CHAPTER 4

Soil Properties and Carbon-Nutrient Storages in Two-series Rubber Plantations

4.1 Introduction

Development of northeastern region as part of the country's rubber production source will need a study on environmental affect on growth pattern in different areas of the region, especially rainwater, humidity, soil characteristic and rock formation. Different soil qualities have strong affect to the debt of water drainable, physical, chemical and biological properties (Bowen & Nambiar, 1989; Fisher & Binkley, 2000). It will also influence the amount of carbon stock stored in different age group of rubber trees hence will affect the environmental role of rubber plantation and will be an important data for better management at relevant organizations.

Chaipanich *et al*. (1998) reported the assessment of soil properties for planting rubber in the northeast is quite necessary. This assessment should cover physical properties such as soil structure, soil depth, slope of the area, soil water drainage, and duration of soil surface flooding. Chemical properties evaluations are 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, 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 Pisai, Phusana and Lee soil series. The last group is not suitable for planting rubber. It is including Borabu, Chaibadan, Roiet, Phen and Muaklek soil series (shallow surface soil).

Chaipanich *et al*. (2000) studied on types and distribution of improper soils in the new area of rubber cultivation. They found that Nong Khai Province has a distribution of laterititic soil at the highest level. Those laterite type consists of 30 soil series and 21 series can be used as a rubber plantation soil such as Kabin buri, Phon Pisai, and Surin series. Although the results found in field surveys in the Northeast, the North and the West showed that there was 11.3 % of laterite scattering, these areas can be used as a rubber plantation reaching to 82.98 % of entire area. It can be assumed that local farmers still have 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 are also significant.

Thumsiri *et al*. (1999) studied on the classification system of fertility capability classification (FCC) in 19 provinces in the Northeast namely 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

province. Implementation period covers 4 years, since October 1997 -September 2001. The results showed that the Northeast has a total area of 15,899,337 ha with 100 soil series. Proper area for growing rubber covers 6,652,752 ha with 37 soil series, or equal to 41.84%. Korat is a soil series which is most found. The province which has most appropriate area of rubber cultivation is Sakon Nakhon. By applying the fertility capability classification (FCC-R), The researchers found that there is not any area in the Northeast suitable for planting rubber in class of FCC-R I. Meanwhile, planting area in FCC-R II class covers 2,172,509 ha or 32.66%. 22 soil series were discovered in this class. Finally, planting area in FCC-R III class covers 4,480,243 ha or equal to 67.34% of entire area. In this class composed of 15 soil series. The suitable soil for growing rubber can be divided into two main groups are the clayey soil (C) with an area 2,329,786 ha or 35.02. % of the area suitable for growing rubber, this consists of 23 soil series. The other is Loamy sand (L) covered an area about 4,322,966 ha, or 64.98% of the suitable area for growing rubber, it consists of 14 soil series. By applying the FCC system, It found that the texture of almost soil are sandy, with low cation exchangeable capacity (CEC), the high iron concentration that can chelate the phosphorus, low content of available potassium and phosphorus (Seikp). The other soil is loamy texture in the surface soil, the sub soil is gravelly with about 15-35 % of gravel, with low cation exchangeable capacity (CEC), the high iron concentration that can chelate the phosphorus, low content of available potassium and phosphorus (LGei).

Vichichonchai *et al.* (2001) researched for nutrient levels in the soil and in rubber trees planted in the new area of the East and the Northeast including 24 provinces. They discovered that an average yield of rubber product was 39.2 grams per tree per tap or equal to 1,853.19 kilograms per ha per year. The average height of rubber trees was 3.07 meters. An average diameter was 7.27 meters. Average amount of rubber wood was 0.125 cubic meter per unit or equal to 59.31 cubic meter per ha. The ratio of fresh leaf weight: dry leaf weight was around 2.77: 1. Water content in rubber leaf was approximately 177.08%. Average number of rubber leaves was 17,569 leaves per unit. Average total leaf area reached to 134.66 square meters per tree. Nutrient levels in Kabinburi soil, which was a representative of soil found in the Eastern, was higher than Korat series, a representative of soil found in the Northeast. As a result, rubber trees planted in the East have higher rate of growth, yield and other components than those rubber trees planted in the Northeast area. The correlation between the age and average growth of RRIM 600 varieties planted in the East and in the Northeast area 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 most found in leaves, followed by the roots and stems, respectively. Total nitrogen contained within all parts of rubber was about 182.54 grams, whereas phosphorus was about 972.50 grams.

Saengruksawong (2010) reported that Nong Khai province has total area of 724,590 ha Phon Phisai soil series was most found in this area (153,410 ha), followed by Chakkarat soil series which has area of 79,396 ha (Land Development Department, 2003). The properties of Phonpisai soil series is characterized by the lateral flow that will be flooded during the rainy season, The texture is clayey skeleton, which consist

of more than 50% of gravels and plinthite was found within 1.5 meter from the surface. In the very shallow soil, rubber aged 3-9 years will notice a yellow canopy, leaf symptoms narrow, the stem is white, with distribution points throughout the plant. Symptoms broken shell rubber flow Rubber trees have died from symptoms different balance in the dry season, Bush can not be low due to deep roots into the ground significantly. Surface soil texture is loamy sand to sandy loam, subsoil texture as clay loam to sandy clay loam with about 35% of gravels. The organic matter content is very low. The soil fertility of is moderate. The soil water permeability is moderate in the surface soil but slowly in sub soil. Surface runoff is moderate to. The characteristics of Chakkarat soil series are; Soil texture in the surface soil is loamy sand. Soil organic matter in the surface soil (0-25 cm depth) is moderate, but low in the sub soil. Soil fertility is low. The soil permeability is moderate with moderate surface runoff. (Land Development Department, 2004).

Investigation from the Land Development Department shows that most soil type found in the area is the Phonpisai soil coveringin 153,410 ha. Studies on the growth pattern, bio-productivity, and carbon stock potential on Phonpisai soil type is an interesting topic and will provide important data for the development of management and encouragement of appropriate rubber plantation that give high yields and rehabilitate the environment.

