CARBON SEQUESTRATION IN CASSAVA AND PARA RUBBER PLANTATION, RAYONG PROVINCE

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Thesis
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CARBON SEQUESTRATION IN CASSAVA AND PARA RUBBER PLANTATION, RAYONG PROVINCE

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ABSTRACT

The objectives of this study were to estimate Carbon sequestration in one crop yield of Cassava and from the productive stage to falling leaves stage of Para rubber (six month). Carbon content of aboveground, soil surface and below ground biomass was estimated. In addition, the relationships between soil organic carbon and soil properties in the upper soil horizon (0-30 cm) was determined. The carbon content in plants was calculated from biomass and carbon percentage in plant parts. The allometric equation was applied to calculate both aboveground (stem, branches and leaves) and below ground (roots) biomass of Para rubber trees. Ground cover and litter fall were dried by oven drying at 85°C until constant weight was reached, with was weight being used in biomass content estimation.

The results showed that carbon sequestration in one crop yield at a Cassava plantation was 8,368.49 kg/rai, which consisted of total carbon sequestration in Cassava trees, ground cover and in soil at 959.97 kg/rai, 153.88 kg/rai and 7,254.64 kg/rai, respectively. From the growing stage until the harvested stage, there was an increase of carbon sequestration at 30 cm depth soil at the Cassava plantation 1,631.12 kg/rai. Moreover, carbon sequestration in productive stage of the Para rubber plantation was 14,764.57 kg/rai; which consisted of carbon sequestration in Para rubber trees, ground cover, litter fall and soil of 12,226.14 kg/rai, 27.57 kg/rai, 45.50 kg/rai and 2,465.36 kg/rai, respectively. Carbon sequestration in the falling leaves stage of Para rubber plantation was 16,918.29 kg/rai, which consisted of carbon sequestration in Para rubber trees, ground cover, litter fall and soil of 12,533.71 kg/rai, 19.67, 121.87 kg/rai and 4,253.04 kg/rai, respectively. From the productive stage until the falling leaves stage, there was an increase of carbon sequestration at the Para rubber plantation, Para rubber trees, litter fall and soil: 2,153.72 kg/rai, 297.57 kg/rai, 121.87 kg/rai and 1,787.68 kg/rai, respectively.

These results demonstrate that the agricultural area, which grew a suitable type of plant and had suitable physical and chemical soil properties could contribute to an increase in soil organic carbon and carbon sequestration in such an area.

KEY WORDS: CARBON SEQUEATRATION / CASSAVA AND PARA RUBBER PLANTATION / CARBON CONTENT / BIOMASS

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(CARBON SEQUESTRATION IN CASSAVA AND PARA RUBBER PLANTATION, RAYONG PROVINCE)

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บทคัดย่อ

การศึกษาปริมาณการสะสมคาร์บอนในมันสำปะหลังและยางพาราบริเวณพื้นที่จังหวัดระยองนี้มีวัตถุประสงค์เพื่อประเมินปริมาณการสะสมคาร์บอนในหนึ่งรอบการเพาะปลูกมันสำปะหลังและในระยะให้ผลผลิตจนถึงระยะผลัดใบของยางพารา (6 เดือน) ทั้งส่วนเหนือดิน บนผิวดินและใต้ดิน และเพื่อศึกษาความสัมพันธ์ของอินทรีย์คาร์บอนในดินกับคุณสมบัติของดินที่ระดับความลึก 0-30 ซม. ทั้งนี้ปริมาณคาร์บอนที่สะสมในต้นพืชประเมินจากปริมาณมวลชีวภาพและเปอร์เซ็นต์อินทรีย์คาร์บอนในส่วนต่างๆของต้นมันสำปะหลังและยางพารา โดยปริมาณมวลชีวภาพส่วนเหนือดิน (ลำต้น, กิ่งก้าน, ใบ) และส่วนใต้ดิน (ราก) ของต้นยางพาราประเมินด้วยสมการอัลโลเมตริก สำหรับปริมาณมวลชีวภาพของมันสำปะหลัง เศษซากร่วงหล่นและพืชพื้นล่างนำไปอบที่อุณหภูมิ 85 องศาเซลเซียส จนน้ำหนักคงที่ เพื่อใช้น้ำหนักแห้งไปประเมินมวลชีวภาพต่อไป

ผลการศึกษาพบว่าในหนึ่งรอบการเพาะปลูกมันสำปะหลังมีปริมาณการสะสมคาร์บอนทั้งสิ้น 8,368.49 กิโลกรัม/ไร่ ซึ่งประกอบด้วยการสะสมคาร์บอนในต้นมันสำปะหลัง พืชผิวดินและในดิน 959.97, 153.88 และ 7,254.64 กิโลกรัม/ไร่ ตามลำดับ โดยตั้งแต่ระยะปลูกจนถึงระยะเก็บเกี่ยวในไร่มันสำปะหลังมีการสะสมคาร์บอนในดินเพิ่มขึ้น 1,631.12 กิโลกรัม/ไร่ ในยางพาราพบว่าในระยะให้ผลผลิตมีปริมาณการสะสมคาร์บอนทั้งสิ้น 14,764.57 กิโลกรัม/ไร่ ประกอบด้วยการสะสมคาร์บอนในต้นยางพารา พืชผิวดิน ซากพืชร่วงหล่นและในดิน 12,226.14, 27.57, 45.50 และ 2,465.36 กิโลกรัม/ไร่ ตามลำดับ ในระยะผลัดใบมีปริมาณการสะสมคาร์บอนทั้งสิ้น 16,918.29 กิโลกรัม/ไร่ ประกอบด้วยการสะสมคาร์บอนในต้นยางพารา พืชผิวดิน ซากพืชร่วงหล่นและในดิน 12,533.71, 19.67, 121.87 และ 4,253.04 กิโลกรัม/ไร่ ตามลำดับ โดยตั้งแต่ระยะให้ผลผลิตจนถึงระยะผลัดใบของยางพารามีปริมาณการสะสมคาร์บอนเพิ่มขึ้น 2,153.72 กิโลกรัม/ไร่ ซึ่งประกอบด้วยการสะสมคาร์บอนในต้นยางพารา ซากพืชร่วงหล่นและในดิน 297.57, 121.87 และ 1,787.68 กิโลกรัม/ไร่ ตามลำดับ

การปลูกพืชที่เหมาะสมในพื้นที่ที่มีคุณสมบัติทางกายภาพและทางเคมีของดินที่ดี มีส่วนช่วยให้การสะสมคาร์บอนและอินทรีย์คาร์บอนในดินของพื้นที่นั้นเพิ่มขึ้น

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CHAPTER 1
INTRODUCTION

1.1 Background and Justification

During the last century, the Earth's average surface temperature rose by around 0.6°C. Evidence is getting stronger that most of the global warming that has occurred over the last 50 years is attributable to human activities. The Third Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) projects published in 2001 has indicated that the global average surface temperature will raise by a further 1.4 to 5.8 °C by the end of this century. This global temperature increase is likely to trigger serious consequences for humanity and other life forms alike, including a rise in sea levels of an estimation of 9 to 88 cm by the end of this century, which will endanger coastal areas and small islands, and a greater frequency and severity of extreme weather events (1). A phenomenon of the earth warming and inhabitable was resulted from Green House Effect. The major Green house gases (GHGs) are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and chlorofluorocarbon (CFCs) (2). The most important GHGs is carbon dioxide. The increasing atmospheric concentration of carbon dioxide is effect to the growth of 50% (3) of total radiative forcing and also widely effect to natural resources, biological resources and human beings. Human activities that contribute to climate change include in particular the burning of fossil fuels and deforestation, both of which cause emissions of carbon dioxide (CO_2), the main gas responsible for climate change, as well as other greenhouse gases, which trap heat near the planet’s surface (1,4).

As a result of global climate change, an international community concerned about the threatening situations effected by global climate change met together for several times to solve this critical phenomenon. Besides, the United Nation Environment Programme (UNEP) in corporation with the World Meteorological Organization (WMO) has established the Intergovernmental Panel on Climate Change

(IPCC) in 1988. Its main objective was to assess scientific, technical and socio-economic information relevant to the understanding of human induced climate change, potential impacts of climate change and options for mitigation and adaptation. The First Assessment Report of climate situation was disseminated by IPCC in 1990. Two years later, the United Nations Framework Convention on Climate Change (UNFCCC) was launched and opened for the signature at the UN Conference on Environment and Development (UNCED) and entered into force on March 21st, 1994 after Parties to the Convention were ratified to reach the membership required. Many countries include Thailand have ratified the UNFCCC and Thailand has actively participated in the convention process. Kyoto Protocol (KP) was adopted in the Conference of the Parties (COP) third session. Thailand also ratified in the Kyoto Protocol on August 28th, 2002.

Carbon Sequestration is one activity mentioned as meeting the objectives of CDM (The Clean Development Mechanism); one of several mechanisms created in the KP that enabled Parties to cooperate with each other to reduce emissions, FCCC (The UN Framework Convention on Climate Change) and CCD (The subsequent Convention to Combat Desertification). Carbon sequestration could occur in several sites: biomass, forests, wetlands, geologic formations and soils, among others. Article 2.1 of the KP recognized that carbon sequestration was an appropriate option for Parties to use in meeting their domestic obligations to reduce emissions. Additionally, Article 3.3 of the KP permitted net accounting of direct human induced afforestation, deforestation and reforestation activities in assessing a developed country Party's emissions. Article 3.4 said that the Conference of Parties (COP) should make decision "what additional human induced activities related to changes in greenhouse gas emissions by sources and removals, by sinks in the agricultural soils and land-use categories shall be applicable". This decision was reached because the uncertainties regarding measurement of carbon flux particularly in soils were then too great and had to be resolved (5).

Thailand is an agricultural country; therefore agricultural land use pattern has been continually increased. In 2003, agricultural areas in Thailand were 111,949,488 rai or 34.9% of the whole kingdom (6). Cassava and Para rubber plants are commercial crops of Thailand. Most of Cassava and Para rubber crop productions in the world market are exported from Thailand (7, 8). In 2001, there were 11,590,000 rai of Para rubber plantation and 50,322 million baht of farm value. As in 2002 there were 6,223,864 rai of Cassava plantation and 17,711 million baht of farm value (9).

From the problem mentioned above and the importance of Carbon Sequestration that enable to reduce emissions by sink in agricultural soil and land use categories, this study would concentrate on carbon content in Annual crop and Perennial crop; study on Cassava and Para rubber plantations. The result of this study will be a part of the study of Carbon Sequestration has been mentioned to meet the objectives of Kyoto Protocol to reduce emissions.

1.2 Objectives

1. To estimate Carbon Sequestration in Cassava and Para rubber plantations
2. To estimate the relationship between relevant factors and Carbon sequestration in agricultural area

1.3 Scope of study

1.3.1 Study Area

Agricultural area in Nikom Pattana sub-district, Nikom Pattana district, Rayong province was selected as the study area. The selection was based on its land use patterns; Annual crop and Perennial crop, Cassava and Para rubber plantations were grown in the same area and environment.

1.3.2 Scope of the study

1.3.2.1 Estimate carbon content of Cassava and Para rubber plantations, which consisted of

1) Aboveground biomass, considered by

- Biomass of stems and leaves of Cassava plantation in one crop yield
- Biomass of stems, branches and leaves of Para rubber plantation at the age of 15 years during productive to falling leaves stages (six months)

2) Soil surface biomass, considered by

- Ground cover
- Litter fall

3) Below ground biomass, considered by

- Biomass of root
- The Percentage of soil organic carbon

1.3.2.2 Analyze physical and chemical properties of soil in order to find the relationship with the carbon contents

1.3.2.3 Estimate Carbon Sequestration in agricultural area of Cassava and Para rubber plantations

1.4 Expected Results

1.4.1 Estimated carbon sequestration in Cassava and Para rubber plantations

1.4.2 The relationship between relevant factors and Carbon sequestration in Cassava and Para rubber plantations

1.5 Research Concept

The study of Carbon sequestration was studied in 2 difference land use patterns namely Cassava and Para rubber plantations. Biomass of each land use pattern; above ground, soil surface and below ground biomass was also calculated. The assessment of carbon contents in biomass and soil as well as physical and chemical properties of soil in each land use pattern were analyzed. The relationship between biomass, carbon content and some properties of soil in each land use pattern were also described.

1.6 Conceptual Framework

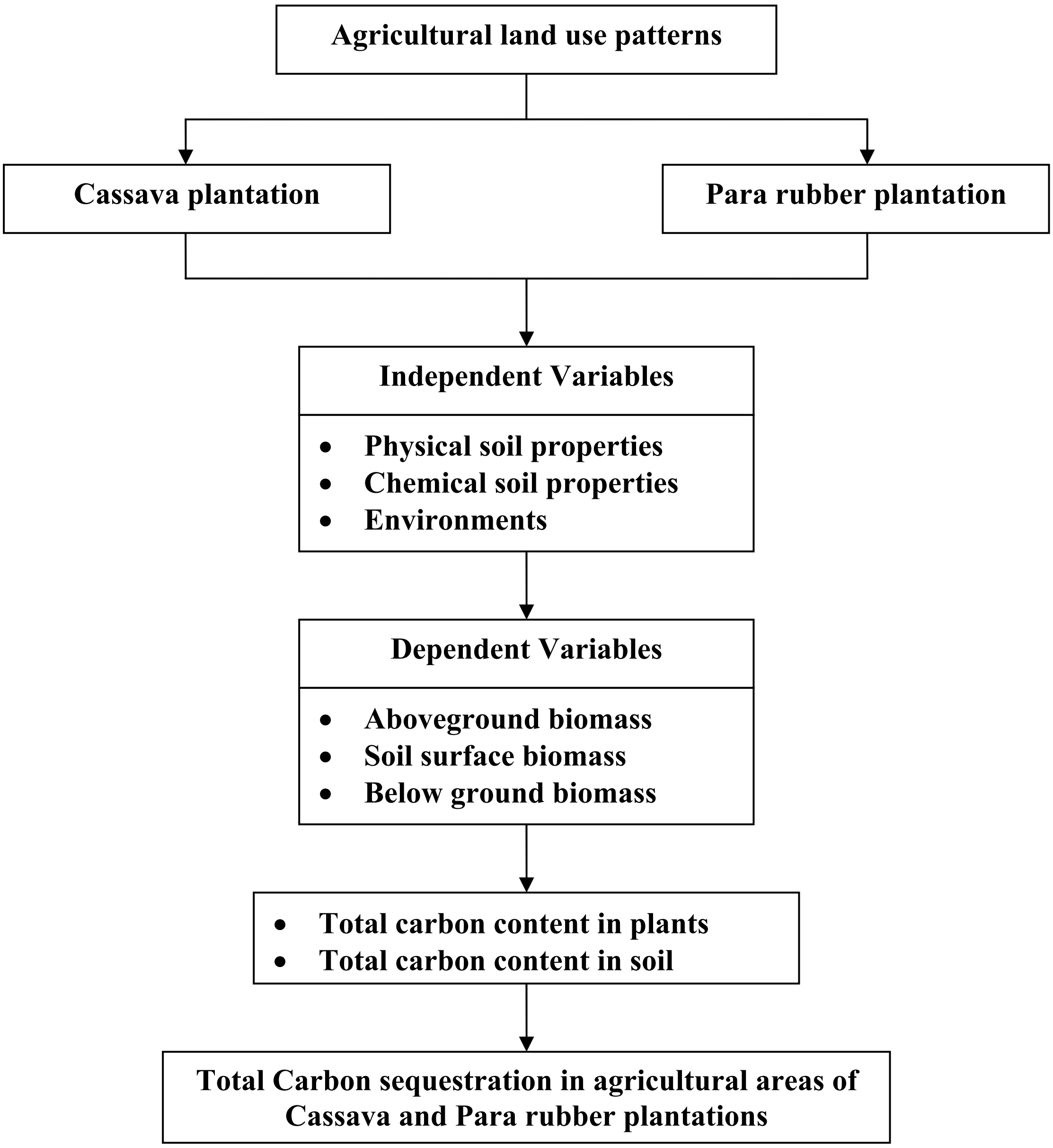

Figure 1-1 Conceptual Framework for the study

1.7 Study Duration

Time frame to study on Carbon sequestration in Cassava plantation was scheduled for conducting the research work in growing and harvested stages, Para rubber plantation was scheduled for conducting the research work at the productive and falling leaves stages.

CHAPTER 2
LITERATURE REVIEWS

2.1 Climate Change

Climate change refers to changes in long-term trends in the average climate, such as changes in average temperatures. In IPCC usage, climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. In UNFCCC usage, climate change refers to a change in climate that is attributable directly or indirectly to human activity that alters atmospheric composition (10).

Over the last 400,000 years the Earth's climate has been unstable, with very significant temperature changes, going from a warm climate to an ice age in as rapidly as a few decades. These rapid changes suggest that climate may be quite sensitive to internal or external climate forcing and feedbacks (11). Before the industrial revolution (1750-1800), the amount of CO_2 in the atmosphere was about 270 ppm, and it has increased substantially to the present level of 356 ppm. that projected to double by 2100. As the result of the amount of greenhouse gases increase, additional heat will be trapped in the atmosphere causing the phenomena called "Climate Change" also known as "Global Warming" or the "Greenhouse Effect". There is a substantial amount of uncertainty regarding how the climate would change, however IPCC (12) and the UN Climate Convention (13) have predicted the following; that to refer a studied on Cheneswasde (14).

- An increase in global mean temperature was about 2 °C by the year 2100, for mid range IPCC scenario of 1.5- 4.5 °C.
- Regional temperature changes may differ substantially from the change in the global mean. However, not yet possible to describe how wit certainty.
- The projected sea-level rise id estimated to range from 15 to 95 cm. with the best estimate of 50 cm. by the year 2100. Sea-level rise would continue to rise even though the global climate and the mean temperature would have stabilized.

- As a consequence of possible changes in the temperature and water availability, a substantial fraction (a global average of one third, varying by region from seventh to two thirds) of the existing forest areas of the earth will undergo major changes in board vegetation types.
- Developing countries will almost likely be more seriously affected by climate change than developed countries. They may also have fewer options for adapting.

Climate changed has been occurred by natural change and human activity, which has led to compose in atmosphere and caused climate change from past up to present time. The conclusion was that the earth temperature might have been increased about 0.6±0.2°C and the sea-level model predicted to increase average 0.09-0.88 meter in 2001 (12, 13, 15).

2.2 Greenhouse Effect

Most of the solar's energy that reaches the earth is absorbed by the oceans and land masses and radiated back into the atmosphere in the form of heat or infrared radiation. Most of this infrared energy is absorbed and reradiated by atmospheric gases such as water vapor and carbon dioxide. This phenomenon, referred to as the greenhouse effect, serves to keep the earth some 33°C (60°F) warmer than it would otherwise be. As concentrations of gases that absorb and reradiate infrared energy (i.e., greenhouse gases GHGs) increase, the warming effect increases.

From figure 2-1 Greenhouse gases were shown as a layer to simplify the drawing. In reality, they are dispersed throughout the atmosphere. Although the atmosphere consists largely of oxygen and nitrogen, neither absorbs infrared energy; thus, they do not play a role in warming the earth and are not greenhouse gases.

The greenhouse effect is important. Without the greenhouse effect, the earth would not be warm enough for humans to live. But if the greenhouse effect becomes stronger, it could make the earth warmer than usual. Even a little extra warming may cause problems for humans, plants, and animals.

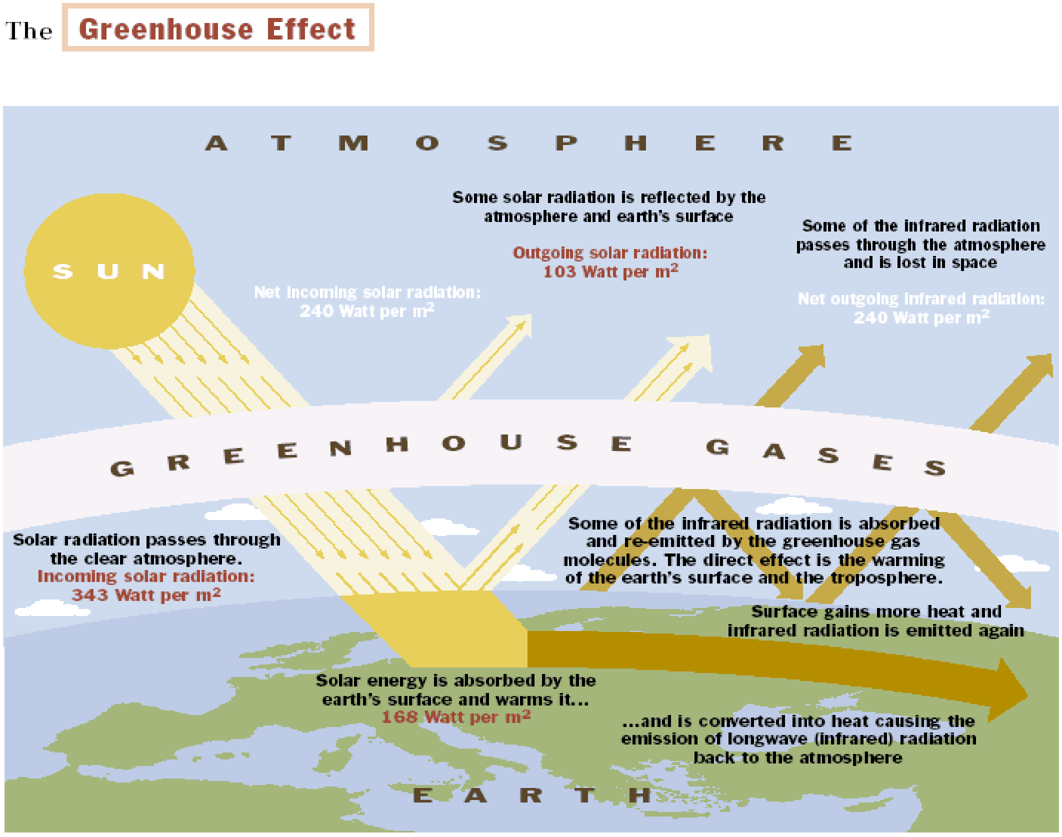

Figure 2-1 Greenhouse effect phenomenon

Source: Rekacewicz, 2000.(16)

2.3 Greenhouse Gases

Greenhouse gases (GHGs) are found naturally in the atmosphere. They absorb outgoing long wave infrared radiation, or heat energy, which the earth and the atmosphere normally radiate back to outer space. Major Greenhouse gases, which are directly influenced by human activities, are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), the chlorofluorocarbons and (CFCs) and ozone (O_3). The carbon dioxide is the most important of the Greenhouse gases, which are increasing in atmospheric concentration because of 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% (17). The present, the prediction for CO_2 is released higher than 0.5% per year; released more than used by photosynthesis of plants and the most are dissolved into the ocean (18).

