



UNIVERSITI PUTRA MALAYSIA

***CARBON STORAGE IN SOIL AND LITTER OF REHABILITATED AND
SECONDARY FORESTS***

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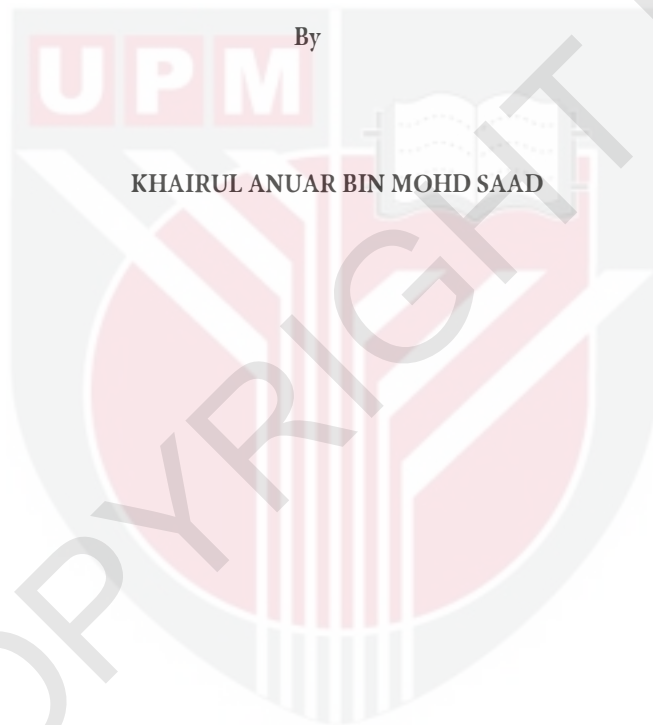
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Carbon storage in soil and litter of rehabilitated and
secondary forests / by Khairul Anuar b. Mohd Saad



By

KHAIRUL ANUAR BIN MOHD SAAD

**A Project Report Submitted in Partial Fulfillment of the Requirement
for the Degree of Bachelor Of Biindustry Science in the
Faculty of Agriculture and Food Science
Universiti Putra Malaysia Bintulu Campus**

2008

The image features a large, semi-transparent watermark of the Universiti Putra Malaysia (UPM) shield logo. The shield is divided into four quadrants: top-left (red with white 'UPM'), top-right (white with a green building), bottom-left (white with a green tree), and bottom-right (red with a white building). A red banner with white text is at the top, and a red base with white vertical lines is at the bottom. The text '© COPYRIGHT UPM' is written diagonally across the page.

UPM

The joy we have...

The pain we share...

Be always in my mind...

Mohd Saad, Suraya, Akma, Izwan, Ikhwan

ABSTRACT

Increasing concentrations of CO₂ in the atmosphere is a major contributor to climate change and forest plays an important role in global carbon cycle because they store large quantities of carbon in the vegetation and soil. A study was conducted at Universiti Putra Malaysia Bintulu Campus to measure the total carbon storage and stability. Three quadrats each measuring 20 m x 20 m of a hectare (ha) were marked in the experimental area. In each quadrat, ten soil samples and four litter samples were collected randomly. Soil samples were taken in these quadrats at 0-15 cm depth using an auger. The bulk density at each sampling point was determined using the coring method. Total carbon in litter and soil was determined by the loss on ignition method and in order to determine the stability of carbon, total nitrogen (N) was analysed by the Kjeldahl method. Rehabilitated forest stored total carbon with a mean value of 2.83 % which is equivalent to a mean value of 33.29 Mg/ha in the soil. Litter gained more total organic carbon compared to the soil with a mean value of 53.27 %. The quantity of total organic carbon in the litter was also higher than soil with the mean value of 20.74 kg/ha. Rehabilitated forest had C/N ratio value of 7.14 in soil and 155.79 for the mean value of litter. It's showed that rehabilitated forest has potential for managed carbon sequestration and further studies should be done in term of different ages of forest and depth of soil.

ABSTRAK

Peningkatan kepekatan gas karbon dioksida (CO_2) di dalam atmosfera merupakan penyumbang utama kepada perubahan cuaca dunia dan hutan memainkan satu peranan penting terhadap kitaran karbon kerana hutan merupakan penyimpan terbesar karbon yakni di dalam tanah dan tumbuhan. Oleh yang demikian, satu kajian terhadap jumlah simpanan dan kestabilan karbon telah dijalankan bertempat di hutan yang di pelihara semula milik Universiti Putra Malaysia Kampus Bintulu. Tiga kuadrat berukuran 20 m x 20 m di bentuk pada satu kawasan kajian yang berkeluasan satu hektar. Sebanyak sepuluh sampel tanah dan empat sampel daun kering di ambil dari setiap kuadrat secara rawak. Sampel tanah tersebut diperolehi dengan menggunakan auger pada kedalaman 0-15 cm. Sampel tersebut kemudiannya diproses dengan menggunakan kaedah "lose on ignition" dan kjeldahl bagi mendapatkan jumlah karbon dan nitrogen yang tersimpan bagi setiap sampel tersebut. Kadar kepadatan tanah diperolehi dengan menggunakan kaedah "coring". Secara amnya hutan tersebut mempunyai 2.83 % kadar purata simpanan karbon di dalam tanah yang mana bersamaan 33.29 Mg/ha. Keadaan yang sama turut boleh di lihat pada daun kering di mana sebanyak 53.27 % karbon tersimpan di dalamnya yang mana bersamaan 20.74 kg/ha. Hutan tersebut juga mempunyai kadar nisbah C/N sebanyak 7.148 bagi tanah dan 155.79 bagi daun kering yang mana sekaligus membuktikan bahawa hutan tersebut mampu untuk berfungsi sebagai salah satu kaedah untuk mengawal kadar kepekatan karbon di atmosfera yang semakin meningkat kini. Kajian lanjut perlulah di jalankan yakni pada tahap umur dan kedalaman tanah yang berbeza bagi mendapatkan keputusan yang lebih jitu.

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APPROVAL SHEET

I certify that this research project report entitled "Carbon Storage in the Soil and Litter of a Rehabilitated Forest" has been examined and approved as a partial fulfillment of the requirement for the degree of Bachelor of Bioindustry Science in the Faculty of Agriculture and Food Science, Universiti Putra Malaysia Bintulu Campus.