4.2 Results

The results included soil properties and carbon-nutrient storages in the 1 to 20 years old rubber plantations on Phon Phisai and Chakkarat soil series, and the two natural forests.

4.2.1 Soil Physical Properties

(1) Soil Texture

Phon Phisai Soil Series:

In the natural forest (DDF), texture of surface soil was sandy clay loam, and clay for subsoil. The surface soils in most rubber plantations were sandy clay loam, and only that of 10-year-old stand was clay. For subsoils, the texture of 1- and 10-year-old stands varied from sandy clay loam to clay, whereas those of 5-, 15- and 20-year-old stands were clay.

Chakkarat Soil Series:

For Chakkarat, soil profile in DEF was A/Bt/Btc. Texture in most horizons were sandy clay loam, except for Bt1 and Bt4 which had sandy loam. In five age-class plantations, surface soils were mainly sandy loam or loamy sand whereas subsoils were sandy clay loam.

The soil in nearby dipterocarp forest was considered the natural soil in the area. The top soil was sandy clay loam soil and bottom soil was clay. Soil texture in top soil found natural forest and 1, 5, 15 and 20 years old rubber plantations to have sandy clay loam and 10 years old planation to have clay soil. For subsoil, natural

forest and 20 years old plantations had clay soil, 1 and 10 years old plantations had sandy clay loam to clay and 5 and 15 years old plantation had sandy clay loam to clay soil.

(2) Soil Bulk Density

Fisher and Binkley (2000) have defined the soil bulk density as the dry mass (of <2 mm material) of a given volume of intact soil in Megagrams per cubic meter (Mg m^{-3}) (which also equals kilograms per liter).

Phon Phisai Soil Series:

Bulk density of surface soil in the dry dipterocarp forest was medium (1.52 Mg m^{-3}). The deeper soil had the bulk density of moderately low to high, 1.19-1.96 Mg m^{-3}.

In the 1 year old plantation, the bulk density in surface soil was very high (2.21 Mg m^{-3}). It was also very high in the deeper horizons (2.01-2.25 Mg m^{-3}).

For the 5 years old plantation, the density in surface soil was very high (2.21 Mg.m^{-3}). The values in deeper horizons varied from moderately high to very high, 1.18-2.33 Mg m^{-3}.

The density of surface soil under the10 years old plantation was very high (2.20 Mg m^{-3}), and the values in deeper horizons varied between medium to very high, 1.53-2.24 Mg m^{-3}.

The surface soil under the 15 years old plantation had the medium density (1.58 Mg m^{-3}). They varied between moderately low to medium, 1.33-1.59 Mg m^{-3} in the subsoil.

In the 20 years old plantation, the density in surface soil was moderately low (1.33 Mg m^{-3}). The values in deeper soil varied between medium and moderately high, 1.59-1.69 Mg m^{-3}.

The surface soils under the 1 to 10 years old plantations had the very bulk density. The density was declined to medium for the 15 years old plantation and to relatively low for the 20 years old plantation. The surface soil was the ploughed layer. In the young plantations the soil might be exposed to rainfall. The soil erosion through surface runoff might increase the soil density. The canopy closure, decomsition of above-ground litter and manure application in the older plantations might reduce the density of surface soil.

Chakkarat Soil Series:

The bulk density of surface soil in the dry evergreen forest was moderately low (1.26 Mg m^{-3}). The deeper horizons had bulk density of medium to high, 1.48-1.90 Mg m^{-3}.

In the 1 year old plantation, the bulk density in surface soil was high (1.95 Mg m^{-3}). They were varied from moderately low to very high in the deeper horizons (1.34-2.01 Mg m^{-3}).

For the 5 years old plantation, the density in surface soil was very high (2.06 Mg.m^{-3}). The values in deeper horizons varied from moderately high to very high, 1.63-2.08 Mg m^{-3}.

The density of surface soil under the10 years old plantation was very high (2.02 Mg m^{-3}), and the values in deeper horizons varied between moderately low and very high, 1.31-2.08 Mg m^{-3}.

The surface soil under the 15 years old plantation had very high density (2.05 Mg m^{-3}). They varied between moderately low to very high, 1.40-2.12 Mg m^{-3} in the subsoil.

In the 20 years old plantation, the density in surface soil was medium (1.50 Mg m^{-3}). The values in deeper soil varied between medium and moderately high, 1.45-1.62 Mg m^{-3}.

Similar to Phon Phisai soil series, only the surface soils under the 1 to 15 years old plantations had high to very bulk densities. It was declined to medium for the 20 years old plantation. The rubber trees might affect on the bulk density of surface soils, and the densities in deeper soils were influenced mainly by weathering rocks and gravel contents. The effect of rubber plantations on change of soil bulk density was small.

(3) Soil Particle Density

Brady and Weil (2010) have defined the soil particle density as the mass per unit volume of soil solids (in contrast to the volume of the soil, which would laso include spaces between particles). It is the same as the specific gravity of the solid substance. The mineral composition of parent rocks has influenced on the particle density.

Phon Phisai Soil Series:

The particle density of surface soil in the dry dipterocarp forest was 2.09 Mg m^{-3}. The deeper horizons had densites between 2.09 and 2.29 Mg m^{-3}.

In the 1 year old plantation, the particle density in surface soil was 2.42 Mg m^{-3}. They were 2.01-2.25 Mg m^{-3} in the deeper horizons.

For the 5 years old plantation, the particle density in surface soil was 2.66 Mg.m^{-3}. The values in deeper horizons varied between 2.45 and 2.65 Mg m^{-3}.

The particle density of surface soil under the 10 years old plantation was 2.55 Mg m^{-3}, and the values in deeper horizons varied between 2.49 and 2.52 Mg m^{-3}.

The surface soil under the 15 years old plantation had the particle density of 2.28 Mg m^{-3}. They varied between 2.15 and 2.49 Mg m^{-3} in the subsoil.

In the 20 years old plantation, the particle density in surface soil was 2.39 Mg m^{-3}. The values in deeper soil varied between 2.25 and 2.69 Mg m^{-3}.

