UNIVERSITI PUTRA MALAYSIA

VERTICAL AND HORIZONTAL EMISSIONS OF GREEN HOUSE GASES FROM A PINEAPPLE (Ananas comosus L. Merr) TROPICAL PEAT SOIL

ALICIA VANESSA JEFFARY

FSPM 2017 1

VERTICAL AND HORIZONTAL EMISSIONS OF GREENHOUSE GASES FROM A PINEAPPLE (*Ananas comosus* L. Merr) TROPICAL PEAT SOIL

By

ALICIA VANESSA JEFFARY

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

January 2017

DEDICATION

Dedicate to my families and friends.

Thank you for everything

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

VERTICAL AND HORIZONTAL EMISSIONS OF GREENHOUSE GASES FROM A PINEAPPLE (*Ananas comosus* L. Merr) TROPICAL PEAT SOIL

By

ALICIA VANESSA JEFFARY

January 2017

Chairman : Professor Ahmed Osumanu Haruna, PhD
Faculty : Agriculture and Food Sciences (Bintulu Campus)

Peat soils are important natural resources. Peat sols have been cleared, developed, and cultivated for large scale plantations such as oil palm due to their positive contribution to Malaysia's economic growth in agriculture sector. However, these developments contribute to the emissions of greenhouse gases (GHGs). However, concerns by NGOs have been expressed that increasing cultivation of pineapples on peat soils lead to increase in the emissions of harmful greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). To date, there were limited information of GHGs emissions from pineapple cultivation and also inadequate data on horizontally and vertically soil GHGs emissions in peat soil profile. Thus, this study was carried out to determine GHGs emissions horizontally and vertically and to quantify horizontal and vertical GHGs emissions from a drained tropical peat soils from a drained tropical peat soils cultivated with pineapple (*Ananas comosus* (L.) Merr. Horizontal and vertical movements of GHGs were measured from a drained tropical peatland with *Ananas comosus* (L.) Merr. at Malaysian Agricultural Research and Development Institute (MARDI) Saratok, Sarawak, Malaysia. Soil GHGs flux sampling *via* closed chamber method (I and L-shaped closed chambers) and was carried out for 24 hours at a 6 hour interval (between 0600 hr to 0600 hr). Soil GHGs flux sampling were carried out once a month in July and August 2015 which represent dry seasons and September and December 2015 which represent wet season. The GHGs concentration was measured using a Gas Chromatography (GC – Agilent 7890A). Tropical peat soils cultivated with Ananas comosus (L.) Merr. contributed to 79.7 % of CO_2, 20.1 % of N_2O, and 0.2 % of CH_4 based on the yearly basis regardless of the differences in diurnal transportation; horizontal and vertical emission. Soil GHGs were emitted the most through horizontal transportation with 70.84 % CO_2, 18.72 % N_2O, and 0.19 % CH_4 compared to 8.85 % CO_2, 1.38 % N_2O, and 0.02 % CH_4 in vertical transportation. The emission of CO_2 was influenced by depth of water table and temperature. It is generally believed that lowering of peats water table leads to emission of higher CO_2 emission because this process leads to exposure of peat soils to oxidation. Factors influencing N_2O production include peat temperature, soil

moisture, water-filled pore space, and nitrogen status of the peat. Seasonal variation in CH_4 flux was higher in the wet seasons due to rainfall; this might have increased the water table of the peat soil. Therefore, it is hoped that from the findings of this study, farmers have an idea regarding the appropriate approach and methodology in managing GHG emissions especially from peat soils and so as to improve the accuracy and subsequently minimize controversies. It is also a hoped that through this study, it will provide insights on farm management procedures in dealing with the emission of the GHG such as the appropriate peat soil land management, fertilization, types of crop to be cultivate and others. Last but not least, information obtained from this study will also give awareness not only to the farmer but also to the societies regarding the controlling of GHG emissions from a drained tropical peat soils cultivated with pineapples.

Abstrak tesis yang dikemukakan kepada Senat Univesiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

PELEPASAN MENEGAK DAN MENDATAR GAS RUMAH HIJAU DALAM PENANAMAN NANAS (*Ananas comosus* L. Merr.) DARI TANAH GAMBUT TROPIKA

Oleh

ALICIA VANESSA JEFFARY

Januari 2017

Pengerusi : Profesor Ahmed Osumanu Haruna, PhD
Fakulti : Sains Pertanian dan Makanan (Kampus Bintulu)