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LIST OF ABBREVIATIONS

ABBREVIATION

C	Carbon
N	Nitrogen
P	Phosphorus
CO ₂	Carbon Dioxide
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
°C	Degree Celcius
tC	Tonne Carbon
%	Percent
ha	Hectare
cm	Centimetre
m	Metre
g	Gram
kg	Kilogram
ml	Mililitre
SAS	Statistical Analysis System
SOM	Soil Organic Matter

CHAPTER 1

INTRODUCTION

1.1 General Background

There is widespread concern that an increase in the concentration of carbon dioxide and other greenhouse gases in the earth's atmosphere will ultimately lead to changes in the earth's climate. Although it is clear that the atmospheric concentration of carbon dioxide is increasing and that the increase is being driven in large measure by the burning of fossil fuels (coal, oil, and natural gas), the climatic consequences of increasing atmospheric carbon dioxide are not so clear. The global carbon (C) cycle is recognized as one of the major biogeochemical cycles because of its role in regulating the concentration of carbon dioxide (CO₂), an important greenhouse gas (GHG), in the atmosphere. Increasing concentrations of CO₂ in the atmosphere are a major contributor to climate change (Schime *et al.* 1995).

Forests play an important role in the global C cycle because they store large quantities of C in the vegetation and soil. The exchange of C with the atmosphere through photosynthesis and respiration are sources of atmospheric C and when they are disturbed by human or natural causes (e.g., wildfires, use of poor harvesting procedures, cleared and burned for conversion to non-forest uses), and become atmospheric C sinks (i.e., net transfer of CO₂ from the atmosphere to the land) during land abandonment and regrowth after disturbance. Humans have the potential through forest management to alter forest C pools and flux, and thus alter their role in the C cycle and their potential to change climate.

Many forests, in both boreal and tropical latitudes contain large amounts of C. Undisturbed anaerobic, peatlands are sinks for CO₂ and sources of CH₄. Drainage of these soils to improve forest productivity virtually stops CH₄ emissions, but initiates rapid CO₂ emissions by aerobic decomposition. Draining peat soils for forest establishment can produce a C loss from these soils that exceeds that stored in the forest if 20-30 cm of peat decompose as a result of the drainage (Cannell *et al.* 1993).



1.2 Objectives

The objectives of this study were to:

1. Determine the total carbon storage in the soil and litter of a rehabilitated forest.
2. Investigate the total carbon stability at 0-15 cm soil depth.



CHAPTER 2

LITERATURE REVIEW

2.1 Tropical Forestry

Tropical forests consist of dry and moist forests, each accounting for roughly one half of the total worldwide. Tropical rain forests are further divided into rain forests and deciduous forests. Rain forests make up about two thirds of all tropical moist forests and are the richest in terms of biomass and biological diversity. The natural forest environment provides three main types of services necessary to sustain life:

- As a source of raw materials vital for all human activity
- As a sink for waste and residue generated by human activity, and
- As a means of maintaining essential life support functions.

In terms of source functions, the products and services derived from tropical forests are diverse and benefit people at the local, national and global levels. About 2.5 billion people in the tropics rely either directly or indirectly on forest resources. The global community relies on tropical forests to stabilize global climate conditions. Forest related exports generate about US\$100 billion (in 1989) worth of foreign exchange amounting to an average of 2.7 percent of GDP in developing countries (Shanna *et al.*, 1992). For example, Malaysia achieves 5 percent of its GDP from forestry products.

2.1.1 Natural Forest

In former times, natural forests were extensive. However, much of the global tropical forests have been depleted or degraded due to conversion and harvesting of timber. Malaysia still has 62% of its land area as natural forest, most of it being in the hills. However, much of this area has been logged. Land use policies which promoted the conversion of forest land to other crops, notably rubber and oil palm, has resulted in heavy loss of forest areas in the past.

However, these policies have not stopped, and a Permanent Forest Estate has been established in perpetuity. Natural forest management has been implemented in much of the natural forest where silvicultural practices have been implemented. These silvicultural practices comprise climber cutting and/or enrichment planting. Specific economic concerns can still lead to further losses of natural forests at localised locations. There is a debate whether to continue natural forest management or to establish forest plantations to meet future timber needs. Based upon projections on future timber needs, extensive plantations seem inevitable. Brazil, the country with largest natural forest in the world has programmes for plantations. Papua New Guinea, which has more than 70% of its land as natural forest, is establishing plantations (Appanah, 1993).

2.1.2 Rehabilitated Forest

Rehabilitated forest is a forest which is established for an environment purpose, either to enrich an ecosystem or maintain the sustainability of a forest. Tropical

forest have been affected by human activities particularly logging which caused rapid reduction in size and quality of forest (Kobayashi et al., 2001).

Forest rehabilitation is related to human intervention to counter the degradation of the forest such as the promotion of the recovery process in large gaps of dipterocarp forest or conversion of shrub forest to high storey plantation forest (Mori, 2001).

2.1.3 Plantation Forest

Plantation forestry has become increasingly popular as a means of producing wood fibre for specific purposes, such as for a pulp and paper mill. In view of the increasing global demand of wood and wood fibre, the establishment of forest plantations seems to provide the only option as plantations as they are much more productive than natural forests and allow economic management on a sustainable manner. In Malaysia, although the focus has always been on natural forest management, forest plantations can be considered to have begun in the early 1900s, unless the introduction of rubber is taken into account in 1877. Taban (*Palauquium spp*) tree plantation was started in Malaysia as early as in 1900 (Appannah and Weinland, 1993).

In the pre-humid climate of Malaysia and other tropical regions, plants are physiologically active through out the year, including during transplanting, transportation and final planting. Thus tree growth is faster. Growth rates of 20 cu.m/ha/year are common and some hybrid species of Eucalyptus have been known to grow in excess of 50 cu.m/ha/year. These rates can further be increased through the use of proper selection, breeding and the use of modern biotechnology. It is worth mentioning that the most important plantation species used all over the tropics,

such as *Eucalyptus spp.*, *Pinus spp.*, *Tectona grandis*, and *Acacia spp.*, owe much of their success to easy availability of planting stock. Therefore self-sufficiency of planting stock is a prerequisite for successful plantation development. The use of biotechnology, such as tissue culture, offers new opportunities for sustainable supply of good planting stocks. It would seem inevitable that the area of forest plantations in the tropical world will continue to increase in order to supply the increasing global needs for timber and wood fibre, and these plantations offer excellent opportunities for increasing carbon sequestration.

2.2 Accumulation of CO₂

Evident proofs of the quick accumulation of CO₂ and other gases into the atmosphere, which could result in a greenhouse effect in the next century, were obtained in the recent two decades (Conway *et al.*, 1994). This hazard does not only raise alarm in the research circles, but it caused also the responses of these governmental institutions in the world, which made and assumed the declaration. In accordance with the declaration that was held at Rio de Janeiro in 1992 and the obligations undertaken by countries to reduce the release of greenhouse gases in the atmosphere, serious research on the role of the Earth's plant cover in the CO₂ accumulation and in the improvement of the atmosphere's chemical composition is necessary.