The particle densities in these plantations varied from 2.14-2.69 Mg m^{-3}. The rubber trees in plantations affected properties of the soil such as temperature and humidity, which in turned affected the weathering of rocks and minerals as well as reducing soil erosion in the older plantations. The high proportion of minerals in the soil particles might result in the high particle density. If the soil contains the high humus and lower minerals, the particle density may be decreased. Therefore, during 20 years of development of the rubber plantations, the change of soil development was small. No difference of the particle densities particularly in surface soil was observed among these plantations.

Chakkarat Soil Series:

The natural forest, dry evergreen forest, the surface soil had particle density of 2.22 Mg m^{-3}. The deeper horizons had the densites between 2.17 and 2.42 Mg m^{-3}.

In the 1 year old plantation, the particle density in surface soil was 2.40 Mg m^{-3}. They varied between 1.26 and 2.41 Mg m^{-3} in the deeper horizons.

For the 5 years old plantation, the particle density in surface soil was 2.36 Mg.m^{-3}. The densities in deeper horizons varied between 2.20 and 2.54 Mg m^{-3}.

The particle density of surface soil under the 10 years old plantation was 2.55 Mg m^{-3}, and the values in deeper horizons varied between 2.46 and 2.54 Mg m^{-3}.

The surface soil under the 15 years old plantation had the particle density of 2.27 Mg m^{-3}. They varied between 2.16 and 2.34 Mg m^{-3} in the subsoil.

In the 20 years old plantation, the particle density in surface soil was 2.46 Mg m^{-3}. The values in deeper soil varied between 2.46 and 2.63 Mg m^{-3}.

Similar to Phon Phisai soil series, no difference of the particle densities particularly in surface soil was observed among these plantations. The particle densities in these plantations varied from 1.26-2.63 Mg m^{-3}.

4.2.2 Soil Chemical Properties

Table 4-5 and **Table 4-6** show soil chemical properties under the 1 to 20 years old rubber plantations on Phon Phisai and Chakkarat soil series.

(1) Soil reaction

The degree of soil acidity or alkalinity (reaction) is expressed as soil pH. The acidity and alkalinity is all about the balance between hydrogen ions (H^+) and hrydroxyl ions (OH^-), and is quantified using the pH scale, 1-14.

Phon Phisai Soil Series:

The reaction of surface soil in the DDF was very strongly acid (pH = 5.0). They were also very strongly acid in the deeper horizons, pH = 4.6-4.8.

In the 1 year old plantation, the reaction was very strongly acid throughout the soil profile, pH = 4.5-5.0.

For the 5 years old plantation, the reaction was very strongly acid throughout the soil profile, pH = 4.6-4.9.

The soil reaction under the 10 years old plantation was very strongly acid throughout the soil profile, pH = 4.7-5.0.

The surface soil under the 15 years old plantation was very strongly acid throughout the soil profile, pH = 4.7-4.8.

In the 20 years old plantation, the reaction was also very strongly acid throughout the soil profile, pH = 4.6-4.9.

The soil reaction was not change during 20 years of the rubber plantation on Phon Phisai soil series.

Chakkarat Soil Series:

The reaction of surface soil in the DDF was extremely acid (pH = 4.2). The soil was also extremely acid (pH = 4.4) to the depth of 90 cm, and very strongly acid in the deeper horizons, up to 2.0 m, pH = 4.5-5.0.

In the 1 year old plantation, the reaction was extremely in surface soil (0-47 cm depth), and very strongly acid in the deeper horizons, pH = 4.6-5.1.

For the 5 years old plantation, the reaction was extremely acid to the depth of 116 cm (pH = 4.6-5.0), and strongly acid in the deeper horizons, pH = 5.1-5.3.

The soil reaction under the 10 years old plantation was extremely acid throughout soil profile, pH = 4.6-5.0.

The soil under the 15 years old plantation was extremely acid at 0-50 cm depth (pH = 4.4), and very strongly acid in the deeper horizons, pH = 4.5-4.8.

In the 20 years old plantation, the reaction was extremely acid at 0-110 cm (pH = 4.2-4.3), and very strongly acid in the deeper soil, pH = 4.6.

The soil reaction of Chakkarat soil series was more acid than Phon Phisai soil series. However, there was no change of soil reaction with age of the rubber plantations.

(2) Soil organic matter

Phon Phisai Soil Series:

The content of organic matter in surface soil under the DDF was moderately high (pH = 32.9 g kg^{-1}). It was decreased to medium to very low in the deeper soil, 3.0-17.9 g kg^{-1}.

In the 1 year old plantation, the content of organic matter in surface soil was very high (46.9 g kg^{-1}). It was decreased to moderately low to very low in the deeper soil, 1.8-11.2 g kg^{-1}.

For the 5 years old plantation, the content of organic matter in surface soil was moderately low (12.1 g kg^{-1}). It was decreased to moderately low to very low in the deeper soil, 1.7-10.6 g kg^{-1}.

The soil organic matter under the 10 years old plantation was medium in surface soil (17.6 g kg^{-1}). It was decreased to moderately low to very low in the deeper soil, 3.9-10.7 g kg^{-1}.

The surface soil under the 15 years old plantation contained organic matter at the moderately high level (28.5 g kg^{-1}). It was decreased to moderately low to very low in the deeper soil, 1.3-13.6 g kg^{-1}.

In the 20 years old plantation, the organic matter in surface soil was medium (15.1 g kg^{-1}). It was decreased to moderately low to very low in the deeper soil, 1.7-12.6 g kg^{-1}.

There was no difference of soil organic matter among the 1 to 20 years old plantations. The farmers usually apply manure to the soil under rubber plantations that may increase the soil organic matter. However, soil erosion is the important factor which may result in the losss of soil organic matter from the surface soil.

Chakkarat Soil Series:

The content of organic matter in surface soil under the DEF was moderately high (pH = 28.4 g kg^{-1}). It was decreased to very low in the deeper soil, 0.6-3.5 g kg^{-1}.

