EFFECTS OF DEFORESTATION ON SOIL AND ATMOSPHERIC CARBON BALANCE IN SUNGAI MENYALA FOREST, PORT DICKSON, MALAYSIA

By

HOSEA KATO MANDE

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

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DEDICATION

This work is fully dedicated to the Almighty God where I seek my refuge, hope, faith and love. His sufficient grace has kept me to this day; to him I give all the glory, honour and praise. I likewise dedicate this work to my late parents Mrs Inti Aya Mande and HRH Mande Habu Zikku Randa for the quality upbringing, as none of this degree would have been possible without the many years of encouragement and support I have received from them more especially my mother a jewel in the savannah, a lioness and the iron lady of Maitakama clan who fought for me till the point of her death.

.Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the Degree of Doctor of Philosophy

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Chairman: Associate Professor Ahmad Makmom Abdullah, PhD

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Soil CO_2 efflux has been identified as playing a key role in the forest carbon balance, as logging and recovering forest ecosystems increase CO_2 efflux into the atmospheric carbon pool in response to changes in environmental factors such as soil temperature and soil moisture. Hence, it is essential to understand soil CO_2 efflux in forests of different ages, logged-over areas and the carbon cycles in the tropical lowland forest of Peninsular Malaysia.

The aim of this study is to assess soil CO_2 efflux from logged-over forest and recovering forest of different age and it effects on the atmospheric carbon balance. A study was conducted in the recovering tropical lowland forest of Sungai Menyala, Port Dickson, Peninsular Malaysia. Five experimental plots were established based on logged-over area, recovering forests of different ages (10, 30, 50, and 70-year forests) and tree mixed species, as this is significant in efflux estimation and the effect of soil CO_2 efflux from these various forest of different age. Soil CO_2 efflux measurement was conducted in the day time from February to June and September to December 2013, using a constructed continuous open flow chamber technique connected to a multi gas-handling unit and infrared CO_2/H_2O gas analyser.

The soil temperature and soil moisture were measured while forest biomass; total above ground biomass (TAGB), below ground biomass (BGB), total forest carbon (SOCs), soil organic carbon stock (SOCstock) and total organic carbon (TOC), soil organic carbon (SOC), soil pH, bulk density and carbon to nitrogen ratio (C/N) were measured and analysed based on the standard method. The results indicated that the soil CO_2 efflux varies, temporarily increasing from February and peaking in June and decreasing from September to December parallel to the soil temperature and soil moisture. The efflux rate showed a positive and significant correlation between soil CO_2 efflux, soil temperature and soil moisture, forest biomass carbon input, changes in total organic carbon and soil organic carbon (R^2=0.958; p<0.01), suggesting that the environmental factors influence the soil CO_2 efflux. The results showed that soil CO_2 efflux was the highest in the logged-over area and decreased as the forest

increased in age: 10, 30, 50, 70-years old recovering forest at 392.14, 383.07, 372.26, 329.18 and 319.08 mg m^{-2} h^{-1}, respectively, and, in comparison, the primary forest was recorded to emit the lowest CO_2 efflux at 301.23 mg m^{-2} h^{-1}. A high percentage of TOC, SOC and SOCstock concentration occurred within the top 10 cm soil depth and decreased with the depth. Similarly, a high amount of forest biomass carbon input was recorded, both tending to be significantly higher in the older forest and decreased with forest age.

The soil temperature was observed to increase from February to June and decrease from September to December while the soil moisture decreased during the Southwest monsoon regime and increased during the Northeast monsoon period, thereby increasing the soil CO_2 efflux. These results indicated that the soil CO_2 efflux increased in the logged-over forest and decreased as the forest recovered. This is attributed to the high activities of microorganisms in the presence of changes in the environmental factors and soil properties, and exposure of the surface of the land directly to heat in the logged over area. In comparison, the lower soil CO_2 efflux in the recovering forests increased their carbon use efficiency, as the increase in the canopy cover in the recovering forest absorbed the CO_2 for photosynthesis, caused refraction of the solar radiation and regulated the forest floor temperature. The high percentage of CO_2 efflux into the atmospheric carbon pool from the logged area signified that logging activity has wide-reaching consequences and displaced a considerable amount of soil CO_2 into the atmospheric carbon pool, and had a marked influence on the atmospheric carbon balance. In spite high soil CO_2 efflux recorded from the logged-over forest, the percentage of soil CO_2 reduction between the logged-over forest and the recovering forest ranged between 2.31 to 23.18%. This Indicate that forest recovering would serve as a carbon sink and forest logging will be an implication for the atmospheric carbon balance.

