

UNIVERSITI PUTRA MALAYSIA

NUTRIENT LOSS IN RUNOFF AND GROWTH RESPONSE OF IMMATURE OIL PALM FOLLOWING APPLICATION OF CONTROLLED-RELEASE FERTILIZERS

ALAGIE BAH

FP 2015 60



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

January 2015

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DEDICATION

Dedicated to Mbondi Bah (Late dad) Juma Sowe (Mum) Binta Bah (Wife)

Buba Sowe (Uncle)

Dr. Syed Omar Syed Rastan (Mentor)



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

NUTRIENT LOSS IN RUNOFF AND GROWTH RESPONSE OF IMMATURE OIL PALM FOLLOWING APPLICATION OF CONTROLLED-RELEASE FERTILIZERS

By

ALAGIE BAH

January 2015

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Implementation of sound fertilizer management program in the tropics is essential in optimizing production and economic returns. Controlled-release fertilizers (CRFs) are intended to supply plant nutrients in synchrony with crop demand, which should ultimately minimize nutrient loss from crop fields. Studies on the fate and plant response of CRFs in tropical oil palm agro-ecological fields are still lacking. In this study, a one-year field trial was established to investigate whether application of CRFs rather than conventional water-soluble mixture fertilizer can reduce nutrient loss and enhance growth of oil palm at the immature stage. Soil and nutrient loss were monitored in 2012/2013 under erosion plots of 16 m² each planted with immature old oil palm tree on a 10% slope gradient. Fertilizer treatments applied included granular and briquette forms of CRFs (AJIB[®] CRF) in 100% and 60% dosages, a conventional mixture fertilizer in 100% dosage and an unfertilized control. Water Erosion Prediction Project (WEPP) model was also used to predict runoff and soil erosion from the study field. On an annual basis, mean sediments concentration in runoff amounted to about 6.41 t ha⁻¹. On average, total captured runoff as percentage of annual rainfall amounted to 14 %, with yearly total rainfall events of 219 days. Nutrient loss was higher from mixture fertilizer treatments than those treated with CRF. Runoff loss of N was greater $(p=\le 0.001)$ in plots that received conventional mixture fertilizer, amounting to 7% of ammonium sulfate-N applied, and that with CRF application accounted for between 1-2% N loss. Runoff P losses were usually lower for all fertilized treatments than unfertilized control. Large runoff losses of K (13%) and Mg (15%) were observed in plots that received mixture fertilizer. However, runoff losses of K and Mg from applied CRFs were in the range of 4-7%. Meanwhile, runoff process exported less sedimentassociated nutrients, ranging from 0.39-0.93 kg N, 0.15-0.31 kg P, 1.03-2.14 kg K and 0.17-0.29 kg Mg ha⁻¹ yr⁻¹ in fertilized plots. Total yearly precipitation, number of rainfall events and soil loss were predicted fairly well by the WEPP model with a mean difference of 2% and 4% and 15%, respectively. However, the actual and simulated yearly runoff volume differed by 36%. Also, the WEPP model showed good tendency to predict monthly precipitation ($r^2 = 0.57$), rainfall days ($r^2 = 0.79$) and soil erosion (r^2 = 0.62). Prediction of monthly runoff was less accurate ($r^2 = 0.32$). Plant growth parameters such as frond number and bole diameter were significantly greater with granular CRF (100%) than the control and mixture treatments. In conclusion, CRFs proved effective in maintaining robust oil palm growth and in reducing runoffassociated nutrient loss compared to mixture fertilizer. This could be attributed to the fact that nutrient elements in CRFs are readily and slowly available for plant uptake over a given period.



 $\left(\mathbf{C}\right)$

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

KEHILANGAN NUTRIEN MELALUI AIR LARIAN DAN RESPON TUMBESARAN KELAPA SAWIT BELUM MATANG TERHADAP APPLIKASI BAJA LEPAS TERKAWAL