In the 1 year old plantation, the organic matter in surface soil was moderately low (12.4 g kg^{-1}). It was decreased to very low in the deeper soil, 0.6-1.2 g kg^{-1}.

For the 5 years old plantation, the organic matter in surface soil was low (7.4 g kg^{-1}). It was decreased to moderately low to very low in the deeper soil, 0.6-5.3 g kg^{-1}.

The organic matter under the 10 years old plantation was moderately low (13.7 g kg^{-1}). It was decreased to low or very low in the deeper soil, 1.3-11.2 g kg^{-1}.

The surface soil under the 15 years old plantation contained organic matter at the moderately low level (13.1 g kg^{-1}). It was decreased to low or very low in the deeper soil, 0.8-15.5 g kg^{-1}.

In the 20 years old plantation, the organic matter in surface soil was moderately low (14.3 g kg^{-1}). It was decreased to low or very low in the deeper soil, 0.8-5.5 g kg^{-1}.

There was no difference of soil organic matter among the 1 to 20 years old plantations on Chakkarat soil series. The contents of soil organic matter were poor. This soil had the fine sandy texture. Most organic matter might be lost through the soil erosion.

(3) Available phosphorus

Phon Phisai Soil Series:

The concentration of available phosphorus in surface soil under the DDF was moderately low (7.0 mg/kg). It was decreased to moderately low to low or very low in the deeper soil, 2.0-8.0 mg/kg.

In the 1 year old plantation, available phosphorus in surface soil was low (5.0 mg/kg). It was decreased to very low in the deeper soil, 1.0-2.0 mg/kg.

For the 5 years old plantation, available phosphorus in surface soil was also low (3.0 mg/kg). It was decreased to very low in the deeper soil, 1.0-2.0 mg/kg.

The available phosphorus in surface soil under the 10 years old plantation was low (3.0 mg/kg). It was decreased to very low in the deeper soil, 1.0 mg/kg.

The surface soil under the 15 years old plantation contained available phosphorus at the low level (4.0 mg/kg). It was decreased to very low in the deeper soil, 1.0 mg/kg.

In the 20 years old plantation, available phosphorus in surface soil was low (3.0 mg/kg). It was decreased to very low in the deeper soil, 1.0 mg/kg.

There was no difference of available phosphorus in soils among the 1 to 20 years old plantations on Phon Phisai soil series. The concentrations were moderatelt low to low or very low.

Chakkarat Soil Series:

The concentration of available phosphorus in surface soil under the DEF was low (6.0 mg/kg). It was decreased to very low in the deeper soil, 0-2.0 mg/kg.

In the 1 year old plantation, available phosphorus in surface soil was low (4.0 mg/kg). It was decreased to very low in the deeper soil, 1.0-2.0 mg/kg.

For the 5 years old plantation, available phosphorus in surface soil was also low (4.0 mg/kg). It was decreased to very low in the deeper soil, 1.0-3.0 mg/kg.

The available phosphorus in surface soil under the 10 years old plantation was low (4.0 mg/kg). It was decreased to very low in the deeper soil, 1.0-2.0 mg/kg.

The surface soil under the 15 years old plantation contained available phosphorus at the low level (4.0 mg/kg). It was decreased to very low in the deeper soil, 1.0-2.0 mg/kg.

In the 20 years old plantation, available phosphorus in surface soil was moderately low (8.3 mg/kg). It was decreased from moderately low to low or very low in the deeper soil, 2.0-9.0 mg/kg.

There was no difference of available phosphorus in soils among the 1 to 20 years old plantations on Chakkarat soil series. The concentrations were moderatelt low to low or very low.

(4) Extractable potassium

Phon Phisai Soil Series:

The concentration of extractable potassium in surface soil under the DDF was high (110 mg/kg). It was high to very high in the deeper soil, 97.0-128.0 mg/kg.

In the 1 year old plantation, extractable potassium in surface soil was medium (83.0 mg/kg). It was the medium to high or very high in the deeper soil, 82.0-193.0 mg/kg.

For the 5 years old plantation, extractable potassium in surface soil was low (47.0 mg/kg). It was medium in the deeper soil, 62.0-83.0 mg/kg.

The extractable potassium in surface soil under the 10 years old plantation was medium (86.0 mg/kg). It was also the medium in the deeper soil, 61.0-88.0 mg/kg.

The surface soil under the 15 years old plantation contained extractable potassium at the high level (100.0 mg/kg). It was medium to high in the deeper soil, 87.0-121.0 mg/kg.

In the 20 years old plantation, extractable potassium in surface soil was high (110.0 mg/kg). It was low in the deeper soil, 36.0-57.0 mg/kg.

Most soils contained medium to high or very high of extractable potassium, except subsoil under the 20 years old plantation had the low level. There was no change with the plantation age of soil extractable potassium for Phon Phisai soil series.

Chakkarat Soil Series:

The concentration of extractable potassium in surface soil under the DEF was low (110 mg/kg). It was low to very low in the deeper soil, 15.0-52.0 mg/kg.

In the 1 year old plantation, extractable potassium in surface soil was very low (14.0 mg/kg). It was also very low in the deeper soil, 14.0-28.0 mg/kg.

For the 5 years old plantation, extractable potassium in surface soil was very low (47.0 mg/kg). It was medium to very low in the deeper soil, 7.0-78.0 mg/kg.

The extractable potassium in surface soil under the 10 years old plantation was low (49.0 mg/kg). It was very low in the deeper soil, 9.0-20.0 mg/kg.

The surface soil under the 15 years old plantation contained extractable potassium at the low level (47.0 mg/kg). It was very low in the deeper soil, 13.0-25.0 mg/kg.

In the 20 years old plantation, extractable potassium in surface soil was low (55.0 mg/kg). It was low to very low in the deeper soil, 19.0-33.0 mg/kg.

The soils had the fine sandy texture. Some extractable potassium might be leached out to ground water and the remaining amounts might be uptaken by the rubber trees. The soils thus contained the low to very low concentrations of extractable potassium. There was no change with the plantation age of soil extractable potassium for Chakkarat soil series. In contrast, Phon Phisai soil series contained the medium to high or very high concentrations of extractable potassium since the soil texture was mainly clay.