While the tree growth and forest ecosystem can absorb CO_2 for produce biomass. This process carbon sequestration that efficiency only process can reduce

CO_2. Greenhouse gases had long life time and radiation effect, that also known as Global Warming Potential (GWPs). The GWPs defines the warming effects caused by a unit mass of a given gas relative to that of carbon dioxide (19).

CO_2, CH_4 and N_2O were three major Greenhouse gases released in Thailand in 1998 as shown in Table 2-1. Most of Greenhouse gases were released essentially by combustion of fossil fuels, industrial processes and land use change.

Table 2-1 Total emissions of the three Greenhouses gases in Thailand, 1988.

Greenhouses 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

Source: Environmental Resource Management (20)

Human activities were attributed to emission GHGs, such as burning fossil fuels, coal, natural gas and transportation, deforestation or land use change and agricultural activities that fire crops for soil preparing as detail shown in Table 2-2.

Table 2-2 GHGs emission from various sectors in Thailand in 1994, expressed as Carbon dioxide equivalent of Global Warming Potential (GWPs)

Sources	Emission in CO_2 Equivalent (Million Tons)	Percentage of Total Emission
All Energy	130	45.45
Industrial processes	16	5.6
Agriculture	78	27.3
Land use change & Forestry	62	21.67
Waste	0.7	-
Total	**286.7**	**100**

Source: TEI (21)

Table 2-2 showed the three sectors which emitted the largest quantities of greenhouse gases were energy, agriculture and forestry which the emissions in CO_2 equivalents were 130, 78 and 62 million tons, respectively.

2.4 Carbon Cycle

The movement of carbon, in its many forms, between the biosphere, atmosphere, oceans, and geosphere is described by the carbon cycle, illustrated in figure 2-2. The carbon cycle is one of the biogeochemical cycles. In the cycle there are various sinks, or stores, of carbon (represented by the boxes) and processes by which the various sinks exchange carbon (the arrows).

We are all familiar with how the atmosphere and vegetation exchange carbon. Plants absorb CO_2 from the atmosphere during photosynthesis, also called primary production, and release CO_2 back to the atmosphere during respiration. Another major exchange of CO_2 occurs between the oceans and the atmosphere. The dissolved CO_2 in the oceans is used by marine biota in photosynthesis.

Two other important processes are fossil fuel burning and changing land use. In fossil fuel burning, coal, oil, natural gas, and gasoline are consumed by industry, power plants, and automobiles. Notice that the arrow goes only one way: from industry to the atmosphere. Changing land use is a broad term encompasses a host of essentially human activities. They include agriculture, deforestation, and reforestation.

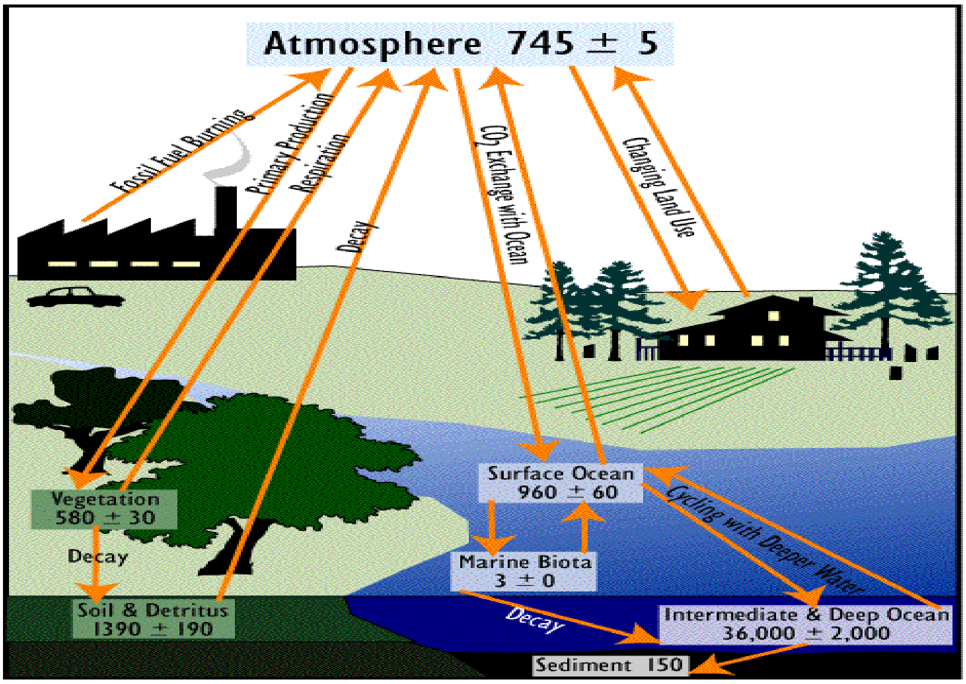

Figure 2-2 Carbon cycle

Source: http://www.cotf.edu/ete/modules/carbon/efcarbon.(22)

Figure 2-2 showed the carbon cycle with the mass of carbon, in gigatons of carbon (Gt C), in each sink and for each process, if known. The amount of carbon being exchanged in each process determines whether the specific sink is growing or shrinking. For instance, the ocean absorbs 2.5 Gt C more from the atmosphere than it gives off to the atmosphere. All other things being equal, the ocean sink is growing at a rate of 2.5 Gt C per year and the atmospheric sink is decreasing at an equal rate. But other things are not equal. Fossil fuel burning is increasing the atmosphere's store of carbon by 6.1 Gt C each year, and the atmosphere is also interacting with vegetation and soil. Furthermore, there is changing land use (22).

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 (23). 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 of it were not for the continual respiratory return of carbon to the atmosphere. However, 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 reverse (24).

2.5 Carbon Dynamics and Stores in Agricultural areas

The vegetation and soils are significant reservoirs of carbon; they actively exchange CO_2 with the atmosphere. Terrestrial vegetation and soils contain about three and a half times as much carbon as the atmosphere; the exchange is controlled by photosynthesis and respiration.

The amount of carbon stored globally in soils is much larger than that in vegetation (Table 2-3). 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, in the amounts and proportions of carbon per unit ground area in vegetation and soil within each biome.

Table 2-3 Global carbon stocks in vegetation and top 1 m of soils

Biome	**Area (10^6 km^2)**	**Carbon Stocks (Gt C)**		
		Vegetation	***Soil***	***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 (13)

Soil is the largest near surface pools in global carbon cycle, containing in the range of 1,400-1,600 Pg C in organic forms. Regardless of whether, the global pool was estimated from an aggregation of vegetation types (25), climatic life zone (26), of soil orders (27). The global carbon pool of the soil at 1 m depth was estimated approximately 1,220 Pg (28), the top soil at 0-30 cm approximately 684-724 Pg and 0-2 m approximately 2,376-2,456 Pg (29). The soil organic matter pool is currently losing about 1 to 2 gigatons of carbon per year to the atmospheric pool. About 60 gigatons of carbon per year enters the soil organic carbon sink as decaying biomass remains in the soil. About 61 to 62 gigatons of carbon are lost from this pool as soil organic matter oxidized by the atmosphere. This is the other main cycle that can be manipulated by human activity. Changes in land use patterns and agricultural practices can affect the amount of carbon released into the atmosphere from soil organic matter (30).

The total amount of soil carbon pool in soil of Thailand at 1 m depth is approximately 6.21 Pg equal as 0.046% of organic carbon, and inorganic carbon is approximately 0.184 Pg equal as 0.019% of organic carbon of the world. The carbon deposit in soil mountain area is approximately 4-8 Kg/m^2/100 cm equal as 40.25% of area, followed by 12-16 Kg/m^2/100 cm equal as 22.34% and 20-40 Kg/m^2/100 cm equal as 15.31% of the total area, respectively (31).

Marlen D. et al (32) studied to estimate net soil carbon stock change for US agricultural soils during the period from 1982 to 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. The results show that, overall, changes in land use and agricultural management have resulted in a net gain of 21.2 MMT C per year (Million Metric Tons Carbon per year) in US agricultural soils during this period. Cropped lands account for 15.1 MMT C per year, while grazing land soil C increased 6.1 MMT C per year. Thus, the land use and management changes those have contributed the most to increasing soil carbon during that period.

Lars K. et al (33) studied on the contemporary stocks of soil organic carbon (SOC) in Denmark to 1 m depth estimated by combining data from two soil and one land use database using four different scaling-up methods, which take into account land use and soil textures. The estimated stocks vary from 563-598 Tg C, with 579 Tg C as the average, when urban area, lakes and open fjords are excluded. Wetland soils have 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 is found within 28 cm depth, which is the median ploughing depth, and 78% within 50 cm depth. Sixty-nine percent of the total SOC stock is under agricultural land and 40% is found in the plough layer. Thus, the land use change and environment have contributed to organic carbon storage in terrestrial ecosystem.

2.6 Biomass

The bodies of living organisms within a unit area make up a standing crop of biomass. More specifically, biomass can be defined as the mass of organisms per unit area and is usually expressed in units of energy (e.g., joules m^{-2}) or dry organic matter (e.g., tons ha^{-1} or grams m^{-2}). Most of the biomass in a community is composed of plants, which are the primary producers of biomass because of their ability to fix carbon through photosynthesis (34).

Dyksterhuis and Schumutz (35) classified aboveground biomass into 4 categories

1. Green herbage: the green and living parts of tree including those ones that the treetop look deadly dry but keep growing.
2. Cure herbage: the dry dead plant which its root stops growing.
3. Fresh mulch of fresh organic material: the remaining litter lying on the top has not been decomposed.
4. Humic mulch or decompose litter: the remaining litter which has been already decomposed.

Litter means the total weigh of organic matters including the dead parts of plant such as leaves, flowers, fruits, branches, barks, and stems, as well as the living materials such as falling seeds, green leaves, animal and insect carcasses piling up on the ground. However, the total weigh of the litter is counted only from the falling little pieces of wood and leaves lying on the organic matter layer, excluding big pieces of wood like big and heavy branches, stems of big fruits (36).

2.6.1 The Study of Biomass

Diameter has been measured and converted to estimate biomass and carbon by using allometric biomass regression equations in live trees. Kittredge (37) was the first one who used the equation to estimate the amount of leaves per tree (W_L) for the study of forest ecosystem by using relationship of diameter at breast height (D). The equation was:

$$\log W_L = b \log D - a$$

Cut down a tree, weigh it, take samples of different tree components and dry those components are general methods for estimating biomass. First cut down a tree to make very close to soil surface. Next measure the total height of tree and diameter at breast height (1.30m), at 0.3 from the soil surface, at 1/10 of the total height. After that, measure the wide and the height of the crown. Lastly, separate samples of different (leaves, branches, stems and roots), weight it, and dry the components for estimating dry mass of the total tree (38).

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 the tree
2. Estimate fresh mass from the samples of plant and search for the relationship of mass and others dimension of plants

The relationship was called allometric equation, which equation was:

$$Y = ax^b \quad \text{or} \quad \log W = \log a + b \log (D^2H)$$

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

a, b were the constant values

2.6.2 The Variable of Biomass

The biomass of plant varies with precipitation and the growth season. Because of the growth of tree relates directly with the sunlight, the proper temperature and enough precipitation. Especially, the temperature and the sunlight cause to plants too much produce food, increasing accumulation of biomass of the tree. The large biomass is much in rainy season and rather constant in winter. The beginning of the winter, changing is rather steady of much less than the beginning of deciduous because decreasing of soil moisture and relatively humidity in atmosphere. So the plants adjust for decreasing of evapotranspiration by falling leaves. According to the precipitation is a factor that controls the scattering of roots in different depth and struggling of the same type of plant. Furthermore, the content of precipitation influence to the ground layer with the size and density of the crown cover. The crown cover of tree is a factor to control receives the content precipitation and sunlight of the ground layer. As well as it control to type of the ground layer also (40, 41, 42, 43).

2.7 Cassava

Common Names: Yuca, Tapioca or Manioc

Scientific Names *Manihot esculenta* Crantz

Cassava is grown for its enlarged starch-filled roots, which contains nearly the maximum theoretical concentration of starch on a dry weight basis among food crops. Fresh roots contain about 30% starch and very little protein. Roots are prepared much like potato. They can be peeled and boiled, baked, or fried. It is not recommended to eat cassava uncooked, because of potentially toxic concentrations of cyanogenic glucosides that are reduced to innocuous levels through cooking.

Young tender leaves can be used as a potherb, containing high levels of protein (8-10% F.W.). Prepared in a similar manner as spinach, care should be taken to eliminate toxic compounds during the cooking process. One clone with variegated leaves is planted as an ornamental.

Varieties in Thailand

Rayong 1, Rayong 2, Rayong 3, Rayong 5, Rayong 60, Rayong 90, Kaset 50, Sriracha 1

Origin

Cassava originated in Brazil and Paraguay. Today it has been given the status of a cultigen with no wild forms of this species being known.

Crops Status

Cassava is a perennial woody shrub, grown as an annual. Cassava is a major source of low cost carbohydrates for populations in the humid tropics. The largest producer of cassava is Brazil, followed by Thailand, Nigeria, Zaire and Indonesia. Production in Africa and Asia continues to increase, while that in Latin America has remained relatively level over the past 30 years. Thailand is the main exporter of cassava with most of it going to Europe. It was carried to Africa by Portuguese traders from the Americas. It is a staple food in many parts for western and central Africa and is found throughout the humid tropics. The world market for cassava starch and meal is limited, due to the abundance of substitutes.

Taxonomy

Early literature on cassava described the genus with two edible species, *M. ultissima* Phol or sweet and *M. aipi* Phol, delineating species which have high and low cyanogenic glucoside concentrations respectively. More recently cassava was classified as all being the same species *M. esculenta*. It is the only one of 98 species in its family that is widely cultivated for food production. Cassava uniformly is 2n = 36. Other ploidy levels are not utilized, but have been produced experimentally. There are several closely related species found in the tropical and subtropical Americas that can be crossed with *M. esculenta*.

Ecology

Cassava is a tropical root crop, requiring at least 8 months of warm weather to produce a crop. It is traditionally grown in a savanna climate, but can be grown in extremes of rainfall. In moist areas it does not tolerate flooding. In droughty areas it looses its leaves to conserve moisture, producing new leaves when rains resume. It takes 18 or more months to produce a crop under adverse conditions such as cool or dry weather. Cassava does not tolerate freezing conditions. It tolerates a wide range of soil pH 4.0 to 8.0 and is most productive in full sun.

Production Practices

Cassava is planted using 7-30 cm portions of the mature stem as propagules. The selection of healthy, disease-free and pest-free propagules is essential. The stem cuttings are sometimes referred to as 'stakes'. In areas where freezing temperatures are possible, the cuttings are planted as soon as danger of frost has past. The cuttings are planted by hand in moist, prepared soil, burying the lower half. When soils are too shallow to plant the cutting in an upright or slanted position, the cutting are laid flat and covered with 2-3 cm soil. Mechanical planters have been developed in Brazil to reduce labor inputs. Observing the polarity of the cutting is essential in successful establishment of the cutting. The top of the cutting must be placed up. Typical plant spacing is 1m by 1m. Cuttings produce roots within a few days and new shoots soon appear at old leaf petiole axes on the stem. Botanical seeds are used only for breeding purposes. Early growth is relatively slow, thus weeds must be controlled during the first few months. Although cassava can produce a crop with minimal inputs, optimal yields are recorded from fields with average soil fertility levels for food crop production and regular moisture availability. Optimal growth and productivity of the plant is related to its harvest index, root weight divided by total plant weight. The desirable indexes range from 0.5 to 0.7. Responses to macro-nutrients vary, with cassava responding most to P and K fertilization. Vesicular-arbuscular (VA) mycorrhizae benefit cassava by scavenging for phosphorus and supplying it to the roots. High N fertilization, more than 100 kg of actual N/ha may result in excessive foliage production at the expense of storage root development and a low harvest index. Fertilizer is only applied during the first few months of growth. Commercially produced fungicides and pesticides are seldom used, with none being registered for use in the U.S.A. There is no mature stage for cassava. Plants are ready for harvest as soon as there are storage roots large enough to meet the requirements of the consumer. Under the most favorable conditions, yields of fresh roots can reach 90 t/ha while average world yields from mostly subsistence agricultural systems are 9.8 t/ha. Typically harvesting can begin as soon as eight months after planting. In the tropics, plants can remain unharvested for more than one growing season, allowing the storage roots to enlarge further. However, as the roots age, the central portion becomes woody and inedible.

Harvesting

Most cassava is harvested by hand, lifting the lower part of stem and pulling the roots out of the ground, then removing them from the base of the plant by hand. The upper parts of the stems with the leaves are removed before harvest. Levers and ropes can be used to assist harvesting. A mechanical harvester has been developed in Brazil. It grabs onto the stem and lifts the roots from the ground. Care must be taken during the harvesting process to minimize damage to the roots, as this greatly reduces shelf life. During the harvesting process, the cuttings for the next crop are selected. These must be kept in a protected location to prevent desiccation (44).

2.8 Para rubber

Thai name: Yang para

Scientifics name *Hevea brasilliensis Muell. Arg*

Botanical characteristic

Para rubber trees are Perennial trees of a height of 25-30 meters. They have stems which are smooth straight and thick. Somewhat soft, trunk unbranched up a long way and then with much branch leafy canopy. They have 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 board, elliptic lanceolate in outline; flowers numerous, monoecious, creamy, yellow or green, in auxiliary 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 (45).

Varieties in Thailand

There are some varieties are planted in Thailand such as BPM 24, Songkla 36, RRIM 600, PB 255 and Pric 110**.**

Origin

Para rubber originated in tropical South America. Today most Para rubber is produced from trees grown on plantations in Asia and to a lesser extent in Africa.

Harvesting

The yellow or white latex from which rubber is made occurs in numerous specialized latex vessels in the bark, especially outside the phloem. The tree is tapped by making careful incisions, as deep as possible without injuring the tree's growth, in a herringbone pattern or often in a left hand spiral of 30° around the trunk, for the latex vessels spiral to the right at an angle of about 30° from the horizontal. The latex is collected in small cups and then treated—usually by coagulating it with acid, pressing it free of water, and drying the resultant sheets in a smokehouse to ready them for shipment. The size of the tree, the quality of the latex, and the number of taps possible varies with individual trees; the quantity of latex increases with the age of the tree, which may grow to a height of over 100 ft (30 m). Cultivated trees are tapped throughout the year, usually in the early morning, when the latex flow is greatest. Sometimes other trees that yield latex are also called Para rubber trees.

Harvested season: All year, mostly in December-January (46, 47)

2.9 Relevant Researches

All carbon on earth can organize into five main pools, listed in order of the size of the pool, Lithosphere, Oceans, Soil organic matter, Atmosphere and Biosphere, respectively (30). Schlesinger (48) estimated that carbon content of soil was about 2 times of carbon in the atmosphere or 3 times of carbon of carbon content of living on the biosphere, was 1/3 times of fossil fuel which 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 and 0.53 of dry mass. Estimation of the total carbon in biomass showed by Table 2-4.

Table 2-4 Carbon: Wood factor from Biomass source

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 are generally based on allometric equations relating earth carbon or biomass to diameter at breast height (DBH). These equations are 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 varies between studies. Furthermore, the carbon concentration of different tree parts is rarely measured directly, and most researchers estimate carbon by assuming the carbon content of dry biomass to be a constant 50% by weight. Occasionally, carbon is measured directly by burning the samples in a carbon analyzer (50). Thus, this study estimated the carbon by burning the samples in a carbon analyzer too.

Witthawatchutikul and Jirasuktaveekul (51) studied on the relationship of allometic for estimate aboveground biomass of the Para rubber plantation in Rayong watershed by harvesting method. Then classified the biomass with square of diameter of stem (W_s), branches (W_b) and leaves (W_L) and estimated the aboveground biomass with square of diameter of stem (D) at 1.30 m and multiplied by the total height of tree (H). These equations were:

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

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

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

According to their study in 1989, the young tree, 5 years old, the average DBH 13.86 cm, the total height average 13.2 m, the total aboveground biomass was 4.67 tons/Rai, and biomass of roots was 0.36 tons/Rai. The cultivation, 8 years old, the average DBH 16.26 cm, the total height average 16.28 m, the total aboveground biomass was 7.27 tons/Rai, and biomass of roots was 0.40 tons/Rai. The mature, 19 years old, the average DBH 24.82 cm, the total height average 20.18 m, the total aboveground biomass was 17.74 tons/Rai, and biomass of roots was 0.58 tons/Rai (52).

Shorrocks (53) studied on the relationship between diameter at 1.50 m from soil surface and aboveground dry biomass of Para rubber and found that the relationship of the linear function between diameter (log G) and dry biomass (log Md) was:

$$\log Md = 2.786 \log G - 2.5843$$

Bangjan (54) studied on Para rubber trees in the Eastern of Thailand for the same relationship of Shorrocks (53) and its issue results in the function was:

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

She estimated that the biomass of Para rubber trees were lower than the true value when girth of Para rubber trees increased. The relationship between dry biomass and volume of tree was formed as:

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

Yoosuk (55) studied on Carbon sink in Rubber plantation of Klaeng District, Rayong Province, Thailand and modified allometric equation of Bangjan (54) by the relationship between biomass of roots, diameter and height of stem. The formed was:

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

In addition, Bangjan (54) found that the mass of Para rubber trees would increase in the form of the square of value when the size of tree increases. The young tree, 1-5 years old had the large proportion of the mass of stem, and the large proportion of the mass of branches when they were tapped.

The mass of each branch related with the size of girth at close to the stem. The proportion of the mass of stem would be decreased by the age of the tree. The below ground biomass was the mass of stump add with 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 14-28% of the total mass of roots. The mass of roots would be increased when the size of tree increase or older. Shorrocks (53) found that the mass of Para rubber roots were about 15% of aboveground dry mass. Bangjan (54) found that the below ground biomass of Para rubber trees in the Eastern of Thailand, RRIM 600, 2.5 years old were about 41.4% of total mass of the stem. The proportion of the mass of below ground biomass would be decreased 8.8% of the mass of the stem when the tree was 20 years old.

