CARBON POOLS IN SIX-YEARS-OLD PLANTED AND NATURALLY REGENERATED *ACACIA MANGIUM* STANDS

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SCHOOL OF INTERNATIONAL TROPICAL FORESTRY
UNIVERSITI MALAYSIA SABAH
2013

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THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE

SCHOOL OF INTERNATIONAL TROPICAL FORESTRY UNIVERSITI MALAYSIA SABAH
2013

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ACKNOWLEDGEMENT

I was blessed to have the help and support of many talented people who have help me directly and indirectly in accomplish this thesis, to which I want to express my sincere thanks. Firstly, I would like to express my gratitude to God for showing me guidance and helping me to accomplish my thesis without much problems and difficulty.

My deepest appreciation to my main supervisor, which is also the Dean of the School Of International Tropical Forestry, Dr. Normah Awang Besar @ Raffie for her advice, support, suggestions, constructive comments, encouragements, patience, and assistance throughout this study. Special thanks goes to my co-supervisor Associate Professor Dr. John Jay, lecturers, and staffs for their support, motivation and helps in this thesis.

I would also like to acknowledge to the staff and workers in Bengkoka Forest Plantation especially the officer from SAFODA, Mr. Hassan and Mr. Martin from Hijauan Bengkoka Plantation for their assistance with field work and information used in this study. Special thanks to my supportive friends and helpers Collin Kong, Albert Ong, Kevin Math Keriah, Jackz Lee, Wee, and Ben Lo for their assistance with field work.

Lastly, I would also like to thank my parents and family members for all their support and endless encouragement throughout the preparation of my thesis from the beginning to the end.

Tan Chun Hung
22 Dec 2013

ABSTRACT

This study investigated the carbon pools in Acacia mangium stands of six-year old planted and natural regenerated stands at the Bengkoka Forest Plantation, Pitas, Sabah. The soil for the study site was classified into Kumansi Family (Sabah System) and Typic Tropudult (USDA). The objective was to determine the aboveground biomass (AGB) and belowground biomass (BGB), carbon content of the AGB and BGB, as well as the soil organic carbon content (SOC) in the two silviculturally treated Acacia mangium stands. A random systematic sampling method was adopted in the study where two circular plots of 0.25 ha were established in each of the Acacia mangium stands. Within each plot, the diameters at breast height (DBH) of all trees were recorded. The shrub and organic layers were quantified at five randomly selected positions in each plot. Five litter traps (1 m x 1 m) were set up at the same position as the shrub and organic layer. Three quadrates (25 cm x 25 cm x 30 cm) were randomly dug for root biomass and carbon content. The soil bulk density was determined by using undisturbed soil samples that were collected by using 51 mm diameter ring (100 ml). The results showed that the total amount of carbon pools was 73.56 (± 5.63) t C ha^{-1} and 82.40 (± 0.69) t C ha^{-1} for planted and natural regenerated stands and not statistically different. In comparison, the naturally-regenerated stand supported higher carbon pools compared to the planted stand. This study also found that the major contributor to total carbon pools for both planted and naturally-regenerated Acacia mangium plantations was the AGB followed by SOC.

KEYWORDS: *Acacia mangium*, Carbon Pools, Aboveground biomass, Belowground biomass, Forest Plantation