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Pelaksanaan program pengurusan baja yang baik di kawasan tropika adalah penting bagi memastikan pengeluaran dan pulangan ekonomi yang optimum. Baja lepas terkawal (CRFs) adalah bertujuan untuk membekalkan nutrien tumbuhan sesuai dengan keperluan tanaman, di samping meminimumkan kehilangan nutrien di kawasan ladang. Kajian ke atas keadaan dan respon tanaman terhadap CRF dalam bidang agro-ekologi kelapa sawit tropika masih belum mencukupi. Dalam kajian ini, ujian lapangan selama setahun telah diwujudkan untuk mengkaji sama ada penggunaan CRFs dan bukannya baja campuran larut air konvensional boleh mengurangkan kehilangan nutrien dan meningkatkan pertumbuhan kelapa sawit muda. Kehilangan tanah dan nutrien dipantau dalam tahun 2012/2013 pada plot hakisan 16 m² di mana setiap plot ditanam dengan pokok muda pada kecerunan 10%. Rawatan baja yang digunakan termasuk bentuk butiran dan briket CRFs (AJIB[®] CRF) pada 100% dan 60% dos, baja campuran konvensional pada dos 100% dan kawalan yang tidak dibaja. Model Projek Ramalan Hakisan Air (WEPP) juga digunakan untuk meramalkan aliran dan hakisan tanah dari plot kajian. Min kepekatan sedimen dalam air larian secara tahunan berjumlah kira-kira 6.41 t ha-1. Secara purata, jumlah air larian yang dikumpul sebagai peratus hujan tahunan adalah sebanyak 14% setiap tahun dengan jumlah peristiwa hujan sebanyak 219 hari. Kehilangan nutrien adalah lebih tinggi pada rawatan baja campuran jika dibandingkan denagan mereka yang dirawat dengan CRF. Kehilangan N melalui air larian adalah lebih besar (p = ≤ 0.001) pada plot yang menerima baja campuran konvensional, sebanyak 7% dalam bentuk ammonium sulfat-N yang ditabur, dan daripada CRF kehilangan N sebanyak 1-2%. Kehilangan P melalui air larian biasanya lebih rendah untuk semua rawatan yang diberi baja berbanding kawalan yang tidak dibaja. Kehilangan K (13%) dan Mg (15%) yang tinggi telah diperhatikan pada plot yang menerima baja campuran melalui air larian. Walau bagaimanapun, kehilangan air larian yang mengandungi K dan Mg dari CRFs yang digunakan adalah dalam lingkungan 4-7%. Sementara itu, air larian yang dieksport mengandungi mendakannutrien yang kurang, antara 0.39-0.93 kg N, P 0.15-0.31 kg, 1.03-2.14 kg K dan Mg 0.17-0.29 kg ha⁻¹ tahun⁻¹ pada plot yang dibaja. Jumlah hujan tahunan, beberapa peristiwa hujan dan hakisan tanah telah diramalkan dengan baik menggunakan model WEPP dengan perbezaan min sebanyak 2%, 4% dan 15% masing-masing. Walau bagaimanapun, jumlah air larian tahunan sebenar dan simulasi berbeza sebanyak 36%. Selain itu, model WEPP juga menunjukkan kecenderungan yang baik untuk meramal hujan bulanan (r2 = 0.57), bilangan hari hujan (r2 = 0.79) dan hakisan tanah (r2 = 0.62). Ramalan air larian bulanan adalah kurang tepat (r2 = 0.32). Parameter pertumbuhan tanaman seperti bilangan pelepah dan diameter pangkal batang nyata lebih besar dengan butiran CRF (100%) berbanding kawalan dan campuran rawatan. Kesimpulannya, CRFs terbukti berkesan dalam mengekalkan pertumbuhan kelapa sawit yang mantap dan mengurangkan kehilangan nutrien daripada air larian berbanding baja campuran. Perkara ini disebabkan oleh unsur-unsur nutrien dalam CRFs adalah tersedia dan secara perlahan boleh didapati untuk pengambilan tumbuhan dalam suatu jangka masa tertentu.



ACKNOWLEDGEMENTS

In the name of ALLAH, the Most Beneficent and the Most Merciful

I thank Almighty ALLAH (SWT) for granting me the wisdom, health and strength to undertake this research task

May Peace and Blessings be upon our Prophet Muhammad (SAW)

I would like to gratefully express my appreciation to Commonwealth Scholarship and Fellowship Plan (CSFP) through the Ministry of Education, Malaysia for the scholarship provided to pursue my PhD program. My deepest and sincere gratitude to Diversatech (M) Fertilizer Sdn. Bhd. for the sponsorship and logistical support provided throughout my PhD journey.

I would like to express my deepest and sincere gratitude to my committee chairman, Associate Professor Dr. Ahmad Husni Mohd Hanif for his outstanding intellectual expertise, guidance and support. His perpetual energy, wide knowledge and enthusiasm in research had greatly motivated me.

