UNIVERSITI PUTRA MALAYSIA

PHOSPHATE USE EFFICIENCY AND PHOSPHATE TRANSPORTER ACTIVITY OF SELECTED OIL PALM GENOTYPES

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PHOSPHATE USE EFFICIENCY AND PHOSPHATE TRANSPORTER ACTIVITY OF SELECTED OIL PALM GENOTYPES

by

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Abstract of thesis submitted to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for Master of Science

PHOSPHATE USE EFFICIENCY AND PHOSPHATE TRANSPORTER ACTIVITY OF SELECTED OIL PALM GENOTYPES

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High yield and increasing the production of oil palm in Malaysia depends much on application of fertilizers due to oil palm high nutrient demand, uptake and removal. Malaysian soils (mainly Ultisols and Oxisols), are known to be highly weathered, acidic and inherently low in phosphate and have high P fixing capacities, thus making it unavailable for plant use. Quantitative information on P-use efficiency for crop is vital to ensure a better design of P-management, economically and ecologically. As such, adopting plants with better nutrient uptake efficiency nonetheless means a more environmentally friendly and ecological feasible strategy to improve the growth of plant in low phosphorus soil. A study was conducted to evaluate the variability of phosphate uptake among oil palm genotypes at nursery stage. Nine months of observation revealed that the percentages of the phosphate uptake by the oil palm genotypes could be ranked as genotype D = B ≥ C ≥ F ≥ E ≥ I ≥ G = A ≥ H, which ranged from 15% to 45% of phosphate derived from fertilizer (PdfF). Cluster analysis showed that two major clusters can be identified; Genotype B, D, C, E, F as cluster which take up higher rate of P-fertilizer compared to cluster which comprised Genotype A, G, I, H. Use of tracer (^{32}P) in the fertilizer application provided a mean to understand the fate of fertilizer in the plant, i.e. the quantity of fertilizer being taken up by the plants. Such information allows better management of selecting better genotypes and monitoring the fertilizer use efficiency thus reducing fertilizer wastage. Another experiment was conducted to evaluate the variable activity of phosphate transporter among the genotypes under phosphate starvation. In second study, a 27kD peptide in the root was identified as the P transporter activity in the roots of these oil palm genotypes by

using probe during phosphate starvation. Phosphate transporters activity among the genotypes can be ranked as genotype A≥ D ≥ B= E ≥ I ≥ H = C = G = F. Cluster analysis grouped cluster genotype A, B, D, E, I with higher phosphate transporters activity compared to cluster genotype C, G, F, H. The presence of phosphate transporters which were detected only during phosphate starvation may suggest the palm is enhancing the phosphate uptake in root to improve the low phosphate level inside the plant. The result on phosphate transporters in this experiment provides some clues that genetic variants may play a role in terms phosphate uptake efficiency among oil palm genotypes.

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KECEKAPAN PENGGUNAAN FOSFAT DAN AKTIVITI PENGANGKUT FOSFAT DALAM GENOTIP KELAPA SAWIT TERPILIH

Oleh

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Hasil tinggi serta peningkatan pengeluaran kelapa sawit di Malaysia amat bergantung kepada penggunaan baja. Tanah di Malaysia (ultisol dan oksisol), amat terluluhawa, berasid, berkadar Fosfat (P) rendah serta mempunyai kadar jerapan P yang tinggi, justeru menghadkan pengambilan P oleh tumbuhan. Maklumat kuantitatif tentang kecekapan penggunaan tanaman terhadap P adalah penting bagi memastikan strategi pengurusan P yang lebih baik dari segi ekonomi dan ekologi. Justeru itu, pengambilan nutrient yang lebih cekap oleh tumbuhan di tanah yang rendah P mengimplikasikan pengurusan ladang yang mesra alam serta memanfaatkan ekologi persekitaran. Satu kajian telah dilaksanakan untuk menilai perbezaan antara genotip kelapa sawit dalam pengambilan fosfat pada peringkat awal pertumbuhan. Pemerhatian selama sembilan bulan menunjukkan bahawa peratusan pengambilan fosfat antara genotip kelapa sawit boleh disenaraikan sebagai D = B ≥ C ≥ F ≥ E ≥ I ≥ G = A ≥ H, sebanyak 15% kepada 45 % daripada fosfat yang diperolehi dari baja (PdfF) direkodkan. Analisis kelompok menunjukkan bahawa genotip B, D, C, E, F boleh dikelaskan kepada kelompok yang lebih cekap mengambil baja fosfat

berbanding dengan kelompok yang merangkumi genotip A, G, I, H. Penggunaan ^{32}P dalam aplikasi pembajaan dapat memberi pemahaman tentang kuantiti baja yang diserap oleh tumbuh-tumbuhan. Maklumat tersebut membolehkan pengurusan yang lebih baik dalam pemilihan genotip, penilaian kecekapan penggunaan baja dan seterusnya mengurangkan pembaziran baja. Dalam eksperimen kedua, peptida 27kD dalam akar telah dikenalpasti sebagai aktiviti pengangkut P dalam keadaan kekurangan fosfat. Aktiviti pengangkut Fosfat antara genotip boleh disenaraikan sebagai genotip A≥ D ≥ B= E ≥ I ≥ H = C = G = F. Analisis kelompok membahagikan kelompok genotip A, B, D, E, I kepada kumpulan yang mempunyai kecekapan pengangkut fosfat yang lebih tinggi berbanding dengan kelompok genotip C, G, F, H. Kehadiran pengangkut fosfat yang dikesan hanya semasa kekurangan fosfat mungkin mencadangkan pokok sawit meningkatkan pengambilan fosfat dari akar untuk meningkatkan tahap fosfat yang rendah dalam tumbuhan. Keputusan eksperimen ini memberikan beberapa petunjuk bahawa kelainan genetik mungkin memainkan peranan dari segi kecekapan pengambilan fosfat di kalangan genotip kelapa sawit.