Tanah gambut tropika adalah sumber semula jadi yang penting. Kebanyakan kawasan ini telah dibersihkan untuk tujuan pertanian berskala besar seperti kelapa sawit yang ditanam disebabkan oleh permintaan yang semakin meningkat bagi pembangunan tanah dan juga disebabkan oleh pulangan ekonomi yang tinggi. Penanaman nanas di tanah gambut adalah menguntungkan. Walau bagaimanapun, kebanyakan Pertubuhan Bukan Kerajaan (NGO) melaporkan bahawa penanaman nanas yang semakin meningkat menyebabkan peningkatan pelepasan gas rumah hijau yang berbahaya. Keprihatinan terhadap fungsi tanah gambut tropika sebagai penyerap karbon timbul kerana kesan pelepasan gas rumah hijau menyumbang kepada fenomena pemanasan global. Kini, terdapat maklumat yang terhad berkenaan pelepasan menegak dan mendatar karbon dioksida, methane, dan nitrus oksida daripada penanaman nanas di tanah gambut tropika yang disalirkan. Kajian dijalankan di tanah gambut saprik di Institut Penyelidikan dan Kemajuan Pertanian Malaysia (MARDI) Saratok, Sarawak, Malaysia. Pergerakan mendatar dan menegak gas karbon dioksida (CO_2), methane (CH_4), dan nitrus oksida (N_2O) dari permukaan dan dinding tanah yang ditanam dengan *Ananas comosus* (L.) Merr. diuukur dengan menggunakan kaedah kebuk wasap berbentuk I dan L setiap enam jam bagi tempoh 24 jam. Kepekatan gas karbon dioksida, methane, dan nitrus oksida diukur menggunakan Gas Kromatografi (GC – Agilent 7890A) yang dilengkapi dengan pengesan kekonduksian haba (TCD). Tanah gambut tropika yang ditanam dengan *Ananas comosus* (L.) Merr. menyumbang kepada 79.7 % CO_2, 20.1 % N_2O, dan 0.2 % CH_4 berdasarkan asas tahunan. Pelepasan gas secara menegak adalah 70.84 % CO_2, 18.72 % N_2O, dan 0.19 % CH_4 berbanding 8.85 % CO_2, 1.38 % N_2O, dan 0.02 % CH_4 secara mendatar. Pelepasan CO_2 adalah yang tertinggi berbanding CH_4 dan N_2O tanpa mengira perbezaan dalam pengangkutan diurnal; pelepasan mendatar dan menegak. Pelepasan CO_2 dipengaruhi oleh kedalaman aras air dan suhu. Ia secara umumnya dipercayai bahawa penurunan paras air di dalam tanah gambut membawa kepada pelepasan CO_2 lebih tinggi kerana proses ini membawa kepada pendedahan tanah gambut kepada pengoksidaan. Variasi

bermusim dalam pelepasan CH_4 adalah lebih tinggi pada musim tengkujuh kerana musim hujan telah meningkatkan paras air di dalam tanah gambut tersebut. Faktor0faktor yang mempengaruhi pengeluaran N_2O termasuk suhu tanah gambut, kelembapan tanah, ruang liang berisi air, dan kandungan nitrogen dalam tanah gambut. Sehubungan dengan itu, melalui hasil daripada kajian ini diharapkan dapat memberikan petunjuk kepada pendekatan dan kaedah yang sesuai dalam pengukuran gas rumah hijau untuk meningkatkan ketepatan dan seterusnya mengurangkan kontroversi. Selain itu, maklumat yang diperoleh daripada kajian ini diharapkan dapat memberi petunjuk mengenai prosedur pengurusan lading dalam menangani pelepasan gas rumah hijau seperti pengenadalian pembajaan, pengurusan tanah, dan sebagainya.

ACKNOWLEDGEMENTS

All glory, praise and thanks be to God for given me the opportunity, strength, and wisdom to complete this thesis. Special thanks to my supervisor, Prof. Dr. Ahmed Osumanu Haruna for his guidance, encouragement, comments, suggestions, and commitment throughout my study. Thank you for never given up on me. Your kindness, support, and care for me, forever I will appreciate. Thanks also to Dr. Roland Kueh Jui Heng, my co-supervisor for helping and coordinating me to finish my work. I am grateful to all the staff of Malaysian Agricultural Research and Development Institute (MARDI) Saratok, Sarawak, Malaysia especially to Miss Liza Nuriati Lim Kim Choo and Madam Shamsiah Sekot for the assisting, help, and guidance during my field and laboratory work. I would like to thanks my parents, Jeffary Jim and Jeti anak Jembai, late grandparents, siblings, and my relatives for their prayers, guidance, support, and endless love in assuring my success. Last but not the least, my appreciation also goes to all friends for their unfailing support and encouragement which made it all possible. Thanks for those wonderful moments, wishes, and support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
CEC	Cation Exchange Capacity
CH4	Methane
CO2	Carbon Dioxide
HSD	Tukey's Studentized Range Test
DOC	Dissolved Organic Carbon
GC	Gas Chromatography
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
MARDI	Malaysian Agricultural Research and Development Institute
N2O	Nitrous Oxide
POC	Particulate Organic Carbon
SAS	Statistical Analysis System
TCD	Thermal Conductivity Detector
USDA	United States Department of Agriculture

CHAPTER 1

INTRODUCTION

Peat soils are important natural resources. Peat soils have been cleared, developed, and cultivated for large scale plantations such as oil palm due to their positive contribution to Malaysia's economic growth in agricultural sector. Cultivation of pineapples on peat soils has now become profitable and popular in Malaysia. Malaysia is known to be the only country in the world that uniquely and largely cultivates pineapples on peat soils. This practice has been in existence for nearly a century. However, concerns by NGOs have been expressed that increasing cultivation of pineapples on peat soils lead to increase in the emissions of harmful greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Previous study on drained peat soil cultivated with pineapple done by Liza (2104) showed that CO_2 were emitted the most with 93.4% followed by 6.2% N_2O with a lower CH_4 at 0.35%.

