SOIL CO_2 EFFLUX UNDER DIFFERENT PLANTATION TYPES AND ITS ASSOCIATION WITH CHRONOSEQUENCE FACTOR

CINDY USUN SIGAU

IPTPH 2018 1

SOIL CO_2 EFFLUX UNDER DIFFERENT PLANTATION TYPES AND ITS ASSOCIATION WITH CHRONOSEQUENCE FACTOR

By

CINDY USUN SIGAU

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

October 2017

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

SOIL CO_2 EFFLUX UNDER DIFFERENT PLANTATION TYPES AND ITS ASSOCIATION WITH CHRONOSEQUENCE FACTOR

By

CINDY USUN SIGAU

October 2017

Chairman: Hazandy Abdul Hamid, PhD
Institute: Tropical Forestry and Forest Products

Impacts of land use modifications from anthropogenic activities towards soil CO_2 efflux are still poorly understood and varies between sites. Therefore, soil CO_2 efflux in three mature plots of *Gmelina arborea* and *Swietenia macrophylla* (exotic broad-leaved trees) and *Pinus caribaea* (an exotic conifer) was studied in relation to soil, air temperature and relative humidity on a monthly basis from January to March of 2016. Soil properties including bulk density, pH, total C, total N, and soil organic carbon were also measured at depth of 0–15 and 15–30 cm. Soil CO_2 efflux was recorded to be significantly different between the plots: gmelina (0.76 ± 0.04 g CO_2 m^{-2} h^{-1}) > mahogany (0.49 ± 0.02 g CO_2 m^{-2} h^{-1}) > conifer (0.40 ± 0.01 g CO_2 m^{-2} h^{-1}). Regression analysis revealed a significant positive correlation between soil CO_2 efflux and temperature in the gmelina plot. There was no significant correlation noted between soil CO_2 efflux and relative humidity in all the three plots. A significant negative correlation was found between soil CO_2 efflux and temperature in the conifer plot, indicating the influence of other factors on soil CO_2 efflux in the plot. Comparing the broad-leaved gmelina and needle-leaved pine, monthly variations in soil relative humidity and soil properties were examined for possible influences on soil CO_2 efflux and temperature sensitivity (Q_{10}) in the plots. Temperature sensitivity of soil CO_2 efflux in the gmelina plot (Q_{10} = 1.19) was significantly higher than that of mahogany and pine plots (Q_{10} = 0.79 and 0.70 respectively). The findings also showed significant result in the chronosequence in oil palm and rubber plantations which influence the soil CO_2 efflux. Twenty-two years old plantation stands (0.91 ± 0.17 g CO_2 m^{-2} h^{-1}) had significantly higher soil CO_2 efflux than 6 years old plantation stands (0.54 ± 0.18 g CO_2 m^{-2} h^{-1}). These findings suggest the chronosequence factor influenced the variations of soil CO_2 efflux in tropical oil palm and rubber plantations, driven significantly by soil relative humidity. The overall significant difference in soil CO_2 efflux was associated with the changes in land structure leading to the evolution in soil respiration variations, especially in the morphological and the physiological aspects. In addition, major environmental influences on soil CO_2 efflux were soil temperature and soil

relative humidity, which reacted differently in different plantation types and age stands. Thus, emphasizing how land use management can affect soil CO_2 efflux significantly by altering the environmental responses accordingly.

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

PENGALIRAN KELUAR CO_2 TANAH DI ANTARA LADANG BERBEZA DAN PERKAITANNYA DENGAN FAKTOR KRONO-TURUTAN

Oleh

CINDY USUN SIGAU

Oktober 2017

Pengerusi: **Hazandy Abdul Hamid, PhD**
Institut: **Perhutanan Tropika dan Produk Hutan**

Kesan penggunaan tanah daripada aktiviti manusia terhadap pengaliran keluar karbon dioksida (CO_2) tanah masih kurang difahami and berbeza di antara setiap lokasi. Oleh itu, pengaliran keluar karbon dioksida (CO_2) tanah pada tiga plot eksperimen yang telah matang iaitu *Gmelina arborea* dan *Swietenia macrophylla* (pokok berdaun lebar eksotik) dan *Pinus caribaea* (konifer eksotik) telah dikaji perkaitan nya dengan tanah, suhu udara dan kelembapan relatif pada setiap bulan mulai Januari sehingga Mac 2016. Sifat-sifat tanah termasuk ketumpatan pukal, pH, jumlah C, jumlah N, dan karbon organik tanah juga diukur pada kedalaman 0-15 dan 15-30 cm. Pengaliran keluar CO_2 tanah didapati berbeza dengan ketara antara plot iaitu, gmelina (0.76 ± 0.04 g CO_2 m^{-2} h^{-1}) > mahogani (0.49 ± 0.02 g CO^2 m^{-2} h^{-1}) > pain (0.40 ± 0.01 g CO_2 m^{-2} h^{-1}). Analisis regresi menunjukkan hubung kait positif yang ketara antara CO_2 tanah dengan suhu di plot gmelina. Kajian tidak mendapati hubung kait yang ketara antara pengaliran keluar CO_2 tanah dan kelembapan relatif tanah dalam ketiga-tiga plot berkenaan. Hubung kait negatif yang ketara didapati wujud antara pengaliran keluar CO_2 tanah dan suhu di plot pain, menunjukkan pengaruh faktor-faktor lain keatas pengaliran keluar CO_2 tanah di plot berkenaan. Dalam membandingkan gmelina yang berdaun lebar dan pain yang berdaun bentuk jarum, perubahan bulanan dalam kelembapan relatif tanah dan sifat-sifat lain telah diteliti atas kemungkinan mempengaruhi pengaliran keluar CO_2 tanah dan kepekaan suhu (Q_{10}) di plot berkenaan. Kepekaan suhu bagi pengaliran keluar CO_2 tanah di plot gmelina (Q_{10} = 1.19) adalah lebih tinggi dengan ketara daripada mahogani dan pain (masing-masing Q_{10} = 0.79 dan 0.70). Kajian juga mendapati bahawa keputusan krono-urutan di ladang kelapa sawit dan getah mempengaruhi pengaliran keluar CO_2 tanah. Ladang yang berumur 22 tahun (0.91 ± 0.17 g CO_2 m^{-2} h^{-1}) mempunyai pengaliran keluar CO_2 tanah yang lebih tinggi daripada ladang berusia 6 tahun (0.54 ± 0.18 g CO2 $m^{-2}h^{-1}$). Penemuan ini menunjukkan bahawa faktor krono-urutan telah mempengaruhi variasi pengaliran keluaran CO_2 tanah di ladang-ladang kelapa sawit dan getah, yang didorong dengan ketara oleh kelembapan relatif tanah. Perbezaan ketara pengaliran keluar CO_2

