CHAPTER 1
Introduction and Literature Review

1.1 Introduction

1.1.1 World's Rubber Producing Countries

Para rubber or rubber [*Hevea brasiliensis* (Willd. ex A. Juss.) Mull. Arg.] is an important cash crop in the world's economy. Thailand, Malaysia and Indonesia have produced the rubber of more than 70% of world's rubber production. These three countries are located between the 6th degree southern and northern latitudes. The latitude ranges of other countries are different: Bangladesh, 23rd and 24th degree N; Brazil, 20th and 21st degree S, and China (Yunnan province), 21st and 24th degree N latitudes. The areas where are suitable for rubber plantation in the world are therefore situated between the 10th degree N and S latitudes (Saengruksawong, 2009). Currently, rubber plantation is carried out in 24 countries worldwide, covering 9.59 million ha with around 93.16% being planted in 12 countries in the Asian continent. Most plantations are grown in six countries: Indonesia, 3.28 million ha; Thailand, 2.29 million ha; Malaysia, 1.25 million ha; China, 0.60 million ha; India, 0.58 million ha, and Vietnam, 0.47 million ha. Africa also has around 0.48 million ha of plantations, (5.03% of the world's plantation area) with three major countries: 0.15 million ha in Nigeria and 0.12 million ha in Cote d'ivoire and 0.11 million ha in Liberia. For the South America, only 0.17 million ha of rubber plantation are in Brazil as the major producer accounting for 0.12 million ha (IRSG, 2011). Also, the Asian continent is responsible for more than 55% of worldwide rubber product industry.

Even if the history of natural rubber (rubber) plantation in Thailand was not precisely recorded, there is sufficient evidence that Praya Ratsadanu Pradit Mahisara Phakdi (พระยารัษฎานุประดิษฐมหิศรภักดี) during his governance of Trang Province introduced the first rubber tree to be planted at Kantang district, during B.E. 2442 to 2444. In year B.E. 2454, Luang Ratcha Maitri (หลวงราชไมตรี) brought the rubber tree to Chanthaburi province and has extended to cover the entire nation as today's plantation practices.

1.1.2 Thailand: Leader Country of Rubber Producer and Exporter

In 2010, Thailand led the pack of major rubber producing countries with output of 3.25 million tons, 88-90% of total production capacity exported to foreign markets, followed by Indonesia, Malaysia, India, Vietnam and China with 2.83, 0.94, 0.85, 0.76 and 0.65 million tons respectively. The average rubber yields of Thailand, Indonesia, Malaysia, India, Vietnam and China were 1.73, 0.98, 1.60, 1.78, 1.72 and 1.14 tons per ha per year respectively (IRSG, 2011). Thailand also has the high potential for increasing production areas and production.

The original rubber plantation areas in Thailand were distributed in 14 provinces in the southern regions, and three provinces in the eastern region. In 1974,

an expansion of rubber production towards the northern and northeastern regions of the country was a success, leading to an interest to plant in other regions such as the central and western regions in place of other crops that are facing pricing pressures. It can be said that Thailand has rubber plantations across the entire country and is a country capable of large increase in production compared to Indonesia and Malaysia which focuses on increasing palm oil production.

Figure 1-1 Praya Ratsadanu Pradit Mahisara Phakdi (left) and the first rubber tree in Thailand (right)

In 2011, Thailand has the rubber plantation area of 3.00 million ha distributed across 67 provinces with more than 68% of the area consisting of harvest-ready trees. The southern region has 1.91 million ha in 14 provinces, 63% of rubber plantation countrywide. Almost all of the plantations with 84% are ready for harvest. Eastern and central regions have 0.40 million ha of plantation in 9 provinces, 13% of rubber plantation countrywide. 64% of the rubber trees are available for harvest. The northeastern region has 0.56 million ha of rubber plantation in 20 provinces, 19% of rubber plantation countrywide, and 20% of the rubber trees are available for harvest. Recently, the northern region has 0.14 million ha of rubber plantations in 17 provinces, 5% of rubber plantation countrywide with 3% of the plantations are ready for harvest (RRIT, 2012).

