UNIVERSITI PUTRA MALAYSIA

USE OF CLINOPTILOLITE ZEOLITE TO IMPROVE EFFICIENCY OF PHOSPHORUS USE IN ACID SOILS

NUR AAINAA HASBULLAH

FSPM 2016 5

USE OF CLINOPTILOLITE ZEOLITE TO IMPROVE EFFICIENCY OF PHOSPHORUS USE IN ACID SOILS

By

NUR AAINAA BINTI HASBULLAH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

June 2016

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Doctor Philosophy

USE OF CLINOPTILOLITE ZEOLITE TO IMPROVE EFFICIENCY OF PHOSPHORUS USE IN ACID SOILS

By

NUR AAINAA BINTI HASBULLAH

June 2016

Chairman : Ahmed Osumanu Haruna, PhD
Faculty : Agriculture and Food Sciences (Bintulu)

In acid soil of the tropics, soluble P is fixed by aluminium (Al) and iron (Fe). Therefore, efficient management of P fertilizers is critical to meet crops demand and to as well ensure good yield of crops and adequate food supply. In addition, mitigating environmental impacts on water quality and conservation of finite P deposit cannot be over emphasized. Clinoptilolite zeolite as an amendment could be used to mitigate P fixation in acid soils. To this end, a series of experiments were conducted including incubation study, pot trial, and two cycles of *Zea mays* L. cultivation at Universiti Putra Malaysia, Bintulu Sarawak Campus, Malaysia to improve P use efficiency and to also reduce amount of fertilizers (N, P, and K) use by amending fertilizers with Clinoptilolite zeolite. The three P fertilizers used in this study were a highly soluble P fertilizer (Triple superphosphate, TSP), rock phosphate fertilizers (Christmas Island rock phosphate, CIRP), and Egypt rock phosphate (ERP). The test crop used in this study was F1 maize hybrid (Hibrimas). In the incubation study, different amounts of Clinoptilolite zeolite and fertilizers were evaluated in a controlled environment. The treatments evaluated were: soil alone (T0), 100% fertilizer recommended rates (T1, E1, and C1), 75% fertilizer + 85% Clinoptilolite zeolite based on weight of fertilizer (T2, E2, and C2), 50% fertilizer + 100% Clinoptilolite zeolite (T3, E3, and C3), and 25% fertilizer rate + 115% Clinoptilolite zeolite (T4, E4, and C4). Soil pH was significantly improved with Clinoptilolite zeolite inclusion, whereas soil exchangeable Ca, Mg, Al, and soil acidity were comparable to the recommended rates. Decreased trend in soil exchangeable K, total P, and available P is related to the fertilizers reduction. Generally, P availability and reduction of P fixation (Al-P, Fe-P, Ca-P, reductant-P, and occluded-P) were not significant (inconsistent) in this incubation study, the effect could be different with plant interaction. These aspects were tested in a pot study. Treatments with 25% fertilizer reduction (T2, E2, and C2) were chosen as they showed the closest effects on selected

soil chemical properties as compared to the recommended fertilizer rates. The pot study conducted in a controlled environment revealed that amending reduced amounts of fertilizers with Clinoptilolite zeolite had similar effects on selected soil chemical properties and plant performance (dry matter production, nutrients uptake, and nutrients use efficiency). Amount of P fixed was similar to the recommended fertilizer rates thus, explaining the lack of differences in soil P availability, total P, plant dry matter production, nutrients uptake, and nutrients use efficiency despite 25% fertilizer reduction. This suggests the beneficial effect of Clinoptilolite zeolite in reducing P fixation besides improving nutrient uptake and use efficiency. The potential of Clinoptilolite zeolite and its effects on soil chemical properties and *Zea mays* L. productivity were further determined in a field trial. In the two field trials, maize plants dry matter production, nutrients uptake, and agronomic efficiency were similar regardless of fertilizer rate. Yield of fresh cobs in the first plant cycle showed that the recommended rates of TSP (T1), ERP (E1), and CIRP (C1) were 17 t ha^{-1}, 9.1 t ha^{-1}, and 8.8 t ha^{-1}, respectively. Reducing fertilizers by 25% but with Clinoptilolite zeolite resulted in comparable fresh cob yield as that of the recommended fertilizer rates. In the second plant cycle, there was an increase in the fresh cob yield. Plots with TSP and the treatments with fertilizers reduction and Clinoptilolite zeolite yielded 25 t ha^{-1} and 22 t ha^{-1} fresh cobs, respectively. Application of ERP resulted in 11.6 t ha^{-1} in both recommended and reduction treatments whereas CIRP recorded 17.5 t ha^{-1} for the recommended treatment and 15 t ha^{-1} fresh cobs for the reduced fertilizer rate. Clinoptilolite zeolite inclusion in the first plant cycle neither increased soil pH, P availability, and basic cations nor reduced P fixation, soil acidity, and exchangeable Al. The aforementioned results remained similar in the second cycle of maize cultivation except for pH. Inclusion of Clinoptilolite zeolite increased soil pH as the recommended fertilizer rates. Although Clinoptilolite zeolite inclusion neither improved P availability nor reduced P adsorption, similar retention and availability of P despite 25% fertilizer reduction was observed. This suggests that Clinoptilolite zeolite enhanced-exchange mechanism, retention of basic cations from leaching, RP dissolution, efficient use of fertilizer thus, producing desirable yield. Clinoptilolite zeolite is beneficial and could be used to reduce the amount of N, P, and K fertilizers use in *Zea mays* L. cultivation on acid soils besides reducing the risk of environmental pollution. Perhaps, in a long term application, selected soil chemical properties could be significantly improved through the conditioning effects of Clinoptilolite zeolite. Clinoptilolite zeolite application reduced leaching losses of Ca and Mg, hence, the similar results obtained in this study regardless of treatment. Availability of N, P, K, and Fe in soil significantly reduced with Clinoptilolite zeolite application with 25% fertilizer reduction. As proven in the two cycles of maize cultivation, the use of Clinoptilolite zeolite in agriculture is beneficial as it can be used to reduce the unbalanced use of N, P, and K fertilizers of *Zea mays* L. and related crops cultivated on acid soils. Besides, it can be used to minimize environmental pollution due to excessive use of chemical fertilizers and mobility of toxic elements. Economic viability analysis for including Clinoptilolite zeolite in maize cultivation revealed that the total cost of production reduced with Clinoptilolite zeolite adoption due to elimination of liming. Benefit cost-ratio for the recommended fertilizer rates was 1.69 whereas Clinoptilolite zeolite inclusion increased benefit cost-ratio (1.83-1.84). Thus, adoption of Clinoptilolite zeolite in reduced amount of fertilization was found to be economically feasible as it not only gives higher profit in return but hopefully could also promote sustainability of agricultural productivity and soil fertility.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan ijazah Doktor Falsafah

PENGGUNAAN ZEOLIT KLINOPTILOLIT MENINGKATKAN KECEKAPAN PENGGUNAAN FOSFORUS DI TANAH BERASID

Oleh

NUR AAINAA BINTI HASBULLAH

Jun 2016

Pengerusi : Ahmed Osumanu Haruna, PhD
Fakulti : Sains Pertanian dan Makanan (Bintulu)

Di dalam tanah berasid di kawasan tropika, fosforus (P) larut diikat oleh aluminium (Al) dan ferum (Fe). Oleh itu, pengurusan yang cekap bagi baja P adalah kritikal untuk memenuhi permintaan tanaman dan juga memastikan hasil tanaman yang baik dan bekalan makanan yang mencukupi. Tambahan pula, pengurangan kesan alam sekitar seperti kualiti air dan pemuliharaan deposit P yang terhad tidak boleh diabaikan. Zeolit Klinoptilolit sebagai bahan penambahbaik boleh digunakan untuk mengurangkan pengikatan P dalam tanah berasid. Untuk tujuan ini, beberapa siri eksperimen termasuk kajian inkubasi, kajian pasu, dan dua pusingan penanaman jagung hibrid F1 (*Zea mays* L.) telah dijalankan di Universiti Putra Malaysia, Kampus Bintulu Sarawak, Malaysia untuk meningkatkan kecekapan penggunaan P dan juga mengurangkan penggunaan baja (N, P, dan K) dengan menambahbaik baja P dengan Zeolit Klinoptilolit. Tiga baja P yang digunakan dalam kajian ini adalah baja P tersangat larut (Triple superphosphate phosphate, TSP), baja batuan fosfat (batuan fosfat Pulau Krismas, CIRP), dan batu fosfat Mesir (ERP). Tanaman yang digunakan dalam kajian ini adalah jagung hibrid F1 (Hibrimas). Dalam kajian inkubasi, jumlah Zeolit Klinoptilolit dan baja yang berbeza telah diuiji di dalam persekitaran yang terkawal. Rawatan yang dinilai ialah: tanah sahaja (T0), 100% kadar baja yang disyorkan (T1, E1, dan C1), 75% baja + 85% Zeolit Klinoptilolit (T2, E2, dan C2), 50% baja + 100% Zeolit Klinoptilolit (T3, E3 dan C3), dan 25% kadar baja + 115% Zeolit Klinoptilolit (T4, E4, dan C4). pH tanah telah meningkat secara bererti dengan kehadiran Zeolit Klinoptilolit, manakala Ca tukar ganti, Mg, Al, dan keasidan tanah adalah sama dengan kadar baja yang disyorkan. Trend menurun untuk K tukar ganti, total P, dan P tersedia dalam tanah adalah ekoran dari pengurangan baja. Umumnya, ketersediaan P dan pengurangan pengikatan P (Al-P, Fe-P, Ca-P, P-*reductant*, dan P-terperangkap) adalah tidak ketara dalam kajian inkubasi ini. Aspek-aspek ini kemudiannya telah diuji dalam kajian pasu. Rawatan dengan 25% pengurangan baja (T2, E2, dan C2) telah dipilih kerana ianya telah memberikan kesan yang hampir sama terhadap sifat kimia