Considerable hopes for reducing the harmful impacts of CO₂ are related to forest vegetation, as it covers 1/3 of the dry land on earth. According to the scenario presented in the IPCC (Intergovernmental Panel on Climate Change) report (1990), rising levels of carbon dioxide together with the other greenhouse gases will cause a

rise by 2-5 °C on the mean temperature of earth during the next century' (Herrington *et al.*, 1991).

Conservation and enlargement of the natural old-growth, or man-made forests was accepted very significant proposal in reducing the carbon dioxide level in atmosphere. All the plants absorb carbon dioxide but because of the less total leave area, (leaf surface index); agricultural crops consume less carbon dioxide compare to forests. Therefore clearing of forests for agricultural crops cause reduction in absorption of carbon dioxide (Panhwar, 1996). Since the usage of fossil fuels, and the destruction of tropical forests are accepted the main causes of the additional carbon content of the atmosphere (Bruenig, 1991), reforestation activities and the use of wood for energy were found as corrective factors that should be encouraged in that course (Bouvarel, 1991).

2.3 Carbon Sequestration

Terrestrial ecosystem and land use changes play a significant role in the global carbon cycle, with an estimated 120 billion tonnes carbon (tC) exchanged annually between vegetation, soils and the atmosphere. Forests account for some 80% of this exchange. Carbon accumulates in forest ecosystem through the absorption of atmospheric CO₂ and its assimilation into biomass. Carbon is stored in various pools of forest ecosystem: above and below ground living biomass, including standing timber, branches, foliage and roots; and necromass, including woody debris, litter, soil organic matter and forest products. Approximately 50% of the dry biomass of trees is carbon (Dyson, 1977).

Overall, forests are estimated to contain just over half of the carbon residing in vegetation and soil of terrestrial biomes, amounting to some 1100 billion tonnes of the carbon stored in forests, an estimated 49% resides in boreal forests with tropical and temperate forests accounting for 37% and 14% respectively. The total estimated terrestrial carbon stocks are as follows: Tropical forests: 20%, Temperate forests: 7%, Boreal forests: 26%, Tropical Savannas: 8%, Tropical grass lands: 10%, Desert: 5%, Tundra: 8%, Wetlands: 7% and Agriculture: 9% (Houghton *et al.* 1987).

Carbon sequestration can be managed through the following strategies (Dixon *et al.*, 1993):

- Afforestation, reforestation, and restoration of degraded lands
- Improved silvicultural techniques to increase growth rates, and
- Agroforestry on agricultural lands.

2.3.1 Bio-diversity and Carbon sequestration

Researchers believe bio-diversity plays an effective part in carbon sequestration. All plants of course absorb carbon as they grow but the rate of absorption differs from species to species. Different environmental conditions also affect how well plants can absorb carbon. According to some findings, more diverse plant ecosystems have better absorption of carbon dioxide and nitrogen, both of which are on the steady rise due to human activities and industrialization (Lazarof, 2001).

Some studies carried out by physiologists also concluded that high biodiversity would take up and sequester more carbon and nitrogen than do ecosystems with reduced biodiversity. An experiment carried out by University of Minnesota in a controlled grassland environment, using free air carbon dioxide enrichment

technology, proved the above factor well beyond any doubt. Scientists suggest that protecting biodiversity worldwide would contribute to safeguarding the capacity of ecosystems to capture a large fraction of additional carbon and nitrogen entering the global environment.

2.3.2 Carbon Sequestration in Tropical Forests

Studies of tropical forests indicate that a significant amount of biomass and vegetation become lumber, slash, charcoal and ash through forest harvesting and forest clearance. However, the proportion differs for closed and open forests. If tropical forest land is converted to pasture or permanent agriculture, then the amount of carbon stored in secondary vegetation is equivalent to the carbon content of the biomass of crops planted, or the grass grown on the pasture. If a secondary forest is allowed to grow, then carbon will accumulate and maximum biomass density is attained after a relatively short time (Zaini, 1995).

When changes in land use occur resulting in tropical forests being changed into a different land use, the carbon sequestered is lost as shown in the Table 1:

Table 1: Changes in Carbon with Land Use Changes (tC/ha)

	Original C	Shifting agriculture	Permanent agriculture	Pasture
Original C		79	63	63
Closed primary forest	283	-204	-220	-220
Closed secondary forest	194	-106	-152	-122
Open forest	115	-36	-52	-52

(Source: Zaini, 1995)

The negative figures represent emission of carbon; for instance, conversion from closed primary forest to shifting agriculture results in a net loss of 204 tC/ha. Change of land use from closed primary forest to permanent agriculture results in the major loss of carbon (220 tC/ha). Carbon released by deforestation of secondary and primary tropical forest is estimated to be 100 - 200 tonnes per hectare.

Tropical forest burning releases enormous carbon and contributes to global warming. The 1997-98 forest fire in Indonesia is estimated to have resulted in a loss of about US\$ 9.3 billion. About 10 million hectares of Indonesia's national forests, which is the world's centre of biodiversity was destroyed. Zaini (1995) suggests an average value of US\$ 20 of damage for every tonne of carbon released. Applying this figure to the data in the above table, conversion of an open forest to agriculture or pasture would result in global warming damage of between US\$ 600-1,000 per hectare; conversion of closed secondary forest would cause a damage of US\$ 2,000 - 3,000 per hectare, while conversion of primary forest to agriculture would result in a damage of US\$ 4,000 - 4,400 per hectare.

Typical sequestration potential available in the tropics by afforestation / reforestation is estimated to be between 3.2 - 10.0 tC ha yr⁻¹. Assuming a global land availability of 700 million ha for reforestation and afforestation activities, an estimated 42-59 billion tC could be sequestered by afforestation/reforestation in the next fifty years including 7 billion tC from agroforestry.

2.4 Carbon Cycle and Release Dynamics

Exchange of carbon components among the atmosphere, ocean and terrestrial systems is a natural process. The following Table 2 gives the estimated exchange volumes of some cycles/exchanges:

Table 2: Estimated Change Volume of some Cycles

Cycle / Exchange	Volume
Photosynthesis, respiration and decay between atmospheric and terrestrial systems	100 billion tonnes / year
Thermodynamic invasion and evasion between the ocean and atmosphere, the carbon pump at deep ocean	90 billion tonnes / year
Deforestation and fossil fuel burning	07 gt / year
The total carbon in the reservoirs in land biota, soil and detritus	2,000 gt
Atmosphere	750 gt
Oceans	38,000 gt

(Source: IPCC, 1990)

2.5 Carbon/Nitrogen Ratio at Below Ground Level

Apart from carbon, nitrogen, and phosphate are other two major elements found below ground level of tropical forests. These two elements support the growing plants by providing nutrients. Nitrogen, with the help of carbon, interacts with decaying materials at certain temperature and result in compost which increases the fertility of soil.