1.1.3 Environmental Factors for Rubber Plantation

Rubber plantation is viable for all regions of the country. However, even with the rubber tree's outstanding ability to adapt to various environments, the successful

rubber plantation needs to consider important environmental factors which influence on the growth and latex production of rubber trees. The suitable environment is an important factor for the plantation success.

The suitable altitude for rubber trees should not exceed 800 m m.s.l. However, the rubber growth is slow in areas of altitude more than 200 m, and has more decrease for every 100 m to the high area. The harvesting time of rubber maybe delayed for six months for every 100 m of the higher altitude. The decrease in temperate for every 0.5 degrees Celsius affects on the rubber tree's growth. Most of rubber plantations in Thailand are situated below 200 m m.s.l. The rubber plantation in sloping area of more than 12 degrees may results in the slow growth and decreasing latex production. Most of the plantations in Thailand are grown on the sloping areas of 5-8 degrees. If the slope gradient is more than 8 degrees, planting of rubber on contours is required to protect soil erosion.

The original plantation areas in the southern and eastern regions of Thailand receive the rainfall amount of 2,000 to 2,500 mm per year, and have about 175 days of rainfall per year. It is the suitable amount for rubber growth, and allows the harvest time at 6 years after planting. For the northern and northeastern regions, there are about 110 to 120 days of rainfall per year, and annual amount of 1,200 to 1,800 mm. The amount is also suitable for rubber planting, but it needs the longer period of rubber harvest at 7 to 9 years after planting

The soil should be fertile with sufficient minerals for the growths of rubber trees. Soil physical properties are important, particularly water drainage, good aeration, friability and good ability to absorb nutrient. Even if the soil is very fertile in terms of nutrients, the unsuitable physical properties are not allow the rubber tree to uptake nutrients for their growth and latex production. The soil should have 1.0 m in depth with the ground water level below 1.0 m and sufficient water drainage, but not too fast. The rocky and lateritic soils are unsuitable for rubber plantation. The suitable soil reaction is strongly to very strongly acid (pH = 4.5-5.5). The rubber trees can grow well on moderate to fertile soils, and can adapt to soil of slightly low to low fertility. The soil fertility in rubber plantations is usually different due to the soil characteristics and application of manure and chemical fertilizers. The nutrients are necessary and affect the growth and latex production. The rubber trees need different amounts of nutrients. The general plant usually requires the high amounts of macronutrients: nitrogen, phosphorous and potassium. The lower amounts of other nutrients are needed such as calcium, magnesium and sulfur. The vital nutrients needed in the low amounts are micronutrients, particularly manganese, zinc, iron, copper, boron and molybdenum. If the plant does not receive sufficient amounts of these nutrients, the deficiency symptoms maybe appeared. The usual symptoms include yellow leaf, slow growth and deformed structure (Mead, 1989). Currently, the supplementary nutrients have become more important because these nutrients do not contain in chemical fertilizers.

1.1.4 New Areas of Rubber Plantation in Thailand

During the year 2005-2009, the world's demand of natural rubber was about 9.20 to 9.59 tons per year and the rate of use increased on the average of 2.02 percent per year. China was ranked as the leading country which has the highest rate of rubber

consumption, 3.67 million tons per year. However, China can produce rubber only 0.63 million tons per year meanwhile the rate of import product reaches to 3 million tons, and 1-1.2 million tons of those total import amounts are from Thailand. It is expected that the amount of global rubber demand will definitely increase in the near future especially in the period of higher oil prices that affect the price of synthetic rubber which is the byproduct of refinery oil. The amount of rubber production which meets the world's demand in the 5 years as mentioned above is about 8.91 to 9.60 million tons. The percent of increasing production rate is 3.83 per year. However, this percent is considered as a decreasing rate. Thailand is the biggest producer and exporter of natural rubber. Its production volume per year is approximately 3.17 million tons, followed by Indonesia with a production of rubber about 2.53 million tons. Malaysia has the production volumes of approximately 0.86 million tons. Vietnam has the production capacity of about 0.72 million tons (RRIT, 2008). For all these countries, Thailand has the highest potential to increase the rubber planting area, and it is followed by Indonesia. Both Malaysia and Vietnam have a limit increase of rubber planting area.