tanah jika dibandingkan dengan kadar baja yang disyorkan. Kajian pasu yang telah dijalankan dalam persekitaran terkawal mendapati bahawa menambahbaik jumlah baja yang dikurangkan dengan Zeolit Klinoptilolit mempunyai kesan yang sama ke atas sifat kimia tanah terpilih dan prestasi tanaman (penghasilan berat kering, pengambilan nutrien, dan kecekapan penggunaan nutrien). Jumlah pengikatan P adalah sama dengan kadar baja yang disyorkan. Oleh itu ianya menjelaskan tentang perbezaan untuk P tersedia, total P, pengeluaran berat kering, pengambilan nutrien, dan kecekapan penggunaan nutrien meskipun 25% baja telah dikurangkan. Ini menunjukkan bahawa Zeolit Klinoptilolit adalah berfaedah dalam mengurangkan pengikatan P disamping meningkatkan pengambilan nutrien, dan kecekapan penggunaannya. Potensi Zeolit Klinoptilolit dan kesannya terhadap sifat kimia tanah dan produktiviti tanaman jagung (*Zea mays* L.) seterusnya diuji dalam kajian lapangan. Di dalam dua kajian lapangan, pengeluaran berat kering jagung, pengambilan nutrien, dan kecekapan agronomi adalah sama tanpa mengira kadar baja. Hasil tongkol segar jagung dalam pusingan pertama penanaman menunjukkan bahawa kadar TSP (T1), ERP (E1), dan CIRP (C1) yang disyorkan masing-masing memberikan hasil 17 t ha^{-1}, 9.1 t ha^{-1}, dan 8.8 t ha^{-1}. Pengurangan baja sebanyak 25% tetapi penambahan Zeolit Klinoptilolit telah menghasilkan tongkol segar yang setanding dengan kadar baja yang disyorkan. Di dalam pusingan kedua, terdapat peningkatan dalam hasil tongkol segar jagung. Plot dengan rawatan TSP pada kadar yang disyorkan dan rawatan baja kadar baja pada kadar yang dikurangkan dengan penambahan Zeolit Klinoptilolit masing-masing memberikan hasil sebanyak 25 t ha^{-1} dan 22 t ha^{-1} tongkol segar. Penggunaan ERP menghasilkan 11.6 t ha^{-1} di dalam kedua-dua kadar yang disyorkan dan rawatan dengan pengurangan baja CIRP merekodkan sebanyak 17.5 t ha^{-1} untuk baja yang disyorkan dan 15 t ha^{-1} tongkol segar untuk kadar baja yang dikurangkan. Penambahan Zeolit Klinoptilolit dalam pusingan pertama tidak meningkatkan pH tanah, P tersedia, kation asas, dan tidak juga mengurangkan penjerapan P, keasidan tanah, dan Al tukar ganti. Keputusan yang disebutkan di atas kekal sama dalam pusingan kedua penanaman jagung kecuali pH. Penambahan Zeolit Klinoptilolit telah meningkatkan pH tanah setara dengan kadar baja yang disyorkan. Meskipun penambahan Zeolit Klinoptilolit tidak meningkatkan ketersediaan P mahupun mengurangkan penjerapan P, 25% baja telah dikurangkan dan P yang dipegang dan ketersediaan P adalah sama. Ini menunjukkan bahawa Zeolit Klinoptilolit telah meningkatkan mekanisme pertukaran, pemegangan kation asas dari dilarutlesap, kelarutan RP, dan kecekapan penggunaan baja dengan memberikan hasil tanaman yang sama . Zeolit Klinoptilolit adalah bermanfaat dan boleh digunakan untuk mengurangkan penggunaan baja N, P, dan K di dalam penanaman jagung (*Zea mays* L.) di tanah berasid disamping mengurangkan risiko pencemaran alam sekitar. Berkemungkinan, aplikasi jangka masa panjang akan mempertingkatkan sifat kimia tanah terpilih secara bererti melalui kesan perbaikan Zeolit Klinoptilolit. Penggunaan Zeolit Klinoptilolit telah mengurangkan kehilangan larutlesap Ca dan Mg, justeru itu, keputusan yang diperolehi dalam kajian ini tanpa mengira rawatan adalah sama. Ketersediaan N, P, K, dan Fe dalam tanah berkurangan secara bererti dengan aplikasi Zeolit Klinoptilolit ekoran pengurangan baja 25%. Seperti yang dibuktikan dalam dua kitaran penanaman jagung, penggunaan Zeolit Klinoptilolit dalam bidang pertanian adalah bermanfaat memandangkan ianya boleh digunakan untuk mengurangkan penggunaan baja N, P, dan K yang tidak seimbang dalam penanaman jagung (*Zea mays* L.) dan tanaman lain yang ditanam di tanah berasid. Selain itu, ianya mampu mengurangkan pencemaran alam sekitar disebabkan oleh penggunaan baja kimia yang berlebihan dan pergerakan unsur-unsur toksik. Analisis daya maju ekonomi bagi Zeolit Klinoptilolit dalam penanaman jagung mendedahkan bahawa jumlah kos pengeluaran berkurang dengan penggunaan Zeolit Klinoptilolit. Nisbah kos-faedah untuk kadar baja yang disyorkan adalah 1.69 manakala dengan penggunaan Zeolit Klinoptilolit manfaat nisbah-kos meningkat (1.83-1.84). Oleh itu, penggunaan Zeolit Klinoptilolit dengan jumlah baja yang dikurangkan didapati berdaya maju dari segi ekonomi kerana ianya bukan sahaja memberi pulangan yang lebih tinggi tetapi juga dapat memastikan kemampanan produktiviti pertanian dan kesuburan tanah.

ACKNOWLEDGEMENT

First and foremost, all praises to Allah the almighty for granting me the strength to complete my research thesis successfully. This thesis completion is due to the assistance, guidance, and inspiration of the people around me. Therefore, my sincere gratitude goes to all of them.

To my respected supervisory committee chairman and members, Assoc. Prof. Dr. Ahmed Osumanu Haruna, Prof. Dato' Dr. Nik Muhamad Nik Ab. Majid, and Dr. Susilawati Kassim, I could not thank you enough for your guidance, supports, and encouragements during my study.

To my parents and siblings, this thesis is dedicated to you. Your endless love and support kept me going. Thank you for being there for me during challenging times. May Allah bless us.

In this arduous journey, sometimes the light goes out but is blown to flame by others. Thus, my deepest thanks to friends who rekindle the light. You know who you are. Not to forget, to all the support staff at Universiti Putra Malaysia Bintulu Campus (UPMKB) for their assistance.

Last but not the least, I would also like to express my gratitude for financial assistance through research grant and scholarship awarded by Universiti Putra Malaysia and Malaysian Ministry of Education, respectively for making this study possible.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Ahmed Osumanu Haruna, PhD
Associate Professor
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia Bintulu Sarawak Campus
(Chairman)

Nik Muhamad bin Nik Abdul Majid, PhD
Professor
Institute of Tropical Forestry and Forest Product
Universiti Putra Malaysia
(Member)

Susilawati binti Kasim, PhD
Senior Lecturer
Faculty of Agriculture
Universiti Putra Malaysia Bintulu Sarawak Campus
(Member)

BUJANG KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: ________________________

Name and Matric No.: Nur Aainaa Binti Hasbullah, GS29871

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Al-P	Aluminium bound P
BC	Buffering capacity
Ca-P	Calcium bound P
CEC	Cation exchange capacity
DAI	Days after incubation
DAP	Days after planting
DAS	Days after sowing
Fe-P	Iron bound P
Occl-P	Occluded P
OM	Organic matter
Sol-P	Loosely soluble P

CHAPTER 1

INTRODUCTION

1.1 Background and Problem Statement

Phosphorus plays an important role in plant metabolic function as it is one of the essential nutrients required for lucrative crops production. Its deficiency in soils does not only limit nitrogen (N) uptake but it also leads to poor yield of crops (Bundy *et al.,* 2005). Phosphorus supplied in soluble form is rapidly converted to less soluble form by adsorption and precipitation thus, rendering it unavailable for crops uptake.

In acidic soil of the tropics, P is either inherently low or is fixed in forms that are unavailable to crops. Metal oxides and hydroxides such as Al and Fe which are dominant in highly weathered soils of the tropics fix large amounts of soluble P (Wilson *et al.,* 2004). Thus, large amount of P fertilizers are applied to saturate the capacity for P sorption and to ensure P availability for crops uptake. However, this practice in agriculture is neither economical nor environmentally friendly. For example, excessive and inefficient use of P fertilizers endanger water bodies as P can be lost through soil erosion (Zhou and Zhu, 2003) and also leaching to cause eutrophication (Ruban, 1999). Besides, P which originates from non-renewable resources are limited in reserves (Bondre, 2011; Filippelli, 2011; Gilbert, 2009). The responses to P scarcity may include increased cost, more efficient P use, and P recovery and re-use. Moreover, prolonged use of chemical fertilizers in agriculture degrades soil fertility. Therefore, an effective management of P fertilizers will promote not only increase of crops yield but it will also reduce costs of production, mitigate environmental pollution besides conserving finite P deposit.

In Malaysia, the agricultural sector is the third contributor to the Malaysian economic growth. Approximately 90% of chemical fertilizers is required to sustain the agricultural sector of Malaysia. The fertilizer import bills were USD$ 209 million and USD$ 319 million in 2009 and 2013, respectively (FAOSTAT, 2014). The fertilizer import bill of Malaysia is estimated to increase yearly. The use of rock phosphates is preferable because they are cheaper and their dissolution is favorable in acidic condition instead of highly soluble P fertilizers such as Triple superphosphate (Akande *et al.,* 2008; Nnadi and Haque, 1998). Besides, the use of soil amendments such as organic and inorganic materials has been incorporated in some of the agriculture practices. One of the soil amendments is natural zeolites.

