UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF FERTILIZATION METHODS AND NUTRIENT LOSSES ON TENERA OIL PALMS (*Elaeis guineensis* Jacq.)

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ASSESSMENT OF FERTILIZATION METHODS AND NUTRIENT LOSSES ON TENERA OIL PALMS (*Elaeis guineensis* Jacq.)

VIJIANDRAN A/L JUVA RAJAH

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

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DEDICATION

This thesis is dedicated to: -

My father, Mr. N. Juva Rajah, my first hero and role model

My late mother, Mrs Punithavathy Juva Rajah, my first teacher and my best friend

My wife, Christina Vijiandran, who stood by my side in all ups and downs since the very first day we met

My children, Lovinah, Pratamesh and Nitesh, who never fail to cheer me up and make my day

To all the contributors and potential contributors of any kind of knowledge that is beneficial to mankind and is as well in harmony with nature

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

ASSESSMENT OF FERTILIZATION METHODS AND NUTRIENT LOSSES ON TENERA OIL PALMS (*Elaeis guineensis* Jacq.)

By

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March 2019

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The current labour shortage faced by the palm oil industry had caused disruption of the various agricultural activities including manuring. The use of compound or controlled release fertiliser (CRF) instead of the traditional straight fertilisers could help reduce application rounds and concomitantly save labour usage. A study was conducted with the following objectives (i) to quantify nutrient losses through surface runoff for mature oil palm under rolling terrain on palms fertilised with straights, compounds and controlled released fertilisers (ii) to quantify nutrient losses through leaching under flat and rolling terrain on palms fertilised with straights and compounds fertilisers (iii) to access the efficiency of straight and compounds fertilisers on mature oil palm at field conditions. It was hypothesized that compound fertilisers or controlled release fertilisers would have lower nutrient losses through soil erosion, runoff and leaching compared to straight fertilisers. The first study was conducted in a matured oil palm field using three 20 by 6m erosion plots on an inland soil (Serdang Series) with rolling terrain. Studies on leaching losses was conducted on two soil types, the Serdang Series and Jawa Series, an acid sulphate marine alluvial soil. The porous cup leaching tubes was used to quantify nutrient loss through leaching. The evaluation straight and compound fertilisers was carried out through a replicated field trial on a matured oil palm field where yield and vegetative variable was measured for 6 years. Application of straight or compound fertilisers did not show any significant differences in nitrogen (N), phosphorus (P), potassium (K) or magnesium (Mg) losses through eroded sediments or runoff. Application of CRF however showed significantly higher N, P and K losses compared to compound fertilisers for every tonne of soil loss. No significant differences between CRF and other fertiliser forms was noted in the runoff. Even though there were no significant differences between fertiliser forms, application of compound fertilisers generally showed lower loss of N and K compared to straight fertilisers. Studies comparing compound and straight fertilisers on leaching losses showed no significant differences on both soil types. Leaching losses recorded was less than 1.0 % of applied fertilisers

on both soil types for all nutrients studied. In most cases, differences in leaching losses between both fertiliser forms were comparable with marginally lower losses of nitrogen and potassium seen between 1 to 3% with the application of compound fertilisers. Phosphorus losses on the contrast was higher with the application of compound fertilisers as it had higher percentage of soluble phosphorus compared to straight fertilisers. The field trial comparing straights and compound fertilisers did not show any significant differences in all yield and vegetative growth variables measured. Averaged over 6 years, palms fertiliser with straights using urea as N source had an average yield of 28.79 t FFB ha^{-1} $year^{-1}$ while palms fertilised with compound fertilisers yielded comparably at 28.72 t FFB ha^{-1} $year^{-1}$. Palms fertilised with ammonium nitrate as a source of N had lower average yields at 27.83 t FFB ha^{-1} $year^{-1}$. Input of the different fertiliser forms did not show any significant difference in terms of vegetative growth and palm nutrient status. In conclusion, this study had shown that use of straight or compound fertilisers applied at equal rates did not significantly affect nutrient losses or oil palm yields. Nevertheless, applications of compound fertilisers showed consistently lower nutrient losses especially for N both through erosion and leaching. However, losses of P were higher through both pathways with the use of compound fertilisers. Compared to leaching nutrient losses, nutrient losses through erosion is of more concern as nutrient lost through the later pathway are much higher than that of the former. The long-term field trial indicates a possibility of applying compound fertilisers at a lower rate compared to straight fertilisers which is a favourable scenario to oil palm planters. With the lack of labour supply, compound fertiliser usage maybe the better option to reduce fertiliser application rounds.

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

PENILAIAN KAEDAH PENBAJAAN DAN KEHILANGAN NUTRIEN PADA POKOK KELAPA SAWIT TENERA (*Elaesis guineensis* Jacq.)