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I certify that an Examination Committee has met on date of viva voce to conduct the final examination of Tan Ngai Paing on his Master of Science thesis entitled "Increasing Phosphate Use Efficiency of Oil Palm Via High Affinity Phosphate Transporters from Selected Oil Palm Genotypes in Malaysia" in accordance with Universiti Pertanian Malaysia (Higher Degree) Regulations 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

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

TAN NGAI PAING

Date: 7th March 2012

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LIST OF ABBREVIATION

ADP	Adenosine Double Phosphate
Al	Aluminum
ANOVA	Analysis of Variance
AP	Alkaline phosphatase
AP	Alkaline Phosphatase Conjugate
ATP	Adenosine Triple Phosphate
BD	Banting Dura
BPRO	Breeding population of restricted origin
BSA	Bovine Serum Albumin
Ca	Calcium
CCD	Charge-Coupled Device
CPR	China Phosphate Rock
D x P	Crosses between Dura and Pisifera
EDTA	Ethylenediaminetetraacetic acid
EGTA	ethylene glycol tetraacetic acid
FAO	Food and Agriculture Organisation
Fe	Ferum
FFB	Fresh Fruit Bunch
GPR	Gafsa Phoshpate Rock
HCl	Hidrochloric acid
HSD	Honestly Significantly Different
IAEA	International Atomic Energy Agency
IFDC	International Fertilizer Development Center
IgG	Immunoglobulin G
IMPHOS	World Phosphate Institute
JL	Johore Labis Dura
JPR	Jordanian Phosphate Rock
K	Potassium
KF	Potassium Fluorite
L	Litter
MFS	Major Facilitator Super Family
MOPS KOH	3-(N-morpholino)propanesulfonic acid in Potassium hydroxide
MPOB	Malaysia Palm Oil Board
N	Nitrogen
NCPR	North Carolina Phosphate Rock
P	Phosphorus
PdfF	Phosphate derived from fertizer
P_i	Inorganic phosphorus
P_o	Organic phosphorus
PVDF	Polyvinylidene Fluoride
PVP	Polyvinylpolypyrrolidone

PVPP	Cross linked- Polyvinylpolypyrrolidone
RCBD	Randomized Complete Block Design
RNA	Ribonucleic acid
SAS	Statistical Analytical System
SDS PAGE	sodium dodecyl sulfate polyacrylamide gel electrophoresis
S.E.	Standard error
TBS	Tris- Buffered Saline
TEMED	Tetramethylethylenediamine
TPR	Tunisian Phosphate Rock
Tris-Cl	tris(hydroxymethyl)amino methane
TSP	Tripple Super Phosphate
UR	Ulu Remis Dura
USDA	United States Department of Agriculture
^{32}P/P-32	Radioactive isotope phosphorus

CHAPTER 1

INTRODUCTION

Over the years, oil palm has become the main perennial crop in Malaysia. The total planted area of oil palm expands to 4.85 million hectares in 2009 (MPOB 2010) as compared to 1960s which accounted only 55,000 hectares (MPOB 2000). Oil palm is the most productive plant in terms of oil yield per hectare, surpassing corn and soy beans (Corley and Tinker, 2003). In addition, oil palm is also less prone to pest and diseases to other domestic crops such as rubber and cocoa. However, 85 % of production cost of oil palm goes to the purchase of fertilizers (Goh, 2005). The dependence on fertilizers in oil palm industry to maintain high yield is indispensable. This is due to oil palm having a high nutrient demand, uptake and removal (Von Uexkull and Fairhurst, 1991).

The application of P fertilizer is a common routine in oil palm plantation fertilization regime to improve fresh fruit bunch yield. However, with the raising price of fertilizers, quantitative information is needed for environment and crop performance. Phosphorus use efficiency is vital to ensure a better design of appropriate P-management, economically and ecologically (Tchienkoua *et al*, 2008). Under Malaysian conditions, the requirement of phosphate fertilizer per mature oil palm tree ranges from 0.3 kg P to 0.7 kg P (Goh and Härdter, 2003) with the planting density of oil palm between 110-160 palms per hectare of land (Gillbanks, 2003). As the number of planted area increased substantially every year, a substantial amount of P fertilizer is required for oil palm cultivation industry. The use of huge amount of phosphate fertilizers not only represents a significant financial burden to the planters but over dosage of phosphate inputs present a threat to the environment. Phosphate fertilizers are susceptible to loss by erosion and surface runoff (Goh and Härdter, 2003). Accumulation of phosphate in soil could lead to eutrophication effect to ground water and other water sources such as rivers and lake (Johnston and Dawson, 2005). Furthermore, Runge Metzger (1995) claimed that the consumption of high-grade phosphate rocks may be depleted within 60 to 90 years. Thus, the deposit of phosphate resources left in the world needs to be used sustainably.