(5) Extractable calcium

Phon Phisai Soil Series:

The concentration of extractable calcium in surface soil under the DDF was very low (384.0 mg/kg). It was also very low in the deeper soil, 50.0-163.0 mg/kg.

In the 1 year old plantation, extractable calcium in surface soil was very low (205.0 mg/kg). It was very low in the deeper soil, 18.0-49.0 mg/kg.

For the 5 years old plantation, extractable calcium in surface soil was very low (45.0 mg/kg). It was very low in the deeper soil, 27.0-61.0 mg/kg.

The extractable calcium in surface soil under the 10 years old plantation was very low (67.0 mg/kg). It was very low in the deeper soil, 16.0-55.0 mg/kg.

The surface soil under the 15 years old plantation contained extractable calcium at the very low level (131.0 mg/kg). It was very low in the deeper soil, 8.0-68.0 mg/kg.

In the 20 years old plantation, extractable calcium in surface soil was very low (44.0 mg/kg). It was very low in the deeper soil, 27.0-90.0 mg/kg.

The soils contained very low concentrations of extractable calcium. There was no change with the plantation age of soil extractable calcium for Phon Phisai soil series. It was the low base soil.

Chakkarat Soil Series:

The concentration of extractable calcium in surface soil under the DEF was very low (19.0 mg/kg). It was also very low in the deeper soil, 8.0-43.0 mg/kg.

In the 1 year old plantation, extractable calcium in surface soil was very low (25.0 mg/kg). It was very low in the deeper soil, 16.0-32.0 mg/kg.

For the 5 years old plantation, extractable calcium in surface soil was very low (22.0 mg/kg). It was very low in the deeper soil, 10.0-55.0 mg/kg.

The extractable calcium in surface soil under the 10 years old plantation was very low (27.0 mg/kg). It was very low in the deeper soil, 7.0-34.0 mg/kg.

The surface soil under the 15 years old plantation contained extractable calcium at the very low level (19.0 mg/kg). It was very low in the deeper soil, 12.0-34.0 mg/kg.

In the 20 years old plantation, extractable calcium in surface soil was very low (66.0 mg/kg). It was very low in the deeper soil, 7.0-39.0 mg/kg.

The soils also contained the very low concentrations of extractable calcium. There was no change with the plantation age of soil extractable calcium for Chakkarat soil series. It was the low base soil as same as the Phon Phisai soil series.

(6) Extractable magnesium

Phon Phisai Soil Series:

The concentration of extractable magnesium in surface soil under the DDF was medium (195.0 mg/kg). It was medium in the deeper soil, 186.0-197.0 mg/kg.

In the 1 year old plantation, extractable magnesium in surface soil was low (65.0 mg/kg). It was low to very low in the deeper soil, 13.0-68.0 mg/kg.

For the 5 years old plantation, extractable magnesium in surface soil was very low (19.0 mg/kg). It was also very low in the deeper soil, 10.0-33.0 mg/kg.

The extractable magnesium in surface soil under the 10 years old plantation was low (37.0 mg/kg). It was very low in the deeper soil, 26.0-33.0 mg/kg.

The surface soil under the 15 years old plantation contained extractable magnesium at the low level (41.0 mg/kg). It was very low in the deeper soil, 8.0-73.0 mg/kg.

In the 20 years old plantation, extractable magnesium in surface soil was very low (15.0 mg/kg). It was very low in the deeper soil, 6.0-19.0 mg/kg.

The soils in DDF contained medium concentrations of extractable magnesium throughout the soil profile. There was no change with the plantation age of soil extractable magnesium for Phon Phisai soil series. The concentrations were low to very levels.

Chakkarat Soil Series:

The concentration of extractable magnesium in surface soil under the DEF was very low (10.0 mg/kg). It was very low in the deeper soil, 2.0-10.0 mg/kg.

In the 1 year old plantation, extractable magnesium in surface soil was very low (2.0 mg/kg). It was also very low in the deeper soil, 2.0-9.0 mg/kg.

For the 5 years old plantation, extractable magnesium in surface soil was very low (12.0 mg/kg). It was low to very low in the deeper soil, 11.0-39.0 mg/kg.

The extractable magnesium in surface soil under the 10 years old plantation was low (6.0 mg/kg). It was very low in the deeper soil, 2.0-5.0 mg/kg.

The surface soil under the 15 years old plantation contained extractable magnesium at the very low level (5.0 mg/kg). It was very low in the deeper soil, 2.0-4.0 mg/kg.

In the 20 years old plantation, extractable magnesium in surface soil was very low (11.0 mg/kg). It was very low in the deeper soil, 2.0-5.0 mg/kg.

Chakkarat soils in DDF and rubber plantations contained very low concentrations of extractable magnesium throughout the soil profile. There was no change with the plantation age of the soil extractable magnesium.

(7) Cation exchange capacity (CEC)

Brady and Weil (2010) have defined that the CEC is expressed as the number of centimoles of positive charge ($cmol_c$) that can be adsorbed per unit mass.

Phon Phisai Soil Series:

The CEC in surface soil under the DDF was 7.7 cmol/kg. They were 12.6-19.0 cmol/kg in the deeper soil.

In the 1 year old plantation, the CEC in surface soil was 7.6 cmol/kg. They were 7.7-15.6 cmol/kg in the deeper soil.

For the 5 years old plantation, the CEC in surface soil was 4.1 cmol/kg. They were 3.3-7.4 cmol/kg in the deeper soil.

The CEC in surface soil under the 10 years old plantation was 7.1 cmol/kg. They were 6.1-9.6 cmol/kg in the deeper soil.

The surface soil under the 15 years old plantation had CEC of 6.4 cmol/kg. They were 8.6-14.0 cmol/kg in the deeper soil.

In the 20 years old plantation, the CEC in surface soil was 3.6 cmol/kg. They were 5.2-7.3 cmol/kg in the deeper soil.