Table 3 summarizes C, N and P content in below ground biomass in tropical forests.

Table 3: Carbon, Nitrogen and Phosphorus Content in Below Ground Biomass in Tropical Forests

Forest type	Root			Soil		
	C	N	P	C	N	P
Secondary forest (logged)	45.28	1.12	0.03	4.18	0.27	0.05
0.5 year old plantation forest	45.28	1.06	0.07	4.89	0.17	0.16
Plantation forest 3.5 year old	42.52	1.10	0.04	3.99	0.23	0.04
Degraded forest area	43.42	1.08	0.04	1.92	0.17	0.04

(Source: Zaini, 1995)

The following Table 4 indicates storage of C and N both above and below level of ground in a tropical forest:

Table 4: Carbon and Nitrogen for Both Above and Below Level of Ground in a Tropical Forest

Site	C (kg ha ⁻¹)	N (kg ha ⁻¹)
<u>Secondary forest (logged)</u>		
Above ground biomass	430	19
Litter	1,644	63
Root biomass	12,474	233
Soil	250,950	8,385
<u>Rehabilitated forest</u>		
Above ground biomass	868	45
Litter	1,188	40
Root biomass	4,944	129
Charcoal	110	2
Soil	239,200	6,900

(Source: Zaini, 1995)

Nitrogen, an important plant nutrient, is absorbed from the soil to become part of the biomass. Biomass is an indicator of the amount of carbon the plants accumulate through photosynthesis. The researchers found that elevated levels of carbon dioxide and nitrogen resulted in increased biomass when compared with plots exposed to ambient levels of carbon dioxide and nitrogen.

2.6 Litter Production

Litterfall includes leaf fall, shoot fall, bark fall and bud scale fall. In the forest, litterfall is an important source of nutrient. Litterfall is also the formation and renewal of the forest floor, and litter mass on the forest is an important structural component of the ecosystem (Samra and Raizada, 2002). The quantity and composition of litterfall vary in a number of factors, such as tree species, stand age and development, and is affected by environmental conditions, particularly water and nutrient availability (Binkley, 1986).

Litterfall plays three main functions in the ecosystem, namely, i) energy input for soil microflora and fauna, ii) nutrient input for plant nutrition, and iii) a material input for soil organic matter building up. All these functions are complete through mineralization, decomposition and humification process and influenced by biological activity, nutrient cycling and soil structure (Bernhard-Reversat and Louneto, 2002).

2.7 Role of Forests in the Global C Cycle

Role of forests in the global C cycle is not only a function of present forest land use, but also of past use and disturbance. Prior to this century CO₂ emissions from changes in forest land use, mainly caused by agricultural expansion in mid- and high

latitude countries, were higher than emissions from the combustion of fossil fuels (Houghton and Skole, 1990).

From the turn of the century until about the 1930s, global CO₂ emissions from changes in forest land use were similar in magnitude to those from fossil fuel combustion. After about the 1940s, CO₂ emissions from the changes in forest land use in the tropics dominated the flux from the biota to the atmosphere. Since then, world-wide fossil fuel use has soared, biotic emissions from the mid- and high-latitude regions has declined greatly as forests expanded onto abandoned agricultural lands and as logged stands regrew and deforestation in the tropics has accelerated (Houghton *et al.*, 1987). The past and present patterns of land use are responsible for the current situation in regard to the C pools and flux of the world's forests. With the storage of large quantity of carbon in vegetation and soil, forest ecosystems play an important role in the regulation of atmospheric carbon balance

2.8 Increasing C Sinks Through Forest Management

Forests have the potential to be managed to reduce atmospheric concentrations of CO₂ and thus mitigate climate change. Major objectives for managing forest lands generally include: industrial wood and fuel production, traditional forest uses, protection of natural resources (e.g., biodiversity, water, and soil), recreation, rehabilitation of damaged lands, and the like. 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 CO₂: management for C conservation, C storage, or C substitution (Brown *et al.*, 1996).

CHAPTER 3

MATERIALS AND METHODS

3.1 The Study Area

The study was conducted in an 18-year old rehabilitated forest at Universiti Putra Malaysia Bintulu Campus (Plate 1). It is located approximately 600 km northeast of Kuching with a latitude $3^{\circ} 12' N$, longitude $113^{\circ} 05' E$ and 50 m above sea level. The rehabilitated forest was established in 1990 through a joint project between Yokohama National University of Japan and Universiti Putra Malaysia to rehabilitate degraded land.

3.2 Data Collection

Three quadrats each measuring 20 m x 20 m of a hectare (ha) were marked in the experimental area (Plate 2). In each quadrat, ten soil samples and four litter samples were collected randomly. Soil samples were taken in these quadrats at 0-15 cm depth using an auger. The bulk density at each sampling point was determined by using the coring method.



Plate 1: Location of study area within Universiti Putra Malaysia Bintulu Campus.