In 2008, the rubber plantations in Thailand covered the total area of 2.70 million ha. The area of 2.10 million ha or 78 per cent of total planting areas was in the original areas: 1.82 million ha in the South, 0.29 million ha in the East. The rest 0.93 million ha, representing 22 per cent of rubber plantations, were in the new planting areas. This could be divided into 0.46 million ha in the Northeast, 0.09 million ha in the North and 0.05 million ha in the Central. The production capacity of Thailand was 3.1 to 3.2 million tons per year. It was considered as the first rank country which could produce and export rubber (RRIT, 2008). Consequently, Thailand has a high opportunity of increasing rubber productions and also has a great potential for increasing rubber cultivation areas to meet the global markets' needs as mentioned above.

The latex production in the new rubber plantation areas, the northern and northeastern regions, was only a little and less than the productions in the southern and eastern regions. In the future, the northern and northeastern regions may replace the southern and eastern regions of Thailand as the most important regions for rubber production, both due to the decrease in rubber plantations in the original areas and the shortage of labor.

The categorization of new rubber plantation areas according to the plantation capacity and latex production includes three categories as follows.

(1) Hight Level (L1): It is the most suitable area for rubber plantation. The rubber tree can be harvested before 6 years after planting, and has the high production capacity of more than 2.50 tons per ha per year. These areas are found in the southern and eastern regions of Thailand but are not found in the northern and northeastern regions.

(2) Moderate Level (L2): It is a suitable area for rubber plantation at the medium to excellent level. The rubber tree can be harvested within 7 years after planting, and has the production capacity of 1.56 to 2.50 tons per ha per year. The area has the high temperature and long drought season of about 3 to 4 months with the low yields at the beginning of season, increasing during rainy season and is the highest from the end of rainy to cold season.

(3) Low level (L3): It is the area with high limits to rubber production as the

low suitability for rubber plantation. The rubber trees planted in this area can be harvested after 8 years or more with the low production capacity, less than 1.56 tons per ha per year. The area also has the long drought season for more than 4 months with low rain fall and terrible rain distribution.

The rubber plantation should be done in areas of at least the moderate level capacity (L2). Further analysis on appropriate details of the environment is also important on a case by case basis to reduce the risk of rubber plantation and ensure the success as already planned. Moreover, the economic return from rubber plantations is also important for making decision as compared to other cash crops.

In 2006, the northern and northeastern regions had capacity areas for rubber plantation of 5.23 million ha. The area of 3.43 million ha was the moderate level (L2) and 1.80 million ha for the low level (L3). There was none for the high level (L1). The northern region had areas of the moderate level (L2) and low level (L3) of 1.21 million ha distributed across 17 provinces. The area of the moderate level (L2) was 0.34 million ha with the production level of 1.56 tons per ha per year and the low level (L3) of 0.87 million ha with the production level of 1.25 to 1.56 tons per ha per year. The northeastern region had areas of the moderate level (L2) and low level (L3) of 4.03 million ha distributed across 19 provinces. The area of the moderate level (L2) was 3.09 million ha with the production level of 1.56 to 2.50 tons per ha per year and the low level (L3) of 0.93 million ha with the production level of 1.25 to 1.56 tons per ha per year (Pratoomintra and Suwanmonkal, 1987).