I am immensely grateful to Dr. Syed Omar Syed Rastan, my external committee member and Honorary President of Diversatech (M) Fertilizer Sdn. Bhd for providing me with the much needed financial assistance and for his unwavering intellectual support. Dr. Syed Omar's inspiring guidance and tremendous mentorship has made my work a thoughtful and rewarding journey.

I am deeply grateful to Dr. Christopher Teh Boon Sung, my internal committee member for his scholarly and constructive contribution, especially on the soil physics aspect of this work. My warm thanks are also due to Professor Dr. Mohd Rafii Yusop, internal committee member his intellectual support and guidance.

I extend my appreciation to Haji Syed Osman Syed Rastan (President), Syed Muhamad Amir Syed Omar (Executive Director), Haji Muhammad Fairus Bin Hussain (General Manager), Dr. Muhammad Imran Khan (Technical Manager), Mr. Najmi Yani Bin Ahmad (Financial Executive), Haji Faisal, Farhan, Khusairi, Firdaus, Fakhruddin and Fiqree of Diversatech (M) Fertilizer Sdn. Bhd for their support and the co-operation rendered during the tenure of my work.

During this work I have collaborated with many colleagues and academicians for whom I have great regard. I am extremely thankful to the Faculty of Agriculture, Universiti Putra Malaysia, especially the academic and technical staff at the Department of Land Management for providing me with the necessary facilities for the research. In particular, I wish to express special thanks to the late Junaidi Jaafar (May Allah grant him a place in Jannah), Mr Rosli, Madam Nor Asma, Norfarhana binti Abdul Khalil, Puan Sarimah Bt Hashim, Jamil Bin Omar, Mohd Fuzi Bin Mohd Sharif and Noorashikin Salha Bt Zamzuri for their assistance in my research. I wish to sincerely thank all those who assisted me directly or indirectly in the research work. I would like to thank my fellow postgraduate students and friends for their comradeship and encouragement. I would especially like to thank Dr. Qurban Ali Panhwar, Yussof Salam Mohamed, Ahmed Muhammed Aida, Dawda Badgie, Dr. Babucarr Njie, Lamin Sanyang, Omar Sowe, Lamin Drammeh, Aunty Haddy Jallow, Sister Binta Bah, Samba Bah, Rehema M Said, Bangally Kanuteh, Dr. Ali Reza Bahraminejad, Assan Sowe, Pa Samba Sowe, Momodou Jallow, Paul L Mendy, Peter L Mendy, Paul Fanu Mendy, Dr. Demba B Jallow, Carlos Gomez, Matthew Mendy and many others for their constant support and wholehearted solidarity.

Special appreciation is also expressed to my wife, Binta Bah for her care, support, patience and love. My deepest gratitude goes to my family for their unflagging love and support throughout my life. I offer my profound gratitude to Uncle Buba Sowe for the inspiration and exemplary guidance in my life. I am also grateful to my siblings and relatives who have always encouraged me during this time. Last, but certainly not the least, I am forever indebted to my late father (Mbondi Bah) and mum (Juma Sowe) for their enduring love, support and prayers.

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

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LIST OF ABBREVIATIONS

AnnAGNPS	Annualized Agricultural Non-Point Source Pollutant Loading model
ANSWERS	Areal Non-Point Source Watershed Environment Response Simulation
CCF	Common Compound Fertilizer
CREAMS	Chemicals Runoff and Erosion from Agricultural Management Systems
CRFs	Controlled-release Fertilizers
EPIC	Environmental Policy Integrated Climate
FAO	Food and Agriculture Organization
FBMPs	Fertilizer Best Management Practices
FFB	Fresh Fruit Bunch
FRE	Fertilizer Recovery Efficiency
FUE	Fertilizer-use efficiency
KINEROS	Kinematic Runoff and Erosion Model
LCP	Legume Cover Plants
МРОВ	Malaysia Oil Palm Board
NUE	Nutrient Use Efficiency
POME	Palm Oil Mill Effluent
RUSLE	Revised Universal Soil Loss Equation
SRFs	Slow-release Fertilizers
SWAT	Soil and Water Assessment Tool
USDA	United States Department of Agriculture
WEPP	Water Erosion Prediction Project

