UNIVERSITI PUTRA MALAYSIA

GREENHOUSE GASES EMISSION FROM OIL PALM PLANTATIONS CONVERTED FROM DIFFERENT LAND USES

NURUL IZZATI BINTI MAT AKHIR

FPAS 2016 11

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By

NURUL IZZATI BINTI MAT AKHIR

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

August 2016

DEDICATION

Dedicated to my beloved parents, Mat Akhir Bin Zain and Faridah Binti Salleh and Sarah Azzahra for their endless love, support, understandings, sacrifices, motivation, advice and encouragement.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

GREENHOUSE GASES EMISSION FROM OIL PALM PLANTATIONS CONVERTED FROM DIFFERENT LAND USES

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August 2016

Chair: Faradiella Binti Mohd Kusin, PhD
Faculty: Environmental Studies

The environmental impacts with regard to agro-based biofuel production have been associated with the impact of greenhouse gas (GHG) emissions. This is particularly related with the release of nitrous oxide (N_2O) emission which result from the plantation activities throughout the production of palm oil. Therefore, this study aims to evaluate on GHG emissions from oil palm plantations converted from different land uses. In this study, field GHG emissions during plantation stage of palm oil-based biofuel production have been evaluated in association with different age of oil palm and land conversion scenarios for oil palm plantation development. Three different sites of different land conversion prior to oil palm plantation were chosen; transformed land-use (large and small-scales) and logged-over forest. Field sampling for determination of soil N-mineralization and soil organic carbon (SOC) was undertaken at sites according to the age of palm, i.e. < 5 years (immature), 5-20 years and >21 years (mature palms). Data of N-fertilizer application was also obtained from scheduled fertilizing scheme at one site to observe the variation of nitrous oxide emissions over years. The field data were incorporated into the estimation of N_2O and the resulting CO_2-eq emissions as well as for estimation of carbon stock changes. Irrespective of the land conversion scenarios, the N_2O emissions were found in the range of 6.47-7.78 kg N_2O-N/ha resulting in 498-590 kg CO_2-eq/ha. There was no apparent difference of N_2O emissions between different land conversion scenarios for oil palm plantation development. However, the amount of N_2O emissions were slightly higher for immature oil palms (< 5 years) compared to mature palms (> 5 years) for all types of land use conversion. The resulting CO_2-eq emissions follow the same trend as for the N_2O emission, i.e. emission is slightly higher during early stage of oil palm development. The N_2O emission constituted the largest portion of GHG emissions among the major inputs of GHGs during the plantation stage of oil palm development, whereby the contribution of N from organic matter decomposition was found significant. On the other hand, the conversion of tropical forest into oil palm plantation has resulted in relatively higher GHG emissions (i.e. 4 times higher and carbon stock reduction by >50%) compared to transformed land use for oil palm development. The conversion from previously rubber plantation into oil palm plantation would increase the carbon savings (19% in increase) thus sustaining the

environmental benefits from the palm oil-based biofuel production. Therefore, the results from this study have highlighted the contribution of GHG emissions from oil palm plantation of different stages and with associated land conversion scenarios. The findings would be of useful contribution to site-specific cases of GHG emissions with regard to oil palm plantation development for biofuel production.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBEBASAN GAS RUMAH HIJAU DARI PERUBAHAN LADANG KELAPA SAWIT YANG BERBEZA GUNA TANAH

