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PHOSPHORUS MANAGEMENT FOR TROPICAL ACID SOILS USING AMENDMENTS FROM AGRO-INDUSTRIAL WASTES

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By

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

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PHOSPHORUS MANAGEMENT FOR TROPICAL ACID SOILS USING AMENDMENTS FROM AGRO-INDUSTRIAL WASTES

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

Phosphorus (P) deficiency in tropical acid soils is a problem because soluble inorganic phosphorus is fixed by aluminium (Al) and iron (Fe). Organic amendments could be used to overcome P fixation in acid soils. Thus, the objectives of this study were to: (i) produce organic amendments from agro-industrial wastes through co-composting; (ii) improve soil P availability by amending phosphate fertilizers with organic amendments; (iii) determine if the use of organic amendments could improve nutrients uptake, dry matter production, and yield of *Zea mays* L. cultivation on a tropical acid soil; and (iv) determine the economic viability of amending phosphate fertilizers with organic amendments in maize cultivation on a tropical acid soil. Compost was produced by mixing 20 kg of shredded pineapple leaf residues + 2 kg of chicken feed + 15.5 L of chicken manure slurry + 1 kg of molasses in each polystyrene box and these ratios apply to sago bagasse too. The composts produced had no foul odour, low heavy metals contents, and they had the desired amount of nutrients. To evaluate the quality of the compost produced, an incubation study was carried out for 90 days. Amending P fertilizers with the organic amendments significantly increased the soil pH to near neutral such that exchangeable Al and iron Fe which normally fix soil P were reduced, thus improved the P availability in acid soil. After the incubation study, a pot trial was conducted in a net house so as to evaluate the effects of treatments on maize growth performance in a controlled environment. The test crop used in this study was Thai Super Sweet hybrid F1 maize (*Zea mays* L.). The results of pot trial showed that amending chemical fertilizers (N-P-K) with the organic amendments improved *Zea mays* L. nutrients uptake and dry matter production. To further evaluate the promising treatments of the pot trial, a field experiment consisting of two maize planting cycles were carried out. The treatments with chemical fertilizers amended with organic amendments increased soil P availability and *Zea mays* L. yield in both cycles of planting. A follow up study of the field trial was embarked on to assess the effect of the organic amendments on P sorption and desorption. The results showed that more P was desorbed onto acidic soils with the presence of organic amendments as P application rates increased. The decrease in P sorption was due to the precipitation of exchangeable Al and Fe at the highly negatively charged humic substances functional group surfaces of the organic amendments due to increase in soil pH. To determine the economic viability of amending P fertilizers with organic amendments, an economic viability study was carried out. Net present value (NPV) was used to compute the viability of the different maize cultivation practices. Although the production cost of

application of chemical fertilizers only are lower compared to amending chemical fertilizers with organic amendments, the ability of P fertilizer amended with pineapple leaf residues compost to improve soil chemical properties, increase yield and revenue indicate more economic viability.

