EFFECTS OF COMMERCIAL FERTILIZERS ON SOIL INVERTEBRATES DIVERSITY AND ITS RELATIONSHIP WITH ENVIRONMENTAL VARIABLES IN OIL PALM PLANTATION

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THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF MASTER OF AGRICULTURAL SCIENCE

FACULTY OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH
2017

UNIVERSITY MALAYSIA SABAH

BORANG PENGESAHAN STATUS TESIS

JUDUL: **EFFECTS OF COMMERCIAL FERTILIZERS ON SOIL INVERTEBRATES DIVERSITY AND ITS RELATIONSHIP WITH ENVIRONMENTAL VARIABLES IN OIL PALM PLANTATION**

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DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, equations, summaries and references, which have been fully acknowledged.

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ACKNOWLEDGEMENT

I would like to thank Associate Professor Dr. Suzan Benedick for her moral supports, ideas, comments, finance and time. Without her kind guidance, I would not be able to finish my master degree research successfully. I would like to express my gratitude to Associate Professor Dr. Bakhtiar Effendi Yahya, my co-supervisor, for his comments and suggestions to improve my thesis writing, and project leader Dr. Mohamadu Boyie Jalloh. I also would like to thank all lecturers in Faculty of Sustainable Agriculture for all their comments and all the laboratory staff who had helped me throughout my research especially Mdm. Anika, Mr. Panjiman, Mr. Zilpiree and Mdm. Ahjia.

I also would like to extend my gratitude to all my family members and friends for their supports and prayers. Special thanks to my parents (Mr. Ador Garang and Mdm. Sue Kar), my brother (Dawson) and sisters (Sarah and Joan) who encourage me to pursue my master degree, and for all their prayers and moral supports. I am also indebted to my friends (Nurul Ain, Lydianie, Robin, Fadzilah, Noor Khairani, Vella, Charlene, Siti Wardah, Nik Nur Rasyidah, Lee Yin Yin and Jhonly) for helping me throughout my research and their moral supports.

Last but not least, million thanks to those who had helped me directly and indirectly throughout my master study.

Kimberly Anak Ador
21 March 2017

ABSTRACT

The main objective of this study was to investigate the diversity and faunal composition of soil invertebrates in oil palm plantation. It was conducted from May 2013 until June 2014 at Sekong Estate, Genting Plantation. The relationship between soil invertebrates, ecological characteristics and types of fertilizer applied in the soil was also examined. The soil samples were collected using soil auger with 30 cm depth. All soil invertebrates were extracted from soil samples using Berlese-Tullgren funnel with 40 W light bulb. In total, ten treatments with four replicates of chemical fertilizer, organic fertilizer and empty fruit bunch, were used in this study. Sampling was conducted ten times, with the total of 400 samples (10 treatments and four replicates per sampling) were collected. A total of 671 individuals from 15 species (four species of Acari, four species of Coleoptera, and one species of Diptera, Thysanoptera, Haplotaxida and Psocoptera respectively) were recorded during the study. Highest diversity (Shannon's index; H' = 1.87), evenness (Simpson's index; D_S = 8.3) and richness (Margalef's index; D_M = 2.29) were found in Treatment 5. There were significance difference in soil invertebrates alpha diversity among the ten treatments (T1-T10; $P<0.05$); species diversity (Shannon-Wiener index; $F_{9,39} = 5.126$, $P<0.001$), species evenness (Simpson index; $F_{9,39}$ = 3.603, $P<0.010$) and species richness (Margalef index; $F_{9,39} = 4.783$, $P<0.001$). There were no significant differences in soil invertebrates beta diversity among the ten treatments (Whittaker index; Mantel test; Z=73.19, P<0.77 and Morisita-Horn index; Mantel test; Z = 47.39, P = 0.39). There were significant differences in species sensitivity index among families (one way ANOVA; $F_{11,14} = 14.27$, p = 0.03) and the importance of species among families of soil invertebrates (one way ANOVA; $F_{11,14} = 0.00$, p = 0.00). There were significant relationships between PCA factor score 4 and alpha diversity (one way ANOVA; $F_{9,39} = 27.87$, $P<0.00$) indicating that number of vegetation and light penetration on oil palm plantation floor have an effect on diversity of soil invertebrates species. Relationship between species alpha diversity and seasonal variation showed no significant correlation. T5 (LSM+EFB) was recommended to be applied as the fertilizer in the oil palm plantation. T5 promotes highest species diversity, richness and evenness of soil invertebrates in this study site. The abundance of soil invertebrates proved that it can improve the physical properties of soil and the minimal inputs of chemical fertilizer helps to increase the abundance of soil invertebrates.