Oleh

NURUL IZZATI BINTI MAT AKHIR

Ogos 2016

Pengerusi: Faradiella Binti Mohd Kusin, PhD
Fakulti: Pengajian Alam Sekitar

Impak pada alam sekitar dengan pengeluaran biofuel yang berasaskan pertanian telah dikaitkan dengan isu pelepasan gas rumah hijau. Fokus kepada kaitannya dengan pelepasan gas nitrous oksida yang terhasil daripada aktiviti perladangan di seluruh proses pengeluaran minyak sawit. Oleh itu, kajian ini dijalankan bertujuan untuk mengenalpasti pelepasan gas rumah hijau dari perubahan ladang kelapa sawit yang berbeza guna tanah. Kajian lapangan pelepasan gas rumah hijau ketika fasa penanaman kelapa sawit akan diambil kira serta kaitannya dengan umur ladang kelapa sawit yang berbeza dan juga senario perubahan tanah. Terdapat tiga kawasan lapangan kelapa sawit yang berbeza perubahan tanah ladang kelapa sawit telah dipilih iaitu bentuk guna tanah yang berubah merangkumi skala besar serta kecil dan hutan log. Mineral N tanah dan organik karbon tanah yang berbeza peringkat umur iaitu < 5 tahun (muda), 5-20 tahun dan > 21 tahun (matang) juga dikenal pasti di kawasan lapangan. Data pembajaan N telah diambil dari jadual pembajaan di salah satu kawasan kajian untuk mengetahui variasi pelepasan gas nitrous oksida sepanjang tahun. Manakala data dari lapangan dalam kajian ini akan digunakan untuk pengiraan N_2O dan juga pengiraan $CO_{2\text{-eq}}$ serta perubahan stok karbon dalam tanah. Tanpa mengambil kira senario perubahan tanah, pelepasan gas N_2O adalah diantara 6.47-7.78 kg N_2O-N/ha yang menghasilkan 498-590 kg CO_2-eq/ha. Mengikut kajian ini, jumlah pelepasan N_2O didapati adalah tinggi untuk peringkat tanaman muda < 5 tahun berbanding dengan peringkat tanaman matang (< 25 tahun) untuk semua jenis perubahan guna tanah. Keputusan pelepasan $CO_{2\text{-eq}}$ juga menunjukkan perkembangan yang sama dengan keputusan pelepasan N_2O. Pelepasan N_2O juga menunjukkan penyumbangan yang terbesar dari segi input utama pelepasan gas rumah hijau ketika fasa perkembangan pertaniaan kelapa sawit serta N dari bahan pengurai organik juga menunjukkan keputusan yang signifikan dalam kajian ini. Selain itu didapati juga, perubahan hutan tropikal kepada ladang kelapa sawit menyebabkan pelepasan yang tinggi (4 kali lebih tinggi dan pengurangan stok karbon sebanyak >50%) berbanding dengan guna tanah yang berubah untuk penanaman kelapa sawit. Manakala perubahan dari ladang penanaman getah kepada ladang penanaman kelapa sawit menunjukkan peningkatan penjimatan karbon sehingga 19%, oleh itu ia dapat mengekalkan manfaat kepada alam sekitar ketika penghasilan kelapa sawit. Maka, keputusan kajian ini telah

menekankan pada penyumbangan dalam pelepasan gas rumah hijau dari ladang kelapa sawit yang berbeza peringkat umur serta senario perubahan tanah. Penemuaan kajian ini juga bermanfaat sebagai sumbangan kepada kajian spesifik lapangan yang berkaitan dengan pelepasan gas rumah hijau yang merujuk di kawasan penanaman kelapa sawit untuk produksi biofuel.

ACKNOWLEDGEMENTS

First and foremost, I would like to offer my heartfelt appreciation and most gratitude to my supervisor, Dr. Faradiella Binti Mohd Kusin for her continuous support and invaluable guidance for my master study, for her patience, motivation and enthusiasm. During my master study, she provided advice and shared a lot of her expertise, research insight and ideas. I simply could not imagine having a better advisor and mentor for master study. I believe that one of the main gains of my master study was working with Dr Faradiella Bt Mohd Kusin.

I am deeply indebted to my dear family Mat Akhir Bin Zain, Faridah Binti Salleh and Sarah Azzahra, who deserve special attention for their unconditional support and also my friend Nuruljannah Khairuddin.

I would like to thank UPM for providing Graduate Research Fellowship (GRF) and research facilities to conduct my master study. I consider it an honor to work with all the administrative and technical staffs of the Faculty of Environmental Studies for helping me throughout my study.