Globally, agriculture contributed to 24% of the greenhouse gases emission (IPCC, 2014). Tropical peatland with high organic matter content is naturally a conducive environment for greenhouse gas emissions especially under agriculture which is characterized by alternate high and low water table. Methane as an example can be consumed by aerobic microbes during its transportation to the soil surface besides dissolving in water, thus, being transported away from peatlands.

CO_2, CH_4, and N_2O are the main greenhouse gases emitted from pineapple cultivation on peat soils where these gases have been implicated in the global warming (Chen *et al.,* 2014; Jassal *et al.,* 2011; Florides and Christoudoulides, 2008). Peat soils contains approximately 15% to 25% of the terrestrial soil carbon and nitrogen worldwide (Bajtes, 1996). The organic carbon and nitrogen of peat soils undergo natural decomposition, causing the loss of mass and release by-products such as nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2) (Hadi *et al.,* 2005). Carbon in peat soils are lost in the forms of CH_4 and CO_2. Naturally, these gases are produced under anaerobic and aerobic conditions.

Concern of the function of peatlands as a major carbon sequestration arises because greenhouse gases (GHGs) contribute to global warming (Daud, 2009). Cultivation of different crops has different impact on the environment (Azqueta and Sotelsek, 2007). Tropical peat soils' carbon and GHG balance is determined largely by the net balance between carbon uptake in photosynthesis and carbon release through ecosystem respiration by: (a) vegetation (autotrophic respiration and resulting in CO_2 emissions from both plant foliage and root systems) and (b) by the organisms involved in organic matter biological decomposition. In addition, carbon is leached out from the system in drainage runoff as dissolved organic carbon (DOC) or particulate organic carbon (POC) (Moore *et al.,* 2011). Furthermore, cycling of N has the tendency of rendering tropical peatlands as source of N_2O, especially if fertilizers are used to promote agricultural or plantation productivity (Jauhiainen *et al.*, 2011; Murdiyarso *et al.*, 2010; Germer and Sauerborn, 2008; Melling *et al.*, 2007).

It is important to note that: (a) carbon cycle and GHG processes are highly dynamic and vary at all spatial and temporal scales owing to regional and local variations in macro- and micro-climate and hydrology, as well as localised variations in vegetation and peat decomposition dynamics (Hooijer *et al.*, 2011; Jauhiainen *et al.*, 2005, 2010); and (b) in terms of emissions and global warming potential, CO_2 is the most important gas emitted from drained peatlands, contributing 98% or more of the total combined global warming potential (GWP) of CO_2, CH_4, and N_2O (Jauhiainen *et al.*, 2011).

Currently, there is limited information on soil CO_2, CH_4, and N_2O emissions emission from pineapple cultivation on drained peat soils. According to Couwenberg (2011), CH_4 emissions from paddy ecosystem on peat soils are within uncertainty range of the Intergovernmental Panel on Climate Change (IPCC) CH_4 default emission factor. Current practices in the measurement of CO_2, CH_4, and N_2O emissions from the surface of peat soils are controversial. Besides, the emissions of CO_2 and CH_4 have recently attracted considerable attention because of their contribution to the global climate change. The losses of these gases are also important because soil carbon and nitrogen must be stored for sustainable crop production. In spite of intensive international research efforts, the newest global CO_2, CH_4, and N_2O balances still have considerable uncertainties in evaluating the specific sources for enhanced CO_2, CH_4, and N_2O (IPCC 1996; Mosier 1996). Uncertainties mainly are because of the variability in soil and environmental conditions, time, and method used for the measurement of CO_2, CH_4, and N_2O (Mosier 1996; Firestone and Davidson 1989).

Research findings on CO_2, CH_4, and N_2O emissions in tropical peats planted with pineapples are usually controversial due to few or lack of standard information (Ahmed and Liza, 2015). Greenhouse gas emissions are commonly measured using closed chamber method in a very limited area and time (Zulkefli *et al.*, 2010; Abdul *et al.*, 2005). This leads to inconsistent and sometimes controversial issues which are related to lack of rigid information. Although pineapples are cultivated on tropical peat soils, there is little information on GHG emissions from peats cultivated with pineapples.