Key words: oil palm plantation, soil invertebrate, environmental variables, diversity

ABSTRAK

KESAN PENGGUNAAN BAJA KOMERSIAL TERHADAP KEPELBAGAIAN SPESIES INVERTEBRATA TANAH DAN HUBUNGANNYA TERHADAP PEMBOLEHUBAH PERSEKITARAN DI LADANG KELAPA SAWIT

Objektif utama kajian ini adalah untuk mengkaji kepelbagaian dan komposisi fauna invertebrata tanah di ladang kelapa sawit dan kajian ini dijalankan dari Mei 2013 hingga Jun 2014 di Sekong Estate, Genting Plantation. Hubungkait antara invertebrata tanah, ciri-ciri ekologi dan jenis baja digunakan di dalam tanah juga dikaji. Sampel tanah diambil dengan menggunakan 'auger' tanah pada kedalaman 30 cm. Invertebrata tanah diekstrak daripada sampel tanah menggunakan corong Berlese-Tullgren dengan mentol 40 W. Secara keseluruhannya, sepuluh rawatan dengan empat ulangan baja kimia, baja organik dan tandan kosong digunakan dalam kajian ini. Persampelan dijalankan sebanyak sepuluh kali dan jumlah kutipan sampel ialah sebanyak 400 (10 rawatan dan empat replikasi) telah dikumpulkan. Sebanyak 671 spesimen invertebrata tanah daripada 15 spesies (Acari, Coleoptera, Diptera, Thysanoptera, Haplotaxida dan Psocoptera) telah direkodkan semasa kajian. Rawatan lima menunjukkan kepelbagaian spesies (indeks Shannon; H' = 1.87), kesetaraan spesies (indeks Simpson; D_S = 8.3) dan kekayaan spesies (indeks Margalef; D_M = 2.29) yang tertinggi berbanding rawatan yang lain. Terdapat perbezaan ketara bagi kepelbagaian alfa antara sepuluh rawatan (T1-T10; P<0.05); kepelbagaian spesies (indeks Shannon-Wiener; $F_{9,39}$ = 5.126, P<0.001), kesetaraan spesies (indeks Simpson; $F_{9,39}$ = 3.603, P<0.010) dan kekayaan spesies (indeks Margalef; $F_{9,39}$ = 4.783, P<0.001). Tiada perbezaan ketara bagi kepelbagaian beta antara sepuluh rawatan (indeks Whittaker; ujian Mantel; Z = 73.19, P<0.77 dan indeks Morisita-Horn; ujian Mantel; Z = 47.39, P=0.39). Terdapat perbezaan ketara bagi indeks sensitiviti spesies antara famili invertebrata tanah (ANOVA sehala; $F_{11,14}$ = 14.27, p = 0.03) dan kepentingan spesies antara famili invertebrata tanah (ANOVA sehala; $F_{11,14}$ = 0.00, p = 0.00). Terdapat hubungan ketara antara PCA skor faktor 4 dan kepelbagaian alfa (ANOVA sehala; $F_{9,39}$ = 27.87, P<0.00). Hubungan antara kepelbaian alfa dan variasi musim menunjukkan tiada hubungan ketara. Rawatan lima (LSM+EFB) disyorkan untuk digunakan sebagai baja di lading kelapa sawit. Rawatan lima menggalakkan kepelbagaian, kesetaraan dan kekayaan spesies invertebrata tanah tertinggi di tapak kajian ini. Kelimpahan invertebrata tanah membuktikan ia dapat memperbaiki ciri-ciri fizikal tanah dan input baja kimia yang minimum dapat membantu meningkatkan kelimpahan invertebrata tanah.