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Kekurangan pekerja yang dialami oleh industri kelapa sawit dewasa ini telah mengakibatkan gangguan kepada kebanyakan aktiviti perkebunan termasuk aktiviti pembajaan. Pengunaan baja kompaun atau baja pelepasan terkawal (CRF) sebagai pengganti kepada baja terus yang digunakan tradisional boleh membantu mengurangkan pusingan pembajaan dan dengan itu menjimatkan pengunaan pekerja. Satu kajian telah dijalankan dengan objektif seperti berikut (i) untuk mengkuantifikasikan kehilangan nutrien melalui hakisan tanah dan larian permukaan untuk kelapa sawit matang yang ditanam di kawasan cerun yang dibaja dengan baja terus, baja kompaun atau CRF, (ii) untuk mengkuantifikasikan kehilangan nutrient melalui larutlesap nutrient di kebun kelapa sawit matang yang ditanam di atas tanah rata dan tanah bercerun yang dibaja dengan baja terus dan baja kompaun dan (ii) untuk menilai efisensi baja terus serta baja kompaun dalam kawasan kebun kelapa sawit matang. Kajian yang pertama telah dijalankan di satu kebun kelapa sawit matang dengan menggunakan plot hakisan tanah berukuran 20 m kali 6 m di atas tanah pendalaman (Siri Serdang) yang bercerun. Kajian untuk kehilangan nutrien melalui larutlesap telah dijalankan diatas dua jenis tanah yang berlainan, Siri Serdang dan Siri Jawa yang merupakan tanah asid sulfat. Sistem tiub-cawan-berliang telah digunakan untuk mengukur larutlesap nutrient. Penilaian baja terus dengan baja kompaun telah dijalankan melalui satu kajian bereplikasi di satu kebun kelapa sawit matang dimana pembolehubah-pembolehubah berkaitan dengan hasil dan pertumbuhan telah diukur selama 6 tahun. Aplikasi baja terus atau baja kompaun tidak menunjukkan sebarang perbezaan bererti untuk kehilangan nitrogen (N), fosforus (P), kalium (K) atau magnesium (Mg) melalui hakisan tanah ataupun larian permukaan. Malakala, pembajaan baja CRF pula menunjukkan perbezaan bererti bagi kehilangan N, P dan K yang lebih tingi jika dibandingkan baja kompaun untuk kehilangan setiap tan tanah yang terhakis. Tiada perbezaan bererti yang dilihat diantara CRF dan bentuk baja yang lain untuk kehilangan nutrien melalui larian permukaan. Walaupun tiada perbezaan yang bererti dilihat diantara bentuk baja yang berlainan, pembajaan dengan baja

kompaun menunjukkan kehilangan N dan K yang lebih rendah berbanding dengan baja terus. Bagi kajian yang membandingkan baja terus dan baja kompaun untuk kehilangan nutrient melalui larutlesap telah menunjukkan bahawa tiada perbezaan bererti diantara kedua-dua baja tersebut pada kedua-dua jenis tanah yang dikaji. Kehilangan nutrien melalui larutlesap adalah kurang daripada 1% daripada jumlah pembajaan diatas kedua-dua jenis tanah bagi semua nutrien yang dikaji. Dalam kebanyakan kes, perbezaan kehilangan nutrien melalui larutlesap adalah rendah bagi kedua-dua jenis baja dan kehilangan nutrient yang sedikit rendah diantara 1% hingga 3% bagi N dan K dengan pengunaan baja kompaun. Kehilangan P pula adalah lebih tinggi dengan pengunaan baja kompaun oleh kerana baja tersebut mempunyai kandungan P mudah larut yang lebih tinggi jika dibandingkan dengan baja terus. Kajian kebun yang membandingkan baja terus dengan baja kompaun tidak menunjukkan sebarang perbezaan yang bererti untuk semua pembolehubah hasil dan pertumbuhan yang diukur. Apabila dipuratakan hasil selama 6 tahun, pokok kelapa sawit yang dibaja dengan baja terus yang menggunakan urea sebagai sumber N telah merekodkan hasil purata sebanyak 28.79 tan buah tandan segar (FFB) sehektar setahun manakala pokok yang dibaja dengan baja kompaun telah merekodkan purata hasil sebanyak 28.72 tan FFB sehektar setahun. Pokok yang telah dibaja dengan ammonium nitrat sebagai sumber nitrogen telah menunjukkan purata hasil yang lebih rendah untuk tempoh yang sama sebanyak 27.83 tan FFB sehektar setahun. Pengunaan baja yang berlainan bentuk tidak menunjukkan sebarang perrbezaan yang bererti dalam pertumbuhan pokok serta kandungan nutrien. Sebagai kesimpulan, kajian ini telah menunjukkan bahawa pembajaan dengan baja terus atau baja kompaun dengan kadar yang sama tidak menunjukkan sebarang perbezaan bererti dalam kehilangan nutrient atau hasil kelapa sawit. Dalam pada itu, pembajaan dengan baja kompaun telah menunjukkan kehilangan nutrient yang lebih rendah untuk unsur N melalui hakisan dan larutlesap. Akantetapi kehilangan unsur P adalah lebih tinggi melalui hakisan atau larutlesap dengan pengunaan baja kompaun. Jika kehilangan nutrient dibandingkan diantara larutlesap dan hakisan, kehilangan nutrient melalui hakisan adalah lebih tinggi dan justeru itu perlu diberi perhatian yang lebih. Kajian kebun jangka panjang telah memberi satu petunjuk bahawa baja kompaun dapat di gunakan dengan kadar yang lebih rendah daripada baja terus yang merupakan satu senario yang memberangsangkan kepada para penanam kelapa sawit. Dengan kekurangan perkerja yang dihadapi, pengunaan baja kompaun boleh menjadi suatu alternatif kepada baja terus dalam inisiatif pengurangan pusingan pembajaan.