1.1.5 Rubber Plantations: A Tool for Reducing Greenhouse Gases

Global warming has been recognized to be critical. Most countries throughout the world are encouraged to take various measures to reduce global warming under the KYOTO protocol. The protocol is a part of the United Nations Framework Convention on Climate Change (UNFCC), enforced in 2005.

Carbon credits and carbon markets are a component of the national and international attempts to mitigate the growth in concentrations of greenhouse gases (GHGs). One carbon credit is equal to one metric ton of carbon dioxide, or in some markets, carbon dioxide equivalent gases. Carbon trading is an application of an emissions trading approach. Greenhouse gas emissions are capped and then markets are used to allocate the emissions among the group of regulated sources.

There are also many companies that sell carbon credits to commercial and individual customers who are interested in lowering their carbon footprint on a voluntary basis. These carbon off setters purchase the credits from an investment fund or a carbon development company that has aggregated the credits from individual projects. Buyers and sellers can also use an exchange platform to trade, such as the Carbon Trade Exchange, which is like a stock exchange for carbon credits. The quality of the credits is based in part on the validation process and sophistication of the fund or development company that acted as the sponsor to the carbon project. This is reflected in their price; voluntary units typically have less value than the units sold through the rigorously validated Clean Development Mechanism (CDM).

Even if Thailand is a non-annex 1 member country that can reduce greenhouse gas emission through the CDM, an appropriate approach is to plant the rubber in

plantations in agricultural areas. Because rubber trees have the long production life, then the plantations can be considered as forest plantations as the rubber tress increase in biological mass as they age and have the high capacity of carbon storage.

Figure 1-2 The view of the rubber plantation in Nong Khai province

The rubber tree is an important cash crop with more than 25 years of productive life time, reaching more than 15 meters height above the ground. The trees can absorb carbon dioxide from atmosphere or decrease greenhouse gas. During the 25 years life cycle, it produced around 6.82 tons of carbon per ha from tree biomass, leaf and branch, litter fall, dry rubber latex and top soil consisting of 3.56 tons, 1.28 tons, 0.73 tons and 1.25 tons of carbon per ha, respectively (Chantuma *et al*, 2012). Thailand has a plan to cut the old rubber trees with low production for replanting the new better trees in an area of 62,000 ha on a yearly basis. These rubber plantations can store no less than 16.54 million tons of carbon per year. Hence, the values from the rubber plantations not only come from the rubber latex and wood, but also from selling tens of billions of Baht worth of carbon credit in the future.

Development of the northeastern region as a part of the country's rubber production source requires more research on the variable environmental effects on growth pattern in different areas of the region, particularly rainfall, moisture, soil characteristics and parent rocks. Different soils have the variable effects on tree growth and production according to different nature especially soil depth, water drainage, physico-chemical and biological properties (Bowen and Nambiar, 1989; Fisher & Binkley, 2000). The soils may have influenced on the amounts of carbon storage in different age rubber plantations. On the other hand, the rubber trees also have the environmental roles. Thus, the research will provide the important data for better management to relevant organizations

In Nong Khai province, rubber plantations cover the total area of 724,590 ha with suitable areas for rubber plantation of 340,606 ha. It is the province in the region which most areas are used for planting rubber, coving 102,051 ha, and has the remaining potential land of 238,3994 ha. It is also the first province which had the pioneer pilot plantation project of the Rubber Research Institute of Thailand (RRIT) in 1978, and nowadays those plantations have ages of 1 to 20 years old.

The investigation of the Land Development Department shows that most soil series found in the areas are the Phonpisai and Chakkarat soil series. The studies on growth pattern, bio-productivity and carbon stock potential in rubber plantations on both soil series are an interesting research, and will provide the important data for improving management and encouraging appropriate practices of rubber plantation to receive the high yields and rehabilitates the environment.