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

KESAN PENGHAPUSAN HUTAN TERHADAP TANAH DAN KESEIMBANGAN KARBON ATMOSFERA, HUTAN SUNGAI MENYALA, PORT DICKSON

Oleh

HOSEA KATO MANDE

Disember 2014

Pengerusi: Profesor. Madya Ahmad Makmom Abdullah, PhD

Fakulti: Pengajian Alam Sekitar

Penghasilan efluks CO_2 tanah telah dikenalpasti memainkan peranan utama dalam keseimbangan karbon hutan. Pembalakan dan pemusnahan ekosistem hutan telah meningkatkan penghasilan efluks CO_2 ke dalam kandungan karbon atmosferik yang bertindak balas kepada perubahan faktor sekeliling seperti suhu tanah dan kelembapan tanah. Oleh itu, adalah penting untuk memahami penghasilan efluks CO_2 tanah di hutan yang mempunyai jangka umur yang berbeza, di kawasan pembalakan dan kitaran karbon di hutan tanah rendah tropika di Semenanjung Malaysia.

Kajian ini bertujuan untuk menafsir penghasilan efluks CO_2 daripada kawasan pembalakan hutan dan pemuliharaan hutan di pelbagai peringkat umur serta penentuan kesan terhadap keseimbangan karbon atmosferik. Kajian telah dijalankan dalam usaha memulihara hutan tanah rendah tropika Sungai Menyala, Port Dikson, Semenanjung Malaysia. Lima plot eksperimen diwujudkan berdasarkan kawasan pembalakan, pemuliharaan hutan pada jangka umur yang berbeza (10, 30 , 50 dan 70 tahun) dan spesis campuran pokok yang difikirkan penting dalam penganggaran efluks CO_2 tanah dan kesannya daripada pelbagai peringkat umur hutan. Pengukuran efluks CO_2 tanah dilakukan pada waktu siang dari bulan Febuari hingga Jun dan September hingga Disember tahun 2013 dengan menggunakan teknik pembinaan kebuk aliran terbuka yang disambungkan kepada unit pengendalian pelbagai gas dan penganalisa gas CO_2/H_2O secara inframerah.

Suhu tanah dan kelembapan tanah diukur manakala biojisim hutan; jumlah biojisim permukaan tanah (TAGB), biojisim bawah tanah (BGB), jumlah karbon hutan (SOCs), stok karbon tanah organik (SOCstock) dan jumlah karbon organik (TOC), karbon organik tanah (SOC), nilai pH tanah, ketumpatan pukal, julat karbon kepada nitrogen (C/N) diukur dan dianalisa berdasarkan kaedah piawaian. Keputusan menunjukkan bahawa penghasilan efluks CO_2 tanah adalah berbeza mengikut musim iaitu meningkat dari bulan Februari dan mencapai puncak pada bulan Jun dengan penurunan dari bulan September hingga Disember selari dengan suhu tanah dan

kelembapan tanah. Kadar penghasilan efluks menunjukkan hubungan yang positif dan signifikan antara efluks CO_2 tanah, suhu tanah, kelembapan tanah, input karbon biojisim hutan dan perubahan jumlah karbon organik dan karbon organik tanah (R^2=0.958; $p<0.01$), mencadangkan bahawa terdapat pengaruh faktor persekitaran ke atas efluks CO_2 tanah. Keputusan yang diperoleh menunjukkan efluks CO_2 tanah berada pada tahan tertinggi di kawasan pembalakan dan menurun berdasarkan pengingkatan umur hutan pada 10, 30, 50, dan 70 tahun hutan pulih pada bacaaan 392.14, 383.07, 372.26, 329.18 dan 319.08$mgm^{-2}h^{-1}$ dan perbandingan dengan hutan primer yang mencatatkan nilai efluks CO_2 yang paling rendah iaitu pada 301.23$mgm^{-2}h^{-1}$. Nilai peratusan yang tinggi pada input biojisim karbon (TOC, SOC dan kepekatan SOCstock) dicatatkan pada kedalaman 10 cm dari aras permukaan tanah dan akan menurun selari dengan pertambahan kedalaman. Tambahan, nilai input biojisim karbon adalah tinggi pada hutan yang lebih berusia dan nilainya akan menurun dengan dengan penurunan umur hutan.