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

PENGURUSAN FOSFORUS TANAH BERASID DENGAN MENGGUNAKAN BAHAN PINDAAN DARIPADA BAHAN BUANGAN AGRO-INDUSTRI

Oleh
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Kekurangan fosforus (P) di tanah tropik berasid adalah satu masalah sebab P bukan organik berlarut dan diikat oleh aluminium (Al) dan ferum (Fe). Bahan pindaan organik dapat digunakan untuk mengatasi masalah pengikatan fosforus di tanah berasid. Justeru, objektif kajian ini adalah untuk: (i) menghasilkan bahan pindaan organik daripada bahan buangan agro-industri melalui pengkomposan; (ii) meningkatkan ketersediaan P dalam tanah melalui pemindaan baja fosfat dengan bahan pindaan organik; (iii) menentukan sama ada bahan pindaan organik dapat meningkatkan pengambilan nutrisi, bahan kering dan hasil tanaman *Zea mays* L. di tanah berasid; (iv) menentukan daya maju ekonomi pemindaan baja fosfat dengan bahan pindaan organik dalam penanaman jagung di tanah berasid. Kompos dihasilkan melalui campuran 20 kg sisa daun nanas yang dicincang + 2 kg bahan makanan ayam + 15.5 L larutan tahi ayam + 2 kg gula perang dalam setiap kotak polistirena dan nisbah campuran adalah sama untuk sisa hampas sago. Kompos yang dihasilkan tidak mempunyai bau yang tidak menyenangkan, mengandungi kandungan logam berat yang rendah dan mempunyai kandungan nutrisi yang bagus. Untuk menentukan kualiti kompos yang dihasilkan, satu kajian inkubasi telah dijalankan untuk 90 hari. Pemindaan baja fosfat dengan bahan pindaan organik meningkatkan pH tanah ke tahap hampir neutral dengan ketara melalui pengurangan kandungan Al dan Fe yang mengikat P, justeru meningkatkan kandungan P tersedia ada dalam tanah. Selepas kajian inkubasi, kajian pasu dijalankan dalam rumah jaring untuk menentukan kesan bahan pindaan organik terhadap pembesaran jagung dalam keadaan terkawal. Tumbuhan kajian yang digunakan adalah jagung Thai Super Sweet F1 (*Zea mays* L.). Hasil kajian menunjukkan pemindaan baja kimia (N-P-K) dengan bahan pindaan organik meningkatkan pengambilan nutrisi dan bahan kering jagung. Untuk menyambung penilaian pilihan rawatan bagus dari kajian pasu, satu kajian ladang yang mengandungi dua tanaman pusingan dijalankan. Rawatan pemindaan baja kimia dengan bahan pindaan organik meningkatkan kandungan P tersedia ada dan hasil jagung dalam kedua-dua tanaman pusingan. Satu lagi kajian penyambungan daripada kajian ladang dijalankan untuk menentukan kesan bahan pindaan organik terhadap tahap penjerapan dan perlepasan P. Kajian menunjukkan bahawa lebih banyak P dilepaskan dengan adanya bahan pindaan organik dalam kandungan larutan P yang tinggi. Kekurangan penjerapan fosforus adalah disebabkan oleh pemendakan Al dan Fe pada permukaan kumpulan berfungsi cas negatif bahan humik di bahan pindaan organik yang disebabkan oleh peningkatan pH tanah. Untuk menentukan daya maju ekonomi melalui pemindaan baja fosforus dengan bahan pindaan organik, satu kajian daya maju ekonomi telah dijalankan. Nilai Kini Bersih telah digunakan untuk mengirakan daya maju cara penanaman jagung yang berbeza. Walaupun kos aplikasi penggunaan baja kimia adalah lebih rendah daripada pemindaan baja kimia

dengan bahan pindaan organik, keupayaan bahan pindaan organik dalam meningkatkan ciri-ciri kimia tanah, hasil jagung dan keuntungan yang tinggi menunjukkan ia adalah lebih berdaya maju.

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I certify that a Thesis Examination Committee has met on (23 March 2015) to conduct the final examination of (Ch'ng Huck Ywih) on his thesis entitled "Phosphorus management for tropical acid soils using amendments from agro-industrial wastes" 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 Doctor of Philosophy.

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LIST OF ABBREVIATIONS

1	$(NH_4)_2Fe(SO_4)_2.6H_2O$ – Ferrous ammonium sulphate
2	ADP – Adenosine diphosphate
3	AEC – Anion exchange capacity
4	Al-P_i – Aluminium bound inorganic phosphorus
5	ATP – Adenosine triphosphate
6	BOD – Biochemical oxygen demand
7	Ca-P_i – Calcium bound inorganic phosphorus
8	COD – Chemical oxygen demand
9	DAI – Days after incubation
10	DAS – Days after sowing
11	E_4:E_6 – Ratio of absorption intensities at 456 and 665 nm
12	Fe- P_i – Iron bound inorganic phosphorus
13	ICP – Inductively Coupled Plasma
14	MBC – Maximum P buffering capacity
15	NPV – Net present value
16	P_i – Inorganic phosphorus
17	P_o – Organic phosphorus
18	SE – Standard error