tanah adalah dikaitkan dengan perubahan dalam struktur tanah yang membawa perbezaan dalam pernafasan tanah, terutamanya dalam aspek morfologi dan fisiologi. Selain daripada itu, pengaruh utama alam sekitar keatas pengaliran keluar CO_2 tanah adalah suhu dan kelembapan relatif tanah yang bertindak-balas dengan berbeza-beza bergantung kepada jenis dan umur hutan. Justeru, memberi penekanan terhadap kepentingan pengurusan guna tanah terhadap pengaliran keluar CO_2 tanah yang seterusnya mengubah reaksi terhadap alam sekitar.

ACKNOWLEDGEMENTS

Praise the Lord for His blessings and guidance which enable me to come this far. I also would like to express my gratitude to my supervisor, Assoc. Prof. Dr. Hazandy bin Abdul Hamid and co-supervisor, Prof. Ahmad Ainuddin bin Nuruddin for their advice and enthusiasm toward the completion of this project. Not to forget Mr. Mohd. Kamil bin Ismail and my fellow friends, Mr. Mohamad Hadzmer bin Sanuddin, and Mr. Raja Abdul Azim bin Raja Azmi for their assistances in the field works. Special thanks to my beloved Mr. Mohamed Daniel bin Mohamed Mokhtar for the love and intellectual reasoning and debates. Of course, to my parents Mr. Louis Sigau Kebing and Mdm. Magdalene Ubong Tebengang who pray and support me all the way, I am really and always appreciative of their understanding and that this thesis would not be possible without them. Last but not least, thanks to the people that I met and worked with during the course of this research. I appreciate the cooperation and help that eased the completion of this thesis. God bless you all.

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

Hazandy Abdul Hamid, PhD
Associate Professor
Institute of Tropical Forestry and Forest Products
Universiti Putra Malaysia
(Chairman)

Ahmad Ainuddin Nuruddin, PhD
Professor
Institute of Tropical Forestry and Forest Products
Universiti Putra Malaysia
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: __________________

Name and Matric No.: Cindy Usun Sigau (GS43689)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ____________________
Name of Chairman of Supervisory Committee: Hazandy bin Abdul Hamid

Signature: ____________________
Name of Member of Supervisory Committee: Ahmad Ainuddin bin Nuruddin

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

asl	Above sea level
ANOVA	Analysis of variance
CO_2	Carbon dioxide
$g\ cm^{-3}$	Gram per cubic centimetre
$pg\ C\ yr^{-1}$	Petagram of carbon per year
$g\ CO_2\ m^{-2}\ h^{-1}$	Gram of carbon dioxide per square meter per hour
ha	Hectare
$kg\ ha^{-1} yr^{-1}$	Kilogram per hectare per year

CHAPTER 1

INTRODUCTION

1.1 General Background

Land use or terrestrial ecosystem is important in providing critical natural resources and ecosystem services for the sustainability of human societies in the long term (Foley *et al.,* 2005). In addition, land use also plays critical roles in influencing global biogeochemical cycles, soil ecosystem functions, and exacerbates climate change at both local and global scales (Leeuwen *et al.,* 2017). However, land-use is perceived as a local environmental issue caused by human disturbances altering the natural earth ecosystems. Globally, net carbon (C) emissions from land use are approximately 1.0 ± 0.8 pg C yr^{-1} (Le Quéré *et al.,* 2015). The C emissions are mostly contributed by soil respiration or soil carbon dioxide efflux where at the slightest alteration can induce considerable change to the concentration of atmospheric carbon dioxide (CO_2) (Schlesinger and Andrews, 2000; Arevalo *et al.,* 2010).

Soil CO_2 efflux refers to the instantaneous CO_2 transports via soil ground surface into the atmosphere and *vice versa* that includes rhizosphere, microbes, and soil fauna respiration (Raich and Schlesinger, 1992; Maher *et al.,* 2010), contributing up to 30% of the total ecosystem respiration (Bond-Lamberty and Thomson, 2000). Therefore, soil CO_2 efflux is one of the most fundamental elements of the global C balance (Bernhardt *et al.,* 2006). Besides that, soil CO_2 efflux varies significantly among plant biomes indicating environmental changes in vegetation via land use conversion potentially alters the soil CO_2 emissions into the atmosphere and *vice versa* (Raich and Tufekcioglu, 2000). Moreover, climate change also affects the capacity and efficiency of land use to absorb the atmospheric CO_2 (Friedlingstein *et al.,* 2001). It is common in scientific studies where soil CO_2 efflux always constituted with climatic factors, but site-specific elements across landscape play a major role in the variations of soil CO_2 efflux as well (Maher *et al.,* 2010). A comprehensive understanding of individual species influencing the ecosystem-level C dynamics and mechanisms help to provide further insights on our awareness on anthropogenic impacts towards the biosphere (Russell *et al.,* 2010).

