# CARBON SINKS IN RUBBER PLANTATIONS OF KLAENG DISTRICT, RAYONG PROVINCE, THAILAND

SASITHORN YOOSUK

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Thesis

Entitled

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Sasithorn Yoosuk


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CARBON SINKS IN RUBBER PLANTATIONS OF KLAENG DISTRICT, RAYONG PROVINCE, THAILAND

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## ABSTRACT

This study of carbon sinks in rubber plantations of Klaeng district, Rayong province, Thailand was conducted during December 2003 to November 2004. The purpose was to estimate the size of the carbon sinks in Para rubber plantations at the aboveground, soil surface and below ground at 3 different stages (young, harvested and mature stages), as well as to determine the relationship between organic carbon in the soil and the properties of soil in the upper soil horizon (0-30 cm). The aboveground and below ground carbon content in Para rubber trees was calculated as 50% of the total biomass. An allometric equation was applied to calculate both the aboveground (stem, branches, and leaves) and below ground (roots) biomass of Para rubber trees. Latex, litter fall and ground layer were evaporated by oven drying at 80°C until a constant weight was reached, and the dried weight was used to estimate the biomass content.

The results showed that the potential of carbon storage for 25 years of these Para rubber plantation was about 9,868.59 tC and the carbon content in vegetation and soil was 9,836.45 and 32.14 tC, respectively. The carbon content in the biomass of the trees at the young (for 8 years), harvested (for 12 years) and mature (for 5 years) stages was 4,984.64, 4,032.36 and 819.45 tC, respectively. The carbon content in the upper soil horizon was 11.21, 13.12 and 7.80 tC, respectively.

The aboveground carbon content found in the Para rubber plantation trees at young, harvested and mature stages was 4.48, 11.96 and 19.14 tC/Rai/yr, respectively. The below ground carbon content was 1.04, 2.18 and 3.09 tC/Rai/yr, respectively. The carbon content in soil surface was 0.37, 0.43 and 0.49 tC/Rai/yr, while the carbon content in the upper soil horizon was 3.77, 3.98, and 4.62 tC/Rai/yr, respectively.

The aboveground carbon content increased with the plant's age. But the rate of growth of Para rubber tree decreased when the tree matured and was tapped. Thus the potential of $CO_2$ sequestration would also decrease. Furthermore, the relationship between the size of tree and carbon content was positive, further decreasing the potential of $CO_2$ sequestration. Carbon content in soil increased according to age, but the differences were not significant at any stage.

KEY WORDS : CARBON SINK / CARBON SEQUESTRATION / BIOMASS / SOIL ORGANIC CARBON / PARA RUBBER PLANTATION

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ปริมาณการเก็บกักคาร์บอนในสวนยางพาราบริเวณพื้นที่อำเภอแกลง จังหวัดระยอง

(CARBON SINKS IN RUBBER PLANTATIONS OF KLAENG DISTRICT, RAYONG PROVINCE, THAILAND)

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**บทคัดย่อ**

การศึกษาปริมาณการเก็บกักคาร์บอนในสวนยางพาราบริเวณพื้นที่ อ.แกลง จ.ระยองได้ดำเนินการระหว่างเดือน ธ.ค. 2546 - พ.ย. 2547 โดยมีวัตถุประสงค์เพื่อประเมินปริมาณการเก็บกักคาร์บอนส่วนเหนือดิน, ส่วนบนผิวดิน และส่วนใต้ดินในสวนยางพาราที่แตกต่างกัน 3 ช่วงอายุ ได้แก่ ช่วงยางอ่อน, ช่วงยางที่ให้ผลผลิตน้ำยาง และช่วงยางควรปลูกทดแทน และศึกษาความสัมพันธ์ของอินทรียคาร์บอน ในดินกับสมบัติของดินในระดับความลึก 0-30 ซม. ปริมาณคาร์บอนส่วนเหนือดินและส่วนใต้ดินของต้นยางพาราคิดเป็น 50% ของปริมาณมวลชีวภาพ โดยปริมาณมวลชีวภาพส่วนเหนือดิน (ลำต้น, กิ่งก้าน, ใบ), และส่วนใต้ดิน (ราก) ของต้นยางพาราประเมินด้วยสมการอัลโลเมตริก สำหรับน้ำยาง, เศษซากร่วงหล่น และพืชพื้นล่างจะอบด้วยอุณหภูมิ 80 องศาเซลเซียสจนน้ำหนักคงที่ เพื่อนำน้ำหนักแห้งไปประเมินปริมาณมวลชีวภาพต่อไป

จากผลการศึกษา พบว่า การปลูกสวนยางพารา 1 ไร่ ในเวลา 25 ปี จะสามารถเก็บกักคาร์บอนในรูปมวลชีวภาพและอินทรียคาร์บอนในดินได้ 9,836.45 และ 32.14 ตันคาร์บอน ตามลำดับ ช่วงยางอ่อน (0-8 ปี), ช่วงยางที่ให้ผลผลิตน้ำยาง (8-20 ปี) และช่วงยางควรปลูกทดแทน (20-25 ปี) เก็บกักคาร์บอนได้ 4,984.64, 4,032.36 และ 819.45 ตันคาร์บอน ตามลำดับ การเก็บกักคาร์บอนในรูปของอินทรียคาร์บอนในดินได้เท่ากับ11.21, 13.12 และ 7.80 ตันคาร์บอน ตามลำดับ

ปริมาณคาร์บอนส่วนเหนือดินในสวนยางพารา ช่วงยางอ่อน, ช่วงยางที่ให้ผลผลิตน้ำยาง และช่วงควรปลูกทดแทนเท่ากับ 4.48, 11.96 และ 19.14 ตันคาร์บอน/ไร่/ปี ปริมาณคาร์บอนส่วนใต้ดินของช่วงอายุต่างๆ ดังกล่าวเท่ากับ 1.04, 2.18 และ 3.09 ตันคาร์บอน/ไร่/ปี และปริมาณอินทรียคาร์บอนในดินของช่วงอายุต่างๆ ดังกล่าวเท่ากับ 3.77, 3.98, และ 4.62 ตันคาร์บอน/ไร่/ปี

ปริมาณมวลชีวภาพส่วนเหนือดินจะเพิ่มขึ้นตามของต้นยางพารา แต่อัตราการเจริญเติบโตของต้นยางจะลดลงเมื่อโตเต็มที่และถูกเปิดกรีด ซึ่งทำให้ประสิทธิภาพในการดูดซับคาร์บอนไดออกไซด์ของต้นยางพาราลดลงด้วย นอกจากนี้พบว่าขนาดของต้นยางพาราและปริมาณคาร์บอนมีความสัมพันธ์กันในเชิงบวก ส่วนอินทรียคาร์บอนในดินเพิ่มขึ้นตามอายุของต้นยางพาราแต่ค่าเฉลี่ยของปริมาณอินทรีย คาร์บอนในดินในแต่ละช่วงอายุ ไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background and Problem Identification

Rapid population growth together with faster industrial development and unrestricted utilization of natural resources have been causing drastic changes in vital ecological processes of the earth. The present greatest crisis-facing mankind is global warming, that caused from the increasing of Greenhouse Gases. Climate change may post serious impacts on way of life and global as a whole. The carbon dioxide ($CO_2$) is considered as an important cause, largely as a result of the burning of fossil fuels, the clearing/burning of large areas of forest, forest fires and accelerates decay of organic matter in the soil. Levels of $CO_2$ and other Greenhouse Gases in the atmosphere have been increasing (1). Rising of these gases has much impact to the world climate systems and has resulted in increase awareness of the global carbon cycle.

The increasing concentration of atmospheric $CO_2$ changed from nearly 315 ppmv in 1957 to nearly 358 ppmv in 1994. The rates of increasing have been estimated about 6% per year (2) and predicted to increase approximately 440-660 ppmv in 2050 (3), which are over content that plant can use for photosynthesis process. The rising $CO_2$ concentrations in the atmosphere about 80% derived from fuel combustion and 20% derived from deforestation and land use change. Houghton and group (4) estimated that carbon content for terrestrial ecosystem about 2,200 Pg, a major component is the soil range 1,462-1,576 Pg. Agricultural land use had been a major contributor of carbon to the atmosphere for a long time. Carbon in soil was decreased approximately 120 Pg into the atmosphere, about 60% was emitted from tropical regions and 40% derived from high and mid-latitude (5). International negotiation (The Parties to the Kyoto Protocol from the United Nations Framework Convention on Climate Change; UNFCCC in 1977) are aimed at reducing the level of $CO_2$ in the atmosphere with Carbon Sequestration system, that means the removing

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$CO_2$ from the atmosphere and using for plant growth. Plants convert atmospheric $CO_2$ to be usable food, fiber, and excess biomass, and also improve the conversion of the excess biomass to soil organic carbon. Accounting for land use, land-use change and forestry (LULUCF) activities (afforestation, reforestation, and deforestation), they were direct human-induced activities. Vegetation exchanges $CO_2$ between the atmosphere and the terrestrial biosphere through photosynthesis of plant and soil respiration. In photosynthesis process, plants utilize atmospheric $CO_2$, and store organic carbon within above and below ground biomass. Carbon stock values have been markedly influenced by regional climate, type of vegetation and land use patterns. Agricultural land use could also have a marked influence on carbon stock.

Para rubber is perennial plant, a type of terrestrial ecosystem, which was changed to be agricultural area. Para rubber trees (*Hevea brasiliensis* Muell.Arg.) are considered to be the major plant uptake $CO_2$ from the atmosphere and accumulate in the form of aboveground biomass, roots, shoot and litter fall, as well as soil organic matter. Furthermore, the Para rubber production is recounted as an important economic crop of Thailand. It is the top five of national export items, which bring tremendous income to the country. In 2002, it was exported about 2.024 millions tons, its value was 74,604 millions baht. Currently, Thailand is the top producer of the world for Para rubber productivity, it could be produced about 2.25 millions tons per year. The demand for internal consumption is only 0.22 millions tons per year, therefore, the policy of Thai government is encouraged to increase the internal consumer. The Ministry of Commerce (6) estimated that demand for internal should increase from 0.25 to 0.4 millions tons per year. Therefore, Thai government has supported to expand harvested area. In the past, Para rubber plantations were planted in the Southern and Eastern parts of Thailand. Currently, the government introduces this plant to be grown in the Northern, Northeastern and some Western parts of Thailand. Para rubber tree is classified as the softwood and rapid growth tree and has economical returns as the good rate. It produces latex for about 25 ages, and could be cut down for other advantage uses in the form of Para rubber wood, then it will be replanted. Para rubber plantation is considered as an agricultural area and can substitute the degraded forest. Because Rayong province has been the most Para rubber plantation in the Eastern part of Thailand. The Para rubber plantations surveyed in 1996

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by satellite photograph data cover the area about 639,790 Rai (7) equal to 29% of the total of Rayong province area. The harvested stage areas have been planted in Klaeng, Moeng and Wangchan districts, respectively. Nevertheless, Rayong province has the forest area only 130,086 Rai (8) or 6% of total Rayong province area.

The Para rubber tree has been suggested as an another mean to reduce the rate of $CO_2$ increase in the atmosphere. As trees grow, they sequester carbon in their tissues, and as the amount of tree biomass increase, the increase $CO_2$ in the atmosphere is mitigated. Therefore, the study of carbon sink in Para rubber plantation was to study the carbon content in agricultural land use area. Throughout this study, the relationship among carbon content at different ages of Para rubber trees would be determined. By the result of this study, it has been expected to be a part of the study about carbon pool by carbon sequestration mechanism.

## 1.2 Objectives

To estimate the carbon sinking in the Para rubber plantation areas at 3 levels (aboveground, soil surface and below ground) at 3 different ages of the plants (young, harvested and mature stages) in Klaeng district, Rayong province.

## 1.3 Scope of the Study

### 1.3.1 Scope of Study

a) This study was determined to derive the biomass values by estimating the components of Para rubber trees (stems, branches, leaves, and roots) by using allometric equations for the relationships between the dry mass of these components, the whole tree to diameter at breast height (DBH), and the total height of tree (9). The model is as the following:

$$\log W = \log a + b \log (D^2H)$$

Where as:

W is dry mass from many parts of plants, which consist of stems, branches, leaves, and roots.

D is diameter of tree at breast height (1.30 m).

H is total height of tree.

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a, b are the variable values.

b) To estimate the carbon in the Para rubber plantations, which consisted of:

**1) Above ground biomass**

- Biomass of stems, branches and leaves at different sizes of trees at 3 different stages of ages
- Biomass of latex (at the harvested and mature stages)

**2) Soil surface biomass**

- Ground layer
- Litter fall

**3) Below ground biomass**

- Biomass of roots
- The percentage of soil organic carbon

### 1.3.2 Scope of Study Area

The total 9 sub-sample plots of RRIM 600 Para rubber plantations in Klaeng district, Rayong province was selected for this study. The study plantations were classified into 3 stages. Each stage consisted of 3 sub-sample plots, and each sub-sample plot covered the area of 1 Rai equal to 40 x 40 $m^2$.

- The young plantation stage (average ages 4-6 years)
- The harvested plantation stage (average ages 14-16 years)
- The mature plantation stage (average ages over 20 years)

## 1.4 Expected Results

1.4.1 The measurement values of the biomass of the Para rubber plantations at 3 different levels (aboveground, soil surface and below ground).

1.4.2 The measurement amount of carbon content in the Para rubber plantations at 3 different stages.

1.4.3 To develop the databases of carbon sink in agricultural area from Para rubber plantation.

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## 1.5 Conceptual Framework

The study area is located in Klaeng district, Rayong province. Data were collected from 3 different ages of Para rubber trees and analyzed both in plants and soil properties. The carbon content was considered in the form of the total biomass of Para rubber trees, which consist of stems, branches, leaves, latex, and roots. Furthermore, the aboveground biomass such as litter fall and ground layer was also collected. Estimating of the carbon was done by assuming the carbon content of dry biomass to be constant 50% by weight (1), added with carbon content in soil (%Organic Carbon). In order to estimate the carbon content of the Para rubber plantations, this study separated samples into 3 different ages. There were:

- The young plantation stage (average ages 4-6 years)
- The harvested plantation stage (average ages 14-16 years)
- The mature plantation stage (average ages over 20 years)

Furthermore, the soil properties (physical and chemical properties) were analyzed. Describing of the relationship between biomass, carbon content, and some soil properties of the Para rubber plantations were shown in Figure 1-1.

## 1.6 Study Duration

Dry season and rainy season was scheduled as time frame to study carbon sink in Para rubber plantations, therefore, the research work was done during December 2003 to November 2004.

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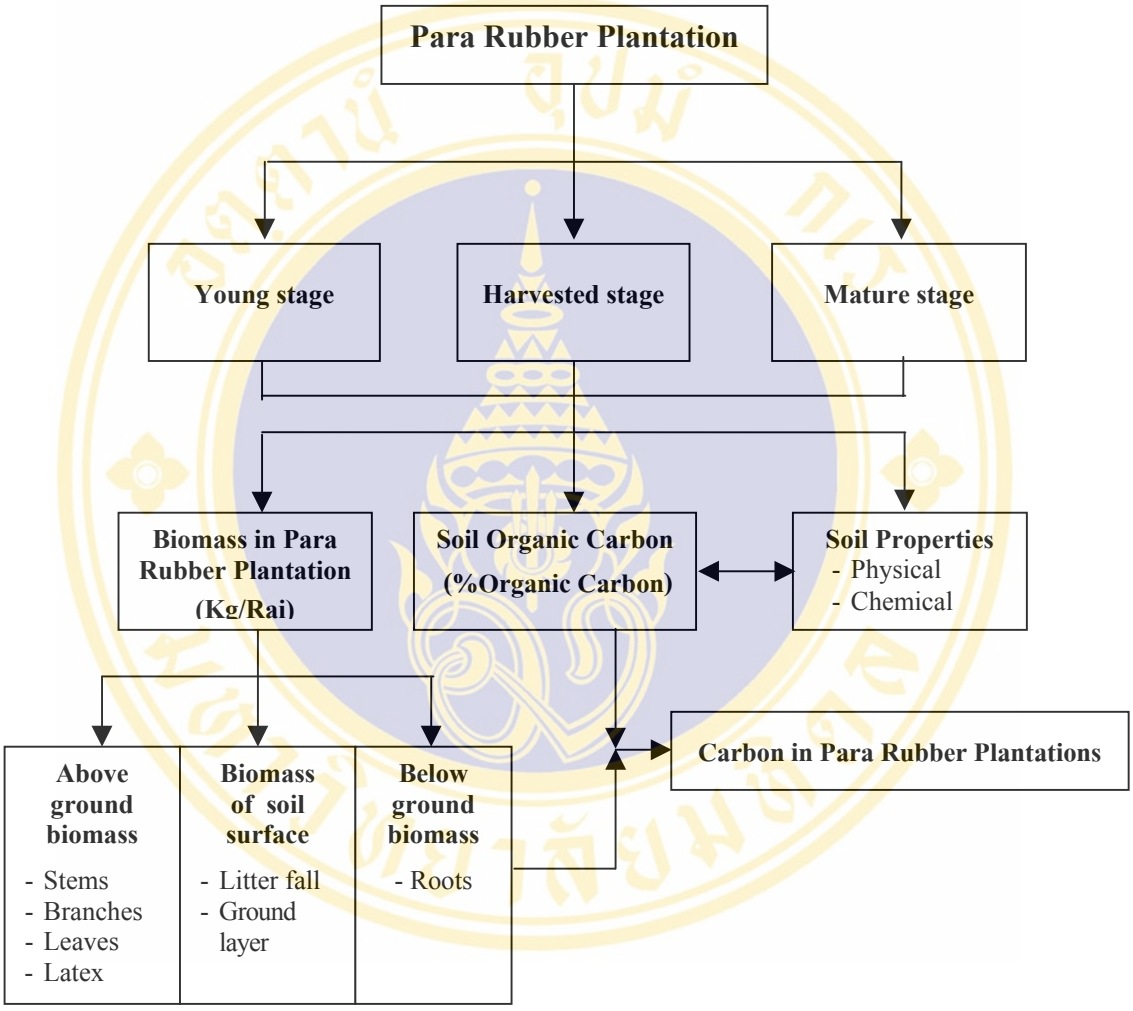


**Figure 1-1** The conceptual framework for the study

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## 1.7 Definition

**Para rubber plantation** is a land use type for agricultural activity in the form of Para rubber plantations, which these trees have been modified of genetic and the Department of Agriculture has recommended to cultivate in Rayong province, such as RRIM 600, and BPM 24 clones, and etc.

**Allometric equation** is an equation to analyze the relationship between biomass of the Para rubber tree and some dimensions of plant, the equation has been written as the following:

$$\log W = \log a + b \log (D^2H)$$

Where as:

W is dry mass from parts of plant consist of stems, branches, leaves, and roots.

D is diameter of tree at breast height (1.30 m).

H is total height of tree.

a, b are the variable values.

**Young stage** is the Para rubber tree younger than 8 years and not tapped.

**Harvested stage** is the Para rubber tree between 8-25 years and has been tapped.

**Mature stage** is the Para rubber tree aged over 20 years and has been tapped. However, tree at this stage should be cut down and replanted since its latex decreases.

**Biomass of the Para rubber tree** is the biomass of Para rubber tree that has resulted from the values of the total height and diameter at breast height in allometric equation.

**Aboveground biomass** is the biomass of each part component of Para rubber tree, such as stem, branches, leaves and latex. That is based on allometric equations relating with biomass to diameter at breast height (DBH) and height.

**Below ground biomass** is the biomass of roots of Para rubber tree that is based on allometric equations relating with biomass to diameter at breast height (DBH) and height.

**Biomass on soil surface** is the fresh mass of plant on soil surface with sub-samples taken to determine moisture content and convert to dry weight. Litter fall and ground layer were also collected for this study.

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**Carbon content in soil** is in a form of percentage of organic carbon (%OC), and has been analyzed according to the Walkley and Black method (10).

**Ground layer plant** is the plant that has diameter of stem at breast height not more than 4.5 cm (11) and sum up with some cover ground and weeds.

**Litter fall** is part of dead Para rubber tree such as leaves, flowers, fruits, branches, bark and stem which have fallen to the ground surface.

**Falling leaves period** is an interval time during January to April that Para rubber tree has shed its leaves or defoliate. So the plant will not be tapped.

**Productive period** is an interval time during May to December that the tree is tapped for its production.

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# CHAPTER 2

# LITERATURE REVIEWS

Carbon dioxide ($CO_2$) is a major Greenhouse Gas, which affects to the global climate change. Decreasing of carbon that storage in woody has been considered to be resulted from deforestation and land use change. On the other hand, they are considered as major factors to increase $CO_2$ in the atmosphere. Therefore, it is very important that all nations over the world have to cooperate in order to decrease the releasing $CO_2$ to the atmosphere. The carbon sequestration is another measurement to support for decreasing of $CO_2$, with photosynthesis system for uptake $CO_2$ from the atmosphere to storage in biomass of plants and deposits in soil organic matter. Relevant researches, knowledge, theories and reports concern with the study of carbon storage in soil and biomass were studied as detail appeared below.

## 2.1 The Carbon Cycle

Carbon is in the form of inorganic and organic compounds, notably $CO_2$, are cycled between the atmosphere, oceans, and terrestrial biosphere. The largest natural exchanges occur between the atmosphere and terrestrial biota and between the atmosphere and ocean surface waters.

The increasing concentration of $CO_2$ in the atmosphere, which is a part of the greenhouse effect, largely as a result of the burning of fossil fuels and the clearing/burning of large areas of forest. Apart from the burning of fossil fuels and forest fires, $CO_2$ is continually produced by all heterotrophs in the biosphere. On the other hand, $CO_2$ is fixed by autotrophs, particularly through the photosynthesis process, that is the autotrophs or primary producers that fix atmospheric $CO_2$ into more complex forms of organic carbon:

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$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2 + 6\,H_2O$$

Although the total global reservoir of carbon is vast, only a small fraction of this carbon is actively involved in the fluxes of the carbon cycle, most of the earth's carbon being 'locked away' in sediments (mainly as carbonates), in carbonate in ocean waters, and in igneous rocks and fossil carbon. Putting the burning of fossil fuels to one side, the earth's active carbon fraction largely consists of carbon in living organisms, carbon in the soil organic matter and atmospheric carbon. The soil carbon pool is approximately five times the size of the atmospheric pool. The latter is approximately the same size as that in living organisms. These three pools together, however, amount to less than one thousandth of global carbon reserves (12). Terrestrial vegetation and soils contain about three and a half times as much carbon as the atmosphere; photosynthesis and respiration control the exchange. The amount of carbon stored globally in soils is much larger than that in vegetation. Soil is a major carbon pool in all biomass, whereas carbon stocks in vegetation are predominantly in the forest biomes (1).

At the steady state, production of $CO_2$ through decomposition and respiration should release an equal amount of carbon back into the atmosphere. The amount of carbon in the atmosphere is so small in relation to the scale of the carbon flux, both into and out of this pool, that consumption of carbon by the plant/soil system would rapidly exhaust atmospheric resources if it were not for the continual respiratory return of carbon to the atmosphere. However, that the rate of release of $CO_2$ from world soil may be as much as twice that of the rate of input. This imbalance is largely the result of the clearing and cultivation of forests and other natural ecosystems, both reducing the capacity for primary production and accelerating the rate of decomposition of the soil's carbon reserves (12).

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## 2.2 Greenhouse Gases

The surface of the Earth is warmed by the sunlight it absorbs. As closed to the surface is heated and rises because of its lower density. The air rises comparatively it expands and cools-just as the cools-air as it comes out of the value of a tyre. As some air masses rises, other air masses descend, so the air is continually turning over as different movements balance each other out a situation of convective equilibrium. Absorbing gases in the atmosphere absorb some of the radiation emitted by the Earth's surface and in turn emit radiation out of space. The amount of thermal radiation they emit is dependent on their temperature. It seems to have a big blanket spreads in the atmosphere and cause global warming. The most important factor of the Greenhouse Gases is water vapor, but its amount in the atmosphere is not changing directly because of human activities. The important Greenhouse Gases, which are directly influenced by human activities, are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), the chlorofluorocarbons (CFCs) and ozone ($O_3$). The $CO_2$ is the most important of the Greenhouse Gases, which are increasing in atmospheric concentration because human activities. The increasing in $CO_2$ has contributed about 70% of the enhanced Greenhouse effect to date, $CH_4$ about 24%, and $N_2O$ about 6% (13). At present, prediction for $CO_2$ is released higher 0.5% per year, released more than used by photosynthesis of plants, and the most are dissolved into the ocean (14).

While the tree growth and the forest ecosystem can absorb $CO_2$ for biomass produce. This process is carbon sequestration that efficiency process can reduce $CO_2$. Naturally, the Greenhouse Gases have long life time and radiation effect, that also known as Global Warming Potential (GWP). The GWP defines the warming effects caused by a unit mass of a given gas relative to that of $CO_2$ (15).

In 1998, Thailand released three major Greenhouse Gases, $CO_2$, $CH_4$ and $N_2O$ (Table 2-1). The most important source of Greenhouse Gases was released from the combustion, mechanism of fossil fuels, land use change, and industrial processes.

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**Table 2-1** Total emissions of the three Greenhouse Gases in Thailand, 1998

| Greenhouse Gases | Emission (Million tons) | GWPs* | $CO_2$ Equivalent (Million tons) | Percentage of Total Emission |
|---|---|---|---|---|
| $CO_2$ | 204,292 | 1 | 204,292 | 68.68 |
| $CH_4$ | 3,787 | 21 | 79,527 | 26.74 |
| $N_2O$ | 44 | 310 | 13,640 | 4.59 |

**Note:** *GWP = Global Warming Potential

**Source:** Environmental Resource Management, 2002 (16)

## 2.3 Dynamics and Carbon Pools

In order to fully account for carbon at a site, the forest, the crops, and the soils as a dynamic multi-component of ecosystem, aboveground and below ground biomass including soil organic matter are considered as the key tracking mechanisms.

The most easily measurable pool is the total standing aboveground biomass of woody vegetation elements. The aboveground biomass comprises all woody stems, branches, and leaves of living trees, creepers, climbers, and epiphytes, as well as herbaceous undergrowth. In some inventories, dead fallen trees and other coarse woody debris, as well as the litter layer are included in biomass estimation. The below ground biomass comprises living and dead roots, soil mesofauna, and the microbial community. There also is a large pool of organic carbon in various forms of soil humus (soil organic carbon). Other forms of soil carbon are charcoal from fires and consolidated carbon in the form of iron-humus pans or concretions. Many soils also contain a subpool of inorganic carbon in the form of hard or soft calcium carbonate (soil inorganic carbon). Another major pool of carbon consists of forest products (timber, pulp products, non-timber forest products such as fruits and latex) and agricultural crops (food, fiber, forage, biofuels) taken off the site.

