UNIVERSITI PUTRA MALAYSIA

CARBON ACCUMULATION AND SOIL ASSESSMENT OF AN EARLY STAGE REHABILITATED TROPICAL FOREST

CH'NG HUCK YWIH

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

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

CARBON ACCUMULATION AND SOIL ASSESSMENT OF AN EARLY STAGE REHABILITATED TROPICAL FOREST

By

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APRIL 2011

Chairman: Associate Professor Osumanu Haruna Ahmed, PhD

Faculty: Faculty of Agriculture and Food Sciences (Bintulu)

Logging and shifting cultivation negatively affect initial soil carbon (C) storage especially at the initial stage of deforestation as such practices lead to global warming. Thus, afforestation programme is needed to mitigate this problem. Many studies have been reported to estimate regional C storage and national C budgets of temperate forests in many countries but little is known about the trend of soil C accumulation and soil fertility for forest regrowth in relation to an initial stage of rehabilitated forests in the tropics such as Malaysia. Information on C accumulation and soil fertility for forest regrowth of rehabilitated forests suggest whether these forests can serve as C sink to mitigate climate change. Thus, the objective of this study was to determine the soil C accumulation quantitative and qualitatively, and soil fertility of an early stage of a rehabilitated forest. The study was conducted in a rehabilitated forest of Universiti Putra Malaysia, Bintulu Sarawak Campus area (Latitude 03º12 N and Longitude 113º02 E at 50 m above sea

level) with the mean annual rainfall, relative humidity and temperature of 2933 mm, 80%, and 27 ^{o}C respectively. The area was previously abandoned after shifting cultivation activity and it has been rehabilitated since 1991 by planting indigenous timber species from the family Dipterocarpaceae and Non-Dipterocarpaceae. The size of each experimental plot was 30 x 40 m. Soil samples were collected randomly using a mineral soil auger from 1- to 7-year-old rehabilitated forest at 0-20, 20-40, and 40-60 cm depths. Ten samples were collected from each depth per plot and each sample was a bulk of three samples. These soil samples were air dried, crushed manually, and sieved to pass a 2-mm sieve, after which they were transferred into plastic bags and labelled. The soil texture of the rehabilitated forest was Typic Paleudalts and is a typical of Ultisols, which is characterized by the coarse loamy yellow podzolic group that developed from weathering of sandstone. The procedures outlined in the Materials and Methods section were used to analyze the soil samples for pH, total C, soil organic matter (SOM), total nitrogen (N), C/N ratio, yield of humic acid (HA), and soil stable C from humic acids (CHA). The bulk densities at these depths were determined by the coring method. The bulk density method was used to quantify soil total N stocks, soil total C, SOM, HA, and CHA at the stated sampling depths on per hectare basis. The first study determined the soil C accumulation of an early stage of a rehabilitated forest. Results showed that pH decreased significantly with increasing age of rehabilitated forest regardless of depth. SOM and total C contents increased with age. No significant difference in the quantity of CHA content for the different ages of rehabilitated forest at 0-20, 20-40 and 40-60 cm soil were observed. Since the CHA is more stable, it is more realistic to quantify the amount of C accumulated in setting up the rehabilitated forest at initial stages. The second study qualitatively assessed the initial soil C accumulation of the rehabilitated forests using Fourier Transform Infrared spectroscopy (FTIR). The spectra of all locations were similar because there was no significant difference in the quantities of CHA regardless of forest age and soil depth. The spectra showed distinct absorbance at 3290, 1720, 1630, 1510, 1460, 1380 and 1270 cm^{-1}. Increase of band at 1630 cm^{-1} and 1510 cm^{-1} from 0-20 cm to 40-60 cm were observed, suggesting C decreased down the depths of 20-40 cm and 40-60 cm. However, the CHA in the soil depths were not different. The band at 1630 cm^{-1} was assigned to carboxylic and aromatic groups. Increase in peak intensity at 1510 cm^{-1} was because C/N ratio increased with increasing soil depth. This indicates that decomposition rate decreased with increasing soil depth and but decreased with stable C. FTIR allows qualitative identification of functional groups and thus providing a better understanding of decomposition pathways of soil organic matter and C build up. The third study assessed the initial soil fertility by comparing the soil factors of different ages of the rehabilitated forest. The SEF values of the rehabilitated forest showed low fertility and showed slight increase with increasing depth. In the depths of 20-40 and 40-60 cm, SEF values were high due to nutrient absorption of tree roots and nutrient leaching. Nutrients such as potassium (K), aluminium (Al), and SOM were found to be important variables influencing trees growth rate in this nutrient poor soil. Al and SOM in particular, had significant influence on the soil fertility and thus may have effect on the tree growth rate in this poor fertility site. Low

