UNIVERSITI PUTRA MALAYSIA

IMPROVING NITROGEN USE EFFICIENCY OF MIXED FERTILIZERS USING CLINOPTILOLITE ZEOLITE

KRYSTLE AMANDA RABAI NASIP

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By

KRYSTLE AMANDA RABAI NASIP

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

April 2013

DEDICATION

Dedicated to my family and love ones who supported me throughout my research work

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

IMPROVING NITROGEN USE EFFICIENCY OF MIXED FERTILIZERS USING CLINOPTILOLITE ZEOLITE

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April 2013

Chairman : Ahmed Osumanu Haruna, PhD

Faculty : Faculty of Agriculture and Food Sciences, (Bintulu)

According to Wu and Liu (2008), up to 70% of N, 90% of P, and 70% of K are lost to the environment and not available for plant uptake. This leads to economic losses and causes serious environmental pollution. Blending mixed fertilizers with clinoptilolite zeolite where the zeolite acts as excellent carrier regulator and stabilizes mineral fertilizers could be an alternative way of formulating desired fertilizers in agriculture. An incubation experiment was carried out to compare the effects of different ratios of mixed fertilizers amended with clinoptilolite zeolite on ammonia (NH_3) volatilization, soil exchangeable ammonium (NH_4^+) and available nitrate (NO_3^-) contents on a fine, loamy, siliceous, hyperthermic, *Typic Paleudults*, Ultisol (Bekenu Series). In this study, the seven treatments compared were: 14.88 g commercial fertilizer with grade 15 N:15 P:15K – zeolite (T1), 14.88 g mixed fertilizer with

grade 15 N:15 P:15 K + zeolite (T2), 22.35 g mixed fertilizer with grade 10 N:10 P:10 K + zeolite (T3), 27.87 g mixed fertilizer with grade 8 N:8 P:8 K + zeolite (T4), 40.46 g mixed fertilizer with grade 5.5 N:5.5 P:5.5 K + zeolite (T5), 2.425 g urea without additives (T6) and soil only (T7). Standard procedures were used to evaluate these treatments. Treatments with zeolite significantly reduced NH_3 loss compared with urea without addictives. They also improved retention of exchangeable NH_4^+ and NO_3^-, and this was possible because zeolite favoured formation of NH_4^+ and NO_3^- over NH_3. T1, T2, T3, T4 and T5 reduced maximum of NH_3 loss from 8.4 to 0.12, 5.16, 4.02, 4.5 and 3.41% (of the N added as urea), respectively. The maximum NH_3 loss occurred on day 2 for T6, day 3 for T1, day 4 for T3 and day 5 for T2, T4 and T5 of incubation. Afterwards, there was a general decline until day 15 when the NH_3 loss was about 1% of the N added as urea. T1 caused the highest accumulation of exchangeable NH_4^+ while T5 caused the highest accumulation of available NO_3^-. These mixed fertilizers were further tested in a pot experiment where Masmadu maize (*Zea mays* L) was used as a test crop. The objectives of this study were to evaluate the effects of the treatments on: (1) Plant height, dry matter, N, P, and K uptake N, P, and K use efficiency and their production efficiency in maize cultivation, and (2) Soil exchangeable NH_4^+, available NO_3^-, pH, exchangeable K and available P contents. The treatments evaluated were: 14.88 g commercial fertilizer with grade 15 N:15 P:15K - zeolite (T1), 14.88 g mixed fertilizer with grade 15 N:15 P:15 K + zeolite (T2), 22.35 g mixed fertilizer with grade 10 N:10 P:10 K + zeolite (T3), 27.87 g mixed fertilizer with grade 8 N:8 P:8 K + zeolite (T4), 40.46 g mixed fertilizer with grade 5.5

N:5.5 P:5.5 K + zeolite (T5) and soil only (T7). The amounts of mixed fertilizer applied were based on the standard recommendation for mature Masmadu Maize. The effect of T1 and T5 on soil total N was significant compared with T7. Treatments with higher amounts of clinoptilolite zeolite (T4 and T5) significantly improved soil total P, K and available K compared to T1 and T7. T4 and T5 caused the highest accumulation of exchangeable NH_4^+ and available NO_3^- compared to T1 and T7. T4 and T5 had a similar effect on plant height, dry matter, N, P and K concentrations, and uptake and use efficiency compared with T1. It may be concluded that treatments with higher amounts clinoptilolite zeolite, 27.87 g mixed fertilizer with grade 8 N:8 P:8 K + zeolite (T4), and 40.46 g mixed fertilizer with grade 5.5 N:5.5 P:5.5 K + zeolite (T5) ensured good retention of soil exchangeable cations within the Ultisol. However, field evaluation for the treatments for at least three cropping cycles, for corn yield (cob) and cost and benefits analysis are recommended as a further research for economic viability.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