The amount of carbon stored globally in soils is much larger than that in vegetation about 4.5 times. Soil is a major carbon pool in all biomes, whereas carbon stocks in vegetation are predominantly in the forest biomes. Boreal forests have a larger proportion of carbon stored in soils than in trees, compared with temperate or tropical forests. There are wide local variations, however, the amounts and proportions

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of carbon per unit ground area in vegetation and soil within each biome are shown in Table 2-2.

**Table 2-2** Global carbon stocks in vegetation and top 1 m of soils

| Biome | Area ($10^6$ $Km^2$) | Carbon Stocks (Gt C) | | |
|---|---|---|---|---|
| | | *Vegetation* | *Soils* | *Total* |
| Tropical Forests | 17.6 | 212 | 216 | 428 |
| Temperate Forests | 10.4 | 59 | 100 | 159 |
| Boreal Forests | 13.7 | 88 | 471 | 559 |
| Tropical Savannas | 22.5 | 66 | 264 | 330 |
| Temperate Grasslands | 12.5 | 9 | 295 | 304 |
| Deserts and Semideserts | 45.5 | 8 | 191 | 199 |
| Tundra | 9.5 | 6 | 121 | 127 |
| Wetlands | 3.5 | 15 | 225 | 240 |
| Croplands | 16.0 | 3 | 128 | 131 |
| **Total** | **151.2** | **446** | **2,011** | **2,477** |

**Source:** WBGU, 1998 (1)

Soil hold is one of the largest near surface pools in the global carbon cycle, containing in the range 1,400-1,600 PgC in organic forms. Regardless of whether the global pool was estimated from an aggregation of vegetation types (17), climatic life zones (18), or soil orders (19). The global total is approximately 55 PgC in fresh litter, or detritus, on the soil surface. Because this value is similar to global terrestrial net primary production, the mean residence time of surface litter globally is approximately 1 year. Within the mineral soil, the concentration of soil organic matter nearly always declines exponentially with depth, reflecting its origin from aboveground plant debris (litter fall) and root turnover (20). Thus, a large proportion of the soil carbon pool lies near the soil surface where it is subject to microbial decay, erosion, and a disruption by human activities.

The global carbon pool of the soil at 1 m depth was estimated approximately 1,220 Pg (21), the top soil at 0-30 cm was approximately 684-724 Pg and at 0-2 m was approximately 2,376-2,456 Pg (22).

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The total amount of soil carbon pool in soil of Thailand at 1 m depth was approximately 6.21 Pg equaled to 0.046% of organic carbon, and inorganic carbon was approximately 0.184 Pg equaled to 0.019% of inorganic carbon of the world. The carbon deposit in mountain soil areas approximately 4-8 $Kg/m^2$/100 cm equaled to 40.25% of the area, followed by 12-16 $Kg/m^2$/100 cm equaled to 22.34% and 20-40 $Kg/m^2$/100 cm equaled to 15.31% of the total area, respectively (23).

### 2.3.1 Carbon storage in forest ecosystem

Thailand's National Greenhouse Gas Inventory 1994 (24) reported that GHGs of Thailand were decreased in 1994 about 241 million tons by IPCC method. Because the reforestation and growth of trees in the national forest that support to uptake $CO_2$ about 39 million tons.

Pongprayura (25), studied on the Greenhouse Gas resulting from land use change and forestry sector in Thailand estimated that GHGs decreased and uptaken by the forest in 1990 and 1994 by IPCC 1996 method. The study also reported that in 1990 the forest area of Thailand was about 87,537,500 Rai and the total carbon storage was 1,690 TgC. Land use change estimated to release $CO_2$ about 33.65 $TgCO_2$/yr, and uptake $CO_2$ about 4.98 $TgCO_2$/yr. In 1994 the forest area of Thailand was about 82,825,200 Rai, and the total carbon storage was 1,519 TgC. Land use change estimated to release $CO_2$ about 10.65 $TgCO_2$/yr, and uptake $CO_2$ about 7.23 $TgCO_2$/yr.

Viriyabuncha and Vacharangkura (26), studied on the evaluation system for carbon storage in forest ecosystems in Thailand (I. Aboveground biomass). The study sites were set in Western and Northern parts of Thailand, Net Primary Production (NPP) was estimated for various types/stages of forest stands. The aboveground biomass in forest at Arawan National Park, Kanchanaburi province, the average value were 4.35-330.57 t/ha. When compared with various forest types, it was found that the old growth of mixed deciduous forest had higher biomass than logged forest and the secondary forest. The aboveground biomass in forest at Suthep-Pui National Park, Chiangmai province, the average value were 31.95-903.29 t/ha. When compared with various forest types, it was found that the old growth dry evergreen forest with no log was the highest biomass. The young growth dry dipterocarp forest was the lowest

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biomass. For the aboveground biomass in the evergreen forest, the average value were 86.16-270.19 t/ha, and were 31.95-175.50 t/ha in the deciduous forest. The average value of aboveground biomass in the teak forest in Chiangmai, Lamphun, Phrae and Kanchanaburi province were 24.45-215.98 t/ha.

Junmahasatain and Phopinit (27), studied on the carbon deposit in soil in the forest ecosystems in Thailand which was carried out in Kanchanaburi and Chiangmai. The results of the carbon deposit in soil in different forest types showed that the highest carbon deposit was in hill evergreen forest with the average value of 237.27 t/ha at the level of 1 m depth from the soil surface. The lesser contents of carbon deposit were found in mixed deciduous forest, dry evergreen forest, and pine forest with the carbon deposit at 148.50, 145.25 and 132.05 t/ha, respectively. Dry dipterocarp forest had lower carbon deposit than that found in the natural forest with the average value of 76.75 t/ha. The deposit of carbon in teak plantation in Kanchanaburi was averaged at 167.9 t/ha, which was comparatively high and had almost the same amount of that found in the other forest type as mention above. In all forest types, the deposit of carbons were higher in the top soil and the amount decreased accordingly with increasing soil depth and also found that the distribution of carbon on soil profile was reflected by the plant community and climatic condition at each individual site.

Yowhan and group (28), studied on the aboveground tree biomass of Korean pine (*Pinus koraiensis*) which was determined as a natural forest of Korean pine and mixed deciduous trees and seven age classes of plantation forests in central Korea. Regression analyses of the dry weights of stem wood, stem bark, branches, and needles versus diameter at breast height were used to calculate regression equations of the form of $\log Y = a + b \log X$. Biomass of Korean pine in the mixed forest was 118 Mg/ha, and biomass in the plantations was linearly related to stand age, ranging from 52.3 Mg/ha in 11-20 years stands to 317.9 Mg/ha in 71-80 years stands. The proportions of stem wood and stem bark in the total aboveground biomass decreased with stand age while those of branch and needle increased. Specific leaf area of Korean pine ranging from 35.2-52.1 $cm^2/g$ was significantly different among crown

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positions and needle ages; in general, lower crown position and current needles had the greatest surface area per unit dry weight.

Christopher J.W. and group (29), studied on the quantified structural features and the aboveground biomass of the deciduous conifer, *Metasequoia glyptostroboides* in 6 plantations in central Japan. In order to derive biomass estimates they dissected 14 *M. glyptostroboides* 3 into three structural components (stem wood, branch wood and foliage) to develop allometric equations relating the mass of these components and of the whole tree to diameter at breast height (DBH). The robust relationships of the branch and whole tree levels were found that allowed accurate prediction of component and whole tree biomass. Dominant tree height was similar within five older (>40 years) plantations (27–33 m) and shorter in a 20 years plantation (18 m). Average stem diameter varied from 12.8 cm in the youngest stand to greater than 35 cm in the oldest stand. *Metasequoia* have relatively compact crowns distributed over the top 30% of the tree although the youngest stand had the deepest crown relative to tree height (up to 38%). At the individual tree level in older stands, 87% of the aboveground biomass was allocated to the stem, 9% to branch wood and 4% to foliage. They found little difference in the relative distribution of aboveground biomass among the stands with the exception of lower foliage biomass in larger diameter trees. Total aboveground biomass of the older stands varied twofold, ranging from a maximum of 450 Mg/ha in a 42 years stand to a minimum of 196 Mg/ha in a 48 years stand. Total above ground biomass of the 20 years stand was 176 Mg/ha.

### 2.3.2 Carbon storage in agricultural area

Lars Krogh and group (30), studied on the contemporary stocks of soil organic carbon (SOC) in Denmark at 1 m depth by combining data from two soil and one land use database using 4 different scaling-up methods including land use and soil textures. The estimated stocks varied from 563-598 TgC, with 579 TgC as the average, when urban areas, lakes and open fjords were excluded. Wetland soils had the highest average SOC density (35.6 $Kg/m^2$), followed by soils under forests (16.9 $Kg/m^2$), agricultural soils (14.0 $Kg/m^2$), and soils under natural vegetation (14.4 $Kg/m^2$). Nationwide, 60% of the total SOC was found within 28 cm depth, which was the

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median ploughing depth, and 78% within 50 cm depth. Sixty-nine percent of the total SOC stock was under agricultural land and 40% was found in the plough layer. So the land use changes and environment have contributed to organic carbon storage in terrestrial ecosystem.

Marlen and group (31), studied on the net soil carbon stock changes for USA agricultural soils during the period of 1982-1997 using the IPCC method for Greenhouse gas inventories. Land use data from the NRI (National Resources Inventory; USDANRCS) were used as input along with ancillary data sets on climate, soils, and agricultural management. Their results shown that, overall, changes in land use and agricultural management was resulted in a net gain of 21.2 MMTC per year (Million Metric Tons Carbon per year) in USA agricultural soils during this period. Cropped lands accounted for 15.1 MMTC per year, while grazing land soil carbon increased 6.1 MMTC per year. So the land use and management changes have contributed mostly to the increasing of carbon in soil during that period.

### 2.3.3 The factors affecting the rate of carbon turnover in the ecosystem

The carbon sequestration potential of terrestrial ecosystems depends on the type and condition of the ecosystem that is, its species composition, structure, and (in the case of forests) age distribution. Site conditions include with climate and soils, natural disturbances, and management is also important.

The net global carbon flux between terrestrial ecosystems and the atmosphere is the result of a small imbalance between uptake by photosynthesis and release by various return processes. Plants, soil microbes, biochemical processes, animals, and disturbances contribute to the latter. Variations of climate and human activities have a major impact through land use and land use changes, as well as indirectly through $CO_2$ fertilization, nutrient deposition, and air pollution.

The carbon penetrates to ecosystem by leaves and accumulates in aboveground biomass of plants. Over half of carbon in soil uptake through absorbency of organic matter and litter by roots. The soil is major for carbon pool of the ecosystem. The carbon is uptaken by soil depend on the amounts, dissemination, ages of plants and organic matter. The decomposition of organic matter is affected from

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physical, chemical and biological factors that control organism and soil microbes, environment (temperature, availability of water, air, pH, nutrients), quality of litter, soil texture, elements, disturbances of soil, root system, depth and chemical biomass of roots. The carbon deposit in soil will increase by adding the plants with carbon through the soil in the form of litter, the rate of decrease decomposition, decrease frequency of plough. In addition, fires and plough will effect to soil structure, air and soil moisture are also influenced. Furthermore, the activities that effect to soil texture, elements, humidity, decreasing of litter and increasing of mulch, drain off the water in proper period in annual will support to decrease activities of soil microbes and the organic carbon will also increased.

Oxidation of soil organic matter provides energy for the soil organism; $CO_2$ the product of respiration is released into the atmosphere. If all the carbon in soil organic matter were released into the atmosphere as the $CO_2$ concentration in the atmosphere would double. In a stable ecosystem with unchanging environmental conditions the organic carbon content of soil reaches a steady state. The rates of addition and loss of carbon become equal and the content of organic carbon is equilibrium. The equilibrium becomes less when the soil is cultivated and will change if the conditions change. A change in the soil organic carbon content will affect the $CO_2$ concentration in the atmosphere (32).

## 2.4 Biomass

**Biomass** is the amount of living organisms in the ecosystem is known as the standing crop, a term that applies equally well to plants or animals, which can be expressed in terms of the number per unit area, that is, organism mass. Biomass can be measured as living weight, dry weight, ash-free dry weight, carbon weight, calories, or any other unit that may be useful for comparative purpose (33).

Dyksterhuis and Schmutz (34) classified 4 types of the aboveground biomass that consisted of:

1. Green herbage, green and alive parts including stems that the top part dried but being growth.
2. Cure herbage, the death dried plant which its roots stop growing.

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3. Fresh mulch or fresh organic material, litter of plant on the top layer and not decayed.

4. Humic mulch or decompose litter, part of litter of plants that decayed on the ground.

Litter is the amount of total organic matter including the dead plants, such as leaves, flowers, fruits, branches, bark and stems, or the parts of alive such as seeds, fresh leaves, as well as the piled of dead animals and insects on the ground (35). This study, the litter specially referred to leaves of trees, the leaves litter was a pile on organic matter layer, excluding large wood, such as branches, stems and large fruits.

**2.4.1 The study of biomass**

For live tree biomass, diameters of a sample of trees were measured and converted to biomass and carbon estimates by using allometric biomass regression equations. This equation was firstly used for the study on forest ecosystem by Kittredge (36) to estimate the amount of leaves per tree ($W_L$) by using the relationship of diameter at breast height (D), which the form was; $log\ W_L = b\ log\ D - a$.

The general procedure of estimating biomass was cut down a tree, weighed it, took samples in each tree components, and dried these components. The cutting down a tree to make very close to soil surface, measured the total height of tree, diameter at breast height (1.30 m), at 0.3 m from the soil surface, at 1/10 of the total height, and measured the wide and the height of the crown. Then, separated samples of different (leaves, branches, stem and roots), weighted it, and dried each of component in order to estimate dry mass of the total tree (37).

The tree biomass (dry weigh) was calculated by applying the moisture loss of the samples to the entire tree. Depending on the researcher, however, the number of samples taken from a tree would be varied. Nelson et al. (1999) dried a single sample of the bole at breast height, while Kraenzel et al. (2003) dried a separate sample for each meter of the bole's length. Moreover, the drying time and temperature varied between researchers. Nelson et al. (1999) dried sample at 105°C until constant weight was reached, while Kraenzel et al. (2003) dried the wood for 1 week at 70°C. Other researchers (Likens and Bormann, 1970) had dried samples at 80°C (38).

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Kira and Shidei (39) separated the estimating for biomass into 2 types 1) harvesting to estimate fresh mass and dry mass of the total of tree and 2) to estimate fresh mass from the samples of plants. Searching for the relationship of mass and others dimension of plants called the relationship allometric equation. The form was; $y = ax^b$ or $log\ W = log\ a + b\ log\ (D^2H)$, when W was the total mass of stem, branches, leaves and root, D was diameter of stem at breath height, H was the total height of stem and a, b were the variable values.

**2.4.2 The variable biomass**

The biomass of plant varied with precipitation and the growth season. The biomass growth was much larger in rainy season and rather constant in the winter. Furthermore, the precipitation was a factor to control scattering of roots in different depth and struggling of the same type of plant (40 and 41). The precipitation content influenced to the ground layer with the size and density of the crown cover. The crown cover of tree was a factor to control the receiving of precipitation and sunlight of the ground layer, as the same times it also controlled the type of ground layer (42).

Bement (43) found that the growth of tree related directly with the sunlight, the proper temperature and enough precipitation. Particularly, the temperature and the sunlight were major causes for plant productivity, increased or accumulated of tree biomass. At beginning of the winter, changing was rather steady or much less because the decreasing of soil moisture and relative humidity in atmosphere, so the plants adjust themselves in decreasing of their evapotranspiration by falling leaves.

The deciduous of each plants were different depend on their physical characteristics and falling period. The Para rubber trees in Klaeng district, Rayong province had fallen during the end of December to the middle of January, then started for refoliation, and the leaves were mature in April.

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## 2.5 Para Rubber Trees

**Para Rubber Trees** are large tree, classified in the division Magnoliophyta, class Magnoliopsida, order Euphorbiales, family Euphorbiaceae, namely ***Hevea brasiliensis***. Origin is a native plant of the Amazon basin in tropical South America. They are perennial trees of a height of 25-30 meters. They have stems smooth, straight and thick, somewhat soft, trunk unbranched up a long way and then with much branched leafy canopy; light brownish gray bark; taproot well-developed; leaves alternate, trifoliate, stipulate, petioles 7.5-10 (-70) cm long; leaflets obovate, apically acuminate, entire, basally acute, penninerved, 10-15 (-50) cm long, 3-6 (-15) cm broad, elliptic-lanceolate in outline; flowers numerous, monoecious, creamy, yellow or green, in axillary pubescent panicles, sweet-scented, small; female flowers apical, the more numerous male flowers lateral in the inflorescence; petals absent; fruit a 3-lobed, 3-seeded ellipsoidal capsule, each carpel with 1 seed; seeds ellipsoidal are oil bearing, variable in size, 2.5-3 cm long, mottled brown, lustrous, weighing 2-4 g each (44).

The young plant shows characteristic growth pattern of alternating period of rapid elongation and consolidated development. The rubber tree is deciduous in start from December to February. Refoliation is quick and copious flowering follows. Flowers are small but appearing in large clusters.

The size of the tree, the quality of the latex, and the number of taps possibly varies with individual trees; the quantity of latex increases with the age of the tree. Cultivated trees are tapped throughout the year, usually in the early morning, when the latex flow is greatest (45). The rubber tree may live for a hundred years or even more, but its economic life period in plantations, on general considerations is, only around 32 years-7 years for immature phase and 25 years for productive phase (46).

## 2.6 Relevant Researches

Carbon deposit in soil was in the form of inorganic and organic compounds. Lal and group (47) classified 5 types of the carbon pools, consisted of pedoshere, atmosphere, hydrosphere, lithosphere, and in content of living on the biosphere. Schlesinger (48) estimated carbon content in soil was about 2 times of carbon in the

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atmosphere or 3 times of carbon content of living on the biosphere, was 1/3 times of fossil fuel in lithosphere and was 1/25 times of carbon in the water.

Gifford (49) studied on the carbon content from the accumulated biomass, the carbon stocks in wood varied between 0.4-0.53 of dry mass. Estimation of the total carbon in biomass was shown in Table 2-3.

**Table 2-3** Carbon: Wood factors from biomass sources

| Biomass Sources | Carbon : Biomass factor |
|---|---|
| Aboveground | 0.50 |
| Leaves | 0.53 |
| Coarse Roots | 0.49 |
| Fine Roots | 0.48 |

**Source:** Gifford, 2000 and Gifford, 2000a (49)

The estimating of carbon stock in forest plantations were generally based on allometric equations relating either carbon or biomass to diameter at breast height (DBH). These equations were usually based on measurement of the fresh mass of each tree with sub-samples taken to determine moisture content to convert to dry weight. However, drying time and the number of sub-samples varied between studies. Furthermore, the carbon concentration of different tree parts was rarely measured directly, and most researchers estimated carbon by assuming the carbon content of dry biomass to be a constant 50% by weight (Brown, 1986; Montagnini and Porras, 1998). Occasionally, carbon was measured directly by burning the samples in a carbon analyzer (Kraenzel et al., 2003) (38). Therefore, this study estimated carbon by assuming the carbon content of dry biomass to be a constant 50% by weight.

Witthawatchutikul and Jirasuktaveekul (9) studied on the relationship of allometric equations to estimate aboveground biomass of the Para rubber plantation in Rayong watershed by harvesting method. The study classified the biomass of stem ($W_S$), branches ($W_B$) and leaves ($W_L$) in order to estimate the aboveground biomass with square of diameter of stem (D) at 1.30 m and multiplied by the total height of tree (H), the equation as the following:

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$$\log W_S = 0.866 \log D^2H - 1.255 \qquad r^2 = 0.991$$

$$\log W_B = 1.140 \log D^2H - 2.657 \qquad r^2 = 0.878$$

$$\log W_L = 0.741 \log D^2H - 1.654 \qquad r^2 = 0.922$$

According to this studied, the young tree at 5 years, the average DBH was 13.86 cm, the average total height was 13.2 m, the total aboveground biomass was 4.67 t/Rai, and biomass of roots was 0.36 t/Rai. For the cultivation stage at 8 years, the average DBH was 16.26 cm, the average total height was 16.28 m, the total aboveground biomass was 7.27 t/Rai, and biomass of roots was 0.40 t/Rai. The mature stage at 19 years, the average DBH was 24.82 cm, the average total height was 20.18 m, the total aboveground biomass was 17.74 t/Rai, and biomass of roots was 0.58 t/Rai (50).

In addition, the management of farmer would not equal rapidly increase the aboveground biomass of the Para rubber plantation. After planting for 25-30 year, biomass was around 25 t/Rai or 378 Kg/stem (66 stems/Rai) which was resulted to the decreasing of latex and would be replantation. Besides, more than 70% of the biomass of roots at 0-50 cm, ages 4, 7 and 8 years would spread at 0-15 cm of soil and increase by the ages (51). That was coincided with the study of Bangjan (52), which found that the density of roots would be 15 cm from soil surface.

Varavaitchalit (53) studied on the biomass of Para rubber trees by using the equations of Witthawatchutikul and Jirasuktaveekul (9). The results found that the Para rubber plantations, RRIM 600 at 10 years, the aboveground biomass was about 8.263 t/Rai (storage of stems 5.439 t/Rai, branches 2.245 t/Rai, and leaves 0.578 t/Rai). The biomass of ground layer and soil surface were 16.64, 0.305 t/Rai, litter of Para rubber trees was 0.303 t/Rai, and litter of ground layer was 0.002 t/Rai.

Shorrocks (54) studied on the relationship between diameter at 1.50 m from soil surface and aboveground biomass of Para rubber trees. The result found that the relationship of the linear function between diameter (log G) and dry biomass (log Md) was:

$$\log Md = 2.7826 \log G - 2.5843$$

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Bangjan (52) studied on the Para rubber trees in the Eastern part of Thailand on the same relationship as Shorrocks (54) and its result in the function was:

$$log\ Md = 2.543\ log\ G - 2.035 \qquad r^2 = 0.999$$

The study was then estimated dry biomass of Para rubber trees and the result was lower than actual value when Para rubber trees had increased of girth. However, the relationship between dry biomass and volume of tree was formed as:

$$log\ Md = 0.856\ log\ D^2H - 0.7188 \qquad r^2 = 0.976$$

The mentioned study could make the relationship between dry mass of roots, diameter and the height of stem in the allometric equation form as:

$$log\ W_R = 0.709\ log\ D^2H - 0.131 \qquad r^2 = 0.997$$

In addition, Bangjan (52) found that the mass of Para rubber trees would increase in the form of the square of value when the size of tree increase or more mature. The young tree, 1-5 years had the large proportion of the mass of stem, and the larger proportion of the mass of branches when they were tapped.

The mass of each branch was related to the size of girth as close to the stem. The proportion of the mass of leaves per the mass of stem would decrease by age of tree. The below ground biomass was the mass of stump add to the mass of lateral root. The mass of stump was been 40-70% of the total below ground biomass. The most density at soil surface or 1-15 cm depth was been 14-28% of the total mass of roots. The mass of roots would increase when the size of tree increases. Shorrocks (54) reported that the Para rubber tree at 4-8 years, the mass of roots was about 15% of the aboveground dry mass. Bangjan (52) found that the RRIM 600 Para rubber trees at 2.5 years in the Eastern part of Thailand had the below ground biomass value about 41.4% of the total mass of stem. The proportion of the mass of below ground biomass would decrease 8.8% of the mass of stem when the tree was 20 years.

Roots of plant were an important part of the carbon cycle because they transferred large amounts of carbon directly into the soil, where it might be stored for a long time. Part of the carbon in roots was used to increase biomass, but carbon was also lost through exudation, respiration, and decomposition. Although some roots might be extended to great depths, the overwhelming proportion of the total root

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biomass was generally found within 30 cm of the soil surface. Measuring the amounts of biomass in roots and their turnover was an extremely costly exercise. So the regression equations were often used to extrapolate aboveground biomass to whole tree biomass (1).

For best practice for the biomass of root measurement, the total of roots should be dug out and measured each content of roots, but such method was very limited. So the allometric equations for estimate the biomass of stem, branches, and leaves could be applied to estimate the biomass of roots instead. The ratio of aboveground biomass to below ground biomass would be less value when the size of tree increased (37). Besides, it was agreed with the study of Bangjan (52), the ratio of below ground biomass would be decreased when the tree was older and the percentage of mass of lateral root was the ratio decreased when the size of tree increased.

## 2.7 The Study Area

### 2.7.1 Location

The study area is in Klaeng district of Rayong province. The area locates at between latitude 12º38´ to 13º10´ N and between longitude 101º30´ to 101º50´ E, and cover with the area of 741 $Km^2$ or 13.5% of Rayong area is shown in Figure 2-1.

| | |
|---|---|
| The North | Bordered with *Khao Chamao sub-districts and Wang Chan district,* Rayong province. |
| The South | Bordered with the coastal of Thailand. |
| The East | Bordered with *Kang Hang Maeo and Na Yai Am district, Chanthaburi* province. |
| The West | Bordered with *Muang Rayong.* |

### 2.7.2 Topography

Klaeng district, Rayong province consists of the high mountain ranges on the East and the North. The middle area is undulating and rolling. This stands a slope with the North to the South aspect, alternate generally with hill and small mountain. The lower part of the area is plain and undulating. The end of South is closed to the sea

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(the Gulf of Thailand) at Prasae estuary, which is the river run through the middle area from the North to the South.

The most of soil in Klaeng district is classified to be sup-group of Typic Paleudults, such as: Khlong Chak (Kc), Nong Khla (Nok), Lamphula (Ll), Tha Sae (Te) series, and etc (55). These soils are suitable for perennial tree, such as: Para rubber tree, perennial fruit, etc.

### 2.7.3 Climate

The climate of Klaeng district is Tropical Monsoon and rainy season ranges from May to October. The statistic in 1983 to 2002 of the Royal Irrigation Department at Chamkho sub district, Klaeng district, Rayong province reported that mean annual temperature was 27.6 ºC, minimum temperature was 15.2 ºC in December and maximum temperature was 35.8 ºC in April. The mean annual precipitation was about 1,800 mm, evaporation 1,400 mm and relative humidity 91%.