Zeolites are natural aluminosilicates with an infinite three-dimensional crystal structure, a polyedric shape, with a great open cavity (Ajirloo *et al.,* 2013;

Ramesh *et al.,* 2011; Daković *et al.,* 2007). These abundant and cheap minerals are used in agriculture as soil conditioners, slow-release fertilizers, and agents for contaminated soils (Ming and Allen, 2001). Phosphorus release through the use of zeolites and rock phosphate (RP) had been demonstrated by exchange-induced dissolution system as (Allen *et al.,* 1993):

$$\text{RP (rock phosphate)} + NH_4^+ + \text{zeolite} \rightleftarrows \text{Ca-zeolite} + NH_4^+ + H_2PO_4^-$$

Clinoptilolite zeolite which is one of the most important natural zeolites is useful to retain nutrients such as NH_4^+ and K^+. The cations selectivity of zeolites is in the order of $Cs^+ > Rb^+ > K^+ > NH_4^+ > Ba^{2+} > Sr > Na^+ > Ca^{2+} > Fe^{3+} > Al^{3+} > Mg^{2+} > Li^+$ (Mumpton, 1999). Crops uptake of cations from Clinoptilolite zeolite leads to vacant exchange sites to which Ca^{2+} are attracted to. This process lowers the activity of Ca^{2+} from soil solution thereby inducing dissolution of rock phosphates (RP) and also, producing ammonium ions as by-product (Pickering *et al.,* 2002; Allen *et al.,* 1995; Barbarick *et al.,* 1993; Lai and Eberl, 1986).

Zeolites are not easily degraded over time and because of this, they remain in soils to improve retention of nutrients and control nutrient release for crop use (Ramesh *et al.,* 2010; Eberl, 1993; Zelazny *et al.,* 1977). Amelioration of soil pH due to Clinoptilolite zeolite catalytic ability as an example could reduce soil acidity and concentration of exchangeable Al and Fe. Hence, reducing P fixation in acid soils, ensure efficient use of nutrients through timely release of nutrients for optimum crop production. Perhaps, in long term application of zeolites, soil properties could be rejuvenated to sustain crop productivity. Although zeolites have been extensively used in agriculture, there is dearth of information on the use of zeolites such as Clinoptilolite zeolite (the most common and abundant type of zeolites) on P sorption and fixation in highly weathered tropical soils not to mention reduction of N, P, and K fertilizers use in agriculture.

1.2 Objectives

The general objective of this study was to improve P use efficiency and to also reduce amount of fertilizers (N, P, and K) use by amending chemical fertilizers with Clinoptilolite zeolite in an acid soil (Bekenu series, Typic Paleudult). Thus, this study was carried out to determine the:

1. Effects of amending different rate of phosphate fertilizers (Triple superphosphate, Egypt rock phosphate, and Christmas Island rock phosphate) with Clinoptilolite zeolite on phosphorus dissolution and selected soil chemical properties.
2. Effects of amending phosphorus fertilizers with Clinoptilolite zeolite on dry matter production, nutrients concentration, nutrients uptake and use efficiency, and yield of *Zea mays* L. cultivated on an acidic soil.
3. Economic viability of amending phosphorus fertilizers with Clinoptilolite zeolite in the fertilization program of *Zea mays* L. cultivated on an acidic soil.

REFERENCES

Abolfazli, F., A. Forghani, and M. Norouzi. 2012. Effects of phosphorus and organic fertilizers on phosphorus fractions in submerged soil. *Journal of Soil Science and Plant Nutrition*, 12(2): 349–362.

Adhami, E. H.R. Owliaie, R. Molavi, M. Rezaei Rashti, and M. Esfandbod. 2013. Effect of soil properties on phosphorus fractions in subtropical soils of Iran. *Journal of Soil Science and Plant Nutrition*, 13: 11–21.

Ahmed, O.H., G, Sumalatha., and N.M.A,. Majid. 2010. Use of zeolite in maize (*Zea mays*) cultivation on nitrogen, potassium, and phosphorus uptake and use efficiency. *International Journal of the Physical Science*, 5(15): 2393-2401.

Aitken, R.L, and P.W Moody. 1994. The effect of valence and ionic strength on the measurement of pH buffer capacity. *Australian Journal of Soil Research*, 32: 975-984.

Aitken, R.L. 1992. Relationships between extractable Al, selected soil properties, pH buffer capacity and lime requirement in some acidic Queensland soils. *Australian Journal of Soil Research*, 30: 119–130.

Ajirloo, G.S., A.P. Jadid, and M.H. Nasirtabrizi. 2013. Effect of zeolite application on soil purification and some chemical properties of soil (case study). *Technical Journal of Engineering and Applied Sciences*, 3(11):970–974.

Al-Busaidi, A., T. Yamamoto, M. Inoue, A.E. Eneji, Y. Mori, and M. Irshad. 2008. Effects of zeolite on soil nutrients and growth of barley following irrigation with saline water. *Journal of Plant Nutrition,* 31:1159-1173.

Allen, E. and D. Ming. 1995. Recent progress in the use of natural zeolites in agronomy and horticulture. In: Ming, D.W., Mumpton, F.A. (Eds.), Natural Zeolites'93: Occurrence, Properties, Use. International Committee on Natural Zeolites, Brockport, New York, pp. 477–490.

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

Allen, E., D. Ming, L. Hossner, D. Henninger, and C. Galindo. 1995. Growth and nutrient uptake of wheat in a clinoptilolite-phosphate rock substrate. *Agronomy Journal,* 87: 1052-1059.

Amaizah, N.R., D. Cakmak, E. Saljnikov, G. Roglic, N. Kokovic, and D. Manojlovic. 2013. Effect of waste Al-phosphate on soil and plant. *Plant Soil and Environment*, 59(3): 130-135.

Anetor, M.O. and E.A. Akinrinde. 2007. Lime effectiveness of some fertilizers in a tropical acid alfisol. *Journal of Central European Agriculture*, 8(1): 17–24.

Anjos, J.T. and D.L. Rowell. 1987. The effect of lime on phosphorus adsorption and barley growth in three acid soils. *Plant and Soil* 103: 75–82.

Aprile, F. and Lorandi, R. 2012. Evaluation of Cation Exchange Capacity (CEC) in Tropical Soils Using Four Different Analytical Methods. *Journal of Agricultural Sciences*, 4(6): 278–289.

Arai, Y. and D.L. Sparks. 2007. Phosphate reaction dynamics in soils and soil minerals: A multiscale approach. *Advances in Agronomy*, 94: 135–179

Azura, A.E., J. Shamshuddin and C.I. Fauziah, 2011. Root elongation, root surface area and organic acid by rice seedling under Al^{3+} and/or H^{+} stress. *American Journal of Agricultural and Biological Sciences*, 6: 324–331.

Bache, B.W. and E.G. Williams. 1971. A phosphate sorption index for soils. *Journal of Soil Science*, 22(3): 289 301.

Baligar, V.C., R.E. Schaffer, C.H. Dos Santos, G.V.E. Pitta, and A.F.C. Bahia Filho. 1993. Growth and nutrient uptake parameters in sorghum as influenced by aluminium. *Agronomy Journal*, 79: 1038-1044.

Barbarick, K.A., T.M. Lai, and D.D. Eberl. 1990. Exchange fertilizer (phosphate rock plus ammonium-zeolite) effects on sorghum-Sudan grass. *Soil Science Society of America Journal*, 54: 911–916.

Barrow, N.J. 1967. Effect of soil's buffering capacity for phosphate on the relation between uptake of phosphorous and the phosphorus extracted by sodium bicarbonate. *Journal of the Australian Institute of Agricultural Science*, 33: 119–121.

Basak, B.B., and D.R Biswas. 2016. Potentiality of Indian rock phosphate as liming material in acid soil. *Geoderma*. 263**:** 104–109.

Basri, M.H., N. Junejo, A. Abdu, H.A Hamid, and M.A Kusno. 2013. Elevation and variability of acidic sandy soil pH : Amended with conditioner, activator, organic and inorganic fertilizers, *African Journal of Agriculture Research,* 8(29): 4020–4024.

Beckett, P.H.T and R.E. White. 1964. Studies on the phosphate potentials of soils: The pool of labile inorganic phosphate. *Plant and Soil,* 21: 253-282.

Bell, R.G. 2001. What are Zeolites. http://www.bza.org/zeolites.html. (Retrieved 2nd October, 2015).

Benton, J.J.J. 2003. Agronomic handbook. New York: CRC Press.

Beqiraj, E., F. Gjoka, F. Muller and P. Baillif. 2008. Use of zeolitic material from munella region (Albania) as fertilizer in the sandy soils of Divjaka region (Albania). *Carpathian Journal of Earth and Environmental Sciences,* 3: 33-47.

Bernardi, A.C.C., P.P.A. Oliviera, M.B.M. Monte, J.C. Polidoro, and F. Souza-Barros. 2013. Brazilian sedimentary zeolite use in agriculture. *Microporous and Mesoporous Materials*, 167: 16–21.

Bianchi, S.R., M. Miyazawa, E.L. De Oliveina, and M.A. Pavan. 2008. Relationship between the Mass of Organic Matter and Carbon in Soil, 51(April), pp. 263–269.

Bidin, A. 1986. Phosphorus utilization in rainfed agriculture in Malaysia. In: Proceedings of the second IMPHOS Regional Seminar: Southern Asia, Fertility Association of India, New Delhi. pp. 161-172.

Bloom, P.R. 2000. Soil pH and pH buffering. In: Handbook of soil science. Sumner, M.E. (ed). CRC Press: Boca Raton, FL. Pp. B333–B352.

Blum, J.D., A. Klaue, C.A. Nezat, C.T. Driscoll, C.E. Johnson, T.G. Siccama, C. Eagar, T.J. Fahey, and G.E. Likens. 2002. Mycorrizhal weathering of apatite as an important calcium source in base-poor forest ecosystems. *Nature*, 417: 729-731.

Bolan, N.S., R. Naidu, S. Mahimairaja, and S. Baskaran. 1994. Influence of low molecular weight organic acids on the solubilisation of phosphates. *Biology and Fertility of Soils,* 18: 311–319.

Bondre, N. 2011, Phosphorus: How much is enough?, Global Change, 76: 14-17.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soils. *Agronomy Journal*, 54: 464-465.