Hence, one of the objectives of this study emphasises on comparing soil CO_2 efflux between three different types of land use (adjacent exotic forest plantations) which are *Gmelina arborea* (gmelina), *Swietenia macrophylla* (mahogany), and *Pinus caribaea* (pine) plantations. Despite the acknowledgement of the importance of soil CO_2 efflux in the global C cycle, the effect of chronosequence factor on soil CO_2 efflux among different types of species is still poorly documented (Maher *et al.,* 2010; Wang *et al.,* 2017). There is less to no information available on comparison of soil CO_2 efflux at different forest ages between forest types in tropical ecosystem leading to alteration of *in-situ* environmental factors (Saleska *et al*. 2003), especially in Malaysia. Therefore, this study also aims to investigate soil CO_2 efflux of two forest plantation types (oil palm and rubber plantation) with its association with chronosequence factor.

It is crucial to quantify and improve CO_2 emissions from soils (Jensen *et al.,* 2014) and establishes an explicit need to understand which factors governs soil CO_2 efflux in the environmental aspects (Almagro *et al.,* 2009). Environmental factors controlling soil CO_2 efflux and its consequences on production rates are essential to access the prospective impacts of environmental alterations (Raich and Tufekcioglu, 2000). Besides that, the understanding of soil CO_2 efflux is also considerably beneficial on gaining further insights on the terrestrial C cycling through a variety of studies both temporally and spatially.

1.2 Problem Statement and Justification

Land use in Malaysia has been actively growing especially for agriculture, shifting conversion, and timber harvesting purposes to sustain the industrial demand and supply needs. The role of land use or terrestrial ecosystems is critical in the global C cycle as it releases CO_2 into the atmosphere accounting for 90% of the total ecosystem respiration that is predominantly facilitated by soil CO_2 efflux (Hanson *et al.,* 2000). Therefore, the slightest alteration of the terrestrial ecosystems may lead to a considerable change of the atmospheric CO_2 concentration. The impacts from anthropogenic activities towards soil CO_2 efflux from land use modifications are still poorly documented and differ among sites (Raich and Schlesinger, 1992; Veldkamp *et al.,* 2008; Nazaries *et al.,* 2015).

Several studies on soil CO_2 efflux have been conducted worldwide at various biomes with different hypotheses and manipulations since soil CO_2 efflux is an essential element in the global C cycle. Soil CO_2 efflux respond differently at a variety of time scales indicating chronosequence aspects also significantly attributing to the soil respiration changes, especially under tropical climates. The changes are fundamental as tropical forests store 40% of global terrestrial carbon stocks and will influence the atmospheric CO_2 concentration (Pan et al., 2011). However, very few studies were carried out on soil CO_2 efflux at site-specific ecosystems specifically in Malaysia. Studies regarding soil CO_2 efflux in Malaysia had been conducted and quantified to improve the understanding of soil CO_2 efflux at various levels. Nonetheless, the studies focused on tropical forests (Mande *et al.,* 2014a; Mande *et al.,* 2014b), peat soils (Lim Kim Choo and Ahmed, 2014), and single plantation species (Firdaus and Husni, 2011; Lim Kim Choo and Ahmed, 2014). In addition, soil CO_2 efflux studies in Malaysia are also generally exploring single ecosystem age (Mande *et al.,* 2014a).

Uncertainties of certain age stand between ecosystems on soil CO_2 efflux remains unclear. A comprehensive understanding of soil CO_2 efflux particularly on its impact on environmental factors from types of land use or forest management is important as it will enhance our knowledge of the fundamental ecological processes controlling soil CO_2 efflux (Fan *et al.,* 2015; Liu *et al.,* 2016). Therefore, the present study also focuses on chronosequence factors that provide a contribution to knowledge acquisition regarding soil CO_2 efflux in Malaysia. The research is essential on soil CO_2 efflux in different land use types (exotic forest plantations) and chronosequence association of the main commodity crops (oil palm and rubber).

Therefore, one of the present studies undertaken assesses soil CO_2 efflux differences at three different types of land use or ecosystem (exotic forest plantations) specifically *Gmelina arborea* (gmelina), *Swietenia macrophylla* (mahogany), and *Pinus caribaea* (pine) plantations. As for the chronosequence factor element, present study explores the association of oil palm and rubber plantations at different ecosystem age stands influence on soil CO_2 efflux.

1.3 Objectives

General objective of the study is to investigate the differences of soil CO_2 efflux under different types of plantation. Meanwhile, the specific objectives are as follows:

1. To quantify and compare soil CO_2 efflux between different exotic forest plantation types (yemane, mahogany, and pine) (Study 1);
2. To quantify and establish the chronosequence association with soil CO_2 efflux under different plantation types (oil palm and rubber) (Study 2); and
3. To determine factors controlling soil CO_2 efflux (Study 1 and 2).

1.4 Significance of Study

The present study proposes to improve our understanding of CO_2 emissions which reveal the effectiveness in selecting the most desirable plantation species and management strategies suitable for plantation along with the country's strategy to double plantation areas while benefitting in reducing C emissions into the atmosphere due to land conversion or forest fragmentation. The efforts aids in maintaining a sustainable biodiversity and environment through improved estimation of both spatial and temporal soil CO_2 efflux rates.

Besides, present study acts as a pioneer in soil CO_2 efflux investigation within the chronosequence association aspects and newly studied plantation species of comparing soil CO_2 efflux in Malaysia. Hence, the study provides beneficial information regarding soil CO_2 efflux and ecosystem types which could attract potential other studies in wider or specific directions of terrestrial-atmosphere C exchanges. Therefore, the identification of potential risks of species selection for plantation can prevent the exposure to faster soil CO_2 emissions that could amplify greenhouse gas emissions. Hence, reliable mitigations can be initiated efficiently from the report findings to protect and monitor environmental changes.

The study proposes basic guidelines or references to gain further insights regarding soil CO_2 efflux vital in controlling global C cycle and ultimately climate change as well as anthropogenic efforts in land use managements in Malaysia. Future generations are well informed on the current soil CO_2 efflux status among different ecosystems and which is useful in the implementation of maintaining and conserving a much more environmentally friendly ecosystem types and services.