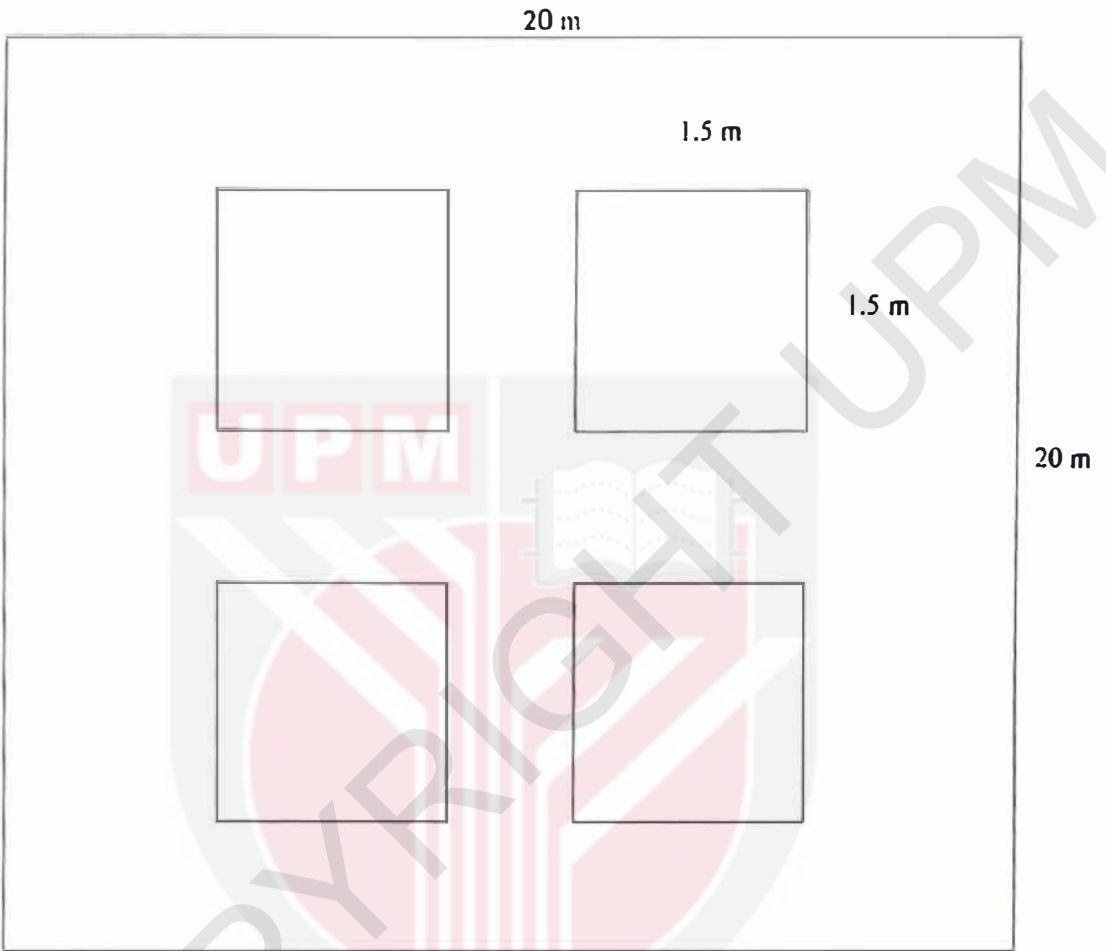


Plate 2: Layout of quadrats in the study area.

3.3 Laboratory Analyses

Total carbon in litter and soil was determined by the loss on ignition method (Chefezt *et al.*, 1990). The dry weight of litter in each quadrat was quantified and the weight multiplied by the total carbon (combustion method) provides the total carbon in litter. Prior to this, air-dry samples were placed in an oven at 60°C for 24 hours after which they were cooled in a desiccator. The initial weight of silica or porcelain dish (crucible) was taken after which 5 g of sample was placed into that silica or the porcelain dish.

The weight of the silica or porcelain dish plus the sample was taken before the sample was placed in a muffle furnace and initially ashed at 300 °C for 1 hour. The temperature was raised to 550 °C and the ashing process was continued for 5 hours. The weight of sample and crucible was taken after the sample is cooled in a desiccator. Total carbon was calculated as:

$$\frac{(\text{Initial weight of sample (g)} - \text{final weight of sample (g)})}{\text{initial of sample (g)}} \times 58/100$$

(Organic carbon was calculated as 58% of organic matter (Chefezt *et al.*, 1990))

The bulk density method was used to determine the carbon storage in the soil at 0-15 cm. Total carbon determined multiplied by weight of soil (0-15 cm) was considered the carbon storage in the experimental plots. In order to determine the stability of carbon, total nitrogen (N) was analysed by the Kjeldahl method (Bremner, 1985). About 0.5 g of soil was placed into 50 ml Kjeldahl digestion tubes with 0.4 g salicylic acid be added. The sample was moistened with few drops of water and 5 ml concentrated sulphuric acid with 1 tablet of Kjeldahl catalyst added. The samples were shaken to allow them to equilibrate for 30 minutes. The samples were heated in a digestion block at 180 °C for 1 hour and then at 320 °C for 4 to 5 hours until samples became colourless. After that, the samples were allowed to cool in 30 ml distilled water. The volume was made up when the solution was cooled. A 10 ml of the sample with a 10 ml of 40% NaOH was pipetted into distillation apparatus. Samples with NaOH were distilled and collected in 10 ml of 2% boric acid-indicator solution. During distillation, the colour changed from purple to green. A 2% boric acid was prepared by weighing 80 g of pure boric acid in a 5 L flask marked to indicate a volume of 4 L. About 3500 ml of water then was added to heat and swirl it until the boric acid dissolves. After the boric acid dissolved, an 80 ml of mixed indicator (0.099 g bromocresolgreen + 0.066 g methyl red in 100 ml of ethanol) was added with 0.1 M NaOH until the solution becomes reddish purple (pH 5.0). The solution then made up to 4 L with distilled water. The 50 ml conical flask containing the distillate then was removed when original volume (20 ml) was obtained. Titration was done against 0.01 M HCL or 0.01 M H₂SO₄ until the colour changed from green to purple.

Percentage N in the soil was calculated using the following formula:

$$\%N = [(V-B) \times M \times R \times 14.01 / Wt \times 1000] \times 1000$$

Where:

V = Volume of 0.01 M HCL or H₂SO₄ titrated for sample (ml).

B = Digested blank titration volume.

M = Molarity of HCL or H₂SO₄ solution.

14.01 = Atomic weight of N

R = Ratio between total of the digest and the digest volume used for Distillation.

Wt = Weight of air-dry soil (g) (Bremner, 1985)

3.4 Statistical Analyses

T-test was used to compare the total carbon storage and nitrogen of rehabilitated forest and secondary forest using Statistical Analysis System (SAS) version 9.1

CHAPTER 4

RESULTS

4.1 Soil

4.1.1 Quantity of Organic Matter in Soil

The percentages of organic matter of the secondary and rehabilitated forest soils were 5.45 % and 4.89 %, respectively (Table 5). There was no significant difference between these two values. However, in terms of amount of organic matter per hectare, that of the secondary forest was significantly higher than the rehabilitated forest (Table 5).

4.1.2 Quantity of Carbon in Soil

The percentages of the total carbon of secondary and rehabilitated forest soils were 3.16 % and 2.83 %, respectively. There was no significant difference between these two values (Tables 6). Nonetheless, the amount of carbon on per hectare basis was significantly high in the secondary forest soil than in the rehabilitated forest soil.

Table 5: Quantity of Organic Matter in Soil

Forest type	Organic Matter (%)	Organic Matter (Mg/ha)
Rehabilitated forest	4.89 ^a ± 0.49	57.41 ^a ± 5.71
Secondary forest	5.45 ^a ± 0.23	91.03 ^b ± 3.61

Note: Means within the same column with different letters indicate significant difference between soil and forest type ($P \leq 0.05$) using T-test.