It is generally understood that phosphorous (P) deficiency is one of the major nutrient that limits growth and overall ecosystem productivity in most humid tropical agroecosystems (IMPHOS 1980; Raghothama and Karthikeyan, 2005). Sharply (2000) reported that P in soil solution can be as low as 0.01mg PL^{-1}. Malaysian soils (mainly Ultisols and Oxisols), like most other tropical soils are known to be highly weathered, acidic and inherently low in P and have high P fixing capacities. Fe (III) and Al (hydro)oxides are the primary sorbents for phosphate in soils and this could result in substantial P-fixation (Zaharah and Sharifuddin, 1979; Goh and Chiew, 1995, Sallade and Sims, 1997, Wilson *et al.*, 2004). It is reported that phosphate has synergistic effects with other nutrients on oil palm yield (Foster *et al*, 1988, Foster and Prabowo, 1996). P enhances many aspects of plant physiology including photosynthesis, N-fixation, flowering, maturation and root growth (Brady and Weil. 2004). Hence, direct application of phosphate rocks in oil palm plantation has been a standard practice since the 1930s (Zaharah *et al.*, 1997). Phosphate rocks have been preferred in acid soils to ameliorate its P fertility status as it is nearly as effective as water-soluble P fertilizer and more cost effective (Chien and Menon, 1995).

However, the average fresh fruit bunch (ffb) yields had remained stagnant between the range of 18-22 t ha^{-1} yr^{-1} (MPOB, 2000) which is contrary to the theoretical yield potential of 44 t ha^{-1} yr^{-1} (Corley and Tinker, 2003). Goh *et al*. (2000) suggested that the lack of understanding in oil palm agronomy is one of the various factors in yield stagnation over the years. This may imply that there is a lack of understanding of oil palm in their uptake of nutrients. For P, many studies has shown that the efficiencies with which plants are able to extract and utilize this element vary between cultivars of various crops (Narang *et al*., 2000, Manske *et al*., 2000; Osborne and Rengel, 2002). In light of this, a concept of "to tailor the plant to fit the soil" (Hell and Hillebrand.,2006) should be implemented in plant and soil phosphorus research. Instead of altering the fertility state of the soil to accommodate the plant nutrient demand, plant with better phosphate uptake should be introduced to the field. Adopting plants with better nutrient uptake efficiency nonetheless means a more environmentally friendly and ecological feasible strategy to improve the growth of plant in low phosphorus soil. Studies on better P uptake among oil palm genotypes could contribute to oil palm breeding selection for nutrient (P) efficient oil palm material.

Therefore, the main objective of the study is to assess the variability of oil palm genotypes in taking up phosphorus both in phosphate fertilized and phosphate limited medium. The specific objectives are:

1) To evaluate the variability of phosphate uptake among oil palm genotypes at nursery stage
2) To evaluate the variable activity of high affinity phosphate transporter among oil palm genotypes under P-deprived condition at nursery stage.

REFERENCE

Abboud, A. (1990). Phosphorous nutrition of crops: a sustainable approach. REAP, Canada. 1990.

Barber, Stanley, A. (1995).Soil nutrient bioavailability : a mechanistic approach. John Wiley & Sons, 1995

Beirnaert A. (1940). Le probleme de la sterilite chez le palmier a huile. *Bull. agric. Congo Belge*, **3**, 95–110 [5.1.5]

Bhadraray, S., Purakayastha, T. J., Chhonkar, P. K., Verma, V. (2002). Phosphorus mobilization in hybrid rice rhizosphere comparaed to high yielding varieties under intergrated nutrient management. Biol Fertil. Soils 35, 73-78

Bieleski, R.L., Lauchli, A. (1992). Phosphate uptake, efflux and deficiency in the water fern *Azolla*. *Plant Cell Environ.* 15:665– 73

Bieleski, R.L., Ferguson, I.B. (1983). Physiology and metabolism of phosphate and its compounds. In: Läuchli A, Bieleski. R.L., (eds) Encyclopedia of plant physiology, NS, vol 15A Springer, Berlin Heidelberg New York, pp 422-449

Brady ,N. C., Weil, R. R. (2004). Elements of the Nature and Properties of Soils. New Jersey: Prentice Hall, 2004.

Broeshart, H. (1974). Quantitative measurement of fertilizer uptake by crops. Netherlands Jou. Agri. Sci., 22, 245-254.

Chien, S. H., Menon, R. G. (1995). Factors affecting the agronomic effectiveness of phosphate rock for direct application. Fertilizer Research 41, 227-234.

Clarkson, D.T., Hawkesford, M.J., Davidian, J.C., Grignon, C.(1992). Contrasting responses of sulfate and phosphate transport in barley roots to protein-modifying reagents and inhibition of protein synthesis. *Planta* 187:306–14

Clarkson, D.T. (1991). Root structure and sites of ion uptake. In Y. Waisel, A. Eshel and U. Kafkafi. *Plant Roots-The hidden half* (pp. 417 – 453). New York: Marcel Dekker, INC. Publishers.