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A Phd Is Not A Race But A Journey

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

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LIST OF ABBREVIATIONS

ABW	Average Bunch Weight
ANOVA	Analysis of Variance
BNo	Bunch Number
CEC	Cation Exchange Capacity
CPO	Crude Palm Oil
CRF	Controlled Released Fertilisers
FAO	Food and Agriculture Organisation of the United Nations
FFB	Fresh Fruit Bunch
K/B	Kernel to Bunch ratio
LAI	Leaf Area Index
LBE	Lima Blas Estate
O/B	Oil to Bunch ratio
OER	Oil Extraction Rate
PORIM	Palm Oil Research Institute of Malaysia
PVC	Polyvinyl Chloride
SEM	Standard Error of Mean
UBE	Ulu Bernam Estate
UPB	United Plantations Berhad

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Oil palm is the largest planted agricultural commodity in Malaysia and has been one of the major income contributors to the country's economy. As of 2018, the crop is cultivated over 5.85 million hectares in Malaysia with the state of Sarawak being the largest oil palm planted state at 1.57 million hectares followed closely by Sabah at 1.55 million hectares (MPOB, 2019). On average, the Malaysian palm oil industry had contributed and average of RM 64 billion through export earnings over the last 5 years making it the most lucrative agricultural crop to be planted in Malaysia (MPOB, 2019). The Malaysian palm oil industry, on average, exported about 20 million tonnes of palm oil products over the last 5 years meeting about 30% of worlds demand for oils and fats (MPOB, 2017b). Currently, Malaysia accounts for 33% of the world's palm oil production and 39% of world palm oil export amounting to 11% and 24% of the world's total production of oil and fats (MPOB, 2017a, 2017b; Thomas Mielke, 2017).

The Malaysian palm oil industry is labour intensive, and it employs some 630,000 people for its upstream and downstream activities ranging from nurseries, plantations, mills, refineries to the oleo-chemical plants. The plantation sector has the largest labour requirement and it employs close to 450 000 workers or 71.4% of the total work force in the palm oil industry. Of this total number of workers in the plantation sector, 350 300 or 77.8% are guest workers making the industry highly dependent on foreign labour to carry out its day-to-day activity (Douglas, 2014). The freeze on recruitment of foreign workers by the Malaysian Government in mid-2015, coupled with better opportunities and improved wages especially in Indonesia, has made labour availability the most difficult challenge faced by the oil palm industry at present.

Oil palm grows well under a tropical climate with mean temperatures ranging between 24 ºC and 28ºC with evenly distributed annual rainfalls of about 2,000 mm (Corley and Tinker, 2015). As most tropical soils have low inherent soil fertility, cultivation of oil palm in the tropics requires large quantities of fertilisers to sustain high yields (Goh *et al.*, 1999, 2003). Fertilisers are the largest cost element taking up about 60% of field upkeep and correspondingly 30% of palm oil production costs (Goh *et al.*, 2003). Hence, most agronomic trials had been focused on oil palm nutrient demands, fertiliser responses to various soil types, nutrient uptake efficiencies and nutrient losses under various conditions. Results from these various trials had ultimately been used to formulate a sound and robust fertiliser recommendation system for the oil palm.

Straight fertilisers had been the preferred source of fertilisers by the industry because of its relatively cheaper prices and ability to facilitate variable nutrient inputs for each individual field as per palm requirements. A typical oil palm field requires application frequency of 7 to 8 rounds a year with use of various straight fertilisers to fulfil the yearly nutrient demand of oil palms. Unfortunately, the current labour shortage faced by the industry in recent times had caused most plantations to be unable to keep up with their yearly fertilisation programmes due to the high application rounds. In many instances, the year's fertilisation programme is delayed or in worse case not completed for the year where such scenarios have adverse effects on productivity and profits.