There was no change with the plantation age of CEC for Phon Phisai soil series. The CEC values of these soils were relatively low. There was no change with the plantation age of the CEC in soils.

Chakkarat Soil Series:

The CEC in surface soil under the DEF was 5.6 cmol/kg. They were 2.3-3.3 cmol/kg in the deeper soil.

In the 1 year old plantation, the CEC in surface soil was 2.2 cmol/kg. They were 1.7-2.1 cmol/kg in the deeper soil.

For the 5 years old plantation, the CEC in surface soil was 1.5 cmol/kg. It was 1.4-1.9 cmol/kg in the deeper soil.

The CEC in surface soil under the 10 years old plantation was 2.4 cmol/kg. They were 1.9-2.9 cmol/kg in the deeper soil.

The surface soil under the 15 years old plantation had CEC of 2.4 cmol/kg. They were 1.8-2.3 cmol/kg in the deeper soil.

In the 20 years old plantation, the CEC in surface soil was 2.3 cmol/kg. They were 2.8-.6 cmol/kg in the deeper soil.

There was no change with the plantation age of CEC for Chakarat soil series. The CEC values of these soils were very low since they had the sandy texture and low organic matter throught the soil profile. There was no change with the plantation age of the CEC in the soils.

(8) Base saturation (BS)

Phon Phisai Soil Series:

The BS percentage in surface soil under the DDF was 70.10. They were 13.30-26.27 in the deeper soil.

In the 1 year old plantation, the BS percentage in surface soil was 51.40. They were 5.25-22.12 in the deeper soil.

For the 5 years old plantation, the BS percentage in surface soil was 26.79. They were 13.04-25.54 in the deeper soil.

The BS percentage in surface soil under the 10 years old plantation was 24.12. They were 9.23-22.78 in the deeper soil.

The surface soil under the 15 years old plantation had BS percentage of 35.10. They were 4.62-19.69 in the deeper soil.

In the 20 years old plantation, the BS percentage in surface soil was 24.75. They were 6.0-13.48 in the deeper soil.

The surface soil under DDF and the 1 year old plantation had the high BS percentages. This might be caused by the forest fire, and burning of the plant debris. Most soils had the BS percentages lower than 35. They were classified to the low base soils. There was no change with the plantation age of the BS in soils.

Chakkarat Soil Series:

The BS percentage in surface soil under the DEF was 11.0. They were 7.0-19.0 in the deeper soil.

In the 1 year old plantation, the BS percentage in surface soil was 15.0. They were 18.0-29.0 in the deeper soil.

For the 5 years old plantation, the BS percentage in surface soil was 19.0. They were 11.0-44.0 in the deeper soil.

The BS percentage in surface soil under the 10 years old plantation was 27.0. They were 8.0-23.0 in the deeper soil.

The surface soil under the 15 years old plantation had BS percentage of 22.0. They were 13.0-21.0 in the deeper soil.

In the 20 years old plantation, the BS percentage in surface soil was 40.0. They were 6.0-12.0 in the deeper soil.

The soils had the BS percentages lower than 35, and were therefore classified to the low base soils, Order Ultisols. There was no change with the plantation age of BS in the soils.

Table 4-1 Soil physical properties under different age rubber plantations and adjacent dry dipterocarp forest on Phon Phisai soil series

Soil horizon	Depth (cm)	Particle size distribution (%)			Soil Texture	Gravel (%)	Bulk density		Particle density
		sand	silt	clay			$Mg.m^3$		
1-year-old									
Ap	0-18	63.52	16.00	20.48	Sandy clay loam	56.70	2.21	VH	2.42
Btcv1	18-40	49.52	6.00	44.48	Sandy clay	44.10	2.22	VH	2.49
Btcv2	40-82/88	51.52	8.00	40.48	Sandy clay	59.86	2.25	VH	2.58
Btv	82/88-135/158	23.52	18.00	58.48	Clay	1.41	2.04	VH	2.23
BCv1	135/158-190	13.52	26.00	60.48	Clay	2.87	2.07	VH	2.23
BCv2	190-210+	9.52	32.00	58.48	Clay	1.61	2.01	VH	2.14
5-year-old									
Ap	0-19	65.52	12.00	22.48	Sandy clay loam	35.38	2.21	VH	2.66
Btcv1	19-36	61.52	8.00	30.48	Sandy loam	26.66	2.24	VH	2.65
Btcv2	36-110	41.52	10.00	48.48	Sandy clay	29.25	1.80	MH	2.59
Btcv3	110-143	39.52	14.00	46.48	Clay	36.20	2.25	VH	2.45
BCv1	143-182	41.52	12.00	46.48	Clay	32.83	2.33	VH	2.50
BCv2	182-210+	31.52	18.00	50.48	Clay	35.63	2.32	VH	2.54
10-year-old									
Ap	0-19	43.52	12.00	44.48	Sandy clay loam	50.56	2.20	VH	2.55
Btcv1	19-46	25.52	10.00	64.48	Clay	20.40	2.24	VH	2.51
Btcv2	46-92/101	33.52	16.00	50.48	Clay	51.01	1.53	M	2.51
Btcv3	92/101-135	51.52	10.00	38.48	Sandy clay	5.16	1.40	ML	2.51
BCv1	135-182	53.52	10.00	36.48	Sandy clay loam	6.07	1.97	H	2.49
BCv2	182-210+	35.52	16.00	48.48	Clay	9.65	1.90	H	2.52
15-year-old									
Ap	0-20	48.80	24.00	27.20	Sandy clay loam	42.91	1.58	M	2.28
Btcv1	20-40	30.80	18.00	51.20	Clay	37.28	1.59	M	2.45
Btcv2	40-80	22.80	20.00	57.20	Clay	19.71	1.35	ML	2.49
Btv1	80100	22.80	22.00	55.20	Clay	1.59	1.33	ML	2.28
Btv2	100-140	14.80	16.00	69.20	Clay	1.09	1.44	M	2.23
BCv1	140-180	28.80	20.00	51.20	Clay	8.76	1.50	M	2.15
BCv2	180-210+	12.80	28.00	59.20	Clay	7.35	1.49	M	2.40
20-year-old									
Ap	0-17	66.80	12.00	21.20	Sandy clay loam	14.49	1.33	ML	2.39
Btcv1	17-40	50.80	18.00	31.20	Sandy clay loam	79.74	1.59	M	2.69
Btcv2	40-107	38.80	12.00	49.20	Clay	25.73	1.69	MH	2.32
BCv1	107-145	34.80	18.00	47.20	Clay	31.19	1.61	MH	2.42
BCv2	145-185	30.80	26.00	43.20	Clay	22.37	1.69	MH	2.25
BCv3	185-203+	34.80	24.00	41.20	Clay	11.28	1.61	MH	2.40
Dry dipterocarp forest									
A	0-5	57.52	16.00	26.48	Sandy clay loam	54.08	1.52	M	2.09
BA	5-15	35.52	18.00	46.48	Clay	34.04	1.96	H	2.17
Btcv1	15-50	13.52	32.00	54.48	Clay	36.72	1.79	MH	2.07
Btcv2	50-98	5.52	40.00	54.48	Clay	18.77	1.24	ML	2.09
Btv	98-154	13.52	32.00	54.48	Clay	14.59	1.19	L	2.21
BCv	154-210+	29.52	16.00	54.48	Clay	43.49	1.25	ML	2.29