MEMPERTINGKATKAN KECEKAPAN PENGGUNAAN NITROGEN DARI BAJA CAMPURAN DENGAN MENGGUNAKAN ZEOLIT KLINOPTILOLIT

Oleh

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Menurut Wu dan Liu (2008), sehingga 70% N, 90% daripada P, dan 70% daripada K hilang kepada alam sekitar dan tidak boleh digunakan untuk pengambilan tumbuhan. Ini membawa kepada kerugian dalam ekonomi dan menyebabkan pencemaran alam sekitar yang serius. Campuran baja campuran dengan zeolit klinoptilolit dimana zeolit bertindak sebagai pengatur pembawa cemerlang dan kestabilkan baja mineral merupakan kaedah alternatif dalam mengformulasi baja yang diingini dalam pertanian. Satu eksperimen inkubasi telah dijalankan untuk membanding kesan nisbah yang berbeza yang digabungkan dengan zeolit klinoptilolit terhadap pemeruapan ammonia (NH_3) , tukar ganti ammonium (NH_4^+) dan kandungan nitrat (NO_3^-) tersedia di dalam tanah yang halus, liat, silika, hyperthermic, *Typic Paleudults*, Ultisol (Siri Bekenu). Kajian ini telah membandingkan tujuh rawatan: 14.88 g baja

kompoun komersial dengan gred 15:15:15 -zeolit (T1), 14.88 g baja campuran dengan gred 15 N:15 P:15 K + zeolit (T2), 22.35 g baja campuran dengan gred 10 N:10 P:10 K + zeolit T3), 27.87 g baja campuran dengan nisbah 8 N:8 P:8 K + zeolit (T4), 40.46 g baja campuran dengan gred 5.5 N:5.5 P:5.5 K + zeolit (T5), urea 2.425 g tanpa aditif (T6) dan tanah sahaja (T7). Prosedur piawai telah digunakan untuk menilai rawatan ini. Rawatan dengan zeolit mengurangkan kehilangan NH_3 dengan urea tanpa aditif. Zeolit juga telah meningkatkan keupayaan pemegang NH_4^+ tukar ganti dan NO_3^- tersedia. Ini adalah berkemungkinan kerana zeolit menggalakan pembentukan NH_4^+ dan NO_3^- berbanding NH_3. T1, T2, T3, T4, T5 telah berjaya mengurangkan kehilangan NH_3 secara maksimum nilai 8.4 kepada 0.12, 5.16, 4.02, 4.5 and 3.41% (N yang ditambah sebagai urea) masing-masing. Kehilangan NH_3 secara maksimum bagi setiap rawatan berlaku pada hari ke-2 (T6) , hari ke-3 (T1), hari ke-4 (T3) dan hari ke-5 (T2, T4 dan T5) pengeraman sebelum berlakunya penurunan umum sehingga hari ke-15 apabila kehilangan NH_3 mencapai 1% daripada N yang ditambah sebagai urea. T1 telah menyebabkan pengumpulan tertinggi NH_4^+ tukar ganti manakala T5 telah menyebabkan pengumpulan tertinggi NO_3^- tersedia. Baja kompoun kemudiannya diuji dengan skala yang dinaikan di dalam eksperimen menggunakan pasu di mana jagung Masmadu (*Zea mays* L) telah digunakan sebagai tanaman diuji. Objektif kajian ini adalah untuk menilai kesan rawatan ke atas: (1) Tinggi, berat kering, pengambilan N, P, dan K, kecekapan penggunaan dan kecekapan pengeluaran dalam penanaman jagung, dan (2) NH_4^+ tukar ganti, NO_3^- tersedia, pH, tukar ganti K dan P tersedia. Kajian membandingkan enam rawatan: 14.88 g baja kompoun