Compound or controlled released fertilisers (CRF) could be a possible alternative to straight fertilisers especially in times of labour shortage as the use of these fertilisers provide two or more nutrients at each application rounds thus reducing application frequency. However, the relatively higher prices of compound or CRF compared to straight fertilisers and the fixed nutrient ratios in these fertilisers had made the oil palm industry shy away from using them. The physical form of compound and controlled released fertilisers, either in a granular or prilled form, would make them solubilise at a much slower rate compared to straight fertilisers. Such properties would in turn likely lead towards lower nutrient losses and better nutrient uptake compared to straight fertilisers. However, there had been minimal studies on comparing the efficiency of straight fertilisers with other forms of fertilisers such as compound fertilisers and CRF in terms of nutrient losses and yield parameters for oil palm. Hence, this study was conducted to mainly compare the efficiency of straight and compound fertilisers in terms of nutrient losses and also on yield variables under matured oil palm.

1.2 Objectives

This study mainly compares straights and compound fertilisers on nutrient losses and field efficiency on matured oil palm with three main objectives: -

i. to quantify nutrient losses through surface runoff for matured oil palm under rolling terrain on palms fertilised with straights, compounds or controlled released fertilisers
ii. to quantify nutrient losses through leaching in matured oil palms planted on flat and rolling terrain for palms fertilised with straights and compound fertilisers
iii. to access the efficiency of straight and compound fertilisers on matured oil palm under field conditions.

1.3 Hypothesis

It is hypothesised that compound fertilisers would have lower nutrient losses through surface runoff and leaching compared to straight fertilisers under matured oil palm. It is also hypothesised that application of compound fertilisers would provide better oil palm yields compared to palms fertilised with straight fertilisers.

REFERENCES

Bah, A. (2015). *Nutrient Loss In Runoff And Growth Response Of Immature Oil Palm Following Appliciation Of Controlled Release Fertilisers*. PhD Thesis. Universiti Putra Malaysia.

Banabas, M., Turner, M. A., Scotter, D. R., and Nelson, P. N. (2008). Losses of nitrogen fertiliser under oil palm in Papua New Guinea: 1. Water balance, and nitrogen in soil solution and runoff. *Australian Journal of Soil Research*, *46*(4), 332–339.

Blaak, G., Spaarnaaij, L. D., and Menendez, T. (1963). Breeding for inheritance in the oil palm (Elaeis guineensis Jacq.) Part II Methods of bunch quality analysis. *Journal African Institute of Oil Palm Research*, *4*, 146–155.

Bolton, J. (1968). Leaching of Fertilisers Applied to a Latosol in Lysimeter. *Journal of the Rubber Research Insitute of Malaya*, *20*, 274–284.

Brady, N. C., and Weil, R. R. (2014). *The nature and properties of soils 14th edition.* Pearson.

Bremner, J. M., and Keeney, D. R. (1965). Steam distillation methods for determination of ammonium, nitrate and nitrite. *Analytica Chimica Acta*, *32*, 485–495.

Chang, K. C., and Zakaria, A. (1986). Leaching losses of N and K fertilisers from mature fields of perennial crop in Malaysia - a review of local work. *The Planter*.ISP Kuala Lumpur

Chew, P. S., Kee, K. K., and Goh, K. J. (1999). Cultural Practices and their Impact. In S. Gurmit, H. L.K, L. T, and K. D.l (Eds.), *Oil palm and the environment* (p. 277). Kuala Lumpus: Malaysian Oil Palm Grower's Council.

Comte, I., Colin, F., Grünberger, O., Whalen, J. K., Harto Widodo, R., and Caliman, J. P. (2015). Watershed-scale assessment of oil palm cultivation impact on water quality and nutrient fluxes: a case study in Sumatra (Indonesia). *Environmental Science and Pollution Research*, *22*(10), 7676–7695.

Corley, R. H. V., and Tinker, P. B. (2015). *The Oil Palm*.Wiley Blackwell, UK

Corley, R. H. V., Hardon, J. J., and Tan, G. Y. (1971). Analysis of growth of the oil palm (Elaeis guineensis Jacq.) I. Estimation of growth parameters and application in breeding. *Euphytica*, *20*(2), 307–315.

Cottenie, A. (1979). Workshop on standardisation of analytical methods for manure, soils, plant and water. In *C.E.E. Agricultures series,* (p. 57).

Douglas, E. (2014). *Minister's Speech Text In Palm Industry Labour: Issues, Performance And Sustainability Seminar*. Ministry of Plantations Industry and Commodities,Malaysia. https://www.mpic.gov.my/mpic/index.php/en/speeches/speeches-year-2014

Douglas, I. (1967). Natural and man-made erosion in the humid tropics of Australia, Malaysia and Singapore. *Int. Assoc. Hydrol. Sci. Publ.*, *75*, 17–30.

