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Improving plant growth performance and phosphorus use
efficiency in *Zea mays L.* cultivated in tropical acid soil
upon amending paddy husk compost

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DECLARATION

I hereby declare that the work embodied in this report is the result of the original research and has not been submitted for a higher degree to any universities or institution.

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I certify that the report of this final year project entitled "Improving Plant Growth Performance and Phosphorus Use Efficiency in _Zea mays L._ Cultivated in Tropical Acid Soil upon Amending Paddy Husk Compost" by SITI MAZIYYAH BINTI MADZALAN, F15A0211 has been examined and all the correction recommended by examiners have been done for degree of Bachelor of Applied Science (Agrotechnology) with Honours, Faculty of Agro-Based Industry, Universiti Malaysia Kelantan.

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Improving Plant Growth Performance and Phosphorus Use Efficiency in *Zea mays L.* Cultivated in Tropical Acid Soil upon Amending Paddy Husk Compost

ABSTRACT

In tropical acid soils, P is often being a limited because the soluble form of inorganic P in the soil is fixed by Al and Fe, thus reduces the P availability in the soil. Application of organic amendment is highly recommended to mitigate P losses in acid soil by increasing P availability in these soils. This process will enable long term bonding of Al and Fe by compost instead of P. Therefore, this study is aimed to (i) characterize the selected physio-chemical properties of the soil samples and chemical properties of paddy husk compost, (ii) assess the selected plant growth parameters of *Zea mays L.* upon amending chemical fertiliser with paddy husk compost and (iii) determine the soil P availability, P uptake, and dry matter production of *Zea mays L.* by amending chemical fertiliser with paddy husk compost. A pot test experiment was conducted in a net house at Universiti Malaysia Kelantan, Jeli Campus for 60 days and a F1 hybrid sweet corn 801 variety was used as a test crop. The soil samples from each pot test trials were then collected and analysed. The *Zea mays L.* was harvested and partitioned into leaves, stems, and roots at 60 DAS. The result showed, treatments with paddy husk compost showed significant increase in the soil pH, and significant reduction of exchangeable Al and Fe in the soil compared to treatments with soil only and soil with chemical fertilizer only. There was also significant increase in growth performance, phosphorus uptake and dry matter production (leaves, stems and roots) of *Zea mays L.* in treatments amended with paddy husk compost. This was due to the reduction of exchangeable toxicity in the root zone and increase in the phosphorus availability in the soil. As a conclusion, compost derived from paddy husk compost can be used to improve the growth performance, phosphorus uptake, phosphorus availability and dry matter production of *Zea mays L.* cultivated in tropical acid soil by reducing the soil phosphorus fixation.

Keywords: Soil phosphorus fixation, paddy husk compost, *Zea mays L.*, phosphorus uptake, dry matter production.

Meningkatkan Kadar Pertumbuhan dan Kecekapan Penggunaan Fosforus Bagi *Zea mays L*. Dengan menggunakan Kompos Sekam Padi.

ABSTRAK

Dalam tanah asid tropika, P sering menjadi terhad kerana bentuk keterlarutan P inorganik di dalam tanah mengalami pengikatan oleh Al dan Fe, sehingga mengurangkan ketersediaan P di dalam tanah. Penggunaan bahan organik boleh digunakan untuk mengurangkan kehilangan P dengan meningkatkan ketersediaan P dalam tanah. Proses ini akan membolehkan ikatan jangka panjang antara Al dan Fe dengan kompos berbanding P. Oleh itu, kajian ini bertujuan untuk (i) mempercirikan sifat fisiokimia terpilih sampel tanah dan sifat kimia kompos sekam padi, (ii) menilai parameter terpilih bagi pertumbuhan *Zea mays L.* apabila baja kimia dengan kompos sekam padi digunakan dan (iii) menentukan ketersediaan P dalam tanah, pengambilan P, dan pengeluaran jisim kering *Zea mays L.* apabila diletakkan baja kimia dengan kompos sekam padi. Eksperimen pasu dijalankan di sebuah rumah berjaring di Universiti Malaysia Kelantan, Kampus Jeli selama 60 hari dan hybrid jagung manis varieti F1 801 digunakan sebagai tanaman ujian. Sampel tanah dari setiap pasu ujian kemudian dikumpulkan dan dianalisis. Pokok dituai dan dibahagikan kepada daun, batang, dan akar pada 60 DAS. Rawatan dengan kompos menunjukkan peningkatan yang signifikan dalam pH tanah, serta peningkatan pertukaran Al dan Fe dalam tanah dengan kompos berbanding dengan rawatan dengan tanah sahaja dan tanah dengan baja kimia sahaja. Terdapat peningkatan yang signifikan dalam prestasi pertumbuhan, pengambilan P dan pengeluaran jisim kering (daun, batang dan akar) *Zea mays L.* dalam rawatan yang menggunakan kompos. Ini disebabkan oleh pengurangan ketoksikan di zon akar dan peningkatan ketersediaan fosforus dalam tanah. Sebagai kesimpulan, kompos yang diperoleh daripada kompos sekam padi boleh digunakan untuk meningkatkan prestasi pertumbuhan, pengambilan P, ketersediaan P dan pengeluaran jisim kering *Zea mays L.* yang ditanam di dalam tanah asid tropika dengan mengurangkan pengikatan P tanah.

Kata kunci: Pengikatan fosforus tanah, kompos sekam padi, *Zea mays L.,* pengambilan fosforus, pengeluaran jisim kering.

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LIST OF ABBREVIATION AND SYMBOLS

N	Nitrogen
P	Phosphorus
K	Potassium
Al	Aluminium
Fe	Iron
OH	Hydroxide
C	Carbon
Si	Silicon
Mn	Manganese
H	Hydrogen
Ca	Calcium
Mg	Magnesium
Na	Sodium
Zn	Zinc
Cu	Copper
HPO_4^-. HPO_4^{2-}	Orthophosphate
NaOH	Sodium hydroxide
HCl	Hydrochloric acid
H_2SO_4	Sulphuric acid
$Al_2(MoO_4)_3$	Ammonium molybdate
pH	Potential of hydrogen
EC	Electrical Conductivity
CIRP	Christmas Island Rock Phosphate
MOP	Muriate of Potash

ATP	Adenosine triphosphate
DNA	Deoxyribosenuclease acid
DAS	Day After Sowing
FAO	Food and Agriculture Organization of United Nation
MARDI	Malaysian Agriculture Research and Development Institute
SPSS	Statistical Package for Social Science
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTION

1.1 Background

Phosphorus (P) is one of the important soil macronutrient that is required by plants for optimum growth. Dissolved P and other essential nutrients will be utilized by plant to build their tissues using energy from the sun. Highest concentration of P can be found in seeds of mature plants, and in young cells, such as shoots and root tips. It is because at this stage, P is required in large quantities for rapid cell division and high metabolism. The P has been found to enhance the quality of certain crops and reduce the disease in some plants (Uchida, 2000). However, the lack of P can be seen in initial overall symptom of P deficiency, where the growth of plant will be stunted, slow and weak. Symptoms of dark to blue-green coloration also can be seen on older leaves of plants because P has been transferred to sites of new growth through the mobilization of P in plants. Under severe deficiency, purpling of leaves and stems may appear. Furthermore, lack of P can cause delayed maturity and poor seed and fruit development (Uchida, 2000). On the other hand, too much supply of P can be detrimental to plant and

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the environment. Excess P indirectly affects plant growth by reducing iron (Fe), manganese (Mn) and zinc (Zn) uptake and potentially causing deficiency symptoms of these nutrients to occur. Zinc deficiency is most common under excess P conditions (McCauley, Jones & Jacobsen, 2009). Furthermore, over application of P, whether inorganic or organic sources such as fertilizers and manures can result in high levels of inorganic phosphate in soil. If these soils are close to surface waters, then this P can be exported to water either as soluble P in runoff water or as P adsorbed. These can result in the elevation of the bioavailable P in water and thus lead to eutrophication of the waters (Mullen, 2005). Eutrophication is the excessive plant and algal growth due to the increased availability of one or more limiting growth factors such as sunlight, carbon dioxide, and nutrient fertilizers (such as N and P) that are required for photosynthesis (Schindler, 2006; Chislock, Doster, Zitomer & Wilson, 2013). The most obvious effect of eutrophication is the creation of dense algal blooms that reduce the water quality and causing die offs of plants and other organism in littoral zones (Lehtiniemi *et al.* 2005).

1.2 Problem Statement

In Malaysia, cropping in tropical acid soils can cause problems because tropical acid soils are highly weathered which can results in leaching of plant nutrients such as P. Furthermore, in acidic soils, P tends to react with aluminium (Al), and Fe and make the P unavailable to plant (Torbert et al., 2005). To reverse this impact, compost can be applied as a direct source of nutrients in conjunction with chemical fertilizers. High

organic matter of the composts (typically> 40%) will increase the soils fertility due to the effects of organic matter on soil biota as well to the physico-chemical characteristics of the soil (Raviv, 2005). Composts derived from agricultural wastes such as paddy husk can be used as an organic amendment to supply the nutrients to plant (Chandrasekhar et al., 2003). Composting of paddy husk is one of the best methods to solve waste management problems, because composting enables conversion of paddy husk into a stabilized organic amendment, and this end product has the ability to improve nutrients availability (Latifah et al., 2015). Furthermore, Malaysia is blessed by plenty of biomass resources, and one of them is the paddy residues (paddy husk). About 3.66 million tonne of paddy residue is left in the fields per annum (Shafie, 2015).

In addition, emerging of technological development in agro-industry, has gained the production of paddy husk to 0.48 Million tonne (UNDP, 2002) in a year (Malaysia Economics Statistics, 2011) and if the future target is achieved with 10 tonnes of paddy production per hectare, the output of paddy will be increased to 6, 575, 474.8 tonnes per year. However, this potential increase of rice husk production in Malaysia will cause the abundant of availability of this resource, and then create the problem of waste management if this residue cannot be manage in good solutions (Singh, 2015). Studies showed that compost derived from agricultural wastes such as paddy husk and manure was used to obtain high nutrients and use efficiency value which is more nutrients available for crop uptake and less leaching or loss (Ros et al., 2006). The use of composts can improve soil structure and nutrients supply to crops and thus reduce the input of mineral fertilizers. Furthermore, Ros *et al.,* (2006) reported that compost derived from composting of paddy husk and chicken slurry is an approach to make beneficial use of agricultural wastes to supply nutrients for crop and to reduce environment pollution from the disposal of these wastes.