Kata utama: ladang kelapa sawit, invertebrata tanah, pembolehubah persekitaran, kepelbagaian

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ha	hectare
<	less than
>	more than
°	degree
%	percentage

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Commercial fertilizer helps in maintaining the supply of nutrients required for plant growth and production. Commercial fertilizer with the content of organic and inorganic fertilizers, can be referred to as a substance that contains one or more recognized plant nutrients, which is then used for plant nutrient content for the use of promoting plant growth and sustaining soil fertility (Kala, Rosenani, Fauziah, Ahmad, Radziah and Rosazlin 2011; Linderman and Davis 2004). Both organic and inorganic sources of nutrients are essential for promoting sustainable crop production (Linderman and Davis 2004). The choice of fertilizer is often based on specific formulations of major elements such as nitrogen (N), phosphorus (P) and potassium (K), which known collectively as NPK. In Malaysia, commercial fertilizers have been widely used to improve crop yield and quality of plant health in monoculture oil palm plantation (Verheye, 2010; Zakaria, 2006).

As the world's second largest producer of palm oil after Indonesia, Malaysia has now consider this commodity's production to be vital for the economy of the country. Oil palm was first planted widely in Peninsular Malaysia since 1917 and between 1990 to 2005, the area of oil palm in this country has increased to 4.2 million ha from 1.8 million ha (Hamzah, Phan, Yong and Ridzuan, 2014). Heavy application of agricultural inputs generally contributed to biodiversity loss, environmental degradation, and deterioration of soils condition (Singh, Jain, Gupta and Nema, 2013; Brühl and Eltz, 2010; Fayle, Turner, Snaddon, Chey, Chung, Eggleton and Foster, 2010; Mikula, Laška, Šarapatka, Tufová and Tuf, 2010; Rana, Rana, Khan and Sohail, 2010). Furthermore, the application of excessive chemical fertilizers on agricultural land have shown to affect the soil quality and the survival of soil dwelling fauna (Rai, Ashiya and Rathore, 2014).

The soil community in agricultural area is closely related to fertilization because the application of fertilizers can enhance soil fertility and promote soil rehabilitation (Williams, Borjesson and Hedlund, 2013; Coleman and Whitman, 2005). Jiang, Wang, Liusui, Sun, Zhao and Liu (2015) also found that the diversity and abundance of soil community in grey dessert soil in China, were higher in soil treated with organic fertilizers such as sheep manure and crop residues compared to chemical fertilizers. However, more evidence on the effects of commercial fertilizers on soil fauna composition in the agricultural plantation is still required to further confirm previous findings. To date, the effect of agricultural practices on biodiversity has not been well understood, particularly in oil palm plantation.

Soil invertebrate diversity is expressed as species richness, species diversity and species evenness. The effects of chemical, organic, and bioorganic fertilizers towards soil invertebrate diversity will be investigated in this study. The arthropods are often used as bioindicators for estimating the anthropogenic impacts on landscape and ecological ecosystem (Paoletti, 1999; Paoletti and Bressan, 1996). The shortage of humus and leaf litter layer in the recently formed plantations were often associated with the loss of the top soil surface due to water runoff and soil erosion, which estimated can reach more than twice the amount measured on land under forest cover (MacKinnon, 1996). Invertebrates have the ability to minimize surface runoff by altering surface roughness and promoting water infiltration as they create structural porosity in soils (Lavelle, Decaëns, Aubert, Barot, Blouin, Bureau, Margerie, Mora and Rossi, 2006). Paoletti and Bressan (1996) also previously found that soil animal activity is an actual indicator of soil fertility.