1.5 Scope of Study

The present study focuses on the determination of soil CO_2 efflux at site-specific vegetation types (land use) and explores its association with chronosequence factors between different kinds of the terrestrial ecosystem. Three different exotic forest plantations located at the Universiti Putra Malaysia were utilised to compare the soil CO_2 efflux. Meanwhile, oil palm and rubber plantations were selected to investigate the chronosequence association with soil CO_2 efflux. The primary data used in the study centralised within different vegetation types at areas located adjacently from each other for six months. Existing soils are from the same parent materials based on the assumption of similar previous land management histories within the sites. The main equipment employed in the study was an LI-COR 8100A Automated Soil Respiration Flux System (LI-COR 8100A, LI-COR Inc., Lincoln, NE, USA) for soil CO_2 efflux measurements. Other aspects taken into considerations were the environmental factors and soil characteristics as the additional covariates describing the sites. The results of the soil CO_2 efflux between different forest types and chronosequence association were used as an environmental indicator and for guidelines on anthropogenic impacts in land use managements to the ecosystem.

1.6 Thesis Structure

There are five chapters in the thesis as follows:

Chapter 1: Chapter 1 provides a general overview of the study. It portrays the general background, problem statement and justification, objectives, and significance of the research.

Chapter 2: Chapter 2 provides a more detailed literature review regarding the research which further describes the effects land use on soil CO_2 efflux and also its association with chronosequence factor.

Chapter 3: Chapter 3 describes the methodology of the studies used in the studies and are divided into two main headings: (a) comparison of soil CO_2 efflux between different exotic forest plantations and (b) investigation of soil CO_2 efflux under different forest types with its association with chronosequence factor.

Chapter 4: Chapter 4 elucidates results and discussion of the studies with two main headings as described in Chapter 3.

Chapter 5: Chapter 5 is the concluding chapter of the thesis with recommendations for future research based on the output gained from the studies.

REFERENCES

Abdullah, S. A., & Nakagoshi, N. (2007). Forest fragmentation and its correlation to human land use change in the state of Selangor, Peninsular Malaysia. *Forest Ecology and Management, 241*(1-3), 39-48.

Acosta, M., Pavelka, M., Montagnani, L., Kutsch, W., Lindroth, A., Juszczak, R., & Janouš, D. (2013). Soil surface CO_2 efflux measurements in Norway spruce forests: comparison between four different sites across Europe - from boreal to alpine forest. *Geoderma, 192*, 295-303.

Adachi, M., Bekku, Y. S., Konuma, A., Kadir, W. R., Okuda, T., & Koizumi, H. (2005). Required sample size for estimating soil respiration rates in large areas of two tropical forests and of two types of plantation in Malaysia. *Forest Ecology and Management*, *210*(1), 455-459.

Adachi, M., Bekku, Y. S., Rashidah, W., Okuda, T., & Koizumi, H. (2006). Differences in soil respiration between different tropical ecosystems. *Applied Soil Ecology*, *34*(2-3), 258-265.

Almagro, M., López, J., Querejeta, J. I., & Martínez-Mena, M. (2009). Temperature dependence of soil CO_2 efflux is strongly modulated by seasonal patterns of moisture availability in a Mediterranean ecosystem. *Soil Biology and Biochemistry, 41*(3), 594-605.

ArchMiller, A. A., Samuelson, L. J., & Li, Y. (2016). Spatial variability of soil respiration in a 64-year-old longleaf pine forest. *Plant and Soil*, *403*(1-2), 419-435.

Arevalo, C., Bhatti, J. S., Chang, S. X., Jassal, R. S., & Sidders, D. (2010). Soil respiration in four different land use systems in north central Alberta, Canada. *Journal of Geophysical Research: Biogeosciences, 115*(G1), G01003.

Bernhardt, E. S., Barber, J. J., Pippen, J. S., Taneva, L., Andrews, J. A., & Schlesinger, W. H. (2006). Long-term effects of free air CO_2 enrichment (FACE) on soil respiration. *Biogeochemistry, 77*(1), 91-116.

Bond-Lamberty, B., & Thomson, A. (2010). A global database of soil respiration data. *Biogeosciences, 7*(6), 1915-1926.

Bond-Lamberty, B., Wang, C., & Gower, S. T. (2004). Contribution of root respiration to soil surface CO2 flux in a boreal black spruce chronosequence. *Tree Physiology*, *24*(12), 1387-1395.

Boone, R. D., Nadelhoffer, K. J., Canary, J. D., & Kaye, J. P. (1998). Roots exert a strong influence on the temperature sensitivity of soil respiration. *Nature*, *396*(6711), 570-572.

Campbell, J. L., & Law, B. E. (2005). Forest soil respiration across climatically distinct chronosequence in Oregon. *Biogeochemistry, 73,* 109-125.

Corley, R. H. V., & Tinker, P. B. (2008). *The oil palm*. John Wiley & Sons.

Davidson, E., Belk, E., & Boone, R. D. (1998). Soil water content and temperature as independent or confounded factors controlling soil respiration in a temperate mixed hardwood forest. *Global Change Biology*, *4*(2), 217-227.

Davidson, E. A., & Janssens, I. A. (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, *440*(7081), 165-173.

Davidson, E. A., Verchot, L. V., Cattânio, J. H., Ackerman, I. L., & Carvalho, J. E. M. (2000). Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. *Biogeochemistry*, *48*(1), 53-69.

Dilustro, J. J., Collins, B., Duncan, L., & Crawford, C. (2005). Moisture and soil texture effects on soil CO_2 efflux components in southeastern mixed pine forests. *Forest Ecology and Management, 204*(1), 85–95.

Epron, D., Bosc, A., Bonal, D., & Freycon, V. (2006). Spatial variation of soil respiration across a topographic gradient in a tropical rain forest in French Guiana. *Journal of Tropical Ecology*, *22*(5), 565-574.

Fan, L. C., Yang, M. Z., & Han, W. Y. (2015). Soil respiration under different land uses in eastern China. *PloS one, 10*(4), e0124198.