The government should take this opportunity to extend rubber cultivation in order to meet to the world's demands as mentioned above. Kongsilp (2000) reported that the Rubber Research Institute have planted the rubber in the northeastern areas since 1978 which cover the areas of Phon Phisai Nikhom Sang Ton Eng in Nong Khai province, Ban Kruat Nikhom Sang Ton Eng in Buri Ram province and Prasat Nikhom Sang Ton Eng in Surin province. The results showed that the rubber trees planted in areas along the Mekong river, from the upper to the lower parts, had grow well nearly the same as those planted in the South, but the tree sizes which were ready for the latex tapping were different (2-3 years late), and the latex yield was about 75 to 80% of the southern production. In the future, the Northeast maybe become another important source of rubber cultivation. In addition, the rubber trees can store and accumulate carbon in all parts of them. Therefore, this region will be the new major source of biomass (dry weight) production.

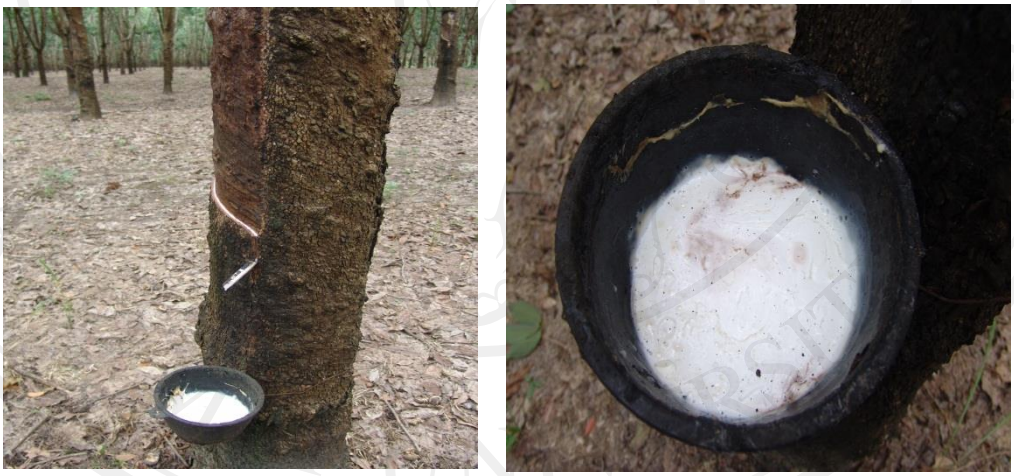

Figure 1-3 Collection of rubber resin (yang) from rubber tree

Ministry of Agriculture and Cooperatives (MOA) has increased the rubber growing areas since 1989 under the project to expedite the distribution of income. The project period was five years (1989 to 1993). The aim was to plant 32,000 ha of rubber trees in the Northeast, but they were planted successful only 14,084 ha, representing 44% of the entire targets. In 2003, the Ministry also organized the project of planting rubber in the new planting areas, phase I or One Million Rai of Rubber Project. This project was set up to enhance income and security for farmers. The target was 160,000 ha of rubber planting in the period of three years (2003 to 2006). It could be divided into planting in the Northeast, 112,000 ha and in the North, 48,000 ha. The project was successful since the rubber cultivation areas reached to higher than 90% per cent of the planting target (Saengruksawong, 2008). At present, the Northeast has the potential areas for growing rubber, 3,090,2548 ha, and the latex

yield can be produced about 1,560 to 2,500 kg year per ha. In fact, the rubber trees have already been planted in these areas only 455,286 ha. Therefore, the remaining area is equal to 2,634,962 ha. This statistic number is close to the rubber growing areas of the whole country.

The main problem which affects rubber planting in the northeastern region is the lack of deep studies on the effects of environmental factors on the rubber production. Almost technologies used for rubber planting in the northeastern region are adopted from the research results carried out in the southern and eastern regions. For example, the research on the properties of different soil series, which influence the growths of rubber. There is none research related to the biomass and amount of carbon storage. For this reason, it is necessary to study on the properties of different soil series and biomass production of rubber trees so that it can be able to take advantage from the research for proper planning and development.