Soil invertebrates are important for effective function of the ecosystem processes such as nutrient cycling, maintenance of soil fertility and decomposition. They also play important roles in stabilizing and forming soil structure. They redistribute and decompose organic matter in the soil which contribute to soil structure, recycling nutrients and maintain ecological niche (Rana *et al.*, 2010). Soil invertebrates can act as bioindicators, biocontrol agents, soil structure improvement, and recovery and ecosystem management (Neese, 2004). These soil invertebrates ability as bioindicators was further confirmed by Wicaksono, Buana and Situmorang (2011), in their study on soil contamination before and after a bioremediation process. Soil is probably one of the most complex and poorly studied habitats of terrestrial ecosystem thus, highly important for further additional studies. In this study, soil invertebrate communities in oil palm plantation were studied at 0 cm to 30 cm of soil depth.

Activities of soil invertebrates include the process of breaking down litter into soil, maintaining and building of structural aggregation and porosity in soils through casting, burrowing, and nesting activities (Lavelle *et al.*, 2006). Soil invertebrates are important in the soil ecosystem, especially in the decaying of soil organic matter and nutrient cycling (Wardle and Giller, 1997). They are proven to be effective in altering litter decomposition rates, soil aeration, nutrient mineralization, primary production, and other ecosystem services linked to the soil ecosystem function and agroecological conservation (Six, Feller, Denef, Ogle, Sa and Albrect, 2002). In order to understand anthropogenic pressure on soil ecosystem, the environmental variables comprising of soil pH levels, temperature, ground cover, soil texture, drainage, slope and light penetration were also taken into consideration with sampled organisms from each habitat.

1.2 Justification of study

This study will examine the responses of soil community other than microorganisms to oil palm soil that is treated with commercial fertilizers that comprise of chemical, organic and bioorganic. This finding is expected to provide basic information on the effects of different types of fertilizers towards the diversity and faunal composition of soil invertebrates. The results from this study can be utilized to enhance knowledge in similar areas and to encourage conservation priorities for sustainable oil palm management in Malaysia, which is previously lacking.

1.3 Objective

The aim of this study is to examine the diversity and faunal composition of soil invertebrates in oil palm plantation. The specific objectives are:

i. To investigate the effects of fertilization on alpha and beta diversity of soil invertebrates in oil palm plantation, and
ii. To examine the effects of oil palm soil treated with commercial fertilizers on soil invertebrates communities in relation to environmental variables and their ecological traits.

CHAPTER 2

LITERATURE REVIEW

2.1 Oil palm

Oil palm (*Elaeis guineensis* Jacq.) originated from West Africa. It grows in the wild and then become an important agricultural crop in most of tropical countries. The major oil-palm-producing countries include Indonesia, Malaysia, Democratic Republic of the Congo, Nigeria, Brazil, the Ivory Coast, Costa Rica, Colombia, and Ecuador (Corley, 2003). Palm oil is the most important vegetable oil in the world (Teh, 2016). It was introduced to Malaya as an ornamental plant and then being commercialized in 1917. Oil palm is a monoecious crop which produces both female and male flowers from the same tree. Malaysia is the second largest producers of palm oil in the world and is currently contributing 49% of world palm oil exports and 39% of world oil production (Kongsager and Reenberg, 2012). The oil palm trees planted in Malaysia are mainly Tenera variety, which is a hybrid between the Dura and Pisifera (MPOB, 2016). Each tree produces 10 to 25 kg of fresh fruit bunch. The oil palm produces two types of oils; crude palm oil and crude palm kernel oil. The crude palm oil was obtained from the fibrous mesocarp while the crude palm kernel oil from the kernel. The products of oil that produced from the fruits are crude palm oil (CPO), palm kernel oil (PKO), refined bleached and deodorised palm oil (RBD), neutralized palm oil (NPO), palm stearin, palm olein and palm kernel meal (Corley, 2003). Oil palm biomass from the fresh fruit bunches (FFB) are palm oil effluent (POME) 58%, empty fruit bunch 21%, mesocarp fibres 15% and kernel shells 6% (Teh, 2016). During trees planting, contour terracing is carried out along steep slopes on hilly land. It is to prevent soil degradation and to conserve soil fertility (Shamshuddin and Noordin, 2011). Pruned fronds were placed along the slope to reduce soil erosion and loss of fertilizer.