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Although there are some information stated that the application of organic amendment has the ability to improve nutrients availability, but there is still lack of information on the effect of application of paddy husk compost in the growth performance and P uptake efficiency of maize (*Zea mays L.*) planted in acidic soil.

1.3 Research question

If P in acidic soil is less available due to fixation by Al and Fe, runoff and leaching, would it possible that the compost produced from the paddy husk with a pool of negative charges and large surface area will bind P^{3+} and reduce the leaching and fixation of P and thus increase the P availability for plant uptake?

1.4 Objectives

1. Characterize the selected physiochemical properties of the soil samples and paddy husk compost.
2. Determine the soil P availability, P uptake, and dry matter of *Zea mays L.* upon amending chemical fertilizers with paddy husk compost.
3. Assess the selected plant growth parameters of *Zea mays L.* (plant height, number of leaves, leaf area index and root length) upon amending chemical fertilizers with paddy husk compost.

1.5 Hypothesis

1)

H_0- The soil P availability, P uptake and dry matter production in *Zea mays L.* remain unchanged upon application of chemical fertilizers with paddy husk compost.

H_1- The soil P availability, P uptake and dry matter production in *Zea mays L.* change upon application of chemical fertilizers with paddy husk compost.

2)

H_0- Plant height, number of leaves, leaf area and root length remain unchanged upon amending chemical fertilizer with paddy husk compost.

H_1- Plant height, number of leaves, leaf area and root length change upon amending chemical fertilizer with paddy husk compost.

1.6 Scope of study

This study focuses on utilising compost that developed from agricultural waste (paddy husk) to minimize P fixation in acid soil, increase growth performance and nutrient use efficiency in maize plant.

1.7 Significance of study

This work may not only contribute to the reduction of P fertilizers import in Malaysia but it also can add value to the agro-industrial in terms of reducing wastes such as paddy husk to avoid environmental pollution.
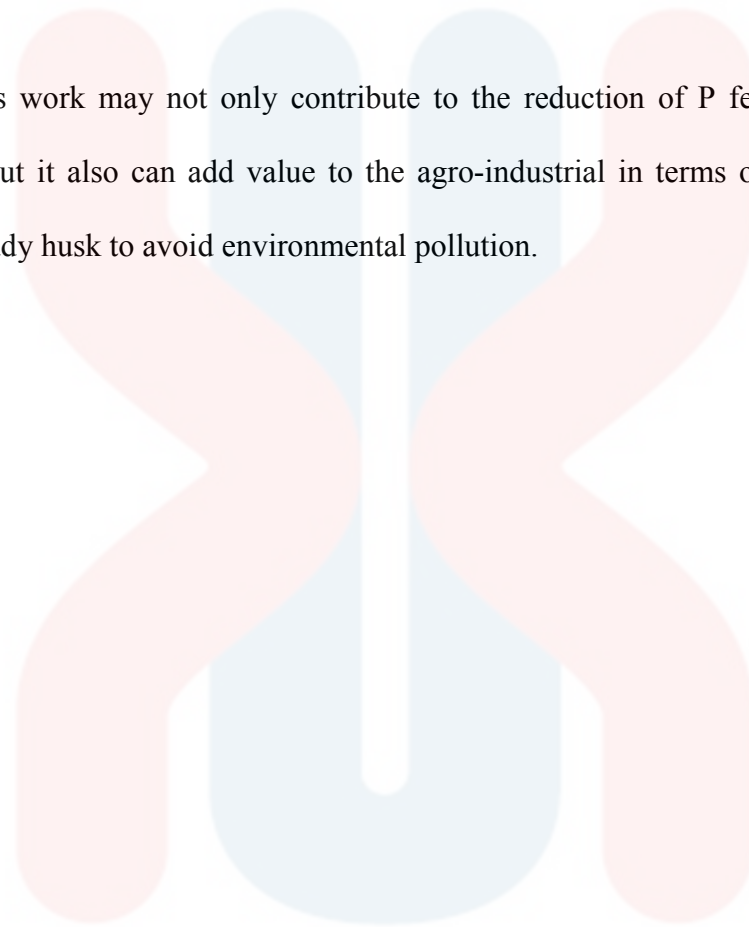
CHAPTER 2

LITERATURE REVIEW

2.1 Phosphorus

2.1.1 Phosphorus Cycle

Bedrock, soils, and sediments are the source of P that is locked and not directly available to organisms. However, these unavailable forms of P can be converted to dissolve orthophosphate, which can be directly assimilated, through geochemical and biochemical reactions at various stages in the P cycle (Ruttenberg, 2003). The P can also be originated from weathering of the residue minerals from the phosphate additions in form of fertilizer, animal, sediments and plant residue as well as agricultural wastes. In P cycle, there are several processes occur. These process include chemical (precipitation and weathering), biological (mineralization and immobilization), and physic-chemical process (sorption and desorption) (Lehmann et al., 2005).
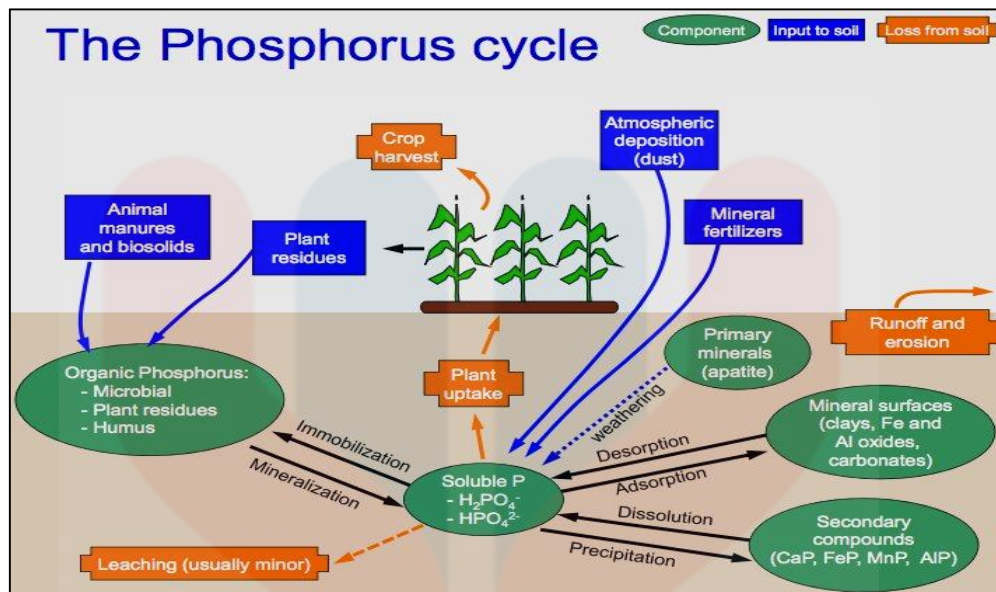
Figure 2.1: Phosphorus Cycle

Source: Lehmann et al., 2005

2.1.1.1 Precipitation and Weathering

Precipitation can be described as any type of water that forms in the earth's atmosphere and then drops back onto the surface of the earth. The earth's atmosphere which is build-up by water vapour that suspended in the air will turns into a liquid when the clouds get too full of water vapour. Precipitation is part of the P cycle. On the other hand, the breaking down or dissolving of rocks and minerals on the surface of the earth can be described as weathering. Water, ice, acids, salts, plants, animals, and changes in temperature are all agents of weathering. Weathering and precipitation are complementary, as nature needs them both to continue the cycles (National geographic, 2018). Over time, precipitation and weathering will cause the rocks to release the phosphate ions and other minerals that will be distributed in soils and water. However,

P can become unavailable through precipitation. This may due to the P that dissolves with rainfall is flowed away with rainfall runoff and a large amount of adsorbed P is lost with sediments. Therefore, the more rainfall occurred, the more rainfall runoff and sediments yielded, the heavier the total P loss was (Ding, Xue, Lin & Liu, 2017).

2.1.1.2 Mineralization and Immobilization

The mineralization is the transformation of organic P into inorganic orthophosphate P (available phosphate for plant uptake) by the aids of soil microorganism (Mullen, 2005). Mineralization and immobilization of phosphorus occur simultaneously in the soil. This process mainly occurs if there is high amount of organic matter which favours the condition for effective microorganism activities. In this process, soil microbes will help in mineralization to convert the organic P into orthophosphate. Besides, immobilization is the transformation of P back into organic forms (Mullen, 2005). This process is important in preventing the P sorption to the soil, and increasing the efficiency of phosphate fertilization. Immobilization occurs when these available P are consumed by microbes, turning the P into organic P forms that are not available to plants. The inorganic P will become available again over time as the microbes die. After the death, the microbes would be mineralized and gradually released in the soil solution. Therefore, maintaining soil organic matter levels is important in maintaining P availability (Lehmann *et al.,* 2005).

2.1.1.3 Sorption and Desorption

Phosphorus sorption occurs when the orthophosphates, $H_2PO_4^-$ and HPO_4^{2-}, bind tightly to soil particles, which makes it unavailable to plants (McClellan, Deenik & Singleton, 2013). On the other hand, desorption is the release of adsorbed P from its bound state into the soil solution. Since phosphate is an anion, particles that generate an anion exchange capacity will form strong bonds with phosphate. Examples of particles with anion exchange capacity are Al and Fe oxides (McClellan, Deenik & Singleton, 2013). There are several factors that affect P sorption. First is the soil mineralogy. Highly weathered soils (such as Oxisols and Ultisols) have the great P sorption capacities. This is due to the presence of large amounts of Al and Fe oxides. Next, as the amount of clay increases in the soil, the P sorption capacity will also increase. This is because clay particles have a large amount of surface area, which phosphate sorption can take place. In addition, at low pH, soils have greater amounts of Al in the soil solution, which forms very strong bonds with phosphate. In fact, a soil binds twice the amount of P under acidic conditions. Lastly, the increase in temperature will also increase P sorption (McClellan, Deenik & Singleton, 2013). Besides, in acidic soil the highest P availability is between pH 6 and 7 (Figure 2.2). At higher pH, P can precipitate with Ca while at lower pH, P tends to bind to Fe and Al compounds in the soil (Series, 2005).
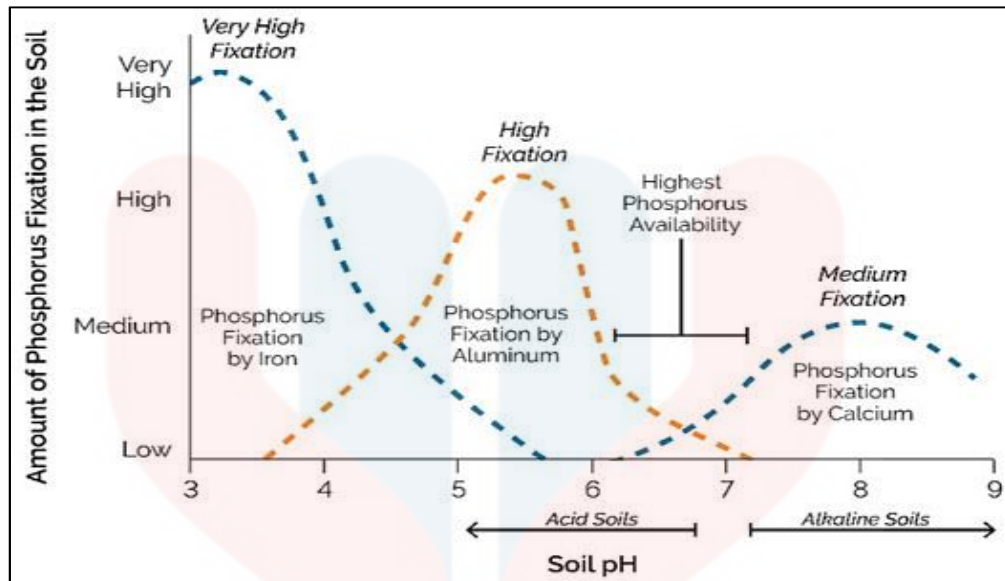
Figure 2.2: Effect of soil pH on P availability