komersial dengan gred 15:15:15 - zeolit (T1), 14.88 g baja campuran dengan gred 15 N:15 P:15 K + zeolit Zeolit (T2), 22.35 g baja campuran dengan gred 10 N:10 P:10 K + zeolit (T3), 27.87 g baja campuran dengan gred 8 N:8 P:8 K + zeolit (T4), 40.46 g baja campuran dengan gred 5.5 N:5.5 P:5.5 K + zeolit (T5) dan tanah sahaja (T7). Jumlah baja campuran yang digunakan adalah berasaskan cadangan piawai Jagung Masmadu matang. Kesan T1 dan T5 pada jumlah N-tanah adalah bererti berbanding dengan T7. Rawatan dengan jumlah zeolit klinoptilolit yang lebih tinggi (T4 dan T5) telah meningkatkan jumlah P, jumlah K dan K tersedia secara bererti berbanding T1 dan T7. T4 dan T5 menyebabkan pengumpulan tertinggi NH_4^+ tukar ganti dan NO_3^- tersedia tertinggi berbanding T1 dan T7. T4 dan T5 memberi kesan yang sama pada ketinggian pokok, berat kering, kandungan N, P dan serta pengambilan kecekapanya berbanding T1. Walau bagaimanapun, kesan ini berbeza secara bererti berbanding T7. Terdapat potensi untuk baja kompaun ini digabungkan dengan zeolit untuk memberi fungsi yang lebih baik daripada baja komersial sedia ada. Dengan itu, satu kesimpulan bahawa rawatan dengan jumlah yang lebih tinggi zeolit, 27.87 g baja campuran dengan gred 8 N:8 P:8 K + zeolit (T4), dan 40.46 g baja campuran dengan gred 5.5 N:5.5 P:5.5 K + zeolit (T5) memastikan pengekalan kation tukar ganti yang baik dalam tanah dan mengurangkan kehilangan NH_3. Walau bagaimanapun, penilaian untuk rawatan sekurang-kurangnya tiga kitaran tanaman, pengukuran hasil jagung (bongkah) dan kos analisis rawatan adalah disyorkan sebagai kajian lanjutan bagi daya maju ekonomi.

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I certify that a Thesis Examination Committee has met on 18th April 2013 to conduct the final examination of **Krystle Amanda Rabai Nasip** on her thesis entitled **IMPROVING NITROGEN USE EFFICIENCY OF MIXED FERTILIZERS USING CLINOPTILOLITE ZEOLITE** in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science (Agrotechnology).

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that is has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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KRYSTLE AMANDA RABAI NASIP

Date: 18 APRIL 2013

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LIST OF ABBREVIATIONS

N	Nitrogen
P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
Na	Sodium
Al	Aluminium
O	Oxygen
P_2O_5	Phosphorus pentoxide
K_2O	Potassium oxide
AlO_4	Aluminium oxide
SiO_4^{-4}	Silicate oxide
NH_4^+	Ammonium
NH_3	Ammonia
NO_3^-	Nitrate
HPO_4^{-2}	Hydrogen phosphate
$H_2PO_4^-$	Dihydrogen phosphate
HCO_3	Bicarbonate
N_2O	Nitrous oxide
PO_4^{-3}	Phosphate
RP	Rock phosphate

TSP	Triple superphosphate
MOP	Muriate of potash
DW	Dry weight
AAS	Atomic absorption spectrophotometry
CEC	Cation exchange capacity
DAP	Day after planting
KCl	Potassium chloride
ANOVA	Analysis of variance
mg	miligram
kg	kilogram
g	gram
µm	micrometer
M	Molar
%	Percentage
m	meter

CHAPTER 1

INTRODUCTION

Soil is the principal reservoir from which nutrients essential from plant growth and development are drawn (Reddy, 2004). Intensive cultivation due to high food demand has lowered soil fertility. Restoration of soil fertility is a necessity for the attainment of sustainable agriculture. Thus, fertilizer inputs are needed to cultivate crops. About 4.48 million hectares of land in 2008 were cultivated with perennial tree crops such as oil palm (Malaysia Palm Oil Board and America Palm Oil Council, 2010) where large quantities of fertilizers are required annually to sustain high crop yield. The bulk of the fertilizers used in Malaysia are for plantation crops and this accounts for 90% of all fertilizer use (Ramli *et al.*, 2012). The total import for urea, TSP and MOP since 2007 was 1,680,000 metric tonnes (Matassan, 2007) . However, according to Wu and Liu (2008), up to 70% of N, 90% of P, and 70% of K are lost to the environment and not available for plant uptake. This leads to economic losses and causes serious environmental pollution.

Mixed fertilizers are the mixtures of straight fertilizer materials containing all of the three major elements and a range of minor elements (Greer, 1987). They are prepared by dry blending of straight fertilizers or by chemical reactions. Example of N:P:K grade for mixed fertilisers that have been developed such as are 8:8:8, , 13:13:22, and 15:15:15. The N:P:K indicates the percentage of N, P_2O_5 and K_2O. The typical content of nutrients (N + P_2O_5+ K_2O) range from 40% to 60% (European Fertilizer Manufacturers' Association, 2000).). The main advantages of using mixed fertilizers are: (i) to provide a known level of NKP, (ii) to supply all major elements, (iii) for easy application, and (iv) cost efficient comparison with one-way fertilizers (Greer, 1987).