SOM content and coarse sand soil texture caused nutrients to leach rapidly in Ultisols, thus causing soils to be poor in plant nutrients. The SEF used in this study allows comparative analysis of soil fertility and evaluation and identification of soil conditions among initial ages of rehabilitated forests. Overall, this study did not show any significant statistical accumulation in the soil C stocks up to 7-year-old rehabilitated forest and this was mainly due to the supply of raw materials since the trees were considered as immature stage (1- to 7-year-old) in comparison to a continuous supply of organic matter from mature vegetation in the existing older stand of rehabilitated forest and secondary forest. This clearly shows that afforestation program requires a long period (20 years) to recover the C stocks in soil and it is serious to clear the forest for unsustainable land usage.

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

KAJIAN PENAMBAHAN KARBON DAN KESUBURAN TANAH PADA HUTAN PEMULIHARAAN TROPIKAL PERINGKAT AWAL

Oleh

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Penebangan hutan dan perladangan berpindah mempengaruhi penyimpanan karbon (C) tanah secara negatif terutama pada peringkat awal penebangan hutan dan kegiatan tersebut menyumbang kepada pemanasan global. Oleh itu, program penanaman hutan adalah diperlukan untuk menangani masalah tersebut. Banyak kajian telah melaporkan penganggaran penyimpanan C daerah dan bajet C kebangsaan di hutan negara bermusim tetapi terdapat kekurangan kajian tentang aliran penambahan karbon tanah dan maklumat kesuburan tanah untuk penjanaan semula hutan pada peringkat awal hutan pemuliharaan di negara tropik seperti Malaysia. Maklumat tentang penambahan karbon dan kesuburan tanah untuk penjanaan semula hutan pada hutan pemuliharaan mencadangkan sama ada hutan pemuliharaan berpotensi untuk berfungsi sebagai tabung penambahan karbon tanah untuk menyelesaikan masalah perubahan cuaca. Oleh itu, objektif kajian ini adalah untuk menentukan penambahan karbon tanah secara kuantitatif dan