Fiedler, S. R., Buczko, U., Jurasinski, G., & Glatzel, S. (2015). Soil respiration after tillage under different fertiliser treatments–implications for modelling and balancing. *Soil and Tillage Research*, *150*, 30-42.

Firdaus, M. S., & Husni, M. H. A. (2012). Planting *Jatropha curcas* on constrained land: emission and effects from land use change. *The Scientific World Journal, 2012*, 405084.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Stuart Chapin, F., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N., & Snyder, P. K. (2005). Global consequences of land use. *Science*, *309*(5734), 570-574.

Fraterrigo, J. M., Turner, M. G., Pearson, S. M., & Dixon, P. (2005). Effects of past land use on spatial heterogeneity of soil nutrients in southern Appalachian forests. *Ecological Monographs*, *75*(2), 215-230.

Friedlingstein, P., Bopp, L., Ciais, P., Dufresne, J., Fairhead, L., Monfray, P., & Orr, J. (2001). Positive feedback between future climate change and the carbon cycle climate impact on and uptake. *Geophysical Research Letters, 28*(8), 1543–1546.

Gilliam, F. S. (1991). Ecosystem-level significance of acid forest soils. In *Plant-soil interactions at low pH* (pp. 187-195). Springer Netherlands.

Gong, J. R., Wang, Y., Liu, M., Huang, Y., Yan, X., Zhang, Z., & Zhang, W. (2014). Effects of land use on soil respiration in the temperate steppe of Inner Mongolia, China. *Soil and Tillage Research*, *144*, 20-31.

Grand, S., Rubin, A., Verrecchia, E. P., & Vittoz, P. (2016). Variation in soil respiration across soil and vegetation types in an Alpine Valley. *PloS one, 11*(9), e0163968.

Gritsch, C., Zimmermann, M., & Zechmeister-Boltenstern, S. (2015). Interdependencies between temperature and moisture sensitivities of CO_2 emissions in European land ecosystems. *Biogeosciences*, *12*(20), 5981-5993.

Gupta, S. D., & Mackenzie, M. D. (2016). Spatial Patterns of Soil Respiration Links Above and Belowground Processes along a Boreal Aspen Fire Chronosequence. *PloS one*, *11*(11), e0165602.

Hagen-Thorn, A., Callesen, I., Armolaitis, K., & Nihlgård, B. (2004). The impact of six European tree species on the chemistry of mineral topsoil in forest plantations on former agricultural land. *Forest Ecology and Management*, *195*(3), 373-384.

Hansen, M. C., Potapov, P. V, Moore, R., Hancher, M., Turubanova, S. A., & Tyukavina, A. (2013). High-resolution global maps of 21st-century forest cover change. *Science*, *342*(6160), 830-853.

Hanson, P. J., Edwards, N. T., Garten, C. T., & Andrews, J. A. (2000). Separating root and soil microbial contributions to soil respiration: A review of methods and observations. *Biogeochemistry, 48*(1), 115-146.

Houghton, R. A., House, J. I., Pongratz, J., Van der Werf, G. R., DeFries, R. S., Hansen, M. C., Le Quéré, C., & Ramankutty, N. (2012). Carbon emissions from land use and land-cover change. *Biogeosciences, 9*(12), 5125-5142.

Hui, D., & Luo, Y. (2004). Evaluation of soil CO_2 production and transport in Duke Forest using a process-based modeling approach. *Global Biogeochemical Cycles*, *18*(4), GB4029.

Hunt, N., & Gilkes, B. (1992). *Farm monitoring handbook*. Perth: University of Western Australia Press.

Janssens, I. A., & Pilegaard, K. I. M. (2003). Large seasonal changes in Q_{10} of soil respiration in a beech forest. *Global Change Biology*, *9*(6), 911-918.

Jensen, A. E., Lohse, K. A, Crosby, B. T., & Mora, C. I. (2014). Variations in soil carbon dioxide efflux across a thaw slump chronosequence in northwestern Alaska. *Environmental Research Letters, 9*(2), 25001.

Jia, B., & Zhou, G. (2009). Integrated diurnal soil respiration model during growing season of a typical temperate steppe: Effects of temperature, soil water content and biomass production. *Soil Biology and Biochemistry*, *41*(4), 681-686.

Kara, O., Bolat, I., Cakıroglu, K., & Senturk, M. (2014). Litter decomposition and microbial biomass in temperate forests in northwestern Turkey. *Journal of Soil Science and Plant Nutrition*, *14*(1), 31-41.

Kim, D. G., Mu, S., Kang, S., & Lee, D. (2010). Factors controlling soil CO_2 effluxes and the effects of rewetting on effluxes in adjacent deciduous, coniferous, and mixed forests in Korea. *Soil Biology and Biochemistry*, *42*(4), 576-585.

Kirschbaum, M. U. (1995). The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic C storage. *Soil Biology and Biochemistry*, *27*(6), 753-760.

Kongsager, R., Napier, J., & Mertz, O. (2013). The carbon sequestration potential of tree crop plantations. *Mitigation and Adaptation Strategies for Global Change, 18*(8), 1197-1213.

Kukumägi, M., Ostonen, I., Uri, V., Helmisaari, H. S., Kanal, A., Kull, O., & Lõhmus, K. (2017). Variation of soil respiration and its components in hemiboreal Norway spruce stands of different ages. *Plant and Soil*, *414*(1-2), 265-280.

Kursar, T. A. (1989). Evaluation of soil respiration and soil CO_2 concentration in a lowland moist forest in Panama. *Plant and Soil*, *113*(1), 21-29.

La Scala, N., Marques, J., Pereira, G. T., & Cora, J. E. (2000). Carbon dioxide emission related to chemical properties of a tropical bare soil. *Soil Biology and Biochemistry*, *32*(10), 1469-1473.

Leeuwen, J. P. Van, Djukic, I., Bloem, J., Lehtinen, T., & Hemerik, L. (2017). Effects of land use on soil microbial biomass, activity and community structure at different soil depths in the Danube floodplain. *European Journal of Soil Biology, 79*, 14-20.