Du, C. W., Zhou, J. M., and Shaviv, A. (2006). Release characteristics of nutrients from polymer-coated compound controlled release fertilizers. *Journal of Polymers and the Environment*, *14*(3), 223–230.

Edmeades, D. . (2003). *Nutrient Handbook - Ballace Agri Nutrients 2003*. (D. C. Edmeades, Ed.). Ballance Agri Nutrients Ltd.

El-Swaify, S. A., Dangler, E. W., and Armstrong, C. L. (1982). *Soil Erosion by Water in the Tropics*. *Research Extension Series 024*.

Engelsjord, M. E., Fostad, O., and Singh, B. R. (1996). Effects of temperature on nutrient release from slow-release fertilizers - I. Commerical and Experimental products. *Nutrient Cycling in Agroecosystems*, *46*(3), 179–187.

Fairhurst, T. H., and Mutert, E. (1999). *Interpretation and Management of Oil Palm Leaf Analysis Data*. *Better Crops International* (Vol. 13).

FAO. (1984). *Fertiliser and plant nutrition guide*. Food And Agriculture Organisation of the United Nations.

FAO. (2017). Soil Heath - Physical | FAO SOILS PORTAL | Food and Agriculture Organization of the United Nations. Retrieved December 6, 2017, from http://www.fao.org/soils-portal/soil-degradation-restoration/global-soil-health-indicators-and-assessment/soil-heath-physical/en/

FAO and ITPS. (2015). *Status of the World's Soil Resources (Main Report)*. *FAO*.

Fogg, D. N., and Wilkinson, N. T. (1958). The colorimetric determination of phosphorus. *The Analyst*, *83*(988), 406.

Foong, S. . (1991). Potential evaporation, potential yield and leaching losses of oil palm. In *PORIM International Palm Oil COnference* (pp. 105–119). Palm Oil Research Institute of Malaysia.

Foong, S. . (1993). Potential evaporation yield and leaching losses of oil palm. In *Proc. of the 1991 PORIM International Oil Palm Conference Agriculture* (p. . 105-119.).

Foster, H. (2003). Assessment of oil palm fertilizer requirements. In T. Fairhust and R. Hardter (Eds.), *Oil Palm: Management For Large And Sustainable Yields* (pp. 231–257). Singapore: Potash and Phosphate Institute.

Glibert, P. M., Harrison, J., Heil, C., and Seitzinger, S. (n.d.). Escalating worldwide use of urea-a global change contributing to coastal eutrophication.

Goh, K. J. (2004). Fertilizer Recommendation Systems for Oil Palm : Estimating the Fertilizer Rates. *Proceedings of MOSTA Best Practices Workshops: Agronomy and Crop Management, Malaysia, March to August 2004. Sdn*, , 235–268.

Goh, K. J., Hardter, R., and Fairhust, T. (2003). Fertilizing for maximum return. In *Oil Palm: Management for Large and Sustainable Yields* (pp. 279–306).

Goh, K., Teo, C., Chew, P., and Chiu, S. (1999). Fertiliser management in oil palm: Agronomic principles and field practices. *Fertiliser Management for Oil Palm Plantations*, , 20–21.

Grissinger, E. H. (1996). Rill and Gullies Erosion. In M. Dekker (Ed.), *Soil Erosion, Conservation and Rehabilitation* (p. 399). Marcel Dekker, Inc.

Hashim, G. M. (2003). *Managing Soil Erosion and Nutrient Depletion*. Malaysian Agriculture Research and Development Institute (MARDI).

Hashim, G. M., Ciesiolka, C. A. A., Yusoff, W. A., Nafis, A. W., Mispan, M. R., Rose, C. W., and Coughlan, K. J. (1995). Soil erosion processes in sloping land in the east coast of Peninsular Malaysia. *Soil Technology*, *8*(3), 215–233.

HASNOL, O., TARMIZI, A. M., and TAYEB, M. D. (2005). *Mpob Information Series : Bunch Ash: An Efficient And Cost-Effective K Fertilizer Source For Mature Oil Palm On Peat Under High Rainfall Environment 258* (258). Bangi, Selangor.

Havlin, J. L., Beaton, J. D., Tisdale, S. L., and Nelson, W. L. (1999). *Soil fertility and fertilizers: an introduction to nutrient management. Soil fertility and fertilizers: an introduction to nutrient management.* Prentice-Hall Inc.

Havlin, J. L., Tisdale, S. L., Nelson, W. L., and Beaton, J. D. (2014). *Soil fertility and nutrient management: An introduction to nutrient management*. *8th Edition. Pearson, Upper Saddle River* (Vol. 8). Pearson.

Henson, I. E. (1994). *Environmental impacts of oil palm plantations in Malaysia*. *PORIM Occasional Paper* (Vol. 33). Institiut Penyelidikan Minyak Kelapa Sawit Malaysia.