**Table 2-4** The statistic of precipitation, evaporation, relative humidity, and temperature of Klaeng district, Rayong province in the two decadal periods (1983-2002)

| Month | Precipitation (mm) | Evaporation (mm) | Relative humidity (%) | Temperature (ºC) | | |
|---|---|---|---|---|---|---|
| | | | | max | min | mean |
| Jan. | 19.9 | 133.33 | 79.3 | 34.5 | 15.8 | 25.6 |
| Feb. | 24.3 | 127.39 | 91 | 35.0 | 17.1 | 26.9 |
| Mar. | 57.2 | 146.7 | 97 | 34.8 | 19.2 | 28.2 |
| Apr. | 101.1 | 130.4 | 91.8 | 35.8 | 21.1 | 29.1 |
| May | 220.8 | 119.69 | 94.4 | 35.8 | 22.2 | 28.7 |
| June | 263.0 | 102.28 | 95.6 | 34.3 | 22.2 | 28.2 |
| July | 245.5 | 107.94 | 95.6 | 35.2 | 21.9 | 27.7 |
| Aug. | 266.4 | 99.21 | 95.2 | 34.2 | 22.0 | 27.8 |
| Sep. | 309.8 | 88.76 | 94.5 | 34.3 | 21.5 | 27.7 |
| Oct. | 232.8 | 106.78 | 92.6 | 34.5 | 21.2 | 28.1 |
| Nov. | 48.3 | 131.3 | 86 | 34.4 | 19.1 | 27.9 |
| Dec. | 6.3 | 150.79 | 86 | 33.9 | 15.2 | 25.6 |
| **Total/Mean** | **1,795.4** | **1,444.57** | **91.58** | **34.73** | **19.88** | **27.63** |

**Source:** The Royal Irrigation Department, 2003 (56)

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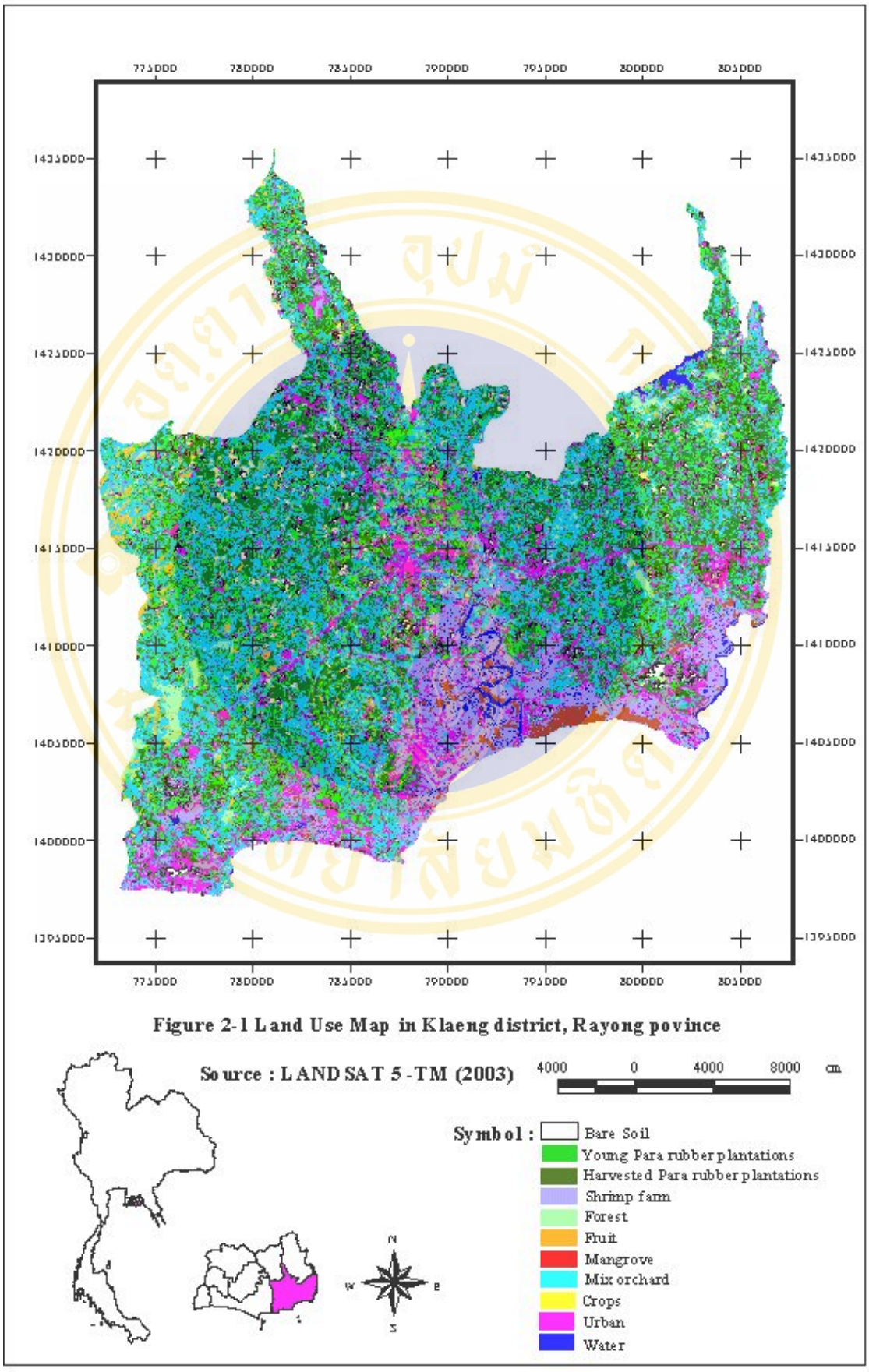


**Figure 2-1 Land Use Map in Klaeng district, Rayong povince**

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### 2.7.4 The Para rubber plantations area in Rayong province

From studied report concerned with the Para rubber plantations in Rayong province by satellite data (LANDSAT 5-TM, at the scale 1:125,000) of the Rubber Research Institute in 1996, the Para rubber plantations were 639,790 Rai or 29% of Rayong province area (Table 2-5).

**Table 2-5** The Para rubber plantations area in Rayong province, 1996

| District | Young plantation (0-5 years) | Harvested plantation (> 5 years) | Total (Rai) |
|---|---|---|---|
| *Muang Rayong* | 13,194 | 97,953 | 111,147 |
| *Wang Chan* | 18,643 | 75,965 | 94,608 |
| *Ban Khai* | 14,097 | 76,297 | 90,394 |
| *Pluak Daeng* | 13,731 | 34,332 | 48,063 |
| *Klaeng* | 53,303 | 242,275 | 295,578 |
| **Total** | **112,968** | **526,822** | **639,790** |

**Source:** The Rubber Research Institute, 1996 (57)

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# CHAPTER 3

# METHODOLOGY

This research was carried out in term of survey and analytical research. The relevant data were collected at 3 different age groups in the Para rubber plantations in order to analyze for carbon content.

## 3.1 Data Collection

Secondary data were collected from relevant documents, as the following:

**3.1.1 Basic data of the study area were consisted of:**

- Topography
- Climate
- Soil properties

**3.1.2 Data of the Para rubber tree were consisted of:**

- Physiology of the Para rubber tree
- Aged period and diameter of the Para rubber tree

## 3.2 Materials

**3.2.1 Maps**

1) Topographic maps at the scale of 1:50,000 from the Royal Thai Survey Department in 1991, series L7017, sheets No. 5334 I, 5334 III, 5334 IV, 5335 II, and 5335 III.

2) LANDSAT 5-TM Geocoded sheet 128051, Rayong province on 30 December, 2003.

3) Detailed Reconnaissance Soil Survey maps of Rayong province at the scale of 1:100,000 from the Land Development Department, in 1985.

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4) Maps of Agro-ecological zoning for Para rubber plantation at the scale of 1:100,000 from the Rubber Research Institute, the Department of Agriculture, in 2000.

**3.2.2 Field equipments consisted of the following items:**

1) Global Positioning System (GPS)
2) Measuring tape
3) Haga hypsometer
4) Rope
5) Soil moisture can
6) Litter trap at the size of 1 x 1 $m^2$ with nylon net
7) Frame at the size of 1 x 1 $m^2$
8) Soil Augers
9) Hoe, Spade and Knife
10) Plastic bags

**3.2.3 Laboratory equipments and chemical substance consisted of the following:**

1) Grinder
2) 2 mm. Sieve
3) pH meter
4) Hydrometer
5) Conductivity meter
6) Kjeldahl distillation apparatus
7) Oven
8) Glasses
9) Chemical substances

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## 3.3 Methods

Data from the sample plots were collected during December 2003 to November 2004. The methodologies of this study were done as the following:

### 3.3.1 Data collection

Secondary data of the study area are topographic, climate. Soil was collected and analyzed for soil properties.

### 3.3.2 Samples collection

Samples were collected in dry and rainy seasons which consisted of:

**1) Vegetation sample**

Vegetation samples were collected from 3 sample plots of 3 different age of Para rubber tree. The young stage (average 4-6 years) the harvested stage (average 14-16 years), and the mature stage (average over 20 years) was the sample plots. Each sample plot was on the size of 40 x 40 $m^2$. The data of component of the Para rubber tree were collected at aboveground and below ground biomass. The DBH (1.30 m) was measured for all individuals sample plots. The height was measured and calculated with Haga hypsometer for 10% of total trees in individual sample plot. The DBH and height were measured for the first time in January (during the falling leaves period) and the second time in October (during the productive period). The latex was also randomly collected for 2 sub-samples in each sample plots. The litter fall was collected for 5 sub-samples in each sample plots by litter trap at the size of 1 x 1 $m^2$. The ground layer was collected for 5 sub-samples in each sample plots at the size of 1 x 1 $m^2$ (Figures 3-1, 3-2, 3-3 and 3-4).

**2) Soil sample**

Individual sample plot was on the size of 40 x 40 $m^2$. Soil samples were collected at $A_p$ horizon (0-15 cm) and B horizon (15-30 cm) for physical and chemical analysis. The soil samples were collected for 3 replication in each sample plots.

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**Figure 3-1** The characteristics of sample plot

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**Figure 3-2** Collected litter fall samples

**Figure 3-3** Collected ground layer samples

**Figure 3-4** Collected latex samples

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### 3.3.3 Samples analysis

#### 1) Vegetation sample

Indirect method was used to estimate the aboveground biomass for each component of the Para rubber tree, such as stems, branches, leaves and roots, which all were related to allometric equation. The allometric equation is the relationship between the square diameter and height ($D^2H$), and biomass of the component of tree (9). The allometric equation to estimate the biomass of root was developed with some data of roots of Bangjan (52) as detail shown in Table 3-1.

**Table 3-1** The allometric equation for biomass estimation in the Para rubber tree

| Part | Allometric equation | $r^2$ |
|---|---|---|
| Stem | $\log W_S = 0.866 \log D^2H - 1.255$ | 0.991 |
| Branch | $\log W_B = 1.140 \log D^2H - 2.657$ | 0.878 |
| Leaf | $\log W_L = 0.741 \log D^2H - 1.654$ | 0.922 |
| Root | $\log W_R = 0.709 \log D^2H - 0.131$ | 0.997 |

**Source:** Witthawatchutikul and Jirasuktaveekul (9), and Bangjan (52)

Vegetation samples of latex, litter fall and ground layer were dried in the oven at 80°C for 3-5 hours or until constant weight were reached (38). Biomass estimation of these samples were done by the following equation:

$$\% \text{ Moisture} = \frac{(\text{Fresh mass} - \text{Dry mass})}{\text{Dry mass}} \times 100$$

$$\text{Dry mass (or biomass)} = \frac{100 \times \text{Fresh mass}}{\% \text{ Moisture} + 100}$$

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**2) Soil sample**

Soil samples were collected by hand auger and core, and dried at between 95°C-105°C for 24 hours or until constant weight were reached in the oven and calculated $D_b$, grinded and sieved soil samples for the following analysis:

2.1) Physical analysis for Soil Texture

2.2) Chemical analysis for Soil Reaction (pH), Soil Organic Matter (SOM), %Organic Carbon (%OC), Cation Exchange Capacity (CEC) and Electrical Conductivity ($EC_e$).

**Table 3-2** Soil samples analysis method

| Parameter | Method |
|---|---|
| Soil Texture | Hydrometer method |
| Bulk Density : $D_b$ | $D_b$ = Dry mass (g) /Total of soil volume ($cm^3$) |
| Soil Moisture | % by weight = ((weight of fresh mass - weight of dry mass) / weight dry mass) x 100 |
| Soil Reaction: pH | Peech method (1965) |
| Soil Organic Matter: SOM | Walkley & Black method (1947) |
| % Organic Carbon : %OC | Walkley & Black method (1947) |
| Cation Exchange Capacity : CEC | Buchner funnel filtration method (Ammonium acetate 1 N pH 7) |
| Electrical Conductivity : $EC_e$ | Tiumrat and group method (2000) |

**Source:** Monjaroen and Sangounsappayakorn (10)

## 3.4 Estimation of Carbon Content in Vegetation and Soil Sample

Carbon content was estimated from vegetation biomass and %Organic Matter in the Para rubber plantations. They were estimated as the following:

### 3.4.1 Estimating carbon for individual trees

The Para rubber tree biomass was summed in each part of the tree components, and separated into 2 parts of the aboveground and below ground biomass. The above ground biomass consisted of biomass of stems, branches, leaves, and latex. The below ground biomass consisted of biomass of roots (52).

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The carbon calculation of trees were done by multiplying the biomass value of each parts of the Para rubber tree with 0.5 (1), in order to get the carbon contents of each part of tree. Then, all components were summed up to estimate the carbon content for each tree and the total carbon content in the Para rubber plantation (Kg/Rai), respectively by the following equation:

$$M_T = M_S + M_B + M_L + M_{La} + M_R$$

$$C_T = 0.5M_T$$

Where as:
- $M_T$ Total biomass of trees (Kg/Rai)
- $M_S$ Biomass of stems (Kg/Rai)
- $M_B$ Biomass of branches (Kg/Rai)
- $M_L$ Biomass of leaves (Kg/Rai)
- $M_{La}$ Biomass of latex (Kg/Rai)
- $M_R$ Biomass of roots (Kg/Rai)
- $C_T$ Total carbon of trees (Kg/Rai)

**3.4.2 Estimating carbon for vegetation on soil surface**

The carbon calculation of vegetation on soil surface was estimated by multiplying the total biomass values of litter fall and ground layer with 0.5 (1) and the total carbon on soil surface in the Para rubber plantation (Kg/Rai) was also calculated by the following equation:

$$M_{SS} = M_{LF} + M_{GL}$$

$$C_{SS} = 0.5\ M_{SS}$$

Where as:
- $M_{SS}$ Total biomass of vegetation on soil surface (Kg/Rai)
- $M_{LF}$ Biomass of litter fall (Kg/Rai)
- $M_{GL}$ Biomass of ground layer (Kg/Rai)
- $C_{SS}$ Total carbon of vegetation on soil surface (Kg/Rai)

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### 3.4.3 Estimating for Soil Organic Carbon

Soil organic carbon content was calculated by multiplying the concentrated value of organic carbon in each layer of soil ($A_p$ and B horizon) (% volume) with soil bulk density value (g/cm$^3$) and multiplied again with the depth of soil layer (15 cm) and then summed up the result of each layer. This was the total amount of soil carbon stock (58).

The carbon calculation for the total soil carbon content in $A_p$ and B horizon (Kg/Rai) was calculated by the following equation:

$$C_{Ap} = [\text{Conc. } C_{Ap}] \times D_{bAp} \times V_{Ap}$$

$$C_B = [\text{Conc. } C_B] \times D_{bB} \times V_B$$

$$C_{Soil} = \frac{(C_{Ap} \times LA_p) + (C_B \times LB)}{LA_p + LB}$$

Where as;

| | |
|---|---|
| $C_{Ap}$ | Carbon in soil of $A_p$ horizon (Kg/Rai) |
| $C_B$ | Carbon in soil of B horizon (Kg/Rai) |
| $D_b$ | Soil bulk density (g/cm$^3$) |
| V | Soil volume of $A_p$ and B horizon (cm$^3$) |
| $C_{Soil}$ | Total Carbon in soil of $A_p$-B horizon (Kg/Rai) |
| $LA_p$ | Depth of $A_p$ horizon (15 cm) |
| LB | Depth of B horizon (15 cm) |

### 3.4.4 Estimating for the total carbon in the Para rubber plantation

The total carbon in the Para rubber plantation was calculated by summing up the carbon contents in vegetation and soil as the equation written below:

$$C_{Total} = C_T + C_{SS} + C_{Soil}$$

Where as;

| | |
|---|---|
| $C_{Total}$ | Total carbon of the Para rubber plantation (Kg/Rai) |
| $C_T$ | Total carbon of trees (Kg/Rai) |
| $C_{SS}$ | Total carbon of vegetation on soil surface (Kg/Rai) |
| $C_{Soil}$ | Total carbon in soil of $A_p$ to B horizon (Kg/Rai) |

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## 3.5 Statistical Analysis

Statistical analysis by Paired T-Test was used to distinguish significant differences between the soil properties in dry and rainy seasons.

Differences between the size of tree (diameter and height) in each stage and sum of carbon content in each part (stem, branches, leaves, latex, roots, litter fall, ground layer and soil) were calculated for each sample plot and tested by SPSS for Windows by using a one-way analysis of variance (ANOVA).

Furthermore, Pearson correlation was used to study the relationship between soil organic carbon, soil properties and amount of biomass. In addition, it was also used to study the relationship between the size of tree and tree biomass.

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# CHAPTER 4

# RESULTS AND DISCUSSION

This study is focused on the estimation of carbon content in biomass of plant components (stems, branches, leaves, latex and roots), biomass of litter fall and ground layer on soil surface, and carbon content in soil. In addition, the soil properties in the Para rubber plantations in Klaeng district, Rayong province were analyzed. The data were collected from 9 sample plots and each plot was on the size of 40 x 40 $m^2$. The sample plots were separated into 3 stages; they were young stage (average 4-6 years), the harvested stage (average 14-16 years), and the mature stage or the re-plantation (average over 20 years). From such separation, the sample plots were grouped into 3 main sample plots and each plot consisted of 3 sub sample plots. The results of this study were shown as the following:

## 4.1 General Characteristics of the Study Area

Individuals of the Para rubber sample plots are located in Klaeng district, Rayong province, located at 12°43′ N to 12°44′ N and 101°35′ E to 101°37′ E (Table A-1). The characteristic of area is undulating terrain with 2-5% slope and surround by agricultural area. The climate is Tropical Monsoon and much usually rains a lot in May to October every year.

The characteristic of the Para rubber plantations, which were representatives of this study area were RRIM 600 on individuals of stages. The trees were planted at 3m x 7m spacing (78 stems/Rai).

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### 4.1.1 The young plantation

The young plantations, average 4-6 years, were planted at 3m x 7m spacing with the most dominant variety of RRIM 600. Current stem density was about 78 stems/Rai, the average DBH and total height were approximately 16.25 cm, 14.89 m, respectively.

**Figure 4-1** The young plantation at 4 years during the falling leaves period

**Figure 4-2** The young plantation at 4 years during the productive period

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### 4.1.2 The harvested plantation

The harvested plantations, average 14-16 years, were planted at 3m x 7m spacing with the most dominant variety of RRIM 600. Current stem density was about 78 stems/Rai, the average number of trees that produced latex was approximately 69 stems/Rai (88.46% of the total trees). The average DBH and total height were approximately 23.23 cm, 21.18 m, respectively.

**Figure 4-3** The harvested plantation at 15 years during the falling leaves period

**Figure 4-4** The harvested plantation at 15 years during the productive period

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### 4.1.3 The mature plantation

The mature plantations, average over 20 years, were planted at 3m x 7m spacing with the most dominant variety of RRIM 600. Current stem density was about 78 stems/Rai, the average number of trees that produced latex was about 55 stems/Rai (70.51% of the total trees). The average DBH and total height were approximately 28.79 cm, 22.29 m, respectively.

**Figure 4-5** The mature plantation, over 20 years during the falling leaves period

**Figure 4-6** The mature plantation, over 20 years during the productive period

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## 4.2 Para Rubber Trees Biomass

The study about the Para rubber trees biomass for individual sample plots were considered in 2 parts; 1) aboveground biomass (stems, branches, leaves and latex) and 2) below ground biomass (roots). Tables 4-1 and 4-2 presented the total biomass of 5 components of each stand at 3 different stages during the falling leaves and productive period by using the allometric equation.

**Table 4-1** The Para rubber trees biomass during the falling leaves period

| Parameter | | Plant Stage | | |
|---|---|---|---|---|
| | | Young | Harvested | Mature |
| Average Size | Perimeter (cm) | 48.09 | 72.63 | 90.88 |
| | Diameter (cm) | 15.30 | 23.11 | 28.92 |
| | Height (m) | 14.40 | 20.82 | 21.97 |
| Calculated Biomass (Kg/Rai) | Stems | 5,175.89 | 14,029.81 | 21,957.40 |
| | Branches | 2,001.44 | 7,344.77 | 13,326.70 |
| | Leaves | 733.01 | 1,727.04 | 2,528.65 |
| | Latex | - | 231.48 | 174.95 |
| | Roots | 1,880.41 | 4,275.03 | 6,155.17 |
| | **Total** | **9,790.75** | **27,608.13** | **44,142.87** |

**Table 4-2** The Para rubber trees biomass during the productive period

| Parameter | | Plant Stage | | |
|---|---|---|---|---|
| | | Young | Harvested | Mature |
| Average Size | Perimeter (cm) | 51.06 | 73.02 | 90.48 |
| | Diameter (cm) | 16.25 | 23.23 | 28.79 |
| | Height (m) | 14.89 | 21.18 | 22.29 |
| Calculated Biomass (Kg/Rai) | Stems | 5,825.14 | 14,360.81 | 22,105.04 |
| | Branches | 2,321.14 | 7,566.94 | 13,462.80 |
| | Leaves | 812.99 | 1,762.26 | 2,542.08 |
| | Latex | - | 277.24 | 261.42 |
| | Roots | 2,077.65 | 4,358.71 | 6,185.79 |
| | **Total** | **11,036.92** | **28,325.96** | **44,557.13** |

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### 4.2.1 The falling leaves period

In the falling leaves period, the estimation of aboveground biomass of each trees components for each sample plots were identified as the following (Table 4-1):

The young stage, the average DBH and total height were about 15.30 cm, and 14.40 m, respectively. The average total aboveground and below ground biomass of trees were about 7,910.34 and 1,880.41 Kg/Rai, respectively. The average total biomass was about 9,790.75 Kg/Rai.

The harvested stage, the average DBH and total height were about 23.11 cm, and 20.82 m, respectively. The average total aboveground and below ground biomass of trees was about 23,333.10 (the latex biomass was about 231.48 Kg/Rai) and 4,275.03 Kg/Rai, respectively. The average total biomass was about 27,608.13 Kg/Rai.

The mature stage, the average DBH and total height were about 28.92 cm, and 21.97 m, respectively. The average total aboveground and below ground biomass of trees was about 37,987.70 (the latex biomass was about 174.95 Kg/Rai) and 6,155.17 Kg/Rai, respectively. The average total biomass was about 44,142.87 Kg/Rai.

### 4.2.2 The productive period

In the productive period, the estimation of aboveground biomass of each trees components for each sample plots were identified as the following (Table 4-2):

The young stage, the average DBH and total height were about 16.25 cm, and 14.89 m, respectively. The average total aboveground and below ground biomass of trees were about 8,959.27 and 2,077.65 Kg/Rai, respectively. The average total biomass was about 11,036.92 Kg/Rai.

The harvested stage, the average DBH and total height were about 23.23 cm, and 21.18 m, respectively. The average total aboveground and below ground biomass of trees was about 23,967.25 (the latex biomass was about 277.24 Kg/Rai) and 4,358.71 Kg/Rai, respectively. The average total biomass was about 28,325.96 Kg/Rai.

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The mature stage, the average DBH was about 28.79 cm. The DBH value was less than the DBH in the falling leaves period because its bark was peeled off in flakes. The total height was about 22.29 m. The average total aboveground and below ground biomass of trees was about 38,371.34 (the latex biomass was about 261.42 Kg/Rai) and 6,185.79 Kg/Rai, respectively. The average total biomass was about 44,557.13 Kg/Rai.

These results found that the mean difference of diameter for 3 stages in each periods were statistical significant at the level of 0.05 (Table A-22 and Figure 4-7). It was agreed with the study of Bangjan (52) found that the diameter of tree and amount of biomass were linear function relationship with the age. The mean difference of total height of the young, the harvested and mature stage were statistical significant at the level of 0.05. But the harvested stage was not different statistical significant with the mature stage (Table A-23 and Figure 4-8). Because the rate of increasing height of Para rubber tree would decrease, while the branches would increase. The young stage had the large proportion of stem biomass about 50% of the total tree biomass. The proportion of stem biomass would decrease when it had been tapped, while the proportion of leaves and roots biomass would also decrease when the girth of tree increased or older. The results of this study was agreed with the study of Bangjan (52). It reported that the young tree had the large proportion of stem biomass, and the branches biomass would increase when it was tapped.

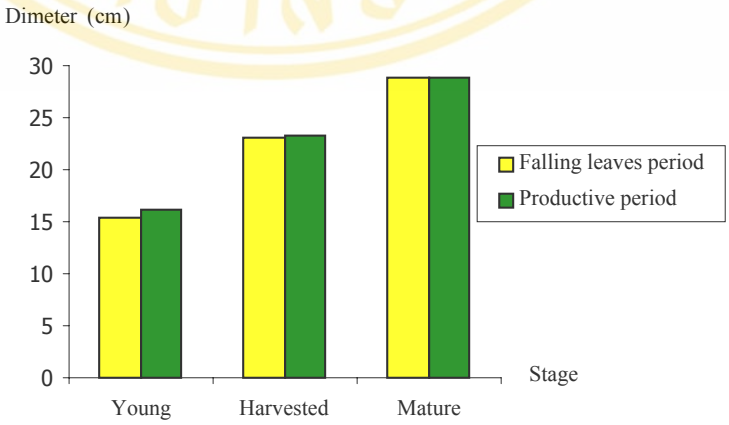


**Figure 4-7** Comparing the Diameter at Breast Height (DBH)

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**Figure 4-8** Comparing the total height of tree

In addition, the study found that the mean difference of biomass in each tree components, such as stems, branches, leaves and roots were statistical significant at the level of 0.05 for 3 different stages in each periods (Tables A-24 to A-27). For the mean difference of latex biomass in harvested and mature stages were not statistical significant (Table A-28 and Figure 4-9).