kualitatif, dan kesuburan tanah pada peringkat awal hutan pemuliharaan. Kajian ini dijalankan di hutan pemuliharaan Universiti Putra Malaysia Kampus Bintulu Sarawak (Latitud 03^{o}12U dan Longitud 113^{o}02T pada 50 m atas paras laut) dengan purata hujan tahunan, kelembapan relatif dan suhu sebanyak 2933 mm, 80% dan 27 ^{o}C masing-masing. Kawasan kajian pada masa awal adalah kawasan terbiar akibat aktiviti pertanian berpindah dan dipulihara sejak tahun 1991 dengan penanaman pokok pribumi tempatan dari keluarga Dipterocarpaceae dan bukan Dipterocarpaceae. Saiz setiap kawasan kajian adalah 30 x 40 m. Sampel tanah dikumpul secara rawak dengan menggunakan pengorek tanah mineral dari hutan pemuliharaan berumur 1 hingga 7 tahun pada kedalaman 0-20, 20-40, dan 40-60 cm. Sepuluh sample tanah dikumpul dari setiap kedalaman pada setiap kawasan kajian dan setiap sampel merupakan gabungan tiga sampel. Semua sampel tanah dikeringkan, ditumbuk dan dituras melalui penuras bersaiz 2 mm. Tekstur tanah hutan pemuliharaan merupakan tanah liat berpasir dan merupakan Typic Paleudalts, dan merupakan Ultisol di mana ia mempunyai ciri liat berpasir warna kuning akibat luluhawa batu pasir. Rangka kerja yang diterangkan di bahagian Bahan dan Cara digunakan untuk menganalisa sampel tanah untuk pH, jumlah karbon, bahan organik tanah, jumlah Nitrogen, nisbah C/N, jumlah asid humik, dan karbon tanah stabil dari asid humik. Kepadatan tanah digunakan untuk menentukan jumlah Nitrogen, karbon tanah, bahan organik tanah, asid humik dan karbon tanah stabil dari asid humik pada kedalaman ternyata dalam skala satu hektar. Kajian pertama adalah untuk menentukan penambahan karbon dalam tanah hutan pemuliharaan. Keputusan menunjukkan bahawa pH berkurang secara nyata dengan penambahan umur hutan pemuliharaan tidak kira kedalaman. Bahan organik tanah dan jumlah karbon bertambah selaras dengan penambahan umur hutan pemuliharaan. Tidak ada perbezaan nyata dalam jumlah karbon stabil dari asid humik untuk umur yang berbeza bagi tanah hutan pemuliharaan pada kedalaman 0-20, 20-40, dan 40-60 cm. Oleh sebab karbon dari asid humik adalah lebih stabil, maka ia lebih realistik digunakan untuk mengkuantifikasikan jumlah karbon yang disimpan dalam hutan pemuliharaan pada peringkat awal. Kajian kedua mengkaji penambahan karbon pada peringkat awal di hutan pemuliharaan secara kualitatif dengan menggunakan Fourier Transform Infrared spectroscopy (FTIR). Spektra untuk semua lokasi adalah sama sebab tidak ada perbezaan nyata dalam kuantiti karbon stabil dari asid humik pada semua umur hutan pemuliharaan dan kedalaman tanah yang dikaji. Spektra tersebut menunjukkan beza penyerapan pada 3290, 1720, 1630, 1510, 1460, 1380, dan 1270 cm^{-1}. Terdapat penambahan pada puncak 1630 cm^{-1} dan 1510 cm^{-1} dari 0-20 cm ke 40-60 cm, dan ini menunjukkan jumlah karbon berkurang ke bawah kedalaman 20-40 cm dan 40-60 cm. Walau bagaimanapun, tidak terdapat perbezaan nyata dalam kandungan karbon stabil dari asid humik di antara ketiga-tiga kedalaman tersebut. Puncak pada 1630 cm^{-1} adalah disebabkan oleh kumpulan karbosilik dan aromatik. Peningkatan pada titik puncak di 1510 cm^{-1} adalah disebabkan oleh penambahan nisbah C/N apabila kedalaman tanah bertambah. Ini menunjukkan bahawa kadar pereputan berkurang dengan penambahan kedalaman tanah tetapi berkurang dengan karbon stabil dari asid humik. FTIR membolehkan penentuan secara kualitatif kumpulan berfungsi dan seterusnya memberikan pemahaman tentang proses pereputan bahan organik dan penambahan karbon. Kajian ketiga mengakaji kesuburan tanah pada peringkat awal dengan membandingkan Faktor Penilaian Tanah (SEF) pada umur berbeza hutan pemuliharaan. Nilai SEF menunjukkan tanah kurang subur dan bertambah menuruni kedalaman tanah. Pada kedalaman 20-40 dan 40-60 cm, nilai SEF adalah lebih tinggi sebab penyerapan nutrien oleh akar pokok dan pengluluhan nutrien. Kalium (K), aluminium (Al) dan bahan organik merupakan unsur penting yang mempengaruhi kadar pertumbuhan pokok dalam tanah yang kurang subur ini. Terutamanya Al dan bahan organik, mempunyai pengaruh yang nyata terhadap kesuburan tanah dan seterusnya mempunyai kesan terhadap pertumbuhan pokok di tanah kurang subur ini. Kandungan bahan organik yang rendah dan tanah liat berpasir menyebabkan nutrient diluluh di Ultisols, dan seterusnya menyebabkan ketidaksuburan tanah. SEF yang digunakan dalam kajian ini membolehkan perbandingan kesuburan tanah dan penilaian keadaan tanah di antara umur-umur peringkat awal hutan pemuliharaan. Secara keseluruhannya, kajian ini tidak menunjukkan penambahan karbon tanah yang nyata di hutan pemuliharaan dari tahun 1 hingga 7. Ini adalah disebabkan bekalan sumber bahan mentah yang kurang sejak pokok-pokok dicirikan sebagai masih dalam peringkat muda berbanding dengan bekalan bahan organik secara berterusan dari pokok-pokok matang di hutan pemuliharaan yang lebih tua dan hutan sekunder. Ini menunjukkan program pemuliharaan hutan memerlukan masa yang panjang (20 tahun) untuk memuliharakan tabungan karbon dalam tanah dan ia adalah serius atas penebangan hutan untuk tujuan penggunaan tanah yang tidak mesra alam.