Suhu tanah diperhatikan meningkat dari Februari hingga Jun dan menurun dari bulan September hingga Disember manakala penurunan kelembapan tanah mencatatkan penurunan semasa musim kering (Monsun Barat Daya) dan mengingkat pada musim hujan (Monsun Timur Laut) yang akhirnya meningkatkan efluks CO_2 tanah. Keputusan ini menunjukkan bahawa efluks CO_2 tanah meningkat dengan aktiviti pembalakan dan menurun dengan pemuliharaan hutan, kerana dikaitkan dengan aktiviti-aktiviti mikroorganisma yang tinggi dengan perubahan dalam keadaan iklim dan tanah serta pendedahan permukaan tanah secara langsung kepada haba di kawasan pembalakan. Perbandingan dilakukan dan menunjukkan bahawa efluks CO_2 tanah aras bawah di hutan pulih mengingkatkan penggunaan karbon yang efisyen di mana peningkatan perlindungan kanopi membolehkan penyerapan oleh hutan melalui proses fotosintesis selain pembiasan sinar suria untuk tujuan mengawal suhu lantai hutan. Peratusan efluks CO_2 yang tinggi dalam kolam karbon atmosferik (*atmospheric carbon pool)* dari kawasan yang telah dibalak menandakan aktiviti pembalakan menunjukkan sejumlah besar efluks CO_2 tanah telah berpindah ke dalam kolam karbon atmosfera dan mempengaruhi keseimbangan karbon atmosfera. Walaupun kadar efluks CO_2 direkod tinggi dari hutan yang telah dilakukan pembalakan, peratusan penurunan CO_2 tanah antara kawasan pembalakan hutan dengan kawasan baikpulih hutan berada pada julat 2.31 hingga 23.18%. Ini menunjukkan pemulihan hutan akan mengalami fenomena pengurangan karbon (*carbon sink*) dan pembalakan hutan menjadi penyebab kepada ketidakseimbangan karbon atmosferik.

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

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This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision,
- Supervision responsibilities as slated in Rule 41 in Rules 2003 (Revision 2012-2013) were adhered to.

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LIST OF ABBREVIATIONS

CO_2	Carbon dioxide
BGB	Below Ground Biomass
GHG	Green House Gas
IPCC	International Panel of Climate Change
NEE	Net Ecosystem CO_2 Exchange
NEP	Net Ecosystem Productivity
PAR	Photo-synthetically Active Radiation
RF	Radiactive Force
SOCs	Total Forest Carbon stock
SOCstock	Soil Organic Carbon stock
TAGB	Total Above ground Biomass
TOC	Total Organic Carbo

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

One of the topical challenges of recent times is the determination of soil carbon dioxide (CO_2) efflux from deforestation (logged-over), recovering forest. Likewise how regional and global climate will respond to the increase in atmospheric carbon dioxide concentrations and the effect on the carbon balance. Carbon dioxide (CO_2) is the dominant gas classified as one of the greenhouse gases due to their ability to absorb long wave radiation radiated from the earth's surface and this has altered the global temperature. In the 18th century, it had been realised that there had been a pronounced warming trend in the global average temperature by 0.5°C (Lal, 2003).

The average result from many stations in the eastern United States and scattered locations elsewhere around the world showing that the temperature had risen several degrees Fahrenheit in most regions (Kintisch, 2010). In eastern North America and western Europe were the only parts of the world found to be cooler in the winter and the snows deeper in 1930, (Brookfield & Byron, 1990). IPCC (2007) reported that in the 1940s and 1950s there was a striking event of glaciers retreating, while crops were growing farther north, Arctic ice had become thinner than ever before in historic time. In the early 1970s temperature took a new dimension with a series of droughts and other exceptionally bad spells of weather in various parts of the world provoked warning that world food stock might run out. Records showed that the global temperature in the 19th century has increased by 0.8°C. Enough evidence in 2005 indicated a striking change everywhere from Argentina (Glacier National park) to New Guinea (Mount Kilimanjaro). The majority of mountain glaciers and ice-caps were in retreat (IPCC, 2007b), also the heat content of the ocean rose steadily, leading to sea-level rise of about 15-23 cm (IPCC, 2007b). With notable shift in ecosystem (Greene & Pershing, 2007), frequency and intensity of occurrences of wild fire, (Westerling et al., 2006). The earth's temperature for the 21st century has been projected to increase by 1.5–5.8°C per decade, (Lal, 2003; IPCC, 2007c).