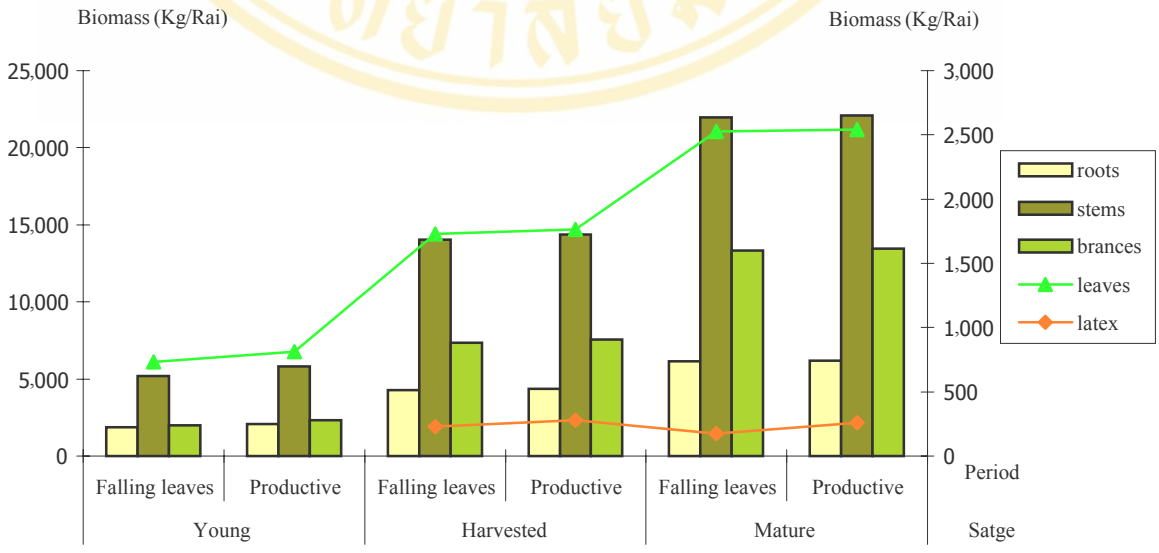


**Figure 4-9** Comparing the biomass in each the Para rubber tree components

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## 4.3 Vegetation Biomass on Soil Surface

The vegetation biomass on soil surface for individual sample plots were considered in 2 parts, litter fall and ground layer, were identified as the following:

**Table 4-3** The vegetation biomass on soil surface

| Plant Stage | Period | Vegetation biomass on soil surface (Kg/Rai) | | |
|---|---|---|---|---|
| | | Litter fall | Ground layer | Total |
| Young | Falling leaves | 391.01 | 44.44 | 435.45 |
| | Productive | 241.99 | 54.82 | 296.81 |
| | **Total** | **633.00** | **99.26** | **732.26** |
| Harvested | Falling leaves | 549.50 | 29.63 | 579.13 |
| | Productive | 264.37 | 43.74 | 308.11 |
| | **Total** | **813.87** | **73.37** | **887.24** |
| Mature | Falling leaves | 611.15 | 41.26 | 652.41 |
| | Productive | 284.10 | 37.46 | 321.56 |
| | **Total** | **895.25** | **78.72** | **973.97** |

### 4.3.1 The falling leaves period

In the falling leaves period, the estimating of biomass on soil surface of each sample plots were identified as the following (Table 4-3):

The young stage, the maximum litter fall biomass was about 252.88 Kg/Rai in December; the minimum was about 6.28 Kg/Rai in March (Figure 4-10). The total litter fall biomass was about 391.01 Kg/Rai. The ground layer biomass was about 44.44 Kg/Rai. The average total biomass on soil surface was about 435.45 Kg/Rai.

The harvested stage, the maximum litter fall biomass was about 289.69 Kg/Rai in December; the minimum was about 21.14 Kg/Rai in April (Figure 4-10). The total litter fall biomass was about 549.50 Kg/Rai. The ground layer biomass was about 29.63 Kg/Rai. The average total biomass on soil surface was about 579.13 Kg/Rai.

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The mature stage, the maximum litter fall biomass was about 227.53 Kg/Rai in January; the minimum was about 30.87 Kg/Rai in April (Figure 4-10). The total litter fall biomass was about 611.15 Kg/Rai. The ground layer biomass was about 41.26 Kg/Rai. The average total biomass on soil surface was about 652.41 Kg/Rai.

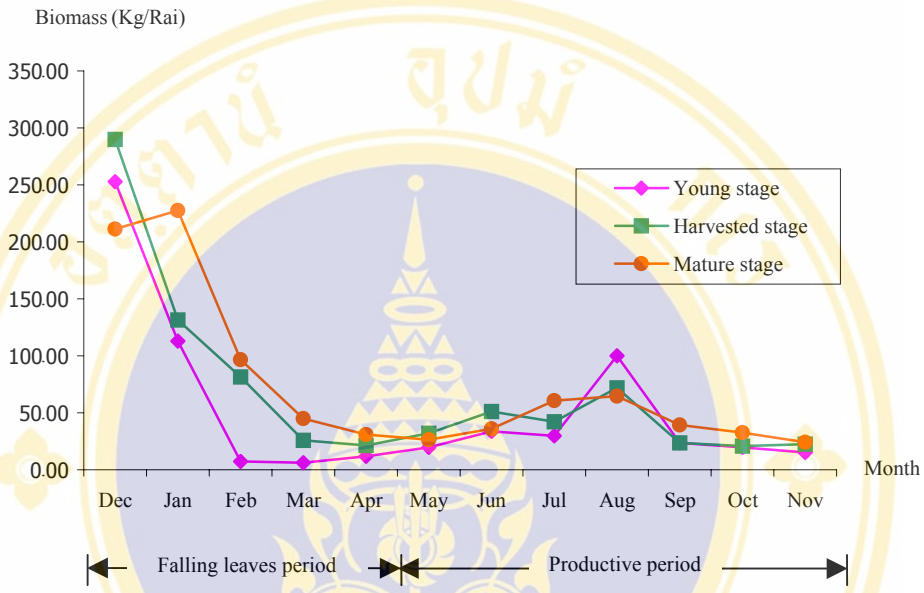


**Figure 4-10** Comparing the litter fall biomass in the Para rubber plantation

### 4.3.2 The productive period

In the productive period, the estimating of biomass on soil surface of each sample plots were identified as the following:

The young stage, the maximum litter fall biomass was about 100.20 Kg/Rai in August; the minimum was about 15.33 Kg/Rai in November (Figure 4-10). The total litter fall biomass was about 241.99 Kg/Rai. The ground layer biomass was about 54.82 Kg/Rai. The average total biomass on soil surface was about 296.81 Kg/Rai.

The harvested stage, the maximum litter fall biomass was about 72.05 Kg/Rai in August; the minimum was about 20.71 Kg/Rai in October (Figure 4-10). The total litter fall biomass was about 264.37 Kg/Rai. The ground layer biomass was about 43.74 Kg/Rai. The average total biomass on soil surface was about 308.11 Kg/Rai.

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The mature stage, the maximum litter fall biomass was about 64.74 Kg/Rai in August; the minimum was about 24.17 Kg/Rai in November (Figure 4-10). The total litter fall biomass was about 284.10 Kg/Rai. The ground layer biomass was about 37.46 Kg/Rai. The average total biomass on soil surface was about 321.56 Kg/Rai.

For the annual total litter fall biomass of the young, harvested and mature stages were 633.00, 813.87 and 895.25 Kg/Rai, respectively. The annual total ground layer biomass of the young, harvested and the mature stages were 99.26, 73.37 and 78.72 Kg/Rai, respectively (Figure 4-11). The average total biomass on soil surface of the young, harvested and mature stages were 732.26, 887.24 and 973.97 Kg/Rai, respectively.

The studied result indicated that the mean difference of total litter fall biomass for 3 stages during the productive period were not statistical significant at the level of 0.05 (Table A-21 and Figure 4-11). For the falling leaves period, the mean difference of total litter fall biomass of the young stage was statistical significant with the harvested and mature stages, but the harvested stage was not statistical significant with the mature stage. The harvested tree might be unusual fall in the productive period (August) because the Phytophthora palmivora disease spread in the Para rubber plantations. The mean difference of total ground layer biomass for 3 stages in each period were not statistical significant at the level of 0.05 because of they were been weeded annually (Table A-29 and Figure 4-11).

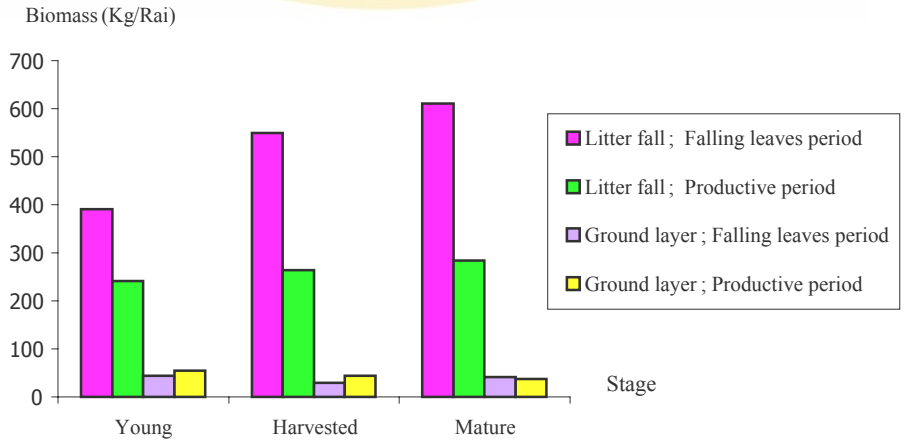


**Figure 4-11** Comparing the biomass on soil surface

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The leaf fraction was found as the most portion of the total litter fall. The other parts of litter consisted of reproductive part, small branches, and trash. For the average of all litter fall biomass, the largest amount of biomass was in December to January since the Para rubber trees shed their leaves. The ground layer had been slightly accumulated that was weeded annually, which was the cause of it had small stem and few amounts.

## 4.4 Soil Properties in the Para Rubber Plantations

The 3 soil samples were collected by random sampling method from each sample plots at the size of 40 x 40 $m^2$, separated to be the top soil at 0-15 cm depth ($A_p$ horizon) and the sub soil at 15-30 cm depth (B horizon). The result analysis found that most of soil in the study area was classified into Typic Paleudults sub group, such as Tha Sae series (Te), Khlong Thom series (Km) and Khok Kiean series (Ko). Tables 4-4 and 4-5 showed the soil properties in the Para rubber plantations in each stage.

### 4.4.1 Physical soil properties

The factors of physical soil properties consisted of Soil Texture, Bulk Density ($D_b$) and Soil Moisture (%Moisture). The results of physical soil properties were identified as the following:

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**1) Soil Texture**

The soil texture was analyzed by Hydrometer method. The percentages of soil particle showed in Figure 4-12. The results found that the soil texture of the young plantations were Sandy Clay in $A_p$ and B horizon, the harvested plantations were Sandy Clay Loam in $A_p$, and Sandy Clay in B horizon. For the mature plantation, they were Sandy Clay Loam in $A_p$ and B horizon as detail in Table 4-4.

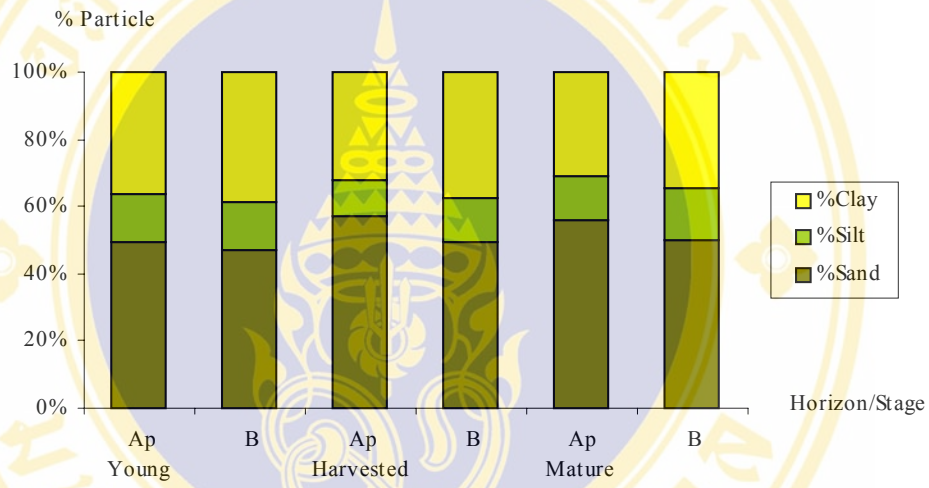


**Figure 4-12** The soil particle in $A_p$ and B horizon

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**2) Soil Bulk Density: $D_b$**

The $D_b$ values showed in Figure 4-13. In $A_p$ horizon, the maximum and minimum $D_b$ values in dry season were 1.58, and 1.50 g/cm$^3$, respectively. The maximum and minimum $D_b$ values in rainy season were 1.60 and 1.49 g/cm$^3$, respectively. In B horizon, the maximum and minimum $D_b$ values in dry season were about 1.59 and 1.46 g/cm$^3$, respectively. The maximum and minimum $D_b$ values in rainy season were 1.63 and 1.47 g/cm$^3$, respectively. The statistical analysis found that the mean difference of $D_b$ values in $A_p$ and B horizon of the young and harvested stages in each season were not statistical significant, but the mature stage was significant at the level of 0.05. The range of $D_b$ values in the upper soil horizon (0-30 cm) were about 1.48 to 1.58 g/cm$^3$ in dry season and 1.48 to 1.62 g/cm$^3$ in rainy season.

In rainy season, the $D_b$ value of B horizon was increased for a little because the rain leached light clay particle to accumulate in B horizon. The soil mass increased that resulted to the $D_b$ value was also increased.

In addition, the soil in the mature plantations were trodden by mechanical device to control weeds, and the soil was pressed. The soil pore volumes were decreased so the soil bulk density was also increased.

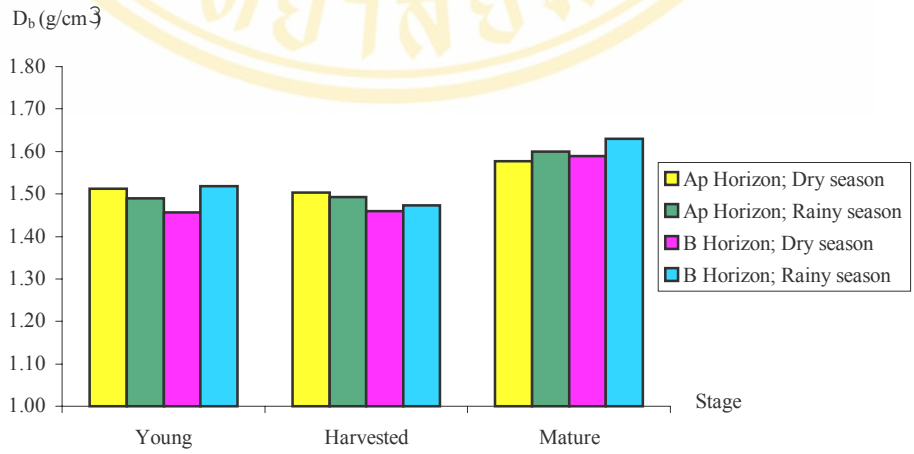


**Figure 4-13** The Soil Bulk Density of the Para rubber plantations

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**3) Soil Moisture: % Moisture**

The %moisture values showed in Figure 4-14. In $A_p$ horizon, the maximum and minimum %moisture values in dry season were 12.60, and 12.20, respectively. The maximum and minimum %moisture values in rainy season were 20.32 and 17.71, respectively. In B horizon, the maximum and minimum %moisture values in dry season were about 14.61 and 12.51, respectively. The maximum and minimum %moisture values in rainy season were 21.29 and 18.06, respectively. The statistical analysis found that the mean difference of %moisture values in $A_p$ and B horizon in each season were statistical significant at the level of 0.05. The range of %moisture values in the upper soil horizon (0-30 cm) was about 12.56 to 13.41 in dry season and 17.89 to 20.80 in rainy season.

The results of analysis also found that the average %moisture values in $A_p$ and B horizon in rainy season increased from dry season about 54.87% and 44.43%, respectively.

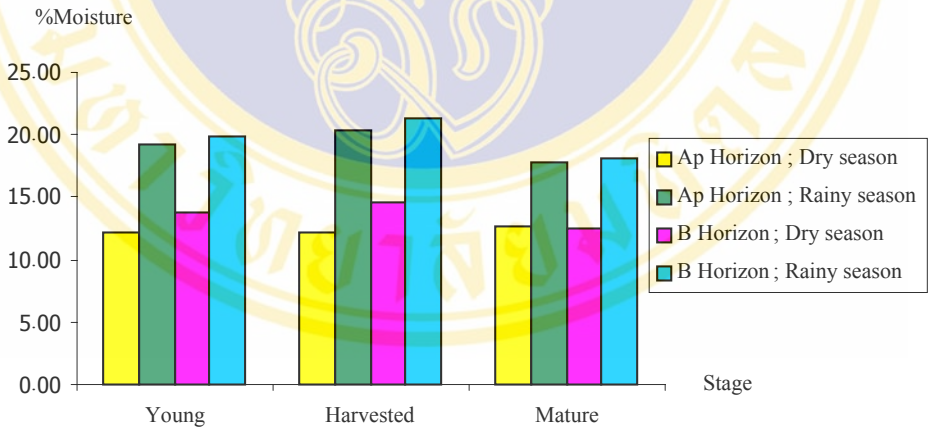


**Figure 4-14** The Soil Moisture of the Para rubber plantations

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**Table 4-4** The physical soil properties of the Para rubber plantations in Klaeng district, Rayong province

| Plant Stage | Soil Classification (USDA, 1975) | Soil Series | Soil Horizon | Soil Texture | | | | Moisture Content (%) | | Soil Bulk Density (g/cm$^3$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | %Sand | %Silt | %Clay | Texture | Dry season | Rainy season | Dry season | Rainy season |
| **Young** | Typic Paleudults | Tha Sae (Te) | $A_p$ | 49.23 | 14.52 | 36.25 | Sandy Clay | 12.20 | 19.22 | 1.51 | 1.49 |
| | | | **B** | 47.07 | 14.29 | 38.65 | Sandy Clay | 13.84 | 19.83 | 1.46 | 1.52 |
| **Harvested** | Typic Paleudults | Tha Sae (Te) | $A_p$ | 57.15 | 10.60 | 32.25 | Sandy Clay Loam | 12.21 | 20.32 | 1.50 | 1.49 |
| | | | **B** | 49.44 | 12.95 | 37.61 | Sandy Clay | 14.61 | 21.29 | 1.46 | 1.47 |
| **Mature** | Typic Paleudults | Tha Sae (Te) | $A_p$ | 55.67 | 13.40 | 30.93 | Sandy Clay Loam | 12.60 | 17.71 | 1.58 | 1.60 |
| | | | **B** | 50.28 | 15.21 | 34.52 | Sandy Clay Loam | 12.51 | 18.06 | 1.59 | 1.63 |



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### 4.4.2 Chemical soil properties

The factors of chemical soil properties consisted of Soil Reaction (pH), Soil Organic Matter (SOM), %Organic Carbon (%OC), Cation Exchange Capacity (CEC) and Electrical Conductivity ($EC_e$). The results of chemical soil properties were identified as the following:

**1) Soil Reaction: pH**

The soil reaction was analyzed by using pH meter measured the soil sample at 1:1 of soil and water. The pH values showed in Figure 4-15. In $A_p$ horizon, the maximum and minimum pH values in dry season were 4.66 and 4.51, respectively. The maximum and minimum pH values in rainy season were 4.49 and 4.32, respectively. In B horizon, the maximum and minimum pH values in dry season were about 4.68 and 4.54, respectively. The maximum and minimum pH values in rainy season were 4.58 and 4.26, respectively. The statistical analysis found that the mean difference of pH in $A_p$ and B horizon of the young and mature stage in each season were significant at the level of 0.05, but the harvested stage was not significant. The range of pH values in the upper soil horizon (0-30 cm) was about 4.52 to 4.67 in dry season and 4.29 to 4.54 in rainy season.

It could be summarized that the soil reaction of the Para rubber plantations in this study area were very strongly or extremely acid. The results of analysis showed that the pH of soil in rainy season was lesser than dry season.

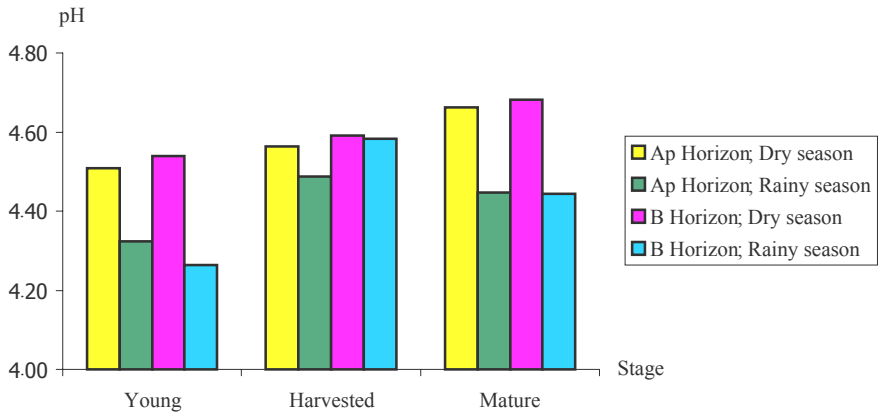


**Figure 4-15** The soil reaction of the Para rubber plantations

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**2) Electrical Conductivity: $EC_e$**

The Electrical Conductivity ($EC_e$) was analyzed by using Conductivity meter. The $EC_e$ values showed in Figure 4-16. In $A_p$ horizon, the maximum and minimum $EC_e$ values in dry season were 0.031 and 0.020 dS/m, respectively. The maximum and minimum $EC_e$ values in rainy season were 0.038 and 0.031 dS/m, respectively. In B horizon, the maximum and minimum $EC_e$ values in dry season were about 0.026 and 0.018 dS/m, respectively. The maximum and minimum $EC_e$ values in rainy season were 0.044 and 0.023 dS/m, respectively. The statistical analysis found that the mean difference of $EC_e$ in $A_p$ and B horizon in each season were not significant at the level of 0.05, but the mean difference of $EC_e$ in $A_p$ horizon of the mature stage was significant. The range of $EC_e$ values in the upper soil horizon (0-30 cm) was about 0.019 to 0.029 dS/m in dry season and 0.027 to 0.040 dS/m in rainy season.

In the rainy season, the $EC_e$ values were increased because some elements could be more dissolved into the soil than in the dry season. Fertilizer application was also another cause of the increasing of $EC_e$ values. From such results, it could be concluded that the soil of this area was not affected by salinity.

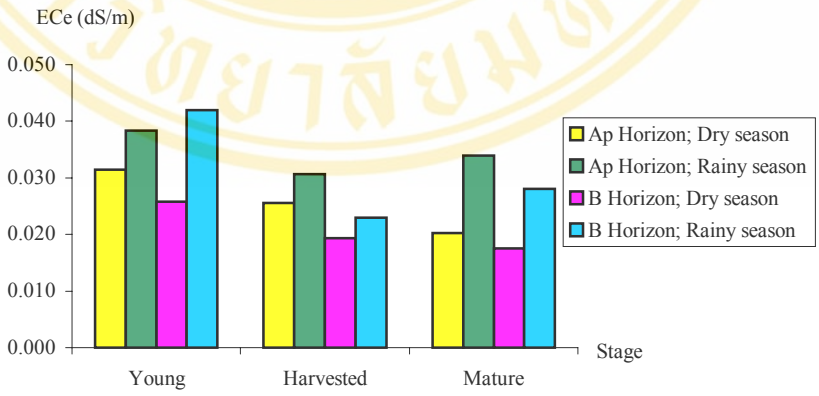


**Figure 4-16** The Electrical Conductivity of the Para rubber plantations

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### 3) Cation Exchange Capacity: CEC

The Cation Exchange Capacity (CEC) was analyzed by ammonium acetate 1 N pH 7. The CEC values showed in Figure 4-17. In $A_p$ horizon, the maximum and minimum CEC values in dry season were 3.734 and 3.076 me/100 g soil, respectively. The maximum and minimum CEC values in rainy season were 5.522 and 4.450 me/100 g soil, respectively. In B horizon, the maximum and minimum CEC values in dry season were 3.562 about and 3.381 me/100 g soil, respectively. The maximum and minimum CEC values in rainy season were 5.622 and 3.461 me/100 g soil, respectively. The statistical analysis found that the mean difference of CEC in $A_p$ and B horizon of the young and harvested plantations in each season were significant at the level of 0.05, but the mature stage was not significant. The range of CEC values in the upper soil horizon (0-30 cm) was about 3.261 to 3.558 me/100 g soil in dry season and 3.956 to 5.572 me/100 g soil in rainy season. Therefore, it could be concluded that the CEC value was at low level.

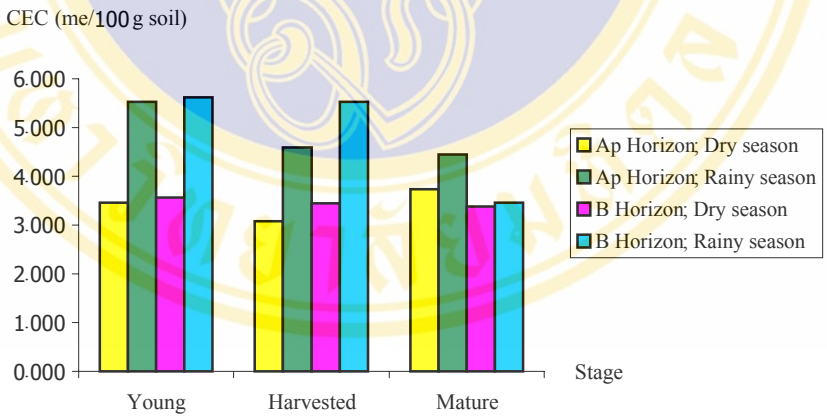


**Figure 4-17** The Cation Exchange Capacity of the Para rubber plantations

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**4) Soil Organic Matter: SOM**

The organic matter content of the soil consisted of plant, animal and microbial residues in various stages of decay, represents the dominant source for microbial nutrition (60).

The soil organic matter (SOM) was analyzed by using Walkley and Black method (10) (SOM (g/Kg) = %OC x 1.724 x 10) (59). The SOM values showed in Figure 4-18. In $A_p$ horizon, the maximum and minimum SOM values in dry season were 10.70 and 8.46 g/Kg, respectively. The maximum and minimum SOM values in rainy season were 13.76 and 16.66 g/Kg, respectively. In B horizon, the maximum and minimum SOM values in dry season were 6.71 and 6.39 g/Kg, respectively. The maximum and minimum SOM values in rainy season were 7.60 and 7.35 g/Kg, respectively. The SOM value in rainy season was higher than in dry season because the decay amount of plant residues was greater while the SOM of B horizon in each season was nearly the same values. The statistical analysis found that the mean difference of SOM in $A_p$ horizon in each stage in each season was significant at the level of 0.05. For B horizon, the harvested and mature stages in each season were not significant, but the young stage was significant. The range of SOM values in the upper soil horizon (0-30 cm) was about 7.43 to 8.71 g/Kg in dry season and 10.68 to 12.01g/Kg in rainy season. This result could be concluded that the SOM value was at low to moderate low level.