Palm oil is utilized worldwide as pharmaceuticals, foods and cosmetics. In addition, palm oil also used as biodiesel and contributing to the fuel requirements of Malaysia (Paterson, Sariah and Lima, 2013). Oil palm is a tropical tree crop which is primarily grown for the production of vegetable oil and the most important supplier of vegetable oil in the world (Verheye, 2010). High demands for palm oil worldwide have made oil palm as the most valuable plantation crop in Malaysia and contributes to high National Gross Export. Palm oil is most productive during the nine to 15 years after planting (MPOB, 2016). At the age of 25 years, the maintenance is high and the trees are too tall to harvest. Oil palm is a typical crop of the rainy tropical lowlands. The tree needs deep soil, constant moisture throughout the year, and relatively stable high temperature. For optimal production and growth the tree needs balanced climatic conditions, particularly moisture and light supply (Verheye, 2010).

2.2 Soil

Soil serves as one of the most important sources of biodiversity. Soil ecosystems consist of a large variety of fauna such as microarthropods, meso and macrofauna (Menta, 2012). Soil is a huge ecosystem which harbours diversity of various activities (Agwunobi and Ugwumba, 2013). Soil is composed of four broad elements which are minerals (45%), water (25%), air (25%) and organic matter (5%). The organic matter component is a vital living system of the soil (Pattison, 2006). Soil compactions have a tendency to severely restrict aeration, movement and water storage unless porosity is formed by powerful biological or physical processes (Lavelle *et al.*, 2006). Due to vigorous agricultural practices, there is notable loss of biodiversity in agricultural ecosystems compared to natural ecosystems (Agwunobi and Ugwumba, 2013). Soil sustains most agro-silvo-pastoral production system through the favourable services that they mediate: nutrient cycling, soil formation and primary production (Lavelle *et al.*, 2006).

Most nutrients in soil that are accessible for plant growth rely upon the complex interactions between microorganism, plant roots and soil fauna (Agwunobi and Ugwumba, 2013). The organic component is made up of the residues of dead animals and plants, and living organisms that consume other soil organisms and organic matter. The amount of these elements may vary slightly between soils but in the soil management system, the organic element is the most variable (Pattison, 2006). Soil pH ranges from 6.08 to 6.89 is favorable for the proliferation of soil invertebrates. Their distribution is very much affected by a highly acidic condition in soils, which causes only a few of them can survive in such condition (Agwunobi and Ugwumba, 2013). The plant grows on tropical soils within pH 4-8 and requires open areas, as it cannot compete with faster-growing trees. It does not grow under continuous flooding but can tolerate fluctuating water tables with periods of standing water (Paterson *et al.*, 2013).

Soils that have poor physical, chemical or hydrological properties will certainly have poor invertebrate communities (Stork and Eggleton, 1992). Nakamura (1988) showed that rotary digging and direct drilling decreased the abundance of oribatid, other mites, Enchytraeidae (Annelida), and springtails and other invertebrates, while the application of organic mulch enhanced the abundance of the mentioned fauna. High maintenance conditions (herbicide, fertilizer and insecticide treatments) cause greater biomass and abundance of invertebrates (Stork and Eggleton, 1992).

2.2.1 Oil palm plantation's soil

Oil palm trees can be grown on a wide range of soils (Verheye, 2010). In Malaysia, 87% of oil palm is planted on highly weathered soil and 13% on peat soils (Gunarso, Hartoyo, Agus and Killeen, 2013; Shamshuddin and Noordin, 2011). Four types of soil commonly used to plant oil palm are well structured soils (15-35% clay content and unrestricted rooting volume), deep sandy or loam soils (limited water holding capacity), moderately deep soils (variable texture, but slightly impeded by dispersed gravel, or shallow soils and rapid run-off), and soils with variable texture (very high water table or with rooting restricted to less than 1 m by a hard pan) (Verheye, 2010). However, most favoured soils to plant oil palm in Malaysia are of the order Oxisols and Ultisols. When oil palm being planted in these soils that have low fertility status, further soil degradation can happen. Therefore, additional fertilizers were applied to compensate nutrient loss from soils (Law, Zaharah, Husni and Siti Nor Akmar, 2012). Soil moisture is more important than nutrient supply as it can be corrected by the application of fertilizer. The crop must be planted on undulating or flat land. Planting it on steep slopes increased the risk of the cost of establishment and production, as well as soil erosion (Verheye, 2010).