Cogliatti, D.H., Clarkson, D.T., (1983). Physiological changes in, and phosphate uptake by potato plants during development of, and recovery from phosphate deficiency. Physiol. Plant. 58:287–94

Cooper, A.J. (1979). "The A B C of NFT", Growers Books, London, 181cp

Corley, R.H.V and Tinker, P.B. (2003). The oil palm fourth edition Blackwell publishing.

Daram, P., Brunner, S., Amrhein, N., Bucher, M., (1998). Functional analysis and cellspecific expression of a phosphate transporter from tomato. *Planta* 206:225– 33

FAO. (2004). Use of Phosphate rocks for sustainable agriculture. Rome, FAO. 2004.

Fardeau, J.C., Jappe, J. (1988). Valeurs caracteristiques des cin6tiques de dilution isotopique des ions phosphate dans les syst6mes sol-solution.In: Gachon (ed) Phosphore et Potassium dans les relations Sol-plante. Cons6quences sur la Fertilisation, pp 77- 99. INRA, Paris, France

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

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

Foong, S. F., Lee, C. T. (1998). Paper for Discussion Agronomic Audit 1998: Early results on the effect of various sources of phosphate rock on oil palm yield. FELDA Agriculture Services Sdn. Bhd.. 1998.

Foong, S.F. (1993). In *Comparative efficacy of various rock phosphates on the growth of oil palm seedling using radio-isotopic and conventional techniques*, Proceeding of the 1993 PORIM International Palm Oil Congress – Update and Vision, Kuala Lumpur, 1993.

Foster H.L., Tarmizi A.M., Tayeb M.D., Zin Z.Z. (1988). Oil palm yield response to P fertilizer in Peninsular Malaysia. *PORIM bulletin No. 17, 1-8pp*

Foster, H.L. and Prabowo, N.E. (1996). Yield response of oil palm to P fertilizers on different soil in North Sumatra. *In : International Conference on Sustainability of Oil Palm Plantations: Agronomic and Environmental Perspectives. Kuala Lumpur , 27-28 Sept. ISOPA, PORIM, 16p*

Foster, H.L. and Prabowo, N.E. (1996). Yield response of oil palm to P fertilizers on different soil in North Sumatra. *In : International Conference on Sustainability of Oil Palm Plantations: Agronomic and Environmental Perspectives. Kuala Lumpur , 27-28 Sept. ISOPA, PORIM, 16p*

Fried, M. (1954). Quantitative evaluation of processed and natural phosphates. Agric Food Chem 2:241-24

Fried, M. (1964). 'E', 'L', and 'A' values. In: Trans 8th Int Congr Soil Sci, Vol 4, pp 29-41, Bucharest, Romania. Pub. House Academy Soc Rep Romania

Furihata, T, Suzuki, M., Sakurai, H. (1992). Kinetic characterization of two phosphate uptake systems with different affinities in suspension-cultured *Catharanthus roseus* protoplasts. *Plant Cell Physiol.* 33:1151–57

Gahoonia, T. S. Nielson, N. E. (1996). Variation in acquisition of soil phosphorus among wheat and barley genotypes. Plant Soil 178: 223-230

Gahoonia, T.S., Nielsen, N.E.(1998). Direct evidence on participation of root hairs in phosphorus (^{32}P) uptake from soil. *Plant Soil* 1998, 198:147-152.

Gillbanks, R. A. (2003) Standard Agronomic Procedures and Practices *in*: Fairhurst, Thomas and Härdter Rolf, Oil Palm: Management for Large and Sustainable Yields. Potash and Phosphate Institute/ Potash & Phosphate Institute of Canada, International Potash Institute.2003 pp.115-150

Goh, K.J. (2005). Fertilizers recommendation systems for oil palm: estimating the fertilizers rates. In: Chew, P.S. and TanY.P. (eds) Proceeedings of MOSTA Best Practices Workshops-Agronomy and Crop Management. Malaysian Oil Scientists and Technologies Association (MOSTA) 235-268

Goh, K.J. and Chew, P.S. (1995). Direct application of phosphate rocks to plantation tree crops in Malaysia. In Dahanyake, K, van Kauwenbergh, J. andhellums, D.T. (eds) Direct Application of Phosphate rock and Appropirate Technology Fertilizers in Asia – What Hinders Acceptance and Growth. Institute of Fundamental Studies, IFDC, Kandy, pp. 59-76

Goh, K.J. and Härdter R. (2003) General Oil Palm Nutrition *in* Fairhurst, Thomas and Härdter Rolf, Oil Palm: Management for Large and Sustainable Yields. Potash and Phosphate Institute/ Potash & Phosphate Institute of Canada, International Potash Institute.2003 Pp 191-228

Goh, K.J., Tee, B.H., Anuar, A.R. (2000). Applicability of precision farming for oil palm plantations in Malaysia. In: Seminar on Precision Farming, 16 Oct. 2000, Universiti Putra Malaysia and Agricultural Inst. of Malaysia, Serdang: Preprint

Hase, A., Nishikoori, M., Okuyama, H. (2004) Induction of high affinity phosphate transporter in the duckweed *Spirodela oligorrhiza* Physiologia Plantarum 120: 271-279. 2004

Hasset, J. L., Bainwart, W. L. (1992). Soil and their environment. New Jersey: Prentice Hall.