2.1.2 Importance of P

Phosphorus plays an essential role in biological systems. Earth's biological systems have depended on P since the beginning of life. Phosphorus is vital in every plant process that involves energy transfer (Nealson and Rye, 2004). Phosphorus acts as a component of adenosine diphosphate (ADP) and ATP the "energy unit" of plants that drives lots of chemical reactions within the plant. Next, P is important in genetic transfer as it is a vital component of the substances that are building blocks of genes and chromosomes that carrying the genetic code from one generation to the next, providing the "blueprint" for all aspects of plant growth and development. The development of new cells and transferring of the genetic code from one cell to another also depend on adequate supply of P when new cells are formed (Sultenfuss & Doyle, 1999). Next, P is

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important in the photosynthesis process. During photosynthesis, chlorophyll will utilize the light energy that captured in ATP to combine the carbon dioxide and water and convert it into simple sugars. Then, the sugars will be used to produce other cell structural and storage components. Furthermore, P is important as an energy provider. The movement of nutrients within the plant through cell membranes also used the energy provided by ATP and other high energy P compounds to oppose the forces of osmosis as the plant cells have a capacity to accumulate higher concentrations of nutrients that present in the soil solution surrounds them. This advantage allows them to extract nutrients from the soil solution even the nutrients are present in very low concentrations (Sultenfuss & Doyle, 1999).

2.1.3   Present Concern with Phosphorus

2.1.3.1 Phosphorus Fixation

Warren (1992) stated that P deficiency is one of the largest constraints to food production in tropical acid soils due to low native P and high fixation by Fe and Al oxides. It has also been supported by Ojo, Adetunji, Okeleye & Adejuyigbe, (2015) that P is relatively unavailable for plant uptake in highly weathered soils like the Ultisols and Oxisols. The removal of the Fe oxide content from soil can reduces the magnitude of P fixation, and deduced from this that these compounds must be partially responsible for P fixation. Conventionally, large amounts of lime and inorganic P fertilizers such as phosphate rocks and Triple Superphosphate are used to saturate Al and Fe ions.

However, these strategies are not environmental friendly (Ch'ng, Ahmed & Ab. Majid, 2014).

2.2   Form of P in Soils

2.2.1 Solution P Pool

The P compounds in the soils may be categorized into 3 pools, namely solution P pools, active pools and fixed pools (Busman, Lamb, Randall, Rehm &Schmitt, 2002).

Solution P pools is very small pool in the soil. It is usually exist in the orthophosphate form of P. In soil, the orthophosphate form is the only form that is available for plant uptake (Busman et al., 2002). Therefore, this type of pool has significant importance for plant nutrition uptake. However, there will be depletion of the P in the solution P pool as continuous uptake of P by plant. Hence, continuous supply of P is important to sustain the soluble P in the solution (Busman et al., 2002).

2.2.2 Active P Pool

Active P pool is the inorganic P that is attached to small particles in soil. The P can react with element such as Ca and Al to form soluble solids. Plant would absorb the inorganic P from solution P pool and cause the concentration of inorganic P to decrease.

For backup, the inorganic P from active pool will be released and available for plant use. As the solution P pool is small and limited, the active P pool becomes the main source of available P.

2.2.3 Fixed P Pool

Phosphorus fixation reactions occur rapidly in soil profiles. This reaction usually involves dissolve P anions with the soil. Fixed P pool usually consists of inorganic P which are in crystalline structure and less soluble than P compound that available in active P pool. Significantly the fertilizers will provide good result for P availability in soil but not remain for a long period due to faster reaction between fertilizers with soil profiles. The P fixed in soil as calcium iron or Al phosphate which relative insoluble and unavailable to plant uptake (Trazzi et al., 2016).

2.3 Factors Affecting P Availability and P Use Efficiency in Soil

2.3.1 P Availability: Soil Type, pH, Texture and Temperature

The P tends to be greater on sandy soils than in the soil that contains more silt and clay after the application of P fertilizer on certain P soil test level. When soil clay content increases the P fixation also increase as well. This means in order to increase

the P availability to plants, a large amount of P must be applied (Amstrong, 1999). The efficiency of P applied also influence by the soil pH which plays an important role in P availability. In acid soil P fixation by Fe and Al oxides is greatest, but it decline when liming is applied as the pH increase. The P is available at maximum amount in the pH range of 6 to 7 in most soils. However, when the pH increases above 7, Ca and Mg would react with P and reduce the P availability (Amstrong, 1999). However, if the soils are compacted, it would results in pore space diminished, oxygen limited and make the adsorption of P by plant roots suffers since the soil compaction will decreased the thickness of water films on soil particles which limit the P moving to root surface (Amstrong, 1999). The P availability and P uptake also can be affected by lower temperatures by reducing the rate of mineralization of soil organic P and lowered the microbial activity. In addition, lower temperature also reduces the rate of diffusion of P and decrease the amount of P accessed by roots. Mostly, lower soil temperature is caused by the reduced tillage systems which shade the surface area by residues (Amstrong, 1999).

2.3.2   P Use Efficiency: Soil pH, Soil Mineralogy and Soil Water Status.

Soil pH affects the P use efficiency in soils for two reasons. Firstly, extreme pH can limit the plant growth. It is because in low pH soils Al and Mn toxicity can restrict root growth and in high pH soils micronutrient deficiencies can limit crop growth. Secondly, soil pH will affects P use efficiency in soils through P sorption, and lead to the precipitation of P into solid forms. Next is soil mineralogy. Both the amount and the

type of clay present in soil strongly affect P use efficiency. Soils with high clay content will retain P most strongly especially soil that dominated by Al and Fe oxide minerals (Syers, Johnston & Curtin, 2008). Besides, soil water status also affects the P use efficiency. Diffusion of P will be severely limited and much more complex in dry soils as there are less water-filled pores as most of the P taken up by plants arrives at the root surface by diffusion (A higher concentration in the soil solution and a low concentration at the root surface) through the soil. Therefore, drought can severely limit P use efficiency. However, excess of water such as flooding in soils can reduce the soils oxygen status but, at the same time can made Fe and Mn oxides which are active in retention decreased and solubilized, thus releasing the P that they held (Willett and Higgins, 1978).

2.4 Common Management of P fixation

2.4.1 Liming

One of the common practices to manage P fixation in soil is to apply lime material in the soil. Liming is well known as an effective way to correct the soil pH *via* direct effect. Unfortunately, the liming do not last longer compared to the organic amendment. The lime application acts to reduce the Al, Mn, and Fe toxicity in soil structure, mainly in acidic soil. However, applying the lime material alone do not help to increase the yield production of crop as lime only function to correct the pH, but not supplying the nutrients. Research by Osundawa et al., (2013) showed that there was no

significant difference on the yield production although the amount of lime was increased on other treatments in the same study. This showed that, even though the lime has increase the P availability by increasing the pH, but it is not enough to supply the optimum nutrients to the plant (Osundawa et al., 2013).

2.4.2 Phosphorus Fertilizer Supply

High adsorption of P in the soil is due to the presence of large amount of sesquioxides (an oxide that containing three atoms of oxygen with two atoms of another element) that binds the P tightly, thus, no P is available for plant uptake. High input of the P fertilizer will be added to meet the optimum level for plant uptake. However, the strategy seems to be not environmental friendly due to the arising concern of fresh water pollution. This may result in leaching and runoff of the respective soil to the nearest water resources, thus causing the eutrophication (Ch'ng et al., 2015).

2.4.3 Application of Organic Matter

Organic supplements such as leaves, manures, wood and food processing wastes have been reported to strongly contribute to the reduction of P fixation (Gichangi, 2009) and enhancing the humic substances to increase the bioavailability of P fertilizers in acidic soils (Hua *et al.,* 2008). The addition of organic matter associated with the

organic acid reduces the fixation of Al-P and Fe-P in neutral and acidic soils and Ca-P in alkaline soil (Zhuo *et al.,* 2009b; Zhang *et al.,* 2009), causing an increase in the levels of readily available P for use by plants.

2.4.4   Natural Zeolite as Plant Fertilizer

Clinoptilolite zeolite is a hydrated alumina-silicate of alkali and alkaline earth metals that can increase the nutrients use efficiency (Ramesh *et al.,* 2010). Clinoptilolite zeolite is widely used in cultivating different crops due to their exceptionally high ion-exchange capacity (Butorac *et al.,* 2002). Based on this rationale, it was hypothesized that the use of different rates of chemical fertilizers and compost amended with clinoptilolite zeolite could improve nutrients uptake, use efficiency and grain yield of *Zea mays L.* cultivated on tropical acid soil. This was proven in a field study carried out for two cropping cycles of *Zea mays L.* as a test crop to determine the effects of different rates of chemical fertilizers and paddy husk compost amended with clinoptilolite zeolite on nutrients uptake and use efficiency as well as grain yield of *Zea mays L.* cultivated on a tropical acid soil (Latifah *et al.,* 2017).