The contribution of pineapples cultivation on tropical peat soils to GHG emissions is important. For example, 90% of pineapples are widely grown on peat soils of Malaysia (Raziah and Alam, 2010). Kuzyakov (2006) reported that it was important to partition the GHG emissions into respiration components such as microbial and root respirations before deciding on whether peat soils are net sinks or net sources of atmospheric GHG. Failure to account for these GHG losses from drained tropical peatlands could underestimate future rates of increase in atmospheric greenhouse gases and their effects on global environmental change processes (Page *et al.*, 2007).

Based on the foregoing discussion, the objectives of this study were:

i. To determine CO_2, CH_4, and N_2O emissions horizontally and vertically from a drained tropical peat soil cultivated with pineapple (*Ananas comosus* (L.) Merr
ii. To quantify horizontal and vertical CO_2, CH_4, and N_2O emissions from a drained tropical peat soil

In this study, it was hypothesized that the emissions of CO_2, CH_4, and N_2O into the atmosphere from peat soils cultivated with pineapple (*Ananas comosus* (L.) Merr are affected by horizontal and vertical transportations. This hypothesis is based on the assumption that the mechanism of transportation where gases can lost to the environment in many ways outside or within the soil profile; horizontally and vertically. The results from this study could be used to give ideas on appropriate procedure in CO_2, CH_4, and N_2O emissions measurement on a drained tropical peat soil cultivated with (*Ananas comosus* (L.) Merr. Besides, information obtained from different emissions measurement method will also provide insights on the possible future measures in controlling CO_2, CH_4, and N_2O emissions on a drained tropical peat soil cultivated with (*Ananas comosus* (L.) Merr.

REFERENCES

Abdul, H., Kazuyuku, I., Yuichiro, F., Erry, P., Muhammad, R. and Haruo, T. (2005). Greenhouse Gas Emissions from Tropical Peatlands of Kalimantan, Indonesia. *Nutrient Cycling in Agrosystems* 71:73-80.

Abdul, H., Inubushi, K., Purnomo, E., Razie, F., Yamakawa, K. and Tsuruta, H. (2000). Effect of Land-Use Change on Nitrous Oxide (N_2O) Emission from Tropical Peatlands. *Chemosphere – Global Change Science* 2:347-358.

Adams, P., Graves, C.J. and insor, G.W. (1978). Effects of Copper Deficiency and Liming on the Yiled, Quality and Copper Status of Tomatoes, Lettuce and Cucumbers Grown in Peats. *Scientia Horticulturae* 9:199-205.

Ahmed, O.H. and Liza Nuriati, L.K.C. (2005). *Greenhouse Gas Emission & Carbon Leaching in Pineapple Cultivation on Tropical Peat Soil.* Serdang: Universiti Putra Malaysia Press.

Ahmed, O.H., Husni, M.H.A., Anuar, A.R., Hanafi, M.M. (2013). *Sustainable Production of Pineapples on Tropical Peat Soils.* pp. 12-95. Selangor: UPM Press.

Ahmed, O.H., Aminuddin, H. and Husni, M.H.A. (2006). Reducing Ammonia Loss from Urea and Improving Soil-Exchangeable Ammonium Retention through Mixing Triple Superphosphate, Humic Acid and Zeolite. *Soil Use and Management* 22:315-319.

Ambak, K. and Tadano, T. (1991) Effect of Micronutrient Application on the Growth and Occurrence of Sterility in Barley and Rice in a Malaysian Deep Peat Soil. *Soil Science and Plant Nutrition* 37(4):715-724.

Andriesse, J.P. (1988). *Nature and Management of Tropical Peat Soils.* FAO Soils Bulletin 59. Rome: FAO.

Attanandana, T., Chakranin, B., Kyuma, K. and Monchareon, P. (1995). Amelioration of a Peat Soil for Rice in Thailand, *In: International Conference on Soil Resources and Sustainable Agriculture*. Kuala Lumpur, Malaysia, pp. 1-15.

Azqueta, D., Sotelsek, D. (2007). Valuing Nature: From Environmental impacts to Natural Capital. *Ecological Economics* 63:22-30.

Batjes, N.H. (1996). Total Carbon and Nitrogen in the Soils of the World. *Eur. J. Soil Sci.* 47:151-163.

Ball, B.C., Dobbie, K.E., Parker, J.P., and Smith K.A. (1997). The Influence of Gas Transport and Porosity on Methane Oxidation in Soils. *Journal of Geophysical Research* 102:23301-23308.

Berglund, ö. and Berglund, K. (2011). Influence of Water Table Level and Soil Properties on Emissions of Greenhouse Gases from Cultivated Peat Soil. *Soil Biology & Biochemistry* 43:923-931.

Berglund, ö., Berglund, K. and Klemedtsson, L. (2010). A Lysimeter Study on the Effect of Temperature on CO_2 Emission from Cultivated Peat Soils. *Geoderma* 154 (3-4):211-218.

Charman, D.J., Joosten, H., Laine, J., Lee, D., Minayeva, T., Opdam, S., Parish, F., Silvius, M. and Sirin, A. (2008). *Assessment on Peatlands, Biodiversity and Climate Change: Main Report,* Wageningen, Global Environment Centre, Kuala Lumpur & Wetlands International.