Brady, N.C. and R.R. Weil, 2002. The Nature and Properties of Soils.13 Edn., Prentice Hall, USA., ISBN: 0130167630, pp. 960

Brady, N.C. and Weil, R.R. 2004. Elements of the Nature and Properties of Soils. Pearson Education, Inc., Upper Saddle River, NJ.

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

Bundy, L.G., H. Tunney, and A.D. Halvorson. 2005. Agronomic aspects of phosphorus management. In: *Phosphorus: Agriculture and the Environment*. (Eds. Sims J.T. and A.N. Sharpley). ASA, CSSA and SSSA, Madison, Wisconsin, USA pp. 685- 728

Buresh, R.J., P.C. Smithson, and D.T. Hellums. 1997. Building soil phosphorus capital in Africa. In: *Replenishing soil fertility in Africa.* Buresh *et al.* (Eds). Soil Science Society of America, SSSA Special Publication No.51. Madison Wisconsin, USA, pp. 111-149.

Campbell, K.L. and D.R. Edwards. 2001. Phosphorus and water quality impacts In: *Agricultural nonpoint source pollution: Watershed management and hydrology*. W.F. Ritter, and A. Shirmohammadi (eds.). CRC Press LLC, Florida.

Cassman, K.G., A. Dobermann, and D. Walters. 2002. Agroecosystems, nitrogen-use efficiency, and nitrogen management. *Ambio: A Journal of the Human Environment,* 31(2):132-140.

Ch'ng, H.Y., O.H. Ahmed, and N.M.A Majid. 2014. Improving phosphorus availability in an acid soil using organic amendments produced from agroindustrial wastes. *The Scientific World Journal*, pp. 1-6. doi.org/10.1155/2014/506356.

Chacon, N., W.L. Silver, E.A. Dubinsky, and D.F. Cusack. 2006. Iron reduction and soil phosphorus solubilization in humid tropical forests soils: The roles of labile carbon pools and an electron shuttle compound. *Biogeochemistry*, 78:67–84.

Chapin, F.S., E.D. Schulze, and H.A. Mooney. 1990. The ecology and economics of storage in plants. *Annual Review of Ecology, Evolution, and Systematics,* 21: 423–447.

Comerford, N.B. 2005. 1 Soil Factors Affecting Nutrient Bioavailability. *Ecological Studies*, 181: 1–14.

Cordell, D., J. Drangert, and S. White. 2009. The story of phosphorus: global food security and food for thought. *Global Environment Change*, 19: 292–305.

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

Crews, T., K. Kitayama, J. Fownes, R. Riley, D. Herbert, D. Mueller-Dombois, and P. Vitousek. 1995. Changes in soil phosphorus fractions and ecosystem dynamics across a long chronosequence in Hawaii, *Ecology*, 76:1407–1424. doi:10.2307/1938144.

Cross, A.F. and W.H. Schlesinger, 1995. A literature review and evaluation of the Hedley fractionation: Applications to the biogeochemical cycle of soil phosphorus in natural ecosystems. *Geoderma*, 64: 197-214.

Daković A., Tomašević-Čanović M., Rottinghaus E.G., Matijašević S., and Sekulić Ž. 2007. Fumonisin B1 adsorption to octadecyldimetylbenzyl ammonium modified clinoptilolite rich zeolitic tuff. In: *Microporous and Mesoporous Materials*, 105: 285–290.

David, J.G., and C.R. Wilson. 2005. Choosing a Soil Amendment. Colorado State University Cooperative Extension Horticulture, 7: 235.

Delgado, A. and J. Torrent. 2000. Phosphorus forms and desorption patterns in heavily fertilized calcareous and limed acid soils. *Soil Science Society of America Journal,* 64: 2031- 2037.

Department of Agriculture, 2015. Retrieved 5 November 2015. http://animhosnan.blogspot.my/2015/05/kosting-jagung-manis.html.

Devau, N., Hinsinger, P., Le Cadre, E., and Gerard, F. 2011. Root-induced processes controlling phosphate availability in soils with contrasted P-fertilized treatments. *Plant and Soil,* 348:203–218.

Dobermann, A., 2005. Nitrogen use efficiency: State of the art. Proceedings of the IFA International Workshop on Enhanced-Efficiency Fertilizers, June 28-30, 2005, Frankfurt, Germany, pp. 1-16.

Donahue, S. 2003. Managing Soil Organic Matter The Key to Air and Water Quality. Soil Quality Technical Note (5). Available at soils.usda.gov/sqi.

Duputel, M., N. Devau, M. Brossard, B. Jaillard, P. Hinsinger, and F. Gérard, 2013. Citrate adsorption can decrease soluble phosphate concentration in soils: Result of theoretical modeling. *Applied Geochemistry*, 35: 120-131.

Eberl D.D. 1993. Controlled-Release fertilizers Using Zeolites, U.S. department of the Interior U.S Geological Survey. Available at http://www.usgs.gov/tech-transfer/factsheets/94-066b.html

Eghball, B., D.H.M. Sander, and J.M. Skopp. 1990. Diffusion, adsorption, and predictive longevity of banded phosphorus-fertilizer in three soils. Soil *Science Society of America Journal*, 54: 1161–1165.

Elser, J.J., W.F. Fagan, R.F. Denno, D.R. Dobberfuhl, A. Folarin, A. Huberty, S.Interlandi, S.S. Kilham, E. McCauley, and K.L. Schulz. 2000. Nutritional constraints in terrestrial and freshwater food webs, *Nature*, 408: 578–580, doi:10.1038/35046058.

Erich, M.S, C.B Fitzgerald, and G.A Porter. 2002. The effect of organic amendments on phosphorus chemistry in a potato cropping system. *Agriculture, Ecosystems and Environment*, 88: 79-88.

Fageria, N.K. 1984. Response of rice cultivars to liming in cerrado soil. *Pesquisa Agropecuária Brasileira,* 19:883–889.

Fageria, N.K., V.C. Baligar, and C.A. Jones. 2010. Growth and Mineral Nutrition of Field Crops. 3rd edition. CRC Press, Boca Raton, FL.

Fageria, N.K., V.C. Baligar, and D.G. Edwards. 1990. Soil-plant nutrient relationships at low pH stress. In:Crops as Enhancers of Nutrient Use Eds: Baligar V.C. and R.R. Duncan. Academic Press, San Diego, California. pp. 475–507.

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

Fenn, L.B. and J. Richards. 1989. Ammonia loss from surface applied urea-acid products. *Fertilizer Research,* 9: 265-275.

Fenn, L.B., G. Tatum, and G. Horst. 1990. Ammonia loss from surface-applied mixtures of urea-calcium-potassium salts in the presence of phosphorus. *Fertilizer Research,* 21: 125-131.

Filippelli, G.M 2011. Phosphate rock formation and marine phosphorus geochemistry: the deep time perspective, *Chemosphere*, 84: 759-766

Fixen, P.E. 2009. World fertilizer nutrient reserves – a view to the future. Better Crops 93: 8–11.

Fontes, M.P.F. and S.B. Weed. 1996. Phosphate adsorption by calys from Brazilian Oxisols: Relationships with specific surface area and mineralogy. *Geoderma*, 72: 37-51.

Food and Agriculture Organization of the United Nations, FAOSTAT database. 2014. Accessed on 20/02/2014. http://faostat3.fao.org/download/R/RV/E

Franzluebbers, A.J. 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil and Tillage Research 66: 197– 205. Available at www.elsevier.com/locate/still.

Freundlich, H. 1926. Colloid and Capillary Chemistry, Methuen, London, pp. 114-122.

Friesen, D.K., M.H. Miller, and A.S.R. Juo. 1980. Lime and lime-phosphate-zinc interactions in two Nigerian Ultisols. II. Effects on maize root and shoot growth. *Soil Science Society of America Journal,* 44: 1227–1232.

Frossard E., L.M. Condron, A. Oberson, S. Sinaj, J.C. Fardeau, and A.N. Sharpley. 2000. Practical and innovative measures for the control of agricultural phosphorus. *Journal of Environmental Quality,* 29: 15–23.

Gasparatos, D., C. Haidouti, A. Haroulis, and P. Tsaousidou. 2006, Estimation of phosphorus status of soil Fe-enriched concretions with the acid ammonium oxalate method, *Communications in Soil Science and Plant Analysis,* 37: 2375-2387

Ge, T., S. Nie, J. Wu, J. Shen, H. Xiao, C. Tong, D. Huang, Y. Hong, and K. Iwasaki. 2010. Chemical properties, microbial biomass, and activity differ between soils of organic and conventional horticultural systems under greenhouse and open field management: A case study. *Journal of Soils and Sediments,* 11(1): 25–36.

Geelhoed, J.S., W.H. Van Riemsdijk, and G.R. Findenegg. 1999. Simulation of the effect of citrate exudation from roots on the plant availability of phos- phate adsorbed on goethite. *European Journal of Soil Science,* 50: 379–390.

Geiger, C.A. 2012. A low-temperature IR spectroscopic investigation of the H_2O molecules in the zeolite mesolite. *European Journal of Mineralogy,* 24(3): 439–445.

Gilbert, N. 2009. The disappearing nutrient, *Nature*, 48: 716-718.

Ginkel van CE. 2011. Eutrophication: Present reality and future challenges for South Africa, *Water SA*, 37(5):693-702.

Goh, K.J. and P.S. Chew. 1995. Direct Application of Phosphates to Plantation Tree Crops in Malaysia. In: Workshop on direct application of phosphate rocks and appropriate technology fertilisers in Asia: what hinder acceptance and growth. Proceeding workshop IFS and IFDC, Kandy, Sri Lanka, Feb 20-25, 1995, pp. 59–76.

Goto, I., and M. Ninaki. 1980. Studies on the agriculture utilization of natural zeolites as soil conditioners, III: Determination of the ion-exchange selectivity coefficients of natural zeolites. *Journal of Agriculture Science,* Tokyo Nogyo, Daigaku, 25:164–168.

Grant, C., S. Bittman, M. Montreal, C. Plenchette, C. Morel, T. Transfert, and S. Cycle. 2005. Soil and fertilizer phosphorus : Effects on plant P supply and mycorrhizal development. *Canadian Journal of Plant Science,* 85: 3-14.