Table 6: Quantity of Carbon in Soil

Forest type	Carbon (%)	Carbon (Mg/ha)
Rehabilitated forest	2.83 ^a ± 0.28	33.30 ^a ± 3.31
Secondary forest	3.16 ^a ± 0.13	53.72 ^b ± 2.34

Note: Means within the same column with different letters indicate significant difference between soil and forest type ($P \leq 0.05$) using T-test.

4.1.3 Quantity of Nitrogen in Soil

The percentages of nitrogen of the rehabilitated and secondary forest soils were 0.53 % and 0.18 %, respectively (Table 7). There was significant difference between these two values. Similar observation was made in terms of the amount of nitrogen on per hectare basis where that rehabilitated forest soil was significantly higher than in the secondary forest soil.

4.1.4 C/N ratio of soil

The percentages of C/N ratio of secondary forest and rehabilitated forest were 19.17 and 7.15, respectively, (Table 8). There was a significant difference between these two values.

Table 7: Quantity of Nitrogen in Soil

Forest type	Nitrogen (%)	Nitrogen (Mg/1a)
Rehabilitated forest	$0.53^a \pm 0.05$	$6.26^a \pm 0.56$
Secondary forest	$0.18^b \pm 0.01$	$3.08^b \pm 0.21$

Note: Means within the same column with different letters indicate significant difference between soil and forest type ($P \leq 0.05$) using T-test.

Table 8: C/N Ratio of Soil

Forest type	C/N ratio
Rehabilitated forest	$7.15^a \pm 1.14$
Secondary forest	$19.17^b \pm 1.57$

Note: Means within the same column with different letters indicate significant difference between C/N ratio and forest type ($P \leq 0.05$) using T-test.

4.2 Litter

4.2.1 Quantity of Organic Matter in Litter

The percentages of organic matter of the secondary and rehabilitated forest litter were 94.22 % and 91.85 %, respectively (Table 9). There was no significant difference between these two values. Nonetheless, the amount of organic matter on per hectare basis was significantly higher in the rehabilitated forest litter than in the rehabilitated forest litter (Table 9).

4.2.2 Quantity of Organic Carbon in Litter

The percentages of the total organic carbon of the secondary and rehabilitated forest litter were 54.65% and 53.27 % respectively, (Table 10). There was no significant difference between these two values. However, in terms of amount of organic carbon per hectare, that of the rehabilitated forest was significantly higher than the secondary forest (Table 10).

Table 9: Quantity of Organic Matter in Litter

Forest type	Organic Matter (%)	Organic Matter (Kg/ha)
Rehabilitated forest	91.85 ^a ± 1.25	35.76 ^a ± 0.66
Secondary forest	94.22 ^a ± 0.52	33.38 ± 1.76

Note: Means within the same column with different letters indicate significant difference between litter and forest type ($P \leq 0.05$) using T-test.

Table 10: Quantity of Organic Carbon in Litter

Forest type	Carbon (%)	Carbon (Kg/ha)
Rehabilitated forest	53.27 ^a ± 0.72	20.74 ^a ± 0.38
Secondary forest	54.65 ^a ± 0.30	19.36 ± 1.20

Note: Means within the same column with different letters indicate significant difference between litter and forest type ($P < 0.05$) using T-test.

4.2.3 Quantity of Nitrogen in Litter

The percentages of nitrogen of the secondary and rehabilitated forest litter were 1.09 % and 0.50 %, respectively (Table 11). There was a significant difference between these two values. Similar observation was made in terms of the amount of nitrogen on per hectare basis where secondary forest litter was significantly higher than in the rehabilitated forest litter.

4.2.4 C/N Ratio of Litter

The percentages of C/N ratio of rehabilitated forest and secondary forest were 155.79 and 51.57 respectively, (Table 12). There was significant difference between these two values.

Table 11: Quantity of Nitrogen in Litter

Forest type	Nitrogen (%)	Nitrogen (Kg/Ha)
Rehabilitated forest	0.50 ^a ± 0.08	0.19 ^a ± 0.03
Secondary forest	1.09 ^b ± 0.07	0.38 ^b ± 0.02

Note: Means within the same column with different letters indicate significant difference between litter and forest type ($P \leq 0.05$) using T-test.

Table 12: C/N Ratio of Litter

Forest type	C/N ratio
Rehabilitated forest	155.79 ^a ± 33.56
Secondary forest	51.57 ^b ± 2.66

Note: Means within the same column with different letters indicate significant difference between C/N ratio and forest type ($P \leq 0.05$) using T-test.

4.3 Bulk Density of Rehabilitated and Secondary Forests

The soil bulk densities of the rehabilitated forest and secondary forest were 1.18 kg/m³ and 1.13kg/m³ respectively, (Table 13). There was no significant difference between these two values.

4.4 Soil pH of Rehabilitated and Secondary Forests

pH of the rehabilitated forest soil and secondary forest soil were 4.90 and 4.73 respectively, (Table 14). There was no significant difference between these two values.

Table 13: Bulk Density of Rehabilitated and Secondary Forests

Forest type	Bulk density (Kg/m ³)
Rehabilitated forest	1.18 ^a ± 0.01
Secondary forest	1.13 ^a ± 0.04

Note: Means within the same column with different letters indicate significant difference between bulk density and forest type ($P \leq 0.05$) using T-test.

Table 14: Soil pH of Rehabilitated and Secondary Forests

Forest type	pH
	Water
Rehabilitated forest	4.90 ^a ± 0.06
Secondary forest	4.73 ^a ± 0.02
	Kcl
Rehabilitated forest	3.72 ^a ± 0.03
Secondary forest	3.82 ^a ± 0.06

Note: Means within column with different letters indicate significant difference between pH and forest type ($P \leq 0.05$) using T-test.

CHAPTER 5

DISCUSSION

The higher organic matter in the secondary forest soil compared with the rehabilitated forest soil was consistent with that reported by Brown and Lugo (1990). This observation suggests that recovery of soil organic matter (SOM) is rapid under secondary forests because of high leaf litter and root inputs to the soil during the first 20 years of regrowth. Palm *et al.* (1986) reported a period of 10-15 years for soil organic matter to recover in a secondary forest (75% of SOM in primary forests) following deforestation global carbon fluxes. Werner (1984) reported that at one extreme, soil organic matter may show little change in relation to disturbance or may decrease under intensive land use to a point where it may take 20-60 years to recover under forest fallow.