I certify that a Thesis Examination Committee has met on 25 August 2016 to conduct the final examination of Nurul Izzati binti Mat Akhir on her thesis entitled "Greenhouse Gases Emission from Oil Palm Plantations Converted from Different Land Uses" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Wan Nor Azmin bin Sulaiman, PhD
Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Ahmad Makmom bin Abdullah, PhD
Associate Professor
Faculty of Environmental Studies
Universiti Putra Malaysia
(Internal Examiner)

Hj. Mohd Ekhwan Hj. Toriman, PhD
Professor
Universiti Sultan Zainal Abidin
Malaysia
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 26 January 2017

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

Faradiella Bt Mohd Kusin, PhD
Senior Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Ferdaus@Ferdius Bt Mohamat Yusuff, PhD
Senior Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

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ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
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This is to confirm that:

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Signature:	
Name of Chairman of Supervisory Committee:	Faradiella Mohd Kusin,PhD
(On Maternity Leave)	

Signature:	
Name of Member of Supervisory Committee:	Ferdaus@Ferdius Bt Mohamat Yusuff, PhD

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LIST OF ABBREVIATIONS

cm	Centimeter
EFB	Empty fruit bunch
FFB	Fresh fruit brunch
GHG	Greenhouse gases
g CO_2-eq/MJ	Gram of carbon dioxide equivalent per mega joule
Ha	Hectare
km^2	Kilometer square
kg N/ha	Kilogram of nitrogen per hectare
kg N_2O-N/ha	Kilogram of nitrous oxide emission per hectare
kg CO_2-eq/ha	Kilogram of carbon dioxide equivalent per hectare
LOF	Logged over forest
Mha	Mega hectare
TLU	Transformed land use
t C/ha	tonnes of carbon per hectare
t CO_2-eq/ha	tonnes of carbon dioxide equivalent per hectare
W m^{-2}	Watt per square meter

CHAPTER 1

INTRODUCTION

1.1 Background

The environmental aspect regarding greenhouse gas emissions and impact associated with the process and utilization of biofuel to support the sustainability of agro-based energy industries have become the interest of many relevant sectors. Biofuel production from palm oil has been promoted and initiated in Malaysia since a few years back so as to sustain energy production using alternative source of bio-energy and to reduce the dependency on fossil fuel. Environmental impacts in terms of energy balance and greenhouse gas (GHG) balance would be of great concern when addressing this issue with regard to sustainability of palm oil-based biofuel production (Siangjaeo et al., 2011; Hansen et al., 2014).

Palm oil production chain includes several important elements, i.e. system boundaries in typical life cycle inventory, which have been discussed in many life cycle assessments for oil palm-related studies (e.g. Henson, 2004; Schmidt, 2007; Siangjaeo et al., 2011; Castanheira et al., 2014). Generally, it is known that land use changes (often related to carbon stock changes), oil palm plantation (agricultural stage) and palm oil extraction phases significantly contribute to the emissions of greenhouse gases over the life cycle of palm oil production. The GHG emissions from palm oil production have generally been categorized as the emissions arising from operations during oil palm growing and fresh fruit bunch (FFB) processing (i.e. emissions related to the use of fertilizer, use of fuel for internal transportation, use of fuel in palm oil mill and emissions from palm oil mill effluent), and the emissions arising from carbon stock changes (i.e. during the development of new plantation and during the operations of plantations (Klaarenbeeksingel, 2009).

Studies regarding the oil palm production and the concerns on the environmental issues focusing on greenhouse gas emissions had been discovered by many previous research, however there are still limited studies comparing the amount of N fertilizer and N-mineralized and also the amount of N_2O and CO_2-eq in oil palm plantation of different scales. Therefore, this study provides an evaluation of field-determined data to help strengthen a detailed analysis with higher degree of confidence. The data may also be useful for evaluation of site-specific emission for area of concern. In this study, the emissions arising during the plantation of palm oil production were estimated. Field determination of the greenhouse gases emitted during agricultural stage may not be relatively straightforward as it requires the understanding of detailed elements that contribute to the emissions. Castanheira et al. (2014) stated that contributions of fertilizers and fuel were the main input. These elements contribute significantly to the release primarily of N_2O alongside CO_2 and CH_4 (Kim and Dale, 2008; Inselsbacher et al., 2011).