Gregory, T., C.L. Karns, and K.D.Shimizu, 2005. A critical examination of the use of the Freundlich isotherm in characterizing molecularly imprinted polymers (MIPS). *Analytica Chimica Acta,* 528: 107-113.

Grierson, P.F. 1992. Organic Acids in the Rhizosphere of Banksia integrifolia L. F. *Plant and Soil,* 44: 259-265.

Grossl, P.R. and W.P. Inskeep. 1991. Precipitation of dicalcium phos- phate dihydrate in the presence of organic acids. *Soil Science Society of America Journal,* 55: 670–675.

Gu, Y.C. and S.W. Qin. 1997. Phosphorus accumulation, transformation and availability under long-term application of phosphorus fertilizer, *China Journal of Soil Science,* 29: 13–17.

Gunary, D. 1970, A new adsorption isotherm for phosphate in soil. *Journal of Soil Science,* 21: 72-77.

Gupta, P.K. 2009. Soil, Plant, Water and Fertilizer Analysis (2nd ed.). Joghpur, India: *Agrobios*, pp. 350.

Haggerty, G.M. and R.S. Bowman. 1994. Sorption of Chromate and Other Inorganic Anions by Organo-Clinoptilolite zeolite. *Environmental Science and Technology,* 28(3): 452-458. doi:10.1021/es00052a017.

Hamon, R.E and M.J. McLaughlin. 2002, Interferences in the determination of isotopically exchangeable P in soils and a method to minimise them, *Australian Journal of Soil Research,* 40: 1383-1397

Hansen, J.C, B.J. Cade-Menun, and D.G. Strawn. 2004. Phosphorus speciation in manure-amended alkaline soils. *Journal of Environmental Quality,* 33: 1521–1527.

Hariprasad, P. and S.R. Niranjana. 2008. Isolation and characterization of phosphate solubilising rhizobacteria to improve plant health of tomato. *Plant Soil*, 316: 13-24.

Harris, W.G. 2002. Phosphate minerals. *In*: J.B. Dixon and D.G. Schulze (eds). Soil mineralogy with environmental applications. *Soil Science Society of America Journal,* Madison, WI. pp. 637-665.

Harter, R.D., and G. Smith. 1981. Langmuir equation and alternate methods of studying “adsorption” reactions in soils. In: *Chemistry in the soil environment.* R.H. Dowdy et al. (ed.) ASA Spec. Publ. 40. ASA and SSSA, Madison, WI. pp. 167–182.

Havlin, J.L., J.D. Beaton, L.S. Tisdale, and L.W. Nelson. 1999. Soil fertility and fertilizers: An introduction to nutrient management, 6th edn, Prentice Hall,Inc., New Delhi, India.

Haynes, R.J., and M.S. Mokolobate. 2001. Amelioration of Al toxicity and P deficiency in acid soils by additions of organic residues : A critical review of the phenomenon and the mechanisms involved, *Nutrient Cycling in Agroecosystems,*59: 47–63.

He, X.T., S.J. Traina, and T.J. Logan. 1992. Chemical properties of municipal solid waste composts. *Journal of Environmental Quality,* 21: 318–329.

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 and Soil,* 247: 253-260.

Hinsinger, P. 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: A review. *Plant and Soil,* 237(2):173–195.

Hinsinger, P. and R.J. Gilkes. 1995. Root-induced dissolution of phosphate rock in the rhizosphere of lupins grown in alkaline soil. *Australian Journal of Soil Research*, 33: 477–489.

Hinsinger, P. and R.J. Gilkes. 1997. Dissolution of phosphate rock in the rhizosphere of five plant species grown in an acid, P-fixing mineral substrate. *Geoderma,* 75: 231-249.

Hinsinger, P., A.G. Bengough, D. Vetterlein, and I.M. Young. 2009. Rhizosphere: Biophysics, biogeochemistry, and ecological relevance. *Plant Soil,* 321: 117–152.

Hinsinger, P., G.R. Gobran, P.J. Gregory, and W.W. Wenzel. 2005. Rhizosphere geometry and heterogeneity arising from root-mediated physical and chemical processes. *New Phytologist,* 168: 293–303.

Hocking, P.J. 2001. Organic acids exuded from roots in phosphorus uptake and aluminium tolerance of plants in acid soils. *Advances in Agronomy,* 74: 64-89.

Hocking, P.J., J.A. Kirkegard, J.F. Angus, A. Bernardi, and L.M. Mason. 2002. Comparison of canola, Indian mustard and linola in two contrasting environments III. Effect of nitrogen fertilizer on nitrogen uptake by plants and on soil nitrogen extraction. *Field Crop Research,* 79:153–172.

Hoffland, E. 1992. Quantitative Evaluation of the Role of Organic Exudation in the Mobilization of Rock Phosphate by Rape. *Plant and Soil,* 140: 279-289.

Holford, I.C.R. 1976. Effects of phosphate buffer capacity of soil on the phosphate requirements of plants. *Plant and soil*, 45:433-444.

Holford, I.C.R. 1989. Phosphorous behavior in soils. *Agricultural Sciences,* 12: 15- 20.

Holford, I.C.R. and G.E.G. Mattingly. 1976. A model for the behavior of labile phosphates in soil. *Plant and Soil,* 44:219–229.

Hongqing, H., L. Xueyuan, T. Chunying, C. Chongfa, and H. Jizheng. 2001. Availability and residual effects of phosphate rocks and inorganic p fractionation in a red soil of central china. *Nutrient Cycling in Agroecosystems*, 59(3): 251–258.

Hue, N.V. 1992. Correcting Soil Acidity of a highly weathered ultisol with chicken manure and sewage sludge. *Communications in Soil Science and Plant Analysis,* 23: 241-264.

Inglezakis, V., M. Loizidou, and H. Grigoropoulou. 2004. Ion exchange studies on natural and modified zeolites and the concept of exchange site accessibility. *Journal of Colloid and Interface Science*, 275: 570-576.

Iyamuremye, F. and R.P. Dick. 1996. Organic amendments and phosphorus sorption by soils. *Advances in Agronomy,* 56: 139-185.

Johan, S., C. Feller, K. Denef, and S.M. Ogle. 2002. Soil organic matter , biota and aggregation in temperate and tropical soils – Effects of no-tillage. *Agronomie*, 22: 755–775.

Jones, C. and J. Jacobsen, 2001. Plant Nutrition and Soil Fertility. *Nutrient Management,* (2): 1–12.

Jones, D.L. 1998. Organic acids in the rhizosphere – a critical review. *Plant and Soil,* 205: 25– 44.

Kamprath, E.J. and M.E. Watson. 1980. Conventional soil and tissue test for assessing the phosphorus status of soils. In: The role of Phosphorus in Agriculture. F.E. Khasawneh, E.C. Sample and E.J. Kamprath (eds.). *Soil Science Society of America*, Madison, WI., USA. pp. 433-469

Kantiranis, N., C. Chrissafis, A. Filippidis, and K.M. Paraskevopoulos. 2006. Thermal distinction of HEU-type mineral phases contained in Greek zeolite-rich volcaniclastic tuffs. *European Journal of Mineralogy,* 18(4): 509–516

Kasim, S., O.H. Ahmed, N.M.A. Majid, M.K. Yusop, and M.B. Jalloh. 2009. Effect of Organic Based N Fertilizer on Dry Matter (*Zea mays* L.), Ammonium and Nitrate Recovery in an Acid Soil of Sarawak, Malaysia. *American Journal of Applied Sciences*, 6: 1289-1294.

Kavoosi, M. 2007. Effects of Zeolite Application on Rice Yield, Nitrogen Recovery, and Nitrogen Use Efficiency. *Communications in Soil Science and Plant Analysis*, 38(1): 69–76.

Keeney, D.R. and D.W. Nelson. 1982. Nitrogen-Inorganic Forms. In: Methods of Soil Analysis, Part 2, Page, A.L., D.R. Keeney, D.E. Baker, R.H. Miller, R.J. Ellis and J.D. Rhoades (Eds.). Vol. 9, *American Society of Agronomy,* Madison, Wisconsin, USA., ISBN: 0891180729, pp. 159-165.

Khomami, A.M. 2011. Influence of Substitution of Peat with Iranian Zeolite (Clinoptilolite) in Peat Medium on Fiscus benjamina Growth. *Journal of Ornamental and Horticultural Plants,* 1(1): 13–18.

Kingston, G. 2001. Cost Benefit Analysis in Theory and Practice. Australian Economic Review, 34(4): 478-487. http://dx.doi.org/10.1111/1467-8462.00217

Kochian, K.V. 1995. Cellular mechanisms of aluminium toxicity and resistance in plant*. Annual Review of Plant Physiology and Plant Molecular Biology*, 46: 237-260.

Koerselman, W., and A.F.M. Meuleman. 1996. The vegetation N: P ratio:A new tool to detect the nature of nutrient limitation. *Journal of Applied Ecology,* 33: 1441–1450.

Kong W.D., Y.G. Zhu B.J. Fu X.Z. Han L. Zhang and J.Z. He. 2008. Effect of long-term application of chemical fertilizers on microbial biomass and functional diversity of a black soil. *Pedosphere*,18(6): 801–808.

Krstic, D., I. Djalovic, D. Nikezic, and D. Bjelic. 2012. Aluminium in Acid Soils: Chemistry, Toxicity and Impact on Maize Plants. In: Food Production - Approaches, Challenges and Tasks. Ed. Anna Aladjadjiyan. pp. 231-242. ISBN: 978-953-307-887-8.

Kumar, V., R.J. Gilkes, T.M. Armitage, and M.D.A. Bolland. 1994. Identification of residual P compounds in fertilized soils using density fractionation, X-ray diffraction, scanning and transmission electron microscopy. *Fertilizer Research,* 37: 133–149.

Kundu, S. and A.K. Gupta. 2006. Arsenic adsorption onto iron oxide-coated cement (IOCC): regression analysis of equilibrium data with several isotherm models and their optimization, *Chemical Engineering Journal,* 122: 93–106.