Ighodaro, I. D., Lategan, F. S., and Yusuf, S. F. G. (2013). The Impact of Soil Erosion on Agricultural Potential and Performance of Sheshegu Community Farmers in the Eastern Cape of South Africa. *Journal of Agricultural Science*, *5*(5).

IPNI. (n.d.). Nutrient Source Specifics - Compound Fertilizer. Retrieved January 25, 2018,from https://www.ipni.net/publication/nss.nsf/0/63E7EAC542B8352A852579AF007462C6/$FILE/NSS-04 Compound Fertilizer.pdf

JPS. (2010). *Guideline For Erosion And Sediment Control Plan*.

Kanapathy, K. (1976). *Guide to fertilizer use in Peninsular Malaysia*. *Malays,Minist Agric Rural Dev Bull* (Vol. 143).

Kashyap, R. K. (2009). *Soil Fertility, Fertiliser and Intergrated Nutrient Management*. New Delhi, India: Oxford Book Company.

Kee, K. K., and Chew, P. S. (1996). Nutrient Losses Through Surface Runoff and Soil Erosion - Implications for Improved Fertiliser Efficiency in Mature Oil Palms. In *1996 PORIM International Palm Oil Congress: Competitiveness for the 21st Century, Kuala Lumpur* (pp. 153–169).

Khalid, H., Ahmad, T. M., and Zulkifli, H. (2011). Nutrient Management and Agronomic Utilization of Wastes for Sustainable Oil Palm Production. In W. Mohd Basri, Y. M. Choo, and K. W. Chan (Eds.), *Further Advances in Oil Palm Research Volume 1* (pp. 310–340). Malaysian Palm Oil Board.

Khalid, H., Zin, Z. Z., and Anderson, J. . (2000). Nutrient Cycling in an oil plam plantation The effects of residue management practice during replanting on dry matter and nutrient uptake of young plam. *Journal of Oil Palm Research*, *12*(2), 29–37.

Kitson, R. E., and Mellon, M. G. (1944). Colorimetric Determination of Phosphorus as Molybdivanadophosphoric Acid. *Industrial & Engineering Chemistry Analytical Edition*, *16*(6), 379–383.

Kjeldahl, J. (1883). Neue Methode zur Bestimmung des Stickstoffs in organischen K??rpern. *Zeitschrift f??R Analytische Chemie*, *22*(1), 366–382.

Lægreid, M. (Marit), Bøckman, O. C., and Kaarstad, O. (Ola). (1999). *Agriculture, fertilizers, and the environment*. CABI.

Lal, R. (1990). *Soil Erosion in the Tropics. Principles and Management*. Mc-Graw-Hill.

Larum, D. (2017). *Long Lasting Fertiliser: When To Use A Slow Release Fertilizer.* Retrieved February 3, 2018, from https://www.gardeningknowhow.com/garden-how-to/soil-fertilizers/what-is-slow-release-fertilizer.htm

Lehmann, J., and Schroth, G. (2003). Nutrient Leaching. *Trees, Crops, and Soil Fertility*, , 151–166.

Liu, G., Zotarelli, L., Li, Y., Dinkins, D., and Wang, Q. (2014). Controlled-Release and Slow-Release Fertilizers as Nutrient Management Tools. *Horticultural Sciences Department, HS1255*, , 1–7.

Maene, L. M., Thong, K. C., Ong, T. S., and Mokhtaruddin, A. M. (1979). Surface wash under mature oil palm. In *Symposium on Water in Malaysian Agriculture,*

Kuala Lumpur (pp. 203–216).

McLaughlin, M. (2009). Technical Bulletin: Fertilisers and Soil Acidity. Retrieved August 16, 2018, from www.adelaide.edu.au/fertiliser

Moody, L. . (2006). Leaching and Illuviatoin. In R. Lal (Ed.), *Encyclopedia of Soil Science, Volume 2* (pp. 1022–1025). Marcel Dekker, Inc.

Morgan, R. P. C. (Royston P. C. (2005). *Soil erosion and conservation*. Blackwell Pub.

MPOB. (2017a). *Malaysian Oil Palm Statistics 2016*. Malaysian Palm Oil Board.

MPOB. (2017b). *Overview of the Malaysian Oil Palm Industry 2016*. Malaysian Palm Oil Board.

MPOB. (2019). *Overview of the Malaysian Oil Palm Industry 2018*. Malaysian Palm Oil Board.

Nachmansohn, J. (2016). *Minimized nutrient leaching through fertilizer management – An evaluation of fertilization strategies*. Swedish University of Agricultural Sciences.

Ng, P. H. C., Chew, P. S., Goh, K. J., and Kee, K. K. (1999). Nutrient requirements and sustainability in mature oil palms - an assessment. *The Planter*, *75*(880), 331–345.

Ng, S. K. (1977). Review of oil palm nutrition and manuring. Scope for greater economy in fertilizer usage. *Oleagineux*, *32*(5), 197–209.