Although the Northeast covers more cultivation areas than the South, the total area of rubber plantation is only 0.45 million ha or 25 per cent of the southern area. It is necessary to choose the province in the Northeast which has a large area of rubber plantations with different ages. Nong Khai province (on March 23, 2010 Nong Khai province was split into 2 provinces, Nong Khai and Bueng Kan.) is therefore selected because it is the first province of the region which grows the rubber trees in plantations. Nowadays, the older plantations in the province have age of around 20 years old, and it is the major rubber plantations which have the area of about 102,052 ha. The rubber plantations are grown mainly on two soil types, Phon Phisai and Chakkarat series, which are suitable for growing rubber trees at the moderate and low levels, respectively. These two soil series are the majority soils in the northeastern areas and are used as the representative soils for this study. The research results will be used as information of extension of rubber growing to meet the target, up to 340,446 ha. As above reasons, the research on growth, biological production and carbon stock potentials of rubber plantations are chose to set up the experiment at Nong Khai and Bueng Kan provinces, under Phon Phisai and Chakkarat soil series for both rubber plantations and natural forests

1.2 Literature Reviews

1.2.1 Growth and biomass production of rubber plantations

RRIT (1988) studied the suitable area for rubber planting in the Northeast. It found that Nong Khai is located in the climate zone 1 (C1) and 2 (C2). C1 covers an area of Phon Phisai along to the east namely Pak Khat, So Pisai, Bueng Kan, Phon Charoen, Bung Khla, Bueng Khong Long, Rattanawapi, Seka and Fao Rai districts. These areas have a great potential for rubber cultivation but have a limitation during the dry season with about 5 months. However, the soil water deficit during the dry season is not severe. The growing period in this zone is about 7 months starting from mid-March to mid-October. Climate zone 2 is classified as the moderate potential. This zone consists of the areas in western Phon Phisai, Tha Bo, Si Chiang Mai, Sangkhom and Sakhrai districts. This zone has a long drought period because the reduction of monthly rainfall and number of rainy days. The water deficit during the drought period is critical. Establishment of rubber plantations in the region requires more knowledge. The growing period is about six months, from May to October

Pratoomintra and Suwanmonkal (1987) reported about factors affecting the success of rubber plantation in the East. He explained the evaluation of soil suitability for rubber planting not either soil fertility that affected on the rubber growth but also soil physical properties. Normally, deep soil with thick surface horizon is suitable for a growth of rubber because their roots can penetrate easily and stick to the soil firmly then rubber tree are not easily fall down. However, the soil fertility is also important. It should contain sufficient nutrients for the growth. In addition, the soil physical properties include the drainage classes, soil aeration, soil water holding capacity and capacity of exchangeable cations. The suitability of soil physico-chemical properties for planting rubber tree comprises of the following characteristics:

(1) Soil depth is not less than one meter. This characterized by (a) without hard plan, or compact soil or hard rock (b) groundwater table should not exceed and (c) well drained soil or good water permeability and (d) no mottling in soil profile.

(2) The suitable soil structure is subangular blocky structure with about 35% of clay particles and about 30% of soil aeration. These are the ideal for the good soil that can keep soil moisture and nutrients.

(3) The suitable soil pH is ranged from 4.5 to 5.5.