Kuo, S. 1996. Phosphorus. In: *Methods of soil analysis. Part 3: Chemical Methods.* Sparks, D.L. (ed.) *Agronomy 9.* The American Society of Anesthesiologists, Soil Science Society of America, Madison, Wis, USA. pp. 869–920.

Lai, T.M. and D.D. Eberl. 1986. Controlled and renewable release of phosphorous in soils from mixtures of phosphate rock and NH_4^+ exchanged clinoptilolite. *Zeolites*, 6:129-132.

Lambers, H., F. S. Chapin, and T. L. Pons. 1998. Plant physiological ecology. Springer, New York, NY.

Lambers, H., M.W. Shane, M.D. Cramer, S.J. Pearse, and E.J. Veneklaas. 2006. Root structure and functioning for efficient acquisition of phosphorus: matching morphological and physiological traits*. Annals of Botany* (Lond) 98: 693–713.

Langmuir, I. 1918. The adsorption of gases on plane surfaces of glass, mica and platinum. *Journal of American Chemical Society*, 40: 1361-1402.

Latifah, O., O.H. Ahmed, and N.M.A Majid. 2011. Effect of mixing urea with zeolite and sago waste water on nutrient use efficiency of maize (*Zea mays* L.). *African Journal of Microbiology Research*, 5(21): 3462-3467.

Latifah, O., O.H. Ahmed, and N.M.A Majid. 2015. Improving Ammonium and Nitrate Release from Urea Using Clinoptilolite Zeolite and Compost Produced from Agricultural Wastes. *The Scientific World Journal*, vol. 2015, Article ID 574201, 12 pages, 2015. doi:10.1155/2015/574201.

Leader, JW., E.J. Dunne, and K.R Reddy. 2008. Phosphorus sorbing materials: Sorption dynamics and physicochemical characteristics. *Journal of Environmental Quality,* 37(1): 174-181.

Leinonen, H., and J. Letho. 2001. Purification of metal finishing waste waters with zeolites and activated carbons. *Waste Management and Research,* 19: 45–57.

Lewis, D.W and M.B. McGechan. 2002. A review of field scale phosphorus dynamics models. *Biosystems Engineering*, 82: 359-380.

Liao, B., Guo, Z., Probst, A., and Probst, J.L. 2005. Soil heavy metal contamination and acid deposition: experimental approach on two forest soils in Hunan, Southern China. *Geoderma*, 127(1-2): 91-103. ISSN 0016-7061

Lija, W.B.M., O.H. Ahmed and S. Kasim. 2012. Reducing ammonia volatilization from compound fertilizers amended with zeolite. *African Journal of Biotechnology,* 11: 13903-13906.

Liptzin, D., and W.L. Silver. 2009. Effects of carbon additions on iron reduction and phosphorus availability in a humid tropical forest soil, *Soil Biology and Biochemistry,* 41(8): 1696–1702,

Lookman, R., K. Jansen, R. Merckx, and K. Vlassak, 1996. Relationship between soil properties and phosphate saturation parameters: A transect study in northern Belgium. *Geoderma,* 69: 265-274.

Maguire, R.O., J.T. Sims and F.J. Coale, 2000. Phosphorus solubility in biosolids- amended farm soils in the mid-Atlantic region of the USA. *Journal of Environmental Quality,* 29: 1225- 1233.

Mahler, R.L., and R.E. McDole. 1985. The influence of lime and phosphorus on crop production in northern Idaho. *Communications in Soil Science and Plant Analysis,* 16: 485–499.

Makungwe, M. 2014. Evaluation of the potential of zeolite as a soil conditioner for two Zambian Soils. Unpublished master dissertation. The University of Zambia.

Malaysian Agricultural Research and Development Institute (MARDI), 1990 Jagung Manis Baru, Masmadu [New Sweet Corn, Masmadu]. Institute of Malaysian Agricultural Research and Development Institute, Serdang, Malaysia, pp. 3-5.

Malaysian Meteorological Department, "10-Day Agrometeorological Bulletin," 2014, http://www.met.gov.my/. Retrieved 25th December, 2014.

Manolov, I., D. Antonov, G. Stoilov, I.Tsareva, and M. Baev. 2005. Jordanian Zeolitic Tuff as a Raw Material for the Preparation of Substrates used for Plant Growth. *Journal of Central European Agriculture.* 6(4): 485-494.

Marschner, H. 1995. Mineral Nutrition of Higher Plants. 2nd Edn., Academic Press, San Diego, CA., USA., ISBN-13: 9780124735439, pp. 889.

Marschner, H., and P. Marschner. 2012. Marschner's mineral nutrition of higher plants. Elsevier Academic Press, London, Waltham, MA.

McBride, M.B. 1994. Environmental chemistry of soils. Oxford University Press, Inc. New York, NY.

McCauley, A., C. Jones, and J. Jacobsen. 2009. Soil pH and Organic Matter. Nutrient Management. Module 8: 1–11. Available at http://www.msuextension.org/publications.a.

McCauley, A., C. Jones, and J. Jacobsen. 2005. Basic Soil Properties. Soil and Water Management Module 1. pp. 1–12.

McDowell, R.W., R.M. Monaghan, and D. Wheeler, 2005. Modelling phosphorus losses from pastoral farming systems in New Zealand. *New Zealand Journal of Agricultural Research,* 48: 131–141.

Mehlich, A. 1953. Determination of P, K, Na, Ca, Mg and NH4. Soil Test Division Mimeo, North Carolina Department of Agriculture, Raleigh, NC USA.

Melese, A., H. Gebrekidan, M. Yli-halla, and B. Yitaferu. 2015. Phosphorus Status, Inorganic Phosphorus Forms, and Other Physicochemical Properties of Acid Soils of Farta District , Northwestern Highlands of Ethiopia. *Applied and Environmental Soil Science*, Volume 2015, Article ID 748390, 11 pages.

Mengel, K. and E.A. Kirkby. 2001. Principles of Plant Nutrition. 5th Ed., Kluwer Academic Publishers, London.

Micheal, A. 2010. Soil CEC Explained.The Voice of Eco-agriculture Volume 40(3). Available at www.acresusa.com

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

Moody, P.W., and M.D.A., Bolland. 1999. Phosphorus. In 'Soil analysis: An interpretation manual'. (Eds KI Peverill, LA Sparrow, DJ Reuter) (CSIRO Publishing: Collingwood, Vic.). pp.187–220.

Moreno-Pirajan, J.C., Rangel, D., Amaya B., Vargas, E.M., Giraldo, L. 2006. Scale up of pilot plant for the adsorption of heavy metals. *Journal the Argentine Chemical Society*, 94: 365- 375.

Motsi, T., N.A. Rowson, and M.J.H. Simmons. 2009. Adsorption of heavy metals from acid mine drainage by natural zeolite. *International Journal of Mineral Processing*, 92(1-2): 42–48.

Mumpton, F.A. 1999. La roca magica: uses of natural zeolite in agriculture and industry. *Proceedings of the National Academy of Sciences, United States of America,* 96: 3463–3470.

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

Myint, A.K., T. Yamakawa, Y. Kajihara, and T. Zenmyo. 2010. Application of Organic and Mineralised Fertilisers on Growth, Yield and Nutrient Accummulation of Rice. *Science World Journal.* 2010:(5): 47-54.

Naidu, R. and J.K. Syers. 1990. Effect of liming on phosphate sorption by acid soil. *Journal of Soil Science*, 41: 163–175.

Nair, K.P.P. and K. Mengel. 1984. Importance of phosphate buffer capacity on phosphate uptake by rye. *Soil Science Society of America Journal*, 48: 92-95.

Nelson, P.N. and N. Su. 2010. Soil pH buffering capacity: A descriptive function and its application to some acidic tropical soils, *Australian Journal of Soil Research,* 48: 201–207.

Nibou, D.. H. Mekatel, S. Amokrane, M. Barkat, and M. Trari. 2009. Adsorption of Zn^{2+} ions onto NaA and NaX zeolites: Kinetic, equilibrium and thermodynamic studies. *Journal of Hazardous Materials,* 173: 637-646.

Nnadi, L.A and I, Haque. 1998. Agronomic effectiveness of rock phosphate in an Andept of Ethiopia. *Communications in Soil Science and Plant Analysis*, 19: 79-90.

Oburger, E., G.J.D. Kirk, W.W. Wenzel, M. Puschenreiter, and D.L. Jones. 2009. Interactive effects of organic acids in the rhizosphere. *Soil Biology and Biochemistry,* 41: 449-457.

Oelkers, E.H. and E. Valsami-Jones. 2008. Phosphate mineral reactivity and global sustainability. *Elements,* 4: 83–87

Olubukola, A,S., O. Aderemi, O.E. Adewoyin, D. Tinuke, and A. Henry. 2010. Comparing the use of Tithonia diversifolia and Compost as soil amendments for growth and yield of Celosia argentea. *New York Science Journal*, 3(6):133–138.

Omar, L., O.H. Ahmed, and N.M.A. Majid. 2011. Effect of mixing urea with zeolite and sago waste water on nutrient use efficiency of maize (*Zea mays* L.). *African Journal of Microbiology Research*, 5: 3462-3467.

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

Ozanne, P.G, and T.C., Shaw. 1967. Phosphate sorption by soils as a measure of the phosphate requirement for pasture growth. *Australian Journal of Agriculture Research*, 18: 601-612.

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

Paulos, 1996. Availability of phosphorus in the coffee soil of Southwest Ethiopia. In: Soil the Resource Base for Survival: Proceeding of the 2nd Conference of Ethiopian Society of Soil Science (ESSS '93), AddisAbaba, Ethiopia, 23-24 September 1993, M. Tekalign and H. Mitiku, Eds. pp. 119–129.

Pavinato, P.S.; Merlin, A.; Rosolem, C.A. 2009. Phosphorus fractions in Brazilian Cerrado soils as affected by tillage. *Soil and Tillage Research*, 105: 149-155

Peech, M. 1965. Hydrogen-ion Activity. In: Methods of Soil Analysis Chemical and Microbiological Properties, Black, C.A., D.D. Evans, J.L. White, L.E. Ensminger and F.E. Clark (Eds.). American Society of Agronomy, Madison, WI. USA., ISBN-10: 0891180729, pp. 914-925.