ABSTRAK

TABUNG KARBON DALAM DIRIAN *ACACIA MANGIUM* BERUSIA ENAM TAHUN DI ANTARA YANG DITANAM DAN TUMBUH SEMULAJADI

Kajian ini menentukan jumlah tabung karbon dalam dirian Acacia mangium yang ditanam dan dirian tumbuh semulajadi berumur enam tahun di Ladang Hutan Bengkoka, Pitas, Sabah. Tanah di kawasan kajian diklasifikasikan dalam Famili Kumansi (Sistem Sabah) dan Typic Tropudult (USDA). Tujuan kajian ini adalah untuk menentukan biojisim di atas permukaan (AGB) dan di bawah permukaan tanah (BGB), jumlah simpanan karbon oleh AGB dan BGB, dan juga kandungan karbon organik tanah (SOC) pada kedalaman 30 cm di antara kedua-dua dirian Acacia mangium. Kaedah pensampelan secara rawak bersistematik telah digunakan dimana dua plot yang berbentuk bulat dan berkeluasan 0.25 ha telah dibuat bagi setiap dirian Acacia mangium tersebut. Dalam setiap plot, diameter paras dada (DBH) bagi setiap pokok telah dicatat. Sebanyak 5 sampel bagi pokok renek dan lapisan organik telah diambil secara rawak di setiap plot. Lima perangkap (1m x 1m) daun dan dahan gugur (litterfall) telah didirikan pada posisi yang sama dengan lapisan organik dan pokok renek. Tiga kuadrat (25 cm x 25 cm x 30 cm) telah digali bagi setiap plot untuk mendapatkan akar pokok bagi tujuan mengukur biojisim akar dan kandungan karbon. Ketumpatan pukal tanah diuji dengan mengambil sampel tanah tidak terganggu dengan silinder besi berdiameter 51 mm (100 ml). Keputusan menunjukkan bahawa jumlah simpanan karbon adalah 73.56 t C ha^{-1} *dan 82.40 t C ha*$^{-1}$ *bagi dirian ditanam dan dirian tumbuh semulajadi dan analisis statistic tiada perbezaan yang significant. Secara perbandingan, blok regenerasi sendiri menyumbang lebih simpanan karbon berbanding dengan blok tanam. Kajian ini juga mendapati bahawa penyumbang utama kepada tabung karbon bagi kedua-dua blok dirian Acacia mangium adalah AGB dan diikuti oleh SOC.*

KATA KUNCI: *Acacia mangium*, Tabung Karbon, Biojisim Atas Tanah, Biojisim Bawah Tanah, Perladangan Hutan

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LIST OF SYMBOLS AND ABBREVIATIONS

AGB	Above Ground Biomass (stem, branches, twigs)
BD	Bulk density
BGB	Below Ground Biomass
C	Carbon
CP	Carbon Pool
C_{plant}	Carbon pool in the plant biomass
C_{pool}	Carbon pool in the soil sample
CO_2	Carbon dioxide
DBH	Diameter at breast height
DWsample	Total dry weigh of plant biomass in the sample of the sampling area
dw	Dry weigh of soil
d	Soil horizon depth
FWD	Fine wood debris
GHG	Greenhouse gas
H	Height
h	hour
ha	Hectare
n	Number of sample
T	Temperature (K)
t	Tonne, Metric Ton
TCP	Total Carbon Pool

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Forest plantations are known by many different names, such as industrial timber plantation, industrial tree plantation, planted forest or plantation forest. The International Tropical Timber Organisation (ITTO) defines them as "a forest stand that has been established by planting or seeding" while the United Nation's Food and Agriculture Organisation (FAO) defines planted forests as "forest predominantly composed of trees established through planting and/or deliberate seeding".

Forest plantations have increased from 180 million ha in 1990 to 264 million ha in 2010, and occupied about 7% of the world total forest area of 4 billion ha (FAO, 2011). The World's industrial roundwood consumption has been rising annually, reaching 1.54 billion m^3 in 2008 (FAO, 2011). According to a report, State of the World's Forest 2011, forest plantations in the Asia-Pacific region have increased by 29.33 million ha in the last decade making up 16% of forested area in the region and supplying 10% of total wood resource in this region (FAO, 2011). In South-East Asia, planted forest had increased by about 2.8 million ha over this 10-year period (2001-2010), an annual increase of 2.16% (FAO, 2011).

Plantation forestry has been considered to be an effective medium for removing carbon dioxide (CO_2) from the atmosphere and sequestering it in trees through the process of photosynthesis by fixing carbon in aboveground and belowground biomass (Ogawa *et al*, 2005). Conversely, the carbon fixed in trees could be released to the atmosphere by various means of forest degradation (Hall and Uhlig, 1991; Houghton, 1991; Fearnside, 1996; Houghton *et al.*, 2000). Large carbon stock harvested from the forests would release CO_2 into the atmosphere. The continuing increase in CO_2 accumulation in the atmosphere averaging 1.9 ppm per year now accounts for about 90% of the current annual increase in greenhouse gases forcing of global climate (Hansen and Sato, 2004).

Given the scenario above, the International Panel on Climate Change (IPCC) has recommended a catalogue of remedial measures to mitigate increasing CO_2 emissions. Among these remedial measures are reaforestation and the adoption of agrosilvicultural systems in mono-agricultural land (IPCC, 2001). Governments had also agreed to reduce emissions of CO_2 by limiting fossil fuel consumption and by increasing net carbon sequestration in the terrestrial sinks through afforestation/reforestation and change in land management (IPCC, 2001).