Claudia S. Z. et al (56) studied on Carbon sequestration in perennial bioenergy, annual corn and uncultivated systems in southern Quebec. In the study, carbon storage was compared among five ecosystems in southwestern Quebec including two perennial crops, switchgrass (*Panicum virgatum* L.), and willow (*Salix alba*×*glatfelteri* L.), and an annual corn (*Zea mays* L.) crop at two sites of different soil fertility, a 20-year-old abandoned field, and a mature hardwood forest. After 4 years of production, corn had significantly higher levels of aboveground carbon than willow at the less fertile site, but no significant differences were detected at the more fertile site. Both perennial systems had significantly higher root C than the corn system but switchgrass had significantly higher root C levels below 30 cm compared with willow and corn. Soil organic C under willow at the more fertile site was higher than under the other managed or unmanaged systems, including willow at the less fertile site. The results of this study suggest that perennial energy crops grown on relatively fertile soils, have the potential to increase substantially soil C levels compared with conventional agricultural systems or unmanaged systems.

Nagaraja et al (57) studied in the eastern dry zone of Karnataka, India, to assess the soil carbon stocks (0-50 cm. soil depth) under different land use systems, both natural and manmade, comprising of forests, grasslands, horticulture and agricultural system. The carbon stocks in soils ranged from 26.46 t/ha in dryland agricultural systems (without manure) to 89.20 t/ha in mixed forest. Among natural systems, ungrazed grassland (71.78 t/ha) and mixed forest (89.20 t/ha) recorded higher levels of soil carbon while grazing in grassland and litter removal in teak plantations resulted in its reduction (39.32 and 32.74 t/ha respectively). Intensively managed horticultural systems namely grapes (85.52 t/ha) and pomegranate (78.78 t/ha) maintained higher carbon stocks. However, agricultural systems recorded moderate to lower levels of soil carbon. Total carbon stocks in top 0-50 cm soils of agricultural systems was of the order irrigated lands with manure (52.77 t/ha) > irrigated lands without manure (44.47 t/ha) > drylands with manure (37.79 t/ha) drylands without manure (26.46 t/ha). Interestingly, seasonal changes were also recorded in all the land use systems.

Nualngam and Wachrinrat (58) studied on the Role of Reforestation on Carbon sink at Re-afforestation Research and Training Station, Changwat Nakhon Ratchasima, the study found that the highest carbon sink both in plant and soil was found in *A. mangium* with the amount of 145.692 ton/ha followed by *A. auriculaeformis, E. camaldulensis, X. xylocarpa var. kerrii, D. cochinchinensis, P. macrocarpus, N. reynaudiana* and *I. cylindrical* with the amount of 94.009, 93.557, 85.041, 80.043, 62.300, 53.140 and 47.700 ton/ha, respectively. Furthermore, plot of *A. mangium* showed the maximum amount of carbon sink in soil from surface through 30 cm depth with the amount of 53.242 ton/ha.

Petsri (59) and Tangsinmankong (60) studied on the total carbon content in the mixed deciduous forest and the teak plantation in Uthaithani province at the ages of 6, 15 and 24 years were 142.56, 196.56, 112.62 and 146.81 t/ha, respectively. The carbon content in plant was 71.62, 39.5, 33.88 and 41.13 t/ha, respectively, while the carbon content in soil 0-30 depth from soil surface was 70.94, 157, 78.75 and 105.69 t/ha, respectively. The aboveground carbon content of tree was 60.63, 29.75, 29.38 and 37.56 t/ha, respectively.

Jindanuch (61) studied on the carbon distribution in the mangrove area of Thung Kha estuary, Chumphon province, the study found that the total carbon content in natural mangrove, mangrove plantation and reforestation mangrove were 191.44, 147.19 and 186.25 tC/ha. The aboveground carbon content in natural mangrove, mangrove plantation and reforestation mangrove were 38.69, 23 and 8.63 tC/ha while the soil organic carbon at 30 cm depth from soil surface were 152.75, 124.19 and 177.63 tC/ha, respectively.

2.10 The Study Area

2.10.1 Location

The study area is in Nikom Pattana sub-district, Nikom Pattana district, Rayong province. Nikom Pattana district covers with total 145,313 Rai of Rayong area and consists of 131,563 Rai as flat plain area, 5,625 of hilly area, and 8,125 as water body.

The North	Bordered with *Mae Num Koo and Mab Yang Porn sub-district, Pluak Daeng district, Rayong province.*
The South	Bordered with *Hauy Pong sub-district, Maung district and Sumnug Katorn sub-district, Ban Chang district, Rayong province.*
The East	Bordered with *Nhong Lalog and Mab Nhong Tapan sub-district, Ban Khai district, Rayong province.*
The West	Bordered with *Pong Sub-district, Bang Lamung district, Chon Buri province.*

2.10.2 Climate

The climate of Nikom Pattana District is under the influence of tropical monsoon, has abundant rain during May to October, and the approximately annual rainfall are between 1,200-1,300 mm. per year. The records of the Meteorological Department of Thailand at Hauy Pong station, Rayong province, during the period of 1971-2000 reported that the yearly mean of temperature was 27.8 ºC, the mean of minimum and maximum temperatures were 12.5 ºC and 38.7 ºC in December and May, respectively. The mean of rainfall was 1,383 mm a year, mean of relative humidity was 71%, and mean of evaporation was 4.8 mm a year.

Table 2-5 Statistics of rainfall, evaporation, relative humidity, and temperature of Rayong province (Based on the period of 1971-2000)

Month	**Rainfall (mm)**	**Relative Humidity (%)**	**Evaporation (mm)**	**Temperature(ºC)**		
				max	**min**	**mean**
Jan.	22.8	65	4.9	35.2	12.7	25.3
Feb.	40.1	70	5.0	35.4	13.3	27.2
Mar.	39.0	71	5.3	37.6	16.0	28.4
Apr.	90.1	72	5.5	38.2	19.0	29.6
May	183.5	74	5.1	38.7	20.8	29.0
June	151.5	76	4.5	36.7	20.1	28.6
July	139.4	75	4.7	36.4	19.8	28.3
Aug.	135.4	75	4.6	35.2	21.0	28.0
Sep.	234.5	76	4.0	35.3	20.0	27.4
Oct.	255.5	74	4.3	34.9	18.7	27.2
Nov.	85.5	88	4.8	36.0	14.3	25.8
Dec.	5.2	61	5.3	35.2	12.5	26.2
Total/Average	**1383.2**	**71**	**4.8**	**38.7**	**12.5**	**27.8**

Source: Thai Meteorological Department (62)

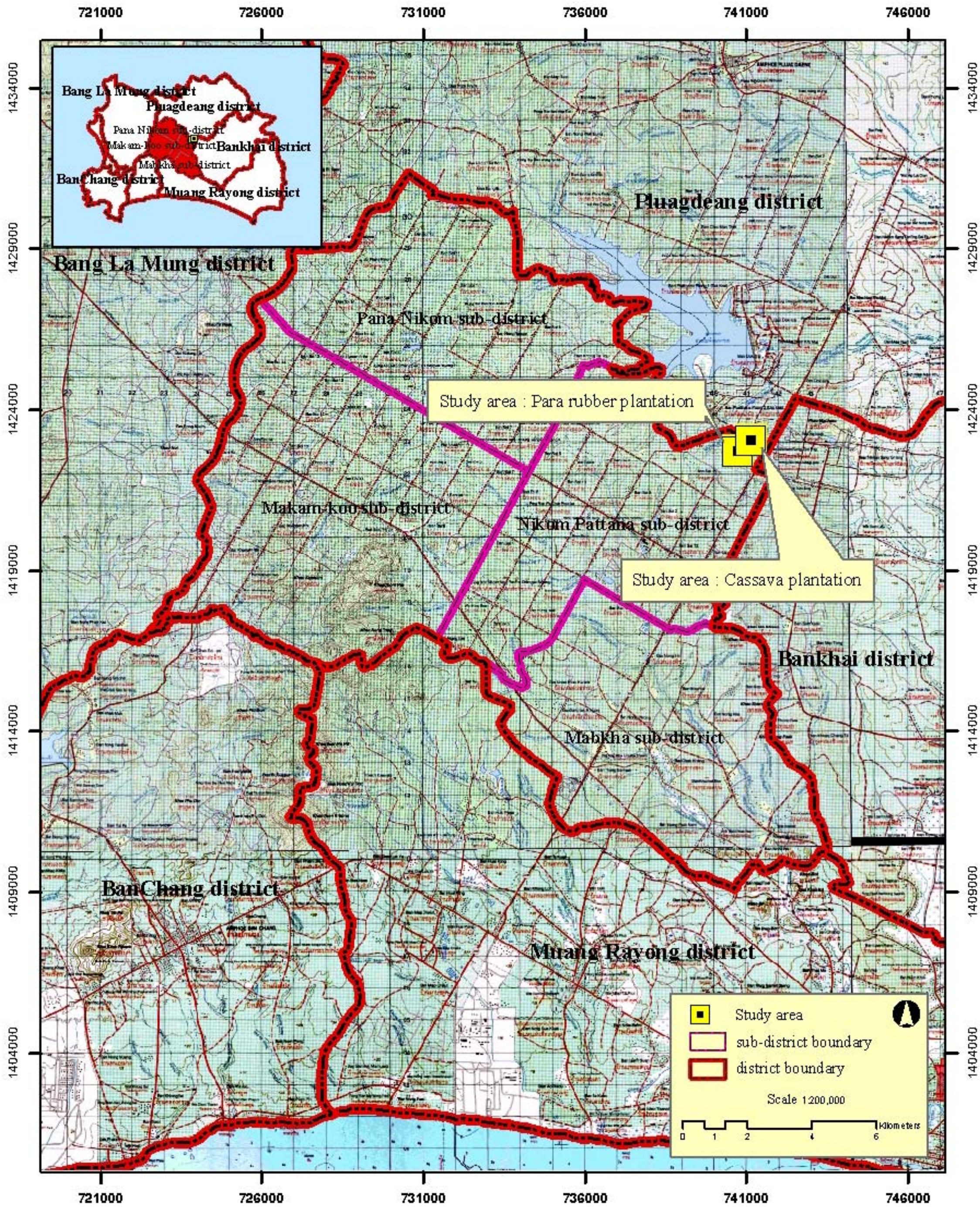

Figure 2-3 The study area located at Nikom Pattana sub-district, Nikom Pattana district, Rayong province

Source: Royal Thai Survey Department

CHAPTER 3
MATERIALS AND METHODS

This research was carried out in term of survey and analytical research, collected data from Cassava and Para rubber plantation areas in Nikom Pattana sub-district, Nikom Pattana district, Rayong province.

3.1 Data collection

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

3.1.1 General data of the study area were

- Soil properties
- Topography
- Climate

3.1.2 Data of plant

- Botanical characteristic of Cassava and Para rubber plant
- Age period and growth of Cassava and Para rubber plant

3.2 Study area and Data collection

Agricultural area in Nikom Pattana sub-district, Nikom Pattana district, Rayong province was selected as the study area. The selection was based on its land use patterns, Cassava and Para rubber plants that grown in the same climate and topography. Soil and plant samples were collected at 2 times.

First data collection The samples were collected in May, which Cassava was in growing stage and Para rubber was in productive stage.

Second data collection The samples were collected in November, which Cassava was in harvested stage and Para rubber was in falling leaves stage.

3.3 Materials

3.3.1 Maps

1) Rayong's topography map in 1991: scale 1:50,000, sheet series L7017, sheet no. 5234 IV, from Royal Thai Survey Department.

2) Rayong's detailed reconnaissance soil survey map in 1985: scale 1:100,000 from Land Development Department.

3.3.2 Equipments for field study consisted of the following items:

1) Geographic Positioning System (GPS)
2) Haga hypsometer
3) Soil core
4) Measuring tape
5) Litter trap size 1 m^2
6) Frame size 1 m^2
7) Hoe, spade and knife
8) Plastic rope
9) Plastic bags
10) Weighing scale
11) Borer

3.3.3 Laboratory equipments and Chemical substance consisted of the following items:

1) Glasses
2) Oven
3) Shaker
4) C/N Corder (Yanaco)
5) Grinder
6) pH meter
7) Hydrometer
8) Spectrophotometer
9) ICP
10) Conductivity meter

11) Kjeldahl distillation apparatus
12) Digestion system
13) Sieve plate No.10 (2 mm.)
14) Chemical substances

3.4 Methods

3.4.1 Plot size and Sample collection

Random sampling method (63) was selected for this research. Carbon sequestration of Cassava and Para rubber plantations were estimated from total biomass and soil organic carbon in Cassava and Para rubber plantations.

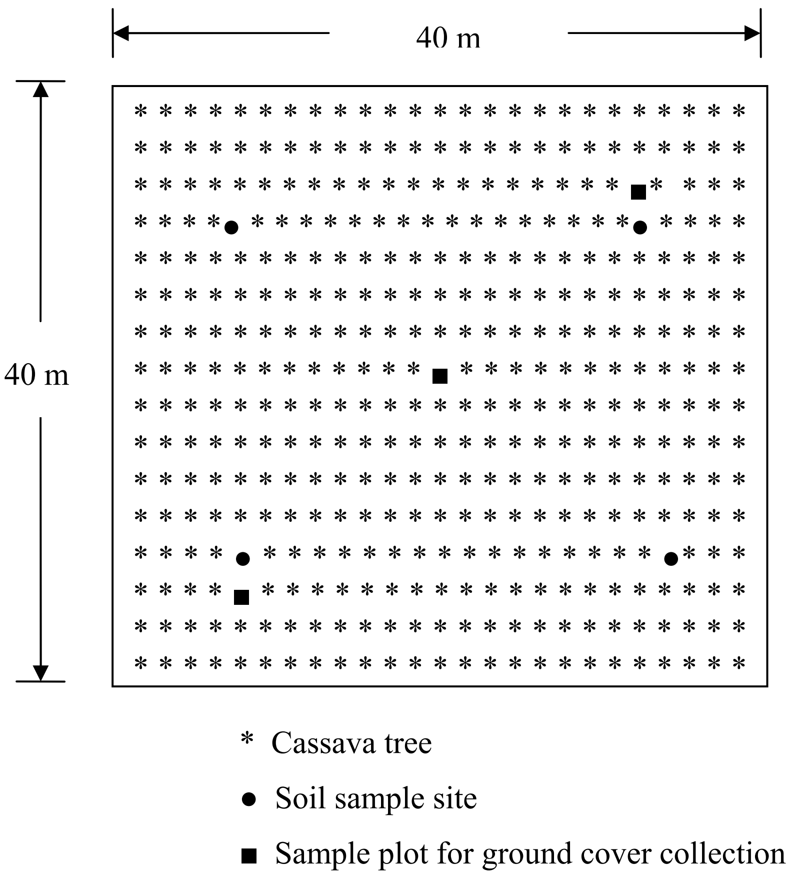

Figure 3-1 The characteristics of Cassava sample plot

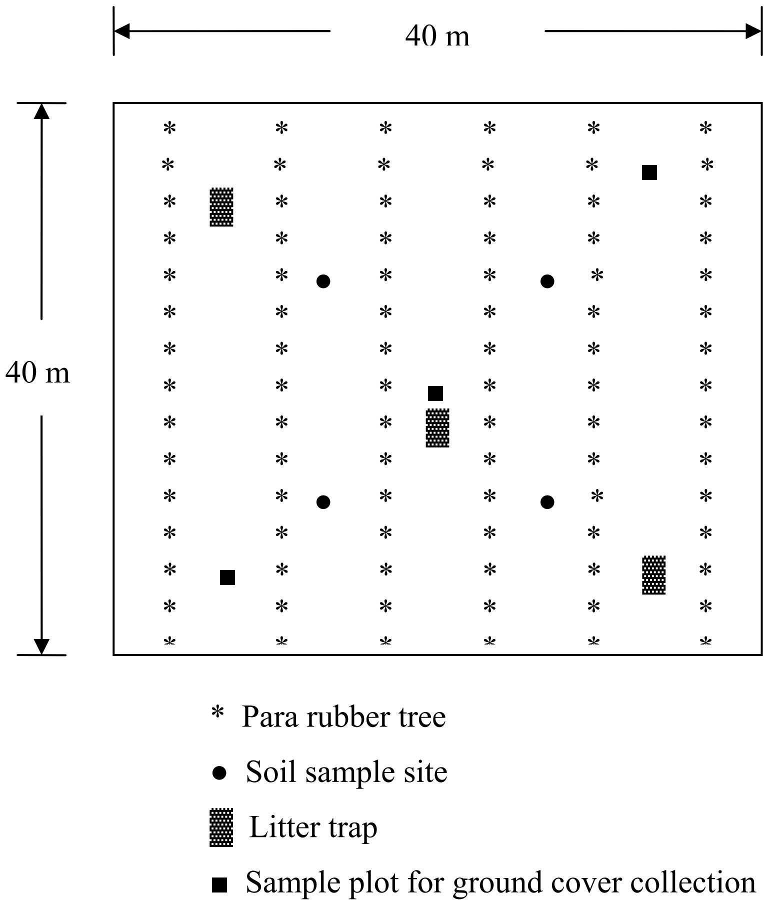

Figure 3-2 The characteristics of Para rubber sample plot

3.4.1.1 Biomass

1) Cassava

The samples were collected from 3 sample plots. Each sample plot was at the size of 40×40 m^2. The total weight of Cassava, which consisted of stem, leaves and roots, were collected and converted into total biomass of each sample plots in the second data collection for the biomass of Cassava in one yield crop.

2) Para rubber

The samples were collected from 3 sample plots. Each sample plot was at the size of 40×40 m^2. The biomass of Para rubber in both data collections were estimated by allometric equations, which needed the data of DBH (1.30 m) and height of Para rubber tree in each sample plot. The height of Para rubber tree was measured and calculated with Haga hypsometer for 10% of the whole tree in each sample plot.

Then, data used to make the equation to find out the height of each tree in the sample plot from the relevant of DBH and height by regression equations.

3) Ground cover

The samples of ground cover were collected in Cassava and Para rubber plantations in both data collections. The samples were collected from 3 sub plots of each sample plot. Each sub plot was in the size of 1×1 m^2.

4) Litter fall

The samples of litter fall, which had only in Para rubber plantation, were collected in both data collections. The duration of litter fall trapping of each data collection was 1 month. The samples were collected from 3 litter traps of each sample plot. Each trap was at the size of 1×1 m^2.

3.4.1.2 Soil

The soil samples were collected from both plantation areas. The samples were collected from 3 sample plots and collected for 4 replications in each sample plot by Composite sampling method (64). The soil samples were collected at A_p horizon (0-15 cm) and B horizon (15-30 cm) for physical and chemical analysis.

3.4.2 Sample analysis

3.4.2.1 Percentage of carbon content analysis

Some samples of stem, leaves, branches and roots of Cassava and Para rubber trees were collected to estimate percentage of carbon content in each part of tree by C/N corder (Yanaco).

3.4.2.2 Biomass analysis

1) Cassava

The samples of stem, leaves, branches, and roots of Cassava for biomass analysis were dried at 85°C in the oven for 24 hours or until the weight was constant to estimate weight of biomass.

2) Para rubber

Allometric equations were used to estimate biomass of each part of Para rubber tree, which consisted of stem, leaves, branches and roots. Those equations were the relevance between square diameter and height (D^2H), and biomass of each part of Para rubber tree, which referred to the study of Witthawatchutikul and Jirasuktaveekul (51); Bangjan (54); and Yoosuk (55) who modified the allometic equation of root from Bangjan (54).

Table 3-1 Allometric equation for biomass estimation in Para rubber tree.

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

Source: Witthawatchutikul and Jirasuktaveekul (51), Bangjan (54) and Yoosuk (55)

3) Ground cover and Litter fall

The samples of ground cover and litter fall of Cassava and Para rubber plantations for biomass analysis were dried at 85°C in the oven for 24 hours or until the weight was constant. Then estimate weight of biomass by the following equations:

$$\%\ \text{Moisture} = \frac{(\text{weight of fresh mass} - \text{weight of dry mass})}{\text{weight of dry mass}} \times 100$$

$$\text{Weight of dry mass (or biomass)} = \frac{100 \times \text{weight of fresh mass}}{\%\ \text{Moisture} + 100}$$

3.4.2.3 Soil analysis

Soil samples were dried by opened dry air about one week for Texture distribution and Chemical analysis. Next grinded the soil samples until the entire quantity passed through 2 mm sieve. Then the soil samples were taken for the following analysis:

1) Physical properties analysis for Soil Texture.

2) Chemical properties analysis for Soil Reaction (pH), Electrical Conductivity (ECe), Soil Organic Matter (SOM), %Organic Carbon (%OC), Cation Exchange Capacity (CEC), Total Nitrogen (N), Available Phosphorus (avai.P) and Soluble Potassium (sol.K).

3) Collected soil core for Soil Bulk Density analysis.