Piccolo, A., 1996. Humus and Soil Conservation. Humic Substances in Terrestrial Ecosystems, Piccolo, A. (Ed.). Elseiver, Amsterdam, ISBN: 978-0-444-81516-3, pp. 225-264.

Pickering, H.P., N.W. Menzies, and M.N.C. Hunter. 2002. Zeolite/rock phosphate - a novel slow release phosphorus fertilizer for potted plant production. *Scientia Horticulture*. 94: 333-343.

Pierzynski, G.M., R.W. McDowell, and J.T. Sims. 2005. Chemistry, cycling, and potential moment of inorganic phosphorus in soils. In: *Phosphorus:Agriculture and the Environment.* Sims, J.T., and A.N. Sharpley, (eds). American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Inc., Madison, WI, pp 53–86.

Polat, E., K. Mehmet, D. Halil, and A.N. Onus. 2004.Use of natural zeolite (clinoptilolite) in agriculture. *Journal of Fruit Ornamental Plant Research,* 12: 183–189.

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.

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* L.) cultivation. *Emirates Journal of Food and Agriculture,* 25(9): 1-5.

Raghothama, K.G. 1999. Phosphate acquisition. *Annual Review of Plant Physiology and Plant Molecular Biology,* 50: 665–693.

Rahmani, A.R., Mahvi, A.H., Mesdaghinia, A.R., and Nasseri, S. 2004. Investigation of ammonia removal from polluted waters by clinoptilolite zeolite. *International Journal of Environmental Science and Technology*, 1: 125-133.

Ramesh, K. and D.D. Reddy, 2011. Zeolites and their Potential uses in Agriculture. Advances in Agronomy, Donald, L.S. (Ed.). University of Delaware, Newark, USA., ISBN: 978-0-12-386473-4, 113: 219-241.

Ramesh, K., A.K. Biswas, J. Somasundaram, and A.S. Rao, 2010. Nanoporous Zeolites in Farming: Current Status and Issues Ahead. *Current Science*, 99(6): 760 – 764.

Rhue RD, and W.G. Harris. 1999. Phosphorus sorption/desorption reactions in soils and sediments. In: *Phosphorus biogeochemistry in subtropical ecosystems.* Reddy, K.R., G.A. O'Conner, and C.L. Schelske (eds) Lewis Publishers, Boca Raton, pp 187–206.

Ross, D.S. and Ketterings. Q. 1996. Recommended Methods for Determining Soil Cation Exchange Capacity. *Cooperative Bulletin,* 493: 75–86.

Rowell, D.L., 1994. Soil Science: Methods and Applications. Longman Publishers Ltd., London, UK., ISBN: 0-582-087848, Pages: 169.

Ruban, V., Lopez-Sanchez, J.F., Pardo, P., Rauret, G., Muntau, H., and Quevauviller, P.H. 1999. Selection and evaluation of sequential extraction procedures for the determination of phosphorus forms in lake sediments. *Journal of Environmental Monitoring,* 1(1):51-56.

Ruiz J., A. Delgado, and J. Torrent. 1997. Iron related phosphorus in overfertilized European Soils. *Journal of Environmental Quality,* 26: 1548–1554.

Sallade, Y.E. and J.T. Sims. 1997. Phosphorus transformations in the sediments of Delaware's agricultural drainageways: II. Effect of reducing conditions on phosphorus release. *Journal of Environmental Quality,* 26(6): 1579–1588.

SAS, 2008. SAS/STAT Software. Version 9.2, SAS Institute, Cary, NC., USA.

Sato, S. 2003. Phosphorus sorption and desorption in a Brazilian Ultisol: effects of pH and organic anions on phosphorus bioavailability. Doctoral thesis, University of Florida.

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes. Science. 195: 260–262.

Shann, J.R. and P.M. Bertsch. 1993. Differential cultivar response to polynuclear hydroxo-aluminum complexes. Soil Science Society of America Journal, 57: 116–120.

Sharma, A.K. 2002. Biofertilizers for sustainable agriculture, 1st edn, Agrobios, India.

Sharpley, A.N. 2000. Phosphorus availability. In: Hanbook of soil science, M.E.Sumner (ed.). CRC Press, Boca Raton, ISBN 10: 0849331366, FL. pp. D18-D38.

Sharpley, A.N., Daniel, T.C., Sims, J.T., Lemunyon, J., Stevens, R., and Parry, R. 2003. Agricultural phosphorus and eutrophication 2nd edition. ARS 149. USDA, Washington, DC.

Sheela, B.S. 2006. Dynamics of Phosphorus in Acid Soils of North Karnataka. Unpublished master dissertation. University of Agricultural Sciences, Dharwad.

Shen, J., L. Yuan, J. Zhang, H. Li and Z. Bai, 2011. Phosphorus dynamics: From soil to plant. *Plant Physiology*, 156: 997-1005.

Sims, J.T., and G.M. Pierzynski. 2005. Chemistry of phosphorus in soil. In: Tabatabai AM, Sparks DL (eds). Chemical processes in soil, SSSA book series 8. Soil Science Society of America, Madison, WI. pp. 151-193

Sims, J.T., Simard, R.R., and Joern, B.C. 1998. Phosphorus losses in agricultural drainage: historical perspective and current research. *Journal of Environmental Quality*, 27: 277–293.

Singer, M.J. and D.N. Munns. 1996. Soils: An Introduction. Third edition. New Jersey, Prentice Hall, pp 480

Singh, C.P. and Amberger, A. 1998. Organic acids and phosphorus solubilization in straw composted with rock phosphate. Biores. Tech. 63: 13-16.

Smit, A.L., Bindraban, P.S., Schröder, J.J., Conjin, J.G., and van der Meer, H.G. 2009. Phosphorus in Agriculture: Global Resources, Trends and Developments. Report 282. Plant Research International, Waginen.

Snyder, C.S., and T.W. Bruulsema. 2007. Nutrient use efficiency and effectiveness in North America: Indices of agronomic and environmental benefit. Reference # 07076. Norcross, GA: International Plant Nutrition Institute.

Sparks, D.L. 2003. Environmental soil chemistry. Academic Press, San Diego. Ugurlu, A., and B. Salman. 1998. Phosphorus removal by fly ash. *Environment International*, 24(8): 911-918.

Sposito, G. 1980. Derivation of the Fremdlich equation for ion exchange reactions in soils. *Soil Science Society of America Journal*, 49: 652–4.

Stevens C, Dise NB, Gowing DJ .2009. Regional trends in soil acidification and exchangeable metal concentrations in relation to acid deposition rates. *Environmental Pollution*, 157: 313–319.

Stevenson, F.J., and Cole, M.A. 1999. Cycles of soils: carbon, nitrogen, phosphorus, sulfur, micronutrients. 2nd ed. John Wiley and Sons, New York, NY.

Sun, B.H., Z.Y. Hu, , J.L. LüL.N. Zhou, and C.K. Xu. 2006. The leaching solution chemistry of a broad-leaved forest red soil under simulated N deposition in Southern China. *Acta Ecologica Sinica,* 26: 1872–1881.

Swarnam, T.P. and A. Vel murugan. 2014. Evaluation of Coconut Wastes as an Amendment to Acidic Soils in Low-Input Agricultural System. *Communications in Soil Science and plant Analysis,* 45(8): 1071-1082.

Szerement, J., A.K.K. Ambro, and J. Piasek. 2014. Use of zeolite in agriculture and environmental protection . A short review, pp. 172–177.

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

Tarkalson, D.D. and J.A Ippolito. 2011. Clinoptilolite Zeolite Influence on Nitrogen in a Manure-Amended Sandy Agricultural Soil. *Communications in Soil Science and Plant Analysis*, 42(19): 2370–2378.

Tiessen, H, and Stewart, J.W.B. 1985. The biogeochemistry of soil phosphorus. In: Caldwell DE, Brierley JA, Brierley CL (eds) Planetary ecology. Van Nostrand Reinhold Company, New York, pp 463–472

Tiessen, H., Cuevas, E., and Chacon, P. 1994. The role of soil organic matter in sustaining soil fertility. *Nature*, 371: 783–785.

Troeh, F.R., Thompson, L.M., 1993. Soils and soil fertility, fifth ed. Oxford University Press, New York Oxford.

Turner, B.L, Richardson, A.E., and Mullaney, E.J. 2007. Inositol Phosphates: Linking Agriculture and the Environment. CAB International, Wallingford, UK, pp. 304.

Vaananen, R., J. Hristov, N. Tanskanen, H. Hartikainen, M. Nieminen, and H. Ilvesniemi. 2008, Phosphorus sorption properties in podzolic forest soils and soil solution phosphorus concentration in undisturbed and disturbed soil profiles, *Boreal Environment Research*, 13: 553 – 567.

Valsmai-Jones, E., K.V. Ragnarsdottir, A. Putnis, D. Bosbach, A.J. Kemp, and G. Cressey. 1998. The dissolution of apatite in the presence of aqueous metal cations at pH 2-7. *Chemical Geology,* 151: 215-233.

Vance, C.P, Uhde-Stone, C., and Allan, D.L. 2003. Phosphorus acquisition and use: Critical adaptations by plants for securing a nonrenewable resource. *New Phytologist,* 157: 423–447.

Vitousek, P.M. 1984. Literfall, nutrient cycling, and nutrient limitation in tropical forest. *Ecology,* 65: 285–298.

Vitousek, P.M. and R. Howarth. 1991. Nitrogen limitation on land and in the sea: how can it occur?, *Biogeochemistry*, 13: 87–115

Von Uexküll, H.R. and E. Mutert. 1995. Global extent, development and economic impact of acid soils. *Plant and soil*, 171(1): 1-15.