Blending mixed fertilizers with clinoptilolite zeolite, where clinoptilolite zeolite acts as supplementary nutrients, could be an alternative way of formulating desired fertilizers in agriculture. The importance of this study is to use clinoptilolite zeolite as nutrients carrier so as to reduce NH_3 loss, increase the N, P and K use efficiency of crops and to as well improve soil fertility. A slow release N fertilizer can be produced by amending urea with clinoptilolite zeolite (Omar *et al.*, 2011; Ahmed *et al.*, 2008). Urea is converted into NH_4^+ by urease afterwhich it is converted to readily leachable NO_3^- by soil bacteria (Eberl and Lai, 1992). The rate of N release is slower in three ways: (i) by sequestering urea in zeolite pores to prevent it from being leached out from the root zone; (ii) delaying the formation of ammonium ions by slowing down the release of urea with urease enzyme in soil, and (iii) by taking up ammonium ions into exchange sites and protect them from nitrification by microbes (Eberl and Lai, 1992). Zeolites containing a monovalent exchange ion such as NH_4^+ (Lai and

Eberl, 1986), when mixed with P fertilizers, they take Ca^{2+} from P fertilizers thereby slowing the release of $H_2PO_4^-$ and NH_4^+ for plant uptake.

Clinoptilolite zeolite can be a mineral source of nutrients such as K, Ca, and Mg (Bagdasarov *et al.*, 2004). Clinoptilolite zeolite has three important main properties: high cation exchange capacity, high holding water capacity in its free channels, and high adsorption capacity (Bernaldi *et al.*, 2010a; Payra and Dutta, 2003) which are of great interest in agriculture. This is due to the unique feature of clinoptilolite zeolite, as it is structured in three-dimensional rigid crystalline network, formed by the tetrahedral AlO_4 and SiO_4, which is made up of tunnels that are 10^{-9} m in size containing internal exchange sites. These sites have high affinity for NH_4^+ (Ming and Dixon, 1986; Ferguson and Pepper, 1987). These structures also ensure a permanent water reservoir in the root zone and physically protect NH_4 from nitrification by microbes (Omar *et al.*, 2011; Polat *et al.*, 2004).

In various studies, clinoptilolite zeolite has been used as efficient material to increase crop yield, reducing nutrient losses and improving nutrient use efficiency (Ahmed *et al.*, 2010; Milosevic and Milosevic, 2009; Oosterhuis and Howard, 2008). In Bernardi *et al.* (2010b) study, urea amended with clinoptilolite zeolite improved the efficiency of N use where the effects of urea and zeolite (32.6%) were statistically equivalent to treatments with urease inhibitor (37%). Ahmed *et al.* (2010) also reported that in maize plant, N, P, and K use efficiency were significantly affected by the combination of a chemical fertilizer and clinoptilolite zeolite. In the same study, application of lowest dosage of chemical fertilizer and highest dosage of clinoptilolite zeolite gave the highest N, P, and K concentrations in soils. In another report, application of the highest dosage of chemical fertilizer and highest dosage of clinoptilolite zeolite improved plant height, diameter and yield of sugarcane, and the treatment was considered profitable (Junrungreang *et al.*, 2002).

There is still a dearth of information about the effectiveness of mixed fertilizers and clinoptilolite zeolites in minimizing NH_3 volatilization and as well as improving soil chemical properties and increasing crop height, dry matter and N, P and K use efficiency. The objectives of this study were to: (i) compare the effect of different ratios of mixed fertilizer amended with zeolite on NH_3 volatilization, soil exchangeable NH_4^+ , and available NO_3^- contents of an acid soil, and (ii) clinoptilolite zeolite to improve selected soil chemical properties, nutrient uptake, and nutrient use efficiency using maize as a test crop. In this study, it was expected that the right proportion of mixed fertilizers and clinoptilolite zeolite will increase N use efficiency and improve crop yield.

REFERENCES

Ahmed, O.H., H. Aminuddin, M.H.A. Husni. 2006. Reducing ammonia loss from urea and improving soil-exchangeable ammonium retention through mixing triple superphosphate, humic acid and zeolite. *Soil Use Management*, **22**:315-319.

Ahmed, O.H., H. Aminuddin, M.H.A. Husni. 2008. Ammonia volatilization and ammonium accumulation from urea mixed with zeolite and triple superphosphate. *Soil and Plant Science*, **58**: 182-186.

Ahmed, O.H., A .Hussin, H.M.N. Ahmad, M.B. Jalloh, A.A Rahim, N.M.A. Majid. 2009. Enhancing the urea-N use efficiency in maize (*Zea mays*) cultivation on acid soils using urea amended with zeolite and TSP. *American Journal of Applicatiom Science*, **6**(5): 829-833

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. *International Journal of the Physical Sciences*, **5**(15): 2393-2401.