Table 3-2 Method of Soil Properties Analysis

Parameter	Method
Soil Texture	Hydrometer method
Bulk Density : D_b	D_b = Dry mass (g) / Total of soil volume (cm^3)
Soil Moisture : %Pw	% by weigh = ((weight before dry – weight after dry)/ weight after dry) × 100
Soil Reaction : pH	Peech method (1965)
Electrical Conductivity : ECe	Tiumrat and group method (2000)
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* pH7)
Total Nitrogen : N	Bremner method (1965)
Available Phosphorus : avai.P	Bray and Kurt method (1945)
Soluble Potassium : sol.K	Jackson method (1958)

Source: Monjaroen and Sangounsappayakorn (64)

3.5 Carbon Content Estimation

Carbon contents were estimated from plant biomass and %Organic Matter in Cassava and Para rubber plantations, which were estimated from the following:

3.5.1 Carbon content of Cassava and Para rubber trees

Carbon content of Cassava and Para rubber trees were estimated by the summation of carbon content of each part of tree. The carbon content of each part of tree was calculated by the multiplication of biomass of each part of tree (stems, leaves, branches, and roots) and the percentage of carbon content of each part of tree as described by the following equation:

$$C_T = C_S + C_L + C_B + C_R$$

$$C_S = \%\text{carbon of stem} \times M_S$$

$$C_L = \%\text{carbon of leaf} \times M_L$$

$$C_B = \%\text{carbon of branch} \times M_B$$

$$C_R = \%\text{carbon of root} \times M_R$$

Where as;

Where as;	C_T	Total carbon of trees (kg/rai)
	C_S	Total carbon of stems (kg/rai)
	C_L	Total carbon of leaves (kg/rai)
	C_B	Total carbon of branches (kg/rai)
	C_R	Total carbon of roots (kg/rai)
	M_S	Biomass of stems (kg/rai)
	M_L	Biomass of leaves (kg/rai)
	M_B	Biomass of branches (kg/rai)
	M_R	Biomass of roots (kg/rai)

3.5.2 Carbon content of soil surface

Carbon content of soil surface was consisted of ground cover and litter fall. The carbon content of soil surface was calculated by the multiplication of total biomass of ground cover and litter fall with 0.5 (23) as described by the following equation:

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

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

Where as;

M_{SS} Total biomass of ground cover and litter fall on soil surface (kg/rai)

M_{GL} Biomass of ground cover (kg/rai)

M_{LF} Biomass of litter fall (kg/rai)

C_{SS} Total carbon of ground cover and litter fall on soil surface (kg/rai)

3.5.3 Carbon content of soil

Soil carbon content of A_p-B horizon was calculated by the summation of soil carbon content of each layer, which was calculated by multiplication of percentage of organic carbon of each soil layer (A_p and B horizon) with soil bulk density and volume of soil of each layer as described by the following equation:

$$C_{Ap} = \%OC \text{ of } A_p \text{ horizon} \times D_{Ap} \times V_{Ap}$$

$$C_B = \%OC \text{ of B horizon} \times D_B \times V_B$$

$$C_{Soil} = C_{Ap} + C_B$$

Where as;

C_{Ap} Soil carbon of A_p horizon (kg/rai)

C_B Soil carbon of B horizon (kg/rai)

D_{Ap} Soil bulk density of A_p horizon per rai

D_B Soil bulk density of B horizon per rai

V_{Ap} Soil volume of A_p horizon per rai

V_B Soil volume of B horizon per rai

C_{Soil} Total soil carbon of A_p-B_1 horizon (kg/rai)

3.5.4 Total carbon content of Cassava and Para rubber plantations

Total carbon content of Cassava and Para rubber plantations were calculated by the summation of total carbon of trees, total carbon of ground cover and litter fall on soil surface, and total soil carbon of A_p-B horizon of each plantation. as described by the following equation:

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

Where as: C_{Total} Total carbon of Cassava/ Para rubber plantations (kg/rai)

C_T Total carbon of trees (kg/rai)

C_{SS} Total carbon of ground cover and litter fall on soil surface (kg/rai)

C_{Soil} Total soil carbon of A_p-B horizon (kg/rai)

3.6 Statistical Analysis

This research described the soil properties by employed Pair Samples T-Test.

CHAPTER 4
RESULTS AND DISCUSSION

This study was focused on the estimation of carbon sequestration in the biomass of plant which consisted of stems, branches, leaves and roots, biomass of litter fall and ground cover on soil surface, and carbon deposit in soil. Moreover the physical and chemical properties of soil in the study area of Cassava and Para rubber plantations were analyzed. The samples of plant and soil in both study areas were collected in June, 2004 represented the first data collection and in November, 2004 represented the second data collection. The samples in both plantations were collected from 3 sample plots. The size of each sample plot was 40×40 m^2 and each sample plot had 3 sub plots of 1×1 m^2 for ground cover and litter fall data collections. The results of this study were detailed as the following:

4.1 Biomass

4.1.1 Biomass of Cassava plantation

The samples of Cassava plantation were estimated in one crop yield; therefore, the data of Cassava were planed to collect only in the second data collection, which was in the harvested stage. The biomass of Cassava plantation in the harvested stage was separated into 2 parts, aboveground biomass (stems and leaves) and below ground biomass (roots). The data were collected from 3 sub plots of each main plot. The spacing was 100 cm × 50 cm. Table 4-1 presented the total biomass of Cassava in the harvested stage.

Figure 4-1 Cassava plantation

Table 4-1 Biomass of Cassava plantation in one crop yield

Plot		Plot 1	Plot 2	Plot 3	Average
Fresh weight (kg/rai)	Stems	1036.80	1434.88	1217.44	1229.71
	Leaves	106.72	130.40	282.56	173.23
	Roots	4884.80	5804.96	5848.32	5512.69
Biomass (kg/rai)	Stems	289.29	458.27	349.06	365.54
	Leaves	30.11	42.83	79.23	50.72
	Roots	1692.17	1814.50	2246.42	1917.70
Total (kg/rai)		2011.57	2315.60	2674.71	2333.96

The biomass of Cassava plantation in one crop yield was identified as the following (Table 4-1):

The average total biomass of Cassava was about 2333.96 kg/rai. The part of Cassava that had maximum average biomass were roots 1917.70 kg/rai, stems 365.54 kg/rai and leaves 50.72 kg/rai, respectively. The results of this study found that the average biomass of roots in the study area was less than Thailand's average yield crop of Cassava in 1995, 2,209 kg/rai, which was reported in the Production Year Book of FAO (66).

4.1.2 Biomass of Para rubber plantation

Biomass of Para rubber trees of this study were estimated by allometric equation. The Para rubber plantation, which was the representative of this study, was planted in the spacing of 3 m × 6 m (78 stems/rai). The study of Para rubber tree biomass was separated into 2 parts, aboveground biomass (stems, branches and leaves) and below ground biomass (roots). Table 4-2 and Table 4-3 presented the average DBH and height of sample plots, including the total biomass of Para rubber trees of the first and the second data collections calculated by allometric equation.

Figure 4-2 Para rubber plantation

Table 4-2 Biomass of Para rubber plantation of the first data collection

Parameter		Plot			Average
		A	B	C	
Average	Perimeter (cm)	84.54	81.74	83.73	83.34
	Diameter (cm)	26.90	26.01	26.64	26.52
	Height (m)	14.50	15.84	15.07	15.14
Biomass (kg/rai)	Stems	13,415.22	13,766.27	13,875.49	13,685.66
	Branches	6,861.13	7,127.43	7,218.59	7,069.05
	Leaves	1,667.41	1,702.28	1,712.59	1,694.09
	Roots	4,137.15	4,218.42	4,242.11	4,199.23
	Total	26,080.91	26,814.40	27,048.78	26,648.03

Table 4-3 Biomass of Para rubber plantation of the second data collection

Parameter		Plot			Average
		A	B	C	
Average	Perimeter (cm)	85.17	82.36	84.34	83.96
	Diameter (cm)	27.10	26.21	26.84	26.72
	Height (m)	14.72	16.05	15.23	15.33
Biomass (kg/rai)	Stems	13,776.02	14,106.12	14,131.95	14,004.70
	Branches	7,106.19	7,359.28	7,387.20	7,284.22
	Leaves	1,705.61	1,738.24	1,740.22	1,728.02
	Roots	4,227.79	4,303.75	4,307.99	4,279.84
	Total	26,815.60	27,507.39	27,567.36	27,296.78

4.1.2.1 Biomass of Para rubber plantation of the first data collection

The biomass estimation of Para rubber plantation of the first data collection was identified as the following (Table 4-2):

The average DBH and total height were about 26.52 cm and 15.14 m, respectively. The averages total aboveground biomass (stems, branches and leaves) and below ground biomass (roots) of Para rubber trees were about 22,448.80 kg/rai and 4,199.23 kg/rai, respectively. The average total biomass of the first data collection was about 26,648.03 kg/rai.

4.1.2.2 Biomass of Para rubber plantation of the second data collection

The biomass estimation of Para rubber plantation of the second data collection was identified as the following (Table 4-3):

The average DBH and total height were about 26.72 cm and 15.33 m, respectively. The averages total aboveground biomass (stems, branches and leaves) and below ground biomass (roots) of Para rubber trees were about 23,016.94 kg/rai and 4,279.84 kg/rai, respectively. The average total biomass of the second data collection was about 27,296.78 kg/rai.

The results of the study indicated that the average DBH, total height and total biomass of Para rubber trees during the first and the second data collections (six months) increased 0.20 cm, 0.19 m and 648.75 kg/rai, respectively. It was agreed with the study of Bangjan (54) and Yoosuk (55) that the diameter of tree and amount of biomass were linear function with the age.

4.1.3 Biomass on soil surface

4.1.3.1 Biomass on soil surface of Cassava plantation

The study of biomass on soil surface of one crop yield in Cassava plantation found that there was only the biomass on soil surface of ground cover in the study area. The biomass of ground cover in Cassava plantation of the first and the second data collections were presented in Table 4-4.

Figure 4-3 Ground cover of Cassava plantation

Table 4-4 Biomass on soil surface of Cassava plantation

Plot	Ground cover biomass (kg/rai)		Total
	First collection	Second collection	
Plot 1	136.72	345.15	481.87
Plot 2	169.99	97.62	267.61
Plot 3	75.07	98.72	173.79
Average	127.26	180.49	307.75

According to Table 4-4, the average biomass of ground cover in Cassava plantation of the first and the second data collections were about 127.26 kg/rai and 180.49 kg/rai, respectively. The total average biomass of ground cover of one yield crop of Cassava plantation was 307.75 kg/rai. The results of the study found that the study area had less management of weed control, which was a significant factor of the decreasing yield crop of Cassava (7).

4.1.3.2 Biomass on soil surface of Para rubber plantation

The study of biomass on soil surface of Para rubber plantation for the first and the second data collections was separated into 2 parts: ground cover and litter fall. The biomass on soil surface of Para rubber plantation was presented in Table 4-5.

Figure 4-4 Ground cover of Para rubber plantation

Figure 4-5 Litter fall of Para rubber plantation

Table 4-5 Biomass on soil surface of Para rubber plantation

Data collection	Plot	Biomass on soil surface (kg/rai)		Total (kg/rai)
		Ground cover	Litter fall	
First collection	Plot A	71.40	116.16	187.56
	Plot B	32.97	43.86	76.83
	Plot C	61.02	112.95	173.97
	Average	55.13	90.99	146.12
Second collection	Plot A	39.59	200.00	239.59
	Plot B	52.25	230.43	282.68
	Plot C	26.15	300.79	326.94
	Average	39.33	243.74	283.07

According to Table 4-5, the total biomass on soil surface of the first and the second data collections were identified as the following:

For the first data collection, the total average biomass on soil surface was about 146.12 kg/rai. The average biomass on soil surface of ground cover and litter fall were 55.13 kg/rai and 90.99 kg/rai, respectively.

For the second data collection, the total average biomass on soil surface was about 283.07 kg/rai. The average biomass on soil surface of ground cover and litter fall were 39.33 kg/rai and 243.74 kg/rai, respectively.

The results of the study found that the average biomass of litter fall on soil surface of the second data collection was increased more than the first data collection, because the second collection was the falling leaves period of Para rubber trees.

4.2 Soil properties of the study areas

Three soil samples in the Cassava and Para rubber plantation areas were collected by random sampling method from each sample plot with the size of 40×40 m^2. The soil layer was separated into 2 layers which were the top soil layer between 0-15 cm depth (A_p horizon) and the subsoil layer between 15-30 cm depth (B horizon). The analysis results showed that the soil in both study plantations was Oxic Paleustults sub group or Map Bon series (Mb).

4.2.1 Physical soil properties

The characteristic of physical soil properties consisted of Soil Texture, Bulk Density (D_b) and Soil Moisture (%Moisture). Tables 4-6 and 4-8 showed the results of physical soil properties of the Cassava and Para rubber plantation areas.

4.2.1.1 Soil Texture

Soil texture is a physical property involved specifies of the other soil properties for example water holding capacity, aeration and soil strength. Soil texture can be defined by the composition of 3 different soil particle sizes, namely sand, silt and clay. The results of soil texture which were analyzed by Hydrometer method were identified as the following:

- **Cassava plantation area**

According to Figure 4-6 and Table 4-6, the percentages of the soil particles were identified that the soil texture in plot 1, both of A_p and B horizons were sandy clay; in plot 2, A_p horizon was clay loam and B horizon was clay and in plot 3, both of A_p and B horizons were clay. Consequently, all of the soil textures in Cassava plantation were classified in fine-textured soils group.

Table 4-6 The Physical soil properties of Cassava plantation area

Plot	Classified Soil (USDA, 1975)	Soil Series	Soil Horizon	Soil Texture				Soil Bulk Density (g/cm^3)		Moisture Content (%)	
				% Sand	% Silt	% Clay	Texture	First collection	Second collection	First collection	Second collection
Plot 1	Oxic Paleustults	Map Bon (Mb)	**A_P**	46.36	17.92	35.72	sandy clay	1.73	1.70	9.04	0.99
			B	44.36	17.56	38.08	sandy clay	1.75	1.59	8.32	2.61
Plot 2	Oxic Paleustults	Map Bon (Mb)	**A_P**	39.36	21.56	39.08	clay loam	1.62	1.74	9.62	1.29
			B	32.36	14.56	53.08	clay	1.71	1.46	9.47	2.10
Plot 3	Oxic Paleustults	Map Bon (Mb)	**A_P**	32.00	19.92	48.08	clay	1.60	1.65	9.38	1.66
			B	34.00	17.92	48.08	clay	1.64	1.57	8.42	2.54

Table 4-7 The Chemical soil properties of Cassava plantation area

Data collection	Soil horizon	Plot	pH	ECe (dS/m)	SOM (g/kg)	%OC	CEC (cmol/kg)	%N	P (ppm)	K (ppm)
First data collection	Ap	**Plot 1**	5.24	0.025	6.54	0.38	1.47	0.037	0.54	2.63
		Plot 2	5.14	0.027	5.40	0.31	1.49	0.037	0.53	2.50
		Plot 3	5.22	0.054	6.66	0.39	2.09	0.035	0.59	5.65
		Average	5.20	0.035	6.20	0.36	1.68	0.037	0.55	3.59
	B	**Plot 1**	5.30	0.022	6.09	0.35	1.64	0.035	0.34	2.33
		Plot 2	5.38	0.025	5.51	0.32	1.80	0.028	0.29	3.10
		Plot 3	5.58	0.032	5.40	0.31	1.89	0.047	0.54	4.68
		Average	5.42	0.026	5.67	0.33	1.78	0.037	0.39	3.37
Second data collection	Ap	**Plot 1**	6.00	0.016	8.14	0.47	1.64	0.042	0.35	3.94
		Plot 2	5.87	0.029	11.17	0.65	1.92	0.054	0.49	5.27
		Plot 3	5.84	0.026	12.60	0.73	2.03	0.056	1.24	5.62
		Average	5.90	0.023	10.64	0.62	1.86	0.051	0.69	4.94
	B	**Plot 1**	6.05	0.018	7.91	0.46	2.06	0.042	0.30	3.65
		Plot 2	5.81	0.026	8.59	0.50	1.72	0.049	0.46	4.93
		Plot 3	5.79	0.020	10.48	0.61	1.95	0.049	0.97	5.78
		Average	5.88	0.021	8.99	0.52	1.91	0.047	0.58	4.79

Table 4-8 The Physical soil properties of Para rubber plantation area

Plot	Classified Soil (USDA, 1975)	Soil Series	Soil Horizon					Soil Bulk Density (g/cm^3)		Moisture Content (%)	
				% Sand	% Silt	% Clay	Texture	First collection	Second collection	First collection	Second collection
Plot A	Oxic Paleustults	Map Bon (Mb)	**A_P**	37.36	24.92	37.72	clay loam	1.33	1.50	17.07	3.93
			B	37.36	24.92	37.72	clay loam	1.48	1.62	32.15	5.56
Plot B	Oxic Paleustults	Map Bon (Mb)	**A_P**	47.36	4.92	47.72	sandy clay	1.65	1.53	9.75	4.01
			B	47.36	14.92	37.72	sandy clay	1.73	1.58	13.57	5.43
Plot C	Oxic Paleustults	Map Bon (Mb)	**A_P**	53.36	14.92	31.72	sandy clay loam	1.74	1.67	13.36	3.10
			B	46.36	17.92	35.72	sandy clay	1.84	1.60	11.94	4.22

Table 4-9 The Chemical soil properties of Para rubber plantation area

Data collection	Soil horizon	Plot	pH	ECe (dS/m)	SOM (g/kg)	%OC	CEC (cmol/kg)	%N	P (ppm)	K (ppm)
First data collection	Ap	Plot A	5.40	0.021	5.51	0.32	1.75	0.047	0.22	5.25
		Plot B	5.46	0.030	8.04	0.47	1.95	0.056	0.26	5.63
		Plot C	5.99	0.025	5.40	0.31	1.47	0.047	0.36	7.99
		Average	5.62	0.025	6.32	0.37	1.72	0.050	0.28	6.29
	B	Plot A	5.24	0.020	5.05	0.29	1.75	0.040	0.15	3.27
		Plot B	5.17	0.019	4.13	0.24	1.69	0.037	0.15	4.83
		Plot C	5.18	0.018	4.59	0.27	1.69	0.033	0.19	5.00
		Average	5.20	0.019	4.59	0.27	1.71	0.037	0.16	4.37
Second data collection	Ap	Plot A	6.13	0.022	13.17	0.76	2.31	0.054	0.23	8.12
		Plot B	6.10	0.021	10.36	0.60	1.97	0.051	0.28	6.22
		Plot C	6.52	0.027	10.81	0.63	2.09	0.051	0.39	8.41
		Average	6.25	0.023	11.45	0.66	2.12	0.052	0.30	7.58
	B	Plot A	5.20	0.019	7.79	0.45	2.06	0.042	0.19	5.56
		Plot B	5.05	0.020	9.25	0.54	2.43	0.047	0.18	5.45
		Plot C	4.97	0.020	6.68	0.39	2.06	0.037	0.13	5.70
		Average	5.07	0.020	7.91	0.46	2.18	0.042	0.17	5.57

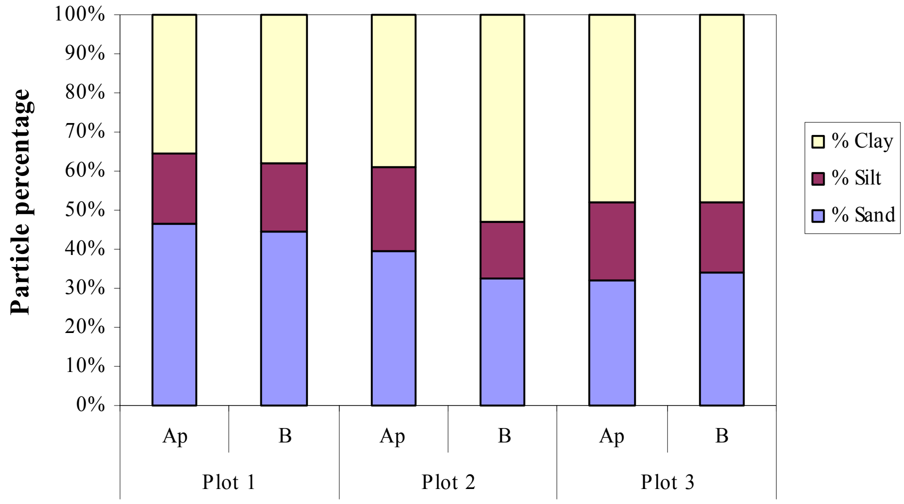

Figure 4-6 Soil particle percentage of Cassava plantation area

- **Para rubber plantation area**

According to Figure 4-7 and Table 4-7, the percentages of the soil particles were identified that the soil texture in plot A, both of A_p and B horizons were clay loam; in plot B, both of A_p and B horizons were sandy clay and in plot C, A_p horizons was sandy clay loam and B horizons was sandy clay. Consequently, most of soil textures of Para rubber plantation area were classified in fine-textured soils group and the rest was in medium-textured soils group.

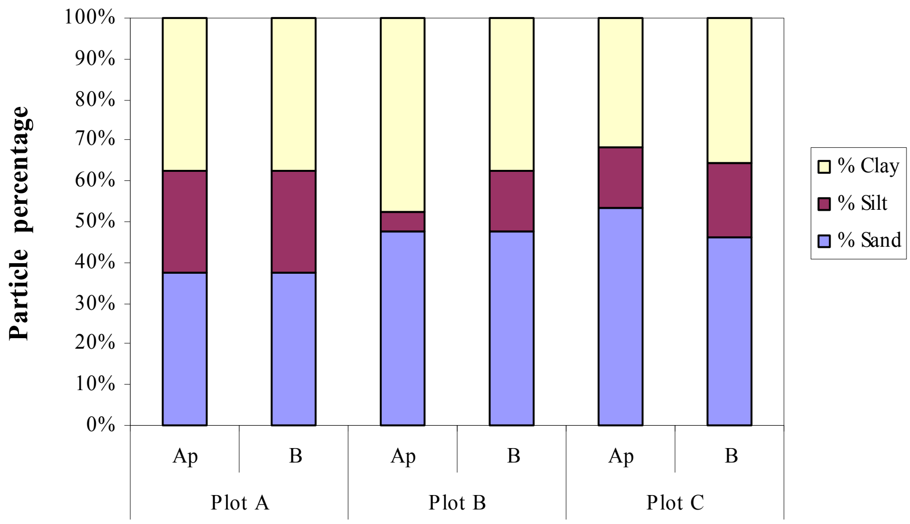

Figure 4-7 Soil particle percentage of Para rubber plantation area

4.2.1.2 Soil Bulk Density: D_b

- **Cassava plantation area**

According to Figure 4-8 and Table 4-6, for the first data collection, the maximum and minimum D_b values of A_p horizon were 1.73 g/cm^3 and 1.60 g/cm^3, respectively. The maximum and minimum D_b values of B horizon were 1.75 g/cm^3 and 1.64 g/cm^3, respectively. For the second data collection, the maximum and minimum D_b values of A_p horizon were 1.74 g/cm^3 and 1.65 g/cm^3, respectively. The maximum and minimum D_b values of B horizon were 1.59 g/cm^3 and 1.46 g/cm^3, respectively.