The oil palm cultivation is restricted to sloped and hilly area (Moradi, Teh, Husni and Ishak, 2012). High rainfall and slope steepness leads to soil erosion and, water and nutrient losses through runoff that causes soil fertility to decrease. Declining in soil fertility would badly affect oil palm growth, nutrition, and yield. Terraces are often built to reduce soil erosion, and therefore avoid water and nutrient losses on sloping lands (Moradi *et al.*, 2012). However, terracing caused soil compacting due to the usage of heavy machineries and reduction in soil fertility as the fertile top of the soil layer was removed. Thus, some plantations opt to plant oil palm trees without building any terraces. Most soils used to plant oil palm are low in fertility (Law *et al.*, 2012). Hence, fertilizers were applied to the soil to compensate for the nutrient removal from the soil by plant. However, application of fertilizers such as nitrogen without proper preventative measure will lead to severe impact to the environment such as pollution (Law *et al.*, 2012).

2.3 Invertebrates

Invertebrates represent most of the animal species, biomass in land, sea, and freshwater ecosystems (Colburn, Weeks, and Reed, 2007). Invertebrates are found in terrestrial and nearly all aquatic habitats. They range in size from gigantic (eg. deep sea squid) to microscopic (eg. nematode). Their body complexity is also highly variable, ranging from highly complex bodies (mollusks and arthropods) to very simple design of sponges (Porifera, in which cells are not organized into tissues) (Hodgson, 2009). Invertebrates drive ecosystem processes. Invertebrates are crucial in nutrient cycling and processing, and energy in ecosystems. They are essential as consumers (herbivores, predators, and detritivores) and prey (secondary producers). Invertebrates have distinctive value for scientific study, monitoring, and assessment because they represented by diverse habitats and large populations, with short life cycle and fast population growth. Invertebrates have important economic impact by their influence on forestry, agriculture (soil development, controlling important pest species, and pollination of plants), and industry (Niwa, Sandquist, Crawford, Frest, Griswold, Hammond, Ingham, James, Johannes, Johnson, Kemp, LaBonte, Lattin, McIver, McMillin, Moldenke, Moser, Ross, Schowalter, Tepedino and Wagner, 2001).

2.3.1 Soil invertebrates

Soil arthropods are plentiful all over the terrestrial ecosystem (Nor Farikhah Haneda and Novia Tri Marfuah, 2013). Soil invertebrates which are involved in the first step of breaking down of litter are categorized as saprophytophages and primary decomposers (Eisenbeis, 2006). Soil invertebrates are highly diverse. According to current estimation, soil invertebrates may constitute about 23% of the total diversity of living organism. It is because of the unique restriction encountered by life in the subterranean environment (Lavelle *et al.*, 2006). Soil invertebrates are the most important part of agricultural biodiversity, and mostly determine the basic functions and structure of natural ecosystems (Cock, Biesmeijer, Cannon, Gerard, Gillespie, Jiménez, Lavelle and Raina, 2012). Fauna is an important component of soil environment (Rotimi and Uwagbae, 2014). It is involved in numerous aspects of partial controlling of microbial activities, organic matter decomposition, nutrient cycles and crumbly soil structure. Arthropods have the ability to fill every niche in the ecosystem (Agwunobi and Ugwumba, 2013). Compared to above-ground fauna, the role of soil invertebrates are poorly represented in relevant web sites and scientific literature (Cock *et al.*, 2012). Belowground biota provides a much larger diversity of organisms than the aboveground biota (Wardle, 2006).