2.4.5 Application of Excess P Fertilizer

The P fertilizer is essential for plant growth. However, excess amounts of P result in leaf chlorosis because Fe, Mn, and Zn become unavailable to the plant. Directly applied micronutrients by foliar sprays such as Fe can help because they are direct to the weakening plant tissue rather than absorbed by the roots. In addition, the growth of mycorrhizae in the soil around the plant root would be inhibited by the excess P fertilizer. It is important to enable the plant roots to form a symbiotic relationship with these beneficial fungi, in order to provide the carbohydrates in exchange for P (Elgar, n.d.).

2.5 Agriculture Waste

2.5.1 Paddy Husk

Paddy husk is an inexpensive by product of human food processing. In Malaysia, about 3.66 million tonne of paddy residue is left in the fields per annum (Shafie, 2015). In addition, emerging of technological development in agro-industry, has gained the production of paddy husk to 0.48 Million tonne (UNDP, 2002) in a year (Malaysia Economics Statistics, 2011) and if the future target is achieved with 10 tonnes of rice production per hectare, the output of paddy will be increased to 6, 575, 474.8 tonnes per year. Paddy husk can provide excellent thermal insulation when

burned as it produces amounts of silica (~96%) (Hamdan, 2009). Commonly, paddy husk is being burnt as waste, releases CO_2 into the atmosphere as greenhouse gas. Increase the volume of CO_2 gas in the atmosphere is believed to cause global warming. The CO_2 gas does not only elevate global temperature, it also gives negative impact to human health because in higher concentrations it can affect respiratory function (Shuhadah, & Rohasliney, 2011).

2.6 Composting

Composting is a bio-decomposition, self-heating and aerobic process of organic waste. It has advantages because it reduces the volume of waste by 40–50% and provides a product that can be used as a soil conditioner or as a good quality fertilizer (Wu *et al.,* 2016). Under natural conditions, various organisms such as earthworms, nematodes and soil insects do most of the initial breakdown of organic materials into smaller particles. Once optimal physical conditions are established, microbes colonize the organic material and initiate the composting process. Many of the microbes involved in decomposition are present in the waste themselves (Chen *et al.,* 2011). In order to produce compost efficiently, the composting organism requires four essential components which are carbohydrate (C source as energy for oxidation), protein or N (to help them to grow and reproduce more organism to oxidize the C), oxygen (oxidize the C and decomposition process) and water at the right amount (maintain the microbial decomposition activity without causing anaerobic condition). An appropriate ratio and element will provide optimum microbial activities (Chen *et al.,* 2011).

2.7 Mechanism of Composting Reduce Soil P Fixation

2.7.1 Compost Introduces Beneficial Microbes

Soil microbes such as bacteria, fungi, and actinomycetes are introduced when the wastes are mixed with the soil or inoculated with finished compost (Chen *et al.,* 2011). The soil microbes will help in the soil mineralization by converting the organic P into inorganic P (an available P for plant uptake), thus it would increase the P supply (Xu *et al.,* 2014).

2.7.2 Compost Increase Soil pH

The mature compost should have slightly alkaline or neutral pH. The addition of compost can increase soil pH and have the ability to buffer the soil pH depending on the compost pH as well as soil pH. An increase of soil pH by the addition of compost is mainly due to addition of basic cations, ammonification and production of NH_3 during decomposition of added compost (Butler *et al.,* 2008). Thus, increase in soil pH will increase the available P for plant uptake (Hubbard *et al.,* 2008).

2.7.3 Compost Introduce Humic Substances

The mineralization and decomposition process of organic matter during composting help to supply the soil with nutrient rich organic acids such as humic substances which help to reduce precipitation in alkaline and acidic soil by binding with the cations that exist in the soil. Humic acid help to increase the P availability due to its high affinity of the functional groups such as carboxyl and phenol (Yong *et al.,* 2012).

CHAPTER 3

METHODOLOGY

3.1 Soil Sampling

The soil samples were taken at 0-20cm from an uncultivated land area in University Malaysia Kelantan, Jeli Campus using soil auger. The soils were air-dried, ground and sieve to pass through a 2 mm sieve and 5 mm sieve respectively, for laboratory analysis and pot experiment.

3.2 Soil Analysis

Before the pot experiment was carry out, the soil samples were analysed for bulk density, soil texture, soil pH, total organic matter, total carbon, soil exchangeable Fe, soil exchangeable acidity, soil electrical conductivity (EC), and soil available P.

3.2.1 Bulk Density Determination

Coring method was used to determine the bulk density (Dixon & Wisniewski, 1995). The coring was hammered into the soil according to the desired depth. Excess soils were trimmed after the coring is being removed carefully. Later, the coring together with the soil was weighted before they are being put in the oven for drying at 105°C until the weight is constant. The determination of bulk density was described by (Dixon & Wisniewski, 1995) as follow:

$$Bulk\ density\ (g\ cm^{-3}) = Dry\ soil\ weight\ (g)\ /\ Soil\ volume\ (cm^{3}) \qquad (3.1)$$

3.2.2 Soil Texture Determination

According to Bouyoucos (1962), a hydrometer method was used in determining the soil texture. A 50g of soil were placed in a blender cup. A 4 M NaOH was dropped wisely to adjust the pH until it becomes 10. Next, distilled water were added into the blender cup until it is within 10 cm of the top rim. Afterwards, the blender was attached on the stirring machine and blended for 15 minutes. After 15 minutes, the soil suspension was transferred into a 1 L measuring cylinder. Distilled water was added until the reading of the measuring cylinder shows 1130 ml. A stirring rod was used to stir the soil suspension for 40 seconds. After that, the hydrometer was placed into the suspension and the reading of the meniscus level on the hydrometer stem was recorded.

The hydrometer was removed. The soil suspension was stirred again and the second reading was recorded. The expected result was equivalent to the amount of silt and clay in grams of the soil sample. The same steps were repeated and the third reading and the temperature was taken after 2 hours. The calculations of the soil texture are as follows (Bouyoucos, 1962):

$$\text{Percentage of silt} + \text{clay} + \text{sand} = 100\% \tag{3.2}$$

For 40 seconds reading:

$$\text{Percentage of silt} + \text{clay} = (a/50) \times 100\% = w \tag{3.3}$$

$$\text{Percentage of sand} = (100 - w)\% = x \tag{3.4}$$

After 2 hours reading:

$$\text{Percentage of clay} = (b/50) \times 100\% = y \tag{3.5}$$

$$\text{By different: Percentage of silt} = w - y = z \tag{3.6}$$

3.2.3 Determination of Soil pH and Soil Electrical Conductivity

The soil pH and electrical conductivity (EC) were determined using the potentiometric method with a ratio of 1:2.5 (soil and distilled water suspension) was used to measure soil pH and EC by using a digital pH meter and EC meter (Peech, 1965). A 12.5 mL of distilled water together with 5 g of air-dry soil were added in a beaker at a ratio of 1:2.5 and this procedure was repeated for 3 samples. The samples

were shaken at 180 rpm by using a mechanical shaker for 15 minutes. After that, the samples were left for 24 hours before using a digital pH meter for pH determination and EC meter for EC determination (Peech, 1965).

3.2.4 Determination of Soil Total Carbon (C) and Soil Organic Matter

Combustion method was used to determine the total carbon (C) and total organic matter (OM) in this study (Tan, 2003). The air-dry samples are placed in an oven and were left to dry for 24 hours at $60^{o}C$. A desiccator was used to cool down the samples. The initial weight of the crucible was taken. Next, the weight of the crucible and addition of 5 g of the sample was taken. The sample was ashed at $300^{o}C$ in the muffle furnace for an hour and the temperature was increased to $550^{o}C$. The ash process was continued for another 8 hours. Lastly, the sample was allowed to cool down before inspection being done. The weight of the sample in the porcelain after ash was recorded. The calculation of total C and organic matter are as follow (Tan, 2003):

Calculation of Total Organic Matter:

$$\frac{Initial\ Weight\ of\ soil\ sample\ (g) - final\ weight\ of\ soil\ sample\ (g)}{Initial\ weight\ of\ soil\ sample\ (g)} x\ 100\% \qquad (3.7)$$

Calculation of Total C:

$$\frac{Initial\ Weight\ of\ soil\ sample\ (g) - final\ weight\ of\ soil\ sample\ (g)}{Initial\ weight\ of\ soil\ sample\ (g)} \times 0.58 \qquad (3.8)$$

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3.2.5 Soil Exchangeable Acidity and Aluminium Determination

The soil exchangeable acidity and Al were determined by using titration method (Rowel, 1994). A 10g of soil and 30 mL of 1 M KCl were placed into a beaker and left for 24 hours. After 24 hours, the sample was filtered with Whatman Filter Paper No.2 into 100 mL volumetric flask and the volume was made up to the mark. Then, 50 mL of the soil extract was pipetted into 250 mL conical flask. After that, five drops of phenolphthalein were added as indicator. The solution was titrated against 0.01 M NaOH until the pink colour appears. This will measure the soil exchangeable acidity. The solution was once again titrated against 0.01 M HCl until the solution become colourless and this will measure the soil exchangeable Al. The soil exchangeable acidity and soil exchangeable Al was calculated by using the following calculation (Rowel, 1994) as follows:

$$\text{Exchangeable acidity (cmol kg}^{-1}) = \frac{[0.2 \; x \; Titrate \; volume \; of \; 0.01 \; M \; NaOH \; x \; 10]}{soil \; mass \; (g)} \qquad (3.9)$$

$$\text{Exchangeable Al (cmol kg}^{-1}) = \frac{[0.2 \; x \; Titrate \; volume \; of \; 0.01 \; M \; HCl \; x \; 10]}{soil \; mass \; (g)} \qquad (4.0)$$

3.2.6 Soil Extractable K, Ca, Mg, Na, Cu, Zn and Fe Determination

Soil extractable K, Ca, Mg, Na, Cu, Zn and Fe were extracted using the Mehlich No. 1 Double Acid Method (Mehlich, 1953). A 4 mL of concentrated HCl and 0.7 mL

of concentrated H$_2$SO$_4$ were pipetted into a 1000 mL volumetric flask and the volume was made up with distilled water. A 5 g of soil sample was weighed and placed into 50 mL beaker. After that, a 25 mL of the extraction reagent was added and the solution was shaken for about 10 minutes on a reciprocal shaker. Then, the supernatant was filtered into another beaker using Whatman Filter Paper No.2, and the extract was collected. An Atomic Absorption Spectrophotometer (AAS) was calibrated and the extract was aspirated into AAS and the reading was recorded. The soil exchangeable cations were calculated using the equation below (Mehlich, 1953):

$$\text{Soil exchangeable cation (ppm)} = \text{AAS reading (ppm)} \times \left[\frac{Volume\ of\ extractant\ (mL)}{Weight\ of\ soil\ sample\ (g)}\right] \quad (4.1)$$

3.2.7 Soil Available P Determination

Mehlich No.1 Double Acid Method was used to extract the soil available P. A 4 mL of concentrated HCl and 0.7 mL of concentrated H$_2$SO$_4$ were pipetted into a 1000 mL volumetric flask and the volume was made up with distilled water. A 5 g of sample was weighed and placed into a 50 mL beaker. After that, a 25 mL of the extraction reagent was added. Then, the solution was shaken for 10 minutes on reciprocal shaker. After that, the supernatant was filtered into beaker using Whatman Filter Paper No. 2 and the P extract was collected (Mehlich, 1953). The solution was analysed by the molybdenum blue method (Murphy & Riley, 1962) and the developed blue colour was analyse by UV Spectrophotometer at 882 nm wavelength.