Hayes, J. E., Zhu, Y. G., Mimura, T. and Reid, R.J. (2004). An assessment of the usefulness of solution culture in screening for phosphorus efficiency in wheat. Plant and Soil, 261, 91-97.

Hell, R., Hillebrand, H. (2006). Plant biotechnology. In: Wink, M. (ed) An introduction to molecular biotechnology: molecular fundamentals, methods and application in modern biotechnology, Wiley_VCH, Weinheim, ISBN 3-527-30992-6, pp. 595-621

Henson, I.E., Chang, K.C., Haniff Harun, M. (1994). Physiology.In: *Palm Oil Res. Inst. Malaysia Sci. Rep. 7*, pp. 204–265[2.2.1.5

Hinsinger, P., Gilkes, R. J. (1996). Dissolution of phosphate rock in the rhizosphere of five plant species grown in an acid, P-fixing mineral substrate. Geoderma 75 (1997) 231-249.

Horst, W. J., Abdou, M., Wiesler, F. (1996). Difference between wheat cultivars in acquisition and utilization of phosphorus. Z Pflanzenernähr. Bodenk. 159: 155-166

IAEA. (1976). Measurement of soil and fertilizer phosphorus availability to plants. In: Tracer Manual on Crops and Soils. Techn Rep Series 171, pp 129-138. IAEA, Vienna, Austria

Ibrahim El-Haj. (2001). Research on Gafsa (Tunisia) Reactive Phosphate Rock and Its Fertilizer Potential for Direct Application. In Direct Application of Phosphate Rock and Related Appropriate Technology- Latest Development and Practical Experiences: Proceeding of an international meeting. Edited by S.S.S. Rajan and S.H. Chien

IFDC. (1999). Evaluation of the Reactivity Effect of Phosphate Rock on Nitrogen, Phosphorus, and Potassium Uptake by Different Crops. Research project summary report. Unpublished data.

Indiati, R., Neri, U. (2004). Time-dependent phosphorous extractability from soil treated with different fertilizer phosphorous sources. Communications in Soil Science and Plant Analysis, Vol. 35, Nos. 11 & 12, pp. 1741-1755, 2004.

Institut Mondial du Phosphore, IMPHOS. (1980). Le phosphore dans les sols intertropicaux: Appréciation des niveaux de carence et des besoins en phosphore, Gerdat,: IMPHOS

Johnston, A. E. and Dawason, C. J. (2005). Phosphorusin Agriculture and in Relation to Water Quality. Agriculture Industries Confederation.

Jourdan, C. and Rey, H. (1997). Modeling and simulation of the architecture and development of the oil palm (*Elaeis guineensis* Jacq.) root system. II Estimation of root parameters using the RACINES postprocessor. *Plant and Soil*. 190: 235-246.

Jourdan, C and Rey, H. (1997b). Architechture and development of the oil palm (Elaeis guineensis Jacq.) root system. *Plant and Soil.* 189: 33-48.

Kpomblekou-A K., Tabatabai, M. A. (2003). Effect of low-molecular weight organic acids on phosphorous release and phytoavaibility of phosphorous in phosphate rocks added to soils. Agriculture, Ecosystems and Environment 100 (2003) 275-284.

Kucey, R.M.N., Bole, J.B. (1984). Availability of phosphorus from 17 rock phosphates in moderately and weakly acidic soils an determined by 32P dilution, a value, and total P uptake methods. Soil Science, 138(2), 180-187

Kushairi, A. & Rajanaidu, N. (2000). Breeding populations, seed production and nursery management. In: *Advances in oil palm research*, Vol. I (Ed. by Y. Basiron, B.S. Jalani & Chan K.W.), pp.39–98, Malaysian Palm Oil Board, Kuala Lumpur [5.1.1.2; 5.1.6.2; 5.2.1.1; 5.3.2; 12.1.10]

Laurer, M.J., Blevins, D.G., Gracz, S.H., (1989). ^{32}P-nuclear magnetic resonance determination of phosphate compartmentation in leaves of reproductive soybeans (Glycine max L.) as affected by phosphate nutrition. Plant Physiol. 89:1331-36

Liew, V. K., Zaharah, A. R., Mohamed, H. M., Aminuddin, H. (2010). Empty Fruith Bunch Application and oil palm root proliferation. Journal of Oil Palm Research Vol. 22 P750-757

Liew, V.K., Norziana, Z.Z., Teo, C.B., Susilawati, K., Zakry, F.A.A., Jalloh, M.B., and Zaharah, A.R. (2006). In *Efficacy of various sources of phosphate rocks using P-32 Isotope dilution technique*, Proceedings of the Soils 2006 Conference, Kuantan, Malaysia, April 18-19, 2006. Hamdan, J., Goh, K.J., Che Fauziah, I., Lulie M., Osumanu, H. A., Mahomadu, B.J., Alexander, S., Siva B.: Malaysian Soil Science Society, 2006.