Al-Busaidi , A., T. Yamamoto, and I. Mitsuhiro, A. E. Eneji, Y. Mori, and M. Irshad.2008. Effects of zeolite on soil nutrients and growth of barley following irrigation with saline water. The 3rd International Conference on Water Resources and Arid Environments and the 1st Arab Water Forum.

Al-Kanani, T., A.F. Mackenzie and N.N Barhakur. 1991. Soil water and ammonia volatilization relationships with surface-applied nitrogen fertilizer solution. *Soil Science Society of American Journal*, **55**: 1761-1766.

Allen, E.A., L.R. Hossner, D.W. Ming, and D.L.Henninger. 1993. Solubility and cation exchange in phosphate rock and saturated clinoptilolite mixtures. *Soil Science Society of America Journal*, **57**: 1368-1374.

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

Bernardi, A.C.C., P.P.A. Oliviera, M.B.M. Monte, J.C. Polidoro, and F.S. Barros. 2010a. Brazilian sedimentary zeolite use in agriculture. World Congress of Soil Science, Soil Solutions for a Changing World, 1 – 6 August 2010, Brisbane, Australia.

Bernardi, A.C.D.C, E.P.D., Mota, S.D.C.H.D. Souza, R.D. Cardodo, and P.P.A. Oliviera. 2010b. Ammonia volatilization, dry matter yield and nitrogen levels of Italian ryegrass fertilized with urea and zeolite. 19th World Congress of Soil Science, Soil solutions for a changing world. August, 1-6, 2010. Australia.

Bogdanov, B., D. Georgiev, K. Angelova, and K. Yaneva. 2009. Natural zeolites: clinoptilolite review "Economics and Society development on the Base of Knowledge", Natural and Mathematical science. International Science conference, 4th - 5th June 2009, Stara Zagora, Bulgaria.

Brady, N.C., and R.R. Weil. 2002. The nature and properties of soils.13th ed. U.S.A: Pearson Education Ltd. New York.

Bremner, J.M. 1965. Total Nitrogen. In, *Method of soil analysis, Part 2*, Black CA, Evants DD, Ensminger LE, White JL, Clark FE, Dinauer RC (eds.). pp. 1149-1178. American Social Agrononomy, Madison, Wisconsin.

Bundan, L., A.M. Nik Muhamad, O.H. Ahmed, M. Jiwan, and F.R. Kundat. 2011. Ammonia volatilization from urea at different levels of zeolite *International Journal of the Physical Sciences*, **6**(34): 7717 – 7720.

Camberato, J.J. 2001. Nitrogen in soils and fertilizers. South Carolina Turfgrass Foundation News, Jan.-Mar., **8**(1):6-10.

Chang, F., W. Zhang and W. Ma. 2009. The Chemical Fertilizer Industry in China: A Review and Its Outlook. International Fertilizer Industry Association, Paris, France. p 119-143.

Chien, S.H., L.I. Prochnow, and H. Cantarella. 2009. Recent developments of fertilizer production and use to improve nutrient efficiency and minimize environmental impacts.

Christianson, C.B. 1989. Ammonia volatilization from urea nitric phosphate and urea applied to the soil surface. *Fertilizer Research*, **19**: 183-189.

Corstanje, R., G.J.D. Kirk, M. Pawlett, R. Read and R.M. Lark. 2008. Spatial variation of ammonia volatilization from soil and its scale-dependent correlation with soil properties. *European Journal of Soil Science*, **59**: 1260-1270.

Cottenie, A. 1980. Soil testing and plant testing as a basis of fertilizer recommendation. *Fertilizer Agriculture Organization Soils Bulletin*, **38**:70-73.

Dougherty. W., L. Burkitt, P. Milham. And D. Harvey. 2010. The effect of soil available P and P buffering on runoff P concentration from pastures. World Congress of Soil Science, Soil Solutions for a Changing World, 1-6 August 2010, Brisbane, Australia.

Eberl, D.D., and T.M. Lai, 1992. Slow-release nitrogen fertilizer and soil conditioner: U.S. Patent Applied.

European Fertilizer Manufacturers' Association. 2000. Production of N P K by the mixed acid route. Brussel, Belgium.**8**: 7

Fan, M.X., and A.F. Mackenzie. 1993. Urea and phosphate interactions in fertilizer microsites: Ammonia volatilization and pH changes. *Soil Science Society of America Journal*, **57**: 839-845.

Ferguson, G.A., and I.L. Pepper. 1987. Ammonia retention in sand amended with clinophilolite. *Soil Science Society of America Journal*, **51:** 231-234.

Ferguson, G.A., D.E. Kissel, J.K. Koelliker, and W. Basel. 1984. Ammonia volatilization from surface-applied urea: effect of hydrogen ion buffering capacity. *Soil Science Society of American Journal*, **48**: 578-582.