The higher carbon content in the secondary forest soil compared with the rehabilitated forest soil was consistent with the findings of Zaini (1995) (Table 15), Doran *et al.* (1994) and Keith (2002). The higher organic carbon in the former forest soil compared to the latter forest soil could be attributed to the difference in soil organic matter.

Table 15: Total of Carbon and Nitrogen of a Secondary and Rehabilitated Forest from Other Sources.

Source	Site	C (kg ha ⁻¹)	N (kg ha ⁻¹)
Zaini, 1995	<u>Secondary forest</u>		
	Litter	1,644	63
	Soil	250,950	8,385
	<u>Rehabilitated forest</u>		
	Litter	1,188	40
	Soil	239,200	6,900
This Study	<u>Secondary forest</u>		
	Litter	19.36	0.38
	Soil	53.72	3.08
	<u>Rehabilitated forest</u>		
	Litter	20.74	0.19
	Soil	33.30	6.26

(Source: Zaini, 1995)

Table 16: C/N ratio of a Rehabilitated Forest and Secondary Forest from Other Sources.

Source	Site	C/N
Zaini, 1995	<u>Rehabilitated forest</u>	
	Litter	29.70
	Soil	34.67
	<u>Secondary forest</u>	
	Litter	26.10
	Soil	29.93
This Study	<u>Rehabilitated forest</u>	
	Litter	155.79
	Soil	7.15
	<u>Secondary forest</u>	
	Litter	51.57
	Soil	19.17

(Source: Zaini, 1995)

However, rehabilitated forest soils gain more nitrogen than the secondary forest soils and it was significantly different to the findings of Zaini (1995) (Table 15). The higher N in the rehabilitated forest soil than the secondary forest soil could be attributed to the difference in soil texture. The soil texture of rehabilitated forest was clay loam compared to the secondary forest which was sandy clay loam N could easily leach especially during high rainfall. In addition, the higher number of tree in the rehabilitated forest compared to the secondary forest could be attributed to the higher nitrogen in the soils.

The higher C/N ratio in the secondary forest could be due to the higher content of carbon compared to the rehabilitated forest soils even though there was a significant accumulation of nitrogen in the secondary forest soils as discussed previously. This observation was not consistent with the report of Zaini (1995) (Table 16). It showed that rehabilitated forest has more carbon stability than secondary forest. In addition, the higher C/N ratio of secondary forest showed that the humification of secondary soils was lower than in the rehabilitated forest where the decomposition of organic matter in the secondary forest soil was lower than rehabilitated forest soil.

There was no significant difference in pH and bulk density for the both places. The observation showed that the rehabilitated forest and secondary forest soils were not affected by pH and bulk density. Kay (1990) claimed that changes in bulk density reflect changes in soil structure because of the relationship between bulk density and total porosity. However, total porosity gives no indication of the pore size distribution and pore continuity, which are important attributes of soil structures and associated functions.

The higher carbon content in the rehabilitated forest litters compared with the secondary forest litters was not consistent with the findings of Zaini (1995) (Table 16). The higher carbon in the rehabilitated forest litter compared to the secondary forest litter could be attributed to the difference in C/N ratio. Rehabilitated forest litters has higher C/N ratio compared to the secondary forest litters which leads to the lower humification rate in rehabilitated forest litter where the decomposition of organic matter in the rehabilitated forest litter was lower than secondary forest litter.

CHAPTER 6

CONCLUSIONS

Rehabilitated forest stored total carbon with a mean value of 2.83 % which is equivalent to a mean value of 33.29 Mg/ha in the soil. Litter gained more total organic carbon compared to the soil with a mean value of 53.27 %. The quantity of total organic carbon in the litter was also higher than soil with the mean value of 20.74 kg/ha.

Rehabilitated forest has C/N ratio value of 7.14 in soil and 155.79 for the mean value of litter which prove that the rehabilitated forest has high carbon stability.

It's showed that rehabilitated forest has potential for managed carbon sequestration and further studies should be done in term of different ages of forest and depth of soil.

REFERENCES:

Alhand, L., Arokaki, S., and Hagihara, A. 2004, *Decomposition of leaf litter of ofur tree species in subtropical evergreen broad-leaved forest*. Okinawa Island, Japan. *Forest Ecology and Management*. 202; 1-11

Appanah, S and Weinland G. (1993) *Enrichment Planting In Planting Quality Timber Trees in Peninsular Malaysia*. Pub: FRIM, ch; 4, pp 78-90

Baker III, T. T. Cockaby, G. Conner, W.II., Meier, C. E. Stanturf J.A. and Burke M. K. 2001. *Leaf litter decomposition and nutrient dynamics in four southern forested flood plain communities*. *Soil Sci. Soc. Am. J.* 1334-1347.

Berg, B. and Staaf, H. 1982. *Leaching, accumulation and release of nitrogen in decomposing forest litter*. *Ecol. Bull.*, 33: 163-178

Bernhard-Reversat, F. and Lourneto, J.J. 2002. *The litter system in the African forest plantations*. In *management of tropical plantation-forest and their soil-litter system*, ed. M. Vikram Reddy, p.11-40 Science Publisher, Inc

Binkley, D. 1986. *Forest nutrition management*. John wily and Son Inc. New York, 290 pp

Bouvaerel, P.: 1991. *Forest Production and Carbon Cycle*. 10. World Forestry Congress Proceedings, 2, 79-86.

Bremner J.M. 1985. *Total nitrogen, in: method in soil analysis, Part 2*, Black C.A (Ed) Soc. Argon., Madison, Wis., USA., , pp. 1149-1170

Brown, S., Sathaye, J., Cannell, M., Kauppi, P.E., 1996: *Management of forests for mitigation of greenhouse gas emissions*. In: R.T Watson, M. C. Zinyowera, and R. H. Moss (eds.), *Climate change 1995 impacts, adaptations and mitigation of climate change: scientific analyses. Contribution of working group II to the second assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. Cambridge, pp. 773-798.

Brown, S. and A . E . Lugo, 1990. *Tropical secondary forests*. *Journal of Tropical Ecology* 6: 1-32.

Bruenig, E.F.:1991.*Forest and Climate New Dimensions and Perspectives*.10 World ForestryCongress Proceedings. 2. 9-15.

Cannell, M.G.R. R.C. Dewar and P.G. Pyatt, 1993: *Conifer plantations on drained peatlands in Britain: a net gain or loss of carbon?* Forestry 66:353-368.

Chefezt B., Hatcher P.G., Hadar Y., Chen Y. 1990, *Chemical and biological characterization of organic matter during composting of municipal solid waste*. J. Environ. Qual. 25, 776-785

Conway, T., P. Tans, I. Weternen, 1994. *Atmospheric CO₂ Records from Sites in the NOAA/CMDL air Sampling Network*. In: *Trends '93. A Compendium of Data on Global Change*. Carbon Dioxide Information Laboratory.