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This thesis was submitted to the Senate of 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:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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CH'NG HUCK YWIH

Date:

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LIST OF ABBREVIATIONS

1	Al – Aluminium
2	ANOVA – Analysis of Variance
3	C – Carbon
4	Ca – Calcium
5	CHA – Stable Carbon from Humic Acids
6	CO_2 - Carbon Dioxide
7	COOH – Carboxylic
8	Cu – Copper
9	E_4/E_6 – Ratio of Absorption Intensities at 465 and 665 nm
10	FTIR – Fourier Transform Infrared Spectroscopy
11	H_2SO_4 – Sulphuric Acid
12	HA – Humic Acids
13	HCl – Hydrochloric Acid
14	HS – Humic Substances
15	K – Potassium
16	KBr – Potassium Bromide
17	KCl – Potassium Chloride
18	Mg – Magnesium
19	N – Nitrogen
20	$NaHCO_3$ – Sodium Bicarbonate
21	NaOH – Sodium Hydroxide
22	OH – Phenolic

23 P – Phosphorus

24 SAS – Statistical Analysis System

25 SEF – Soil Evaluation Factor

26 SFI – Soil Fertility Index

27 SIC – Soil Inorganic Carbon

28 SOC – Soil Organic Carbon

29 SOM – Soil Organic Matter

30 TC – Total Carbon

CHAPTER 1

INTRODUCTION

1.1 Background

Fossil fuel emissions dominate the anthropogenic perturbation of the global carbon cycle. Land use changes currently drive the largest proportion of anthropogenic emissions in a number of tropical regions of Asia (Canadel, 2002). According to the Kyoto Protocol, land use, land-use change, and forestry (LULUCF) are recognized as serving the role of carbon source and sink in relation to a change in land cover and carbon stocks. It also influences the amount of biomass and carbon stored in vegetation (IPCC, 2000). Land-use changes also affects soil carbon (C) storage because soils are either carbon sources or sinks depending on the variable response of soil C pools to land-cover change (Power *et al.*, 2004).

Tropical rainforest covers about 19.37 million hectares of Malaysia's total area and about 8.71 million hectares can be found in Sarawak (Hamzah *et al*., 1995). Land use in Malaysia especially Sarawak has changed significantly because of transmigration and changes in rural economy. Excessive logging, oil palm cultivation and shifting cultivation contribute to deforestation in Sarawak (Dimin, 1988; Leng *et al.*, 2009). Forests are the most important carbon pool on the earth surface. Approximately 60-70% of carbon in the forests is stored as organic material in the soil (Janssen *et al.*, 1999). Deforestation and inappropriate land-use practices have resulted in several environmental problems such as declining soil organic carbon (SOC) through decreased carbon sequestration and increased carbon dioxide (CO_2) emission to the atmosphere (Paustian *et al.*, 2000). Biomass burning or decomposition and release of SOC following cultivation due to enhanced mineralization brought about the change in soil moisture, temperature regimes and low rate of return biomass to the soil are among the causes of C emission (Korschens, 1998). Accordingly, the conversion of forests to other land uses not only reduces C stocks in vegetation but also causes significant losses of soil organic carbon (Post and Kwon, 2000). Reducing soil C stocks are also associated with agricultural management that is residue removal via harvesting or burning, and soil tillage (Hairiah *et al.*, 2001).