Ferguson, R.B., and D.E. Kissel. 1986. Effect of soil drying on ammonia volatilization from surface-applied urea *Soil Science Society of America Journal*, 485-490.

Gholizadeh, A. 2008. Iran International Zeolite Conference. Zeolite slow release fertilizer: A brief review. April 29- May 1, 2008. Tehran-Iran.

Ghorbani, H., and A.A. Babaei. 2008. The effects of natural zeolite on ions adsorption and reducing solution electrical conductivity in Na and K solutions.. pp. 947-955. International Meeting on Soil Fertility Land Management and Agroclimatology. Turkey.

Greer, G.N. 1987. Fertilizer checklist. Old Fruit and Vegetable News. Australia.

Gruhn, P., F. Goletti, and M. Yudelman. 2000. Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges. International Food Policy Research Institute.

Hanafi, M.M., Eltaib S.M., and M.M. Ahmad. 1999. Physical and chemical characteristics of controlled release compound fertilizer. European Polymer Journal **36**(2000): 2081-2088.

Hartel, P.G., D.M. Sylvia, J.J. Fuhrmann, and D.A. Zuberer. 2005. Principles and applications of soil microbiology. Prentice Hall, Upper Saddle River, NJ.

He, Z.L., A.K. Alva, D.V. Calvert, and D.J. Banks. 1999. Amonia volatilization from different nitrogen fertilizers and effects of temperature and soil pH. *Soil Science*, **164**: 750-758.

Hoeft, R.G. and T.R. Peck. 1991. Soil testing and fertility. In: *Illinois Agronomy Hanbook*, Circular 1311,University of Illinois, Urbana-Champaign, IL, USA.

Hodges, S.C. 2000. Soil fertility basics. Soil Science Extension. North Carolina State University.

Hua, Q.X.; J.M. Zhou, H.Y. Wang, C.W. Du, X.Q. Chen and J.Y. Li. 2006. Effects of modified clinoptilolite on phosphorus mobilisation and potassium or ammonium release in Ferrosols. *Australian Journal of Soil Research.* HighBeam Research. http://www.highbeam.com/doc/1G1-146836173.html

International Plant Nutrition Institute, 2012. Nutrient Source Specific: Compound Fertilizer. Georgia, USA.

Jones, C. and J. Jacobsen. 2005. Nitrogen cycling, testing and fertilizer recommendations. Nutrient management Module 3. No. 4449. Montana State University Extension Service. Bozeman, Montana.

Junejo, N., M.Y. Khanif, M.M. Hanfi, K.A. Dharejo, and Z.W.Y. Wan. 2011. Reduced loss of NH_3 by coating urea with biodegradable polymers, palm stearin and selected micronutrients. *African Journal of Biotechnology*, **10**(52):10618-10625.

Junrungreang, S., P. Limtong, K. Wattanaprapat, and T. Patsarayeangyong. 2002. Effect of zeolite and chemical fertilizer on the change of physical and chemical properties on LatYa soil series for sugar cane. 17^{th} WCSS Symposium 2002. August 14-21, 2002. Thailand.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen-inorganic forms. In, *Method of Soil Analysis, Part 2,* Page Al, Keeney DR, Baker DE, Miller RH, Ellis R, Rhoades JD (eds.). Agronomy.Monograph., 9. ASA and SSSA, Madison, Wisconsin.

Khalil, M.I., R. Gutser, and U. Schmidhalter. 2009. Effects of urease and nitrification inhibitors added to urea on nitrous oxide emissions from a loess soil. Journal of Plant Nutrition Soil Science, **172**:651-660.

Lai, C.M., and M.A. Tabatabai. 1992. Kinetics parameters of immobilized urease. *Soil Biology Biochemical*, **24**(3): 225-228.

Lai, T.M., and D.D. Eberl. 1986. Controlled and renewable release of phosphorus in soils from mixtures of phosphate rock and NH_4-exchanged clinophilolite: Zeolite**, 6**: 129-132.

Lazarova, V. and A. Bahri. 2005. Water reuse for irrigation: agriculture, landscapes and turf grass. In *Water Quality Considerations*, ed. Lazarova, V. H. Bouwer.And A. Bahri. p. 31-81. United States of America: CRC Press.

Leggo P.J., B. Lede´sert b, and G. Christie. 2006. The role of clinoptilolite in organo-zeolitic-soil systems used for phytoremediation. *Science of the Total Environment*, **363** :1 – 10

Lewis, M.D., F.D.I. Moore, K.L. Goldsberry. 1984. Ammonium-exchanged clinoptilolite and granulated clinoptilolite with urea as nitrogen fertilizers. In, Zeo-Agriculture: *Use Natural Zeolites in Agriculture and Aquaculture*, Pond, W.G., Mumpton, F.A. (eds). Westview Press, Boulder.