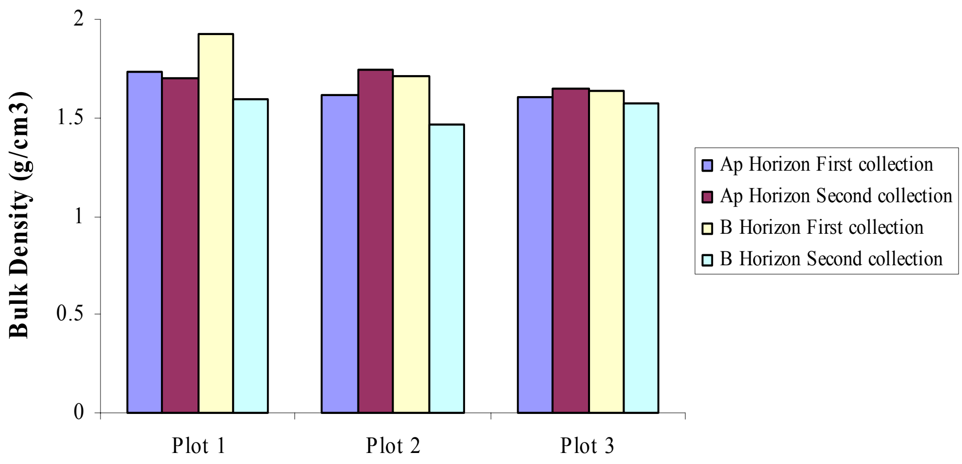

Figure 4-8 Soil Bulk density of Cassava plantation area

For the first data collection, which was rainy season, the D_b values in B horizon of Cassava plantation were higher than A_p horizon because the rain leached light clay particle to accumulate in B horizon. The soil mass increased that resulted to the D_b values was also increased.

The statistic analysis of D_b values in A_p horizon of Cassava plantation between the first and the second data collections (Table A-1) were not significantly difference. Whereas, the statistic analysis of D_b values in B horizon of Cassava plantation between the first and the second data collections (Table A-2) found that D_b values of the first collection were higher than the second data collection with the statistical level of significant ($P<0.05$).

- **Para rubber plantation area**

According to Figure 4-9 and Table 4-8, for the first data collection, the maximum and minimum D_b values of A_p horizon were 1.74 g/cm^3 and 1.33 g/cm^3, respectively. The maximum and minimum D_b values of B horizon were 1.84 g/cm^3 and 1.48 g/cm^3, respectively. For the second data collection, the maximum and minimum D_b values of A_p horizon were 1.67 g/cm^3 and 1.50 g/cm^3, respectively. The maximum and minimum D_b values of B horizon were 1.62 g/cm^3 and 1.58 g/cm^3, respectively.

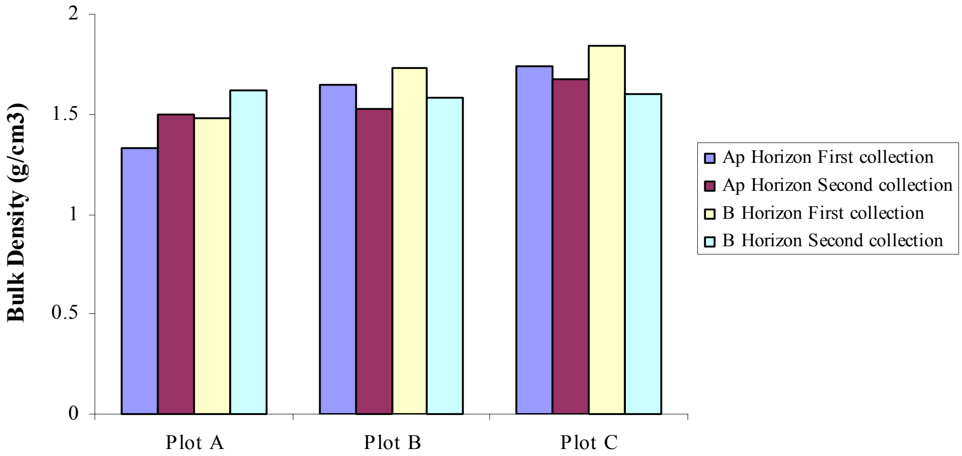

Figure 4-9 Soil Bulk density of Para rubber plantation area

For the first data collection, which was rainy season, the D_b values in B horizon of Para rubber plantation area were higher than A_p horizon because it was rainy season thus the rain leached light clay particle to accumulate in B horizon. The soil mass increased that resulted to the D_b values was also increased.

The statistic analysis of soil bulk density of Para rubber plantation between the first and the second data collections of both horizons (Table A-3 and A-4) were not significantly difference.

4.2.1.3 Soil Moisture: %Moisture

- **Cassava plantation area**

According to Figure 4-10 and Table 4-6, for the first data collection, the maximum and minimum moisture percentage values of A_p horizon were 9.62 and 9.04, respectively. The maximum and minimum moisture percentage values of B horizon were 9.47 and 8.32, respectively. For the second data collection, the maximum and minimum moisture percentage values of A_p horizon were 1.66 and 0.99, respectively. The maximum and minimum moisture percentage values of B horizon were 2.61 and 2.10, respectively.

The statistic analysis of moisture percentage values of Cassava plantation between the first and the second data collections of both horizons (Table A-1 and A-2) found that the moisture percentage values in the first data collection, which was rainy season, were higher than the second data collection, which was dry season, with the statistic level of significant ($P<0.05$). Accordingly, all of soil textures in Cassava plantation were in fine-textured soils group that had high water holding capacity (67).

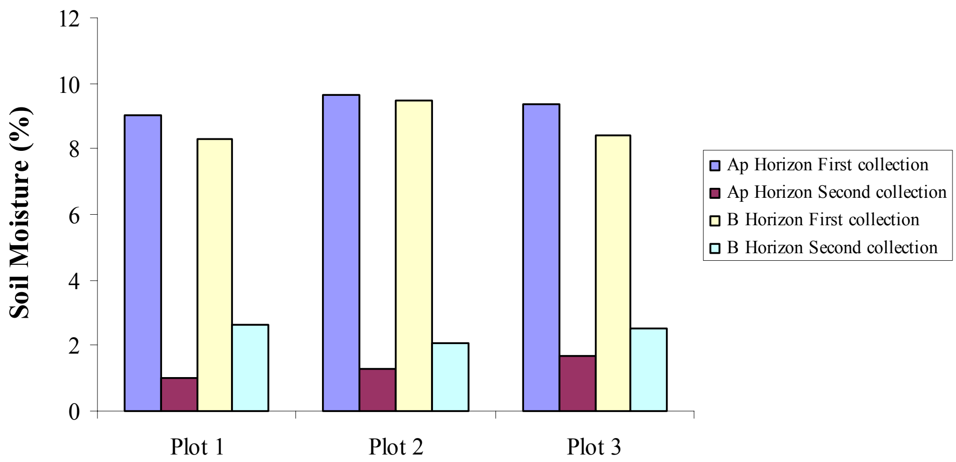

Figure 4-10 Soil Moisture of Cassava plantation area

- **Para rubber plantation area**

According to Figure 4-11 and Table 4-8, for the first data collection, the maximum and minimum moisture percentage values of A_p horizon were 17.07 and 13.36, respectively. The maximum and minimum moisture percentage values of B horizon were 32.15 and 11.94, respectively. For the second data collection, the maximum and minimum moisture percentage values of A_p horizon were 4.01 and 3.10, respectively. The maximum and minimum moisture percentage values of B horizon were 5.56 and 4.22, respectively.

The statistic analysis of moisture percentage values of Para rubber plantation between the first and the second data collections of both horizons (Table A-3 and A-4) found that the moisture percentage values of the first data collection, which was rainy season, were higher than the second data collection, which was dry season, with the statistic level of significant (P<0.05). Accordingly, most of soil textures in Para rubber plantation were in fine-textured soils group that had high water holding capacity (67).

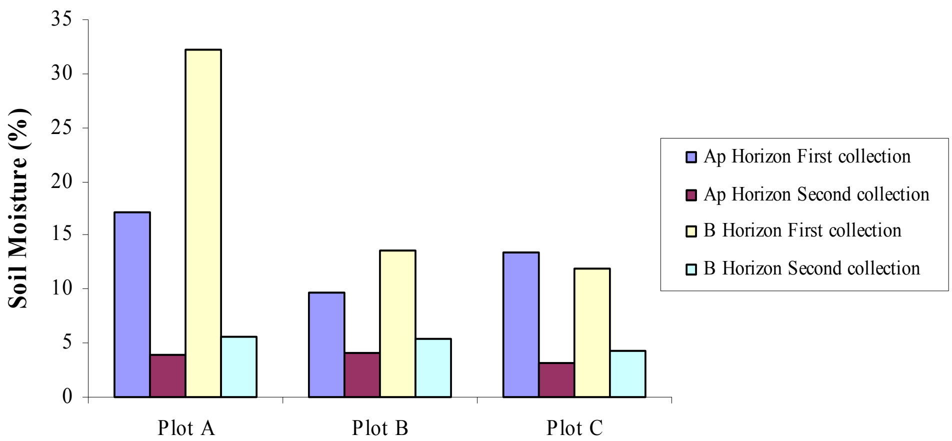

Figure 4- 11 Soil Moisture of Para rubber plantation area

4.2.2 Chemical soil properties

The characteristic of chemical soil properties consisted of Soil Reaction (pH), Electrical Conductivity (ECe), Soil Organic Matter (SOM), % Organic Carbon (OC), Cation Exchange Capacity (CEC), Total Nitrogen (N), Available Phosphorus (avai.P) and Soluble Potassium (sol.K). Tables 4-7 and 4-9 showed the results of chemical soil properties of Cassava and Para rubber plantations. The results were identified as the following:

4.2.2.1 Soil Reaction: pH

The soil reaction in the study areas were analyzed by pH meter measured the soil sample with 1:1 of soil and water.

- **Cassava plantation**

According to Figure 4-12 and Table 4-7, for the first data collection, the maximum and minimum pH values of A_p horizon were 5.24 and 5.14, respectively. The maximum and minimum pH values of B horizon were 5.58 and 5.30, respectively. For the second data collection, the maximum and minimum pH values of A_p horizon were 6.00 and 5.84, respectively. The maximum and minimum pH values of B horizon were 6.05 and 5.79, respectively.

The statistic analysis of pH values of Cassava plantation between the first and the second data collections which were in rainy and dry seasons of both horizons (Table A-5 and A-6) found that the pH values of the second data collection was increased more than the first collection with the statistic level of significant ($P<0.05$).

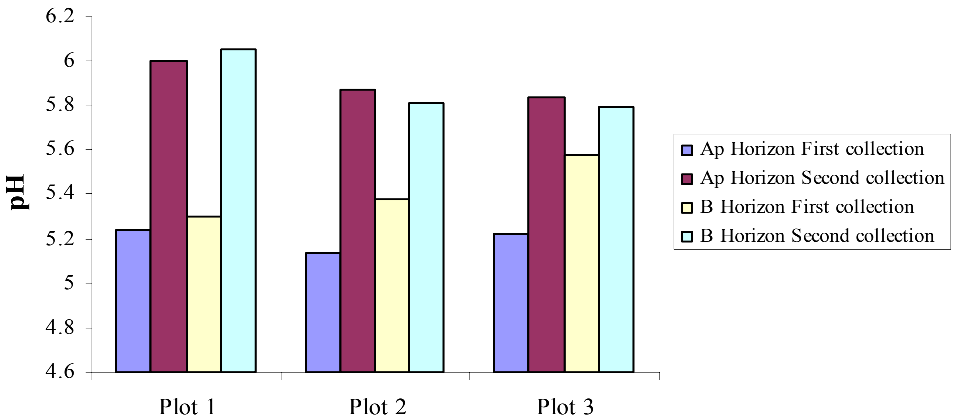

Figure 4-12 Soil pH of Cassava plantation area

The results found that the soil reaction of Cassava plantation of the study areas were strongly acid in rainy season and moderately acid in dry season (67). Because the decreasing of soil moisture in dry season had an effect to the decomposition rate of organic matter in soil, thus the acidity of soil of the second data collection decreased (67).

- **Para rubber plantation**

According to Figure 4-13 and Table 4-9, for the first data collection, the maximum and minimum pH values of A_p horizon were 5.99 and 5.40, respectively. The maximum and minimum pH values of B horizon were 5.24 and 5.17, respectively. For the second data collection, the maximum and minimum pH values of A_p horizon were 6.54 and 6.10, respectively. The maximum and minimum pH values of B horizon were 5.20 and 4.97, respectively.

The statistic analysis of pH values of Para rubber plantation between the first and the second data collections which were in rainy and dry seasons of Ap horizon (Table A-7) found that the pH values in the second data collection was increased more than the first data collection with the statistic level of significant ($P<0.05$). Whereas, pH values of B horizon (Table A-8) of the second data collection were lower than the first data collection with the statistic level of significant ($P<0.05$).

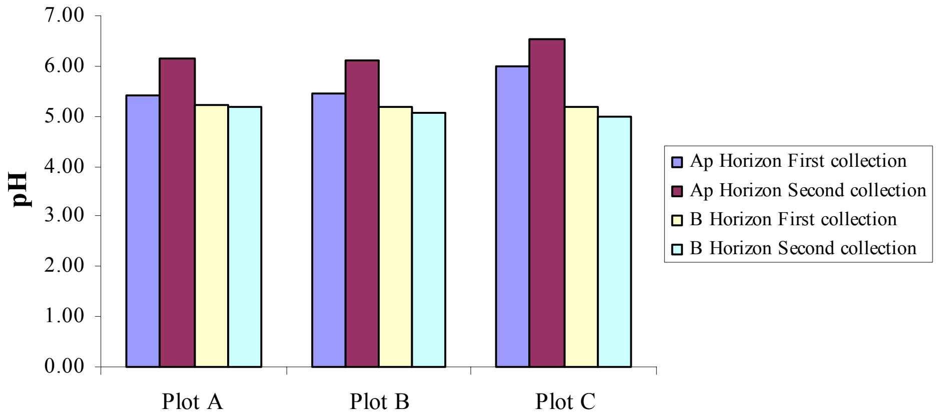

Figure 4-13 Soil pH of Para rubber plantation area

The results of the study found that the decreasing of soil moisture in the second data collection, which was dry season, had an effect to the decomposition rate of organic matter in soil, thus the acidity of soil of the second data collection of A_p horizon decreased (67).

4.2.2.2 Electrical Conductivity: ECe

The Electrical Conductivity (ECe) was analyzed by Conductivity meter.

- **Cassava plantation area**

According to Figure 4-14 and Table 4-7, for the first data collection, the maximum and minimum ECe values of A_p horizon were 0.054 dS/m and 0.025 dS/m, respectively. The maximum and minimum ECe values of B horizon were 0.032 dS/m and 0.022 dS/m, respectively. For the second data collection, the maximum and minimum ECe values of A_p horizon were 0.029 dS/m and 0.016 dS/m, respectively. The maximum and minimum ECe values of B horizon were 0.026 dS/m and 0.018 dS/m, respectively.

The statistic analysis of ECe values of Cassava plantation between the first and the second data collections, which were in rainy and dry seasons, of A_p horizon (Table A-5) found that the ECe values of the first data collection were higher than the second data collection with the statistic level of significant (P<0.05). But in B horizon (Table A-6) were not significant.

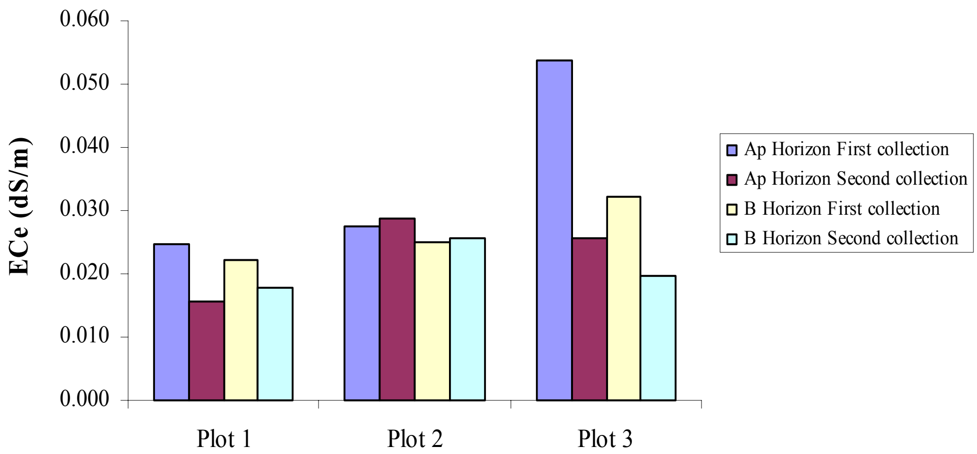

Figure 4-14 Soil Electrical Conductivity of Cassava plantation area

- **Para rubber plantation area**

According to Figure 4-15 and Table 4-9, for the first data collection, the maximum and minimum ECe values of A_p horizon were 0.030 dS/m and 0.021 dS/m, respectively. The maximum and minimum ECe values of B horizon were 0.020 dS/m and 0.018 dS/m, respectively. For the second data collection, the maximum and minimum ECe values of A_p horizon were 0.027 dS/m and 0.021 dS/m, respectively. The maximum and minimum ECe values of B horizon were 0.020 dS/m and 0.019 dS/m, respectively.

The statistic analysis of ECe values of Para rubber plantation between the first and the second data collections of both horizons (Table A-7 and A-8) were not significant.

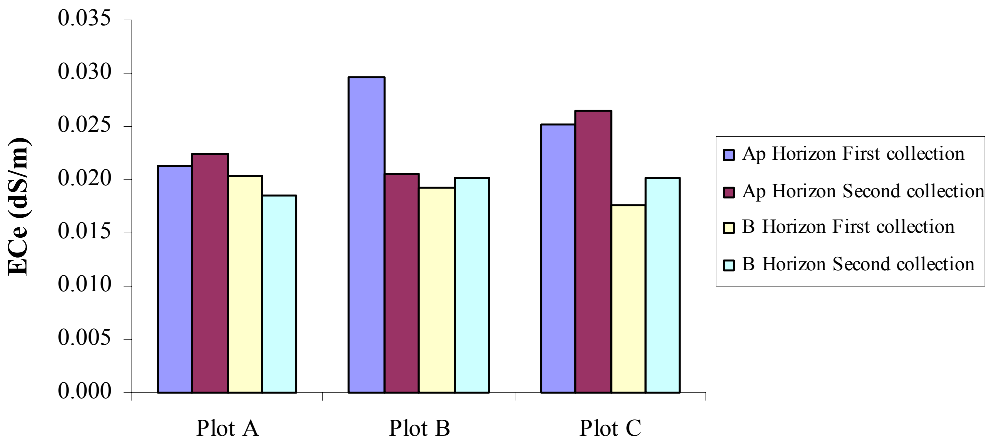

Figure 4-15 Soil Electrical Conductivity of Para rubber plantation area

In both plantation areas, the ECe values of the first data collection, which was in rainy season, were higher than the second data collection, which was in dry season, because some elements could be more dissolved into soil in rainy season. Fertilizer application was also another cause of the increasing of ECe values. From such results and the results of ECe values, it could be concluded that the soil of both plantation areas were not affected by salt (67).

4.2.2.3 Soil Organic Matter: SOM

The organic matter of soil consists of animal, plant and microbial residues in various stages of decay. The soil organic matter (SOM) was analyzes by Walkley and Black method (SOM (g/kg) = %OC × 1.724 × 10) (65).

- **Cassava plantation area**

According to Figure 4-16 and Table 4-7, for the first data collection, the maximum and minimum SOM values of A_p horizon were 6.66 g/kg and 5.40 g/kg, respectively. The maximum and minimum SOM values of B horizon were 6.09 g/kg and 5.40 g/kg, respectively. For the second data collection, the maximum and minimum SOM values of A_p horizon were 12.60 g/kg and 8.14 g/kg, respectively. The maximum and minimum SOM values of B horizon were 10.48 g/kg and 7.91 g/kg, respectively.

The statistic analysis of SOM values of Cassava plantation between the first and the second data collections of both horizons (Table A-5 and A-16) found that SOM values in the second data collection increased more than the first data collection with the statistic level of significant ($P<0.05$).

The results of the study found that when the Cassava trees grew up, the organic matter deposit in soil within Cassava plantation area was increased. Therefore, gathering of plant residues in soil during the growth period of Cassava was increased accordingly.

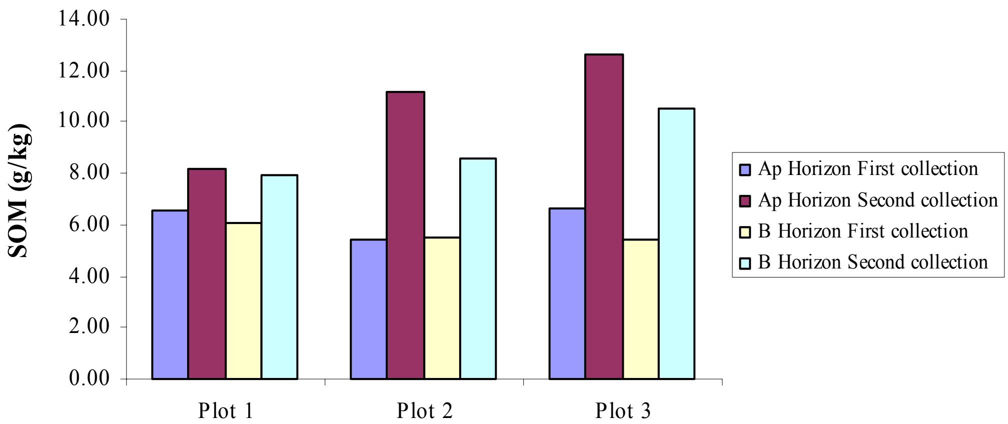

Figure 4-16 Soil Organic Matter of Cassava plantation area

- **Para rubber plantation area**

According to Figure 4-17 and Table 4-9, for the first data collection, the maximum and minimum SOM values of A_p horizon were 8.04 g/kg and 5.40 g/kg, respectively. The maximum and minimum SOM values of B horizon were 5.05 g/kg and 4.13 g/kg, respectively. For the second data collection, the maximum and minimum SOM values of A_p horizon were 13.17 g/kg and 10.36 g/kg, respectively. The maximum and minimum SOM values of B horizon were 9.25 g/kg and 6.68 g/kg, respectively.

The statistic analysis of SOM values of Para rubber plantation between the first and the second data collections of both horizons (Table A-7 and A-8) found that SOM values of the second data collection was increased more than the first data collection with the statistic level of significant ($P<0.05$).