Generally, high demand in palm oil is reflected by the growing need for oil crops (e.g. oil palm, soybeans, rapeseed and sunflower seed), vegetable oils and non-food uses (e.g. biofuels, paints and detergents) (FAO, 2012). In year 2012, the global consumption for palm oil was estimated to be 52.1 million tons, representing the highest consumed among the 17 oils and fats that reach three billion people in 150 countries (Sime Darby, 2012). Malaysia and Indonesia contribute about 84% of world's palm oil production followed by Thailand, Columbia, Nigeria, Papua New Guinea and Ecuador. Note that, the oil crops products also include the consumption for non-food purposes for example biodiesel. Palm oil-based biodiesel has been introduced globally as a step to overcome the deficiency of fossil fuels and as alternative of bio-energy sources. Malaysia, through the Malaysia Palm Oil Board (MPOB) in 2006 had established its first biodiesel commercial plant to initiate commercialized use of biodiesel in the country. The growing agricultural land area for oil palm in Malaysia reflects the large worldwide demand in palm oil production in Malaysia up to 2011. A total area of about 500, 000 km^2 has been planted with oil palm and the rapid growth has been seen in the period 1965–1970, 1970–1975, and in 1975–1980, due to the crop diversification program (MPOB, 2014).

1.2 Overview of GHG emissions related to oil palm plantation

Carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) are the potent gases that contribute to GHG emission. N_2O emissions to atmosphere grew by about 50% due mainly to increased use of fertilizer and the growth of agriculture (IPCC, 2007). Furthermore, field N_2O emission plays a major role in the GHG emission from soils N inputs to crop, while the emission of CH_4 comes primarily from livestock (Castanheira et al., 2014; Synder et al., 2009). N_2O is produced in agricultural soils by microbial transformation of nitrogen (N) containing compounds such as fertilizer and animal dung and urine (Giltrap et al., 2014). According to Corley and Tinker (2003) more than half of the fertilizer use in Malaysia is used in the palm oil industry. Furthermore, Malaysian soils are highly weathered which is suitable for palm oil planting but it requires high N-fertilizer input in order to maintain high yield output, resulting in increase in production cost as well as inducing negative impacts to the environment (Law et al. 2012). Hence, in this study, the emissions due to the plantation stage activities of palm oil production were highlighted.

It is generally known that among the factors that contribute to the increase of N_2O includes fertilized soil in agro-industrialization (Hewitta et al., 2009; Vandermeer et al., 2009; Akhir et al., 2014). Application of inorganic N-fertilizers can contribute to the effect of greenhouse gases through increasing emissions of N_2O, CO_2 and CH_4 from soil (Treseder, 2008; Inselsbacher et al., 2011). Siangjaeo et al. (2011) also found that application of N-fertilizer is the main source of N_2O emission, which is among the major greenhouse gases during plantation stage. N_2O can be emitted as a result of nitrification and denitrification processes in natural ecosystems (Giltrap et al., 2014). Therefore, increase in N-fertilizer in soil may directly enhance N_2O emission because N_2O is produced naturally in soils through the process of nitrification and denitrification (IPCC, 2000). It has been found that soil microbial processes also have influence on the production and consumption of N_2O from soils. The processes are, to a certain extent controlled by the soil oxygen content, temperature, mineral N content in organic matter and pH (Mosquera et al., 2007; Yuan et al., 2016). Furthermore, N-fertilizer was typically applied to enhance rapid growth of oil palm through the root respiration and generally this will lead to increasing CO_2 emission in the atmosphere. The direct and indirect N_2O emissions include; direct emission of N as N_2O, leaching to groundwater as nitrate, and volatilization of N as NH_3 (IPCC, 2000; Millar et al., 2010). In oil palm plantation, the inputs of nitrogen come from synthetic fertilizers and crop residues including decomposition of organic matter residues (IPCC, 2000). In Malaysia, expansion of palm oil plantation is said to have occurred primarily on logged-over forest and on former rubber and coconut plantation (Wicke et al., 2011). Abdullah and Nakagoshi (2007) revealed that oil palm and rubber plantations appeared as the major agricultural land uses in natural landscapes, and found that these land use changes had caused forest fragmentation in some areas. Carbon loss is resulted when the natural habitats on peat soils are being transformed to palm oil plantation. Therefore, carbon emission from the agricultural stage of oil palm plantation was also emphasized in this study.