Records have pointed directly to greenhouse warming by CO_2 as the major greenhouse gas in the atmosphere, and the concentration of atmospheric greenhouse gases and their radiative forces have progressively increased since the onset of the industrial age. Atmospheric CO_2 levels have been steadily rising as a result of changes in deforestation, land use patterns and combustion of fossil fuels (Houghton et al., 1983; Harmon et al., 1990). Investigation of the ice core samples from the Antarctic have shown that atmospheric CO_2 levels were relatively stable at about 280 ppm for most of the past years (National Research Council, 1998). While as of 2014, the ambient CO_2 level has risen to about 400 ppm, and it is hoped that future concentrations can be stabilized between 350 and 700 ppm (Sarmiento et al., 1995).

To understand soil CO_2 efflux, its impact on the atmospheric carbon balance and to stabilize future concentrations, there should be a clear knowledge of the individual contributing environmental factors and the components of the total carbon balance. It has been estimated that CO_2 existing in some portion of the global carbon pool such as soil, the atmosphere, terrestrial vegetation and oceans total approximately 38,000, 1500, 750, and 560 Pg C each (1 Pg C = 1015 g carbon) (Rustad et al., 2000; Schlesinger et al., 2000). While carbon stored in the soil is about 1576 gigatons (Eswaran et al., 1993) and the soil respiration in the terrestrial ecosystem contributes 55-85% of CO_2 to the atmosphere, greater than terrestrial net primary productivity (Davidson et al., 2006). The soil CO_2 efflux is as a result of deforestation and logging with increase in atmospheric temperature, and even if there is an increase in atmospheric temperature by 0.03°C per year, it will result in soil CO_2 respiration producing a net release of additional CO_2 into the atmosphere. This temperature changes has a negative effect on the atmospheric carbon balance (Ming et al., 2001).

In turn the direct output of the temperature could be great enough to disturb the entire global climate (Wingham, 2009). This scenario will increase surface, subsurface and storage water evaporation with increase in flooding. This will affect agricultural productivity, human health and consumption, energy production, irrigation and other essential services that support the standard of living. Therefore, it will raise the poverty level on the human population (Groisman et al., 2004). The forest ecosystems and oceans are acting as a net sink for carbon at an estimated rate of 3.8 and 2.0 Pg Cyr^{-1} respectively. Whereas deforestation (logging) and fossil fuel combustion serve as net sources of carbon at an approximate rate of 1.6 and 5.4 Pg C yr^{-1} respectively (Rustad et al., 2000). Raich and Schlesinger (1992) have also reported on the gross primary productivity (GPP) of carbon annual uptake from the terrestrial ecosystems to be between 100 and 120 Pg C yr^{-1}, with net primary productivity (NPP) of about 50-60 Pg C yr^{-1}. While the carbon efflux rate from soil respiration, decomposed materials and root respiration stand at 63-77 Pg C yr^{-1} (Schlesinger & Andrews, 2000). These changes in the flux can potentially alter the carbon balance and create partitioning between the atmosphere, soil, terrestrial vegetation and oceanic carbon pools (Raich & Tufekcioglu, 2000).

The magnitude of soil CO_2 efflux is large enough to affect an increase in the atmospheric CO_2 with an implication on climate change (Tang et al., 2006). This has been the environmental management scientists' key concern in view of the fact that the rate of increasing levels of greenhouse gases (CO_2) in the atmosphere is alarmingly high.