The Kyoto Protocol recognizes that land use, land-use change, and forestry activities can play an important role in meeting the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC), in stabilizing greenhouse gases (GHGs) concentration at a level that will not worsen the present situation. The strategies of the UNFCCC are to: (1) conserve existing carbon pools (avoiding deforestation), (2) sequester and increase the size of carbon pools through afforestation and reforestation, and (3) substitute fossil fuel energy by use of modern biomass.

The carbon-sink of afforestation and reforestation activities meeting certain specific criteria were considered for inclusion in the Clean Development Mechanism (CDM) of Kyoto Protocol leading to interest in the plantations related to CDM in some countries. Information on biomass of industrial plantations as carbon stock is important for planning and managing operating industrial plantations related to CDM (Yamada *et al.*, 2004). Establishing and managing man-made forests on former forested lands may mitigate the effects of global warming by sequestration of atmospheric CO_2 in the forests. The carbon pools in these forests will be maintained if the forests are managed in a sustainable fashion with a long rotation cycle.

Global climate change has inspired an increasing interest of scientific and political communities in the study of global carbon storage and carbon balance (Landsberg*et al.*, 1995; INBAR, 2006). Several 'no regret' policies and forest management practices were considered to address the impacts of climate change (Ravindranath, 2006). Yet, it is essential to evaluate the role of *Acacia mangium* in

C storage and C sequestration to understand its effectiveness in atmospheric CO_2 mitigation (Arun *et al.*, 2009).

1.2 Justification

Although there are several estimates of carbon storage in various forest types, few estimates of individual species C storage potential have been published. To allow informed choices between species when establishing C storage projects, it is important to characterize various traits which influence C storage on per species basis. Such information would also be useful for inclusion in global C storage/cycling models (Margeret *et al.*, 2001).

In most studies, the above-ground biomass potentials are well-known but not belowground biomass. It is necessary to include belowground biomass in C studies to complete the estimate of C storage. One must know aboveground-to-belowground biomass allocation patterns. Belowground allocation of biomass in forests ranges widely, such as in tropical dry forests the contribution of roots to total biomass has been estimated to range from 18 to 46% (Margeret *et al.*, 2001).

Thus, in the context of managing the terrestrial biosphere, understanding the consequences of reforestation of ecosystem carbon storage becomes a necessity. In order to calculate the carbon pools, we must obtain precise estimates of the forest biomass and quantify carbon pools in different compartments.

1.3 Objectives

The objectives of this study were:

1. Soil Profile characterization of the six-years-old planted and naturally regenerated *Acacia mangium* stands;

2. Quantification of the above ground biomass (AGB) and below ground biomass (BGB) in six-years-old planted and naturally regenerated *Acacia mangium* stands;

3. Quantification of the soil carbon stocks in six-years-old planted and naturally regenerated *Acacia mangium* stands;

4. Quantification of the carbon content in AGB and BGB in six-years-old planted and naturally regenerated *Acacia mangium* stands;

5. Comparison of carbon pools in six-years-old planted and naturally regenerated *Acacia mangium* stands.

CHAPTER 2

LITERATURE REVIEW

2.1 Role of Forests in Climate Change

Forests play a very critical role in influencing earth's climate, as globally important carbon storehouses. Forest plants and soils drive the global carbon cycle by sequestering carbon dioxide through photosynthesis and releasing it through respiration. Although carbon uptake by photosynthesis eventually declines as trees aged, many mature forests continue to sequester carbon in their soils (Schulze *et al.*, 2000). Forests absorb approximately one third of the anthropogenic emissions of carbon dioxide (CO_2) to the atmosphere, acting as carbon sink. However, our activities in the forest have also been a source of carbon emitted to the atmosphere through decay. Global deforestation rate in the tropics contribute about one fifth of the annual anthropogenic emissions (UNFCCC, 2007).

As the world mobilizes to address the issue of climate change, forest management is being used to increase sequestration of carbon in the biosphere in the short to medium term through reforestation and afforestation. This attention on forests and forestry has increased the demand for detailed knowledge of forest functioning and accurate information about the state of the world's forests (Schimel *et al.*, 2001, IPCC, 2001).