The results of the study found that soil organic matter of Para rubber plantation increased in the second data collection because of the increasing of litter fall in the falling leaves stage of Para rubber trees.

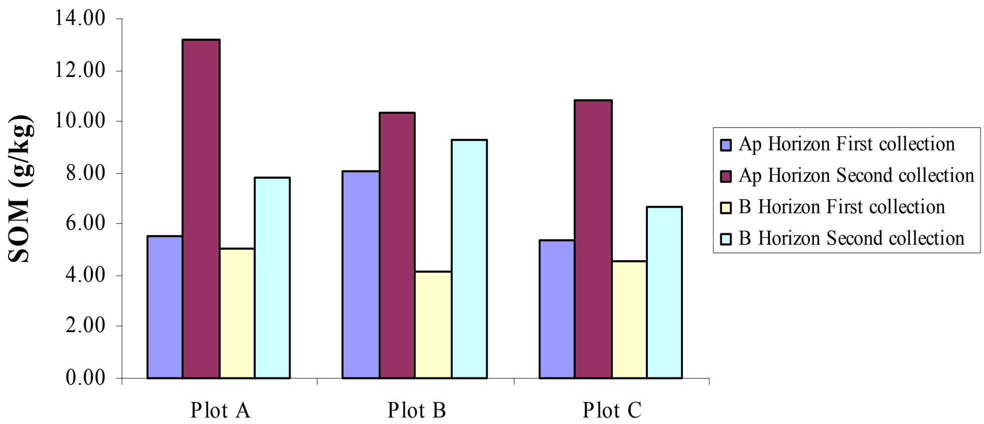

Figure 4-17 Soil Organic Matter of Para rubber plantation area

4.2.2.4 Organic Carbon: OC

The percentage of soil organic carbon (%OC) was analyzed by Walkley and Black method (65).

- **Cassava plantation area**

According to Figure 4-18 and Table 4-7, for the first data collection, the maximum and minimum %OC values of A_p horizon were 0.39 and 0.31, respectively. The maximum and minimum %OC values of B horizon were 0.35 and 0.31, respectively. For the second data collection, the maximum and minimum %OC values of A_p horizon were 0.73 and 0.47, respectively. The maximum and minimum %OC values of B horizon were 0.61 and 0.46, respectively.

The statistic analysis of %OC values of Cassava plantation between the first and the second data collections (Table A-5 and A-6) found that %OC values of the second data collection increased more than the first data collection with the statistic level of significant ($P<0.05$).

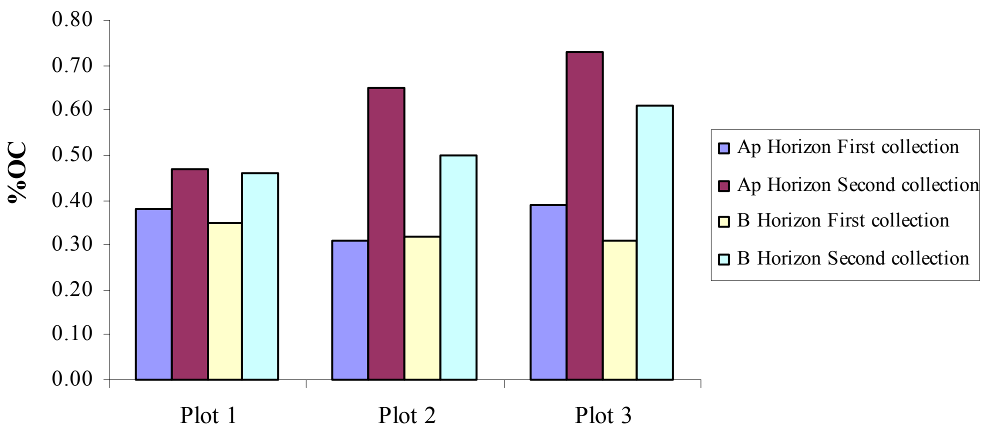

Figure 4-18 Soil Organic Carbon of Cassava plantation area

- **Para rubber plantation area**

According to Figure 4-19 and Table 4-9, for the first data collection, the maximum and minimum %OC values of A_p horizon were 0.47 and 0.31, respectively. The maximum and minimum %OC values of B horizon were 0.29 and 0.24, respectively. For the second data collection, the maximum and minimum %OC values of A_p horizon were 0.76 and 0.60, respectively. The maximum and minimum %OC values of B horizon were 0.54 and 0.39, respectively.

The statistic analysis of %OC values of Para rubber plantation between the first and the second data collections, which were rainy season and dry seasons of both horizons (Table A-7 and A-8) found that %OC values of the second data collection was increased more than the first data collection with the statistic level of significant ($P<0.05$).

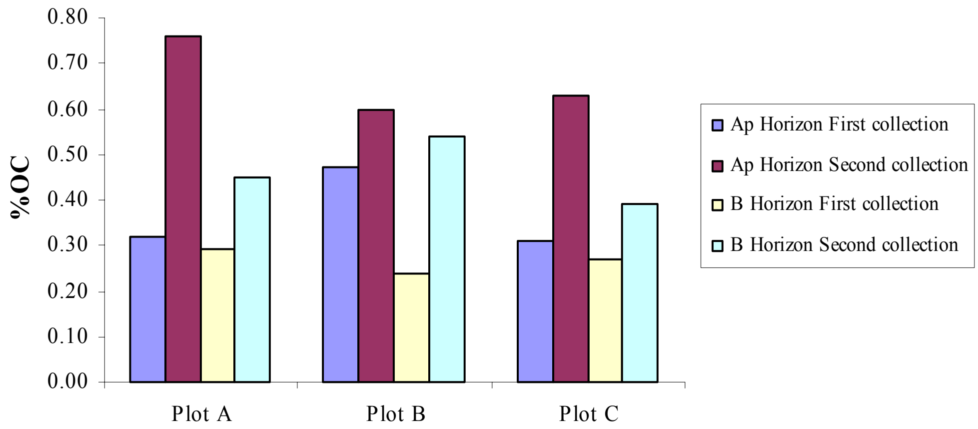

Figure 4-19 Soil Organic Carbon of Para rubber plantation area

4.2.2.5 Cation Exchange Capacity: CEC

The Cation Exchange Capacity (CEC) was analyzed by Buchner funnel filtration method (Ammonium acetate 1 *N* pH 7) (65).

- **Cassava plantation area**

According to Figure 4-20 and Table 4-7, for the first data collection, the maximum and minimum CEC values of A_p horizon were 2.09 cmol/kg and 1.47 cmol/kg, respectively. The maximum and minimum CEC values of B horizon were 1.89 cmol/kg and 1.64 cmol/kg, respectively. For the second data collection, the maximum and minimum CEC values of A_p horizon were 2.03 cmol/kg and 1.64 cmol/kg, respectively. The maximum and minimum CEC values of B horizon were 2.06 cmol/kg and 1.72 cmol/kg, respectively.

The statistic analysis of CEC values of Cassava plantation between the first and the second data collections of both periods, which were rainy and dry seasons of both horizons (Table A-5 and A-6), found that the CEC values of both horizons were not significantly difference.

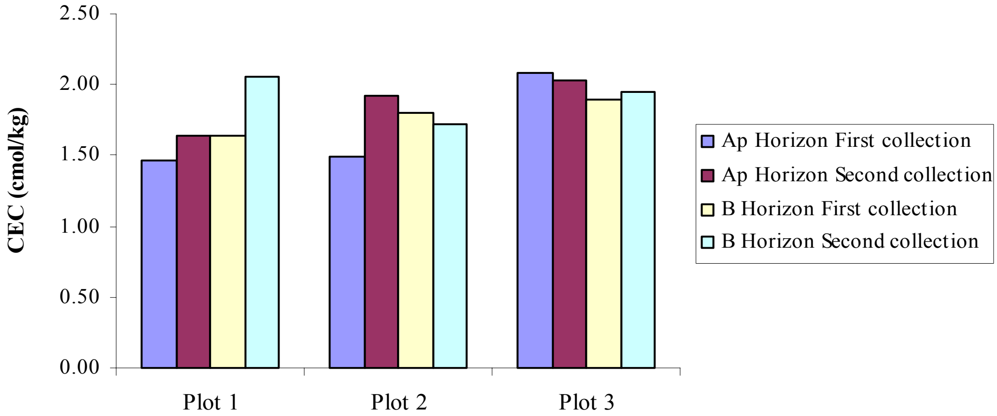

Figure 4-20 Soil Cation Exchange Capacity of Cassava plantation area

- **Para rubber plantation area**

According to Figure 4-21 and Table 4-9, for the first data collection, the maximum and minimum CEC values of A_p horizon were 1.95 cmol/kg and 1.47 cmol/kg, respectively. The maximum and minimum CEC values of B horizon were 1.75 cmol/kg and 1.69 cmol/kg, respectively. For the second data collection, the maximum and minimum CEC values of A_p horizon were 2.31 cmol/kg and 1.97 cmol/kg, respectively. The maximum and minimum CEC values of B horizon were 2.43 cmol/kg and 2.06 cmol/kg, respectively.

The statistic analysis of CEC values of Para rubber plantation between the first and the second data collections, which were rainy and dry seasons of both horizons (Table A-7 and A-8) found that the CEC values of the second data collection was increased more than the first data collection with the statistic level of significant ($P<0.05$).

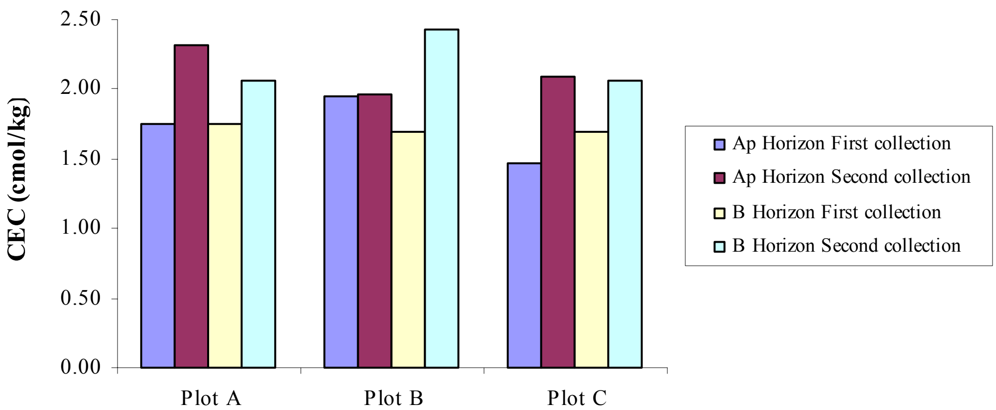

Figure 4-21 Soil Cation Exchange Capacity of Para rubber plantation area

Yoosuk (55) studied on Carbon sink in Rubber plantation of Klaeng District, Rayong Province and found that the range of CEC values in the upper soil (0-30 cm) were about 3.261 to 3.558 me/100g soil (cmol/kg) in dry season and 3.956 to 5.572 me/100g soil (cmol/kg) in rainy season . Therefore, it could be concluded that the CEC values of both study areas were at low level.

4.2.2.6 Total Nitrogen: N

The total Nitrogen was analyzed by Bremner method (65).

- **Cassava plantation area**

According to Figure 4-22 and Table 4-7, for the first data collection, the maximum and minimum %N values of A_p horizon were 0.037 and 0.035, respectively. The maximum and minimum %N values of B horizon were 0.047 and 0.028, respectively. For the second data collection, the maximum and minimum %N values of A_p horizon were 0.056 and 0.042, respectively. The maximum and minimum %N values of B horizon were 0.049 and 0.042, respectively.

The statistic analysis of %N values of Cassava plantation between the first and the second data collections, which were rainy and dry seasons in both horizons (Table A-5 and A-6) found that %N values of the second data collection were increased more than the first data collection with the statistic level of significant (P<0.05).

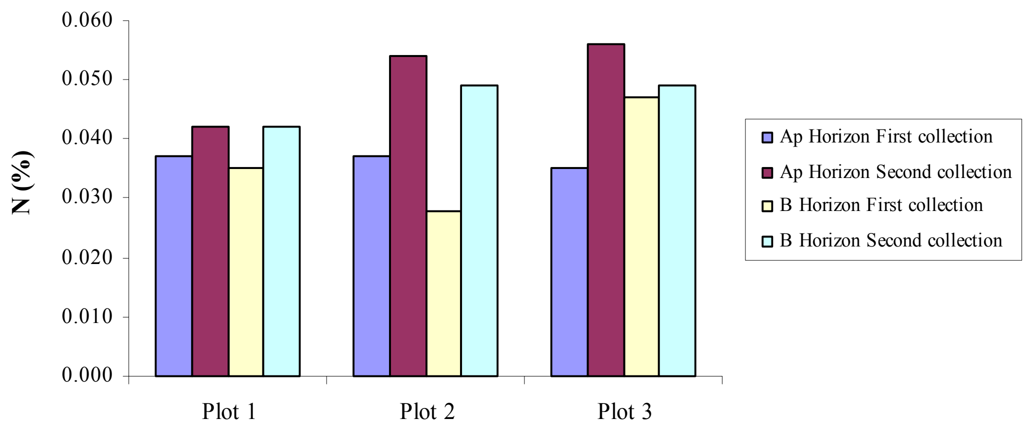

Figure 4-22 Soil Nitrogen of Cassava plantation area

Nitrogen is a macronutrient which is necessary to vegetative growth period of plant. The results of the study area found that not only in the first data collection which was the vegetative growth period of cassava that % N values was in low level, but also in the second data collection as well.

- **Para rubber plantation area**

According to Figure 4-23 and Table 4-9, for the first data collection, the maximum and minimum %N values of A_p horizon were 0.056 and 0.047 respectively. The maximum and minimum %N values of B horizon were 0.040 and 0.033, respectively. For the second data collection, the maximum and minimum %N values of A_p horizon were 0.054 and 0.051, respectively. The maximum and minimum %N values of B horizon were 0.047 and 0.042, respectively.

The statistic analysis of %N values of Cassava plantation between the first and the second data collections, which were rainy and dry seasons, of A_p horizon (Table A-5) was not significantly difference. Whereas, in B horizons (A-6) found that %N values of the second data collection increased more than the first collection with the statistic level of significant (P<0.05). The result of the increasing %N values in the second data collection was related with the falling leaves period of Para rubber trees in dry season.

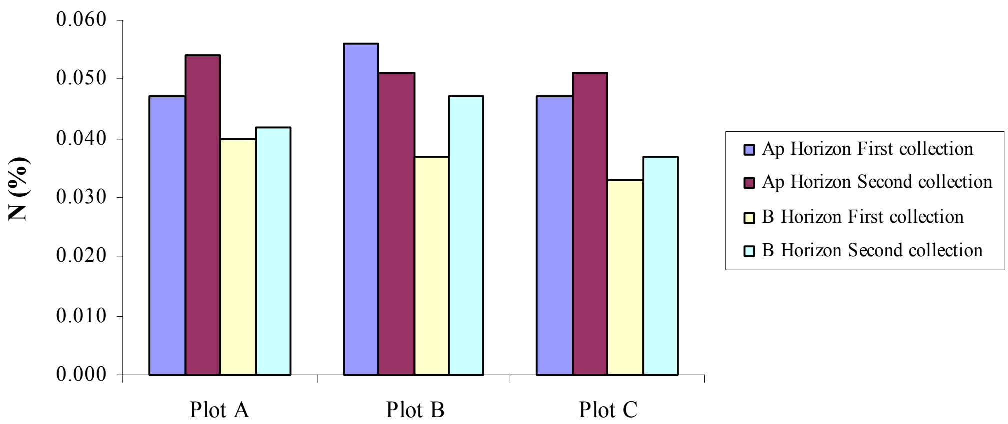

Figure 4-23 Soil Nitrogen of Para rubber plantation area

4.2.2.7 Available Phosphorus: P

The Available Phosphorus was analyzed by Bray and Kurt method (65).

- **Cassava plantation area**

According to Figure 4-24 and Table 4-7, for the first data collection, the maximum and minimum P values of A_p horizon were 0.59 ppm and 0.53 ppm, respectively. The maximum and minimum P values of B horizon were 0.54 ppm and 0.29 ppm, respectively. For the second data collection, the maximum and minimum P values of A_p horizon were 1.24 ppm and 0.35 ppm, respectively. The maximum and minimum P values of B horizon were 0.97 ppm and 0.30 ppm, respectively.

The statistic analysis of P values of Cassava plantation between the first and the second data collections, which were rainy and dry seasons, in A_p horizon (Table A-5) was not significantly difference. Whereas, in B horizons (A-6) found that P values of the second collection was increased more than the first collection with the statistic level of significant ($P<0.05$).

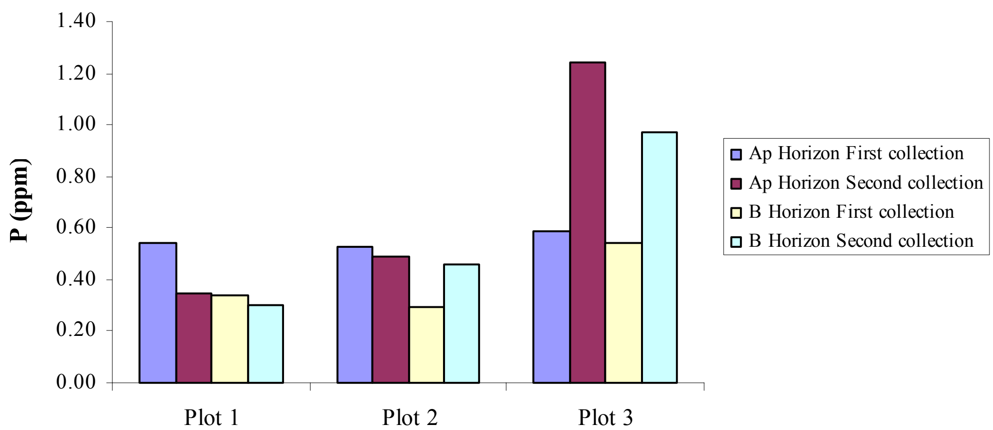

Figure 4-24 Soil Phosphorus of Cassava plantation area

- **Para rubber plantation area**

According to Figure 4-25 and Table 4-9, for the first data collection, the maximum and minimum P values of A_p horizon were 0.36 ppm and 0.22 ppm, respectively. The maximum and minimum P values of B horizon were 0.19 ppm and 0.15 ppm, respectively. For the second data collection, the maximum and minimum values of A_p horizon were 0.39 ppm and 0.23 ppm, respectively. The maximum and minimum P values of B horizon were 0.19 ppm and 0.13 ppm, respectively.

The statistic analysis of P values of Para rubber plantation between the first and the second data collections, which were rainy and dry seasons of both horizons (Table A-7 and A-8) were not significantly difference.

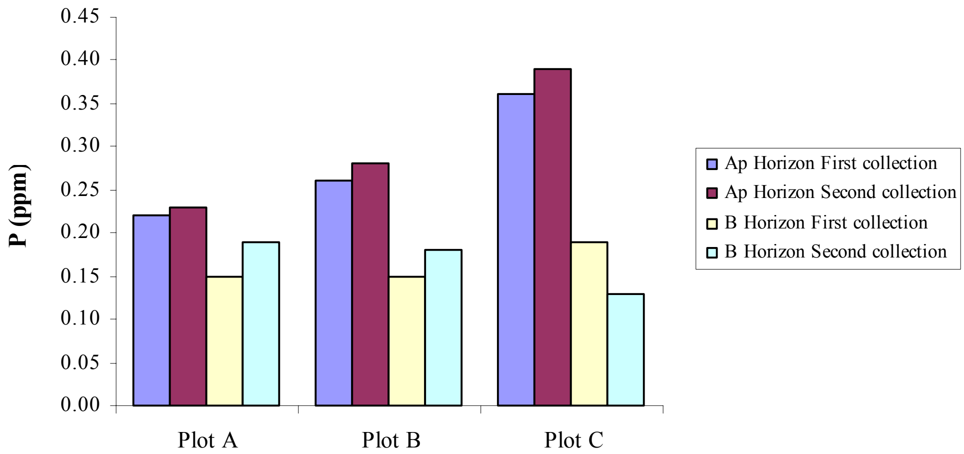

Figure 4- 25 Soil Phosphorus of Para rubber plantation area

4.2.2.8 Soluble Potassium: K

The Soluble Potassium was analyzed by Jackson method (64).

- **Cassava plantation area**

According to Figure 4-26 and Table 4-7, for the first data collection, the maximum and minimum K values of A_p horizon were 5.65 ppm and 2.50 ppm, respectively. The maximum and minimum K values of B horizon were 4.68 ppm and 2.33 ppm, respectively. For the second data collection, the maximum and minimum K values of A_p horizon were 5.62 ppm and 3.94 ppm, respectively. The maximum and minimum K values of B horizon were 5.78 ppm and 3.65 ppm, respectively.

The statistic analysis of K values of Cassava plantation between the first and the second data collections which were rainy and dry seasons of both horizons (Table A-5 and A-6) found that K values of the second data collection were increased more than the first collection with the statistic level of significant ($P<0.05$).

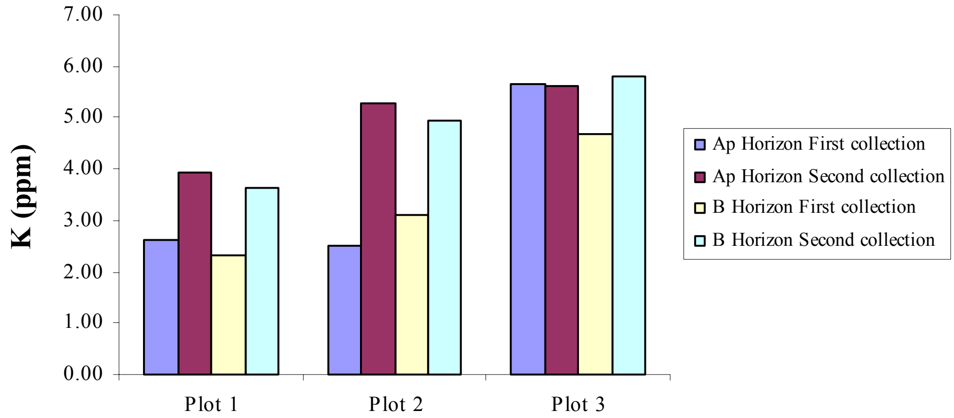

Figure 4-26 Soil Potassium of Cassava plantation area

- **Para rubber plantation area**

According to Figure 4-27 and Table 4-9, for the first data collection, the maximum and minimum K values of A_p horizon were 7.99 ppm and 5.25 ppm, respectively. The maximum and minimum K values of B horizon were 5.00 ppm and 3.27 ppm, respectively. For the second data collection, the maximum and minimum K values of A_p horizon were 8.41 ppm and 6.22 ppm, respectively. The maximum and minimum K values of B horizon were 5.70 ppm and 5.45 ppm, respectively.