Liu, H., Trieu, A.T., Blaylock, L.A., Harrison, M.J., (1998). Cloning and characterization of two phosphate transporters from *Medicago truncatula* roots. Regulation in response to phosphate and to colonization by arbuscular mycorrhizal (AM) fungi. *Mol. Plant Microbe Interact.* 11:14–22

Maene, L. M. (2001). Direct Application of Phosphate Rock: A Global Perspective of the Past, Present and Future. International Fertilizer Industry Association, IFA, Paris, 2001.

Manske, F. F. B., Ortiz-Monasterio, J. I., van Ginkel, M., Gonzalez, R. M., Rajaram, S., Molina, E., Vlek, P. L. G.(2000). Traits associated with improved P-uptake efficiency in CIMMYT's semidwarf spring bread wheat grown on an acid Andisol in Meixco. Plant soil 221 : 189-204

Marshner, H.(1995). Mineral nutrition of higher plants. Academic Press, Press Ltd. Harcourt Brace & Co. Publishers. London

Mchlachlan, D.(1980). Acid phosphatase activity of intact roots and phosphorus nutrition of plants . II Variation among wheat roots. Aust. J. Agric. Res. 31 :441-448

Mengel, K. and Kirkbly, M. (1987). Phosphorous Deficiency: A Situation Analysis. Albama: Potash/Phosphate Institute.

Mimura, T. (1999). Regulation of phosphate transport and homeostasis in plant cells. Int Rev Cytol 191:149-200

Mimura, T. (1995). Homeostasis and transport of inorganic phosphate in plants. Plant Cell Physiol. 36:1–7

Mission, J., Raghothama, K.G., Jain, A., Jouhet, J., Block, M.A., Bligny, R., Ortet, P., Creff, A., Somerville, S., Rolland, N., Doumas, P., Nacry, P., Herrerra-Estrella, L., Nussaume, L., Thibaud, M-C. (2005). A genome-wide transcriptional analysis using Arabidopsis thaliana Affymetrix gene chips determined plant responses to phosphate deprivation. Proc Natl Acad Sci USA 102:11934-11939

Mitsukawa, N., Okumura, S., Shirano, Y., Sato, S., Kato, T., Harashima, S., Shibata, D., (1997). Over expression of an Arabidopsis thaliana high affinity phosphate transporter gene in tobacco cultured cells enhances cell growth under phosphate-limited conditions. Proc Natl. Acad Sci. USA 94:7098-7102

Morton, A.G. (1942). A study of the relationship between growth and mycorrhizal development in the oil palm. Internal Report, Lever Bros & Unilever [2.2.1.5; 11.2.2]

MPOB (2010). Overview of the Malaysian Oil Palm Industry . Retrieved 30 April 2011 from http://econ.mpob.gov.my/economy/Overview%202010_final.pdf

MPOB. (2000). Review of the Malaysian oil palm industry 1999. Malaysian Palm Oil Board, Ministry of Primary Industries, Malaysia, Kuala Lumpur: 108 pp.

Muchhal, U. S., Pardo, J. M., Raghothama, K. G.(1996). Phosphate transporters from the higher plant Arabidopsis thaliana. Proc. Natl. Acad. Sci. USA 93: 10519–10523.

Mudge, S. R., Rae, A. L., Diatloff, E. and Smith, F. W. (2002). Expression analysis suggests novel roles for members of the Pht1 family of phosphate transporters in Arabidopsis. 31: 341–353.

Mukatira, U., Liu, C., Varadarajan, D. K. and Raghothama, K. G. (2001). Negative regulation of phosphate starvation induced genes. Plant Physiol. 127: 1854–1862 active regulation of phosphate starvation induced genes. Plant Physiol. 127: 1854–1862

Murphy J., Riley J.P. (1962) A modified single solution method for the determination of phosphate in natural waters Analytica Chimica Acta, 27 (C) , pp. 31-36

Nadarajah, P.(1980). Species of Endogonaceae and mycorrhizal association of *Elaeis guineensis* and *Theobroma cacao*. In: *Tropical mycorrhiza research* (Ed. by P. Mikola), pp. 232–237, Oxford Science Publishers, Oxford [2.2.1.5; 11.2.2]

Narang, R. A., Bruene, A. and Altmann, T. (2000). Analysis of Phosphate Acquisition Efficiency in Different Arabidopsis Accessions Plant Physiol, December 2000, Vol. 124, pp. 1786-1799

Ng, S.K. (1977). Review of oil palm nutrition and manuring –scope for greater economy in fertiliser usage. *Oléagineux*, 32,197–209 [11.1.3.1; 11.1.4; 11.6.1.1; 11.7.1; 11.9.4]

Ng, S.K., Thamboo, S. and de Souza, P. (1968). Nutrient contents of oil palms in Malaya. II. Nutrients in vegetative tissues,. The Malaysian Agricultural Journal, 46, 332-391.

Osborne, L. D. and Rengel, Z. (2002). Growth and P uptake by wheat genotypes supplied with phytate as the only P source. Aust. J. Agric. Res. 53:845-850

Pao, S. S., Paulsen, I. T. and Saier, M. H. (1998). Major facilitator superfamily. Microbiol. Mol. Biol. Rev. 62: 1–34.

Perrott, K. W. and Kear, M. J. (2001). Direct application phosphate rocks: do soil phosphate tests take site influence into account. Communications in Soil Science and Plant Analysis, 32 (13&14), 2133-2144 (2001).