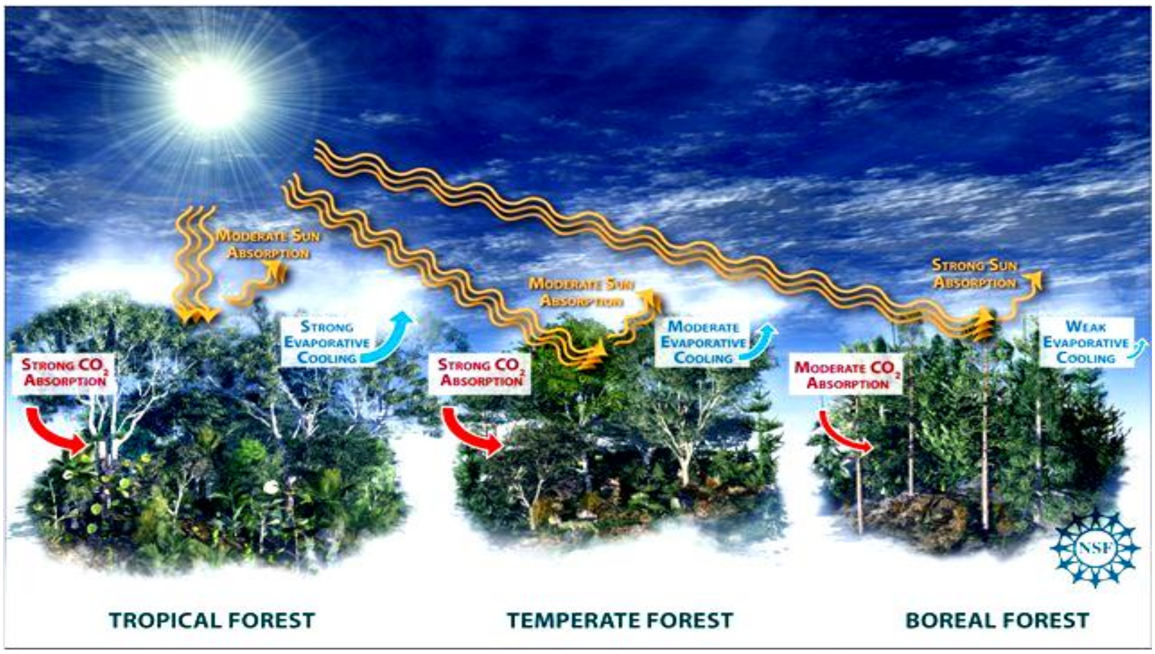

Figure 2.1: Forests play an integral role in Earth's climate.

Source : National Science Foundation, 2008

Each forest type (e.g. tropical, temperate and boreal) has varying impacts on the climate, serving to both cool and warm the earth. Forests help reduce global warming by absorbing greenhouse gases, for example carbon dioxide, through photosynthesis and by cooling the atmosphere through evaporation and transpiration. However, some forests, such as boreal forests in the northern latitudes, can be darker than their surrounding terrain and absorb the sun's energy more readily, which can lead to increased warming. The interaction between these competing influences is an area that scientists are intensely studying (National Science Foundation, 2008).

Forests are important in mitigating of climate change through increasing forest carbon absorption (carbon sequestration) capacity - either by planting trees on un-forested land (i.e. afforestation), facilitating the natural regeneration of forests on marginal land and by managing forests to increase biomass accumulation. Conserve and maintain existing forests to avoid emissions associated with tropical deforestation, forest degradation or clearing.

2.2 Carbon Cycle

Plants produce biomass by a process called photosynthesis in which the energy from the sun converts carbon dioxide and water to carbohydrates and oxygen. When plant biomass is burned, carbon dioxide (a greenhouse gas partly responsible for climate change) is released into the atmosphere. However, the amount of carbon dioxide released is not more than the amount absorbed by the plant when it is growing. This is a part of the global carbon cycle and a simple illustration of the carbon cycle is shown in Figure 2.2.

Forest biomass is defined as any plant or tree material produced by forest growth. Much of the forest biomass is currently used as a raw material in the manufacturing and refining of traditional types of wood products, such as lumber, plywood, paper, chemicals, and many other items. These types of items are typically produced from trees that are over 5" in diameter at breast height (DBH), reasonably straight, and otherwise sound. Biomass used in these trees is considered "merchantable".