The statistic analysis of K values of Para rubber plantation between the first and the second data collections, which were rainy and dry seasons of both horizons (Table A-7 and A-8), found that K values of the second data collection was increased from the first data collection with the statistic level of significant ($P<0.05$).

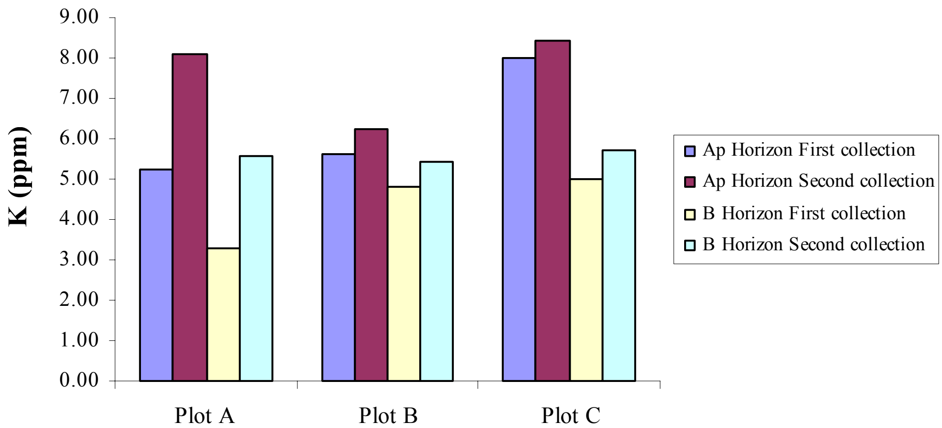

Figure 4-27 Soil Potassium of Para rubber plantation area

4.3 Carbon content in plant and soil

Carbon content in plant samples was analyzed in 3 levels; aboveground biomass (stems, branches and leaves), biomass on soil surface (ground cover and litter fall) and below ground biomass (roots). Carbon content in soil samples was analyzed by the relationship between soil organic carbon and soil organic matter (1.724×%Organic carbon = %Organic matter) (65). The relationship between %OC and %OM was found that the area had high organic matter would have high organic carbon as well. Soil organic carbon was considered in 2 parts, A_p horizon (0-15 cm depth) and B horizon (15-30 cm depth). The carbon content in plant and soil were identified as the following:

4.3.1 Carbon content percentage in plant

Carbon content percentage in plant, Cassava and Para rubber trees was estimated by using C/N Corder (Yanaco).

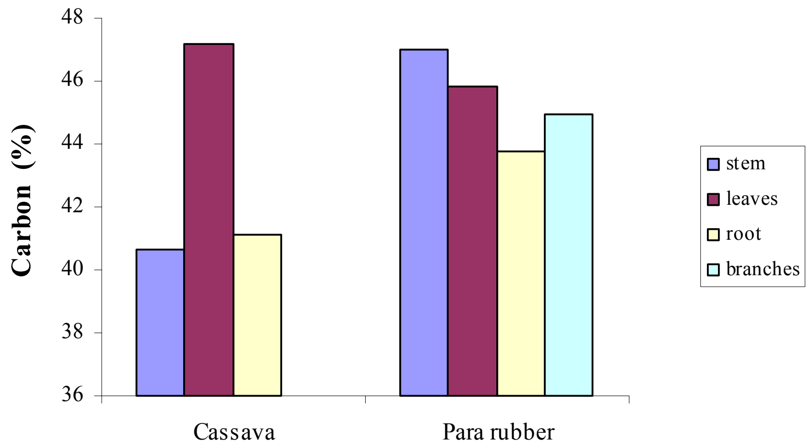

Figure 4-28 Carbon percentage in plant of Cassava and Para rubber trees

According to Figure 4-28, the carbon content percentage of stem, leaves and roots of Cassava were 40.63, 47.16 and 41.23, respectively. The carbon content percentage of stem, branches leaves and root of Para rubber were 47.01, 44.97, 45.83 and 43.75, respectively. The average carbon content percentage of Cassava and Para rubber of the study area were 43.01 and 45.39, respectively.

The result of this study was similar to the study of Nualngam and Wachrinrat (64), which found that the average carbon content percentage of *Acacia mangium,* *Acacia auriculaeformis, Eucalyptus camaldulensis, Xylia xylocarpa var. kerrii, Dalbergia cochinchinensis, Pterocarpus macrocarpus, N. reynaudiana* and *I. cylindrical* were 47.59, 46.89, 44.66, 47.40, 44.98, 46.31, 45.33 and 45.66, respectively.

4.3.2 Carbon content in plant of Cassava plantation area

The carbon content in plant of cassava was estimated from biomass in 3 parts: aboveground biomass (stem and leaves), soil surface biomass (ground cover) and below ground biomass (roots). The carbon content in plant of Cassava plantation in one crop yield was identified as the following (Table 4-10):

Table 4-10 The carbon content in plant of Cassava plantation

Plot	Carbon Content (kg/rai)					
	Aboveground biomass		Below ground biomass	Total in Cassava tree	Biomass on soil surface	Total
	Stems	Leaves	Roots		Ground cover	
Plot 1	118.61	14.15	693.79	826.55	240.94	1,067.49
Plot 2	187.89	20.13	743.95	951.97	133.81	1,085.78
Plot 3	143.11	37.24	921.03	1101.38	86.90	1,188.28
Average	149.87	23.84	786.26	959.97	153.88	1,113.85

According to Table 4-10, the average total carbon content in one yield crop of Cassava plantation was 1,113.85 kg/rai, which were separated into the average total carbon content in Cassava tree 959.97 kg/rai and in ground cover 153.88 kg/rai. The carbon content in roots was the highest in comparison to the other parts of Cassava tree.

The results of the study were found that less management of weed control in the study area affected to the low carbon content of stems, leaves and roots in Cassava plantation. Weed control after planting was necessary for the growth of Cassava during the first 3-4 months after planting (44). Moreover weed control was a significant factor that decreased crop yield of Cassava (7).

4.3.3 Carbon content in plant of Para rubber plantation area

The carbon content in Para rubber tree was estimated from biomass in 3 parts: aboveground biomass (stems, branches and leaves), soil surface biomass (ground cover and litter fall), and below ground biomass (roots). The carbon content in Para rubber plantation was identified as the following (Table 4-11):

Table 4-11 The carbon content in plant of Para rubber plantation

Data collection	Plot	Carbon content (kg/rai)							
		Aboveground biomass			Below ground biomass	Total in Para rubber	Biomass on soil surface		Total
		Stems	Branches	Leaves	Roots		Ground cover	Litter fall	
First collection	A	6,306.50	3,085.45	764.17	1,810.00	11,966.12	35.70	58.08	12,059.90
	B	6,471.52	3,205.21	780.16	1,845.56	12,302.44	16.49	21.93	12,340.86
	C	6,522.87	3,246.20	784.88	1,855.93	12,409.87	30.51	56.48	12,496.66
	Average	6,433.63	3,178.95	776.40	1,837.16	12,226.14	27.57	45.50	12,299.14
Second collection	A	6,476.11	3,195.65	781.68	1,849.66	12,303.10	19.80	100.00	12,422.90
	B	6,631.29	3,309.47	796.64	1,882.89	12,620.28	26.13	115.22	12,761.63
	C	6,643.43	3,322.02	797.54	1,884.75	12,647.74	13.08	150.40	12,811.22
	Average	6,583.61	3,275.71	791.95	1,872.43	12,523.71	19.63	121.87	12,665.25

For the first data collection, the average total carbon content of Para rubber plantation was 12,299.14 kg/rai, separated into the averages total carbon content in Para rubber tree, ground cover and litter fall as 12,226.14 kg/rai, 27.57 kg/rai and 45.50 kg/rai, respectively. For the second data collection, the average total carbon content of Para rubber plantation was 12,665.25 kg/rai, separated into the averages total carbon content in Para rubber tree, ground cover and litter fall as 12,523.71 kg/rai, 19.63 kg/rai and 121.87 kg/rai, respectively. The carbon content in stems was the highest in comparison with the other parts of Para rubber tree.

For the first and the second data collections of Para rubber plantation, the average total carbon content was 366.11 kg/rai. The average total carbon content in Para rubber tree was 297.57 kg/rai; which were separated into the averages total carbon content in stems, branches, leaves and roots 149.98 kg/rai, 96.76 kg/rai, 15.55 kg/rai and 35.27 kg/rai, respectively.

The results of this study were similar with the study of Bangjan (54) and Yoosuk (55), which the carbon content of Para rubber tree in the Eastern part of Thailand was a linear function relationship between size of perimeter and height of tree. Although the carbon content of Para rubber tree in this study was less than the study of Yoosuk (55); which the carbon content in stems, branches leaves and roots at the age between 14-16 years of Para rubber tree were 7,180.41 kg/rai, 3,783.47 kg/rai, 881.13 kg/rai, 2,179.36 kg/rai, respectively.

4.3.4 Carbon content in soil of Cassava plantation area

The carbon content in the soil samples of Cassava plantation was analyzed by the relationship between soil organic carbon and soil organic matter (1.724×%Organic carbon = %Organic matter) (65). Carbon content in soil of Cassava plantation was considered in 2 parts, A_p horizon (0-15 cm depth) and B horizon (15-30 cm depth). The carbon content in soil of Cassava plantation area was estimated and shown in Table 4-12:

Table 4-12 The soil organic carbon of Cassava plantation

Soil Horizon	Plot	Soil Organic Carbon (kg/rai)		
		First collection	**Second collection**	**Total in one crop yield**
Ap	**Plot 1**	1,577.76	1,917.60	3,495.36
	Plot 2	1,205.28	2,714.40	3,919.68
	Plot 3	1,497.60	2,890.80	4,388.40
	Average	1,426.88	2,507.60	3,934.48
B	**Plot 1**	1,621.20	1,755.36	3,376.56
	Plot 2	1,313.28	1,752.00	3,065.28
	Plot 3	1,220.16	2,298.48	3,518.64
	Average	1,384.88	1,935.28	3,320.16
Average total in 30 cm depth		2,811.76	4,442.88	7,254.64

According to Table 4-12, the average total soil organic carbon content of the crop yield of Cassava plantation was 7,254.64 kg/rai, which were 3,934.48 kg/rai in A_p horizon and 3,320.16 kg/rai in B horizon. For the first data collection, the average total soil organic carbon content in 30 cm depth was 2,811.76 kg/rai, which were 1,426.88 kg/rai in A_p horizon and 1,384.88 kg/rai in B horizon. For the second data collection, the average total soil organic carbon content in 30 cm depth was 4,442.88 kg/rai, which were 2,507.60 kg/rai in A_p horizon and 1,935.28 kg/rai in B horizon.

For the first and the second data collections, the average total carbon content in 30 cm depth soil of Cassava plantation was 1,631.12 kg/rai, which were 1,080.72 kg/rai in A_p horizon and 550.40 kg/rai in B horizon.

4.3.5 Carbon content in soil of Para rubber plantation

The carbon content in the soil samples of Para rubber plantation was analyzed by relationship between soil organic carbon and soil organic matter (1.724×%Organic carbon = %Organic matter) (65). Carbon content in soil of Para rubber plantation was considered at A_p horizon (0-15 cm depth) and B horizon (15-30 cm depth). Carbon content in the soil of Para rubber plantation was estimated and shown in Table 4-13:

Table 4-13 The soil organic carbon of Para rubber plantation

Soil Horizon	Plot	Soil Organic Carbon (kg/rai)		
		First collection	Second collection	Total
Ap	Plot A	1,021.44	2,736.00	3,757.44
	Plot B	1,861.20	2,203.20	4,064.40
	Plot C	1,294.56	2,525.04	3,819.60
	Average	1,392.40	2,488.08	3,880.48
B	Plot A	1,030.08	1,749.60	2,779.68
	Plot B	996.48	2,047.68	3,044.16
	Plot C	1,192.32	1,497.60	2,689.92
	Average	1,072.96	1,764.96	2,837.92
Average total in 30 cm depth		2,465.36	4,253.04	6,718.40

According to Table 4-13, the average total soil organic carbon content during the productive and falling leaves stages of Para rubber plantation was 6,718.40 kg/rai, which were 3,880.48 kg/rai in A_p horizon and 2,837.92 kg/rai in B horizon. For the first data collection, the average total soil organic carbon content in 30 cm depth was 2,465.36 kg/rai, which were 1,392.40 kg/rai in A_p horizon and 1,072.96 kg/rai in B horizon. For the second data collection, the average total soil organic carbon content in 30 cm depth was 4,253.04 kg/rai, which were 2,488.08 kg/rai in A_p horizon and 1,764.96 kg/rai in B horizon.

From the first and the second data collections, the average total carbon content in 30 cm depth soil of Para rubber plantation was 1,787.68 kg/rai, which were 1,095.68 kg/rai in A_p horizon and 692 kg/rai in B horizon.

4.4 Carbon sequestration

4.4.1 Carbon sequestration in Cassava plantation area

Carbon sequestration in one crop yield of Cassava plantation area was identified as the following:

Table 4-14 The carbon sequestration of Cassava plantation area

Plot	Carbon content (kg/rai)						
	Stem	**Leaves**	**Root**	**Total in Cassava tree**	**Ground cover**	**Soil**	**Total**
Plot 1	118.86	14.15	693.79	862.55	240.94	6,871.92	7,975.41
Plot 2	187.89	20.13	743.95	951.97	133.81	6,984.96	8,070.74
Plot 3	143.11	37.24	921.03	1101.38	86.90	7,907.04	9,095.32
Average	149.87	23.84	786.26	959.97	153.88	7,254.64	8,368.49

According to Table 4-14, the average total carbon sequestration of Cassava plantation in one crop yield was 8,368.49 kg/rai, which were separated into carbon sequestration in Cassava tree, ground cover and soil 959.97 kg/rai, 153.88 kg/rai and 7,254.64 kg/rai, respectively.

4.4.2 Carbon sequestration in Para rubber plantation area

Carbon sequestration during productive and falling leaves stages (six months) of Para rubber plantation area was identified as the following (Table 4-15):

Table 4-15 The carbon sequestration of Para rubber plantation area

Data collection	Plot	Carbon content (kg/rai)								
		Stem	Branch	Leaves	Root	Total in Para rubber tree	Ground cover	Litter fall	Soil	Total
First collection	A	6,306.50	3,085.45	764.17	1,810.00	11,966.12	35.70	58.08	2,051.52	14,111.42
	B	6,471.52	3,205.21	780.16	1,845.56	12,302.44	16.49	21.93	2,857.68	15,198.54
	C	6,522.87	3,246.20	784.88	1,855.93	12,409.87	30.51	56.48	2,486.88	14,983.74
	Average	6,433.63	3,178.95	776.40	1,837.16	12,226.14	27.57	45.50	2,465.36	14,764.57
Second collection	A	6,476.11	3,195.65	781.68	1,849.66	12,303.10	19.80	100.00	4,485.60	16,908.50
	B	6,631.29	3,309.47	796.64	1,882.89	12,620.28	26.13	115.22	4,250.88	17,012.51
	C	6,643.43	3,322.02	797.54	1,884.75	12,647.74	13.08	150.40	4,022.64	16,833.86
	Average	6,583.61	3,275.71	791.95	1,872.43	12,523.71	19.67	121.87	4,253.04	16,918.29

According to Table 4-15, the average total carbon sequestration of Para rubber plantation area in productive stage (the first data collection) was 14,764.57 kg/rai; which were separated into carbon sequestration in Para rubber tree, ground cover, litter fall and soil 12,226.14 kg/rai, 27.57 kg/rai, 45.50 kg/rai and 2,465.36 kg/rai, respectively. The average total carbon sequestration of Para rubber plantation area in falling leave stage (the second data collection) was 16,918.29 kg/rai, which were separated into carbon sequestration in Para rubber tree, ground cover, litter fall and soil 12,523.71 kg/rai, 19.67 kg/rai, 121.87 kg/rai and 4,253.04 kg/rai, respectively.

From the productive stage (the first data collection) to the falling leaves stage (the second data collection), the increasing of averages total carbon sequestration in Para rubber plantation, Para rubber tree, litter fall and soil were 2,153.72 kg/rai, 297.57 kg/rai, 21.87 kg/rai and 1,787.68 kg/rai, respectively.

The results of this study showed that the carbon sequestration in one crop yield of Cassava plantation were 8,368.49 kg/rai (52.30 tC/ha) and the carbon sequestration during productive stage and falling leaves stage of Para rubber plantation were 16,918.29 kg/rai (105.74 tC/ha). It could explain in detail as follow; the carbon content in Cassava and Para rubber tree were 1,113.85 kg/rai (6.96 tC/ha) and 12,523.71 kg/rai (12.52 tC/ha), respectively. The carbon content in soil of Cassava and Para rubber plantation were 7,254.64 kg/rai (45.28 tC/ha) and 6,718.40 kg/rai (41.99 tC/ha), respectively.

The result that the carbon content in Para rubber tree (Perennial crop) was higher than the carbon content in Cassava tree (Annual crop), and was also different from the study of Claudia S. Z. et al (56); studied on Carbon sequestration in perennial bioenergy, annual corn and uncultivated systems in southern Quebec, that corn (Annual crop) had higher levels of the aboveground carbon than willow (Perennial crop).

In contrast, the result about carbon sequestration in perennial tree was at high level comparing with other plants, and was agreed with the study of Nualngam and Wacharinrat (58), studied on Role of Reforestation on Carbon sink at Re-afforestation Research and Training Station, Changwat Nakhon Ratchasima, reported that the highest carbon sink both in plant and soil was found in *A. mangium* , *A. auriculaeformis, E. camaldulensis, X. xylocarpa var. kerrii, D. cochinchinensis, P. macrocarpus*, which were perennial tree, and was higher than *N. reynaudiana* and *I. cylindrical*.

Yoosuk (55), studied on carbon sink in rubber plantation at Klaeng district, Rayong province, found that the total carbon content in Para rubber plantation at the harvested stages, which was 115 tC/ha/yr, was similar to the result of this study that the carbon sequestration of Para rubber plantation was 105.80 tC/ha. However, the carbon content in the upper soil horizon of Para rubber plantation in this study (41.99 tC/ha) was higher than the result of Yoosuk (55) (24.88 tC/ha/yr).

The carbon content in soil of Cassava and Para rubber plantations, which were 45.28 tC/ha and 41.99 tC/ha, were similar to the study of Nagaraja et al (57); studied on the soil carbon stocks under different land use systems in the eastern dry zone of Karnataka, India, that total carbon stocks in top 0-50 cm soils of agricultural systems was of the order irrigated lands with manure 52.77 t/ha followed by irrigated lands without manure, drylands with manure and drylands without manure 44.47 t/ha, 37.79 t/ha and 26.46 t/ha, respectively.

Furthermore, The results of the carbon sequestration of Cassava and Para rubber plantations, which were 52.30 tC/ha and 105.80 tC/ha, were different from the study of Petsri (59) and Tangsinmankong (60), studied on the total carbon content in the mixed deciduous forest and the teak plantation in Uthaithani province, that the total carbon content at the ages of 6, 15 and 24 years were 142.56, 196.56, 112.62 and 146.81 t/ha, respectively, while the carbon content in soil 0-30 depth from soil surface was 70.94, 157, 78.75 and 105.69 t/ha, respectively and the study of Jindanuch (61), studied on the carbon distribution in the mangrove area of Thung Kha estuary, Chumphon province, that the total carbon content in natural mangrove, mangrove plantation and reforestation mangrove were 191.44, 147.19 and 186.25 tC/ha, while the soil organic carbon at 30 cm depth from soil surface were 152.75, 124.19 and 177.63 tC/ha, respectively.

Moreover, the result of this study and the related researches of Petsri (59), Tangsinmankong (60) and Jindanuch (61) were agreed with the study of Lars K. et al (33), studied on the contemporary stocks of soil organic carbon (SOC) in Denmark to 1 m depth, that Wetland soils have 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).

Finally, the result of the study and the related researches could be summarized that different type of plants, land use and management changes had influences on the levels of soil organic carbon and carbon sequestration of that area.