Chen, H., Mothapo, N.V. and Shi, W. (2014). The Significant Contribution of Fungi to Soil N_2O Production across Diverse Ecosystems. *Applied Soil Ecology* 73:70-77.

Chimner, R.A. amd Cooper, D.J. (2003). Influence of Water Table Levels on CO_2 Emissions in a Colorado Subalpine Fen: an in situ microcosm study. *Soil Biology & Biochemistry* 35:345-351.

Couwenberg. J. (2011). Greenhouse Gas Emissions from Managed Peat Soils: Is the IPCC reporting guidance realistic? *Mires and Peat* 8:1-10.

Couwenberg, J., Dommain, R. and Joosten, H. (2010). Greenhouse Gas Fluxes from Tropical Peatlands in South-East Asia. *Global Change Biology* 16:1715-1732.

Couwenberg, J. (2009). *Emission factors for Managed Peat Soils (organic soils, Histosols):* An analysis of IPCC default values. Ede, the Netherlands: Wetlands International.

Crill, P.M. (1991). Seasonal Patterns of Methane Uptake and Carbon Dioxide Release by a Temperate Woodland Soil. *Global Biogeochem. Cyc.* 5:319-334.

Daud, A. (2009). Economic Valuation of Pineapple Cultivation on Peat Soil at the Integrated Agricultural Development Area, Samarahan, Sarawak. Ph.D. dissertation, Universiti Putra Malaysia.

Delicato, D.M.S. (1996). Physical-Chemical Properties and Sorption Characteristics of Peat. Ph.D. dissertation, Dublin City University.

Dinsmore, K.J, Skiba, U.M., Billett, M.F. and Rees, R.M. (2009). Effect of Water Table on Greenhouse Gas Emissions from Peatland Mesocosms. *Plant Soil* 318:229-242.

Farmer, J., Mattherw, R., Smith, J.U., Smith, P. and Singh, B.K. (2011). Assessing

Existing Peatland Models for their Applicability for Modelling Greenhouse Gas

Emissions from Tropical Peat Soils. *Current Opinion in Environmental Sustainability* 3:339-349.

Firestone, M.K. and Davidson, E.A. (1989). Microbiological Basis of NO and N_2O Production and Consumption in soil. In Exchange of Trace Gases between Terrestrial Ecosystem and the Atmosphere. Eds. MO Andreae and DS Schimel, 7-21. John Wiley, New York.

Florides, G.A. and Christodoulides, P. (2008). Global Warming and Carbon Dioxide through Sciences. *Environmental International* 35:390-401.

Fuchsman, C.H. (1980). Peat. *Industrial Chemistry and Technology.* Academic Press.

Graves, C.J., Adams, P. and Winsor, G.G. (1978). Some Effects of Micronutrients and Liming on the Yield, Quality and Micronutrient Status of Tomatoes Grown in Peat. *Plant and Soil* 50:343-354.

Hadi, A., Inubushi, K., Furukawa, Y., Purnomo, E., Rasmade, M. and Tsuruta, H. (2005).

Greenhouse Gas Emissions from Tropical Peatlands of Kalimantan, Indonesia. *Nutrient Cycling in Agroecosystems* 71:73-80.

Hadi, A., Inubushi, K., Purnomo, Razie, F., Yamakawa, K. and Tsuruta, H. (2000). Effects of Land-Use Change on Nitrous Oxide (N_2O) Emission from Tropical Peatlands. *Chemosphere-Global Change Sci* 2:347-358.

Hargreaves, K.J. and Fowler, D. (1998). Quantifying the Effects of Water Tables and Soil Temperature on the Emission of Methane from Peat Wetland at the Field Scale. *Atmospheric Environment* 32(19):3275-3282.

Hirano, T.M Jauhiainen, J., Inoue, T. and Takahashi, H. (2009). Controls on the Carbon Balance of Tropical Peatlands. *Ecosystems* 12:873-887.

Hirano, T., Segah, H., Harada, T., Limin, S., June, T., Hirata, R. and Osaki, M. (2007). Carbon Dioxide Balance of a Tropical Peat Swamp Forest in Kalimantan, Indonesia. *Glob. Change Biol.* 13:412-425.

Hoojier, A., Page, S., Canadell, J.G., Silvius, M., Kwadijk, J., Wösten, H. and Jauhiainen, J. (2010). Current and Future CO_2 Emissions from Drained Peatlands in Southeast Asia. *Biogeoscience* 7:1505-1514.

Hoojier, A., Silvius, M., Wösten, H. and Page, S. (2006). PEAT-CO_2, *Assessment of CO_2 Emissions from Drained Peatlands in SE Asia,* Delft Hydraulics Report Q3943.

Huat, B.B.K., Kazemian, S., Prasad, A. and Barghchi, M. (2011). State of an Art Review of Peat: General Perspective: *International Journal of the Physical Sciences* 6(8):1988-1996.