CHAPTER 1
INTRODUCTION

1.1 Background and Problem Statement

Phosphorus (P) is a key element in both crop production and environmental sustainability. It has been recognised as one of the important elements required to maintain profitable crop production (Sharpley and Tunney, 2000). Phosphorus is classified as a macronutrient in agronomy because of the relatively large amounts in which it is needed by plants. Ultisols and Oxisols are predominant in the tropics. These soils are acidic due to high weathering and high rainfall that results in loss of basic cations. In such soils, acidic cations such as Al and Fe predominate, and depending on soil pH, they fix the applied inorganic P (Adnan *et al.*, 2003). Phosphorus is generally available to crops at soil pH of between slightly acidic to neutral (6 to 7). Below this range, P is fixed due to active forms of Al and Fe oxides and hydroxides whereas at higher pH (>7), P becomes less available due to precipitation with calcium. Therefore, in acidic soils, application of regular P fertilizers such as rock phosphates are required to saturate Al and Fe ions so as to maintain an adequate supply of plant-available P (Rahman *et al.*, 2014). However, this approach has not been successful because it is not economical. The practice is also not environmental friendly as excessive or unbalanced use of P fertilizers causes water pollution such as eutrophication.

One of the challenges in agro-industrial wastes management in Malaysia is to develop new techniques that could put wastes into good use. In Malaysia, approximately 13 t ha^{-1} pineapple wastes per cropping cycle on peat soils are produced. However, these pineapple residues are usually managed through open burning (Ahmed *et al.*, 2004). Burning does not only cause haze and pollution, but it also causes peat fires which are difficult to control. Sarawak at present is the principal producer of sago, exporting about 15,000 to 40,000 tonnes of sago starch annually (Apun *et al.*, 2009). The sago palm trunk waste produced by the sago starch industries is a type of lignocellulosic waste material available in large quantities but its commercial value is less exploited (Akmar and Kennedy, 2001). The amount of waste (fiber and water) from processing sago is about 20 times the total starch production (Haska, 2002) and about seven tones of sago fiber are produced daily from a single sago starch processing mill (Bujang *et al.*, 1996). The sago waste is usually washed off into drains. In some situations, the waste from processing sago is drained into nearby rivers or sea and this method of disposal may cause water pollution. This type of waste disposal causes reduction in dissolved oxygen in water for fishes which require more than 10 g m^{-3} of dissolved oxygen (Cecil, 2002). Normal chemical oxygen demand (COD) and biochemical oxygen demand (BOD) should be around 100 mg L^{-1} but Sarawak State Environment Department has reported that water samples from affected rivers showed COD reading of 450 to 700 mg L^{-1} and BOD level from 150 to 200 mg L^{-1} which contravened the standard limit discharge enacted in the Environmental Quality Act, 1974 (sewage and industrial effluents regulation, 1979) (Awg-Adeni *et al.*, 2010).

In recent times, wastes generated from chicken farms are increasing as a result of rapid growth of the chicken farm industry (Arifin *et al.,* 2006). Thus, the use of chicken farm wastes as sources of nutrients for the agricultural sector has become popular. Currently, chicken manure is applied directly as an organic fertilizer in agriculture. However, direct application of chicken manure in agriculture causes environmental pollution and diseases outbreak (Bowman *et al.,* 2000).

Organic amendments are currently being used to restore the fertility of problem soils such as Ultisols which have high P-fixing capacity. Organic amendments additions have been used in the tropics to improve soil chemical properties and nutrients bioavailability especially P *via* minimizing P sorption sites (Ohno and Amirbahma, 2010; Ohno *et al.*, 2007). Organic amendments have the ability to enhance soil fertility and crop productivity, soil water retention, and carbon (C) sequestration (Galinato *et al.*, 2011). Besides, several studies have shown that addition of green manures and animal wastes to acid soils improve soil fertility (Berek *et al.,* 1995; Hue, 1992). In order to mitigate soil P fixation and to as well overcome agro-industrial wastes management challenges in Malaysia, co-composting of sago and pineapple wastes with chicken manure slurry in a way that solves the problem of P fixation in acid soils and environmental pollution could be novel. It is the most suitable approach for waste treatment due to the ever-increasing awareness about environmental pollution. This hypothesis was adopted in the present study as pineapple and sago wastes have high C:N ratios and slow to decompose on their own. If these wastes are co-composted with a low C:N material such as chicken manure slurry which is also serves as source of microorganisms, more favourable ratios can be achieved for rapid decomposition of pineapple leaf residues and sago bagasse. This may lead to production of composts that are rich in plant nutrients (Abdulla, 2007).