6

CHAPTER 1

INTRODUCTION

1.1 Background

The world's population is projected to reach around 8 billion by 2030, which will disproportionally require an equivalence of 60% increase in global food production through intensive agricultural practices (Fresco, 2003). Globally, the world's oilseed market is characterized by rising demand for consumption of vegetable oils (Oil World, 2008). Owing to its capability of producing five to seven times more oil per hectare than all other oil crops, the planting of oil palm (*Elaeis guineensis* Jacq.) is currently a lucrative business in some countries in the humid tropics (Sheil *et al.*, 2009). The crop has emerged as the most important source of vegetable oil due to its very high productivity, versatility and profitability compared with other oil seeds such as soya bean, rapeseed, sunflower and peanut.

Oil palm cultivation is one of the most rapidly expanding agricultural ventures in the tropics (Comte et al., 2012), attaining nearly 15 million hectares in 2009 and accounting for 10% of the world's permanent crop land (FAOSTATS, 2011; Sheil et al., 2009). According to estimates by Corley (2009) in 2050, the demand for vegetable oil will reach between 201 and 340 Mt and that of palm oil alone is expected to be in the range of 93 and 190 million Mt. In 2012 alone, the estimated global production of total palm oil was about 65 million Mt (USDA, 2012). Oil palm accounts for nearly 30% of the world's vegetable oil, of which Malaysia and Indonesia are the world's largest producers of palm oil, commanding nearly 85% of the total global annual production of 46.5 million Mt of crude oil palm (Oil World, 2013). In Malaysia, oil palm production increased from 1.5 million hectares in 1985 to over 5 million hectares as of 2012, with an estimated total export value of over \$20 billion in 2013 (MPOB, 2014). Oil palm is unique in the sense that with good agronomic management under optimum agro-ecological conditions, it can potentially yield over 10 Mt of oil per hectare. However, according to recent observation, current yields are below this figure and typically about 4-6 t ha⁻¹ for the best commercial plantations and between 3-4 t ha⁻¹ for the small holders (Murphy, 2014). This yield disparity can be partly due to low efficiency of conventional fertilizers used in most oil palm plantations. On average, the current fresh fruit bunch (FFB) yield in Malaysia is about 19 t ha⁻¹ (MPOB, 2014).

1.2 Importance of fertilizers in oil palm

Fertilizer input is a key determinant in our quest to augment food production and plays a vital role in our pursuit to attain global food security (Yan *et al.*, 2008). It has been noted that our efforts to cater for the world's increasing food demands may not be achieved in the absence of fertilizers, and commercial fertilizers alone account for 40-60% of global food production (Stewart and Roberts, 2012; Roberts, 2009). Oil palm is predominantly cultivated on highly weathered soils such as Ultisols and Oxisols. These soils are chemically acidic and low in fertility (Shamshuddin and Anda, 2012). Fertilizers are therefore crucial in oil palm production, accounting for 50-70% of field operational costs and about 25% of the total cost of production (Caliman *et al.*, 2007;

Goh and Härdter, 2003). In general, the oil palm requires quite large quantities of fertilizers to achieve good yields (Comte *et al.*, 2012). In Malaysia, mineral fertilizers account for more than 90% of the fertilizers used by all the farming systems (FAO, 2004) and the main types are conventional water-soluble forms.

The main goal of fertilizers is to increase or sustain optimal crop yield (Chien et al., 2009). Therefore, improving fertilizer use efficiency is pertinent to both fertilizer manufacturers and users. Accelerated use of chemical fertilizers in the tropics during the past few decades raises major environmental and economic concerns regarding sustainability. In the tropics, the high level of precipitation on deeply weathered tropical soils, often results in rapid depletion of nutrients, eventually leaving such soils incapable of sustaining crop production. Frequent application of large amounts of conventional water-soluble fertilizers in crop fields under high rainfall conditions may lead to substantial loss of nutrients through various pathways such as surface runoff, soil erosion, leaching and volatilization, consequently causing environmental contamination and financial loss. Excess application of conventional compound fertilizer can potentially cause huge loss of nutrients to the surface or sub-surface soil environment, subsequently affecting water quality, human health and biodiversity (Goulding et al., 2008). The amount of nutrient runoff from crop fields in the tropics can be substantial and is mainly influenced by weather, rainfall intensity, soil and aquifer characteristics, land management practices, fertilizer management and the chemical properties of the nutrient compounds used (American Farm trust, 2013). It is believed that even when such fertilizers are applied at the recommended agronomic rates, only 30-50 % of the added nutrient (nitrogen) to the soil is utilized by the plant (McAllister et al., 2012). Previous study on corn-based cropping systems reported that most of the systems had nitrogen recovery efficiency below 50% (Cassman et al., 2002). For example, urea application is associated with low crop utilization efficiency, causing environmental contamination (Rahman et al., 2009). In oil palm ecosystems, the recovery of applied fertilizers is inherently low, due to susceptibility of the fertilizers to surface runoff and leaching losses (Gerendas et al., 2013).