Table 4-2 Soil physical properties under five age-class rubber plantations and dry evergreen forest on Chakkarat soil series

Horizon	Depth (cm)	Particle size distribution (%)			Texture	Gravel	Bulk density		Particle density
		sand	silt	clay		(%)	Mg m^{-3}		
1-year-old									
Ap1	0-20	78.96	8.72	12.32	sandy loam	0.07	1.95	H	2.40
Ap2	20-47	74.96	6.72	18.32	sandy loam	0.08	2.01	VH	2.41
Bt1	40-89/96	74.96	6.72	18.32	sandy loam	0.49	2.00	H	2.26
Btc1	89/96-144	66.96	8.72	24.32	sandy clay loam	94.27	1.63	MH	2.24
Btc2	144-183	66.96	10.72	22.32	sandy clay loam	65.01	1.26	ML	1.26
Btc3	183-210+	68.96	8.72	22.32	sandy clay loam	58.22	1.34	ML	1.34
5-year-old									
Ap1	0-11	86.96	4.72	8.32	loamy sand	0.07	2.06	VH	2.36
Ap2	11-26/31	80.96	8.72	10.32	loamy sand	0.08	2.04	VH	2.34
Bt1	26/31-60	74.96	8.72	16.32	sandy loam	0.13	2.08	VH	2.54
Bt2	60-99	74.96	8.72	16.32	sandy loam	0.14	2.05	VH	2.20
Btc1	99/116	70.96	8.72	20.32	sandy clay loam	70.15	1.63	MH	2.34
Btc2	116-170/177	66.96	10.72	22.32	sandy clay loam	66.71	1.70	MH	2.49
Btc3	170/177-215+	64.96	12.72	22.32	sandy clay loam	41.13	1.70	MH	2.28
10-year-old									
Ap1	0-8	80.96	6.72	12.32	sandy loam	0.05	2.02	VH	2.55
Ap2	8-24	74.96	8.72	16.32	sandy loam	0.07	2.08	VH	2.49
Bt1	24-44	72.96	8.72	18.32	sandy clay loam	0.08	2.13	VH	2.54
Bt2	44-60/71	70.96	8.72	20.32	sandy clay loam	0.48	2.02	VH	2.46
Btc1	60/71-133	68.96	6.72	24.32	sandy clay loam	62.54	1.31	ML	2.49
Btc2	133-175	66.96	8.72	24.32	sandy clay loam	46.36	1.39	ML	2.49
BC	175-210+	64.96	10.72	24.32	sandy clay loam	33.68	1.38	ML	2.56
15-year-old									
Ap1	0-10	76.96	8.72	14.32	sandy loam	0.12	2.05	VH	2.27
Ap2	10-23	74.96	8.72	16.32	sandy loam	0.05	2.12	VH	2.34
Bt1	23-50	74.96	6.72	18.32	sandy loam	0.12	2.10	VH	2.25
Bt2	50-82	74.96	6.72	18.32	sandy loam	0.54	2.18	VH	2.27
Btc	82-161	68.96	8.72	22.32	sandy clay loam	70.53	1.57	M	2.16
BC	161-210+	62.96	12.72	24.32	sandy clay loam	23.57	1.40	ML	2.20
20-year-old									
Ap1	0-13	84.96	6.72	8.32	loamy sand	0.08	1.50	M	2.46
Ap2	13-28	74.96	8.72	16.32	sandy loam	0.06	1.45	M	2.46
Bt1	28-60	70.96	8.72	20.32	sandy clay loam	0.06	1.50	M	2.55
Bt2	60-110	70.96	8.72	20.32	sandy clay loam	0.45	1.51	M	2.63
Btc	110-144/165	58.96	14.72	26.32	sandy clay loam	56.91	1.62	MH	2.55
BC1	144/165-/196	64.96	14.72	20.32	sandy clay loam	19.04	1.49	M	2.60
BC2	196-210+	74.96	12.72	12.32	sandy loam	63.90	1.58	M	2.46
Dry evergreen forest									
A	0-11	54.80	24.16	21.04	sandy clay loam	0.13	1.26	ML	2.22
Bt1	11-30	68.80	12.16	19.04	sandy loam	0.45	1.51	M	2.24
Bt2	30-55	64.80	14.16	21.04	sandy clay loam	0.61	1.55	M	2.26
Bt3	55-75/90	66.80	12.16	21.04	sandy clay loam	3.95	1.51	M	2.23
Btc1	75/90-104/130	70.80	6.16	23.04	sandy clay loam	75.43	1.90	H	2.17
Btc2	104/130-129/150	64.80	14.16	21.04	sandy clay loam	65.05	1.76	MH	2.42
Btc3	129/150-170	60.80	16.16	23.04	sandy clay loam	24.85	1.52	M	2.26
Btc4	170-193	64.80	14.16	21.04	sandy clay loam	14.29	1.61	MH	2.25
Bt4	193-210+	68.80	14.16	17.04	sandy loam	7.40	1.48	M	2.35