Co-composting can be defined as biological decomposition and stabilization of two different types of wastes (Angelidaki and Ahring, 1997; Ahring *et al.*, 1992), by producing thermophilic temperatures to produce a compost product that is free from pathogens, heavy metals and weed seeds (Gopinathan and Thirumurthy, 2012). In addition, co-composting allows resource recovery with many advantages such as it costs less than separate treatment systems, developing a better handling and digestibility of the solid waste (Angelidaki and Ahring, 1997). Besides, through co-composting, one is able to produce a better nutrient balance output which in return can save cost besides serving as an alternative to the use of chemical fertilizers that could lead to soil pollution.

Although there exist some information on P sorption and fixation using organic matter (Ohno and Amirbahma, 2010; Ohno *et al.*, 2007), there is dearth of information on the use of compost with large surface area and high negative charges to minimize P fixation in acid soils. The problem of P fixation can potentially be solved by the progressive return of organic materials to soils. This process will fundamentally enable long term chelation of Al and Fe by compost instead of P. This is possible because functional groups such as carboxyls and phenols in of humic substances such as humic acids, fulvic acids, and humin in composts known to be negatively charged in alkaline condition will chelate Al and Fe. This is so because the functional groups have high affinity for Al and Fe. Hence, P will become available for plants uptake. In addition, compost is alkaline in nature and may increase soil pH (Yan *et al.*, 1996; Haynes and Swift, 1993). The additional benefits are high porosity, high specific surface area and surface functional groups which can sorb the Al and Fe thus minimizing P fixation (Iyamuremye and Dick, 1996; Violante and Gianfreda, 1993). Hence, P and basic cations will become readily and timely available for crop use. In addition, compost will release essential nutrients into soils.

1.2 Objectives

The objectives of this study were to:

1. Produce organic amendments from agro-industrial wastes (pineapple leaf residues and sago bagasse) through co-composting.
2. Improve soil phosphorus availability by amending phosphate fertilizers (Triple superphosphate, Egypt rock phosphate, and Christmas Island rock phosphate) with organic amendments.
3. Determine if the use of organic amendments could improve nutrients uptake, dry matter production, and yield of *Zea mays* L. cultivation on a tropical acid soil.
4. Determine the economic viability of amending phosphate fertilizers with organic amendments in maize cultivation on a tropical acid soil.

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BIODATA OF STUDENT

Ch'ng Huck Ywih, born in 11 October 1985, originated from Penang, studied in Sekolah Rendah Jenis Kebangsaan Union in 1991. After completing his primary school, he studied in Sekolah Menengah Chung Ling in 1997. He successfully obtained a First-class Honours in Bachelor of Science Bioindustry from Universiti Putra Malaysia in 2009. He was assigned to Training Department and Road Department at Grand Perfect Sdn. Bhd. Plantation, Bintulu, Sarawak, Malaysia during his internship. After graduating from Bachelor of Science Bioindustry, he successfully obtained a Master of Science (Land Resources Management) from Faculty of Agriculture and Food Sciences, Universitii Putra Malaysia Bintulu Sarawak Campus in 2011. He attended 2010 Universiti Brunei Darussalam 1st Graduate Science Student Research Conference during his Masters study. He is currently undertaking Doctor of Philosophy (Agronomy) in Faculty of Agriculture and Food Sciences, Universitii Putra Malaysia Bintulu Sarawak Campus. During his PhD study, he attended 2013 2nd International Symposium on Tropical Forest Ecosystem Science and Management: Challenges and Solution in Universiti Putra Malaysia Bintulu Sarawak Campus, 2014 Agrobiodiversity and Agroenvironment Symposium in Pullman Hotel, Kuching, Sarawak, and 2014 The International Bioscience Conference and the 5th Joint International PSU-UNS Bioscience Conference in Phuket, Thailand. Besides, he has also won Bronze Medal at Malaysia Innovation Expo (MIExpo 2013) in UPM Serdang, Gold Award and Most Promising Innovation Award in BioMalaysia 2013, and Gold Medal in Pameran Rekacipta, Penyelidikan dan Inovasi (PRPI) 2014.