IAEA. (1992). *Manual on Measurement of Methane and Nitrous Oxide Emissions from Agriculture.* In Sampling Techniques and Sampling Handling. pp. 45-67 IAEA-TECDOC-674. Vienna, Austria: IAEA.

International Panel on Climate Change. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories.* Geneva, Switzerland.

IPCC. (1997). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.* Houghton, J.T., Meira Filho, L.G., Lim, B., Treanton, K., Mamaty, I., Bonduki, Y., Griggs, D.J., Callander, B.A. (eds.), volumes 1-3, IPCC, OECD and IEA, London. [Available: http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm].

Ismail, A.B. and Jamaludin, J. (2007). Land Clearing Techniques Employed at MARDI Peat Research Station, Sessang, Sarawak, and Their Immediate Impacts, in *A Case study at MARDI Peat Research Station Sessang, Sarawak, Malaysia,* eds. A.B. Ismail, H.K. Ong, M.J. Mohamad Hanif, and M.S. Umi Kalsom. Pp. 1-8.

Malaysia: MARDI.Inubushi. K., Furakawa, Y., Hadi, A., Purnomo, E. and Tsuruta, H. (2003). Seasonal Changes of CO_2, CH_4 and N_2O Fluxes in Relation to Land-Use Chage in Tropical

Peatlands Located in Coastal Area of South Kalimantan. *Chemosphere* 52:603-608.

Ismail, A.B. (2010). Farm Management Practices for Mitigation of Carbon Dioxide Emission in Peatland Agrosystems. *In Proceedings of the International Conference on Balanced Nutrient Management for Tropical Agriculture.* Kuantan, Pahang. 12-16 April. pp. 72-76.

Jassal, R.S., Black, T.A., Roy, R. and Ethier, G. (2011). Effect of Nitrogen Fertilization on Soil CH_4 and N_2O Fluxes, and Soil and Bole Respiration. *Geoderma* 162:182-186.

Jauhiainen, J., Hoojier, A. and Page, S.E. (2012). Carbon Dioxide Emissions from an Acacia Plantation on Peatland in Sumatra, Indonesia. *Biogeoscience* 9:617-630.

Jauhiainen, J., Hoojier, A. and Page, S.E. (2011). Carbon Dioxide Fluxes in an Acacia Plantation on on Tropical Peatland. *Biogeosciences Discussions* 8:8269-8302.

Jauhiainen, J., Silvennoinen, H., Hämäläinen, R., Kusin, K., Limin, S., Raison, R.J. and Vasander, H. (2011). Nitrous Oxide Fluxes from Tropical Peat with different Disturbance History and Management. *Biogeosciences Discussions* 8, pp. 5423-5450.

Jauhianien, J., Vasander, H., Rieley, J. and Page, S.E. (2010). *Tropical Peat Carbon Gas Interaction: Technical Report 2.* Leicester, United Kingdom: University of Leicester.

Jauhianien, J., Takahashi, H., Juha, Heikkinen, E.P., Martikainen, P.J. and Vasander, H. (2005). Carbon Fluxes from a Tropical Peat Swamp Forest Floor. *Global Change Biology* 11:1788-1797.

Kanapathy, K. (1972). Copper Requirement and Residual Effect with Maize on a Peat Soil. *The Malaysia Agricultural Journal* 48(3):249-263.

Kasimir-Klemedtsson, A., Klemedtsson, L., Berglund, K., Martikainen, P., Silvola, J. and Oenema, O. (1997). Greenhouse Gas Emissions from Farmed Organic Soils: A Review. *Soil Use and Management* 13:245-250.

Kechavarzi, C., Dawson, Q., Bartlett, M. and Leeds-Harrison, P.B. (2010). The Role of Soil Moisture, Temperature and Nutrient Amendment on CO_2 Efflux from Agricultural Peat Soil Microcosms. *Geoderma* 154:203-210.

Kløve, B., Sveistrup, T.E. and Hauge, A. (2010) Leaching of Nutrients and Emission of Greenhouse Gases from Peatland Cultivation at Bodin, Northern Norway. *Geoderma* 154:219-232.

Kuzyakov, Y. (2006). Sources of CO_2 Efflux from Soil and Review of Partitioning Methods. *Soil Biology & Biochemistry* 38:425-448.

Kuzyakov, Y. and Larionova, A.A. (2006). Contribution of Rhizomicrobial and Root Respiration to the CO_2 Emission from Soil (A Review). *Eurasian Soil Science* 39(7):753-764.

Liza Nuriati, L.K.C. (2014). Greenhouse Gas Emission Partitioning and Carbon

Leaching in Drained Tropical Peatland, Saratok, Sarawak, Malaysia. Ph.D. dissertation, Universiti Putra Malaysia.

Ma, W. and Tobin, J.M. (2004). Determination and Modelling Effects of pH on Peat Biosorption of Chromium, Copper and Cadmium. *Biochemical Engineering* 18:33-40.