3.2.8 Soil Total N Determination

The total N of soil and plant tissues was determined by Kjedhal Method (Bremner, 1965) which was divided into 3 parts, digestion, distillation and titration. During digestion, 0.1 g of plant tissues or 0.5 g of soil were weighed and added into digestion tubes. Next, 5 ml of concentrated Sulphuric acid (H_2SO_4) followed by 1 g of Kjedahl catalyst were added into the tubes. Then, the samples were shaken and calibrated for 30 minutes (Bremner, 1965). After that, the samples were heated at 400 ^oC for 1 hour. The samples were allowed to cool down. A 30 ml of distilled water was added to the samples and the volume was made up to 100 ml when the solution is cool. For distillation, 10 ml of sample from the digestion part were added in distillation tube. Then, 10 ml of 40%, NaOH was added into the same tube and was distilled for 50 seconds. After that, the distillate was collected with another flask that contained 10 ml of 2% boric acid-indicator solution (Bremner, 1965). The flask that contained 10 ml of 2% boric acid-indicator solution were distilled until it reached 20 ml. For titration, the 20 ml solution from the digestion part was titrated against 0.01 M Sulphuric acid (H_2SO_4) until the colour change from green to purple.

3.3 Compost Preparation

The paddy husk composts were prepared from the mixture of paddy husks, goat manures, molasses as well as chicken feeds. The paddy husks were taken from a paddy

field at Pasir Puteh, Kelantan, Malaysia. These paddy husk were later bulked, air dried, and shredded. The sampling of goat manure was acquired from a dairy farm located in Kemahang, Kelantan. The composting process was carried out at an open space of research area in Universiti Malaysia Kelantan, Jeli Campus, Malaysia. The 3 composting containers with 435 mm (height) × 425 mm (base) were prepared for composting purposes. The 12 holes were made with a hole size 0.5 cm diameter, respectively. The paddy husk compost was made by the mixture of 80% shredded paddy husk + 10% of goat manure slurry + 5% of chicken feed + 5% of molasses in composting container. The preparation of paddy husk compost was referred on the formulation ratio done by Ch'ng et al. (2013). The composting processes were repeated for 3 replications and it took 60 days for maturation.

3.4 Compost Characterization

The compost was analysed for pH, EC, total OM, total C, total N, total P and total K. The procedure for analysing pH, EC, total OM, total C and total N were similar to the aforementioned procedures described in the previous sections. The concentrations of total cations were eventually determined by AAS while the molybdenum blue method was used to determine the concentration of total P. The C/N and C/P ratios of paddy husk compost were calculated using the respective total C, N and P content.

3.4.1 Total P and K Determination

Total P and K in the compost were determined by using the Single Dry Ashing method (Cottenie, 1980). A 1 g of ground and dried sample were weighted and placed into the crucible. The sample was placed in a muffle furnace and initially ashed at $300^{o}C$ for one hour. After one hour, the temperature of the muffle furnace was raised to $520^{o}C$ and was ashed for another 5 hours. The sample was cooled in a dessicator. After that, the sample was added with a few drops of distilled water followed by 2 ml of concentrated HCl. The sample then was evaporated to dry in the fume chamber by using the hot plate. Next, 10 ml of 20% HNO_3 was added to the sample and was allowed to heat for another one hour. The sample then was filtered to pass through Whatman Filter Paper No.2 into 100 mL volumetric flask and was made up to the volume. For the K determination, the sample was aspirated into AAS and the absorbance reading was taken (Cottenie, 1980). The molybdenum blue method (Murphy & Riley, 1962) was used to determine the total P in the compost. The blue colour was analysed using UV spectrophotometer at 882 nm wavelength.

3.4 Pot Experiment

A pot experiment was conducted in a net house at University Malaysia Kelantan Jeli Campus. A total of 21 pots were filled with 7 kg of soil which have been sieved with 5mm sieve. The test crop used in this pot experiment was *Zea mays L.* As the

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cultivation of *Zea mays L.* was done in this pot experiment, each of the pots was supplied with N, P and K fertilizer to ensure the optimum growth of the plants. The fertilizers that were applied to ensure the optimum growth of the plants are Urea (46%), Christmas Island Rock Phosphate (CIRP) (30% P_2O_5) and Muriate of Potash (MOP) (60% K_2O) and each of them was applied at 60 kg N ha^{-1} (130 kg N ha^{-1} Urea), 60 kg P_2O_5 ha^{-1} (200 kg CIRP ha^{-1}) and 40 kg K_2O ha^{-1} (67 kg K_2O ha^{-1}) rate based on the recommendation by MARDI. However, the amount of compost application was different based on the listed treatment below. These fertilizers were applied on 10th day of sowing (DAS) and 28th DAS by equal splits. The experimental design used in this study was completely randomized design (CRD) with 3 times replication.

Table 3.1: List of treatments in pot experiment

Treatment Number	Treatments
T_0	Soil Only (No Fertilizer)
T_1	Soil + 130 kg Urea ha^{-1} + 200 kg CIRP ha^{-1} + 67 kg MOP ha^{-1}
T_2	Soil + 130 kg Urea ha^{-1} + 200 kg CIRP ha^{-1} + 67 kg MOP ha^{-1} + 5 t ha^{-1} compost
T_3	Soil + 130 kg Urea ha^{-1} + 200 kg CIRP ha^{-1} + 67 kg MOP ha^{-1} + 10 t ha^{-1} compost
T_4	Soil + 130 kg Urea ha^{-1} + 200 kg CIRP ha^{-1} + 67 kg MOP ha^{-1} + 15 t ha^{-1} compost
T_5	Soil + 130 kg Urea ha^{-1} + 200 kg CIRP ha^{-1} + 67 kg MOP ha^{-1} + 20 t ha^{-1} compost

3.5 Post-Treatment Soil Analysis

The soil samples were collected during the tasselling stage, which is on 60th DAS. The soil samples were collected, air-dry, crushed and sieved using 2 mm sieve. After that, the soil samples were analysed for pH, soil EC, soil total C, soil total OM, soil total N, soil available P, soil exchangeable Al, and soil exchangeable acidity using the same procedure described previously.

3.5.1 Plant Tissue Analysis

The plants in the pot experiment were harvested and partitioned into leaves, stem and root separated at 60 DAS for plant tissues analysis. For plant tissue analysis, single dry ashing method was used in order to extract the total P in plant tissues (root, stem, and leaves) (Tan, 2003). The total N of plant tissues was determined by Kjedhal Method (Bremner, 1965). The concentration of P in roots, stems, and leaves were multiplied by respective dry weight to obtain the amount of P uptake by plants.

3.6 Statistical Analysis

Statistical analysis for all the data was performed using SPSS software version 24.0. The effects of different rates of paddy husk compost additions on all the replicated measurement were tested via one-way analysis of variance (ANOVA). Significant differences among treatment means were separated using the Tukey's test. All result was considered significant at $P \leq 0.05$.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Characteristic of Soil and Paddy Husk Compost

The selected physico-chemical properties of Rengam series (*Typic Paleudult*, clayey, kaolinitic, isohyperthermic) soil is shown in Table 4.1. The texture of the soil used in laboratory was a sandy clay loam with a bulk density of 1.03 g cm^{-3}. The soil was acidic with a pH of 5.19 and had low concentration of available P (0.81 ppm) (Table 4.1). The low concentration of P was due to the maximum sorption of P occurs in the acidic soil (Simonsson *et al.,* 2018). The soil also showed relatively high concentration of Al and Fe because of the low soil pH and the ions occupied most of cation exchange sites (Table 4.1). In acidic soil, the Al will be solubilized into ionic forms which have been shown to be very toxic to plants (Zheng, 2010).

The C/N and C/P ratios of paddy husk compost were 15.75 and 68.73, respectively (Table 4.2). These ratios suggest net mineralization of the organic amendments (Ch'ng *et al.,* 2016; Sanusi *et al.,* 2018). The paddy husk compost also contains relatively high concentration of exchangeable cations especially K (8.97%),

Ca (1.03%), Mg (0.55%) and Na (34.6%) (Table 4.2). The neutral pH of the compost (7.62) (Table 4.2) is very useful because it further confirm that the compost can increase the soil pH which contributed to the improvement of soil fertility and quality. Application of compost can increase the pH of acid soils which can result in more nutrients available for crop uptake and less leaching or loss (Latifah *et al.,* 2017).