LIST OF PUBLICATIONS

(a) Book

1. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, Susilawati Kasim, Nik Muhamad Ab. Majid. Improving phosphorus availability for plant uptake in tropical acid soil using organic amendments derived from agro-industrial wastes. (Submitted to UPM Press).

(b) Papers Submitted or Published

1. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, Susilawati Kasim, and Nik Muhamad Ab. Majid. 2013. Co-composting of pineapple leaves and chicken manure slurry. International Journal of Recycling of Organic Waste in Agriculture 2(25): 1-7.

2. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, Susilawati Kasim, and Nik Muhamad Ab. Majid. 2014. Recycling of sago (*Metroxylon sagu*) bagasse with chicken manure slurry through co-composting. Journal of Agricultural Science and Technology 16(6): 1441-1454.

3. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, Nik Muhamad Ab. Majid 2014. Improving phosphorus availability in an acid soil using organic amendments produced from agroindustrial wastes. The Scientific World Journal 506356(2014): 1-6.

4. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, Nik Muhamad Ab. Majid 2014. Biochar and compost influence the phosphorus availability, nutrient uptake, and growth of maize (*Zea mays* L.) in tropical acid soil. Pakistan Journal of Agricultural Sciences 51(4): 797-806.

5. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, and Nik Muhamad Ab. Majid. Using chicken litter biochar and pineapple waste compost to reduce phosphorus fixation of a tropical acid soil. Canadian Journal of Soil Science (Under review).

6. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, and Nik Muhamad Ab. Majid. Improving phosphorus availability, nutrient uptake and dry matter production of *Zea mays* L. on tropical acid soil using chicken litter biochar and pineapple leaves compost. Experimental Agriculture (Under review).

(c) Presented Works

1. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, and Nik Muhamad Ab. Majid. 2014. Use of chicken litter biochar and pineapple leaf compost to reduce soil P-fixation and improving nutrient uptake in maize (*Zea mays*) cultivation on acid soil. Presented at The International Bioscience Conference 2014 and the 5th Joint PSU-UNS International Bioscience Conference, Phuket, Thailand, during September 29-30, 2014.

2. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, and Nik Muhamad Ab. Majid. 2014. Reducing phosphorus fixation on tropical acid soil using chicken litter biochar and pineapple leaves compost. Presented at Agrobiodiversity and Agroenvironment Symposium A-BES 2014, Pullman Hotel, Kuching, Malaysia, during September 15-18, 2014.

(d) Papers to be Submitted

1. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, and Nik Muhamad Ab. Majid. Biochar and compost had effects on phosphorus sorption and desorption in tropical acid soil.

2. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, and Nik Muhamad Ab. Majid. Leaching study of a tropical acid soil as influenced by incorporation of biochar and pineapple leaves compost.

3. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, and Nik Muhamad Ab. Majid. Reducing phosphorus fixation and improving yield of *Zea mays* L. cultivation on a tropical acid soil using biochar and pineapple leaves compost.

4. Huck Ywih Ch'ng, Osumanu Haruna Ahmed, and Nik Muhamad Ab. Majid. Effect of incorporation of organic amendments with phosphate fertilizer on yield and economic viability of maize cultivation on tropical acid soil.

LIST OF AWARDS

1. Bronze Medal, “Maximizing yield of crops by reducing phosphorus fixation”. Malaysian Innovation Expo (MIExpo 2013) on 26th-28th September 2013, Banquet Hall, UPM Serdang.

2. Gold Medal, “Maximizing yield of crops by reducing phosphorus fixation”. BioMalaysia & Bioeconomy Asia Pacific 2013 Conference & Exhibition on 21st– 23rd October, Persada Johor.

3. Most Promising Innovation, ““Maximizing yield of crops by reducing phosphorus fixation”. BioMalaysia & Bioeconomy Asia Pacific 2013 Conference & Exhibition on 21st– 23rd October, Persada Johor.

4. Gold Medal, “Unlocking fixed nutrients in acid soil to increase crop yield”. Pameran Rekacipta, Penyelidikan dan Innovasi (PRPI) 2014 on 30th-1st October 2014, Dewan Besar PKKSSAAS, UPM Serdang.