Ng, S. K., and Thamboo, S. (1967). Nutrient contents of oil palms in Malaysia. I. Nutrients in reproductive tissue fruit bunches and male inflorescence. *Malaysian Agricultural Journal*.

Ng, S. K., Thamboo, S., and de Souza, P. (1968). Nutrient contents of oil palms in Malaya. II. Nutrients in vegetative tissues. *Malaysia Agriculture*.

Omoti, U., Ataga, D. O., and Isenmila, A. E. (1983). Leaching losses of nutrients in oil palm plantations determined by tension lysimeters. *Plant and Soil*, *73*(3), 365–376.

Paramanathan, S. (2003). Land Selection for Oil Palm. In *Oil Palm : Management for Large and Sustainable Yields* (pp. 27–58). International Plant Nutrition Institute (IPNI) and International Potash Institute (IPI).

Peryea, F. J., and Burrows, R. L. (1999). Soil acidification caused by four commercial nitrogen fertilizer solutions and subsequent soil pH rebound. *Communications in Soil Science and Plant Analysis*, *30*(3–4), 525–533.

Petronella, T. G. A., Mohd, K. Y., Nik, M. M., Goh, K. J., and Gan, H. (2009). Effect of N and K fertilizers on nutrient leaching and groundwater quality under mature oil palm in Sabah during the monsoon period. *American Journal of Applied Sciences*, *6*(10), 1788–1799.

Piggott, C. J. (1990). *Growing oil palms : an illustrated guide*. Inc. Society of Planters.

PORIM. (1994). *Environmental Impacts of Oil Palm Plantations*. Palm Oil Research Institute of Malaysia.

Pushparajah, E., and Chew, P. S. (1998). Integrated Nutrient Management for Sustaining High Yields of Plantation Tree Crop in Tropical Asia. In *Soil Science Conference of Malaysia*. Malaysian Society of Soil Science.

Pushparajah, E., Ng, S. K., and Ratnasingam, K. (1977). Leaching Losses of Nitrogen, Potassium and Magnesium on Peninsular Malaysia Soil. In *Conference on Chemistry and Fertility of Tropical Soils* (pp. 121–129). Kuala Lumpur: Malaysian Society of Soil Science.

Rao, V., Soh, A. C., Corley, R. H. V, Lee, C. H., and Rajanaidu, N. (1983). Critical Reexamination of the Method of Bunch Quality Analysis in Oil Palm Breeding. *PORIM Occasional Paper-Palm Oil Research Institute of Malaysia*.

Roslan, M., Noor, M., and Harun, M. H. (2004). The Role of Leaf Area Index (LAI) in Oil Palm. *Oil Palm Bulletin*, *48*, 11–16.

Shamsuddin, J., and Che Fauziah, I. (2010). *Weathered Tropical Soils : The Ultisols & Oxisols*. UPM Press.

Shaviv, A. (2001). Advances in controlled-release fertilizers. In *Advances in Agronomy* (Vol. 71, pp. 1–49). Academic Press.

Shukla, S., Hanlon, E. A., Jaber, F. H., Stoffella, P. J., and Obreza, T. A. (2010). Groundwater Nitrogen : Behavior in Flatwoods and Gravel Soils Using Organic Amendments for Vegetable, , 1–9.

Soil Moisture Equip Corporation. (2017). Soil Water Sampler, Model 1900. CA, USA: Soil Moisture Equipment Corp.

Soon, B. B. F., and Hoong, H. W. (2002). Agronomic Practices to Alleviate Soi and Surface Runoof Losses in an Oil Palm Estate. *Malaysian Journal of Soil Science*.

Staff, S. S. (2014). *Keys to Soil Taxonomy* (12th ed.). United States Department of Agriculture.

Tarmizi, A. M., and Tayeb, M. (2006). NUTRIENT DEMANDS OF Tenera OIL PALM PLANTED ON INLAND SOILS OF MALAYSIA. *Journal of Oil Palm Research*, *18*, 204–209.

Teoh, C. . (2002). *The palm oil industry in Malaysia: From seed to frying pan*. WWF Report.

Tessens, E., and Shamsuddin, J. (1983). *Quantitative Relationships between Mineralogy and Properties of Tropical Soils*. *Quantitative relationships between mineralogy and properties of tropical soils.* Universiti Pertanian Malaysia.

Thomas Mielke. (2017). Global Oil Supply, Demand and Price Outlook With Special Emphasis on Palm Oil. In *Palm Oil Trade Seminar, Iran*. Oil World.

Tiemann, T. T., Donough, C. R., Lim, Y. L., Härdter, R., Norton, R., Tao, H. H., Jaramillo, R., Satyanarayana, T., Zingore, S., and Oberthür, T. (2018). Feeding the Palm: A Review of Oil Palm Nutrition. *Advances in Agronomy*, *152*, 149–243.