Table 4.1: Selected Physico – Chemical Properties of Soil Samples

Property	Value obtained
Bulk density (g cm^{-3})	1.03
Soil texture	Sand: 75%
	Clay: 24%
	Silt: 1%
	δ Sandy clay loam
	(*Typic Paleudult*, clayey, kaolinitic, isohyperthemic)
pH (water)	5.19
Total organic matter (%)	3.36
Total C (%)	1.95
Available P (ppm)	0.81
Exchangeable acidity (cmol$_c$ kg^{-1})	0.57
Exchangeable Al (cmol$_c$ kg^{-1})	1.23
Exchangeable K (ppm)	180.16
Exchangeable Ca (ppm)	959.2
Exchangeable Mg (ppm)	1,774.13
Exchangeable Fe (ppm)	186.44
Exchangeable Zn (ppm)	0.85

Table 4.2: Selected chemical properties of paddy husk compost

Property	Paddy husk compost
Ph	7.62
Electrical conductivity (dS m^1)	1.78
Total organic matter (%)	74.66
Total C (%)	43.3
Total N (%)	2.75
Total P (%)	0.63
C/N ratio	15.75
C/P ratio	68.73
Total K (%)	8.97
Total Ca (%)	1.03
Total Mg (%)	0.55
Total Na (%)	34.6
Total Zn (µg/g)	211
Total Cu (µg/g)	6.4
Total Fe (µg/g)	3,006.00

4.2 The Effect of Treatment on Selected Chemical Properties of Soil after Pot Experiment

Treatments with paddy husk compost (T2, T3, T4, and T5) significantly increased the soil pH and EC compared to treatments without addition of paddy husk compost (T0-soil only and T1-soil with chemical fertilizers only) (Table 4.3). The significant higher soil pH and EC observed was because of the rapid adsorption of proton (H+) ions by negative surface charge on organic materials (paddy husk compost) (Tang *et. al.,* 1999; Wong *et. al.,* 1998). Furthermore, the higher pH of the paddy husk compost was due to the basic cations such as Ca, Mg and K (Tables 4.3) which contributed to the significant increase in soil pH of the (T2, T3, T4 and T5) compared

with T0 and T1. On the other hand, in T0 (soil only) the soil pH is lower, due to the low concentration of organic matter in the soil (Table 4.3). This observation was consistent with a study by Latifah *et al.,* (2015). Furthermore, the soil EC was higher in treatments with paddy husk compost (T2, T3, T4, and T5) compared to treatments without addition of paddy husk compost (T0 and T1) (Table 4.3), indicating that paddy husk compost had more soluble salts. This was confirmed by the data in Table 4.2 which shows that paddy husk compost had higher concentrations of K, Ca, and Mg. Besides, there were significant difference between treatments with paddy husk compost (T2, T3, T4, and T5) and treatment without paddy husk compost (T0 and T1) on total organic matter and total C (Table 4.3). However, there was no significant difference in the total organic matter and total C for treatments with paddy husk compost in T4 and T5 when the application rate of compost increases. This is due to the slow mineralization process that decomposed the paddy husk compost (Ch'ng *et al.,* 2015). Treatments with paddy husk compost (T2, T3, T4, and T5) significantly reduced the exchangeable acidity, exchangeable Al, and exchangeable Fe compared with treatments without paddy husk compost (T0 and T1). The reduction in exchangeable acidity, exchangeable Al and exchangeable Fe for treatment with paddy husk compost (T2, T3, T4 and T5) were due to the increase in soil pH (Ch'ng *et al.,* 2015).

Table 4.3: Selected chemical properties of soil sample after pot experiment.

Treatments	pH (water)	EC (dS m^{-1})	Total organic matter (%)	Total C (%)	Exchangeable acidity (cmol kg^{-1})	Exchangeable Al (cmol kg^{-1})	Total N (%)	Available P (Ppm)	Exchangeable K (mg/L)	Exchangeable Ca (mg/L)	Exchangeable Mg (mg/L)	Exchangeable Fe (mg/L)
T0	5.28 ± 0.06 e	0.12 ± 0.02 d	7.47 ± 0.09 c	4.33 ± 0.05 c	1.13 ± 0.03 a	0.92 ± 0.21 a	0.06 ± 0.003 b	29.61 ± 4.98 c	639.33 ± 158.48 c	1,329.00 ± 56.36 d	2,570.33 ± 192.07 e	358.33 ± 50.08 b
T1	6.12 ± 0.01 d	0.30 ± 0.03 c	7.63 ± 0.09 c	4.43 ± 0.05 c	0.98 ± 0.01 b	0.99 ± 0.12 a	0.06 ± 0.003 b	14.59 ± 0.50 c	431.33 ± 168.54 c	711.00 ± 304.85 e	2,360.33 ± 180.92 de	524.00 ± 56.13 a
T2	6.50 ± 0.05 c	0.65 ± 0.01 b	10.13 ± 0.67 b	5.87 ± 0.39 b	0.35 ± 0.04 c	0.41 ± 0.04 b	0.08 ± 0.000 ab	267.17 ± 30.57 b	3,057.00 ± 504.53 b	5,205.33 ± 659.33 b	6,641.33 ± 737.05 c	157.00 ± 12.50 c
T3	6.77 ± 0.05 a	0.77 ± 0.01 a	12.27 ± 0.47 ab	7.11 ± 0.27 ab	0.25 ± 0.04 cd	0.24 ± 0.07 b	0.1 ± 0.010 a	368.60 ± 7.35 a	6,678.67 ± 558.84 a	8,718.67 ± 2388.15 a	15,824.00 ± 1,810.37 a	170.67 ± 15.07 c
T4	6.71 ± 0.02 ab	0.77 ± 0.01 a	12.93 ± 0.55 a	7.50 ± 0.32 a	0.08 ± 0.01 e	0.09 ± 0.03 b	0.1 ± 0.010 a	227.37 ± 0.84 b	5,302.00 ± 121.24 a	5,664.00 ± 786.63 b	10,768.00 ± 403.17 b	162.67 ± 10.71 c
T5	6.56 ± 0.02 bc	0.74 ± 0.003 a	14.13 ± 0.97 a	8.20 ± 0.56 a	0.11 ± 0.02 de	0.12 ± 0.04 b	0.08 ± 0.003 ab	353.77 ± 2.00 a	3,481.00 ± 433.09 b	2,258.67 ± 432.93 c	7,701.33 ± 665.49 bc	128.67 ± 19.67 c

Different letters within a column indicate significant difference between means using Tukey's test $P \leq 0.05$

4.4 **Dry Weight Production, Soil P Availability, P Uptake and in *Zea Mays L.***
After Pot Experiment

The dry mass production of each part (leave, stem and root) of *Zea mays L.* and the P uptake by plants were illustrated in Figures 4.1-4.2. The treatment with chemical fertilizer and compost (T2, T3, T4 and T5) showed significant increase in the dry mass production of leaves, stem and root compared to treatments with no rice husk compost (T0 and T1) (Figure 4.1). This finding is consistent with the results obtained in studies by Ch'ng *et al.,* (2015) and Mokolobate & Haynes, (2003) (Figure 4.1). Besides, the treatment with chemical fertilizer and compost (T2, T3, T4 and T5) also increased the P uptake compared to treatments with no rice husk compost (T0 and T1) (Table 4.2). This indicates that, there was significant increase in the soil pH that increased the available P in soil and contributed to the increase of P uptake (Figure 4.2). This can be seen in the improvement of the root growth and elongation where Al toxicity was reduced. On the other hand, increasing in the dry matter production can be due to the supply of organic material by compost that aid in microorganism efficiency by providing them a suitable environment. The soil microorganism helps in the soil mineralization process by converting organic P into an orthophosphate form that available for plant uptake (Lehmann *et al.,* 2005) (Figure 4.1 and 4.2). Apart from the mineralization process, another factor that contributes to the increase in plant tissue after the application of compost (T2, T3, T4, and T5) was the chelation of Al and Fe which release the available P for plant uptake. Chelation of Al and Fe are needed because in acidic soil, most of the P are fixed by Al and Fe which also known as sesquioxides by forming a strong bond between them, thus make the P unavailable to plant uptake (Figure 4.1).

Furthermore, with the aid of microorganism, the introduction of compost also produced humic substances and an organic acid which have negative charges and large surface. The high affinity of anion in those substances increased the tendency of ion exchange to take place with the positively charge surface of cations. As the Al and Fe were being bind with functional group of humic substances of compost instead, the initially bounded P were released, thus increase the P availability and P uptake in maize (Figure 4.1) (Figure 4.2).

Treatments (T2, T3, T4, T5) showed a significant increase in soil available P compared to treatments with no rice husk compost (T0 and T1) (Table 4.3). This was due to the application rate of paddy husk compost which could had increased the soil pH and eventually precipitated the exchangeable and soluble Al and Fe as insoluble Al and Fe hydroxides, thus increasing the soil P availability. Moreover, it also implies the effectiveness of paddy husk compost in minimizing the loss of P due to P fixation in soil. Besides, the absence of significant increase of soil available P when the rate of paddy husk compost increase in T4 (Table 4.3) due to slow microbial mediated mineralization of soil organic P to inorganic P (Ch'ng *et al.,* 2016). That is to say, if the organic P in paddy husk compost mineralizes readily, the soil available P will increase rapidly. Treatment with only soil (T0) and soil with chemical fertilizers only (T1) had the lowest soil available P relative to other treatments, thus confirming that P was deficient in this soil. Ch'ng *et al.,* (2015) concluded that the soil available P increased under treatments applied with poultry manure biochar and pineapple leaves compost because of the efficient retention of P in the soil as a result of chelation of Al and Fe by the biochar and compost.

Figure 4.1: Effect of treatments on dry weight pf leaf, stem and root in *Zea mays L.* after pot experiment

Mean between columns with different letter(s) indicate significant difference between treatments by Turkey's test at p≤0.05.
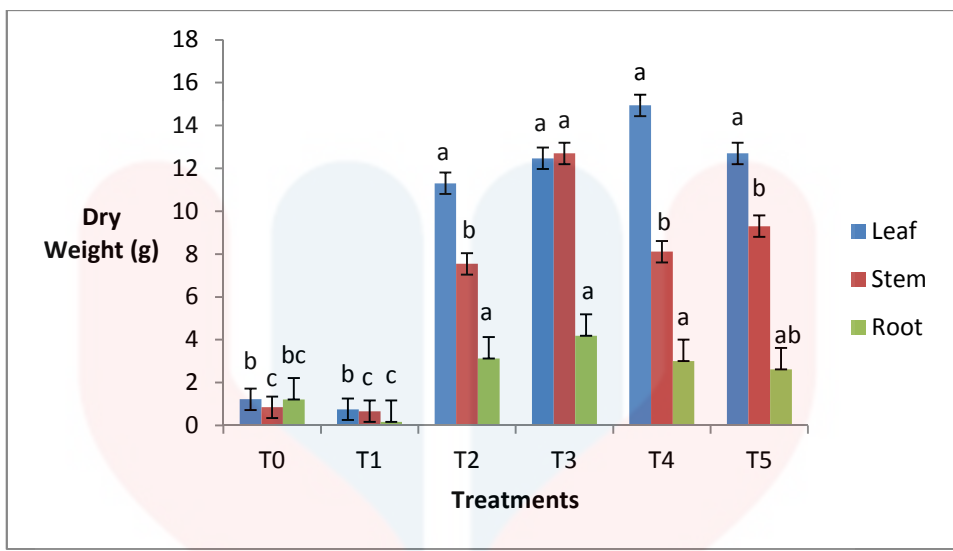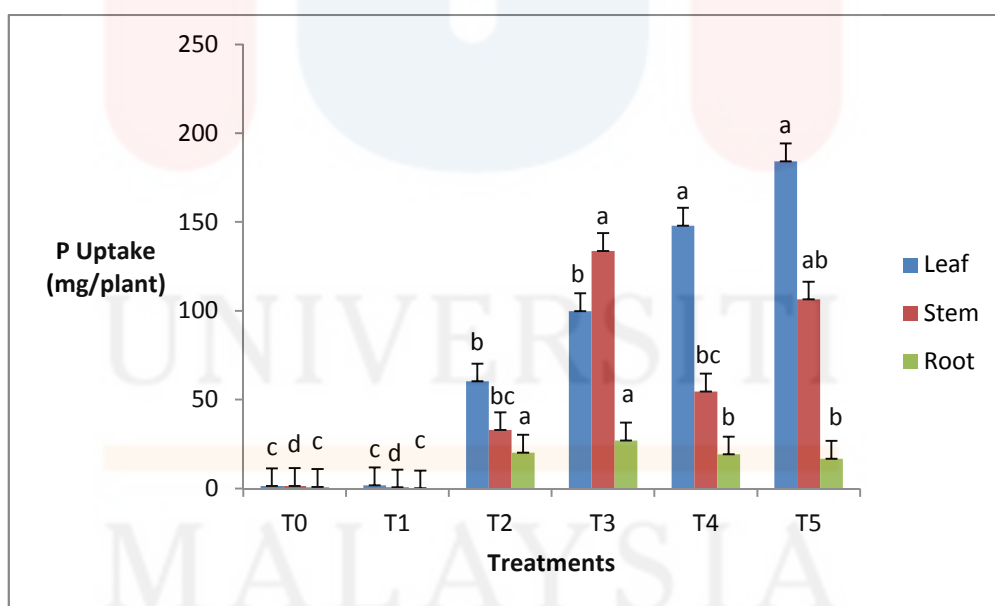