Li, Z., D. Alessi, and L. Allen. 2000. Influence of quaternary ammonium on sorption of selected metal cations onto clinoptilolite zeolite. *Journal of Environment. Quality*, **31**: 1106-1114.

Malaysia Palm Oil Board and America Palm Oil Council, 2010. Palm oil development and performance in Malaysia. Presentation to USIC Washingston DC. February 3, 2010.

Malaysian Agricultural Research and Development Institute. 2010. Jagung Manis Baru, Masmadu.

Maria-Ramirez, A., E.S. Osuna-Ceja and A. Limón-Ortega. 2011. Two sources of zeolite as substitutes of nitrogen fertilizer for wheat (*Triticum Aestivum*) production in Tlaxcala, Mexico. *Tropical and Subtropical Agroecosystems*. **13**: 533-536.

Matassan, Z.A. 2007. The Malaysian Fertilizet Market. Fertilizer Industry Association of Malaysia. Malaysia.

McCauley, A. 2009. Commercial fertilizers and soil amendments. Soil Scientist Nutrient Management, Module No. 10, Montana State University Extension.

Micu, D., C. Proca, C. Ioana, C. Podaru, and G. Burtica. 2005. Improvement possibilities of soil quality. *Chemical Bulletin of Politehnica" University of Timisoara*, **50**(64): 1-2.

Milosevic, T., and N. Milosevic. 2009. The effect of zeolite, organic and inorganic fertilizers on soil chemical properties, growth and biomass yield of apple trees. *Plant Soil Environment*, **12**: 528-535.

Mineyev, V.G., A.V. Kochetavkin, and N.V. Bo. 1990. Use of natural zeolites to prevent heavy metal pollution of soils and plants. *Soviet Soil Science*, **22**:72–79.

Ming, D.W., and J.B. Dixon. 1986. Clinoptilolite in South Texas soils. *Soil Science Society of America Journal*, **50**: 1618-1622.

Ming, D.W., and F.A. Mumptom. 1989. Zeolite in soils. In, *Mineral in soil environment, 2nd ed*, Dixon JB, Weed SB (eds.). pp 874-911. SSSA Publisher Incorporation, Madison, Wisconsin.

Mishra, P.K. and H.S. Shriastava. 1985. Role of inorganic nitrogen in sythesis and degradation of protein in maize leaves. *Indian Journal Plant Physiology*, **28**(1): 43-52.

Mumpton, F.A. 1999. La Roca Magica: Uses of natural zeolites in agriculture and industry. Proceedings of the National Academy of Sciences**, 96**(7): 3463-3470.

Omar, L., O.H. Ahmed, and A.M. Nik Muhamad. 2011. Minimizing ammonia volatilization in waterlogged soils through mixing of urea with zeolite and peat soil water. *International Journal of the Physical Sciences*, **5**(11): 2193-2197.

Oosterhuis, D.M., and D.D. Howard .2008. Evaluation of slow-release nitrogen and potassium fertilizers for cotton production. *African Journal of Agricultural Research*, **3**(1): 68-73.

Oste, L.A., T.M. Lexmond, W.H.V. Riemsdij. 2002. Metal immobilization in soils using synthetic zeolites. *Journal of Environmental Quality*, **31**: 813-821.

Paramananthan, S. 2000. Soil of Malaysia: Their characteristics and identification. Academy of Science Malaysia, Kuala Lumpur, Malaysia.

Payra, P., and P.K. Dutta. 2003. Handbook of zeolite science and technology. Ohio, USA.

Perez, R., J. Caballero, C. Gil., J. Benitez, and L. Gonazalez. 2008. The effect of adding zeolite to soils in order to improve the N-K nutrition of olive trees: preliminary results. *American Journal Agricultural and Biological Science*, **2**(1):321-324.

Piccolo, A. (1996).Humic and Soil Conservation.Humic Substances in Terrestrial Ecosystem. Amsterdam: Elseiver.

Pickering, H.W., N.W. Menzies, and M.N. Hunter. 2002. Zeolite or rock phosphate: a novel slow release phosphorus fertilizer for potted plant production. *Scientia Horticulturae*, **94**:333–343

Plaster, E.J. 2009. Fertilizers. In, *Soil science and management* , Plaster EJ (5th eds.), pp. **14**:236-238. Delmar, USA.

Polat, E., M. Karaca, H. Demir, and A. Naci-Onus. 2004. Use of natural zeolite (clinophilolite) in agriculture. *Journal of Fruit Ornamental and Plant Research*, **12**: 183-189.

Pomares-Gracia, F., and P.F. Pratt. 1987. Recovery of 15N-labelled fertilizer from manured and sludge-amended soils. *Soil Science Society of America Journal*, **42**: 712-720.