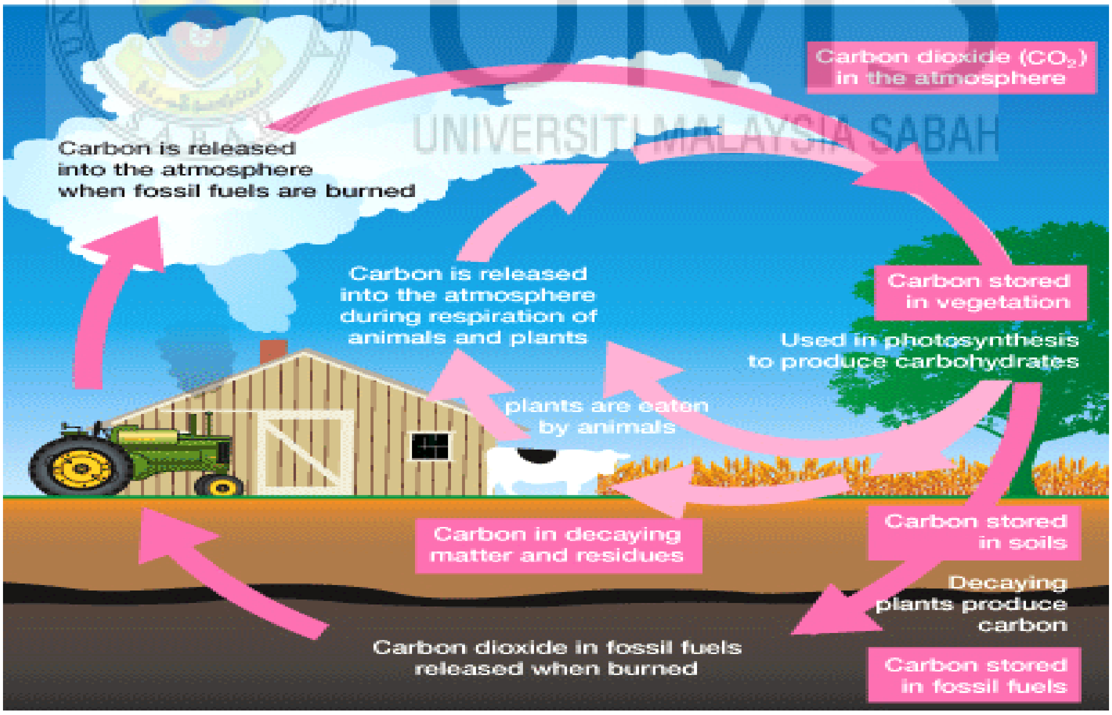

Figure 2.2: Carbon cycle within a farm economy

Source : Sustainable Cities Network, 2009

2.3 Forest as Carbon Pool: Some Basic Concepts

Carbon in the globe is held in a variety of different stocks. Natural stocks include oceans, fossil-fuel deposits, the terrestrial system, and the atmosphere. About two-thirds of the globe's terrestrial carbon, exclusive of that sequestered in rocks and sediments, is sequestered in the standing forests, forest understory plants, leaf and forest debris, and forest soils (Masahiro and Sedjo, 2006). The global C cycle is recognized as one of the major biogeochemical cycles because of its role in regulating the concentration of CO_2, an important greenhouse gas (GHG), in the atmosphere (Brown, 1996).

A stock that is taking up carbon is called a "sink" and one that is releasing carbon is called a "source." Five pools of carbon are involved in forest ecosystems which are above-ground biomass, below-ground biomass, litter, dead wood, and organic carbon in soil. Carbon is sequestered in the process of plant growth where it is captured in plant cell formation and oxygen is released. As the forest biomass experiences growth, the carbon held captive in the forest stock increases. Simultaneously, plants grow on the forest floor and add to this carbon store. Over time, branches, leaves, and other materials fall to the forest floor and may store carbon until they decompose. Additionally, forest soils may sequester some of the decomposing plant litter through root-soil interactions (Masahiro and Sedjo, 2006).

Forests have the potential to be managed to reduce atmospheric concentrations of CO_2 and thus mitigate climate change. Forest management practices that meet the objectives given above can be grouped into three categories based on how they are viewed to curb the rate of increase in atmospheric CO_2 including the management for C conservation, C storage, or C substitution (Brown *et al.*, 1996).

The global sink in forest vegetation and soils is estimated to be 1,200 Gt of carbon (1Gt = 1000,000,000 tonnes). This increases at a rate of 1-3 Gt annually. Forest and land-use measures have the potential to reduce net carbon emissions by the equivalent of 10-20% of projected fossil fuel emissions through 2050 (COFORD, 2006). Forests are the most likely candidates as carbon pools, because their wood