1.3 Problem statement

In Malaysia, about 32,600 km^2 of land was planted with oil palm which corresponds to 41% of the agricultural land use and 10% of the total land area (Schmidt, 2010). During the interventions, issues such as the type of agricultural practices (e.g. estate or small holder that affect the oil palm yield) and type of cultivated soils (e.g. mineral or peat soils) are often associated with the extent of land degradation for this agricultural purposes. Important environmental concerns have emerged concerning the impacts of oil palm area expansion, in particular concerning the carbon stocks due to land use changes. Greenhouse gas (GHG) emissions from palm oil production have generally been related to the use of fertilizer and emissions from Palm Oil Mill Effluent (POME), and also the emission from changes in the carbon stocks. This includes in particular changes in aboveground and underground biomass and soil organic matter (Castanheira et al., 2014). The increased demand for palm oil-based biofuel has promoted the changes in land use. Land use changes may affect the carbon content in soil (often regarded as the carbon stocks), which is released into the atmosphere thereby contributing to the GHG emissions (Siangjaeo et al., 2011; Castanheira et al., 2014). While it has been found that some land use conversions for oil palm plantation development have resulted in carbon savings (e.g. Klaarenbeeksingel, 2009), some studies have also highlighted the negative effect of transforming the forest and peatlands into oil palm plantations, i.e. the associated carbon debt (e.g. Fargione et al., 2008; Danielsen et al., 2008). Because it has been known that globally the oil palm area expansion is to a great extent influenced by the carbon stock changes due to changes in land use, site- and country-specific investigation on the resulting emissions would help in determining potential for future oil palm plantation development. Therefore, this study focuses on the emissions during the plantation stage of palm oil production which is mainly associated with the N-related emissions. While it is known that factors such the effect of CN ratio and microbes in different soils, and weather conditions may have effects on GHG emission, these are not the main scope of the study and are minimally discussed throughout the discussion.

1.4 Significance of study

Recently, the extension on palm oil industry has received much attention especially on the aspect of GHG emission. The impact is also significant for palm oil plantation particularly when associated with different agricultural land use changes. However, field experiment data would provide more reliable evaluation so as for verification of specific emission from the reported data. The direct N emissions include contribution from fertilizer use and other elements such as from decomposition of organic matter residues returned to soils (N-mineralization) (Schmidt, 2010; Yuan et al., 2016). Additionally, the oil palms may also need supplementary inputs of nitrogen from application of empty fruit bunch (EFB) and treated palm oil mill effluent (POME) apart from addition of phosphate and potassium inputs (Castanheira et al., 2014). These elements contribute significantly to the release primarily of N_2O alongside CO_2 and CH_4 (Kim and Dale, 2008; Inselsbacher et al., 2011).

Various techniques can be adopted to determine the GHGs emission in the field, examples by using chamber measurement techniques (e.g. Hadi et al., 2005; Furukawa et al., 2005; Melling et al., 2007; Zhang et al., 2014; Goa et al., 2014). Such methods enable quantification of the amount of gas release in the field. In this study, the amount of N fertilizer and the soil N-mineralization from decomposition of soil organic matter were determined from field data. Quantification of mineralized-N in soil organic matter has not been widely investigated for oil palm plantation especially in Malaysian cases (Hansen et al., 2014). In fact, this fraction of N (i.e. the soluble N) has significant contribution to the overall N-related emissions (Schmidt, 2010). Additionally, the soil organic carbon (SOC) content was also determined to relate the amount of carbon stocks and land use changes in oil palm plantations of different categories.

1.5 Objectives

This study aims to evaluate on GHG emissions from oil palm plantations converted from different land uses. The specific objectives are;

1. To determine the amount of N fertilizer and N-mineralized in soil for oil palm plantation of different scales.
2. To estimate the amount of nitrous oxide (N_2O) and carbon equivalent (CO_2-eq) emissions in oil palm plantations of different ages.
3. To determine the carbon stock changes due to different agricultural land use scenarios for oil palm plantation.

1.6 Research hypothesis

1. Amount of N fertilizer and N-mineralized in soil vary according to different ages of plantation.
2. Amount of N_2O and CO_2-eq would be high at immature stage (<5 years of plantation.
3. Carbon stock changes would be different due to different conversion of land use for oil palm plantation.