Mäkiranta, P., Minkkinen, K., Hytönen, J. and Laine, J. (2008). Factors causing Temporal and Spatial Variation in Heterotropic and Rhizospheric components of Soil Respiration in Afforested Organic Soil Croplands in Finland. *Soil Biology & Biochemistry* 40:1592-1600.

Maljanen, M., Komułainen, V.M., Hytönen, J., Martikainen, P.J. and Laine, J. (2004). Carbon Dioxide, Nitrous Oxide and Methane Dynamics in Boreal Organic Agricultural Soils with Different Soil Characteristics. *Soil Biology & Biochemistry* 36:1801-1808.

MARDI. (1996). *Master Plan for Malaysian Agricultural Research and Development Institute Sessang Peat Research Station* pp. 34-67. Malaysia: MARDI.

Maria, S. (2008). *Peatland and Climate Change.* Finland: International Peat Society.

Melling, L. and Henson, I.E. (2009). Greenhouse Gas Exchange of Tropical Peatlands. *Agriculture, Biotechnology and Sustainability Conference,* pp. 1-15.

Melling, L., Goh, K.J., Beauvais, C. and Hatano, R. (2007). Carbon Flow and Budget in a Young Mature Oil Palm Agrosystem on Deep Tropical Peat. In: Rieley., J.O., Banks, C.J. and Radjagukguk, B. (Ed.) *Proceedings of the International Symposium and Workshop on Tropical Peatland,* Yogyakarta, Indonesia.

Melling, L., Hatano, R. and Goh, K.J. (2007). Nitrous Oxide Emissions from Three Ecosystem in Tropical Peatland of Sarawak, Malaysia. *Soil Science and Plant Nutrition* 53:792-805.

Melling, L., Goh, K.J. and Hatano, R. (2006). Short-term Effect of Urea on CH_4 Flux under the Oil Palm (*Elaeis guineensis*) on Tropical Peatland in Sarawak,

Malaysia. *Soil Science and Plant Nutrition* 52:788-792.

Melling, L., Hatano, R. and Goh K.J. (2005). Methane Fluxes from Three Ecosystems in Tropical Peatland of Sarawak, Malaysia. *Soil Biology and Biogeochemistry* 37:1445-1453.

Melling, L., Hatano, R. and Goh K.J. (2005). Soil CO_2 Flux from Three Ecosystems in Tropical Peatland of Sarawak, Malaysia. *Tellus B* 57:1-11.

Melling, L. (2005). Soil of the Study Area, Physical Properties. In *Dalat and Mukah Sago Plantation Peat Soil Study Final Report,* pp. 23-32. Malaysia: Department of Agriculture Sarawak.

MPOB. (2012). Rainfall Distribution at MPOB Sessang Peat Research Station, Sarawak:

MPOB.Moore, T.R. and Dalva, M. (2001). Some controls on the release of Dissolved Organic Carbon by Plant Tissues and Soils. *Soil Science* 166:38-47.

Moore, T.R. and Dalva, M. (1993). The Influence of Temperature and Water Table position on Carbon Dioxide and Methane Emissions from Laboratory Columns of Peatland Soils. *Journal of Soil Science* 44:651-664.

Mosier, A.R., Duxbury, J.M., Freney, J.R., Heinemeyer, O. and Minam, K. (1996). Nitrous Oxide Emissions from Agriculture Fields: Assessment, Measurement and Mitigation. *Development in Plant and Soil Sciences* 68:589-602.

Murdiyarso, D., Hergoualch, K. and Verchot, L.V. (2010). Opportunities for Reducing Greenhouse Gas Emissions in Tropical Peatlands. *P. Natl.Acad. Sci.* USA, 107:19665-19660.

Mutalib. A.A., Lim, J.S. Wong, M.H. and Koonvai, L. (1991). Characterization, Distribution and Utilization of Peat in Malaysia. In Proceedings of the International Symposium on Tropical Peatland. Kuching, Sarawak, Malaysia. 6-10 May, pp. 7-16.

Norman, J.M. Kucharik, C.J., Gower, S.T., Baldocchi, D.D., Crill, P.M., Rayment, M., Savage, K., Striegl, R.G. (1997). A Comparison of Six Methods for Measuring Soil- Surface Carbon Dioxide Fluxes. Journal of Geophysical Research. 102:28771-28777.

Nyakanen, H., Alm, J., Lang, K. Silvola, . and Martikainen, P.J. (1995). Emission of CH_4, N_2O and CO_2 from a Virgin Fen Drained for Grassland in Finland. *Journal of Biogeography* 22:351-357.Page, S.E., Banks, C.J. and Rieley, J.O. (2007). Tropical Peatlands: Distribution, Extent and Carbon Storage – Uncertainties and Knowledge Gaps. Paper presented at the International Symposium and Workshop on Tropical Peatland: Carbon-climate Human Interaction on Tropical Peatland: Yogyakarta, Indonesia, 27-29 August.