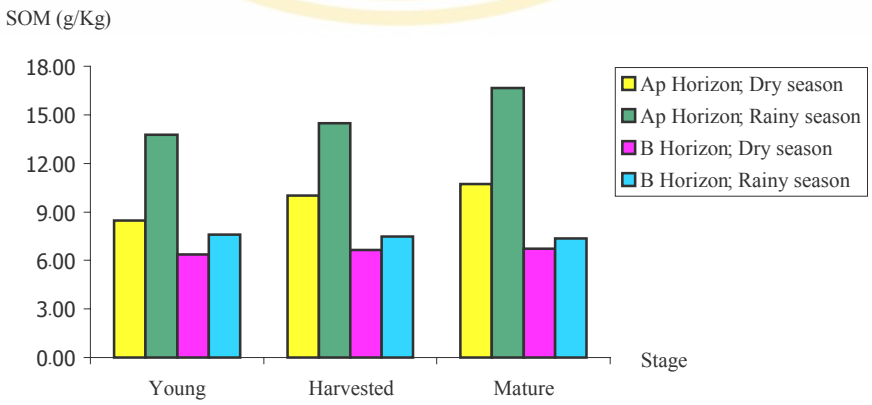


**Figure 4-18** The Soil Organic Matter of the Para rubber plantations

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### 5) Percentage of Soil Organic Carbon: %OC

The percentage of soil organic carbon (%OC) was analyzed by using Walkley and Black method (10). The %OC values showed in Figure 4-19. In $A_p$ horizon, the maximum and minimum %OC values in dry season were 0.62 and 0.49, respectively. The maximum and minimum %OC values in rainy season were 0.97 and 0.80, respectively. In B horizon, the maximum and minimum %OC values in dry season were 0.39 and 0.37, respectively. The maximum and minimum %OC values in rainy season were 0.44 and 0.43, respectively. The %OC value in rainy season was higher than in dry season because the decay amount of plant residues, such as litter, branches, root detritus and exudates, was the largest fraction of the carbon entering the soil (60) while the %OC of B horizon in each season was nearly the same values. The statistical analysis found that the mean difference of %OC in $A_p$ horizon in each stage in each season was significant at the level of 0.05. For B horizon, the harvested and mature stages in each season were not significant, but the young stage was significant. The range of %OC values in the upper soil horizon (0-30 cm) was about 0.43 to 0.51 in dry season and 0.62 to 0.70 in rainy season.

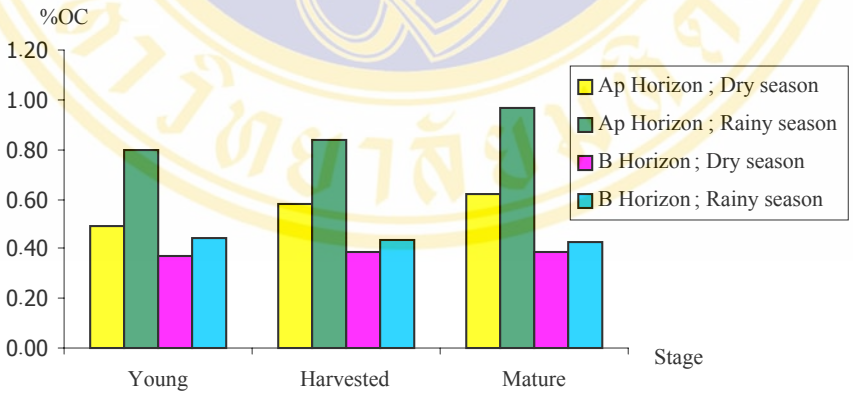


**Figure 4-19** The percentage of Soil Organic Carbon of the Para rubber plantations

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**Table 4-5** The chemical soil properties of the Para rubber plantations in Klaeng district, Rayong province

| Plant Stage | Soil Horizon | Soil Reaction: pH | | Electrical Conductivity: $EC_e$ (dS/m) | | Cation Exchange Capacity: CEC (me/100 g soil) | | Soil Organic Matter: SOM (g/Kg soil) | | %Organic Carbon: %OC | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | season | | season | | season | | season | | season | |
| | | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy |
| Young | $A_p$ | 4.51 | 4.32 | 0.031 | 0.038 | 3.457 | 5.522 | 8.46 | 13.76 | 0.49 | 0.80 |
| | B | 4.54 | 4.26 | 0.026 | 0.044 | 3.562 | 5.622 | 6.39 | 7.60 | 0.37 | 0.44 |
| Harvested | $A_p$ | 4.56 | 4.49 | 0.026 | 0.031 | 3.076 | 4.594 | 10.03 | 14.47 | 0.58 | 0.84 |
| | B | 4.59 | 4.58 | 0.019 | 0.023 | 3.446 | 5.522 | 6.63 | 7.46 | 0.39 | 0.43 |
| Mature | $A_p$ | 4.66 | 4.45 | 0.020 | 0.034 | 3.734 | 4.450 | 10.70 | 16.66 | 0.62 | 0.97 |
| | B | 4.68 | 4.44 | 0.018 | 0.028 | 3.381 | 3.461 | 6.71 | 7.35 | 0.39 | 0.43 |



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## 4.5 Carbon Content in Vegetation and Soil in the Para Rubber Plantations

The carbon content in vegetation samples and soil samples were analyzed in 3 parts; 1) the aboveground biomass (stems, branches, leaves and latex), 2) the biomass on soil surface (litter fall and ground layer) and 3) the below ground biomass (roots and soil). The carbon content in the Para rubber plantations were identified as the following:

### 4.5.1 Carbon content in vegetation

The carbon content in vegetation samples were analyzed in 3 parts; 1) the aboveground biomass was separately considered in each tree components (stems, branches, leaves and latex), 2) the biomass on soil surface was separately considered in 2 components (litter fall and ground layer), and 3) the below ground biomass was considered in roots of trees. Table 4-6 showed the analysis results of carbon content in vegetation.

**Table 4-6** The carbon content in vegetation in the Para rubber plantations

| Plant Stage | Period | Carbon Content (Kg/Rai) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Aboveground biomass | | | | Below ground biomass | Biomass on soil surface | | Total |
| | | Stems | Branches | Leaves | Latex | Roots | Litter fall | Ground layer | |
| Young | Falling leaves | 2,587.95 | 1,000.72 | 366.51 | - | 940.21 | 121 | 27.41 | **5,043.80** |
| | Productive | 2,912.57 | 1,160.57 | 406.5 | - | 1,038.83 | 195.51 | 22.22 | **5,736.20** |
| Harvested | Falling leaves | 7,014.91 | 3,672.39 | 863.52 | 138.62 | 2,137.52 | 132.19 | 21.87 | **13,981.02** |
| | Productive | 7,180.41 | 3,783.47 | 881.13 | 115.74 | 2,179.36 | 274.75 | 14.82 | **14,429.68** |
| Mature | Falling leaves | 10,978.70 | 6,663.35 | 1,264.33 | 130.71 | 3,077.59 | 142.05 | 18.73 | **22,275.46** |
| | Productive | 11,052.52 | 6,731.40 | 1,271.04 | 87.47 | 3,092.90 | 305.58 | 20.63 | **22,561.54** |

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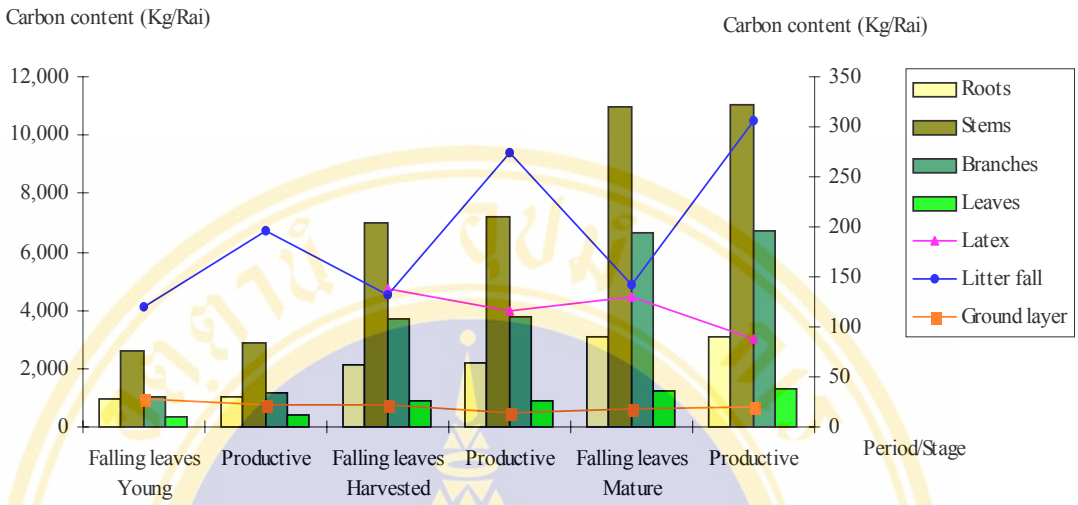


**Figure 4-20** The carbon content in vegetation in the Para rubber plantations

From Figure 4-20, the carbon content in tree biomass was likely to increase according to age. At the young stage, the tree was not tapped yet, therefore, it had the large proportion of the carbon content in stem and it would decrease, as well as a proportion in branches would increase when the tree had been tapped (Tables A-4 and A-5). The rate of growing of the tree would also decrease, when it was mature and tapped.

This studied results were agreed with the study of Bangjan (52), which found that the Para rubber tree in the Eastern part of Thailand was a linear function relationship between size of perimeter, height and age of tree. The young tree had rate of increasing of perimeter 7 cm/yr, height 1.65 m/yr. The tree has been tapped, perimeter was about 50 cm, had rate of increasing of perimeter 2.1 cm/yr, height 0.51 m/yr. Since expanding of branches were more than stem, so the height of tree would slowly increase.

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The increasing of biomass would be slow at the initial stage. After being maturate and the tree had sufficient water absorption by roots, then the biomass would increase rapidly. The relationship of perimeter and biomass was a linear function with the age of Para rubber tree. The increasing of biomass was divided into 2 stages. At the first stage, biomass of tree was varied with perimeter at the rate of 6 Kg/cm. The second stage, the size of tree was increased and the proportion of biomass and diameter would be 31 Kg/cm. The extending of diameter of tree would decrease when the tree was older while the proportion of biomass would increase by the age. The increasing of biomass was the mass of branches, and the tree has allocated biomass into branches more than stem. The increasing rate of biomass was 27 Kg/yr, later the rate would slowly increase up to maximum at 42 Kg/yr. The tree at the age of 16-17 years, the increasing rate of biomass would slowly decrease (52). It could be concluded that the potential of $CO_2$ sequestration would also decrease, when the tree was elder.

The below ground carbon content or the carbon content in part of roots was likely to increase according to girth or age. But the increasing rate of carbon content in roots would decrease when the tree was maturated (Table A-4 and A-5).

### 4.5.2 Carbon content in soil

The soil carbon content or organic carbon had relative with the percentage of soil organic matter (1.724 x %Organic Carbon = %Organic Matter) (59). Soil organic carbon was considered in 2 parts, $A_p$ horizon (soil surface at 0-15 cm depth) and B horizon (sub soil surface at 15-30 cm depth). For the relationship between %OM and %OC, it was found that the area had high organic matter and high organic carbon was in the area too.

The results were also found that the %OC in the older stages were higher than the younger stages in both the $A_p$ and B horizon, and in both seasons (Figure 4-21). Table 4-7 showed the soil organic carbon in the Para rubber plantations.

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**Table 4-7** The Soil Organic Carbon in the Para rubber plantations

| Plant Stage | Soil Horizon | Organic Carbon (%OC) | | Soil Organic Carbon (Kg/Rai) | |
|---|---|---|---|---|---|
| | | Dry season | Rainy season | Dry season | Rainy season |
| Young | $A_p$ | 0.49 | 0.80 | 1,782.08 | 2,853.73 |
| | B | 0.37 | 0.44 | 1,295.29 | 1,604.87 |
| | **Mean** | **0.43** | **0.62** | **3,069.22** | **4,470.55** |
| Harvested | $A_p$ | 0.58 | 0.84 | 2,098.03 | 3,009.00 |
| | B | 0.39 | 0.43 | 1,348.45 | 1,530.74 |
| | **Mean** | **0.48** | **0.64** | **3,436.32** | **4,529.98** |
| Mature | $A_p$ | 0.62 | 0.97 | 2,349.67 | 3,710.87 |
| | B | 0.39 | 0.43 | 1,484.27 | 1,667.85 |
| | **Mean** | **0.51** | **0.70** | **3,837.39** | **5,398.16** |

The Table 4-7 indicated that the mean value of soil organic carbon of the young, harvested, and mature stages in the upper soil horizon (30 cm depth form soil surface) were 3,069.22, 3,436.32 and 3,837.39 Kg/Rai, respectively in dry season. And they were 4,470.55, 4,529.98 and 5,398.16 Kg/Rai, respectively in rainy season.

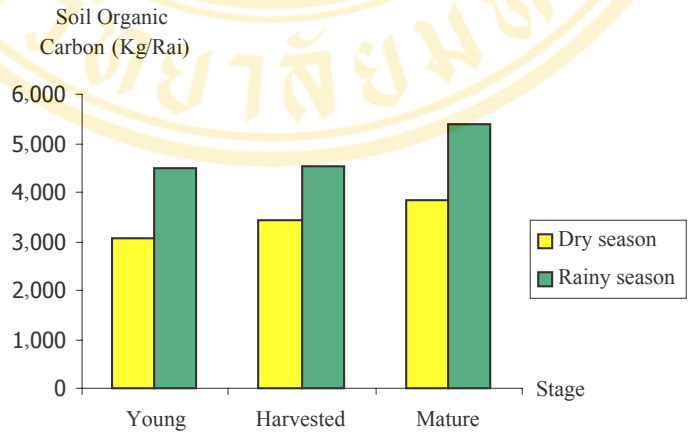


**Figure 4-21** The Soil Organic Carbon of Para rubber plantations

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Varavaitchalit (53) studied on the decomposition of litter fall in Para rubber plantation in the Eastern part of Thailand annually. The decomposition was about 38.40% and the remains were on the soil surface. For the result of this study, the litter fall at the young, harvested and mature stages were about 633.00, 813.87 and 895.25 Kg/Rai/yr, respectively (Table 4-3). The litter fall could be decomposed about 243.07, 312.53 and 343.78 Kg/Rai/yr, respectively. Thus, the turnover of organic carbon in soil was about 121.54, 156.26 and 171.89 Kg/Rai/yr, respectively.

Finally, the results of this study found that the total carbon content in Para rubber plantations at the young stage (4-6 years), harvested stage (14-16 years) and mature stage (over 20 years) were 9.51, 18.40 and 27.18 tC/Rai, respectively. From such amount, it could explain in detail as follows; the carbon content in vegetation were 5.37, 13.99 and 22.07 tC/Rai; the carbon content in soil were 3.77, 3.98 and 4.62 tC/Rai, respectively. The aboveground carbon content in tree were 4.48, 11.96 and 19.14 tC/Rai while the below ground carbon content in tree were 1.04, 2.18 and 3.09 tC/Rai, respectively. The carbon content in litter fall and ground layer were 0.32, 0.4, 0.45 and 0.05, 0.03, 0.04 tC/Rai, respectively (Table 5-1).

Witthawatchutikul and Jirasuktaveekul (50) studied on the aboveground carbon content in Para rubber tree at the ages 5, 8 and 19 years, they were 2.34, 3.64 and 8.87 tC/Rai, respectively. The below ground carbon content were 0.18, 0.20 and 0.29 tC/Rai.

Varavaitchalit (53) studied on the aboveground carbon content in Para rubber plantation at 10 years, the result was 4.13 tC/Rai while at the ground layer was 8.32 tC/Rai. The carbon content in biomass on soil surface was 0.15 tC/Rai, litter of Para rubber tree was 0.15 tC/Rai.

To compare the aboveground carbon content of the Para rubber plantation according to the chosen ages of this study with other related researches mentioned above, there were some slight differences of the outcomes; it was probably as the result of different amount of Para rubber trees growing in individual study sites. The density of tree in each plantation was related to the aboveground biomass content of such area, that was the aboveground biomass content tended to increase when the stand density was getting greater. Besides, the difference occurred probably came

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from the different factors affecting the growth of stand: topography of the plantation and plantation management.

Petsri (61) and Tangsinmankong (58) studied on the total carbon content in the mixed deciduous forest and the teak plantations in Uthaithani province at the ages of 6, 15 and 24 years, they were 22.81, 31.45, 18.02 and 23.49 t/Rai, respectively. From such amount, it could be given in detail as follows; the carbon content in vegetation were 11.46, 6.32, 5.42 and 6.58 t/Rai, respectively. For the aboveground carbon content in tree, they were 9.70, 4.76, 4.70 and 6.01 t/Rai, while the carbon content in soil at 30 cm depth from soil surface were 11.35, 25.12, 12.60, and 16.91 t/Rai, respectively.

Furthermore, Jindanuch (62) studied on the carbon distribution in the mangrove area of Thung Kha estuary, Chumphon province, the study found that the aboveground carbon content in the natural mangrove, mangrove plantation and reforestation mangrove were 6.19, 3.68 and 1.38 tC/Rai while the soil organic carbon at 30 cm depth from soil surface were 24.44, 19.87 and 28.42 tC/Rai, respectively.

To compare the aboveground carbon content of the Para rubber plantation according to the chosen ages of this study with the teak plantation at the nearly ages, there were some slight difference of the outcomes for the young stage, but for the mature there were much differences of the outcome, it was probably the density of the teak plantation was lesser than the Para rubber plantation. For the carbon content in soil at 30 cm depth in the Para rubber plantation, it was much lesser than the mangrove, followed by the teak plantation and mixed deciduous forest.

Therefore, the above results could be explained that the soil organic carbon in the mangrove forest was higher than any forest types and the agricultural area (Para rubber plantation). It was agreed with the result of Lars and group (47) that studied on the soil organic carbon in Denmark at 1m depth which found that the wetland soils had the highest soil organic carbon, followed by the forest and agricultural soils, respectively.

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## 4.6 The Carbon Content in Para rubber Plantations of Klaeng District

Information from LANDSAT 5-TM (2003) were used for classification the Para rubber plantations of Klaeng district, which was showed in Figure 4-22. It showed 2 different stages as identified by photographic interpretation of satellite images by supervises classification method. For this study, the Para rubber plantations were classified for 2 stages, consisted of the young stage and the harvested stage (harvested stage included the harvested and mature stage). The total Para rubber area was approximately 226,915 Rai, which were classified as the young and harvested plantations cover the areas were approximately of 56,728.75 and 170,186.25 Rai, respectively.

For the information about carbon content in the aboveground biomass, the biomass on soil surface and the below ground biomass (item 4.5.1 and 4.5.2), could be calculated for carbon content in Para rubber plantations of Klaeng district. Table 4-8 and Figure 4-23 showed the carbon contents in the aboveground biomass, the biomass on soil surface and the below ground biomass, they were 2,289,679.57, 96,325.42 and 429,828.63 tC, respectively. The carbon content in soil was about 891,738.35 tC.

**Table 4-8** The carbon content in Para rubber plantations of Klaeng district

| Plantation stage | Area* (Rai) | Carbon content (tC) | | | | Total (tC) |
|---|---|---|---|---|---|---|
| | | Above ground | On soil surface | Below ground | Soil | |
| Young | 56,728.75 | 254,124.38 | 20,762.72 | 58,931.53 | 213,861.05 | 547,679.68 |
| Harvested | 170,186.25 | 2,035,555.19 | 75,562.70 | 370,897.11 | 677,877.30 | 3,159,892.29 |
| Total | 226,915.00 | 2,289,679.57 | 96,325.42 | 429,828.63 | 891,738.35 | **3,707,571.97** |

***Source:** Satellite imagery interpretation from LANDSAT 5-TM (2003)

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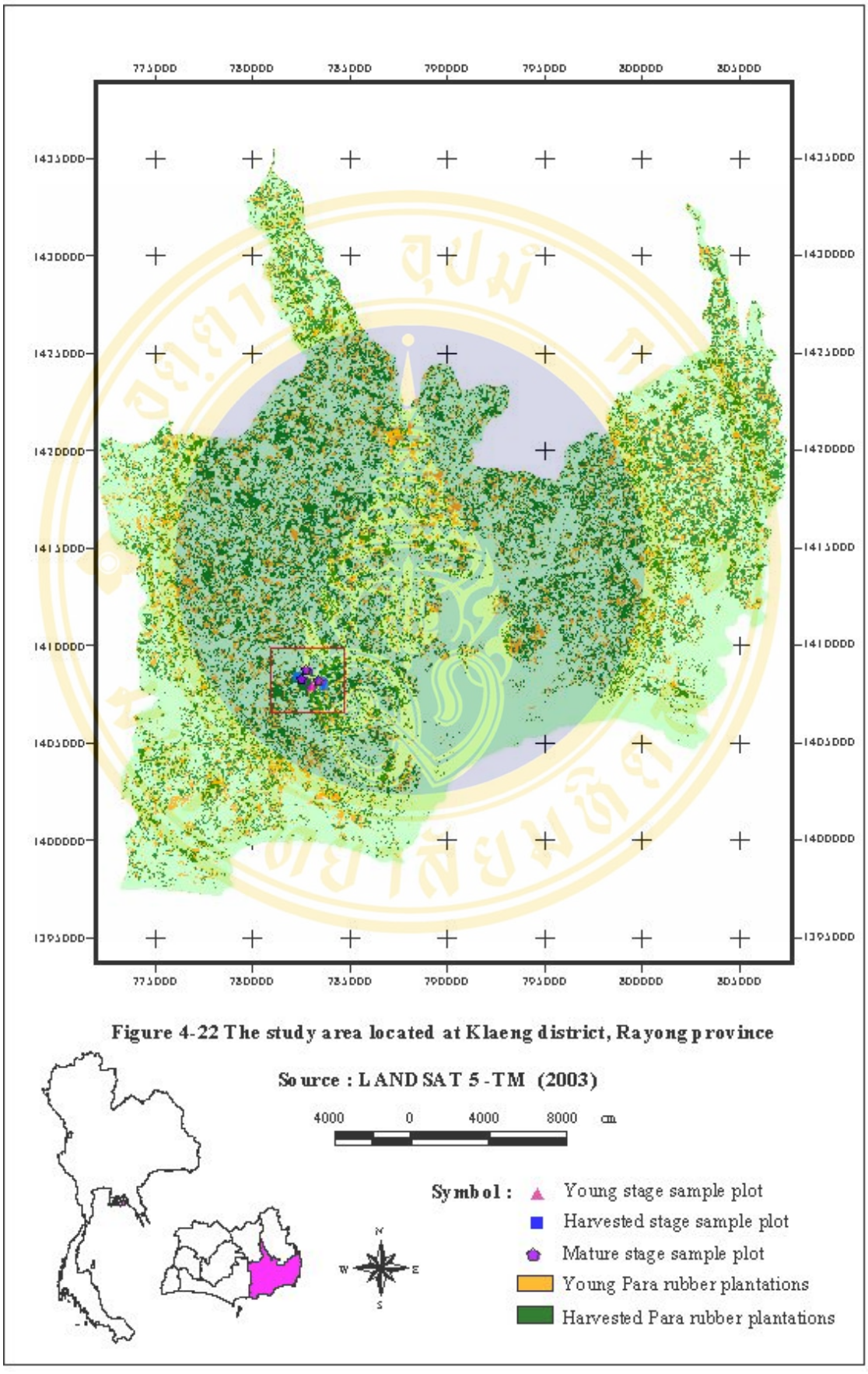


**Figure 4-22 The study area located at Klaeng district, Rayong province**

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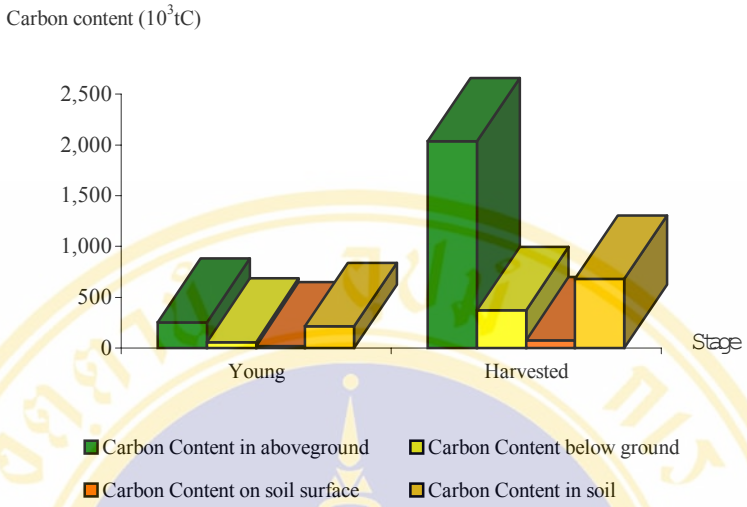


**Figure 4-23** The carbon content in Para rubber plantations of Klaeng district

The Para rubber plantation of Klaeng district could be accumulated at the total carbon approximately 3,707,571.97 tC, which were in the vegetation biomass approximately 2,815,833.62 tC, and in the upper soil horizon approximately 891,738.35 tC (Figure 4-24).

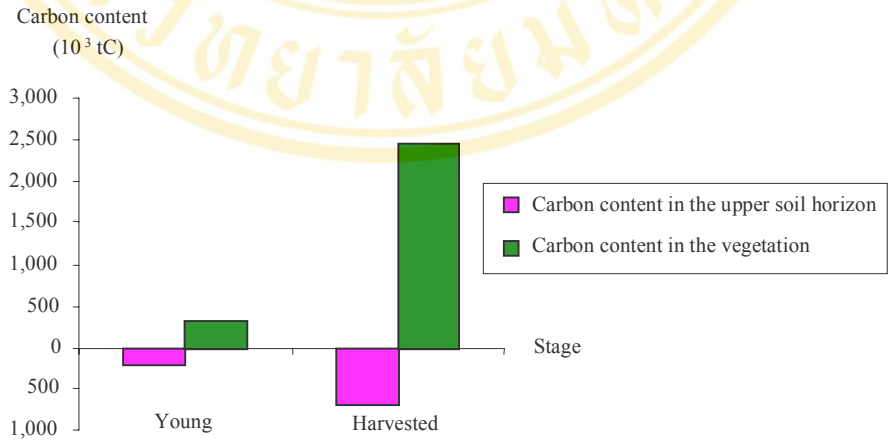


**Figure 4-24** The total carbon content in the vegetation biomass and the upper soil horizon

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# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The estimation of carbon sink in Para rubber plantations was based on allometric equations relating either carbon or biomass to diameter at breast height (DBH). These equations were based on the measurement of fresh mass of each tree with sub-samples taken to determine moisture content and were converted to dry weight. From the literature review, drying times and the number of sub-samples have been varied among the studies. Furthermore, the carbon concentration of different parts of Para rubber tree were rarely directly measured, so generally assumed to be 50% of dry weight were applied (1).