Rachpal-Singh and P.H. Nye. 1986. A model of ammonia volatilization from applied urea. III. Sensitivity analysis, mechanism, and application. *Journal of Soil Science*, **37**: 31-40.

Ramesh, K., and D.D. Reddy. 2011. Zeolite and their potential uses in agriculture. In, *Advances in agronomy*, Sparks DL, (eds.). Indian Institute of Soil Science, India.

Ramli, N.N., M.N. Shamsudin, Z. Mohamed, A. Radam. 2012. The impact of fertilizer subsidy on Malaysia paddy rice industry using a system dynamics approach. *International Journal of the Social Sciences and Humanity*, **2**(3).

Reddy, S.R. 2004.Principle of Agronomy. New Delhi, India. p. 20-123.

Rehakova, M., S. Cuvanova, M. Dzivak, J. Rimar, Z. Gaval'ovac. 2004. Agricultural and agrochemical uses of natural zeolite of the clinoptilolite type. *Current Opinion in Solid State and Materials Science*, **8**: 397-404.

Rengel, Z. and P.M. Damon. 2008. Crops and genotypes differ in efficiency of potassium uptake and use. *Physiologia Plantarum*, **133**: 624-636.

Roy, R.N., A. Finck, G.J. Blair and H.L.S. Tandon. 2006. Plant nutrition for food security: A guide for integrated nutrient management. *Food and Agriculture Organization Fertilizer and Plant nutrition Bulletin.* Rome.

Siva, K.B., H. Aminuddin, M.H.A. Husni, and A.R. Manas. 1999. Ammonia volatilization from urea as affected by tropical-based palm oil effluent (pome) and peat. *Communications in Soil Science and Plant Analysis*, **30**: 785-804.

Soil Survey Staff, 2010. Keys to Soil Taxonomy (11th ed). USDA-Natural Resources Conservation Service, Washington, DC.

Sonmez, I. M. Kaplan, H. Demır, and E. Yilmaz. 2010. Effects of zeolite on seedling quality and nutrient contents of tomato plant (*Solanum lycopersicon* cv. Malike F1) grown in different mixtures of growing media. *Journal of Food, Agriculture and Environment*, **8**(2): 1162 - 1165.

Sulakhudin, A. Syukur, and B.H.Sunarminto. 2011. Zeolite and Hucalcia as Coating Material for Improving Quality of NPK Fertilizer in Costal Sandy Soil *Journal of Tropical Soils*, **16**(2): 99-106.

Tan, K.H. 2005. Soil sampling, preparation, and analysis (2nd ed). Boca raton, Florida, USA.

Torkashvand, M., A. Karami , M. Khomami, and V. Shadparvar. 2012. Zeolite: an appropriate alternative to peat in the growth medium of ornamental plants. *Indian Journal of Fundamental and Applied Life Sciences,* **2**(1): 2231-6345.

Trenkel, M.D. 2010. Slow and controlled-release and stabilized fertilizers: In: *An option for enhancing nutrient efficiency in agriculture, (2nded).* International Fertilizer Industry Association, France..

Trinchera, A., C. Mario Rivera, S. Rinaldi, A. Salerno, E. Rea and P. Sequi. 2010. Granular Size Effect of Clinoptilolite on Maize Seedlings Growth. *The Open Agriculture Journal,* **4**: 23-30.

Vaio, N. 2006. Ammonia volatilization and n-uptake from urea, urea ammonium nitrate (UAN) and nitamin (urea-polymer) applied to tall fescue in Georgia. University of Georgia, Athens.

Watson, C.J. 2000. Urease activity and inhibition-principles and practice. Proceedings No. 454, pp 40. The International Fertiliser Society, York, United Kingdom.
Wu, L. and M. Liu. 2008. Preparation and properties of chitosan-coated NPK compound fertilizer with controlled-release and water-retention.. *Carbohydrate Polymers*, **72**: 240-247.
Yousofi and Sepaskhah. 2005. The effects of zeolite on nitrate and ammonium retention in saturated soil. The 9th Soil Science Congress of Iran, August, 2005, Tehran-Farsi.

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LIST OF PUBLICATIONS

1. Rabai. K. A., O. H. Ahmed and S. Kasim, 2012. Improving formulated nitrogen, phosphorus and potassium compound fertilizer using zeolite. *African Journal of Biotechnology*. **11**(65):12825-12829.

2. Rabai. K. A., O. H. Ahmed and S. Kasim, 2013.Use of formulated nitrogen, phosphorus, and potassium compound fertilizer using clinoptilolite zeolite in maize (Zea mays) cultivation. *Emirates Journal of Food and Agriculture*. **25** (9): 713-722.