Raghothama, K. G. (1999). Phosphate acquisition. Annu. Rev. Plant Physiol. Plant Mol. Biol. 50: 665–693.

Raghothama, K. G. (2000). Phosphate transport and signaling. Curr. Opin. Plant Biol. 3: 182–187.

Raghothama, K.G. and Karthikeyan, A.S. (2005). Phosphate acquisition. Plant and soil 274:37-49

Ramirez, F., Chinchilla, C. and Bulgarelli, J. (2000). Low soil phosphorous content associated with a reduction in trunk diameter in oil palm.

Rao, V. & Kushairi, A. (1999). Quality of oil palm planting material. In: *Proc. 1996 Seminar 'Sourcing of oil palm planting materials for local and overseas joint ventures'* (Ed. by N. Rajanaidu & B.S.Jalani), pp. 188–197, Palm Oil Res. Inst. Malaysia, Kuala Lumpur [5.2.1.2]

Razman, A. R., Mohd., H. T., Ooi, L. H., Tang, M. K. (1999). Fertilizer Requirements and Practices of The Plantation Industry in Malaysia. Proc. IFA Regional Conference for Asia and the Pacific, Kuala Lumpur, 1999.

Romer, W., Augustin, J., and schilling, F. (1988). The relationship between phosphate absorption and root length in nine wheat cultivars. Plant Soil 111, 199-201.

Rosenquist, E.A. (1986). The genetic base of oil palm breeding populations. In: *Proc. Int. Workshop 'Oil palm germplasm and utilisation'*, pp. 27–56, Palm Oil Res. Inst. Malaysia, Kuala Lumpur [5.1; 5.5.1.4]

Rovira, A. D. (1969) Root exudates. Bot. Rev. 35:35-37

Ruer, P. (1967). Repartition en surface du systeme radiculaire du palmier a huile. *Oléagineux*, 22, 535–537 [2.2.1.5; 4.3.8.3;11.2.1.2; 11.2.1.3]

Ruer, P. (1969). Systeme racinaire du palmier a huile et alimentation hydrique. *Oléagineux*, 24, 327–330[2.2.1.5]

Runge-Metzger, A. (1995). Closing The Cycle: Obstacles To Efficient P Management For Improved Global Food Security SCOPE- SCIENTIFIC COMMITTEE ON PROBLEMS OF THE ENVIRONMENT INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS VOL 54, pages 27-42

Siti Mariyam, I. (2011). Isolation and characterization of genees expressed in the roots of phosphate derived oil palm. Master dissertation, Universiti Putra Malaysia, Malayisa.

Sakano, K. (1990). Proton/phosphate stoichiometry in uptake of inorganic phosphate by cultured cells of Catharanthus roseus (L.) G. Don. Plant Physol. 93:479-483

Sakano, K., Yazaki, Y., Okihara, K., Mimura, T., Kiyota, K.(1995). Lack of control in inorganic phosphate uptake by *Catharanthus roseur* (L.) G. Don cells. Plant Physiol. 108: 295-302

Sallade, Y. E., & Sims, J. T. (1997). Phosphorus transformations in the sediments of delaware's agricultural dranageways: II Effect of reducing conditions on phosphorus release. *J. Envrion. Qual., 26: 1579-1588*

Sambrook J, Russell D.W. (2001). Molecular Cloning: a laboratory manual, volume 2 CHSHL Press 2001

Sanderson, J. (1983). Water uptake by different regions of the barley root: pathways of radial flow in relation to development of the endodermis. *Journal of Experimental Botany*. 34: 240-253

SAS Institute Inc., (2001). Statistics Analysis System version 8.2, Cary. NC, USA.

Schulte, E. E., and K. A. Kelling. (1996). Soil and applied phosphorus. Bulletin A2520. University of Wisconsin-Extension. Madison, WI Usda 1994

Sharpley, A. (2000). Phosphorous Availability. In Malcolm E. Sumner (Ed.), Handbook of Soil Science. (pp. D-18 - D-38). USA: CRC Press.

Shimagowara, K. and Usuda, H. (1995). Uptake of inorganic phosphate by suspension-cultured tobacco cells: Kinetics and regulation by Pi Starvation. Plant Cell Physiol. 36: 341-351

Smith, F. W., Ealing, P.M., Dong, B, Delhaize, E. (1997). The cloning of two Arabidopsis genes belonging to a phosphate transporter family. Plant J 11: 83-92

Subramaniam, S. (1998). The Biology Workbench – A seamless database and analysis environment for the biologist. Proteins: Structure, Function, and Genetics, 32, 1-2. <http://www3.interscience.wiley.com/cgi-bin/abstract/36266/START>

Tailliez, B. (1971). The root system of the oil palm on the San Alberto plantation in Colombia. *Oléagineux*, 26, 435 – 448 [2.2.1.5; 3.2.2.2; 4.1.2.3]

Tchienkoua, Nolte, C., Jemo, M., Sanginga, N. and Zech, W. (2008) Biomass and Phosphorus Uptake Responses of Maize to Phosphorus Application in Three Acid Soils from Southern Cameroon, Communications in Soil Science and Plant Analysis, 39:9,1546-1558.