### 5.1.1 The carbon content in Para rubber plantations

The RRIM 600 variety of Para rubber tree was selected for this study located in Klaeng district, Rayong province. The 3 different growing stages of Para rubber plantations were selected and classified as young stage (average 4-6 years), harvested stage (average 14-16 years), and mature stage (average over 20 years) and the details were shown in Table 5-1. The size of tree was explained with diameter and height. The average diameters were about 16.25, 23.23 and 28.79 cm, respectively. The average total heights of trees were about 14.89, 21.18 and 22.29 m, respectively.

Table 5-1 showed the aboveground carbon content values in Para rubber plantations at the young, harvested and mature stages as 4.48, 11.96 and 19.14 tC/Rai, respectively. The below ground carbon content values in Para rubber plantations at the young, harvested and mature stages were 1.04, 2.18 and 3.09 tC/Rai, respectively.

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**Table 5-1** The conclusion of studied results in the Para rubber plantations (2003-2004)

| Parameter | Plant Stage | | |
|---|---|---|---|
| | Young | Harvested | Mature |
| Average age (years) | 4-6 | 14-16 | >20 |
| Average diameter: DBH (cm) | 16.25 | 23.23 | 28.79 |
| Average height (m) | 14.89 | 21.18 | 22.29 |
| Average density (stems/Rai) | 78 | 78 | 78 |
| Latex product (stems/Rai) | - | 69 | 55 |
| Dry weight of latex (KgC/stem/yr) | - | 7.38 | 8.05 |
| Dry weight of latex (tC/Rai/yr) | - | 0.51 | 0.44 |
| Aboveground carbon content in Para rubber tree (tC/Rai) | 4.48 | 11.96 | 19.14 |
| Below ground carbon content in Para rubber tree (tC/Rai) | 1.04 | 2.18 | 3.09 |
| Carbon content in Para rubber tree (tC/Rai) | 5.37 | 13.99 | 22.07 |
| Carbon content in plants on soil surface (tC/Rai) | 0.37 | 0.43 | 0.49 |
| Carbon content in the upper soil horizon (tC/Rai) | 3.77 | 3.98 | 4.62 |
| Total carbon content in Para rubber plantation (tC/Rai) | 9.51 | 18.40 | 27.18 |

From Figure 5-1, it could be shown that the Para rubber plantations at the young stage had the capacity to uptake atmospheric $CO_2$ to accumulate in the form of tree biomass at the highest level. It was 0.62 tC/Rai/yr (stems: 0.32, branches: 0.16, leaves: 0.04 and roots: 0.10 tC/Rai/yr). The harvested stage had the capacity to uptake atmospheric $CO_2$ to accumulate in the form of tree biomass at the amount of 0.34 tC/Rai/yr (stems: 0.17, branches: 0.11, leaves: 0.02 and roots: 0.04 tC/Rai/yr). The mature stage had the capacity to uptake atmospheric $CO_2$ to accumulate in the form of tree biomass at the amount 0.16 tC/Rai/yr (stems: 0.07, branches: 0.07, leaves: 0.01 and roots: 0.01 tC/Rai/yr).

The aboveground carbon content was likely to increase according to the chosen ages. At the young stage, it was not yet tapped, therefore, the large proportion of the carbon content was in stem and it would be decreased when it entered the harvested stage. On the contrary, the proportion of branches was increased when it had been tapped (Table A-4 and A-5). Furthermore, the rate of growth would be decreased when it was at the maturated stage and had been tapped. It could be concluded that the potential of $CO_2$ sequestration should be decreased when the tree has been at the maturated stage.

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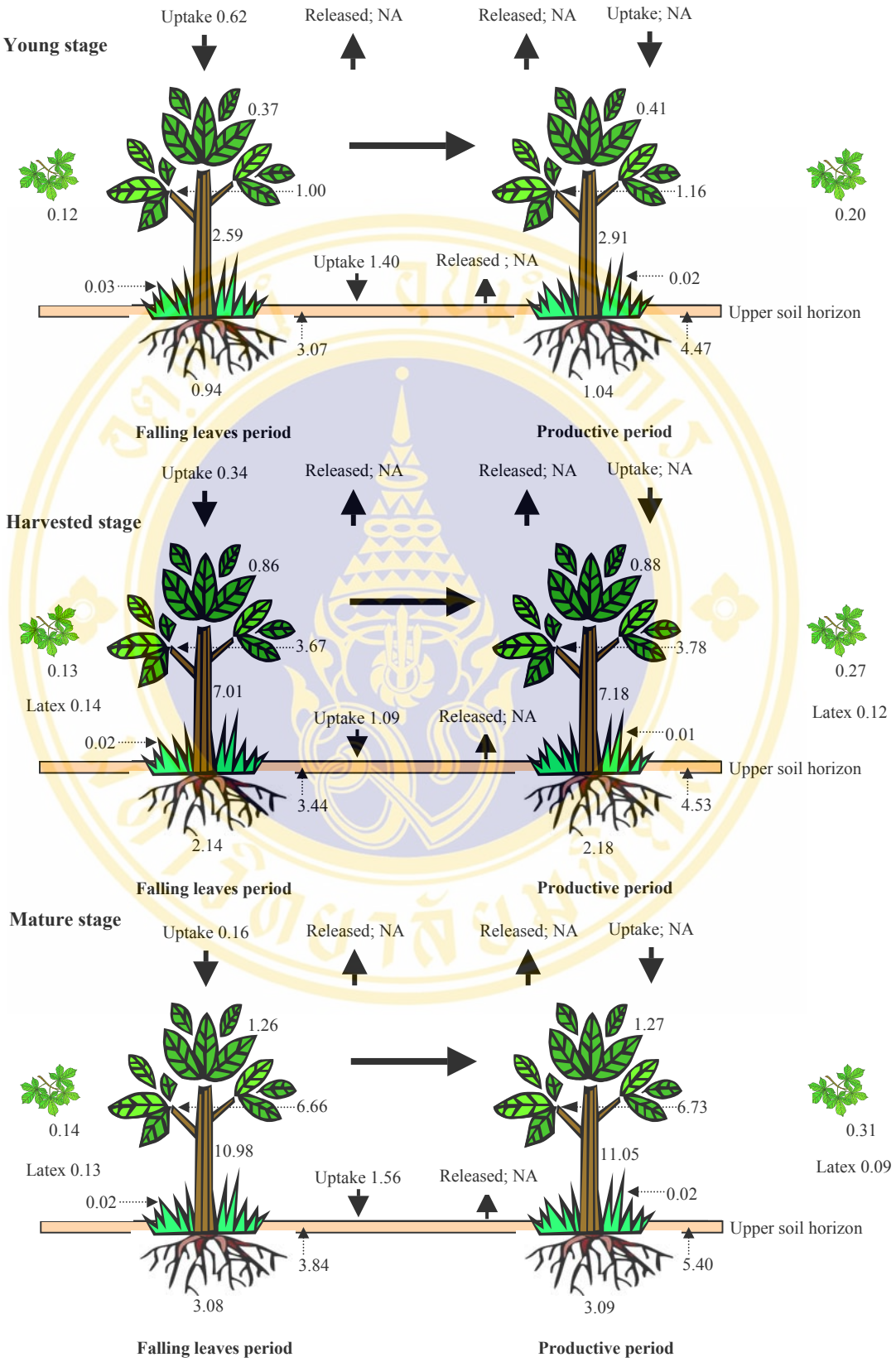


**Figure 5-1** Diagram of carbon cycling in Para rubber plantations (tC/Rai)

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The below ground carbon content (the carbon content in roots) was likely to increase according to the girth and ages. But the increasing rate of carbon content in roots was decreased when the tree was at the maturated stage (Tables A-4 and A-5).

For atmospheric $CO_2$ uptake in the form of biomass by the ground layer at the young, harvested and mature stage plantations, they were found at 0.05, 0.03 and 0.04 tC/Rai/yr, respectively. At the young stage plantation, the crown cover was not so dense and more spacing among trees were available for more sunshine to the ground than the harvested and mature stage plantations, which had more closed crown cover. According to mentioned reasons, the biomass of the ground layer in the young stage plantation get more light and had better growth rate than the ground layer in the harvested and mature stage plantations. This was resulted that the young stage plantation had carbon content in the ground layer biomass more than the harvested and mature stage plantations. However, the Para rubber plantations had been weeded annually, this might cause the biomass values and carbon content at the ground layer varied. Besides, this study also found that the carbon content values at each stage plantations were not different.

In addition, the carbon has been an input to the soil for plant litter (leaves, branches, fruits, flowers, etc.) decomposition to be highly decomposed humus. This study found that the litter fall of Para rubber trees in the young, harvested and mature stage plantations were 0.32, 0.41 and 0.45 tC/Rai/yr, respectively. The litter fall was decomposed about 38.40% per year (53), thus the turnover rates of organic carbon in soil were about 0.12, 0.16 and 0.17 tC/Rai/yr, respectively.

Furthermore, the soil organic carbon content in the upper soil horizon were 3.77, 3.98, and 4.62 tC/Rai/yr, respectively. The young, harvested and mature stage plantations had increased to soil organic carbon were 1.40, 1.09 and 1.56 tC/Rai/yr, respectively.

The results of this study could indicate that carbon distributions were in the aboveground and below ground tree components. For the average of the studied sample trees; the largest amount of carbon was in stem (50.78%), branches (26.73%), root (15.42%), leaves (6.22%), and latex (0.85%), respectively.

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### 5.1.2 Relationship between Para rubber tree biomass and carbon content

The results of this study found that the diameter of tree and the amount of carbon content in tree biomass was a positive linear function relationship with the size of tree and ages (Table A-32). This finding was agreed with the study of Bangjan (52), which found that the biomass of the Para rubber tree in the Eastern part of Thailand increased slowly at the initial stage, but the biomass would rapidly increase when the tree was being maturated, because the tree had sufficient water absorption by roots. The relationship of perimeter and biomass was a linear function with the age of Para rubber tree. The increasing of biomass could be classified into 2 stages. At the first stage, the tree biomass varied by perimeter and the rate was 6 Kg/cm. For the second stage, the size of tree increased including the proportion of biomass and perimeter would be around 31 Kg/cm. The extending of perimeter of tree would be decreased when the tree was mature. The proportion of biomass was increased according to the ages, but the increasing of biomass was in the mass of branches. Especially at the harvested stage, the tree had allocated biomass into branches more than stem.

### 5.1.3 Relationship between some soil properties and soil organic carbon

There was many factors influence on the turnover of organic carbon in soil. The warm climate has been more favorable for rapid turnover rate than cool climate. Furthermore, soil factors (e.g. pH, temperature, water potential, structure, etc.) in any way influenced on the nature and extent of the heterotrophic activity in soil. Besides, type of vegetation also affected to the turnover time since it partly determined the resource quality of the decomposing organic matter. Turnover rates would be varied depending on both climate and soil type, because all these factors are interactive with each other. Even leaf litter from the same plant would be more decomposable if the plant has been grown in a fertile soil with good nutrient supply than the plant grown in unsuitable nutrient soil (60).

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Naturally, the plant continuous provides an input of carbon to the soil system through the decomposition and respiration cycles, and returns the carbon to the atmosphere as $CO_2$. Soil organic carbon consisted of materials in various stages of decomposition from the original inputs of plant litter (leaves, branches, roots, and etc.) to be highly decomposed humus (60). When carbon from plant has been processed by decomposer organism in the soil, the carbon would be either lost as $CO_2$.

The physically protected carbon is related to the structural characteristic of the soil. Part of this soil carbon pool can be rendered accessible to decomposition processes through physical disruption of the matrix. Some of disruption may occur as a result of cultivation of the soil (60).

The soil textures of the studied Para rubber plantations are Sandy Clay Loam and Sandy Clay. The results of study could identify that the percentage of moisture was a linear positive function relationship with the cation exchange capacity (CEC), soil organic matter (SOM) and the percentage of organic carbon (%OC) (Tables A-33 and A-34). Since the soil texture is fine clay particle texture with many soil pore volumes and could hold water retention. In addition, the clay mineral has many soil surface and anion, so it has more cation exchange capacities. The soil in the study area has the highly capacity of soil organic matter, cation exchange capacity and soil organic carbon. And the percentage of moisture was a linear negative function relationship with the soil bulk density ($D_b$). For the pH of soil, it was a linear negative function relationship with the electrical conductivity (EC) (Tables A-33 and A-34).

In addition, the soil reaction was also very strongly or extremely acid. The caused affected from the large amount of chemical fertilizer application, which has been the cause of $NH_4$ accumulation in the soil. By nitrification process, it produces $H^+$ in the soil and cause increasing gradually continuous acid soil. So that pH causes changes in soil chemical and biological properties. It was not suitable for the growth and production of plant. In general, the Para rubber trees only needs the moderate amount of elements (N, P, K, and Mg) and some necessary trace elements. The appropriate range of pH for the Para rubber tree was about 4.5-5.0 (63).

To summarize, the physical and chemical soil properties of the study areas were difference according to seasons and plantation management.

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## 5.2 Recommendation

5.2.1 This study focused on the estimation of carbon concentrations in plants based on 50% of biomass and indirectly measured carbon content in Para rubber tree by using allometric equations. It is an approach to apply for a regression equation that directly converts external measurement (i.e. stem and height) into the total tree biomass. The data might be less accuracy. As tree is a significant carbon sink it is suggested for further study that tree sample should be cut down for actual measure and weight in order to get the actual right value.

5.2.2 Due to the study about root biomass estimating in Para rubber tree has not so many, and this study used only data collected by Bangjan (52) for developing the allometric equation to estimate the root biomass. It is considered that the result might be less accuracy. For more accuracy, further studies should be done on directly root measurement and weight as well as mentioned in 5.2.1.

5.2.3 Data collection of this study was conducted for 1 year only, the aboveground carbon content was specifically assumed for 1 certain year. The future study should concentrate on the change of aboveground carbon content more frequency including the accumulated of the aboveground carbon content in each year. Besides, the land use is rapidly changed, so the yearly land use change should be taken into consideration for estimation.

5.2.4 This study measured carbon content in the selected sampling plots during dry and rainy seasons. There still have many applications on for plantation management (i.e. fertilizers, weed control, and etc.) that should be considered. Furthermore, climate and content of precipitation markedly influenced to decompose of soil microbe. The correlation between soil organic carbon and soil properties is inconspicuous. Thus, in the next study, more samples and relevant factors should be studied.

5.2.5 The Para rubber plantation contributes the accumulation amount of carbon content for the aboveground biomass along with its increasing ages until it reaches the mature stage and carbon accumulates in stems will covert to be carbon sequestration. So at the over mature stage, the tree should be cut down and replanted because the young and harvested trees accumulate not only carbon but also accrue for latex product. This study found that the Para rubber tree had the uptake potential

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atmospheric $CO_2$ into biomass for 0-20 years, later the potential of atmospheric $CO_2$ sequestration would decrease. Because the growth rate had been slow down and latex production was less. So the cutting down the over mature tree and then replanting would be more benefit for not only to support the uptake atmospheric $CO_2$ potential by using growth of plants but also for latex production. The carbon content in tree that was cut down was sunken wood and could be used for any purposes (i.e. furniture).

5.2.6 The aboveground carbon content in the study was collected only in the Para rubber plantations divided into 3 groups at the ages of 4-6, 14-16 and 23-25 years located in Klaeng district, Rayong province. Since such plantations were planted nationwide, especially in the South and the East, therefore, more accuracy value of the national aboveground carbon content. It is suggested to carry on the studies investigating the aboveground carbon content at other ages of other Para rubber plantations in various topography, climate, geology, soil series, etc.

5.2.7 Land use change has an impact on soil carbon content. Therefore, to examine the carbon content in the area where there have been some changes of land use, it is suggested to take such factors consideration in order to complete the carbon cycle. Besides, the next study should be studied about aboveground carbon content in other types of plantation such as agricultural area. It is expected that such evaluated outcome will be beneficial for estimating carbon sequestration in other agricultural sectors and planning for land utilization.

5.2.8 Carbon stocks in soil in this study will be advantage as input for estimating how much carbon stocks in soil for other agricultural sectors too.

5.2.9 Even though the agriculture and carbon sequestration in soil can be accounted to mitigate the $CO_2$ emission according to the application of Kyoto protocol decided in July in Bonn for Annex I countries. However, Thailand (Non-Annex I countries) should have its database of carbon stocks in soil for the future benefit as Thailand is an agricultural country and major productivity is also depended on soil organic carbon.

5.2.10 The results should be utilized as a guideline for management and planning for expanding the Para rubber harvested area, and is databases for further study about carbon sink in Para rubber plantation in the future.

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# APPENDIX

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## 1. Abbreviation and Conversion Units

### ABBREVIATION

**$A_p$ Horizon** The top soil layer of soil profile, its color is darker than the next sub soil. It is planted and ploughed. (For this study is 0-15 cm depth from soil surface)

**B Horizon** The sub soil is next to the $A_p$ horizon, its color is darker than the top soil, that was classified be A horizon. The soil layer was caused chemical changed, or accumulation by making of soil, and not remain clear characteristic of soil parent material. (For this study is 15-30 cm depth from soil surface)

**DBH** The diameter of tree at breast height

**GHGs** Greenhouse Gases

**IPCC** The Intergovernmental Panel on Climate Change

**LULUCF** Land Use, Land-Use Change, and Forestry

**MOSTE** Ministry of Science, Technology and Environment

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# CONVERSION UNITS

| | |
|---|---|
| 1 Kilogram (Kg) | $10^3$ g |
| 1 ton (t) | $10^3$ Kg |
| 1 Megagram (Mg) | $10^6$ g |
| 1 Gigaton Carbon (GtC) | $10^9$ t Carbon ($10^{12}$ g Carbon) |
| 1 Teragram Carbon (TgC) | $10^{12}$ g Carbon |
| 1 Petagram Carbon (PgC) | $10^{15}$ g Carbon |
| 1 ton Carbon (tC) | 3.67 tons Carbon dioxide (t $CO_2$) |
| MMTC | Million Metric Tons Carbon ($10^9$ g Carbon) |
| 1 hectare (ha) | 10,000 $m^2$ (6.25 Rai) |
| t/ha | ton per hectare |
| ppmv | parts per million ($10^6$) by volume |
| me | milliequivalent |

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## 2. The Spatial of the Study Area

**Table A-1** The spatial of the study area

| Plot | Ages (years) | Coordinate (UTM 47 P) | M.S.L. (m) | Density (Stems/Rai) | Harvested Trees |
|---|---|---|---|---|---|
| 1 | 5 | 07 83626<br>14 08076 | 76 | 78 | - |
| 2 | 6 | 07 83656<br>14 07892 | 39 | 77 | - |
| 3 | 4 | 07 83049<br>14 07838 | 13 | 77 | - |
| 4 | 15 | 07 83488<br>14 08080 | 44 | 76 | 72 |
| 5 | 14 | 07 82327<br>14 08325 | 44 | 79 | 70 |
| 6 | 16 | 07 83693<br>14 07838 | 42 | 76 | 64 |
| 7 | 25 | 07 83458<br>14 08089 | 44 | 75 | 49 |
| 8 | 23 | 07 82775<br>14 08650 | 53 | 78 | 65 |
| 9 | 25 | 07 82559<br>14 08203 | 33 | 79 | 51 |

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## 3. The Results of Analysis

**Table A-2** The Para rubber trees biomass during the falling leaves period

| Plot | Ages (years) | Total trees | Average size | | | Calculated Biomass (Kg/Rai) | | | | | | Carbon content (Kg/Rai) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Perimeter (cm) | Diameter (cm) | Height (m) | $W_{stem}$ | $W_{brance}$ | $W_{leaf}$ | $W_{latex}$ | $W_{root}$ | Total | |
| 1 | 5 | 78 | 52.29 | 16.64 | 15.86 | 6,255.20 | 2,489.69 | 870.84 | - | 2,223.39 | 11,839.12 | 5,919.56 |
| 2 | 6 | 77 | 54.24 | 17.26 | 15.94 | 6,647.26 | 2,720.44 | 914.15 | - | 2,326.86 | 12,608.71 | 6,304.36 |
| 3 | 4 | 77 | 37.74 | 12.01 | 11.40 | 2,625.20 | 794.20 | 414.05 | - | 1,090.99 | 4,924.44 | 2,462.22 |
| **Mean** | **4-6** | **77** | **48.09** | **15.30** | **14.40** | **5,175.89** | **2,001.44** | **733.01** | **-** | **1,880.41** | **9,790.75** | **4,895.38** |
| 4 | 15 | 76 | 70.96 | 22.58 | 19.79 | 12,628.52 | 6,362.47 | 1,579.28 | 223.15 | 3,924.31 | 24,717.73 | 12,358.87 |
| 5 | 14 | 79 | 68.24 | 21.71 | 20.4 | 12,607.00 | 6,287.33 | 1,585.03 | 301.62 | 3,944.16 | 24,725.14 | 12,362.57 |
| 6 | 16 | 76 | 78.69 | 25.04 | 22.26 | 16,853.92 | 9,384.49 | 2,016.80 | 169.67 | 4,956.63 | 33,381.51 | 16,690.76 |
| **Mean** | **14-16** | **77** | **72.63** | **23.11** | **20.82** | **14,029.81** | **7,344.77** | **1,727.04** | **231.48** | **4,275.03** | **27,608.13** | **13,804.07** |
| 7 | 25 | 75 | 96.40 | 30.67 | 23.43 | 24,779.52 | 15,686.65 | 2,797.21 | 219.74 | 6,774.06 | 50,257.18 | 25,128.59 |
| 8 | 23 | 78 | 91.62 | 29.15 | 21.95 | 22,193.13 | 13,354.22 | 2,563.12 | 182.07 | 6,242.88 | 44,535.42 | 22,267.71 |
| 9 | 25 | 79 | 84.62 | 26.93 | 20.52 | 18,899.56 | 10,939.25 | 2,225.61 | 123.03 | 5,448.58 | 37,636.03 | 18,818.02 |
| **Mean** | **>20** | **77** | **90.88** | **28.92** | **21.97** | **21,957.40** | **13,326.70** | **2,528.65** | **174.95** | **6,155.17** | **44,142.87** | **22,071.44** |



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**Table A-3** The Para rubber trees biomass during the productive period

| Plot | Ages (years) | Total trees | Average size | | | Calculated Biomass (Kg/Rai) | | | | | | Carbon content (Kg/Rai) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Perimeter (cm) | Diameter (cm) | Height (m) | $W_{stem}$ | $W_{brance}$ | $W_{leaf}$ | $W_{latex}$ | $W_{root}$ | Total | |
| 1 | 5 | 78 | 54.98 | 17.49 | 15.94 | 6,857.31 | 2,811.47 | 941.90 | - | 2,396.63 | 13,007.31 | 6,503.66 |
| 2 | 6 | 77 | 54.92 | 17.47 | 17.11 | 7,229.93 | 3,040.90 | 982.01 | - | 2,491.77 | 13,744.61 | 6,872.31 |
| 3 | 4 | 77 | 43.29 | 13.77 | 11.63 | 3,388.18 | 1,111.06 | 515.06 | - | 1,344.54 | 6,358.84 | 3,179.42 |
| **Mean** | **4-6** | **77** | **51.06** | **16.25** | **14.89** | **5,825.14** | **2,321.14** | **812.99** | **-** | **2,077.65** | **11,036.92** | **5,518.46** |
| 4 | 15 | 76 | 71.41 | 22.72 | 20.11 | 12,949.47 | 6,576.49 | 1,613.51 | 290.75 | 4,005.66 | 25,435.88 | 12,717.94 |
| 5 | 14 | 79 | 69.37 | 22.07 | 20.73 | 13,152.77 | 6,648.14 | 1,643.52 | 304.9 | 4,083.33 | 25,832.66 | 12,916.33 |
| 6 | 16 | 76 | 78.27 | 24.90 | 22.70 | 16,980.19 | 9,476.19 | 2,029.77 | 236.07 | 4,987.15 | 33,709.37 | 16,854.69 |
| **Mean** | **14-16** | **77** | **73.02** | **23.23** | **21.18** | **14,360.81** | **7,566.94** | **1,762.26** | **277.24** | **4,358.71** | **28,325.96** | **14,162.98** |
| 7 | 25 | 75 | 96.31 | 30.64 | 23.75 | 25,055.14 | 15,929.55 | 2,823.00 | 313.94 | 6,833.31 | 50,954.94 | 25,477.47 |
| 8 | 23 | 78 | 91.22 | 29.03 | 22.29 | 22,337.51 | 13,478.51 | 2,576.79 | 281.72 | 6,274.41 | 44,948.94 | 22,474.47 |
| 9 | 25 | 79 | 83.92 | 26.70 | 20.84 | 18,922.46 | 10,980.34 | 2,226.45 | 188.61 | 5,449.66 | 37,767.52 | 18,883.76 |
| **Mean** | **>20** | **77** | **90.48** | **28.79** | **22.29** | **22,105.04** | **13,462.80** | **2,542.08** | **261.42** | **6,185.79** | **44,557.13** | **22,278.57** |

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**Table A-4** The percentage of the Para rubber trees biomass during the falling leaves period

| Plot | Ages (years) | Total trees | Average size | | | Calculated %Biomass | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Perimeter (cm) | Diameter (cm) | Height (m) | $\%W_{stem}$ | $\%W_{brance}$ | $\%W_{leaf}$ | $\%W_{latex}$ | $\%W_{root}$ |
| 1 | 5 | 78 | 52.29 | 16.64 | 15.86 | 52.84 | 21.03 | 7.36 | - | 18.78 |
| 2 | 6 | 77 | 54.24 | 17.26 | 15.94 | 52.72 | 21.58 | 7.25 | - | 18.45 |
| 3 | 4 | 77 | 37.74 | 12.01 | 11.4 | 53.31 | 16.13 | 8.41 | - | 22.15 |
| **Mean** | **4-6** | **77** | **48.09** | **15.30** | **14.40** | **52.87** | **20.44** | **7.49** | **-** | **19.21** |
| 4 | 15 | 76 | 70.96 | 22.58 | 19.79 | 51.09 | 25.74 | 6.39 | 0.90 | 15.88 |
| 5 | 14 | 79 | 68.24 | 21.71 | 20.4 | 50.99 | 25.43 | 6.41 | 1.22 | 15.95 |
| 6 | 16 | 76 | 78.69 | 25.04 | 22.26 | 50.49 | 28.11 | 6.04 | 0.51 | 14.85 |
| **Mean** | **14-16** | **77** | **72.63** | **23.11** | **20.82** | **50.82** | **26.60** | **6.26** | **0.84** | **15.48** |
| 7 | 25 | 75 | 96.40 | 30.67 | 23.43 | 49.31 | 31.21 | 5.57 | 0.44 | 13.48 |
| 8 | 23 | 78 | 91.62 | 29.15 | 21.95 | 49.83 | 29.99 | 5.76 | 0.41 | 14.02 |
| 9 | 25 | 79 | 84.62 | 26.93 | 20.52 | 50.22 | 29.07 | 5.91 | 0.33 | 14.48 |
| **Mean** | **>20** | **77** | **90.88** | **28.92** | **21.97** | **49.74** | **30.19** | **5.73** | **0.40** | **13.94** |