Parmentier, F.J.W, van der Molen, M.K., de Jeu, R.A.M., Hendriks, D.M.D. and Dolman, A.J. (2009). CO_2 Fluxes and Evaporation on a Peatland in the Netherlands appear not affected by Water Table Fluctuations. Agricultural and Forest Meteorology 149:1201-1208.

Petterson, M. (2004). Factors Affecting Rates of Change in Soil Bacterial Communities. Ph.D. dissertation, Lund University, Sweden, http://www.lub.lu.se/luft/diss/sci_649/sci_649.pdf (accessed December 2015).

Pietikäinen, J., Petterson, M. and Bååth, E. (2005). Comparison of Temperature Effects on Soil Respration and Bacterial and Fungal Growth Rates. *FEMS Microbial Ecology* 52(1):49-58.

Puustjarvi, V. and Robertson, R.A. (1975). Physical and Chemicl Properties, p. 23-38. In: D.W. Robinson and J.G.D. Lambs (eds.) Peat in Horticulture. Academic, London.

Sirin, A. and Laine, J. Chapter 7: Peatlands and Greenhouse Gases, 2012, Wetlands International, http://www/wetlands.or.id/PDF/chapter _7-9.pdf (accessed July 2016).Raziah, M.L. and Alam, A.R. (2010). Status and Impact of Pineapple Technology on Mineral Soil. *Economic and Technology Management Review* 5:11-19.

Safford, L. and Maltby, E. (1998). Chapter 2 – Management and Chapter 3 – Nature and Distribution of Tropical Peatlands. In *Guidelines for Integrated Planning and Management of Tropical Lowland Peatlands with Special Reference to Southeast Asia,* Eds. L. Safford and E. Maltby, pp. 7, 37-41. Gland, Switzerland and Cambridge: IUCN Publications.Saggar, S., Jha, N., Deslippe, J., Bolan, N.S., Luo, J., Giltrap, D.L., Kim D.G., Zaman, M. and Tillman, R.W. (2013). Denitrification and N_2O: N_2 Production in Temperate Grasslands: Processes, Measurements, Modelling and Mitigating Negative Impacts. *Science of the Total Environment* 465:173-19.

Takakai, F., Morishita, T., Hashidoko, Y., Darung, U., Kuramochi, K., Dohong, S. amd Hatano, R. (2006). Effects of Agricultural Land-Use Change and Forest Fire in N_2O Emission from Tropical Peatlands, Central Kalimantan, Indonesia. *Soil Science and Plant Nutrition* 52:662-674.

Tay, T.H., Kee, P.C. and Wee, Y.C. (1969). The Nutritional Requirements of Pineapples (*Ananas comosus* (L.) Merr.) Variety Singapore Spanish on Peat Soil in Malaysia I. Effect of Nitrogen, Phosphorus and Potassium on Yield, Sugar and Acid Content of the Fruit. *The Malaysia Agricultural Journal* 47(2):175-186.

Tie, Y.L. and Kueh, H.S. (1979). *A Review of Lowland Organic Soils of Sarawak.*

Technical Paper No. 4, Department of Agriculture, Sarawak, 50 p.Watanabe, A., Purwanto, B.H., Ando, H., Kakuda, K. and Jong, F.S. (2009). Methane and CO_2 Fluxes from an Indonesian Peatland Used for Sago Palm (*Metroxylon sagu* Rottb.) Cultivation: Effects of Fertilizer and Groundwater Level Management. *Agriculture, Ecosystems and Environment* 134:14-18.

Wid'en, B. and Lindroth, A. (92003). A Calibration System for Soil Carbon Dioxide-Efflux Measurement Chambers. *Soil Science Society of America Journal* 67:327-334.

Wong, M.H. (1991). The Distribution, Characteristics and Agricultural Utilization of Peat in Sarawak, Department of Agriculture, Sarawak.

Yanbuaban, M., Osaki, M., Nuyim, T., Onthong, J. and Watanabe, T. (2007). Sago (*Metroxylon sagu* Rottb.) Growth is affected by Weeds in a Tropical Peat Swamp in Thailand. *Soil Science and Plant Nutrition* 53:267-277.

Zhou, Z. (2013). The Application of InSAR Time Series Analysis for Monitoring Long-Term Surface Change in Peatlands. Ph.D. dissertation, University of Glasgow.

Zulkefli, M., Liza Nuriati, L.K.C. and Ismail, A.B. (2010). Soil CO2 Flux from Tropical Peatland under Different Land Clearing Techniques. *Journal of Tropical Agriculture and Food Science* 38(1):131-137.

Zulkefli, M., Liza Nuriati, L.K.C., Ismail, A.B. and Jamaludin, J. (2008). Soil Carbon Loss under Different Land Clearing Techniques and Agriculture Systems on Tropical Peatland. In *Proceedings of the International Symposium and Workshop on Tropical Peatland: Peat Development – Wise Use and Impact Management*. Kuching, Sarawak, Malaysia, August 19-22. Pp. 376-381.