Doran, J. W.; Parkin, T. B. Defining and assessing soil quality. In *Defining soil quality for a sustainable environment*; Doran J. W., Coleman. D. C., Bezdicek. D. F., Stewart. B. A., Eds. : Soil Sci. Soc. Amer Madison, WI, 1994: 3-21.

Dyson, F.J., 1977. *Can we control the carbon dioxide in the atmosphere?*. Energy 2, pp. 287-291

FSC-NTCC - Malaysia (2000) Forest Management Certification. *Forest Certification Guidelines*. Issued jointly by: Forest Stewardship Council and National Timber Certification Council, Malaysia.

Gosz, J. R., Likers, G. E. and Borman, F. H. 1973. *Nutrient release from decomposing leaf and branch litter in the Hubbard Brook Forest*. New Hampshire. Ecol. Monogr., 43: 173-191

Herington, J.;J.Kimmins; D. Lavender.:1991.*The Effect Of Climate Change On Forest Ecology In Canada*.10. World Forestry Congress Proceedings 2, 49-58.

Hirobe, M., Sabang, J., Bhata, B. K. and Takeda., H. 2004. *Leaf-litter decomposition of 15 tree species in lowland tropical in Sarawak; decomposition rate and initial litter chemistry*. J. For. Res. (: 341-346).

Houghton, R. A., R. D. Boone, J. R. Fruci, J. E. Hobbie, J. M. Melillo, C. A. Palm, B. J. Peterson, G. R. Shaver, G. M. Woodwell, B. Moore, D. L. Skole, and N. Myers, 1987: *The flux of carbon from terrestrial ecosystems to the atmosphere in 1980 due to changes in land use: geographic distribution of the global flux*. Tellus 39B: 122-139.

Houghton, R. A. and D. L. Skole. 1990: Carbon. In: B. L. Turner, W. C. Clark, R. W. Kates, J. F. Richards, J. T. Matthews, and W. B. Meyer (eds.): *The Earth as transformed by human action*. Cambridge University Press, NY, pp. 393-408.

Intergovernmental Panel on Climate Change (IPCC). 1990. *The Potential Impact of Climate Change on Agriculture and Forestry*. Likely Impacts of Climate Change. Report from Working Group II to IPCC, WMO, UNEP. 51 pp.

Kobayashi, S., turnbull, J.W. and Cossalter, C. 2001. rehabilitated of degraded tropical forest ecosystem project. In *Rehabilitation of Degraded Tropical Forest Ecosystem*, eds. S.Kobayashi, J.W. Turnbull, T.Toma, T. Mori and N.M.N.A. Majid, p 1-16. SMK Grafika Desa Putera, Indonesia.

Lazarof, C. (2001), *Biodiversity gives Carbon Sinks a Boost*, Newsletter article by electronic medium, site pp 1-4, dt. April 17, 2001

Lin, B., Liu, Q., Wu, Y. and He, H. 2006. *Nutrient and litter pattern in three subalpine coniferus forests of western Sichuan, China*. *Pedosphere*, 16 (3): 380-389

Mori, T. 2001. Rehabilitation of Degraded Forest in Lowland Kutai, east Kalimantan, Indonesia. In *Rehabilitation of Degraded Tropical Forest Ecosystem*, eds. S.Kobayashi, J.W. Turnbull, T.Toma, T. Mori and N.M.N.A. Majid, p 18-26. SMK Grafika Desa Putera, Indonesia.

Palm C . A . , R . A . Houghton, J.M. Melillo & D . L . Skole. 1986. *Atmospheric carbon dioxide from deforestation in Southeast Asia*. *Biotropica* 18: 177-188.

Panhwar, F.:1996.*Caserving, Agro-Forestry Is The Solution Of-Future Global-Warming And Biodiversity*. Sindh A Case.p. 9.

Paper presented in The National Workshop on *Potential market Opportunities for Forests As Carbon Sinks*, Oct 2000.

Salleh M.N., Cyril Pinso, and Abdul Hai Akbar Ali (2001) *Tropical Forestry And Carbon Sequestration*. Proceedings Presented at the Workshop on 'Emission Trading & Clean Development Mechanism (CDM) in Asia at Mandarin Hotel, Singapore.

Samra, J.S. and Raizada, A. 2002. Litter production and nutrient dynamics in tropical forest plantation of India. In *Management of Tropical Plantation-Forest and Their Soil-Litter System*, ed. M.Vikram, Reddy, p 41-72. Science Publisher, Inc.

Schimel, D., I. G. Enting, M. Heimann, T. M. L. Wigley, D. Rayneud, D. Alves, and U. Seigenthaler, 1995: CO₂ and the carbon cycle. In: J. T. Houghton, L. G. Meira Filho, J. Bruce, H. Lee, B. A. Callander, E. Haites, N. Harris, and K. Maskell (eds.), *Climate change 1994 radiative forcing of climate change and an evaluation of the IPCC IS92 emission scenarios*, published for the IPCC, Cambridge University Press, Cambridge, pp.35-71.

Sharma, N. (1992) Deforestation Issues, Valuing Tropical Forests. In: *World Bank Environment Paper 13*, pp1-10.

Swift, T., Heal, O.W. and Anderson, J.M. 1979. *Decomposition in terrestrial ecosystems*. Blackwell Scientifics, Oxford.

The Soil Group, 2006: *Laboratory manual on soil, plant, and fertilizer analyses*, Department Of Crop Sciences Faculty Of Agriculture And Food Sciences, Universiti Putra Malaysia Bintulu Campus. 10:17.

Werner, P. 1984. *Changes in soil properties during tropical wet forest succession*. *Biotropica* 16: 43-50.

Yang, J., Lin J., Yu, J., Wang, J. Li, X. Sun, Z. 2006. *Decomposition and nutrient dynamics of marsh litter in the Sanjiang Plain Northeast China*. *Acta Ecologica Sinica*, 26 (5): 1297-1302.

Zaini, Z., 1995 Slash-and -burn effects on C, N and P Balance insituing Benchmark Area. In: *Alternative to slash-and-burn research in Indonesia*, Ed: Meine wan Noordwijk, Ch: 1 pp 21-58.

PUBLICATION OF THE PROJECT UNDERTAKING

This is to certify that I have no objection to publish the project entitled "Carbon Storage in Soil and Litter of Rehabilitated and Secondary Forests" by the supervisor in a joint authorship. However, it has to be evaluated by the Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Campus and published in the form approved by the Faculty.



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Date: