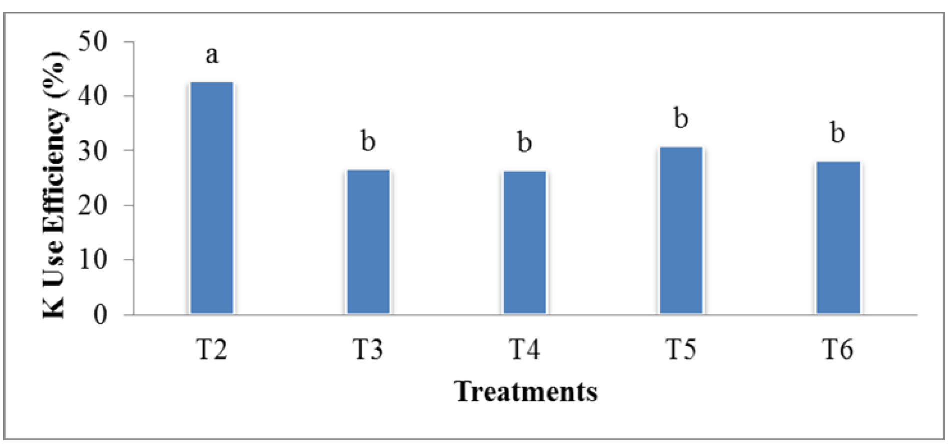

Figure 7. Effect of treatments on K use efficiency of maize (var. Masmadu) at 65 days after planting.
Means with difference alphabets indicate significant difference between treatments by DNMRT's test at $P \leq 0.05$.

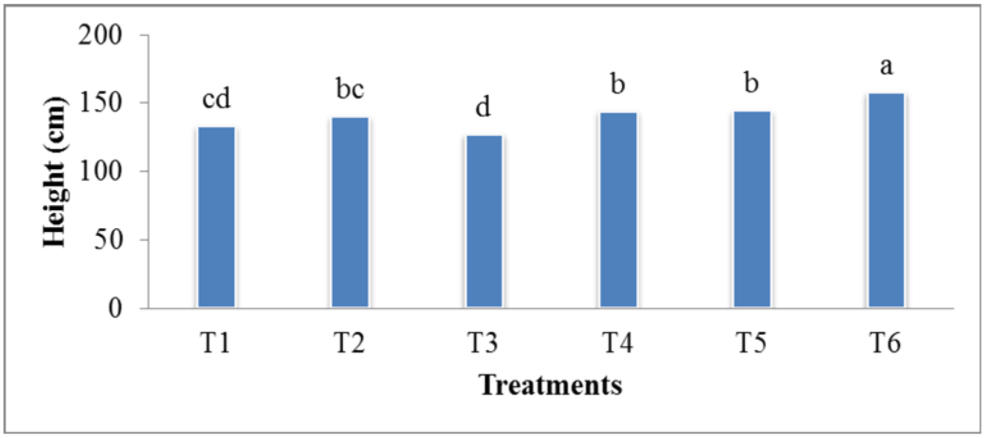

Figure 8. Effect of treatments on height of maize (var. Masmadu) at 65 days after planting.
Means with difference alphabets indicate significant difference between treatments by DNMRT's test at $P \leq 0.05$.

Conclusion

Amending N, P, and K fertilizers with higher dosage of clinoptilolite zeolite improved soil chemical properties, nutrient uptake of Masmadu variety. Compound fertilizers amended with clinoptilolite zeolite enhanced K use efficiency of Masmadu maize variety. Future field study for at least three cycles is recommended for consolidation of these findings.

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References

Abdi, G. H., M. Khosh-Khui and S. Eshghi. 2006. Effects of natural zeolite on growth and flowering of strawberry (*Fragaria ananassa* Duch.). In: Iran international zeolite conference. pp. 384-389.

Ahmed, O. H., G. Sumalatha and A. M. Nik Muhamad. 2010. Use of zeolite in maize (*Zea mays*) cultivation on nitrogen, potassium and phosphorus uptake and use efficiency. Internat. J. Phys. Sci. 5(15):2393-2401.

Bremner, J. M. 1965. Total nitrogen. In: Black et al. (Eds.), p. 1149-1178. Method of Soil Analysis, part 2. American Society of Agronomy, Madison, Wisconcin.

Carlino J. L., K. A. Williams and E. R. Allen. 1998. Evaluation of zeolite based soilless root media for potted *Chrysanthemum* production. Hotric. Technol. 8:373-378

Chesworth, W. 1987. Geology and agriculture. In: J. K. Wachira and A. J. G. Notholt (Eds.) Agrogeology in Africa. Commonw. Sci. Council, Techn. Publ. Ser. 226:5-11.

Cottenie, A. 1980. Soil testing and plant testing as a basis of fertilizer recommendation. FAO Soils Bull. 38:70-73.

Food and Agriculture Organization (FAO). 2006. Maize: International market profile.

Gul, A., D. Erogul and A. R. Ongun. 2005. Comparison of the use of zeolite and perlite as substrate for crisp-head lettuce. Sci. Hort. 106:464-471.

Hattenschwiller, S. and P. M. Vitousek. 2000. The role of polyphenols in terrestrial ecosystem nutrient cycling. Tree 15:238-243.

Hershey, D. R., J. L. Paul, and R. M. Carson. 1980. Zeolite. Hortsci. 15:87-89

Ippolito, J. A, D. D. Tarkalson, and G. A. Lehrsch. 2011. Zeolite soil application method affects inorganic nitrogen, moisture, and corn growth. Soil science. Lippincott Williams & Wilkins, 176(3):136-142.

Keeney, D. R., D. W. Nelson. 1982. Nitrogen-inorganic forms. In: A. L. Page, R. H. Miller (Eds.), p. 643-698. Methods of Soil Analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Lai, T. M. and D. D. Eberl. 1986. Controlled and renewable release of phosphorus in soils from mixture of phosphate rock and NH4-exchanged clinoptilolite. Zeolites 6:129-132.

Malaysia Agriculture Research and Development (MARDI). 1990. Jagung manis baru (new sweet corn): masmadu. MARDI, Kuala Lumpur.

Mumpton, F. A. 1999. La roca magica: uses of natural zeolites in agriculture and industry. Proc. Natl. Acad. Sci. USA 96(7):3463- 3470.

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

Noori, M., M. Zendehdel and A. Ahmadi. 2006. Using natural zeolite for the improvement of soil salinity and crop yield. Toxicol. Environ. Chem. 88:77-84.

Peech, H. M. 1965. Hydrogen-ion activity. In: Black et al. (Eds.). pp. 914-926. Methods of Soil Analysis Part 2. American Society of Agronomy, Madison, Wisconsin.

Perez-Caballero, R., J. Gil, C. Benitez, and J. L. Gonzalez. 2008. The effect of adding zeolite to soils in order to improve the n-k nutrition of olive trees, preliminary results. Am. J. Agric. Biol. Sci. 2(1):321-324.

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

Pomares-Gracia, F. and Pratt P. F. 1987. Recovery of 15n-labelled fertilizer from manured and sludged-amended soils. Soil Sci. Soc. Am. J. 42:717-720.

SAS. 2008. SAS/stat user’s guide. Version 9.2. SAS institute inc. Cary, NC. USA

Tan, K. H. 2005. Soil sampling, preparation, and analysis, second edition. Crc Press, Taylor & Francis group. Boca Raton, Florida, USA. pp. 154-174.

Van Straaten, P. 2002. Rocks for crops: agrominerals of Sub-Saharan Africa. Icraf, Nairobi, Kenya. p. 338.