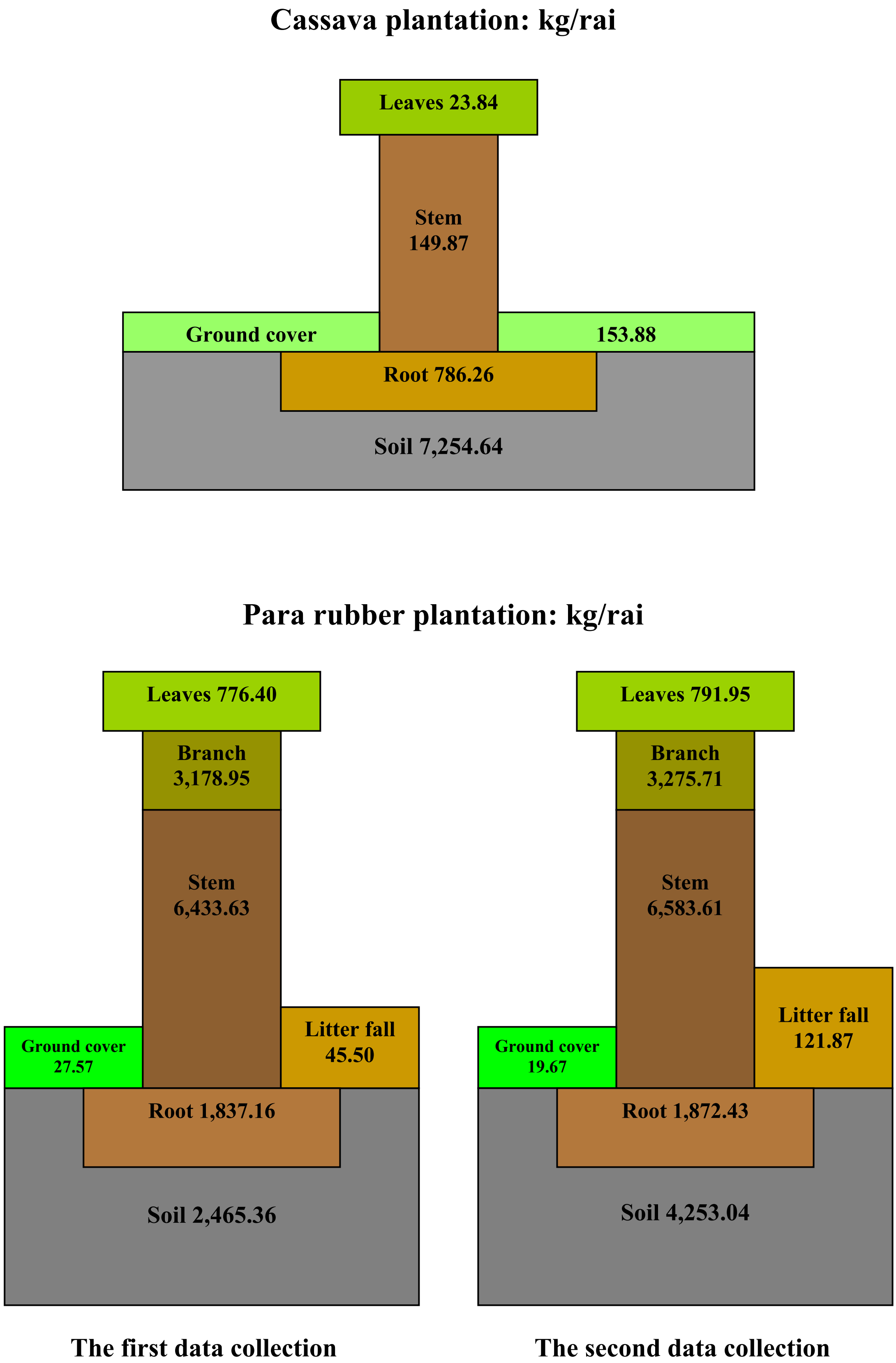

Figure 4-29 Diagrams of Carbon sequestration in Cassava and Para rubber plantations

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study of Carbon sequestration in Cassava and Para rubber plantations, Rayong province were studied on the carbon sequestration in one crop yield of Cassava plantation and during the productive and falling leaves stages of Para rubber plantation, which consisted of carbon sequestration in stems, branches, leaves and roots, soil surface biomass of ground cover and litter fall and carbon deposit in soil of the study area. The results of this study could be concluded as the following.

5.1.1 Carbon sequestration in Cassava plantation area

The carbon sequestration in one crop yield of Cassava plantation was estimated at the harvested stage. There was no litter fall in Cassava plantation area, therefore the biomass on soil surface was collected only on ground cover. The result showed that carbon sequestration in one crop yield of Cassava plantation was 8,368.49 kg/rai, which consisted of total carbon sequestration in Cassava tree, ground cover and in soil at 959.97 kg/rai, 153.88 kg/rai and 7,254.64 kg/rai, respectively. From the growing stage until the harvested stage, there was the increasing of carbon sequestration in 30 cm depth soil of Cassava plantation 1,631.12 kg/rai. It could be summarized that the carbon sequestration in plant and soil were increased according to the growth of plant.

The carbon sequestration in roots was 786.26 kg/rai and was the highest value in comparison to the other parts of Cassava tree. Since the Cassava plantation of the study area had less management of weed control, therefore the average biomass of roots was less than the average Cassava crop yield in Thailand. The results showed that less management of weed control in the study area affected to the low carbon sequestration of stems, leaves and roots of Cassava plantation.

5.1.2 Carbon sequestration in Para rubber plantation area

The carbon sequestration in Para rubber plantation was estimated during productive and falling leaves stages. The results showed that carbon sequestration in productive stage was 14,764.57 kg/rai; which consisted of carbon sequestration in Para rubber tree, ground cover, litter fall and soil: 12,226.14 kg/rai, 27.57 kg/rai, 45.50 kg/rai and 2,465.36 kg/rai, respectively. Carbon sequestration in the falling leaves stage was 16,918.29 kg/rai, which consisted of carbon sequestration in Para rubber tree, ground cover, litter fall and soil: 12,533.71 kg/rai, 19.67 kg/rai, 121.87 kg/rai and 4,253.04 kg/rai, respectively. From the productive stage (the first data collection) until the falling leaves stage (the second data collection), there were the increase of carbon sequestration in Para rubber plantation, Para rubber tree, litter fall and soil: 2,153.72 kg/rai, 297.57 kg/rai, 21.87 kg/rai and 1,787.68 kg/rai, respectively.

The result showed that the increasing of carbon sequestration in falling leave stage directly related with the growth of Para rubber trees and the increasing of litter fall. It could be summarized that growth and physiological change of plant increased the carbon sequestration in plant and soil.

5.2 Relationship between soil properties and soil organic carbon

There were many relevant soil factors that influence on the turnover of soil organic carbon of to the atmosphere such as pH, temperature, water potential and structure of soil. Moreover, type of plant also affected to the turnover times of soil organic carbon to the atmosphere.

5.2.1 Relationship between soil properties and soil organic carbon in agricultural area

The carbon sequestration in Cassava tree was obviously less than Para rubber tree at 959.97 kg/rai and 12,533.71 kg/rai, respectively. Due the perennial plant has more biomass than the annual plant; therefore, Para rubber has higher amount of carbon sequestration than annual plant like Cassava. However, the total carbon sequestration in Cassava plantation was higher than Para rubber plantation at 7,254.64 kg/rai and 6,718.40 kg/rai, respectively.

In case of total soil organic matter (SOM), which plays the vital role in carbon sequestration of soil, the result showed that the total SOM in Cassava plantation was higher than Para rubber plantation. In A_p horizon, SOM of Para rubber plantation was higher than Cassava plantation, because perennial plant has more accumulation of litter fall on soil surface than annual plant. Whereas, the SOM in B horizon of Cassava plantation was higher than Para rubber plantation because the differences of the management system in annual and perennial crop plantations. Annual plantation usually prepares the land by planting crop rotation and ploughing, thus the soil organic matter in the upper soil was turn over into the lower soil. Therefore, the SOM of Cassava plantation was higher than Para rubber plantation.

5.2.2 Relationship between soil properties and soil organic carbon in Cassava plantation area

The soil textures of the study area of Cassava plantation area were clay loam, sandy clay and sandy clay loam. All of those soil textures were classified in fine-textured soils group that had high water holding capacity. Since the finer clay texture has more soil pore volumes and can absorb water and soil nutrient. The soil reaction was strongly acid level in growing stage (rainy season) and moderately acid level in harvested stage (dry season), which were in the range of pH 4.0 – 8.0 that suitable for Cassava.

Nitrogen is a macro nutrient which is necessary to vegetative growth period of plant. For the first data collection, which was the vegetative growth period of cassava, Nitrogen percentage values were in low level. Available Phosphorus and Potassium were also found in low level. Moreover, the acidity of soil in Cassava plantation area affected to the decreasing of mineral and nutrient in soil, which play the vital role with the growth and development of plant. The analysis of soil sample showed that soil of the study area had the low level of N, P and K, which could be affected to the growth and development of Cassava tree.

The ECe values of the study area were in the range of 0-2 dS/m, which was not affected by salt. The SOM in the study area was also in low level. It might be resulted by strongly acid level of soil that affect to the decreasing of decomposition rate and the tillage process of cultivation that SOM can be turns back into the deeper soil layer. Moreover, there was the erosion of soil by runoff water in rainy season, therefore the SOM in A_p horizon of Cassava plantation was decreased and also affected to the decreasing of carbon sequestration in Cassava plantation.

Cation exchange capacity (CEC) was directly related with SOM, because soil with high CEC, also had high cation adsorption capacity for the adsorption of plant nutrients. The result showed that the CEC of Cassava plantation area was in low level, thus, the cation adsorption capacity for the adsorption of plant nutrients was also in low level.

5.2.3 Relationship between soil properties and soil organic carbon in Para rubber plantation area

The soil textures in Para rubber plantation were clay loam, sandy clay and sandy clay loam. They were classified in fine-textured soils group that had high water holding capacity and mineral adsorption, which was advantaged for deep root system of Para rubber. Furthermore, some soil textures of the study area were classified in medium-textured soils group, which was good for soil drainage. The soil reaction level in A_p and B horizons of Para rubber plantation area were in moderate and strongly acid levels in the productive stage (rainy season), and were slightly and very strongly acid levels in the falling leaves stage (dry season), which was not suitable for growth and development of Para rubber tree.

Since Para rubber trees are Perennial crop so Nitrogen is needed to support the growth of stems and leaves. However, the soil analysis result showed that Nitrogen percentage value in soil of the study area was in the low level. It could explain that the low level of available Phosphorus and Potassium in soil might affect to the growth and development of plant in the study area.

The result of ECe values of the study area was in the range of 0-2 dS/m, which was not affected by salt. The SOM in the study area was also in low level, it might be resulted from the strongly acid level of soil that affected to the decrease of decomposition rate. Therefore, the SOM in Ap and B horizon of Para rubber plantation was decreased, which also affected to the decrease of carbon sequestration in Para rubber plantation.

Cation exchange capacity (CEC) was directly related with SOM because soil with high CEC also had high cation adsorption capacity for the adsorption of plant nutrients. The result showed that the CEC of Para rubber plantation was in low level, thus, cation adsorption capacity for the adsorption of plant nutrients in Para rubber plantation was also in low level. Furthermore, Para rubber tree is perennial plant that has deep root system; the less of cation adsorption capacity might result to the decreasing of carbon sequestration in Para rubber plantation.

From those relevance of physical and chemical soil properties in the study area, it could be summarized that agricultural area, which grew suitable type of plant and had suitable physical and chemical soil properties could contribute to increase soil organic carbon and carbon sequestration in such area.

5.3 Recommendation

1. The biomass samples of Cassava in the study area were collected only in the harvested stage. For more complete data, further studies at the growing stage of Cassava should be collected in order to compare the carbon content with the harvested stage.

2. The study on carbon sequestration of this study was studied only in one single age of Para rubber plantation. Further studies are recommended to study on various ages of Para rubber plantations to compare about the carbon sequestration capacity.

3. The estimation of carbon content in Para rubber tree of this study was based on carbon percentage of each part and indirect measurement by using allometric equations. It is an approach to apply for a regression equation that directly converts external measurement (i.e. diameter 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 the tree sample should be cut down for actual measurement and weight in order to get the actual right value.

4. Due to limitation study about the Para rubber biomass of root estimation, this study used only the allometric equation, which was modified by Yoosuk (55), to estimate root biomass. It is considered that the result might be less accuracy. For more accuracy, further studies should be done on direct measurement and weight of root in order to get the actual right value.

5. The selected study areas were lack of micro nutrients; it might be related with the biomass production values of the study area. For more data and information, further studies should be done in various different type areas in order to get more various biomass production data.

6. The soil surface biomass of ground cover and litter fall of this study were collected only one month of each stage of plant. It was considered that the data might be not enough for effective analysis. For more accuracy, further studies are recommended to collect data every month of each stage of plant.

7. The result found that carbon sequestration in agricultural area was depended on type of plant, fertility of soil and management within plantation. To increase carbon sequestration capacity in agricultural areas, perennial plant is preferable suggested to grow and have continually management of soil and plantation systematically.

8. The study on carbon sequestration in Cassava and Para rubber plantations of this study was studied in Nikom Pattana sub-district, Nikom Pattana district, Rayong province, which was only the part of agricultural area of Thailand. The results could be utilized as a guideline for further study about carbon sequestration in other agricultural areas.

9. Changes in greenhouse gas emissions by sinks in the agricultural soils and land-use were human activities that contribute to climate change. Moreover, land use, land-use change and forestry (LULUCF) activity are direct human induced activities that related with the Kyoto protocol. Therefore, the result of this study could be beneficial for further study about carbon sequestration in other agricultural areas that related with Kyoto protocol.

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APPENDIX

APPENDIX

The results of statistic analysis

Table A-1 The results of statistic analysis of Paired T-Test on Physical soil properties in A_p horizon of Cassava plantation area.

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	BULKDEN1 - BULKDEN2	-.0408	.14362	.04146	-.1321	.0504	-.985	11	.346
Pair 2	MOISTUR1 - MOISTUR2	7.7042	1.30503	.37673	6.8750	8.5333	20.450	11	.000

BULKDEN1 = Soil bulk density in the first data collection
BULKDEN2 = Soil bulk density in the second data collection
MOISTUR1 = Soil moisture in the first data collection
MOISTUR2 = Soil moisture in the second data collection

Table A-2 The results of statistic analysis of Paired T-Test on Physical soil properties in B horizon of Cassava plantation area.

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	BULKDEN1 - BULKDEN2	.1633	.11308	.03264	.0915	.2352	5.003	11	.000
Pair 2	MOISTUR1 - MOISTUR2	5.7142	1.70762	.49295	4.6292	6.7991	11.592	11	.000

BULKDEN1 = Soil bulk density in the first data collection
BULKDEN2 = Soil bulk density in the second data collection
MOISTUR1 = Soil moisture in the first data collection
MOISTUR2 = Soil moisture in the second data collection

Table A-3 The results of statistic analysis of Paired T-Test on Physical soil properties in A_p horizon of Para rubber plantation area.

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	BULKDEN1 - BULKDEN2	.0083	.16230	.04685	-.0948	.1115	.178	11	.862
Pair 2	MOISTUR1 - MOISTUR2	9.7133	5.68437	1.64094	6.1017	13.3250	5.919	11	.000

BULKDEN1 = Soil bulk density in the first data collection
BULKDEN2 = Soil bulk density in the second data collection
MOISTUR1 = Soil moisture in the first data collection
MOISTUR2 = Soil moisture in the second data collection

Table A-4 The results of statistic analysis of Paired T-Test on Physical soil properties in B horizon of Para rubber plantation area

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	BULKDEN1 - BULKDEN2	.0817	.21742	.06276	-.0565	.2198	1.301	11	.220
Pair 2	MOISTUR1 - MOISTUR2	14.1558	9.84975	2.84338	7.8976	20.4141	4.979	11	.000

BULKDEN1 = Soil bulk density in the first data collection
BULKDEN2 = Soil bulk density in the second data collection
MOISTUR1 = Soil moisture in the first data collection
MOISTUR2 = Soil moisture in the second data collection

Table A-5 The results of statistic analysis of Paired T-Test on Chemical soil properties in A_p horizon of Cassava plantation area

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	PH1 - PH2	-.7056	.10273	.03424	-.7845	-.6266	-20.605	8	.000
Pair 2	ECE1 - ECE2	11.9778	13.37440	4.45813	1.6973	22.2582	2.687	8	.028
Pair 3	OM1 - OM2	-4.4389	2.49193	.83064	-6.3544	-2.5234	-5.344	8	.001
Pair 4	OC1 - OC2	-.2578	.14455	.04818	-.3689	-.1467	-5.350	8	.001
Pair 5	CEC1 - CEC2	-.1800	.23548	.07849	-.3610	.0010	-2.293	8	.051
Pair 6	NITROGE1- NITROGE2	-.01400	.007826	.002609	-.02002	-.00798	-5.367	8	.001
Pair 7	PHOS1 - PHOS2	-.13667	.392683	.130894	-.43851	.16518	-1.044	8	.327
Pair 8	POTASS1 - POTASS2	-1.3478	1.22621	.40874	-2.2903	-.4052	-3.297	8	.011

PH1 = Soil Reaction in the first data collection
PH2 = Soil Reaction in the second data collection
ECE1 = Soil Electrical Conductivity in the first data collection
ECE2 = Soil Electrical Conductivity in the second data collection
OM1 = Soil Organic Matter in the first data collection
OM1 = Soil Organic Matter in the second data collection
OC1 = Soil Organic Carbon percentage in the first data collection
OC2 = Soil Organic Carbon percentage in the second data collection
CEC1 = Soil Cation Exchange Capacity in the first data collection
CEC2 = Soil Cation Exchange Capacity in the second data collection
NITROGE1 = Total Nitrogen in the first data collection
NITROGE2 = Total Nitrogen in the second data collection
PHOS1 = Available Phosphorus in the first data collection
PHOS2 = Available Phosphorus in the second data collection
POTASS1 = Soluble Potassium in the first data collection
POTASS2 = Soluble Potassium in the second data collection

Table A-6 The results of statistic analysis of Paired T-Test on Chemical soil properties in B horizon of Cassava plantation area

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	PH1 - PH2	-.4622	.24366	.08122	-.6495	-.2749	-5.691	8	.000
Pair 2	ECE1 - ECE2	5.4000	7.91849	2.63950	-.6867	11.4867	2.046	8	.075
Pair 3	OM1 - OM2	-3.3256	1.88749	.62916	-4.7764	-1.8747	-5.286	8	.001
Pair 4	OC1 - OC2	-.1933	.10897	.03632	-.2771	-.1096	-5.322	8	.001
Pair 5	CEC1 - CEC2	-.1322	.22648	.07549	-.3063	.0419	-1.751	8	.118
Pair 6	NITROGE1- NITROGE2	-.01011	.009333	.003111	-.01729	-.00294	-3.250	8	.012
Pair 7	PHOS1- PHOS2	-.18444	.207612	.069204	-.34403	-.02486	-2.665	8	.029
Pair 8	POTASS1- POTASS2	-1.4178	.40892	.13631	-1.7321	-1.1035	-10.401	8	.000

PH1 = Soil Reaction in the first data collection
PH2 = Soil Reaction in the second data collection
ECE1 = Soil Electrical Conductivity in the first data collection
ECE2 = Soil Electrical Conductivity in the second data collection
OM1 = Soil Organic Matter in the first data collection
OM1 = Soil Organic Matter in the second data collection
OC1 = Soil Organic Carbon percentage in the first data collection
OC2 = Soil Organic Carbon percentage in the second data collection
CEC1 = Soil Cation Exchange Capacity in the first data collection
CEC2 = Soil Cation Exchange Capacity in the second data collection
NITROGE1 = Total Nitrogen in the first data collection
NITROGE2 = Total Nitrogen in the second data collection
PHOS1 = Available Phosphorus in the first data collection
PHOS2 = Available Phosphorus in the second data collection
POTASS1 = Soluble Potassium in the first data collection
POTASS2 = Soluble Potassium in the second data collection

Table A-7 The result of statistic analysis of Paired T-Test on Chemical soil properties in A_p horizon of Para rubber plantation area

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	PH1 - PH2	-.6344	.11970	.03990	-.7265	-.5424	-15.901	8	.000
Pair 2	ECE1 - ECE2	2.1889	5.45812	1.81937	-2.0066	6.3844	1.203	8	.263
Pair 3	OM1 - OM2	-5.1322	2.92122	.97374	-7.3777	-2.8868	-5.271	8	.001
Pair 4	OC1 - OC2	-.2956	.16831	.05610	-.4249	-.1662	-5.268	8	.001
Pair 5	CEC1 - CEC2	-.4033	.29065	.09688	-.6267	-.1799	-4.163	8	.003
Pair 6	NITROGE1- NITROGE2	-.00233	.009899	.003300	-.00994	.00528	-.707	8	.500
Pair 7	PHOS1- PHOS2	-.0200	.03742	.01247	-.0488	.0088	-1.604	8	.147
Pair 8	POTASS1- POTASS2	-1.2922	1.26296	.42099	-2.2630	-.3214	-3.070	8	.015

PH1 = Soil Reaction in the first data collection
PH2 = Soil Reaction in the second data collection
ECE1 = Soil Electrical Conductivity in the first data collection
ECE2 = Soil Electrical Conductivity in the second data collection
OM1 = Soil Organic Matter in the first data collection
OM1 = Soil Organic Matter in the second data collection
OC1 = Soil Organic Carbon percentage in the first data collection
OC2 = Soil Organic Carbon percentage in the second data collection
CEC1 = Soil Cation Exchange Capacity in the first data collection
CEC2 = Soil Cation Exchange Capacity in the second data collection
NITROGE1 = Total Nitrogen in the first data collection
NITROGE2 = Total Nitrogen in the second data collection
PHOS1 = Available Phosphorus in the first data collection
PHOS2 = Available Phosphorus in the second data collection
POTASS1 = Soluble Potassium in the first data collection
POTASS2 = Soluble Potassium in the second data collection

Table A-8 The results of statistic analysis of Paired T-Test on Chemical soil properties in B horizon of Para rubber plantation area

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	PH1 - PH2	.1233	.16070	.05357	-.0002	.2469	2.302	8	.050
Pair 2	ECE1 - ECE2	-.5333	2.08686	.69562	-2.1374	1.0708	-.767	8	.465
Pair 3	OM1 - OM2	-3.3133	1.62046	.54015	-4.5589	-2.0677	-6.134	8	.000
Pair 4	OC1 - OC2	-.1922	.09404	.03135	-.2645	-.1199	-6.132	8	.000
Pair 5	CEC1 - CEC2	-.4711	.21820	.07273	-.6388	-.3034	-6.477	8	.000
Pair 6	NITROGE1- NITROGE2	-.00544	.004667	.001556	-.00903	-.00186	-3.500	8	.008
Pair 7	PHOS1- PHOS2	-.0033	.04950	.01650	-.0414	.0347	-.202	8	.845
Pair 8	POTASS1- POTASS2	-1.2000	.83497	.27832	-1.8418	-.5582	-4.312	8	.003

PH1 = Soil Reaction in the first data collection
PH2 = Soil Reaction in the second data collection
ECE1 = Soil Electrical Conductivity in the first data collection
ECE2 = Soil Electrical Conductivity in the second data collection
OM1 = Soil Organic Matter in the first data collection
OM1 = Soil Organic Matter in the second data collection
OC1 = Soil Organic Carbon percentage in the first data collection
OC2 = Soil Organic Carbon percentage in the second data collection
CEC1 = Soil Cation Exchange Capacity in the first data collection
CEC2 = Soil Cation Exchange Capacity in the second data collection
NITROGE1 = Total Nitrogen in the first data collection
NITROGE2 = Total Nitrogen in the second data collection
PHOS1 = Available Phosphorus in the first data collection
PHOS2 = Available Phosphorus in the second data collection
POTASS1 = Soluble Potassium in the first data collection
POTASS2 = Soluble Potassium in the second data collection

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