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**Table A-5** The percentage of the Para rubber trees biomass during the productive period

| Plot | Ages (years) | Total trees | Average size | | | Calculated %Biomass | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Perimeter (cm) | Diameter (cm) | Height (m) | $\%W_{stem}$ | $\%W_{brance}$ | $\%W_{leaf}$ | $\%W_{latex}$ | $\%W_{root}$ |
| 1 | 5 | 78 | 54.98 | 17.49 | 15.94 | 52.72 | 21.61 | 7.24 | - | 18.43 |
| 2 | 6 | 77 | 54.92 | 17.47 | 17.11 | 52.60 | 22.12 | 7.14 | - | 18.13 |
| 3 | 4 | 77 | 43.29 | 13.77 | 11.63 | 53.28 | 17.47 | 8.10 | - | 21.14 |
| **Mean** | **4-6** | **77** | **51.06** | **16.25** | **14.89** | **52.78** | **21.03** | **7.37** | **-** | **18.82** |
| 4 | 15 | 76 | 71.41 | 22.72 | 20.11 | 50.91 | 25.86 | 6.34 | 1.14 | 15.75 |
| 5 | 14 | 79 | 69.37 | 22.07 | 20.73 | 50.92 | 25.74 | 6.36 | 1.18 | 15.81 |
| 6 | 16 | 76 | 78.27 | 24.90 | 22.70 | 50.37 | 28.11 | 6.02 | 0.70 | 14.79 |
| **Mean** | **14-16** | **77** | **73.02** | **23.23** | **21.18** | **50.70** | **26.71** | **6.22** | **0.98** | **15.39** |
| 7 | 25 | 75 | 96.31 | 30.64 | 23.75 | 49.17 | 31.26 | 5.54 | 0.62 | 13.41 |
| 8 | 23 | 78 | 91.22 | 29.03 | 22.29 | 49.70 | 29.99 | 5.73 | 0.63 | 13.96 |
| 9 | 25 | 79 | 83.92 | 26.70 | 20.84 | 50.10 | 29.07 | 5.90 | 0.50 | 14.43 |
| **Mean** | **>20** | **77** | **90.48** | **28.79** | **22.29** | **49.61** | **30.21** | **5.71** | **0.59** | **13.88** |



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**Table A-6** The vegetation biomass on soil surface during the falling leaves period

| Plot | Age (years) | Ground layer (Kg/Rai) | | Litter fall (Kg/Rai) | | Total biomass (Kg/Rai) | Total carbon content (Kg/Rai) |
|---|---|---|---|---|---|---|---|
| | | Biomass | Carbon content | Biomass | Carbon content | | |
| 1 | 5 | 37.37 | 18.68 | 462.69 | 231.35 | 500.06 | 250.03 |
| 2 | 6 | 24.94 | 12.47 | 405.14 | 202.57 | 430.08 | 215.04 |
| 3 | 4 | 71.01 | 35.50 | 305.21 | 152.61 | 376.22 | 188.11 |
| **Mean** | **4-6** | **44.44** | **22.22** | **391.01** | **195.51** | **435.45** | **217.73** |
| 4 | 15 | 27.49 | 13.74 | 526.41 | 263.21 | 553.90 | 276.95 |
| 5 | 14 | 38.73 | 19.36 | 544.76 | 272.38 | 583.49 | 291.74 |
| 6 | 16 | 22.68 | 11.34 | 577.34 | 288.67 | 600.02 | 300.01 |
| **Mean** | **14-16** | **29.63** | **14.82** | **549.50** | **274.75** | **579.13** | **289.57** |
| 7 | 25 | 70.82 | 35.41 | 652.37 | 326.19 | 723.19 | 361.6 |
| 8 | 23 | 28.32 | 14.16 | 629.30 | 314.65 | 657.62 | 328.81 |
| 9 | 25 | 24.64 | 12.32 | 551.79 | 275.90 | 576.43 | 288.22 |
| **Mean** | **>20** | **41.26** | **20.63** | **611.15** | **305.58** | **652.41** | **326.21** |

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**Table A-7** The vegetation biomass on soil surface during the productive period

| Plot | Age (years) | Ground layer (Kg/Rai) | | Litter fall (Kg/Rai) | | Total biomass (Kg/Rai) | Total carbon content (Kg/Rai) |
|---|---|---|---|---|---|---|---|
| | | Biomass | Carbon content | Biomass | Carbon content | | |
| 1 | 5 | 57.74 | 28.87 | 285.42 | 142.71 | 343.16 | 171.58 |
| 2 | 6 | 24.17 | 12.09 | 321.59 | 160.80 | 345.76 | 172.89 |
| 3 | 4 | 82.55 | 41.27 | 118.97 | 59.49 | 201.52 | 100.76 |
| **Mean** | **4-6** | **54.82** | **27.41** | **241.99** | **121.00** | **296.81** | **148.41** |
| 4 | 15 | 53.76 | 26.88 | 242.92 | 121.46 | 296.68 | 148.34 |
| 5 | 14 | 32.30 | 16.15 | 302.88 | 151.44 | 335.18 | 167.59 |
| 6 | 16 | 45.15 | 22.58 | 247.31 | 123.66 | 292.46 | 146.24 |
| **Mean** | **14-16** | **43.74** | **21.87** | **264.37** | **132.19** | **308.11** | **154.06** |
| 7 | 25 | 70.13 | 35.06 | 262.53 | 131.26 | 332.66 | 166.32 |
| 8 | 23 | 30.27 | 15.13 | 236.28 | 118.14 | 266.55 | 133.27 |
| 9 | 25 | 12.00 | 6.00 | 353.48 | 176.74 | 365.48 | 182.74 |
| **Mean** | **>20** | **37.46** | **18.73** | **284.10** | **142.05** | **321.56** | **160.78** |

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**Table A-8** The physical soil properties of the Para rubber plantations, the young stage

| Age (years) | Soil Classification (USDA, 1975) | Soil Series | Soil Texture | Sand | Silt | Clay | Soil Moisture (%) | | Soil Bulk Density ($g/cm^3$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (%) | (%) | (%) | Dry season | Rainy season | Dry season | Rainy season |
| **$A_p$ Horizon** | | | | | | | | | | |
| 5 | Typic Paleudults | Tha Sae (Te) | Sandy clay | 60.34 | 7.49 | 32.18 | 12.00 | 19.18 | 1.46 | 1.64 |
| | | | | 47.84 | 9.99 | 42.18 | 12.55 | 18.86 | 1.47 | 1.49 |
| | | | | 47.75 | 20.08 | 32.18 | 10.36 | 18.93 | 1.51 | 1.47 |
| **mean** | | | | **51.97** | **12.52** | **35.51** | **11.64** | **18.99** | **1.48** | **1.53** |
| 6 | Typic Paleudults | Tha Sae (Te) | Sa ndy clay loam | 42.12 | 20.98 | 36.91 | 10.48 | 17.36 | 1.55 | 1.59 |
| | | | | 55.34 | 10.98 | 33.69 | 12.83 | 19.19 | 1.52 | 1.43 |
| | | | | 48.11 | 15.80 | 36.10 | 12.60 | 18.66 | 1.53 | 1.39 |
| **mean** | | | | **48.52** | **15.92** | **35.57** | **11.97** | **18.41** | **1.54** | **1.47** |
| 4 | Typic Paleudults | Tha Sae (Te) | Sandy clay | 47.30 | 20.17 | 32.54 | 12.46 | 19.35 | 1.50 | 1.51 |
| | | | | 47.21 | 15.08 | 37.72 | 13.00 | 20.78 | 1.53 | 1.53 |
| | | | | 47.12 | 10.17 | 42.72 | 13.50 | 20.69 | 1.54 | 1.36 |
| **mean** | | | | **47.21** | **15.14** | **37.66** | **12.98** | **20.27** | **1.52** | **1.47** |
| **B Horizon** | | | | | | | | | | |
| 5 | Typic Paleudults | Tha Sae (Te) | Sandy clay loam | 44.71 | 18.75 | 36.55 | 13.44 | 20.27 | 1.43 | 1.51 |
| | | | | 42.57 | 16.16 | 41.28 | 14.47 | 19.94 | 1.41 | 1.53 |
| | | | | 47.48 | 16.25 | 36.28 | 14.27 | 20.37 | 1.48 | 1.51 |
| **mean** | | | | **44.92** | **17.05** | **38.04** | **14.06** | **20.20** | **1.44** | **1.52** |
| 6 | Typic Paleudults | Tha Sae (Te) | Sandy clay | 51.76 | 10.71 | 37.54 | 13.73 | 19.01 | 1.47 | 1.55 |
| | | | | 54.26 | 10.44 | 35.31 | 13.95 | 19.93 | 1.40 | 1.51 |
| | | | | 51.76 | 13.03 | 35.22 | 13.85 | 20.18 | 1.43 | 1.53 |
| **mean** | | | | **52.59** | **11.39** | **36.02** | **13.84** | **19.71** | **1.43** | **1.53** |
| 4 | Typic Paleudults | Tha Sae (Te) | Sandy clay | 47.03 | 15.26 | 37.72 | 12.73 | 19.62 | 1.38 | 1.50 |
| | | | | 42.03 | 15.26 | 42.72 | 15.10 | 20.78 | 1.55 | 1.51 |
| | | | | 42.03 | 12.76 | 45.22 | 13.03 | 18.32 | 1.56 | 1.51 |
| **mean** | | | | **43.69** | **14.42** | **41.89** | **13.62** | **19.57** | **1.50** | **1.51** |



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**Table A-9** The physical soil properties of the Para rubber plantations, the harvested stage

| Age (years) | Soil Classification (USDA, 1975) | Soil Series | Soil Texture | Sand | Silt | Clay | Soil Moisture (%) | | Soil Bulk Density ($g/cm^3$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (%) | (%) | (%) | Dry season | Rainy season | Dry season | Rainy season |
| **$A_p$ Horizon** | | | | | | | | | | |
| **15** | Typic Paleudults | Tha Sae (Te) | Sa ndy clay loam | 66.94 | 15.26 | 17.81 | 9.34 | 16.92 | 1.50 | 1.74 |
| | | | | 61.94 | 10.26 | 27.81 | 12.97 | 19.98 | 1.51 | 1.61 |
| | | | | 56.94 | 5.26 | 37.81 | 14.37 | 20.83 | 1.51 | 1.50 |
| **mean** | | | | **61.94** | **10.26** | **27.81** | **12.23** | **19.25** | **1.51** | **1.62** |
| **14** | Typic Paleudults | Tha Sae (Te) | Sandy clay | 49.91 | 10.98 | 39.12 | 12.67 | 21.20 | 1.50 | 1.33 |
| | | | | 42.41 | 5.98 | 51.62 | 15.46 | 22.76 | 1.49 | 1.36 |
| | | | | 44.91 | 10.98 | 44.12 | 13.16 | 23.21 | 1.50 | 1.34 |
| **mean** | | | | **45.74** | **9.31** | **44.95** | **13.76** | **22.39** | **1.49** | **1.34** |
| **16** | Typic Paleudults | Tha Sae (Te) | Sa ndy clay loam | 64.62 | 12.94 | 22.45 | 10.59 | 20.42 | 1.51 | 1.53 |
| | | | | 59.62 | 13.12 | 27.27 | 12.06 | 19.06 | 1.51 | 1.47 |
| | | | | 67.12 | 10.62 | 22.27 | 9.28 | 18.47 | 1.51 | 1.58 |
| **mean** | | | | **63.78** | **12.22** | **24.00** | **10.64** | **19.32** | **1.51** | **1.52** |
| **B Horizon** | | | | | | | | | | |
| **15** | Typic Paleudults | Tha Sae (Te) | Sandy clay loam | 66.94 | 13.39 | 19.68 | 13.57 | 19.24 | 1.55 | 1.60 |
| | | | | 46.94 | 15.89 | 37.18 | 13.03 | 21.84 | 1.74 | 1.47 |
| | | | | 41.94 | 15.89 | 42.18 | 14.43 | 21.58 | 1.43 | 1.46 |
| **mean** | | | | **51.94** | **15.05** | **33.01** | **13.68** | **20.88** | **1.57** | **1.51** |
| **14** | Typic Paleudults | Tha Sae (Te) | Sandy clay | 42.41 | 10.98 | 46.62 | 14.66 | 20.69 | 1.43 | 1.50 |
| | | | | 35.27 | 13.12 | 51.62 | 16.52 | 22.36 | 1.17 | 1.35 |
| | | | | 35.36 | 13.03 | 51.62 | 16.72 | 22.80 | 1.31 | 1.34 |
| **mean** | | | | **37.68** | **12.37** | **49.95** | **15.97** | **21.95** | **1.30** | **1.39** |
| **16** | Typic Paleudults | Tha Sae (Te) | Sa ndy clay loam | 59.62 | 10.71 | 29.68 | 14.20 | 21.15 | 1.51 | 1.48 |
| | | | | 57.03 | 15.62 | 27.36 | 13.96 | 20.74 | 1.52 | 1.51 |
| | | | | 59.53 | 7.94 | 32.54 | 14.40 | 21.20 | 1.48 | 1.57 |
| **mean** | | | | **58.72** | **11.42** | **29.86** | **14.19** | **21.03** | **1.50** | **1.52** |

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**Table A-10** The physical soil properties of the Para rubber plantations, the mature stage

| Age (years) | Soil Classification (USDA, 1975) | Soil Series | Soil Texture | Sand | Silt | Clay | Soil Moisture (%) | | Soil Bulk Density ($g/cm^3$) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (%) | (%) | (%) | Dry season | Rainy season | Dry season | Rainy season |
| **$A_p$ Horizon** | | | | | | | | | | |
| **25** | Typic Paleudults | Tha Sae (Te) | Sandy clay | 57.03 | 15.53 | 27.45 | 11.26 | 18.41 | 1.62 | 1.56 |
| | | | | 59.53 | 8.03 | 32.45 | 13.50 | 19.14 | 1.55 | 1.60 |
| | | | | 54.53 | 10.53 | 34.95 | 12.75 | 21.58 | 1.59 | 1.45 |
| **mean** | | | | **57.03** | **11.36** | **31.62** | **12.50** | **19.71** | **1.59** | **1.53** |
| **23** | Typic Paleudults | Khlong Khom (Km) | Sandy clay | 57.93 | 13.03 | 29.05 | 12.65 | 19.80 | 1.55 | 1.55 |
| | | | | 42.95 | 15.35 | 41.71 | 14.33 | 19.02 | 1.59 | 1.64 |
| | | | | 40.45 | 12.85 | 46.71 | 14.26 | 13.58 | 1.58 | 1.74 |
| **mean** | | | | **47.11** | **13.74** | **39.16** | **13.75** | **17.47** | **1.57** | **1.64** |
| **25** | Typic Paleaquults | Khok Keian (Kk) | Sandy clay loam | 66.13 | 18.57 | 15.31 | 11.54 | 14.80 | 1.57 | 1.60 |
| | | | | 58.81 | 15.89 | 25.31 | 13.50 | 17.30 | 1.57 | 1.49 |
| | | | | 63.72 | 10.89 | 25.40 | 9.59 | 15.78 | 1.57 | 1.77 |
| **mean** | | | | **62.88** | **15.11** | **22.01** | **11.54** | **15.96** | **1.57** | **1.62** |
| **B Horizon** | | | | | | | | | | |
| **25** | Typic Paleudults | Tha Sae (Te) | Sandy clay | 54.53 | 8.03 | 37.45 | 12.60 | 19.30 | 1.66 | 1.54 |
| | | | | 54.53 | 10.26 | 35.22 | 13.15 | 19.87 | 1.65 | 1.61 |
| | | | | 46.85 | 12.94 | 40.22 | 14.93 | 23.23 | 1.45 | 1.43 |
| **mean** | | | | **51.97** | **10.41** | **37.63** | **13.56** | **20.80** | **1.59** | **1.53** |
| **23** | Typic Paleudults | Khlong Khom (Km) | Sandy clay | 51.58 | 15.62 | 32.81 | 13.40 | 20.73 | 1.54 | 1.50 |
| | | | | 47.03 | 15.44 | 37.54 | 13.60 | 16.86 | 1.46 | 1.66 |
| | | | | 52.12 | 10.98 | 36.91 | 12.09 | 13.68 | 1.49 | 1.74 |
| **mean** | | | | **50.24** | **14.01** | **35.75** | **13.03** | **17.09** | **1.50** | **1.63** |
| **25** | Typic Paleaquults | Khok Keian (Kk) | Sandy clay loam | 45.45 | 22.76 | 31.80 | 9.65 | 15.27 | 1.60 | 1.72 |
| | | | | 50.36 | 20.35 | 29.30 | 11.22 | 17.15 | 1.59 | 1.69 |
| | | | | 50.09 | 20.53 | 29.39 | 12.00 | 16.48 | 1.86 | 1.77 |
| **mean** | | | | **48.63** | **21.21** | **30.16** | **10.96** | **16.30** | **1.68** | **1.73** |



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**Table A-11** The chemical soil properties of the Para rubber plantations, the young stage

| Age (years) | PH (1:1) | | $EC_e$ (ds/m) | | CEC (me/ 100 g Soil) | | OM (%) | | OC (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy |
| **$A_p$ Horizon** | | | | | | | | | | |
| **5** | 4.75 | 4.61 | 0.018 | 0.018 | 3.4 | 5.6 | 0.64 | 1.56 | 0.37 | 0.91 |
| | 4.6 | 4.33 | 0.02 | 0.021 | 3.3 | 5.9 | 1 | 1.41 | 0.58 | 0.82 |
| | 4.63 | 4.48 | 0.02 | 0.02 | 3.35 | 5.3 | 0.61 | 1.02 | 0.35 | 0.59 |
| **mean** | **4.66** | **4.47** | **0.019** | **0.020** | **3.350** | **5.600** | **0.75** | **1.33** | **0.43** | **0.77** |
| **6** | 4.64 | 4.25 | 0.04 | 0.049 | 3.4 | 4.9 | 0.88 | 1.22 | 0.51 | 0.71 |
| | 4.44 | 4.27 | 0.039 | 0.092 | 3.2 | 6.3 | 0.81 | 1.2 | 0.47 | 0.7 |
| | 4.09 | 4.1 | 0.06 | 0.08 | 3.1 | 6.2 | 0.54 | 1.17 | 0.31 | 0.68 |
| **mean** | **4.39** | **4.21** | **0.046** | **0.074** | **3.233** | **5.800** | **0.74** | **1.20** | **0.43** | **0.70** |
| **4** | 4.6 | 4.17 | 0.029 | 0.025 | 3.78 | 5.5 | 0.98 | 1.44 | 0.57 | 0.84 |
| | 4.5 | 4.37 | 0.028 | 0.02 | 3.85 | 4.9 | 0.92 | 1.63 | 0.53 | 0.94 |
| | 4.32 | 4.34 | 0.029 | 0.02 | 3.73 | 5.1 | 1.22 | 1.73 | 0.71 | 1 |
| **mean** | **4.47** | **4.29** | **0.029** | **0.022** | **3.787** | **5.167** | **1.04** | **1.60** | **0.60** | **0.93** |
| **B Horizon** | | | | | | | | | | |
| **5** | 4.79 | 4.74 | 0.018 | 0.011 | 3.4 | 4.9 | 0.64 | 0.71 | 0.37 | 0.41 |
| | 4.52 | 4.21 | 0.019 | 0.03 | 3.5 | 5.6 | 0.47 | 0.61 | 0.28 | 0.35 |
| | 4.76 | 4.44 | 0.019 | 0.021 | 3.55 | 5.7 | 0.54 | 0.64 | 0.31 | 0.37 |
| **mean** | **4.69** | **4.46** | **0.019** | **0.021** | **3.483** | **5.400** | **0.55** | **0.65** | **0.32** | **0.38** |
| **6** | 4.63 | 4.29 | 0.04 | 0.049 | 3.9 | 4.9 | 0.64 | 0.7 | 0.37 | 0.4 |
| | 4.73 | 4.09 | 0.02 | 0.09 | 3.85 | 4.8 | 0.49 | 0.73 | 0.29 | 0.42 |
| | 4.12 | 4.21 | 0.052 | 0.085 | 3.88 | 5.8 | 0.53 | 0.64 | 0.3 | 0.37 |
| **mean** | **4.49** | **4.20** | **0.037** | **0.075** | **3.877** | **5.167** | **0.55** | **0.69** | **0.32** | **0.40** |
| **4** | 4.52 | 3.86 | 0.019 | 0.051 | 3.05 | 5.9 | 0.75 | 0.78 | 0.43 | 0.45 |
| | 4.45 | 4.25 | 0.021 | 0.03 | 3.55 | 6.3 | 0.78 | 0.9 | 0.45 | 0.52 |
| | 4.33 | 4.27 | 0.024 | 0.025 | 3.38 | 6.7 | 0.9 | 1.12 | 0.52 | 0.65 |
| **mean** | **4.43** | **4.13** | **0.021** | **0.035** | **3.327** | **6.300** | **0.81** | **0.93** | **0.47** | **0.54** |

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**Table A-12** The chemical soil properties of the Para rubber plantations, the harvested stage

| Age (years) | PH (1:1) | | $EC_e$ (ds/m) | | CEC (me/ 100 g Soil) | | OM (%) | | OC (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy |
| **$A_p$ Horizon** | | | | | | | | | | |
| **15** | 4.93 | 4.70 | 0.020 | 0.02 | 3.30 | 3.95 | 0.93 | 1.26 | 0.54 | 0.73 |
| | 4.23 | 4.25 | 0.039 | 0.034 | 3.05 | 4.10 | 0.78 | 1.02 | 0.45 | 0.59 |
| | 4.56 | 4.44 | 0.020 | 0.032 | 2.90 | 4.75 | 0.88 | 1.09 | 0.51 | 0.63 |
| **mean** | **4.57** | **4.46** | **0.026** | **0.029** | **3.083** | **4.267** | **0.86** | **1.12** | **0.50** | **0.65** |
| **14** | 4.45 | 4.45 | 0.029 | 0.048 | 3.75 | 5.60 | 1.87 | 2.27 | 1.08 | 1.32 |
| | 4.47 | 4.21 | 0.03 | 0.052 | 3.30 | 5.30 | 1.36 | 2.17 | 0.79 | 1.26 |
| | 4.60 | 4.43 | 0.024 | 0.03 | 3.35 | 5.30 | 1.42 | 2.00 | 0.83 | 1.16 |
| **mean** | **4.51** | **4.36** | **0.028** | **0.043** | **3.467** | **5.400** | **1.55** | **2.15** | **0.90** | **1.25** |
| **16** | 4.59 | 4.67 | 0.026 | 0.02 | 2.75 | 3.90 | 0.54 | 1.02 | 0.31 | 0.59 |
| | 4.72 | 4.65 | 0.02 | 0.02 | 2.70 | 4.35 | 0.70 | 1.26 | 0.4 | 0.73 |
| | 4.52 | 4.59 | 0.022 | 0.02 | 2.58 | 4.10 | 0.54 | 0.95 | 0.31 | 0.55 |
| **mean** | **4.61** | **4.64** | **0.023** | **0.020** | **2.677** | **4.117** | **0.59** | **1.08** | **0.34** | **0.62** |
| **B Horizon** | | | | | | | | | | |
| **15** | 4.86 | 4.64 | 0.02 | 0.02 | 3.88 | 3.9 | 0.64 | 0.75 | 0.37 | 0.43 |
| | 4.46 | 4.31 | 0.019 | 0.027 | 4.10 | 6.15 | 0.66 | 0.58 | 0.38 | 0.33 |
| | 4.50 | 4.57 | 0.02 | 0.02 | 4.00 | 8.2 | 0.19 | 0.71 | 0.11 | 0.41 |
| **mean** | **4.61** | **4.51** | **0.020** | **0.022** | **3.993** | **6.083** | **0.50** | **0.68** | **0.29** | **0.39** |
| **14** | 4.55 | 5.32 | 0.02 | 0.022 | 3.55 | 5.2 | 1.19 | 1.09 | 0.69 | 0.63 |
| | 4.55 | 4.19 | 0.02 | 0.04 | 3.38 | 4.4 | 0.98 | 0.88 | 0.57 | 0.51 |
| | 4.58 | 4.50 | 0.02 | 0.022 | 3.47 | 5.1 | 0.85 | 1.12 | 0.49 | 0.65 |
| **mean** | **4.56** | **4.67** | **0.020** | **0.028** | **3.467** | **4.900** | **1.01** | **1.03** | **0.58** | **0.60** |
| **16** | 4.61 | 4.49 | 0.018 | 0.02 | 2.85 | 5 | 0.44 | 0.47 | 0.26 | 0.28 |
| | 4.67 | 4.63 | 0.017 | 0.018 | 2.90 | 4.05 | 0.51 | 0.61 | 0.3 | 0.35 |
| | 4.54 | 4.58 | 0.02 | 0.018 | 2.88 | 7.7 | 0.51 | 0.51 | 0.3 | 0.3 |
| **mean** | **4.61** | **4.57** | **0.018** | **0.019** | **2.877** | **5.583** | **0.49** | **0.53** | **0.29** | **0.31** |