Lenton, T. M., & Huntingford, C. (2003). Global terrestrial carbon storage and uncertainties in its temperature sensitivity examined with a simple model. *Global Change Biology*, *9*(10), 1333-1352.

Le Quéré, C., Moriarty, R., Andrew, R. M., Peters, G. P., Ciais, P., Friedlingstein, P., Jones, S. D., Sitch, S., Tans, P., Arneth, A., Boden, T. A., Bopp, L., Bozec, Y., Canadell, J. G., Chini, L. P., Chevallier, F., Cosca, C. E., Harris, I., Hoppema, M., Houghton, R. A., House, J. I., Jain, A. K., Johannessen, T., Kato, E., Keeling, R. F., Kitidis, V., Klein Goldewijk, K., Koven, C., Landa, C. S., Landschützer, P., Lenton, A., Lima, I. D., Marland, G., Mathis, J. T., Metzl, N., Nojiri, Y., Olsen, A., Ono, T., Peng, S., Peters, W., Pfeil, B., Poulter, B., Raupach, M. R., Regnier, P., Rödenbeck, C., Saito, S., Salisbury, J. E., Schuster, U., Schwinger, J., Séférian, R., Segschneider, J., Steinhoff, Tobias, Stocker, B. D., Sutton, A. J., Takahashi, T., Tilbrook, B., van der Werf, G. R., Viovy, N., Wang, Y.-P., Wanninkhof, R., Wiltshire, A., and Zeng, N. (2015). Global carbon budget 2014. *Earth System Science Data, 7*(1), 47-85.

Lim Kim Choo, L. N., & Ahmed, O. H. (2014). Partitioning carbon dioxide emission and assessing dissolved organic carbon leaching of a drained peatland cultivated with pineapple at Saratok, Malaysia. *Scientific World Journal, 2014*, 906021.

Liu, Q., Edwards, N. T., Post, W. M., Gu, L., Ledford, J., & Lenhart, S. (2006). Temperature-independent diel variation in soil respiration observed from a temperate deciduous forest. *Global Change Biology*, *12*(11), 2136-2145.

Liu, X., Zhang, W., Zhang, B., Yang, Q., Chang, J., & Hou, K. (2016). Diurnal variation in soil respiration under different land uses on Taihang Mountain, North China. *Atmospheric Environment, 125*, 283–292.

Lloyd, J., & Taylor, J. A. (1994). On the temperature dependence of soil respiration. *Functional Ecology, 8*(3), 315-323.

Longdoz, B., Yernaux, M., & Aubinet, M. (2000). Soil CO_2 efflux measurements in a mixed forest: impact of chamber disturbances, spatial variability and seasonal evolution. *Global Change Biology*, *6*(8), 907-917.

Luo, J., Chen, Y., Wu, Y., Shi, P., She, J., & Zhou, P. (2012). Temporal-spatial variation and controls of soil respiration in different primary succession stages on glacier forehead in Gongga Mountain, China. *PLoS one*, *7*(8), e42354.

Luo, S., Liu, G., Li, Z., Hu, C., Gong, L., Wang, M., & Hu, H. (2014). Soil respiration along an altitudinal gradient in a subalpine secondary forest in China. *iForest-Biogeosciences and Forestry*, *8*(4), 526.

Maher, R. M., Asbjornsen, H., Kolka, R. K., Cambardella, C. A., & Raich, J. W. (2010). Changes in soil respiration across a chronosequence of tallgrass prairie reconstructions. *Agriculture, Ecosystems and Environment, 139*(4), 749–753.

Maier, M., Schack-Kirchner, H., Hildebrand, E. E., & Schindler, D. (2011). Soil CO_2 efflux vs. soil respiration: Implications for flux models. *Agricultural and Forest Meteorology, 151*(12), 1723-1730.

Malaysian Meteorological Department. (2016). Records of Monthly Rainfall Amount 08-08 in Serdang Station. Malaysian Meteorological Department, 2016.

Mande, H. K., Abdullah, A. M., Aris, A. Z., & Nuruddin, A. A. (2014a). A comparison of soil CO_2 efflux ate in young rubber plantation, oil palm plantation, recovering and primary forest ecosystems of Malaysia. *Polish Journal of Environmental Studies, 23*(5), 1649–1657.

Mande, K. H., Abdullah, A. M., Zaharin, A. A., & Ainuddin, A. N. (2014b). Drivers of soil carbon dioxide efflux in a 70 years mixed trees species of tropical lowland forest, Peninsular Malaysia. *Sains Malaysiana, 43*(12), 1843–1853.

Mao, R., Zeng, D. H., Hu, Y. L., Li, L. J., & Yang, D. (2010). Soil organic carbon and nitrogen stocks in an age-sequence of poplar stands planted on marginal agricultural land in Northeast China. *Plant and Soil*, *332*(1-2), 277-287.

Martin, J. G., & Bolstad, P. V. (2005). Annual soil respiration in broadleaf forests of northern Wisconsin: influence of moisture and site biological, chemical, and physical characteristics. *Biogeochemistry*, *73*(1), 149-182.

Martin, J. G., & Bolstad, P. V. (2009). Variation of soil respiration at three spatial scales: Components within measurements, intra-site variation and patterns on the landscape. *Soil Biology and Biochemistry*, *41*(3), 530-543.

Morel, A. C., Saatchi, S. S., Malhi, Y., Berry, N. J., Banin, L., Burslem, D., Nilus, R., & Ong, R. C. (2011). Estimating aboveground biomass in forest and oil palm plantation in Sabah, Malaysian Borneo using ALOS PALSAR data. *Forest Ecology and Management*, *262*(9), 1786-1798.

Muñoz-Rojas, M., Lewandrowski, W., Erickson, T. E., Dixon, K. W., & Merritt, D. J., (2015). Soil respiration dynamics in fire affected semi-arid ecosystems: Effects of vegetation type and environmental factors. *Science of the Total Environment, 572*, 1385-1394.