Tinker, P. B. (1976). Soil requirements of the oil palm. In R. H. V. Corley, J. . Hardon, and B. . Wood (Eds.), *Oil Palm Research* (pp. 165–181). Elsevier, Amsterdam.

Trenkel. (2013). *Slow and Controlled-Release and stabilized Fertilizers*. *Journal of Chemical Information and Modeling* (Vol. 53).

Turner, P., and Gillbanks, R. (1974). *Oil palm cultivation and management. Incorporated Society of Planters*. Incorporated Society of Planters.

UP Bhd. (2019). *Annual Report 2018*. Teluk Intan.

Vasant, G., Krishnamurthy, V. N., Sudha, G., Manik, D., and Kalyani, P. (2009). *The Fertiliser Encyclopedia*. John Wiley & Sons, Ltd.

Xaviar, A., Ho, S. ., Vijiandran, J. R., and Gurmit, S. (2011). Managing coastal and alluvial soils under oil palm. In K. J. Goh, S. . Chiu, and S. Paramanathan (Eds.), *Agronomic Principles and Practice of oil palm cultivation* (pp. 641–694).

Xaviar, A., Paramanathan, S., and Lim, K. . (2004). Improvement of Oil Palm Performance on Marginal and Problem Soils and Difficult Terrain. In Y. . Tan and P. S. Chew (Eds.), *MOSTA Series of Seminar : Workshop 5*. Kuala Lumpur.

Yara.(2017).*Yara Fertilizer Industry Handbook 2017*. Yara International. Norway

Yara Inc. (2018). YaraMila PALMAE. Retrieved February 20, 2018, from http://www.yara.com.gh/crop-nutrition/products/yaramila/6753-yaramila-palmae-Remove/

Zaharah, A. R. (1987). Phosphorus Availability In An Acid Tropical Soil, , 294–303 from https://inis.iaea.org/collection/NCLCollectionStore/_Public/33/019/33019247.pdf?r=1&r=1

BIODATA OF STUDENT

Vijiandran Juva Rajah was born on 29 May 1976 in Klang, Selangor. He started his primary education at Batu Road Boys School, Kuala Lumpur in 1983 and subsequently at SRK Kelana Jaya (1), Kelana Jaya. He was among the first batch of students to enrol under the KBSR system introduced then. He completed his primary education in 1988 and joined Sekolah Menengah Seaport (now Sekolah Menengah Seri Permata) in Petaling Jaya again under the newly introduced KBSM education format for his secondary studies. He completed his Sijil Rendah Pelajaran (SRP) in 1991 and Sijil Pelajaran Malaysia (SPM) in 1993. In 1995, he completed his Sijil Tinggi Persekolahan Malaysia (STPM) in Sekolah Menengah Abdul Samad, Petaling Jaya.

On 30 June 1996, Vijiandran gained entry to Universiti Putra Malaysia (then Universiti Pertanian Malaysia) as the pioneer batch of Bachelor of Science Bioindustry. He majored in Land Resource Management and graduated with honours in 1999. Due to the economic turmoil faced by Malaysia during this period, he was offered to be a Graduate Research Assistant at the Department of Land Management, UPM where he had the opportunity to pursue his master's degree. He accepted the offer and graduated in 2007 with a Master of Science majoring in Soil Fertility and Management through his dissertation entitled "Association of Red-Tip of Pineapple Leaves With Nutrient Deficiency". In late 2011, he decided to pursue his PhD in Soil Fertility and enrolled himself at University Putra Malaysia.

Vijiandran joined United Plantations Berhad an 1stApril 2003, as a Cadet Assistant Manager and was subsequently confirmed as an Assistant Manager in 2004. After spending his first 2.5 years as a planter, Vijiandran was transferred to the company's research department as an Assistant Research Officer on 1st September 2005. Over the years, he rose in rank and he is currently the company's Senior Research Manager carrying out his duty as a senior agronomist with the company. He is currently active in the field of oil palm and coconut agronomic research focussing on soil fertility, crop nutrition and nutrient loss studies. In addition, he had also carried out reasonable work on soil survey and basic precision agriculture technologies for the company's estates both in Malaysia and Indonesia.

Vijiandran had authored and co-authored more than 20 papers for both journals and proceedings such as the Elsievier, Malaysian Journal of Soil Science and The Planter. Works on this study had been so far published in 4 proceedings and one journal. Another paper had been submitted for publication and is pending approval at the time of writing this thesis.

PUBLICATION

Vijiandran J.R., Husni M.H.A., Teh C.B.S., Zaharah A.R. and Xaviar A. (2017). Nutrient Losses Through Runoff from Severeal Types of Fertilisers Under Mature Oil Palm. *In Malaysian Journal of Soil Science vol 21. pp 113-121.* Malaysian Society of Soil Science.