Our goal of achieving long-standing agricultural sustainability in the tropics necessitates judicious soil management during field production (Prochnow, 2008). Improving efficient crop productivity can be attained by adopting the concept of 4R nutrient stewardship - right source, right rate, right time and right place (Roberts, 2010). Proper implementation of improved fertilizer-use efficiency (FUE) is associated with the benefits of boosting crop production, augmenting farm profitability and minimizing environmental contamination emanating from nutrient loss (Chien *et al.*, 2009). In the humid tropics, considering the fact that oil palm is mostly grown on highly weathered soils, coupled with problems of low fertilizer efficiency, there is need to develop improved fertilizer management programs that are economically viable and ecologically compatible. It is strongly believed that boosting crop yields and closing the gap between actual and attainable yield can be accomplished by the implementation and advancement of fertilizer management approaches and technologies (Stewart and Roberts, 2012).

Among several crop management practices geared towards improving crop nutrient use efficiency (Aziz and El-Asry, 2009; Prasad, 2009), the use of controlled- (CRFs) and slow-release (SRFs) fertilizers appear promising for widespread use in agriculture (Jarosiewicz and Tomaszewska, 2003; Blaylock *et al.*, 2005; Motavalli *et al.*, 2008; Nelson *et al.*, 2008). In comparison with the use of conventional water-soluble

fertilizers, the gradual release of nutrients from CRFs can match better with plant demand at the different growth stages. According to Isherwood (2000) of the International Fertilizer Industry Association, the use of controlled release fertilizers in tropical agro-eological regions where rainfall is high can be agronomically advantageous. Research efforts on the potential efficiency of CRFs under tropical environmental and agronomic cropping systems are not extensively explored.

Oil palm is a heavy nutrient feeder, and requires proper agronomic management to obtain robust growth and high yields. Efficient fertilization is pertinent for oil palm growers due its cultivation in highly weathered soils under high precipitation agroecological conditions. In Malaysia, most of the large scale oil palm plantations have their own tailored fertilization programs. The fact that most oil palm agronomists recommend fertilizers in the form of singly applied straight fertilizers or in the form of dry blends, poses a colossal challenge to oil palm growers. Presently, one of the major challenges of the oil palm industry is the shortage of labor to carry out large scale fertilization in several splits. There is a need for research efforts to review the impacts of current fertilizer management practices in oil palm fields, with the aim of providing vital information in planning and implementing management interventions that can improve yields and farm profitability.

To date, there have been limited reports regarding the performance of CRFs in oil palm production. This research was undertaken to determine both surface runoff loss and plant response to application of briquette and granular controlled-release (AJIB[®] CRF) and conventional mixture fertilizers under immature oil palm cropping.

1.3 Justification of the study

Despite their crucial roles in improving crop productivity and profitability, the nutrient use efficiency (NUE) of most fertilizers remained significantly low in the tropics. This raises serious economic and environmental concerns, especially in the light of much greater chemical fertilizer use in oil palm fields in the tropics. In most oil palm fields, nutrients are prone to runoff and leaching loss, which ultimately result in poor crop performance, and increased risk of environmental contamination. Therefore, proper adoption of best fertilizer management strategies in cropping systems is fundamental in attaining optimum crop production potential, input efficiency and minimal environmental contamination. The quest to boost global food production requires efficient management of chemical fertilizers in the soil-plant environment. Improvement of fertilizer efficiency is vital to reduce excess nutrients entering the environment and to increase economic returns.