Carbon dioxide in the atmosphere can be reduced via the forest ecosystem as it has the capacity and potential to act as a net sink for atmospheric carbon in the 21st century. On the other hand, soil serves as a source of CO_2 emission if deforestation occurs (Harmon et al., 1990; Rustad et al., 2000). Intensive logging and forest harvesting practices globally are going on at a rate of 100,000—165,000 km^2 per year (UNEP, 1990). This scenario is distorting the carbon dynamics and understanding this sequence is necessary to predict the carbon sequestration and its impact on the atmospheric carbon balance. Forest management and productivity can further enhance the role of forests as a potential carbon sink. However, the potential of soils to sequester additional carbon depends on any newly-formed biomass being added to pools that are relatively stable with slow turnover rates or conversely added to pools with short turnover rates that decompose quickly (Kirschbaum, 2000; Trumbore, 2000). The only setback in this scenario is where environmental and predictor factors such as soil type, moisture, and nutrient availability limit the response of a forest stand density to increasing CO_2 concentrations uptake.

Deforestation, logging activity, land conversion and disturbance have very significant implications on soil CO_2 efflux. This has been reported to either increase or decrease CO_2 efflux from forest soils compared to undisturbed forest (Ewel et al., 1981; Toland & Zak, 1994) as the soil is been exposed directly to high increases in temperature, drastically causing unexpected change in microbial activity, litter fall input, root density, production, insolation, absence of CO_2 storage and photosynthesis. Hence, this will result in predictable changes in CO_2 efflux from forest soils from which CO_2 is emitted directly into the atmosphere. The overall effect of deforestation, logging activity, land conversion and disturbance will displace the aboveground biomass as the forest ecosystem serves as a carbon sink and carbon assimilation via photosynthesis results in the efflux of CO_2 into the atmospheric carbon pool (Striegl & Wickland, 1998).

Deforestation at regional scale had a great uncertainty in Southeast Asia in term of soil CO_2 efflux (Kadir et al., 2010). The Southeast Asia contributed 1.08 Gt yr^{-1} of carbon emission according to Houghton (1999) and 0.30-0.49 Gt yr^{-1} according to Cramer et al. (2004). While in Malaysia, deforestation, land conversion, and logging activities are occurring at an alarming rate; the forest ecosystem has been damaged by high logging activities, conversion of land into palm oil plantations, rubber plantations and other land uses. This scenario has led to a significant rise in temperature in Malaysia by 1.1°C for the last three decades and is expected to warm further at the rate of 0.9°C (Toshihiro et al., 2006). The impact of this temperature increase in Malaysia’s climate will severely test the viability of the many current agricultural practices, change in rainfall pattern, and increase in the intensity and frequency of severe storms. Consequently, the flooding can cause devastating damage to the Malaysia environment if precaution is not taken to check the CO_2 efflux and introduce mitigating strategies.

This study was conducted in a logged-over area and four compartments of different tress ages, mixed species, canopy stand density which were compared with a primary forest. The trees varied in age from 10 to 30, 50, and 70 years old and the logged-over area was all located within a distance of 2500 m, 1800 m and 3 km apart. The objectives were to; (1) to determine the influence of environmental factors on soil CO_2 efflux (2) to determine the contributing effect of forest biomass input on biological process to emit soil CO_2, and (3) to determine the rate of soil CO_2 efflux from logged-over area and recovering forests using innovative constructed equipment.

1.2 Problem Statement

The entire global community is being increasingly jeopardized by unpremeditated, non-military environmental threats which are self-generated by fouling of air and water pollution. Likewise over-harvesting of land resources leading to climate change is causing negative effects over the entire globe which may likely last for the next 50 to 100 years. Despite these omnipresent challenges, environmental issues are still not high on the international and national security agenda. Climate change is the most pressing challenge and life threat, as a result of the high rate of deforestation, logging, poor land use and urban heat where part per million (ppm) of CO_2 are being emitted into the atmosphere. Governments do not see these connections through to its higher-order effects and those who study security problems such as non-proliferation, terrorism, and civil conflict often do not recognise the environmental roots and effects of these problems. Consequently, the nexus of climate change is seen neither as a security issue nor an environmental issue. However, environmental issues are often security concerns because even without directly causing open conflict, they have the potential to destabilize regimes, displace populations, cause hunger, and lead to state collapse. Recent studies have shown significant changes in the climate due to increase in temperature resulting from global increase in $CO_{2.}$ Meanwhile, attention has been focused on the tropical forest ecosystems as forest logging for industrial purposes and conversion of the forest to permanent croplands account for approximately 75% of the total CO_2 emission from tropical Asia (Houghton & Hackler, 1999). The tropical forest ecosystem stands to play a major role in the global terrestrial carbon cycle as its vegetation and soil contain approximately 37% of the global terrestrial carbon pool. Whereas, any change in the tropical CO_2 fluxes would change the global carbon budget (Dixon et al., 1994).