Figure 4.2: Effect of treatments on P uptake of leaf, stem and root in *Zea mays L.* after pot experiment.

Mean between columns with different letter(s) indicate significant difference between treatments by Turkey's test at p≤0.05.

4.5   Plant Growth Parameters of *Zea Mays L.* After Pot Experiment

The treatment with chemical fertilizer and compost (T2, T3, T4 and T5) showed significant increase in plant height, number of leaves, leaves length, leaves width and root length compared to the soil only (T0) and soil with chemical fertilizer only (T1)(Table 4.4). In terms of plant height, the short stature plants (38.7 cm) observed in control pot shows that the application of paddy husk compost and chemical fertilizers at the rate of 0 t ha^{-1} resulted in the shortest stature plants. This indicates that, plants need both paddy husk compost and chemical fertilizers in order to grow well. Besides, significant increase also can be observed in the number of leaves in treatments (T2, T3, T4 and T5) compared to the soil only (T0) and soil with chemical fertilizer only (T1) (Table 4.4). The increase in number of leaves recorded in maize in compost amend soil could be due to the increased in soil pH, that increase the P availability in soil for the plant uptake (Mensah & Frimpong 2018). In addition, significant increase in maize plant height and number of leaves per plant may due to the increased in level of fertilizer and organic amendment application. It is also reported that application of compost can stimulate the root and shoot growth in maize plantlets (Choudhari, 2012).

Table 4 showed the significant increase of leaves length and leaves width in T2, T3, T4 and T5 compared to the soil only (T0) and soil with chemical fertilizer only (T1). Abdulkadir *et al.,* (2002) reported that increasing in leaf area and leaf dry weight in maize could be due to higher dry matter accumulation in different plant parts. The high dry matter accumulation was mainly due to higher assimilatory surface area, which directly related to chlorophyll content and specific leaf weight. In addition, leaf width and leaf length also influence the photosynthetic capacity of the crop (Choudhari,

2012). On the other hand, the observation of the roots length indicated that the soil treated with chemical fertilizer and compost had a better root growth and length compared to the soil only (T0) and soil with chemical fertilizer only (T1) (Table 4.4) (Figure 4.3). Although (T1) was supplied with 100% of NPK, but the chemical fertilizer alone could not support the supply of nutrient to the soil. This statement is proven as several studies suggest that organic source (compost) of P are more effective than the organic ones (P fertilizer) (Adriana *et al.,* 2012; Bidegain *et al.,* 2000; Ch'ng *et al.,* 2015). Supplying compost can release nutrients slowly according to the quantity that is needed by the plant. The humic acid produced from the decomposition of compost assisted in the translocation of P from the root to the aerial parts, thus provide well distribution of P between aerial parts and roots. Besides, the reduction of Al toxicity at the root zone as a result of an increase of soil pH (Table 4.4) (Figure 4.3) after the application of compost allowed a greater volume of soil for root elongation (Bidegain *et al.,* 2000).

Table 4.4: Plant Growth Parameters of *Zea mays L.* after pot experiment

Treatments	Plant height (cm)	Number of leaves	Leaves length (cm)	Leaves width (cm)	Leaf area (cm^2)	Root length (cm)
T0	38.7 ± 8.19 bc	7 ± 1.33 ab	45.9 ± 10.29 b	2.2 ± 0.52 b	82.5 ± 36.54 b	49.4 ± 3.67 c
T1	17.3 ± 2.67 c	4 ± 1.20 b	24.1 ± 4.08 c	1.6 ± 0.23 b	30.5 ± 9.08 b	35.3 ± 4.07 c
T2	154.3 ± 32.63 a	13 ± 1.33 a	85.9 ± 1.34 a	5.3 ± 0.78 a	341.7 ± 45.85 a	57.3 ± 2.42 ab
T3	157.3 ± 29.81 a	13 ± 0.33 a	95.0 ± 6.53 a	6.0 ± 0.37 a	431.5 ± 53.54 a	68.9 ± 5.14 a
T4	129.0 ± 13.58 ab	15 ± 1.00 a	94.0 ± 9.70 a	5.3 ± 0.68 a	386.1 ± 83.18 a	57.3 ± 8.13 ab
T5	131.0 ± 25.60 ab	13 ± 3.38 a	88.3 ± 18.49 a	4.8 ± 1.25 a	353.3 ± 136.02 a	58.2 ± 3.38 ab

Different letters within a column indicate significant different between means using Tukey's test at $P \leq 0.05$

Figure 4.3: Effect of treatments on the root growth after pot experiment

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Compost derived from paddy husk compost can be used to improve the plant growth performance and nutrient use efficiency of *Zea mays L.* cultivated in tropical acid soil by reducing the soil P fixation. This is proven as treatment with compost significantly increased the soil pH, EC, reduced exchangeable Al, Fe and acidity in the soil. Besides, the treatments of compost with chemical fertilizer also increased the dry mass production, total P and P uptake in maize compared to soil only (T0) and soil with chemical fertilizer only (T1). It is conclude that, supplying organic amendment have high tendency to reduce the soil exchangeable Al and Fe, increased soil pH, P availability and reconstruct the chemical properties of the soil by supplying organic materials. Thus, it could reduce the amount of phosphate fertilizer applied to the soil and minimized soil P fixation. As recommendation, this study can be further evaluated in the field for at least 3 cycles to confirm the findings.

REFFERENCES

Adriano, M. D., Gutierrez, F., Dendooven, L., & Salvador-Figueroa, M. (2012). Influence of compost and liquid bio-ferment on chemical and biological characteristics of soil cultivated with banana (Musa spp. L.). *Journal of Soil Science and Plant Nutrition,* pp. 33-43.

Amstrong, D. L. (1999). Important factors affecting crop response to phosphorus. *Better crops 83(1),* pp. 16-19.

Abdulkadir Iman, S. H., Mohamoud and Sharanappa. (2002). Growth and productivity of maize (*Zea mays L.*) as influenced by poultry waste composts and fertilizer levels. *Mysore Journal of Agriculture Science*, *36*, pp. 203-207.

Bremner, J. M. (1965). Total nitrogen. In Method of soil analysis, Part 2, ed. C. A. Black, D. D. Evans, L. E. Ensminger, J.L. White, F. E. Clark and R. C. Dinauer, 1149–78. Madison, WI: American Society of Agronomy.

Bidegain, R., Kaemmerer, M., Hafidi, M., Rey, F., Morard, P., & Revel, J. (2000). Effects of humic substances from composted or chemically decomposed poplar sawdust on mineral nutrition of ryegrass. *Journal of Agriculture Science,* pp. 259-267.

Busman, L., Lamb, J., Randall, G., Rehm, G., & Schmitt, M. (2002). The Nature of Phosphorus in soil. Retrieved April 7, 2018, from University of Minesota Extension: www.extension.umn.edu

Butorac, A., Filipan, T., Basic, F., Butorac, J., Mesic, M., and Kisic, I. (2002). Crop response to the application of special natural amendments based on zeolite tuff. *Rostlinna Vyroba 48*, pp. 118-124.

Butler, T. J., Muir, J. P., Weindorf, D. C., and Lastly, L. (2008). Dairy Manure Compost Effects on Corn Silage Production and Soil Properties. *Agronomy Journal 100,* pp. 1541-1545.

Bouyoucos, G. J. (1962) Hydrometer meter improved for making particle size analysis of soils. *Agronomy Journal 54*, pp. 464−465.

Cottenie, A. (1980). Soil testing and plant testing as a basis of fertilizer recommendation. FAO *Soils Bulletin* 38, pp. 70−73.

Ch'ng, H. Y., Ahmed, O. H., and Ab. Majid, N. M. (2014). "Improving Phosphorus Availability in an Acid Soil Using Organic Amendments Produced from Agro-industrial Wastes," *The Scientific World Journal*.

Ch'ng, H. Y., Ahmed, O. H., Majid, N. M., A. (2015) Improving phosphorus availability, nutrient uptake and dry matter production of Zea mays L. on a tropical acid soil using poultry manure biochar and pineapple leaves compost, pp. 447–465.

Ch'ng, H. Y., Ahmed, O. H., Majid, N. M., A. (2016) Minimizing phosphorus sorption and leaching in a tropical acid soil using Egypt rock phosphate with organic amendments, pp. 176−185.

Chandrasekar, S., Satyanarayana, K. G., and Raghavan, P. N. (2003). Processing, Properties and Applications of Reactive Silica from Rice Husk — an Overview'. *JMSCI 38,* p 3159.

Chen, L., de Haro Marti, M., Moore, A., & Falen, C. (2011). The composting process. University of Idaho Extantion.

Choudhari, V. V. (2012). *Effect of Organics on Growth and Morpho-physiological Characters in Maize (Zea mays l.)*(Doctoral dissertation, UAS, Dharwad).

Chislock, M. F., Doster, E., Zitomer, R. A., & Wilson, A. E. (2013). Eutrophication: causes, consequences, and controls in aquatic ecosystems. *Nature Education Knowledge*, *4(4),* p. 10.