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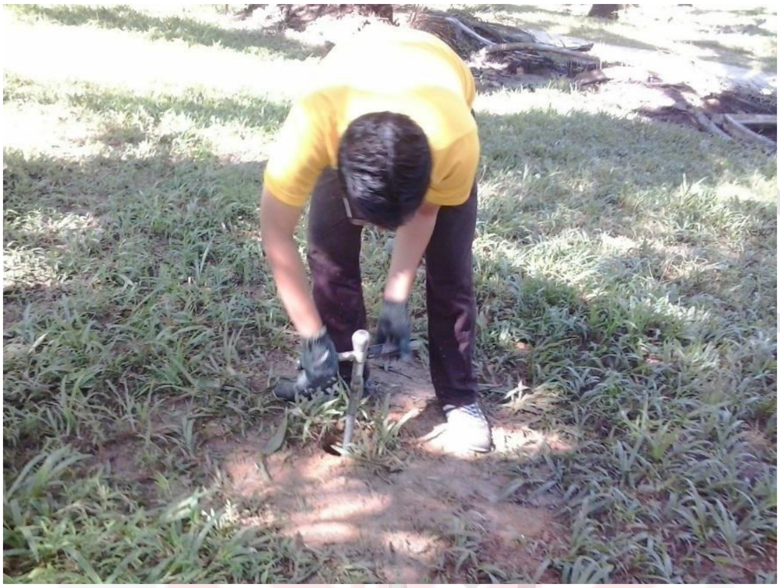
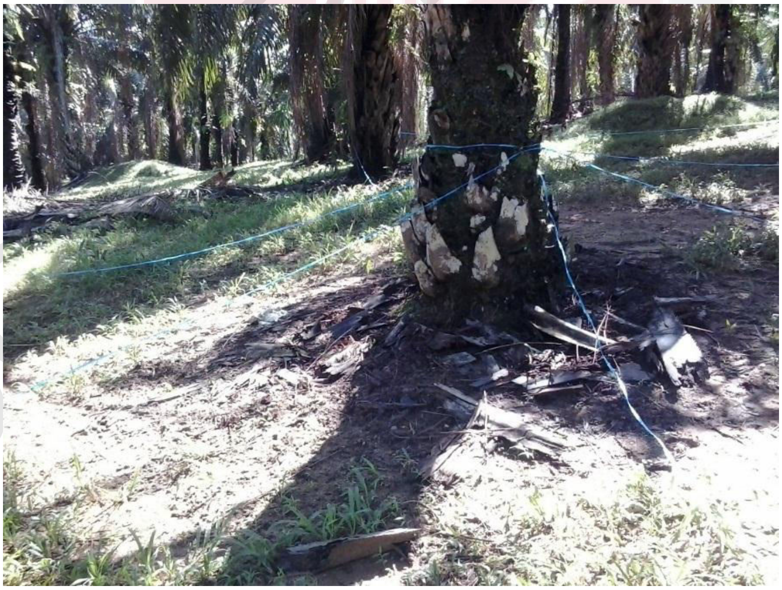
APPENDICES



Appendix 1: Soil sampling by using auger.



Appendix 2: Schematic soil sampling in sampling sites

Appendix 3: Soil sample analysis

BIODATA OF STUDENT

The student, Nurul Izzati Binti Mat Akhir, was born on 23rd April 1990, at Sik, Kedah Darul Aman. She obtained Malaysian Education Certificate from Sekolah Kebangsan Ayer Puteh, Kedah in 2002. Then she obtained her Malaysian Higher Education Certificate in Sekolah Menengah Sains Pokok Sena, Kedah in 2007. In 2012, she graduated in Bachelor of Applied Science in Biodiversit, Universiti Malaysia Terengganu, Malaysia. The author's email is nurulizzatimatakhir@gmail.com.

LIST OF PUBLICATIONS

Akhir, N . I . M., Kusin, F . M., Mohamat-Yusuff, F., Awang, M. & Hamka, F. (2014). Nitrous Oxide Emission from different Land Use Changes Associated with Oil Palm Plantation. *Journal of Agriculture and Environmental Sciences, 3*(2), 421-431.

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