Walker, T.W and J.K. Syers. 1976. The fate of phosphorus during pedogenesis. *Geoderma,* 15: 1–19

Wandruszka, R., 2006. Phosphorus retention in calcareous soils and the effects of organic matter on its mobility. Geochemical Transactions. pp. 7-6. http://doi.org/10.1186/1467-4866-7-6.

Wardle, D., L. Walker, and R. Bardgett. 2004. Ecosystem properties and forest decline in contrasting long-term chronosequences, *Science*, 305: 509-513.

Weisenberger, T. 2009. Zeolites in Fissures of Crystalline Basement Rocks.Unpublished PhD thesis, University of Freiburg, pp. 178.

Welch, S.A, Taunton, A.E, and Banfield, J.F. 2002. Effect of microorganisms and microbial metabolites on apatite dissolution. *Geomicrobiology Journal*, 19: 343– 367.

Whalen, J.K., C. Chang, G.W. Clayton, and J.P. Carefoot. 2000. Cattle manure amendments can increase the pH of acid soils. *Soil Science Society of America Journal*, 64:962–966.

Whitelaw, M.A. 2000. Growth promotion of plants inoculated with phosphate-solubilizing fungi. *Advances in Agronomy*, 69: 100– 151.

Wild, A. 1988. Soil acidity and alkalinity. In: Wild A (ed) Russell's Soil Conditions and Plant Growth. Longman, Harlow, pp. 844–889.

Wilson, G.V., F.E. Rhoton, and H.M. Selim. 2004. Modeling the impact of ferrihydrite on adsorption-desorption of soil phosphorus. *Soil Science*, 169: 271-281.

Wong, J.W.C. and G.E. Ho. 1995. Cation exchange behaviour of bauxite refining residues from Western Australia. *Journal of Environmental Quality*, 24:461–466.

Wong, N.T.F., S. Nortcli, and R.S. Swift. 1998. Method for determining the acid ameliorating capacity of plant residue compost, urban waste compost, framyard manure, and peat applied to tropical soils. *Communications in Soil Science and Plant Analysis*, 29: 2927-2937.

Xu, R., A. Zhao, J. Yuan, and J. Jiang. 2012. pH buffering capacity of acid soils from tropical and subtropical regions of China as influenced by incorporation of crop straw biochars, pp. 494–502.

Yanai, R.D., J.D. Blum, S.P. Hamburg, M.A. Arthur, A.N. Nezat, and T.G. Siccama. 2005. New insights into calcium depletion in northeastern forests. Journal of Forestry January/February:14-20.

Yang, J., Z. He, Y. Yang, P. Stoffella, X. Yang, D. Banks, and S. Mishra. 2007. Use of Amendments to Reduce Leaching Loss of Phosphorus and Other Nutrients from a Sandy Soil in Florida. *Environmental Science* and *Pollution Research,* 14(4): 266–269.

Yang, X., W. Werner, H.W. Scherer, and X. Sun. 1994. Effects of organic manure on solubility and mobility of different phosphate fertilizers in two paddy soils. *Fertilizer Research,* 38:233-238.

Yangyuoru, M., E. Boateng, S.G.K. Adiku, D. Acquah, T.A. Adjadeh, and F. Mawunya. 2006. Effects of Natural and Synthetic Soil Conditioners on Soil Moisture Retention and Maize Yield. *West Africa Journal of Applied Ecology,* 9: 1–8.

Yuan, J.H., R.K. Xu, and H. Zhang. 2011. The forms of alkalis in the biochar produced from crop residues at different temperatures. *BioresourceTechnology*, 102: 3488–3497.

Zaharah, A.R. and H.A.H. Sharifuddin. 1979. Residual effect of applied phosphates on performance of Hevea brasiliensis and Pueraria Phaseoloides. *Journal of Rubber Research Institute Malaysia*, 25(3): 101-108.

Zapata, F. and H. Axmann. 1995. 32P isotopic techniques for evaluating the agronomic effectiveness of rock phosphate materials. *Fertilizer Resources*, 41: 189-195.

Zapata, F. and R.N. Roy. 2004. Use of phosphate rocks for sustainable agriculture. FAO Plant Nutrition Bulletin 13. Food and Agriculture Organization of the United Nations, Rome.

Zech, W., N. Senesi, G. Guggenberger, K. Kaiser, J. Lehmann, T.M. Miano, A. Miltner, and G. Schroth. 1997 Factors controlling humification and mineralization of soil organic matter in the tropics. *Geoderma*, 79: 117–161.

Zelazny, L.W., and F.G. Calhoun. 1977. Palygorskite (attapulgite), sepiolite, talc, pyrophyllite, and clinoptilolite zeolite. In J. B. Dixon & S. B. Weed (Eds.), Minerals in Soil Environments. SSSA, Madison, WI. pp. 435-470.

Zhang, F., S. Kang, J. Kang, R. Zhang and F. Li, 2004. Nitrogen fertilization on uptake of soil inorganic phosphorus fractions in the wheat root zone. *Soil Science Society of America Journal*, 68: 1890-1895.

Zhang, F.S., J. Ma, and Y.P. Cao. 1997. Phosphorus deficiency enhances root exudation of low- molecular weight organic acids and utilization of sparingly soluble inorganic phosphates byradish (*Raphanus sativus* L.) and rape (*Brassica napus* L.) plants. *Plant and Soil*, 196: 261- 264.

Zhang, F.S., X.N. Zhang, and T.R., Yu. 1991. Reactions of hydrogen ions with variable charge soils: I. Mechanisms of reaction. *Soil Science*, 151: 436–442.

Zhang, H. and B. Raun. 2006. Oklahoma Soil Fertility Handbook. 6th ed. Department of Plant and Soil Sciences, Oklahoma State University., Stillwater, OK 74078.

Zhou, K., D. Binkley, and K.G Doxtader. 1992. A new method for estimating gross phosphorus mineraliation and immobilization rates in soils. *Plant Soil,* 147: 243-250.

Zhou, Q, and Y. Zhu. 2003. Potential pollution and recommended critical levers of phosphorus in paddy soils of the southern Lake Tai area, China. *Geoderma*, 115:45-54.

Zhu, M.X, X. Jiang, and G.L. Ji. 2005. Investigation of time-dependent reactions of H^+ ions with variable and constant charge soils: a comparative study. *Applied Geochemistry*, 20: 169–178.

Zou, P., J. Fu., and Z., Cao. 2011, Chronosequence of paddy soils and Phosphorus sorption/desorption properties, *Journal of Soils Sediments*, 11: 249-259.

Zoysa, A.K., P. Loganathan, and M.J. Hedley, 1997. A technique for studying rhizosphere process in tree crops: Soil phosphorus depletion around (*Camellia japonica* L.) roots. *Plant and Soil*, 190: 253-265.

BIODATA OF STUDENT

Nur Aainaa binti Hasbullah, born in 5th January, 1988 in Kuala Lumpur. She received her primary education in Sekolah Rendah Kebangsaan Ampang in 1995. She persued her secondary education in Sekolah Menengah Sains Hulu Selangor in 2000 and entered Malacca Matriculation College in 2005. In the following year, she continued her higher education at Universiti Putra Malaysia Bintulu Campus and graduated with Bachelor of Science Bioindustry (Honours First Class) in 2010. Afterwards, she was enrolled in degree of Doctor of Philosophy in Agronomy in 2011. During her postgraduate studies, she published three journal articles, attended Soil Science Conference of Malaysia in April, 2014 (won best poster award). In June, 2014 she attended the 20th World Congress of Soil Science in Jeju, Korea and her abstract won the Travel Grant for Young Scientist of Developing Country. Her thesis has been converted to a book which is being processed for publication.

LIST OF PUBLICATIONS

Published paper

Hasbullah Nur Aainaa, Osumanu Haruna Ahmed, Susilawati Kasim, And Nik Muhamad Ab. Majid. 2014. Use of Clinoptilolite zeolite on selected soil Chemical Properties, Dry Matter Production, Nutrients Uptake and Use Efficiency of *Zea mays* L. cultivated on An Acid Soil. *International Journal of Agriculture Research,* 9: 136-148.

Hasbullah Nur Aainaa, Osumanu Haruna Ahmed, Susilawati Kasim, And Nik Muhamad Ab. Majid. 2014. Use of Clinoptilolite zeolite to reduce Christmas Island Rock Phosphate use in *Zea mays* Cultivation on an Acid Soil. *International Journal of Soil Science,* 9: 55-66.

Hasbullah Nur Aainaa, Osumanu Haruna Ahmed, Susilawati Kasim, And Nik Muhamad Ab. Majid. 2015. Reducing Egypt Rock Phosphate use in *Zea mays* Cultivation on an Acid Soil Using Clinoptilolite Zeolite. *Sustainable Agriculture Research*, 4(1): 56–66.

Presented paper

Hasbullah Nur Aainaa, Osumanu Haruna Ahmed, Susilawati Kasim, And Nik Muhamad Ab. Majid. 2014. Reducing Egypt Rock Phosphate use in *Zea mays* Cultivation on an Acid Soil Using Clinoptilolite Zeolite. Presented at the 20th world congress of soil science, Jeju, South Korea. 8 – 13 June, 2014.

Hasbullah Nur Aainaa, Osumanu Haruna Ahmed, Susilawati Kasim, And Nik Muhamad Ab. Majid. 2014. Reducing Christmas Island Rock Phosphate use in Zea mays Cultivation on an Acid Soil using Humic Acids. Presented at Soil Science Conference of Malaysia 2014. 8 - 10 April, 2014.

LIST OF AWARDS

Silver Medal, “Biological agriculture to improve crops productivity without polluting the environment”. Invention & Innovation Awards 2016, Malaysia Technology Expo 2016, Kuala Lumpur, Malaysia.

Young scientist travel grant, “Reducing Egypt rock phosphate use in Zea mays cultivation on an acid soil using clinoptilolite Clinoptilolite zeolite”. The 20th World Congress of Soil Science (20WCSS, 2014), Jeju Island, South Korea.

Excellent Poster Presentation, “Reducing Christmas Island rock phosphate use in Zea mays cultivation on an acid soil using humic acids”. Soil Science Conference of Malaysia 2014, Putra Palace Hotel, Kangar Perlis.