Malaysia's oil palm plantations predominantly rely on the application of chemical fertilizers, accounting for over 50% of the field operational costs. Due to periodic events of high rainfall intensity (> 60mm/hr), there is high risk of occurrence of surface runoff. As a result of this, coupled with problems of inherent low soil fertility, oil palm productivity is affected. Another major challenge to the oil palm industry in Malaysia is the shortage of labor. Presently, the standard fertilizer practices involve the application of straight or water-soluble fertilizers in 4-6 splits per annum, which is both costly and labor intensive. In order to curb the growing challenge of labor shortage with over 5.2 million hectares of oil palm cultivation in Malaysia, there is need to adopt improved fertilizer use stewardship for efficient nutrient utilization by the crop.

The use of CRFs can reduce fertilizer application to 2 splits per annum; however there are limited reports about their performance on tropical crops such as oil palm, especially at the immature growth stage. So far, studies on the extent of nutrient efficiency and loss through runoff in the Malaysia's oil palm plantations have only been limited to straight fertilizers (Kee and Chew, 1996). Against this backdrop, field studies need to be conducted to address this knowledge gap in an effort to provide improved and efficient fertilizer recommendation program for sustainable oil palm production.

1.4 Research objectives

This study was primarily aimed at investigating the effect of application of controlledrelease (AJIB[®] CRF) and conventional water-soluble fertilizers (mixture of straight fertilizers) on runoff loss of nutrients and growth of oil palm at the immature stage.

Specifically, the study was conducted to investigate the following objectives:

- 1. To quantify and compare surface runoff loss of nutrients among conventional water-soluble and controlled-release fertilizers (briquette and granular) under immature oil palm cropping.
- 2. To evaluate nutrient release patterns of conventional water-soluble and controlledrelease fertilizers.
- 3. To predict runoff and soil erosion from oil palm crop field using Water Erosion Prediction Project (WEPP) model.
- 4. To evaluate the effects of controlled-release and water-soluble fertilizers on growth and mineral nutrition of oil palm during immature stage.
- 5. To quantify the economic value of fertilizer loss resulting from application of controlled-release and water-soluble fertilizers.

1.5 Significance of the study

Efficient fertilizer management is essential in in improving crop growth and yields. This requires adopting new fertilizer management practices and technologies in our agronomic practices. The advancement of new fertilizer technologies, coupled with innovative management approaches from research and development can increase crop yield significantly without compromising quality of the environment. In consideration of the long term economic implications and environmental factors associated with fertilizer use in oil palm plantations, there is a need to evaluate the fate of added fertilizers in oil palm fields. The findings from this study provide useful information concerning crop use and surface runoff loss of nutrients from the addition of fertilizers in oil palm fields. Furthermore, the prospects of using CRFs in oil palm plantations under tropical agro-ecological conditions are explored. The study also investigates the economic significance of fertilizer loss aimed at improving fertilizer management in oil palm fields. The findings of this study provide important information to agronomists, field managers, environmentalists and policy makers to make informed decisions. In

this experiment, considering climatic, slope and soil conditions, runoff and soil erosion predictions can emploed using process-based models such as WEPP. Since runoff plays a major role in nutrient and sediment transport, implementation of WEPP model in oil palm cropping fields may help in agronomic management practices.

1.6 Scope and limitations of the study

This study primarily focused on plant response and surface runoff loss of added fertilizers from immature oil palm. The investigation was concentrated on runoff loss of nutrients due to the fact that runoff and topsoil erosion are considered to be usually greater than loss associated with leaching. Due to time and logistical constraints, the investigation could not be conducted on mature oil palm fields. The nutrient loss investigation was only limited to surface runoff and erosion pathways. Other pathways of nutrient loss such as leaching and volatilization were not explored in this study. Results from nutrient loss study should be exercised with caution especially in extrapolating the data for use in other field conditions due to huge field variability that may relate to palm age, weather, soil properties, land gradient and contrasting agronomic conditions. This study also applied field scale erosion with emphasis on surface runoff that contributes to soil loss. Processes related to nutrient loss, subsurface flow and seep were not considered in this study, it is hoped that many of the results obtained here will resonate in similar contexts within Malaysia.

1.7 Organization of the thesis

The thesis is organized into four chapters. Chapter one pinpoints background, justification, research objectives, significance, scope and limitations of the study. Chapter two presents review of relevant literature. Chapter three provides comprehensive study on runoff loss of nutrients; nutrients release patterns, runoff and soil loss prediction using WEPP model, growth and mineral nutrition of oil palm and economic value of nutrient loss from application of fertilizers. Chapter four provides a summary of major findings of the study. It further articulates recommendations and possible future directions and perspectives of the research.

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