MTIB. (2017). Forest plantation. Development of forest plantation programme. Retrieved from http://www.mtib.gov.my/index.php?option=com_content&view=article&id=94 (Accessed on 15 May 2017).

Návar, J., Estrada-Salvador, A., & Estrada-Castrillón, E. (2010). The effect of landuse change in the tropical dry forests of Morelos, Mexico on carbon stocks and fluxes. *Journal of Tropical Forest Science*, 295-307.

Nazaries, L., Tottey, W., Robinson, L., Khachane, A., Al-Soud, W. A., Sørensen, S., & Singh, B. K. (2015). Shifts in the microbial community structure explain the response of soil respiration to land-use change but not to climate warming. *Soil Biology and Biochemistry, 89*, 123–134.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G. and Ciais, P., 2011. A large and persistent carbon sink in the world's forests. *Science*, *333*(6045), 988-993.

Pavelka, M., Acosta, M., Marek, M. V., Kutsch, W., & Janous, D. (2007). Dependence of the Q_{10} values on the depth of the soil temperature measuring point. *Plant and Soil*, *292*(1-2), 171-179.

Pawson, S. M., Brin, A., Brockerhoff, E. G., Lamb, D., Payn, T. W., Paquette, A., & Parrotta, J. A. (2013). Plantation forests, climate change and biodiversity. *Biodiversity and Conservation*, *22*(5), 1203–1227.

Perkins, D. M., Yvon-Durocher, G., Demars, B. O., Reiss, J., Pichler, D. E., Friberg, N., Trimmer, M., & Woodward, G. (2012). Consistent temperature dependence of respiration across ecosystems contrasting in thermal history. *Global Change Biology*, *18*(4), 1300-1311.

Raich, J. W., & Schlesinger, W. H. (1992). The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus B, 44*(2), 81–99.

Raich, J. W., & Tufekcioglu, A. (2000). Vegetation and soil respiration: Correlations and controls [review]. *Biogeochemistry, 48*(1), 71–90.

Raich, J. W., Potter, C. S., & Bhagawati, D. (2002). Interannual variability in global soil respiration, 1980–94. *Global Change Biology*, *8*(8), 800-812.

Rong, Y., Ma, L., Johnson, D. A., & Yuan, F. (2015). Soil respiration patterns for four major land-use types of the agro-pastoral region of northern China. *Agriculture, Ecosystems and Environment*, *213*, 142-150.

Rubio, V. E., & Detto, M. (2017). Spatiotemporal variability of soil respiration in a seasonal tropical forest. *Ecology and evolution*, *7*(17), 7104-7116.

Russell, A. E., Raich, J. W., Arrieta, R. B., Valverde-Barrantes, O., & González, E. (2010). Impacts of individual tree species on carbon dynamics in a moist tropical forest environment. *Ecological Applications: A Publication of the Ecological Society of America, 20*(4), 1087–1100.

Ryan, M. G., & Law, B. E. (2005). Interpreting, measuring, and modeling soil respiration. *Biogeochemistry, 73*(1), 3–27.

Saga, B. T., Ahmed, O. H., Jamaluddin, A. S., Abdul-Hamid, H., Jusop, S., Nik Ab. Majid, N. M., Hasan, A., Yusof, K. H., Abdu, A. (2010). Selected soil morphological, mineralogical and sesquioxide properties of rehabilitated and secondary forests. *American Journal of Environmental Sciences, 6*(4),389–394.

Saleska, S. R., Miller, S. D., Matross, D. M., Goulden, M. L., Wofsy, S. C., Da Rocha, H. R., De Camargo, P.B., Crill, P., Daube, B.C., De Freitas, H.C. & Hutyra, L. (2003). Carbon in Amazon forests: unexpected seasonal fluxes and disturbance-induced losses. *Science, 302*(5650), 1554-1557.

Sariyildiz, T., Savaci, G., & Kravkaz, I. S. (2015). Effects of tree species, stand age and land-use change on soil carbon and nitrogen stock rates in northwestern Turkey. *iForest-Biogeosciences and Forestry*, *9*(1), 165.

Schlesinger, W. H., & Andrews, J. A. (2000). Soil respiration and the global carbon cycle. *Biogeochemistry, 48*(1), 7-20.

Savage, K., & Davidson, E. A. (2003). A comparison of manual and automated systems for soil CO_2 flux measurements: trade-offs between spatial and temporal resolution. *Journal of Experimental Botany, 54*(384), 891-899.

Sheng, H., Yang, Y., Yang, Z., Chen, G., Xie, J., Guo, J., & Zou, S. (2010). The dynamic response of soil respiration to land-use changes in subtropical China. *Global Change Biology*, *16*(3), 1107–1121.

Shi, W. Y., Yan, M. J., Zhang, J. G., Guan, J. H., & Du, S. (2014). Soil CO_2 emissions from five different types of land use on the semiarid Loess Plateau of China, with emphasis on the contribution of winter soil respiration. *Atmospheric Environment*, *88*, 74-82.

Tang, J., Baldocchi, D. D., & Xu, L. (2005). Tree photosynthesis modulates soil respiration on a diurnal time scale. *Global Change Biology, 11*(8), 1298-1304.

Tang, X., Fan, S., Qi, L., Guan, F., Cai, C., & Du, M. (2015). Soil respiration and carbon balance in a Moso bamboo (*Phyllostachys heterocycla* (Carr.) Mitford cv. Pubescens) forest in subtropical China. *iForest-Biogeosciences and Forestry*, *8*(5), 606.

Tedeschi, V., Rey, A. N. A., Manca, G., Valentini, R., Jarvis, P. G., & Borghetti, M. (2006). Soil respiration in a Mediterranean oak forest at different developmental stages after coppicing. *Global Change Biology*, *12*(1), 110-121.

Tewary, C. K., Pandey, U., & Singh, J. S. (1982). Soil and litter respiration rates in different microhabitats of a mixed oak-conifer forest and their control by edaphic conditions and substrate quality. *Plant and Soil*, *65*(2), 233-238.