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**Table A-13** The chemical soil properties of the Para rubber plantations, the mature stage

| Age (years) | PH (1:1) | | $EC_e$ (ds/m) | | CEC (me/ 100 g Soil) | | OM (%) | | OC (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy | Dry | Rainy |
| **$A_p$ Horizon** | | | | | | | | | | |
| **25** | 4.40 | 4.62 | 0.02 | 0.03 | 3.58 | 4.35 | 0.88 | 1.59 | 0.51 | 0.92 |
| | 4.64 | 4.32 | 0.02 | 0.035 | 3.80 | 4.90 | 0.98 | 1.09 | 0.57 | 0.63 |
| | 4.57 | 4.45 | 0.02 | 0.028 | 4.18 | 4.65 | 0.87 | 1.39 | 0.50 | 0.81 |
| **mean** | **4.54** | **4.46** | **0.020** | **0.031** | **3.853** | **4.633** | **0.91** | **1.36** | **0.53** | **0.79** |
| **23** | 4.82 | 4.58 | 0.01 | 0.023 | 3.83 | 4.85 | 0.88 | 1.46 | 0.51 | 0.85 |
| | 5.22 | 4.77 | 0.01 | 0.015 | 3.85 | 4.25 | 1.27 | 2.34 | 0.74 | 1.36 |
| | 4.87 | 4.75 | 0.011 | 0.023 | 3.95 | 4.10 | 1.39 | 2.41 | 0.81 | 1.4 |
| **mean** | **4.97** | **4.70** | **0.010** | **0.020** | **3.877** | **4.400** | **1.18** | **2.07** | **0.69** | **1.20** |
| **25** | 4.43 | 4.29 | 0.029 | 0.031 | 3.59 | 2.95 | 1.36 | 1.56 | 0.79 | 0.91 |
| | 4.23 | 4.13 | 0.038 | 0.042 | 3.55 | 7.25 | 1.19 | 1.70 | 0.69 | 0.98 |
| | 4.48 | 4.12 | 0.024 | 0.078 | 3.28 | 2.75 | 0.81 | 1.46 | 0.47 | 0.85 |
| **mean** | **4.38** | **4.18** | **0.030** | **0.050** | **3.473** | **4.317** | **1.12** | **1.57** | **0.65** | **0.91** |
| **B Horizon** | | | | | | | | | | |
| **25** | 4.47 | 4.67 | 0.016 | 0.019 | 3.91 | 4.40 | 0.56 | 0.61 | 0.32 | 0.35 |
| | 4.63 | 4.52 | 0.019 | 0.02 | 3.70 | 4.60 | 0.71 | 0.68 | 0.41 | 0.39 |
| | 4.75 | 4.57 | 0.015 | 0.02 | 3.78 | 4.70 | 0.71 | 0.85 | 0.41 | 0.49 |
| **mean** | **4.62** | **4.59** | **0.017** | **0.020** | **3.797** | **4.567** | **0.66** | **0.71** | **0.38** | **0.41** |
| **23** | 4.82 | 4.56 | 0.012 | 0.02 | 3.63 | 2.90 | 0.66 | 0.64 | 0.38 | 0.37 |
| | 5.12 | 4.86 | 0.01 | 0.019 | 3.50 | 3.30 | 0.81 | 0.95 | 0.47 | 0.55 |
| | 4.97 | 4.77 | 0.012 | 0.019 | 3.53 | 3.35 | 1.02 | 1.26 | 0.59 | 0.73 |
| **mean** | **4.97** | **4.73** | **0.011** | **0.019** | **3.553** | **3.183** | **0.83** | **0.95** | **0.48** | **0.55** |
| **25** | 4.44 | 4.20 | 0.024 | 0.032 | 2.75 | 2.20 | 0.61 | 0.51 | 0.35 | 0.30 |
| | 4.25 | 4.14 | 0.032 | 0.039 | 2.80 | 3.25 | 0.56 | 0.64 | 0.32 | 0.37 |
| | 4.69 | 3.69 | 0.018 | 0.065 | 2.83 | 2.45 | 0.39 | 0.47 | 0.23 | 0.28 |
| **mean** | **4.46** | **4.01** | **0.025** | **0.045** | **2.793** | **2.633** | **0.52** | **0.54** | **0.30** | **0.32** |

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## 4. The Results of Statistic Analysis

**Table A-14** Comparing the result analysis of Paired T-Test on the percentage of Soil Moisture (%Moisture) in the $A_p$ and B horizon of the Para rubber plantations in each age between dry and rainy seasons.

| Plant Stage | Soil horizon | Mean | | Std. Deviation | | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| | | Dry | Rainy | Dry | Rainy | |
| Young | $A_p$ | 12.20 | 19.22 | 1.09 | 1.04 | 0.000* |
| | B | 13.84 | 19.83 | 0.73 | 0.75 | 0.000* |
| Harvested | $A_p$ | 12.21 | 20.32 | 2.13 | 2.00 | 0.000* |
| | B | 14.61 | 21.29 | 1.24 | 1.04 | 0.000* |
| Mature | $A_p$ | 12.60 | 17.71 | 1.56 | 2.58 | 0.001* |
| | B | 12.51 | 18.06 | 1.52 | 2.97 | 0.000* |

**Note:** n =9, df = 8

** Paired T-Test is significant at the 0.05 level (2-tailed)

* Paired T-Test is not significant at the 0.05 level (2-tailed)

**Table A-15** Comparing the result analysis of Paired T-Test on the Soil Bulk Density ($D_B$) in the $A_p$ and B horizon of the Para rubber plantations in each age between dry and rainy seasons.

| Plant Stage | Soil horizon | Mean | | Std. Deviation | | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| | | Dry | Rainy | Dry | Rainy | |
| Young | $A_p$ | 1.513 | 1.490 | 0.031 | 0.092 | 0.546** |
| | B | 1.456 | 1.518 | 0.064 | 0.015 | 0.023* |
| Harvested | $A_p$ | 1.503 | 1.494 | 0.009 | 0.138 | 0.840** |
| | B | 1.460 | 1.475 | 0.159 | 0.089 | 0.728** |
| Mature | $A_p$ | 1.577 | 1.600 | 0.024 | 0.105 | 0.549** |
| | B | 1.589 | 1.630 | 0.127 | 0.116 | 0.376** |

**Note:** n =9, df = 8

** Paired T-Test is significant at the 0.05 level (2-tailed)

* Paired T-Test is not significant at the 0.05 level (2-tailed)

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**Table A-16** Comparing the result analysis of Paired T-Test on the Soil Reaction (pH) in the $A_p$ and B horizon of the Para rubber plantations in each age between dry and rainy seasons.

| Plant Stage | Soil horizon | Mean | | Std. Deviation | | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| | | Dry | Rainy | Dry | Rainy | |
| Young | $A_p$ | 4.51 | 4.32 | 0.20 | 0.15 | 0.008* |
| | B | 4.54 | 4.26 | 0.22 | 0.24 | 0.012* |
| Harvested | $A_p$ | 4.56 | 4.49 | 0.19 | 0.18 | 0.112** |
| | B | 4.59 | 4.58 | 0.12 | 0.31 | 0.928** |
| Mature | $A_p$ | 4.66 | 4.45 | 0.30 | 0.25 | 0.032* |
| | B | 4.68 | 4.44 | 0.27 | 0.37 | 0.133** |

**Note:** n =9, df = 8

** Paired T-Test is significant at the 0.05 level (2-tailed)

* Paired T-Test is not significant at the 0.05 level (2-tailed)

**Table A-17** Comparing the result analysis of Paired T-Test on the Electrical Conductivity of soil ($EC_e$) in the $A_p$ and B horizon of the Para rubber plantations in each age between dry and rainy seasons.

| Plant Stage | Soil horizon | Mean | | Std. Deviation | | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| | | Dry | Rainy | Dry | Rainy | |
| Young | $A_p$ | 0.031 | 0.038 | 0.013 | 0.029 | 0.319** |
| | B | 0.026 | 0.044 | 0.012 | 0.028 | 0.055** |
| Harvested | $A_p$ | 0.026 | 0.031 | 0.006 | 0.012 | 0.176** |
| | B | 0.019 | 0.023 | 0.001 | 0.007 | 0.140** |
| Mature | $A_p$ | 0.020 | 0.034 | 0.009 | 0.018 | 0.031* |
| | B | 0.028 | 0.018 | 0.016 | 0.007 | 0.052** |

**Note:** n =9, df = 8

** Paired T-Test is significant at the 0.05 level (2-tailed)

* Paired T-Test is not significant at the 0.05 level (2-tailed)

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**Table A-18** Comparing the result analysis of Paired T-Test on the Cation Exchange Capacity of soil (CEC) in the $A_p$ and B horizon of the Para rubber plantations in each age between dry and rainy seasons.

| Plant Stage | Soil horizon | Mean | | Std. Deviation | | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| | | Dry | Rainy | Dry | Rainy | |
| Young | $A_p$ | 3.457 | 5.522 | 0.267 | 0.526 | 0.000* |
| | B | 3.562 | 5.622 | 0.279 | 0.657 | 0.000* |
| Harvested | $A_p$ | 3.068 | 4.594 | 0.388 | 0.659 | 0.000* |
| | B | 3.446 | 5.522 | 0.489 | 1.538 | 0.004* |
| Mature | $A_p$ | 3.757 | 4.450 | 0.275 | 1.302 | 0.166** |
| | B | 3.364 | 3.461 | 0.431 | 0.917 | 0.648** |

**Note:** n =9, df = 8

** Paired T-Test is significant at the 0.05 level (2-tailed)

* Paired T-Test is not significant at the 0.05 level (2-tailed)

**Table A-19** Comparing the result analysis of Paired T-Test on the Soil Organic Matter (%OM) in the $A_p$ and B horizon of the Para rubber plantations in each age between dry and rainy seasons.

| Plant Stage | Soil horizon | Mean | | Std. Deviation | | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| | | Dry | Rainy | Dry | Rainy | |
| Young | $A_p$ | 0.84 | 1.38 | 0.22 | 0.24 | 0.000* |
| | B | 0.64 | 0.76 | 0.15 | 0.16 | 0.001* |
| Harvested | $A_p$ | 1.00 | 1.45 | 0.45 | 0.54 | 0.000* |
| | B | 0.66 | 0.75 | 0.30 | 0.24 | 0.253** |
| Mature | $A_p$ | 1.07 | 1.67 | 0.23 | 0.44 | 0.001* |
| | B | 0.67 | 0.73 | 0.18 | 0.25 | 0.099** |

**Note:** n =9, df = 8

** Paired T-Test is significant at the 0.05 level (2-tailed)

* Paired T-Test is not significant at the 0.05 level (2-tailed)

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**Table A-20** Comparing the result analysis of Paired T-Test on the Soil Organic Carbon (%OC) in the $A_p$ and B horizon of the Para rubber plantations in each age between dry and rainy seasons.

| Plant Stage | Soil horizon | Mean | | Std. Deviation | | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| | | Dry | Rainy | Dry | Rainy | |
| Young | $A_p$ | 0.49 | 0.80 | 0.13 | 0.14 | 0.000* |
| | B | 0.37 | 0.44 | 0.08 | 0.09 | 0.001* |
| Harvested | $A_p$ | 0.58 | 0.84 | 0.26 | 0.31 | 0.000* |
| | B | 0.39 | 0.43 | 0.18 | 0.14 | 0.271** |
| Mature | $A_p$ | 0.62 | 0.97 | 0.14 | 0.25 | 0.001* |
| | B | 0.39 | 0.43 | 0.10 | 0.14 | 0.083** |

**Note:** n =9, df = 8

** Paired T-Test is significant at the 0.05 level (2-tailed)

* Paired T-Test is not significant at the 0.05 level (2-tailed)

**Table A-21** Comparing the result analysis of Paired T-Test of litter fall biomass in each stage.

| Differences Stage | | Differences Mean | Std. Deviation | Std. Error Mean | t | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| Young | Harvested | -0.18 | 0.20 | 0.11 | -1.59 | 0.25** |
| | Mature | -0.26 | 0.19 | 0.11 | -2.39 | 0.14** |
| Harvested | Mature | -0.08 | 0.06 | 0.04 | -2.20 | 0.16** |

**Note:** n =3, df = 2

** Paired T-Test is significant at the 0.05 level (2-tailed)

* Paired T-Test is not significant at the 0.05 level (2-tailed)

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**Table A-22** Comparing the result analysis of ANOVA for diameter of tree in each stage

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 237.15 | 2 | 118.57 | 33.22 | .001 |
| **Within Groups** | 21.42 | 6 | 3.57 | | |
| **Total** | **258.57** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Young** | **Harvested** | -6.99* | 1.54 | .004 | -10.76 | -3.21 |
| | **Mature** | -12.55* | 1.54 | .000 | -16.32 | -8.77 |
| **Harvested** | **Mature** | -5.56* | 1.54 | .011 | -16.32 | -8.77 |

* The mean difference is significant at the 0.05 level.

**Table A-23** Comparing the result analysis of ANOVA for heigh of tree in each stage

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 95.52 | 2 | 47.76 | 11.673 | .009 |
| **Within Groups** | 24.55 | 6 | 4.09 | | |
| **Total** | **120.07** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Young** | **Harvested** | -6.29* | 1.65 | .009 | -10.33 | -2.25 |
| | **Mature** | -7.40* | 1.65 | .004 | -11.44 | -3.36 |
| **Harvested** | **Mature** | -1.11 | 1.65 | .525 | -5.15 | 2.93 |

* The mean difference is significant at the 0.05 level.

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**Table A-24** Comparing the result analysis of ANOVA for biomass of stem in each stage

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 397.87 | 2 | 198.94 | 31.264 | .001 |
| **Within Groups** | 38.18 | 6 | 6.36 | | |
| **Total** | **436.05** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Young** | **Harvested** | -8.54* | 2.06 | 0.01 | -13.58 | -3.50 |
| | **Mature** | -16.28* | 2.06 | 0.00 | -21.32 | -11.24 |
| **Harvested** | **Mature** | -7.74* | 2.06 | 0.01 | -12.78 | -2.70 |

* The mean difference is significant at the 0.05 level.

**Table A-25** Comparing the result analysis of ANOVA for biomass of branches in each stage

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 186.43 | 2 | 93.21 | 28.041 | .001 |
| **Within Groups** | 19.95 | 6 | 3.32 | | |
| **Total** | **206.37** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Young** | **Harvested** | -5.25* | 1.49 | 0.01 | -8.89 | -1.60 |
| | **Mature** | -11.14* | 1.49 | 0.00 | -14.78 | -7.50 |
| **Harvested** | **Mature** | -5.90* | 1.49 | 0.01 | -9.54 | -2.25 |

* The mean difference is significant at the 0.05 level.

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**Table A-26** Comparing the result analysis of ANOVA for biomass of leaves in each stage

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 4.50 | 2 | 2.25 | 32.004 | .001 |
| **Within Groups** | 0.42 | 6 | 0.07 | | |
| **Total** | **4.92** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Young** | **Harvested** | -0.95* | 0.22 | 0.00 | -1.48 | -0.42 |
| | **Mature** | -1.73* | 0.22 | 0.00 | -2.26 | -1.20 |
| **Harvested** | **Mature** | -0.78* | 0.22 | 0.01 | -1.31 | -0.25 |

* The mean difference is significant at the 0.05 level.

**Table A-27** Comparing the result analysis of ANOVA for biomass of roots in each stage

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 25.41 | 2 | 12.71 | 32.118 | .001 |
| **Within Groups** | 2.37 | 6 | .40 | | |
| **Total** | **27.79** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Young** | **Harvested** | -2.28* | 0.51 | 0.00 | -3.54 | -1.02 |
| | **Mature** | -4.11* | 0.51 | 0.00 | -5.36 | -2.85 |
| **Harvested** | **Mature** | -1.83* | 0.51 | 0.01 | -3.08 | -.57 |

* The mean difference is significant at the 0.05 level.

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**Table A-28** Comparing the result analysis of ANOVA for biomass of latex in each stage

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 0.45 | 2 | 0.23 | 29.673 | .001 |
| **Within Groups** | 0.05 | 6 | 0.01 | | |
| **Total** | **0.50** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Harvested** | **Mature** | 0.07 | 0.07 | .035 | -0.10 | 0.25 |

* The mean difference is significant at the 0.05 level.

**Table A-29** Comparing the result analysis of ANOVA for biomass of ground layer in each stage

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 0.00 | 2 | 0.001 | 0.289 | 0.759 |
| **Within Groups** | 0.01 | 6 | 0.002 | | |
| **Total** | **0.01** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Young** | **Harvested** | 0.03 | 0.04 | 0.50 | -0.06 | 0.11 |
| | **Mature** | 0.02 | 0.04 | 0.59 | -0.07 | 0.11 |
| **Harvested** | **Mature** | -0.01 | 0.04 | 0.88 | -0.09 | 0.08 |

* The mean difference is significant at the 0.05 level.

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**Table A-30** Comparing the result analysis of ANOVA for Soil Organic Carbon (%OC) in the Para rubber plantations in each stages in dry season.

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 0.46 | 2 | 0.23 | 0.24 | 0.79 |
| **Within Groups** | 5.77 | 6 | 0.96 | | |
| **Total** | **6.23** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Young** | **Harvested** | -0.37 | .80 | 0.66 | -2.33 | 1.59 |
| | **Mature** | -0.54 | .80 | 0.52 | -2.50 | 1.42 |
| **Harvested** | **Mature** | -0.17 | .80 | 0.84 | -2.13 | 1.79 |

* The mean difference is significant at the 0.05 level.

**Table A-31** Comparing the result analysis of ANOVA for Soil Organic Carbon (%OC) in the Para rubber plantations in each stages in rainy season.

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Between Groups** | 1.65 | 2 | 0.82 | 0.57 | 0.59 |
| **Within Groups** | 8.73 | 6 | 1.45 | | |
| **Total** | **10.38** | **8** | | | |

**Multiple Comparisons ; LSD**

| Differences Stage | | Mean Difference | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| **Young** | **Harvested** | 0.08 | 0.98 | 0.94 | -2.33 | 2.49 |
| | **Mature** | -0.87 | 0.98 | 0.41 | -3.28 | 1.54 |
| **Harvested** | **Mature** | -0.95 | 0.98 | 0.37 | -3.35 | 1.46 |

* The mean difference is significant at the 0.05 level.

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**Table A-32** Comparing the result analysis of correlation for age, diameter and amount of biomass

| Parameter | | Age of tree | Biomass of tree (Falling leaves) | Biomass of tree (Productive) | Biomass of litter fall (Falling leaves) | Biomass of litter fall (Productive) | Biomass of ground layer (Falling leaves) | Biomass of ground layer (Productive) | DBH (Falling leaves) | DBH (Productive) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Age of tree** | Pearson Correlation | 1.000 | .965** | .963** | .878** | .324 | -.106 | -.348 | .963** | .967** |
| | Sig. (2-tailed) | . | .000 | .000 | .002 | .394 | .786 | .359 | .000 | .000 |
| **Biomass of tree (Falling leaves)** | Pearson Correlation | .965** | 1.000 | 1.000** | .941** | .280 | -.065 | -.259 | .991** | .996** |
| | Sig. (2-tailed) | .000 | . | .000 | .000 | .465 | .868 | .500 | .000 | .000 |
| **Biomass of tree (Productive)** | Pearson Correlation | .963** | 1.000** | 1.000 | .941** | .275 | -.052 | -.250 | .990** | .995** |
| | Sig. (2-tailed) | .000 | .000 | . | .000 | .473 | .894 | .516 | .000 | .000 |
| **Biomass of litter fall (Falling leaves)** | Pearson Correlation | .878** | .941 | .941** | 1.000 | .388 | -.214 | -.298 | .961** | .958** |
| | Sig. (2-tailed) | .002 | .000 | .000 | . | .302 | .581 | .436 | .000 | .000 |
| **Biomass of litter fall (Productive)** | Pearson Correlation | .324 | .280 | .275 | .388 | 1.000 | -.583 | -.786* | .366 | .326 |
| | Sig. (2-tailed) | .394 | .465 | .473 | .302 | . | .099 | .012 | .333 | .392 |
| **Biomass of ground layer (Falling leaves)** | Pearson Correlation | -.106 | -.065 | -.052 | -.214 | -.583 | 1.000 | .799** | -.177 | -.128 |
| | Sig. (2-tailed) | .786 | .868 | .894 | .581 | .099 | . | .010 | .648 | .743 |
| **Biomass of ground layer (Productive)** | Pearson Correlation | -.348 | -.259 | -.250 | -.298 | -.786* | .799** | 1.000 | -.340 | -.298 |
| | Sig. (2-tailed) | .359 | .500 | .516 | .436 | .012 | .010 | . | .370 | .436 |
| **DBH (Falling leaves)** | Pearson Correlation | .963** | .991** | .990** | .961** | .366 | -.177 | -.340 | 1.000 | .998** |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .333 | .648 | .370 | . | .000 |
| **DBH (Productive)** | Pearson Correlation | .967** | .996** | .995** | .958** | .326 | -.128 | -.298 | .998** | 1.000 |
| | Sig. (2-tailed) | .000 | .000 | .000 | .000 | .392 | .743 | .436 | .000 | . |

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

N = 9

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**Table A-33** Comparing the result analysis of correlation for soil properties and amount of biomass in dry season

| Parameter | | % OM | % moisture | $D_b$ | pH | $EC_e$ | CEC | %OC | Biomass of Para rubber tree | Biomass of Ground layer | Biomass of Litter fall |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **% OM** | Pearson Correlation | 1.000 | .681* | -.313 | .120 | -.222 | .383 | 1.000** | .104 | .255 | .095 |
| | Sig. (2-tailed) | . | .043 | .412 | .759 | .565 | .309 | .000 | .790 | .508 | .807 |
| **% moisture** | Pearson Correlation | .681* | 1.000 | -.761* | .155 | -.172 | .469 | .676* | -.186 | .294 | -.050 |
| | Sig. (2-tailed) | .043 | . | .017 | .690 | .658 | .203 | .046 | .632 | .443 | .898 |
| **$D_b$** | Pearson Correlation | -.313 | -.761* | 1.000 | .019 | -.120 | .008 | -.307 | .572 | .064 | .340 |
| | Sig. (2-tailed) | .412 | .017 | . | .962 | .758 | .983 | .421 | .108 | .870 | .371 |
| **pH** | Pearson Correlation | .120 | .155 | .019 | 1.000 | -.784* | .212 | .099 | .458 | -.218 | .544 |
| | Sig. (2-tailed) | .759 | .690 | .962 | . | .012 | .583 | .800 | .215 | .573 | .130 |
| **$EC_e$** | Pearson Correlation | -.222 | -.172 | -.120 | -.784* | 1.000 | -.136 | -.209 | -.516 | -.203 | -.571 |
| | Sig. (2-tailed) | .565 | .658 | .758 | .012 | . | .727 | .589 | .155 | .601 | .108 |
| **CEC** | Pearson Correlation | .383 | .469 | .008 | .212 | -.136 | 1.000 | .391 | .054 | .527 | -.008 |
| | Sig. (2-tailed) | .309 | .203 | .983 | .583 | .727 | . | .298 | .891 | .145 | .983 |
| **%OC** | Pearson Correlation | 1.000** | .676* | -.307 | .099 | -.209 | .391 | 1.000 | .088 | .268 | .076 |
| | Sig. (2-tailed) | .000 | .046 | .421 | .800 | .589 | .298 | . | .822 | .486 | .846 |
| **Biomass of Para rubber tree** | Pearson Correlation | .104 | -.186 | .572 | .458 | -.516 | .054 | .088 | 1.000 | -.065 | .941** |
| | Sig. (2-tailed) | .790 | .632 | .108 | .215 | .155 | .891 | .822 | . | .868 | .000 |
| **Biomass of Ground layer** | Pearson Correlation | .255 | .294 | .064 | -.218 | -.203 | .527 | .268 | -.065 | 1.000 | -.214 |
| | Sig. (2-tailed) | .508 | .443 | .870 | .573 | .601 | .145 | .486 | .868 | . | .581 |
| **Biomass of Litter fall** | Pearson Correlation | .095 | -.050 | .340 | .544 | -.571 | -.008 | .076 | .941** | -.214 | 1.000 |
| | Sig. (2-tailed) | .807 | .898 | .371 | .130 | .108 | .983 | .846 | .000 | .581 | . |

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

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**Table A-34** Comparing the result analysis of correlation for soil properties and amount of biomass in rainy season

| Parameter | | % OM | % moisture | $D_b$ | pH | $EC_e$ | CEC | %OC | Biomass of Para rubber tree | Biomass of Ground layer | Biomass of Litter fall |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % OM | Pearson Correlation | 1.000 | .080 | -.242 | .211 | -.104 | -.177 | 1.000** | .088 | -.124 | -.154 |
| | Sig. (2-tailed) | . | .837 | .530 | .585 | .790 | .649 | .000 | .822 | .751 | .693 |
| % moisture | Pearson Correlation | .080 | 1.000 | -.915** | .322 | -.213 | .719* | .082 | -.283 | .496 | -.256 |
| | Sig. (2-tailed) | .837 | . | .001 | .398 | .583 | .029 | .833 | .461 | .175 | .506 |
| $D_b$ | Pearson Correlation | -.242 | -.915** | 1.000 | -.098 | -.068 | -.742* | -.244 | .452 | -.306 | .146 |
| | Sig. (2-tailed) | .530 | .001 | . | .801 | .861 | .022 | .527 | .221 | .422 | .707 |
| pH | Pearson Correlation | .211 | .322 | -.098 | 1.000 | -.699* | -.107 | .230 | .473 | .141 | -.166 |
| | Sig. (2-tailed) | .585 | .398 | .801 | . | .036 | .784 | .551 | .198 | .717 | .670 |
| $EC_e$ | Pearson Correlation | -.104 | -.213 | -.068 | -.699* | 1.000 | .069 | -.108 | -.288 | -.541 | .510 |
| | Sig. (2-tailed) | .790 | .583 | .861 | .036 | . | .860 | .782 | .452 | .133 | .161 |
| CEC | Pearson Correlation | -.177 | .719* | -.742* | -.107 | .069 | 1.000 | -.177 | -.806** | .574 | -.396 |
| | Sig. (2-tailed) | .649 | .029 | .022 | .784 | .860 | . | .648 | .009 | .106 | .292 |
| %OC | Pearson Correlation | 1.000** | .082 | -.244 | .230 | -.108 | -.177 | 1.000 | .095 | -.129 | -.148 |
| | Sig. (2-tailed) | .000 | .833 | .527 | .551 | .782 | .648 | . | .808 | .741 | .705 |
| Biomass of Para rubber tree | Pearson Correlation | .088 | -.283 | .452 | .473 | -.288 | -.806** | .095 | 1.000 | -.250 | .275 |
| | Sig. (2-tailed) | .822 | .461 | .221 | .198 | .452 | .009 | .808 | . | .516 | .473 |
| Biomass of Ground layer | Pearson Correlation | -.124 | .496 | -.306 | .141 | -.541 | .574 | -.129 | -.250 | 1.000 | -.786* |
| | Sig. (2-tailed) | .751 | .175 | .422 | .717 | .133 | .106 | .741 | .516 | . | .012 |
| Biomass of Litter fall | Pearson Correlation | -.154 | -.256 | .146 | -.166 | .510 | -.396 | -.148 | .275 | -.786* | 1.000 |
| | Sig. (2-tailed) | .693 | .506 | .707 | .670 | .161 | .292 | .705 | .473 | .012 | . |

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

N = 9

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# BIOGRAPHY

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