Carbon store in forest ecosystems is large and in dynamic equilibrium with its environment. Because of the large areas involved on a global scale, forest soils play an important role in global C cycle (Jabaggy and Jackson, 2000). In recent years, scientists and policy makers have become mindful of the mitigating role of forests in reducing the buildup of CO_2 in the atmosphere. Forests have been reduced from occupying about 46% of the earth's terrestrial ecosystems in preindustrial times to approximately 28% in recent times (Sharma *et al.*, 1992). This reduction, along with other human activities, has contributed to the buildup of atmospheric CO_2.

Due to land clearing of forest to other land uses, the nutrient loss in the soil and change of carbon sequestration and build up in relation to substituted secondary forests are obvious. The cause of soil fertility decline results in a net removal of nutrients from soil either by the harvested product and/or through increased losses as compared with natural ecosystems. Degradation in soil quality associated with the conversion of forest into different land uses is mainly due to decline in the soil organic matter (Smith *et al.,* 2000). McDonald *et al.* (2002) reported that land clearing and subsequent planting and cropping promoted a significant reduction in SOC, total N, exchangeable K, Ca, and Mg, and available P.

Despite the widespread view that forest land-use is best suited for carbon sequestration and build-up, it is essential to assess the potential of soil C enrichment through rehabilitating abandoned land caused by shifting cultivation by planting indigenous species of trees.

1.2 Problem Statement

The tropical rainforests are prevailed at unprecedented rate by human activities due to overexploitation of forest areas through deforestation, excessive logging and shifting cultivation, leading to degradation of forestland. Degradation of forestland commonly refers to the intensity of deterioration of physical and chemical of the areas. Rehabilitation of degraded forestland becomes very important in order to curtail the loss of soil nutrients and improve vegetation stand or composition as well as for environmental concern. The understanding of C stocks and its accumulation in a time series in land use is essential to addressing climate change mitigation efforts, and provide key information on species-site preference in order to improve the strategies and effective technique for future rehabilitation efforts. Rehabilitation of tropical rainforest on severely degraded land requires knowledge on soil science for better understanding of the effective soil conservation and management. However, most of the previous studies have emphasized the growth performance of planted species along with the planting technique with less attention on soil C storage, soil morphological, physico-chemical and charge characteristics and clay mineralogical properties.

1.3 Objectives

The objectives of this study were to:

1. Determine soil carbon accumulation of an early stage (1- to 7-year-old) of a tropical rehabilitated forest.
2. Assess soil carbon accumulation of an early stage (1- to 7-year-old) of a tropical rehabilitated forest using Fourier Transform Infrared Spectroscopy.
3. Assess soil fertility of an early stage (1- to 7-year-old) of a tropical rehabilitated forest by comparing the soil factors.

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= W Mg/ha of HA

The weight of CHA per hectare was determined by multiplying the weight of soil at depth (for example 0–25 cm) with the percentage of stable carbon in HA.

Weight of CHA per hectare = Y x Percentage of stable carbon

= Q Mg/ha of CHA

IX. Calculation of Exchangeable Aluminium

Exchangeable Al^{3+} (cmol kg^{-1}) = [0.2 x Titrate volume of 0.01 M HCl x 10]/soil mass

BIODATA OF STUDENT

Ch'ng Huck Ywih, born in 11 October 1985, originated from Penang, studied in Sekolah Rendah Jenis Kebangsaan Union in 1991. After completing his primary school, he studied in Sekolah Menengah Chung Ling in 1997. He successfully obtained a First-class in Bachelor of Science Bioindustry from Universiti Putra Malaysia in 2009. He was assigned to Training Department and Road Department at Grand Perfect Sdn. Bhd. Plantation, Bintulu, Sarawak, Malaysia during his internship. He is currently undertaking Master of Science (Land Resources Management) in Faculty of Agriculture and Food Sciences, Universitii Putra Malaysia Bintulu Sarawak Campus. He attended 2010 Universiti Brunei Darussalam 1st Graduate Science Student Research Conference.

LIST OF PUBLICATIONS

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2. Ch'ng, H.Y., Ahmed, O.H., Majid, N.M.A. and Jalloh, M.B. (2009). Effects of converting secondary forest on tropical peat soil to oil palm plantation on carbon storage. American Journal of Applied Sciences 4(2): 123-130. [Published]

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