Tosi, M., Correa, O. S., Soria, M. A., Vogrig, J. A., Sydorenko, O., & Montecchia, M. S. (2016). Land-use change affects the functionality of soil microbial communities: a chronosequence approach in the Argentinian Yungas. *Applied Soil Ecology, 108*, 118-127.

Veldkamp, E., Purbopuspito, J., Corre, M. D., Brumme, R., & Murdiyarso, D. (2008). Land use change effects on trace gas fluxes in the forest margins of Central Sulawesi, Indonesia. *Journal of Geophysical Research: Biogeosciences, 113*(G2), G000522.

Verheye, W. (2010). Growth and production of rubber. In *Land use, land cover and soil sciences* (pp. 295-304). UNESCO-EOLSS Publishers.

Wang, C., Ma, Y., Trogisch, S., Huang, Y., Geng, Y., Scherer-Lorenzen, M., & He, J. S. (2017). Soil respiration is driven by fine root biomass along a forest chronosequence in subtropical China. *Journal of Plant Ecology, 10*(1), 36-46.

Wang, C., Yang, J., & Zhang, Q. (2006). Soil respiration in six temperate forests in China. *Global Change Biology, 12*(11), 2103-2114.

Wang, F., Liu, J., Zou, B., Neher, D. A., Zhu, W., & Li, Z. (2014). Species-dependent responses of soil microbial properties to fresh leaf inputs in a subtropical forest soil in South China. *Journal of Plant Ecology*, *7*(1), 86–96.

Wang, W., Chemg, R., Shi, Z., Ingwersen, J., Luo, D., & Liu, S. (2016). Seasonal dynamics of soil respiration and nitrification in three subtropical plantaitons in southern China. *IForest-Biogeosciences and Forestry, 9*(5), 813.

Wang, Y., Bölter, M., Chang, Q., Duttmann, R., Scheltz, A., Petersen, J. F., & Wang, Z. (2015). Driving factors of temporal variation in agricultural soil respiration. *Acta Agriculturae Scandinavica, Section B-Soil and Plant Science*, *65*(7), 589–604.

Wangluk, S., Boonyawat, S., Diloksumpun, S., & Tongdeenok, P. (2013). Role of soil temperature and moisture on soil respiration in a teak plantation and mixed deciduous forest in Thailand. *Journal of Tropical Forest Science*, *25*(3), 339-349.

Wellock, M. L., Rafique, R., LaPerle, C. M., Peichl, M., & Kiely, G. (2014). Changes in ecosystem carbon stocks in a grassland ash (*Fraxinus excelsior*) afforestation chronosequence in Ireland. *Journal of Plant Ecology*, *7*(5), 429-438

Wood, T. E., Detto, M., & Silver, W. L. (2013). Sensitivity of soil respiration to variability in soil moisture and temperature in a humid tropical forest. *PloS one*, *8*(12), e80965.

Xiao, W., Ge, X., Zeng, L., Huang, Z., Lei, J., Zhou, B., & Li, M. (2014). Rates of litter decomposition and soil respiration in relation to soil temperature and water in different-aged *Pinus massoniana* forests in the three gorges reservoir area, China. *PloS one*, *9*(7), e101890.

Xu, M., & Qi, Y. (2001). Spatial and seasonal variations of Q10 determined by soil respiration measurements at a Sierra Nevadan forest. *Global Biogeochemical Cycles*, *15*(3), 687-696.

Yan, J., Zhang, D., Zhou, G., & Liu, J. (2009). Soil respiration associated with forest succession in subtropical forests in Dinghushan Biosphere Reserve. *Soil Biology and Biochemistry*, *41*(5), 991-999.

Yan, M., Guo, N., Ren, H., Zhang, X., & Zhou, G. (2015). Autotrophic and heterotrophic respiration of a poplar plantation chronosequence in northwest China. *Forest Ecology and Management*, *337*, 119-125.

Yan, M., Zhang, X., Jiang, Y., & Zhou, G. (2011). Effects of irrigation and plowing on soil carbon dioxide efflux in a poplar plantation chronosequence in northwest China. *Soil Science and Plant Nutrition*, *57*(3), 466-474.

Yan, W., Chen, X., Tian, D., Peng, Y., Wang, G., & Zheng, W. (2013). Impacts of changed litter inputs on soil CO_2 efflux in three forest types in central south China. *Chinese Science Bulletin*, *58*(7), 750–757.

Yan, W. D., Xu, W. M., Chen, X. Y., Tian, D. L., Peng, Y. Y., Zhen, W., Chang, C., & Xu, J. (2014). Soil CO_2 flux in different types of forests under a subtropical microclimatic environment. *Pedosphere*, *24*(2), 243–250.

Yi, Z., Fu, S., Yi, W., Zhou, G., Mo, J., Zhang, D., Ding, M., Wang, X., & Zhou, L. (2007). Partitioning soil respiration of subtropical forests with different successional stages in south China. *Forest Ecology and Management*, *243*(2), 178-186.

Yuste, J. C., Janssens, I. A., Carrara, A., Meiresonne, L., & Ceulemans, R. (2003). Interactive effects of temperature and precipitation on soil respiration in a temperate maritime pine forest. *Tree physiology*, *23*(18), 1263-1270.

Zeng, X., Zhang, W., Shen, H., Cao, J., & Zhao, X. (2014). Soil respiration response in different vegetation types at Mount Taihang, China. *Catena*, *116*, 78-85.

Zhao, X., Li, F., Zhang, W., Ai, Z., Shen, H., Liu, X., Cao, J., & Manevski, K. (2016). Soil respiration at different stand ages (5, 10, and 20/30 years) in coniferous (*Pinus tabulaeformis* Carrière) and deciduous (*Populus davidiana* Dode) plantations in a sandstorm source area. *Forests, 7*(8), 153-165.

Zhou, Z., Guo, C., & Meng, H. (2013). Temperature sensitivity and basal rate of soil respiration and their determinants in temperate forests of north China. *PloS one*, *8*(12), e81793.