Land degredation and loss of Malaysia's original forest have resulted from rapid logging and conversion of land for agricultural purposes (Gillis & Repetto, 1988), and the forest had decreased by 1.2 million hectare by 1990 (FAO, 2010). Half of the forests in the Peninsular Malaysia witnessed forests cleared in the late 1980s (Gillis & Repetto, 1988), as this decreased the total forest cover to 57% of the original area by 2002 (Langner et al., 2007). This has resulted in a serious land cover challenge in the Peninsular Malaysia (Brookfield & Byron, 1990). This resulted activity have affected soil CO_2 efflux and there is still considerable uncertainty about soil CO_2 efflux and subsequent losses and accumulation rates in the logged area and recovering foresta in the lowland forests Peninsular Malaysia (Pan et al., 2011). In spite of this aforementioned challenge in the tropical forest of Malaysia, few studies has been conducted in the forests of different age of the lowland Peninsular Malaysia (Adachi et al., 2006). A more detailed understanding of the impacts of logging on soil CO_2 efflux and the emission rate in the recovering forest, from the soil into the atmosphere in Malaysia is needed for forest management and mitigation of climate change. This study will determine soil CO_2 efflux from logged-over area and recovering forests of different ages and it influencial factors to ascratin the rate of CO_2 emission rate as result of forests disturbance in the Peninsular Malaysia.

The Malaysian forest logging and land conversion scenario has resulted in high average temperature increases by 1.1°C for the last two decades and is expected to warm further at the rate of 0.9°C. This changing air temperature in Malaysia's climate will severely test the viability of many current agricultural practices, its regional change in rainfall pattern, increase in the intensity and frequency of severe storms, flooding, landslides, and urban heat as gas been observed in several towns and cities in Malaysia. Urgent and precautionary steps need to be taken in order to check the CO_2 emission rate by determining the hotspots and factors responsible and thereby establishing mitigation strategies. Malaysia is already facing the maladies of the environmental problem due to climate change with little research done to ascertain the rate of soil CO_2 efflux from logged-over areas, deforestation, agricultural land changes and recovering forests, which means there are no corresponding concepts being developed to deal with these issues by measuring CO_2 emission (Bari et al., 2012). Over time CO_2 emission is at a high rate of increase in Malaysia: in 2007, the UNDP ranked Malaysia as the 27th largest CO_2 emitter in the world. However, Malaysia will heading in the fast lane towards the top of the list if no action is taken soon to ascertain CO_2 efflux rate, determination of environmental variables and introduce mitigation measures. In such a case there would be serious negative impacts on the environment resulting from soil CO_2 efflux the logged-over area in Sungai Menyala forest. Also this could lead to a general human health and water supply implication as well as impact on the national economy (UNFCC, 2011).

1.3 Scope of the Research

Soil CO_2 efflux is a major contributor to the global carbon cycle. The magnitude of soil CO_2 efflux into the atmospheric carbon pool is estimated to be 68 - 100 Pg C/year (Akburak & Makineci, 2013). While forest harvesting, land conversion and disturbance can have great implication on soil CO_2 efflux, and this has been reported to either increase or decrease CO_2 efflux from forest soils compared to undisturbed forest (Ewel et al., 1981; Toland & Zak, 1994). Therefore, there is need to determine soil CO_2 efflux in recovering forests and logged-over areas and the various associated environmental factors.

This research basically attempts to cover various recovering forests of different ages - 10, 30, 50, and 70-year-old forests - with a logged-over area, forest biomass input, soil carbon stock, soil temperature, soil moisture, water potential and total organic carbon (TOC), soil organic carbon (SOC), soil carbon stock (SOCstock), soil pH and bulk density. The location of this research is within the forest reserve of Sungai Menyala, Port Dickson, Negeri Sembilan in Peninsular Malaysia, with a landmass of 1,273.43 hectares. This study will hopefully bridge the knowledge gap in terms of soil CO_2 efflux data from different forest ages and its impact on the atmospheric carbon balance in the lowland forests of Peninsular.