Dixon, R. K. & Wisniewski, J. (1995). Global forest systems: an uncertain response to atmospheric pollutants and global climate change. Water Air Soil Pollution 85, pp. 101-110.

Ding, X., Xue, Y., Lin, M., & Liu, Y. (2017). Effects of precipitation and topography on total phosphorus loss from purple soil. *Water*, *9(5),* p. 315.

Elgar, C. (n.d.) Phosphorus – Too Much Of A Good Thing. Retrieved April 9, 2018, from the website: https://www.floridacolorsplumeria.com/phosphorus-too-much-of-a-good-thing/

Gichangi, E. M., Mnkeni, P. N. S. (2009). Effects of goat manure and lime addition on phosphate sorption by two soils from the Transkei Region, South Africa. *Commun. Soil Sci. Plan. Anal 40 (21-22)*, pp. 3335-3347.

Hua, Q., Li, J., Zhou, J. (2008). Enhancement of phosphorus solubility by humic substances in Ferrosols. *Pedosphere 18(4)*, pp. 533-538.

Hamdan, H. (2009). Technology: Utilization of Rice Husk. Retrieved April 9, 2018, from http://www.zeolite.utm.my/zeomal/about.html

Hubbard, R. K., Bosch, D. D., Marshall, L.K., Stricland, T. C., Rowland, D., Griffin, T. S., Honeycutt, C. W., Albrecht, S. L., Sistani, K. R., Torbert, H. A., Wienhold, B. J., Woodbury, B.L., Powell, J.M. (2008). Nitrogen mineralization from broiler litter applied to southeastern Coastal Plain soil. *Journal of Soil and Water Conservation 63*, pp. 182-192.

Latifah, O., Ahmed, O. H., and Ab Majid, N. M. (2015). Compost maturity and nitrogen availability by co-composting of paddy husk and chicken manure amended with clinoptilolite zeolite. *Waste Management 34 (4)*, pp. 1-10.

Latifah, O., Ahmed, O. H., and A. Majid, N. M. (2017). Enhancing nutrients use efficiency and grain yield of Zea mays L. cultivated on a tropical acid soil using paddy husk compost and clinoptilolite zeolite. *Bulg. J. Agric. Sci. 23 (3)*, pp. 418–428

Lehmann, J., Lan, Z., Hyland, C., Sato, S., Solomon, D., & Ketterings, Q. M. (2005). Long-term dynamics of phosphorus forms and retention in manure-amended soils. *Environmental Science & Technology*, *39*(17), 6672-6680.

Lehtiniemi, M. (2005). Turbidity decreases anti-predator behaviour in pike larvae, *Esox Lucius*. *Environmental Biology of Fishes* 73, pp. 1-8.

Mehlich, A. (1953). *Determination of P, Ca, Mg, K, Na and NH4*. Releigh, NC: North Carolina State Univeristy Soil Test Division.

McCauley, A., Jones, C., & Jacobsen, J. (2009). Plant nutrient functions and deficiency and toxicity symptoms. *Nutrient management module*, *9*, pp. 1-16.

McClellan, T., Deenik, J., & Singleton, P. (2013). Soil nutrient management for Maui county. *College of Tropical Agriculture and Human Resources (CTAHR). University of Hawaii at Manoa.*

Mullen, M. D. (2005). PHOSPHORUS IN SOILS | Biological Interactions. Encyclopedia of Soils in the Environment, pp. 210–216.

Mensah, A. K., & Frimpong, K. A. (2018). Biochar and/or Compost Applications Improve Soil Properties, Growth, and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana. *International Journal of Agronomy*.

Mokolobate, M. (2003). A glasshouse evaluation of the comparative effects of organic amendments, lime and phosphate on alleviation of Al toxicity and P deficiency in an Oxisol. *Journal of Agriculture Science,* pp. 409-417.

Malaysia Economics Statistics. (2011). Malaysia Economics Statistics. Retrieved April 9, 2018, from Department of Statistics, Malaysia: http://www.statistics.gov.my/portal/index.php.

Murphy, J., Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Anal Chim Act* 27, pp. 31−36.

National geographic bulletin on precipitation (2018). Retrieved November 22, 2018, from portal: https://www.nationalgeographic.org/encyclopedia/precipitation/

Nealson, K. H., Rye, R. (2004). Evolution of metabolism. In: Schlesinger WH (ed) Treatise on Geochemistry 8. Elsevier Science Limited, Amsterdam, pp 41-61

Ojo, A. O., Adetunji, M. T., Okeleye, K. A., & Adejuyigbe, C. O. (2015). Soil fertility, phosphorus fractions, and maize yield as affected by poultry manure and single superphosphate. *International scholarly research notices*.

Osundwa, M., Okalebo, J. R., Ngetich, W., Ochuodho, J. O., Othieno, C. O., Langat, B., & Omenyo, V. S. (2013). Influence of Agriculture lime on soil properties and wheat (*Triticum aestivum L.*) yield on acidic soils of Uasin Gishu Country, Kenya. Agriculture Journal of Experimental Agriculture, pp. 806-823.

Peech, H. M. (1965). *Hydrogen-ion activity*. In: Methods of soil analysis, part 2, C.A. Black, D.D. Evans, L.E. Ensminger, J.L. White, F.E Clark, R.C. Dinauer. Madison, WI: Am Soc Agron.

Raviv, M. (2005). Production of high quality compost for horti-cultural. Hortitechnology, 15 (1), pp. 52-57

Ramesh, K., Biswas, A. K., Somasundaram, J. and Subba Rao, A. (2010). Nanoporous zeolites in farming: Current status and issues ahead. *Current Sci. 99 (6)*, pp. 760-765.

Ros, M., Klammer, S., Knapp, B., Aichberger, K., and Insam, H. (2006). Long term effects of compost amendment of soil on functional and structural diversity and microbial activity. *Soil Use Management 22*, pp. 209-218.

Rowell, D. L. (1994). *Soil science*, methods and applications. Longman Group UK Limited, pp. 86−87.

Ruttenberg, K. C. (2003). The global phosphorus cycle. Treatise on geochemistry, 8, p. 682.

Simonsson, M., Östlund, A., Renfjäll, L., Sigtryggsson, C., Börjesson, G., & Kätterer, T. (2018). Pools and solubility of soil phosphorus as affected by liming in long-term agricultural field experiments. Geoderma, 315, pp. 208–219.

Sanusi, S., Ch'ng, H. Y., & Othman, S. (2018). Effects of incubation period and Christmas Island rock phosphate with different rate of rice straw compost on phosphorus availability in acid soil.

Sultenfuss, J. H., & Doyle, W. J. (1999). Functions of phosphorus in plants. *Better Crops*, *83*(1), pp. 6-7.

Schindler, D. W. (2006). Recent advances in the understanding and management of eutrophication. *Limnology and Oceanography* 51**,** pp. 356-363.

Syers, J. K., Johnston, A. E., & Curtin, D. (2008). Efficiency of soil and fertilizer phosphorus use. *FAO Fertilizer and plant nutrition bulletin, 18*(108).

Series, A. F. S. (2005). Phosphorus Basics–The Phosphorus Cycle. pp. 1-2

Shuhadah, N., and Rohasliney, H. (2011). Rice Husk as Biosorbent: A Review. Universiti Sains Malaysia: Degree Thesis.

Shafie, S. M. (2015). Paddy Residue Based Power Generation In Malaysia: Environmental Assessment Using Lca Approach.

Singh, J. (2015). Overview of electric power potential of surplus agricultural biomass from economic, social, environmental and technical perspective-A case study of Punjab. *Renewable and Sustainable Energy Reviews 42*, pp. 286-297.

Tang, C., Sparling, G. P., McLay, C. D., A. (1999) Effect of short-term legume residue decomposition on soil acidity. *Aust J Soil Res* 37, p. 561.

Torbert, H. A., Potter, K. N., Harmel, R. D. (2005) Evaluation of some phosphorus index criteria in cultivated agriculture in clay soils. *J Soil Water Conservation 60*, pp. 21–28.

Trazzi, P. A., Leahy, M., H., B., & Kwapinski, W. (2016). Adsorption and desorption of phosphate on biochars. *Journal of Environmental Chemical Engineering 4(1)*, pp. 37-46.

Tan, K. (2003). *Soil sampling, preparation and analysis.* New York: Taylor & Francis.

UNDP. (2002). Malaysia Biomass- based Power Generation and Cogeneration the Palm Oil Industry. Malaysia: United Nation Development Programme.

Uchida, R. (2000). Essential nutrients for plant growth: nutrient functions and deficiency symptoms. *Plant Nutrient Management in Hawaii's soils*, pp.31-55.

Warren, G. P. (1992). Fertilizer phosphorus: sorption and residual value in tropical African soils (NRI Bulletin 37).

Wang, Y., Li, H., Xu, Z. (2016) Rainfall-induced nutrient losses from manure-fertilized farmland in an alluvial plain. *Environ Monitoring Assessment 188*, pp. 1–11.

Wong, M. T., F., Nortcliff, S., Swift, R. S. (1998). Method for determining the acid ameliorating capacity of plant residue compost, urban waste compost, farmyard manure, and peat applied to tropical soils. *Commun Soil Sci Plant Analysis* 29, pp. 2927–2937.

Willett, I., R, Higgins, M., L. (1978). Phosphate sorption by reduced and reoxidized rice soils. Australian Journal of Soil Research *16(3),* pp. 319-326.

Wu, H., Lai, C., Zeng, G., Liang, J., Chen, J., Xu, J., Wan, J. (2016). The interactions of composting and biochar and their implications for soil amendment and pollution remediation: a review. Critical Reviews in Biotechnology, *37(6),* pp. 754–764.

Xu, G., Sun, J., Shao, H., & Chang, S. X. (2014). Biochar and effects on phosphorus sorption and desorption in three soils with different acidity. Ecological Engineering, pp. 54-60.

Yong, R., Nakano, M., & Pusch, R. (2012). Environmental soil properties and behaviour. U.S: Taylor & Francis Group.

Zhang, A., He, L., Zhao, H., Wu, Z. (2009). Effect of organic acids on inorganic phosphorus transformation in soil with different phosphorus sources. *China J. Appl. Environ. Biol. 15 (4)*, pp. 474-478.

Zhuo, A., He, L., Zhao, H. (2009). Effect of organic acids on inorganic phosphorus transformation in soil with different phosphorus sources. *China J. Appl. Environ. Biol. 15*, pp. 474-478.

Zheng, S. J. (2010). Crop production on acidic soils: overcoming aluminium toxicity and phosphorus deficiency. Annals of Botany, *106(1),* pp. 183–184.