Tinker, P.B. & Nye P.H. (2000). *Solute movement in the rhizosphere*, Oxford University Press, Oxford [2; 3; 4; 10; 11]

Tinker, P.B. (1976). Soil requirements of the oil palm. In: *Oil palm research* (Ed. by R.H.V. Corley, J.J. Hardon & B.J. Wood), pp. 165–181, Elsevier, Amsterdam

Towbin, H., Sstaehelin, T.,Gordon J., (1979). Electrophoretic transfer of proteins from polyacrylamide gels to nitrocellulose sheets: procedure and some applications. Proc Natl. Acad. Sci. USA 76, 4350-4354(1979)

Tu, S.I., Cananaugh, J.R., Boswell, R.T. (1990). Phosphate uptake by excised maize root tips studied by in vivo 31P nuclear magnetic resonance spectroscopy. *Plant Physiol.* 93:778–84

Ullrich-Eberius, C.I., Novacky, A., Fischer, E., Lüttge, U. (1981). Relationship between energy-dependent phosphate uptake and the electrical membrane potential in *Lemna gibba* G1. *Plant Physiol.*67:797–801

USDA. (2010). Keys to Soil Taxonomy, Eleventh Edition, 2010. United States Department of Agriculture Natural Resources Conservation Service

Uta, P., Kroken, S., Roux, C. and Briggs, S. P. (2002) Rice phosphate transporters include an evolutionarily divergent gene specifically activated in arbuscular mycorrhizal symbiosis. Proc. Natl. Acad. Sci. USA 99: 13324–13329

Von Uexkull, H.R. and Fairhurst, T. H. (1991). Fertilizing for high yield and quality: The oil palm. *(IPI Bulletin No. 12) International Potash Institute, Basel Switzerland*.

Von Uexkull, H.R., and EW.Mutert. (1995). “Gloxtent, Development and EconomicImpact of Acid Soils,”Plan Soil, 171:1-5

Wasaki, J. and Maruyama, H. (2011). Molecular Approaches to the study of Biological Phosphorus Cycling. Phosphorus in Action, Soil Biology 26. Springer-Verlag Berlin Heidelberg 2011.

Wiersma, J. & Allrich T. (2004). Nutrient Deficiency Symptoms. Minnesota Association of Wheat Growers, 2004.

Williamson, L. C., Sebastien, P. C. P., Fitter, A. H. and Ottoline Leyser, H. M. (2001). Phosphate availability regulates root system architecture in Arabidopsis. Plant Physiol. 126: 875-882

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

Yampolsky, C. (1922). A contribution to the study of the oil palm(*Elaeis guineensis,* Jacq.). *Bull. Jard. Bot., Buitenzorg,* 3,107–174 [2.2.1.5]

Yan, X., Liao, H., Cao, A. and He, Y. (2001). The role of root architecture in P acquisition efficiency of different root systems: A case study with common bean and rice. In Plant Nutrition- Food Security and Sustainability of Agro-Ecosystem. Eds. W J Horst, M K Schenk, N Burkert et al. pp 590-591 Kluwer Academic Pubilishers, Dordrecht. The Netherlands.

Zaharah, A.R. and Sharifuddin, H.A.H. (1979). Residual effect of applied phosphates on performance of *Hevea brasiliensis* and *Pueraria Phaseoloides*. J.Rubb. *Res. Inst. Mal. 25(3):101-108*

Zaharah, A.R., Sharifuddin, H.A.H., Ahmad, Sahali, M. and Mohd Hussein, M.S. (1989). Fertilizer placement studies in mature oil palm using isotope technique. *The Planter 65*: 284-388.

Zaharah, A.R., Zulkifli H., Sharifuddin, H.A.H (1997). Evaluating the efficacy of various phosphate fertilizer sources for oil palm seedlings. *Nutrient Cycling in Agrocosystems 47: 3-98*

Zakaria, Z. Z., Foong, S. F., Jamaludin, N., Lee C. T., Hamdan, A. B., Tarmizi, A. M. and Khalid H. (2001). Evaluation of Various Sources of Phosphate Fertilizer for Mature Oil Palm in Peninsular Malaysia. PIPOC International Palm Oil Congress (Agriculture). 2001

Zakaria, Z.Z. and Jamaludin, N. (1992). Secondary and micro nutrients in oil palm production. In: Sharifuddin, H.A.H., Vimala, P.and Aminuddin, H. (eds) Secondary and Micro Nutrients in Malaysian Agriculture. Kuala Lumpur, 29 March 1988. MSSS, pp 22-29

Zapata, F. (1990). Isotope techniques in soil fertility and plant nutrition studies. In: Use of Nuclear Techniques in Studies of Soil- Plant Relationships, pp 109-127. Training Course Series, No.2, IAEA, Vienna, Austria

Zapata, F. and Axmann H.(1995). ^{32}P isotopic techniques for evaluating the agronomic effectiveness of rock phosphate materials. Fertilizer Research 41:189-195, 1995

Zin, Z.Z., Ariffin, D., Tarmizi Mohamad, A., Azizah Hashim & Zambri M.P. (1996). *Effect of VAM inoculation on growth and yield of oil palm in peat soil*. Paper presented at Seminar'Prospect of oil palm planting on peat in Sarawak – the golden opportunity' [2.2.1.5]