1.4 Research Questions

I. What are the rates of soil CO_2 efflux from various forest ecosystems?
II. What are the variations in soil CO_2 efflux across the seasons in forests of different ages?
III. What is the relationship between forest biomass input, soil carbon stock, SOC, TOC, soil pH, microbial activities, soil temperature and soil moisture?
IV. What is the amount of soil CO_2 efflux compared to the various forest ages?
V. What are the percentages of soil CO_2 efflux being contributed to the atmospheric carbon pool and climate change?
VI. What is the ingenuity in the techniques constructed?

1.5 General Objectives

- To Asses soil CO_2 efflux from logged-over forest and recovering forest of different age and it effects on the atmospheric carbon balance.

1.6 Specific Objectives

- To determine the influence of environmental factors on soil CO_2 efflux
- To determine the contributing effect of forest biomass input on biological process to emit soil CO_2
- To determine the rate of soil CO_2 efflux from logged-over area and recovering forests using innovative constructed equipment.

1.7 Hypotheses

Based on the above objectives the following general hypotheses will be tested:

H_O: Soil CO_2 efflux will not significantly be affected based on the forest canopy stand density.

H_1: Soil CO_2 efflux will significantly be affected based on the forest canopy stand density

Ho: Carbon and nitrogen input from litter fall will not significantly increase both microbial activity and root respiration resulting in high soil CO_2 efflux rate.

H_1: Carbon and nitrogen input from litter fall will significantly increase both microbial activity and root respiration resulting in high soil CO_2 efflux rate.

Ho: Soil temperature, soil moisture, TOC, SOC, bulk density will not all be significant positive corrected with soil CO_2 efflux

H_1: Soil temperature, soil moisture, TOC, SOC, bulk density will all be significant positive corrected with soil CO_2 efflux

Ho: Forest biomass will not increase carbon input, thereby will not significantly affect the biological precess to emit soil CO_2 in both forest stand and logged-over areas.

H_1: Forest biomass will increase carbon input, thereby will significantly affect the biological precess to emit soil CO_2 in both forest stand and logged-over areas.

1.7 Significance of the Study

Soil CO_2 efflux determination in the recovering forest of different ages, logged-over area and environmental factors is of paramount importance and conspicuous in recognising that higher-order effects result from more intervening variables. Soil CO_2 efflux from logged-over and forest of different ages will enable prompt action to be taken in addressing sustainable forest management. The detail implication of logging on the net carbon budget of the forest will enable new strategy for carbon management. Whereas, soil CO_2 efflux data generated from this study area will be used by relevant government agencies to sustain their policy on climate change and environmental management strategies. This research will prompt Malaysia government on systematic CO_2 efflux observation for predicting, communicating and environmental planning to curtail adverse effects. The data will be relevant to governmental on adaptation based on wise resource management: mitigation to enhance adaptation and sustainable development. Also government will improve on afforestation for emission reduction and carbon sink enhancement. Furthermore, this data will be important to forest managers and forest stewards for carrying out appropriate action in forest management to serve as a carbon sink.

1.9 Organisation of the Thesis

In order to have a holistic approach to the subject of soil CO_2 efflux and its atmospheric carbon impact from the recovering lowland forests of Peninsular Malaysia, the following steps were taken in this study: Chapter I deal with the introductory aspect of the study. This involved an overview of climate change resulting from CO_2 efflux, deforestation and changing environmental factors likewise objectives, hypothesis and significance of the study were highlighted.

Chapter II focus on a review from the onset to recent issues regarding soil CO_2 efflux determination and environmental measurement of various forest forest age. Likewise the implication of soil CO_2 efflux on the atmospheric carbon balance was study. Measuring techniques was reviewed in order to identify the suitable techniques to be adopted for modification and the conceptual framework of the flow-path of soil CO_2 efflux.

Chapter III elucidates the research methodology which includes; the experimental design and structure, techniques construction and function. Forest site characteristics in terms of leaves area index (LAI), litter fall, total aboveground biomass (TAGB), belowground biomass (BGB), total forest carbon stock (SOCs), soil organic carbon stock (SOCstock), environmental factors measurements and soil samples analyses will also be presented.
Chapter IV was focus on the results presentation, statistical analysis and discussion. Chapter V was deal on conclusion and recommendations for further study.

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