Saengruksawong (2008) reported that Rubber Research Institute, Department of Agriculture, has planted the rubber trees in the Northeast since 1976. He explained that the suitable areas for rubber planting were more than 1,600,000 ha, but the productions were slightly lower than in the South and the East. In the future, the Northeast maybe becomes the important source of rubber plantation and production of the country. The rubber planting areas in the Northeast could be classified to three levels depending on the potential latex production: (1) **High level** (L1), it was characterized by almost rubber trees in the plantation (more than 75%) reach the tappable size (or can be exploited) within 6 years after planting, and the annual production was higher than 2,500 kg of dry rubber per ha. This class was usually found in the South and East of the country, but not in the North and Northeast. (2) **Moderate level** (L2), almost rubber trees could be tapped within 7 years after planting, and the annual production was about 1,560 to 2,500 kg per ha. This class was located in the areas with the high temperature and long drought period (3 to 4 months). The rubber production was low in early season, increasing in the middle of rainy season, maintaining to the late rainy season and early winter. (3) **Low level** (L3), it was characterized by limiting factors to the rubber production. Most rubber trees could be tapped over 8 years after planting, and the annual potential dry rubber production less than 1,560 kg per ha. This class was located in the areas with long drought season (longer than 4 months), low and poor distribution of rainfall. The L3 level should be avoid for planting the rubber trees.

1.2.2 Soil characteristics and rubber plantations

Development of the northeastern region as a part of the country's rubber production source requires more research on the variable environmental effects on growth pattern in different areas of the region, particularly rainfall, moisture, soil characteristics and parent rocks. Different soils have the variable effects on tree growth and production according to different nature especially soil depth, water drainage, physico-chemical and biological properties (Bowen & Nambiar, 1989;

Fisher & Binkley, 2000). The soils may have influenced on the amounts of carbon storage in different age rubber plantations. On the other hand, the rubber trees also have the environmental roles. Thus, the research will provide the important data for better management to relevant organizations

Chaipanich *et al*. (2000) reported that the assessment of soil properties for planting rubber in the Northeast was necessary. This assessment included physical properties such as soil structure, soil depth, slope gradient, water drainage, and duration of soil surface flooding. The evaluation of chemical properties was also important. These properties include amount of organic matter, the ability of nutrient transfer, and the ability to store nutrients of the soil. The Rubber Research Institute, Department of Agriculture, have categorized the assessment of the soil suitability into four groups. The first group is the most suitable for growing rubber, namely, Pakchong and Chokchai soil series. The second group is moderate suitable for planting rubber, namely, Banchong, Donglan, Dansai, Hangchat, Khaoyai, Leoy and Wanghai soil series. The third group is quite suitable for rubber cultivation, including, Buriram, Chiangkhan, Khambong, Korat, Ladya, Satuk, Warin, Yasothon, Takhli, Tali, Thamuang, Wangsaphung, Phon-ngam, Phon Phisai, Phusana and Lee soil series. The last group is not suitable for planting rubber. It includes Borabue, Chaibadan, Roiet, Phen and Muaklek soil series (shallow surface soil).

Chaipanich *et al*. (1998) studied on types and distribution of unsuitable soils in the new areas of rubber cultivation. Nong Khai province had a distribution of lateritic soil at the highest level. The laterite type consisted of 30 soil series and 21 series which could be used for rubber planting such as Kabin buri, Phonpisai and Surin series. Although the Northeast, North and West had 11.3% of laterite scattering, these areas could be used for rubber plantation up to 82.98% of the entire area. It could be assumed that local farmers still had opportunity to plant rubber within the area with such kind of bad soil. Monitoring and inspection of planting area and analysis of collected soil samples were also significant.

Thumsiri *et al*. (1999) studied on classification system of fertility capability classification (FCC) in 19 provinces in the Northeast: Roi Et, Buriram, Nong Khai, Nakhon Phanom, Ubon Ratchathani, Loei, Khon Kaen, Kalasin, Maha Sarakham, Yasothon, Chaiyaphum, Surin, Udon Thani, Nakhon Ratchasima, Sakon Nakhon, Mukdahan, Si Sa Ket, Nong Bua Lam Phu and Amnat Charoen provinces. The implementation period was four years, October 1997-September 2001. The results showed that the Northeast had a total area of 15,899,337 ha with 100 soil series. The proper areas for growing rubber covered 6,652,752 ha with 37 soil series (41.84%). Korat was a soil series which found in most areas. The province which had the largest suitable areas for rubber planting was Sakon Nakhon. According to the fertility capability classification (FCC-R), the researchers found that there was none area in the Northeast suitable for planting rubber in the class of FCC-R I. The planting area in FCC-R II class covered 2,172,509 ha (32.66%). A number of 22 soil series was found for this class. Planting area in FCC-R III class covered 4,480,243 ha (67.34%). This class composed of 15 soil series. The suitable soil for growing rubber was divided into two main groups. The first group was the clayey soil (C) with the area of 2,329,786 ha (35.02 % of the suitable area). It consisted of 23 soil series. The second was loamy sand (L) which covered the area about 4,322,966 ha (64.98%). It consisted of 14 soil series. According to the FCC system, the texture of almost soils was sandy,

low cation exchangeable capacity (CEC), high concentrations of iron which might chelate phosphorus, low available potassium and phosphorus (Seikp). The other soils had loamy in surface soil, the subsoil was gravelly with 15-35 % of gravel, low CEC, high iron concentrations, low contents of available potassium and phosphorus (LGei)

Vichitchonchai *et al.* (2001) did the research about nutrient levels in soil and rubber trees planted in the new areas of the East and Northeast including 24 provinces. They found that an average yield of rubber was 39.2 g per tree per tap (296.51 kg per rai per year). The average height of rubber was 3.07 m whereas the crown diameter was 7.27 m. Average amount of rubber wood was 0.125 m^3 per unit (9.49 m^3 per rai). The ratio of fresh leaf weight: dry leaf weight was around 2.77:1. The water content in rubber leaf was 177.08%. Average total leaf area reached to 134.66 m^2 per tree. Nutrient levels in Kabinburi soil, which was a representative soil found in the East, was higher than Korat series, a representative soil found in the Northeast. As a result, rubber trees planted in the East had the higher rates of growth, yield and other components than those rubber trees planted in the Northeast. The correlation between the age and average growth of RRIM 600 varieties planted in the East and in the Northeast showed as linear line similarly to the correlation between the age and average wood volume. The relationship between age and average yield of rubber showed an unstable linear line features. The relationship between the average amount of nitrogen and phosphorus in leaves, roots and stems showed that nitrogen was found mostly in leaves, followed by the roots and stems, respectively. Total nitrogen contained within all parts of rubber was about 182.54 g, whereas phosphorus was about 972.50 g.

Saengruksawong (2008) reported that Nong Khai province has the total land area of 724,590 ha. Phon Phisai soil series was found in most area (153,410 ha), followed by Chakkarat soil series with the area of 79,396 ha (Land Development Department, 2003). The properties of Phon Phisai soil series was characterized by the lateral flow that had flooding during the rainy season, The texture was clayey skeleton, which consisted of more than 50% of gravels, and plinthite was found within 1.5 m from the surface. In the very shallow soil, 3-9 years old rubber had yellow canopy, leaf symptoms and the white stem. The rubber trees were died from the symptoms in the dry season. Surface soil texture was loamy sand to sandy loam, subsoil texture was clay loam to sandy clay loam with about 35% of gravels. The organic matter content was very low. The soil fertility was medium. The soil water permeability was moderate in the surface soil but slow in subsoil. Surface runoff was moderate. The characteristics of Chakkarat soil series were described. The soil texture in the surface soil was loamy sand. Soil organic matter in the surface soil (0-25 cm depth) was medium, but low in the subsoil. Soil fertility was low whereas the soil permeability was moderate as same as the surface runoff (Land Development Department, 2004).

1.3 Research Objectives

The objectives of this research were:

(1) To investigate growths and biomass productions of two different age series of para rubber plantations (RRIM600 clone) in areas of Phon Phisai and Chakkarat soil series, Nong Khai and Bueng Kan provinces

(2) To assess the ecosystem carbon stock potentials of two different age series of the para rubber plantations grown on these two soil series