Table 4-3 Soil chemical properties in rubber plantations and DDF on Phon Phisai soil series

									Extratable nutrients									
Horizon	**Depth**	**pH**	**OM**	**C**		**N**		**P**		**K**		**Ca**		**Mg**		**CEC**	**BS**
	(cm)		**g/kg**					**mg/kg**								**cmol**	**%**
Dry dipterocarp forest																	
A	0-5	5.0 VSA	32.9	MH	10.08	1.80	L	7	ML	110	H	348	VL	195	M	7.7	70.10
BA	5-18	4.7 VSA	17.9	M	10.38	1.06	L	5	L	97	H	163	VL	195	M	12.6	26.27
Btcv1	18-50	4.7 VSA	10.2	ML	5.91	0.64	VL	4	L	113	H	161	VL	191	M	16.9	17.79
Btcv2	50-98	4.7 VSA	6.0	L	3.48	0.26	VL	3	L	113	H	87	VL	186	M	17.2	14.84
Btv	98-154	4.8 VSA	3.0	VL	1.74	0.18	VL	2	VL	120	H	50	VL	194	M	18.4	13.30
BCv	154-210+	4.6 VSA	3.7	VL	2.14	0.17	VL	8	ML	128	VH	66	VL	197	M	19.0	15.48
1-year-old																	
Ap	0-18	4.9 VSA	46.6	VH	27.02	1.93	L	5	L	83	M	205	VL	65	L	7.6	51.40
Btcv1	18-40	5.0 VSA	11.2	ML	6.49	0.78	VL	1	VL	82	M	45	VL	59	L	7.7	22.12
Btcv2	40-82/88	4.6 VSA	5.8	L	3.36	0.25	VL	2	VL	77	M	49	VL	68	L	8.2	21.96
Btv	82/88-135/158	4.7 VSA	2.5	VL	1.45	0.13	VL	1	VL	100	H	33	VL	23	VL	14.4	6.82
BCv1	135/158-190	4.7 VSA	1.8	VL	1.04	0.10	VL	1	VL	110	H	18	VL	13	VL	15.1	5.25
BCv2	190-210+	4.5 VSA	2.0	VL	1.16	0.10	VL	1	VL	193	VH	27	VL	14	VL	15.6	8.11
5-year-old																	
Ap	0-19	4.7 VSA	12.1	ML	7.01	0.73	L	3	L	47	L	45	VL	19	VL	4.1	26.79
Btcv1	19-36	4.6 VSA	10.6	ML	6.14	0.73	VL	2	VL	69	M	61	VL	17	VL	5.1	22.37
Btcv2	36-110	4.8 VSA	5.4	L	3.13	0.35	VL	1	VL	62	M	52	VL	25	VL	6.3	19.51
Btcv3	110-143	4.9 VSA	1.7	VL	0.98	0.10	VL	1	VL	63	M	41	VL	10	VL	3.3	25.54
BCv1	143-182	4.9 VSA	2.7	VL	1.56	0.10	VL	2	VL	83	M	30	VL	33	VL	7.4	13.72
BCv2	182-210+	4.8 VSA	2.5	VL	1.45	0.10	VL	1	VL	80	M	27	VL	27	VL	7.0	13.04
10-year-old																	
Ap	0-19	5.0 VSA	17.6	M	10.20	1.29	L	3	L	86	M	67	VL	37	L	7.1	24.12
Btcv1	19-46	4.9 VSA	10.7	ML	6.20	0.74	VL	1	VL	88	M	25	VL	33	VL	7.8	17.81
Btcv2	46-92/101	5.0 VSA	5.7	L	3.30	0.29	VL	1	VL	88	M	16	VL	33	VL	6.9	19.99
Btcv3	92/101-135	5.0 VSA	5.0	L	2.90	0.10	VL	1	VL	61	M	55	VL	26	VL	6.1	22.78
BCv1	135-182	4.9 VSA	5.0	L	2.90	0.10	VL	1	VL	77	M	32	VL	33	VL	8.3	13.32
BCv2	182-210+	4.7 VSA	3.9	VL	2.26	0.10	VL	1	VL	80	M	35	VL	30	VL	9.6	9.23
15-year-old																	
Ap	0-20	4.8 VSA	28.5	MH	16.53	1.10	L	4	L	100	H	131	VL	41	L	6.4	35.10
Btc1	20-40	4.8 VSA	13.6	ML	7.88	0.71	VL	1	VL	87	M	44	VL	54	L	8.6	14.36
Btc2	40-80	4.8 VSA	6.2	L	3.59	0.37	VL	1	VL	103	H	68	VL	73	L	8.8	19.69
Btv3	80-100	4.7 VSA	3.0	VL	1.74	0.27	VL	1	VL	85	M	19	VL	36	VL	10.9	7.26
2Btv4	100-140	4.7 VSA	3.0	VL	1.74	0.10	VL	1	VL	109	H	20	VL	23	VL	14.0	5.37
2BCv1	140-180	4.6 VSA	1.3	VL	0.75	0.10	VL	1	VL	121	H	8	VL	9	VL	11.4	5.29
2BCv2	180-210+	4.7 VSA	1.7	VL	0.98	0.10	VL	1	VL	105	H	23	VL	8	VL	11.6	4.62
20-year-old																	
Ap	0-17	4.8 VSA	15.1	M	8.75	0.88	L	3	L	110	H	44	VL	15	VL	3.6	24.75
Btcv1	17-40	4.8 VSA	12.6	ML	7.30	0.58	VL	2	VL	57	L	27	VL	8	VL	5.2	10.56
Btcv2	40-107	4.9 VSA	5.4	L	3.13	0.38	VL	1	VL	44	L	90	VL	19	VL	7.3	13.48
BCv1	107-145	4.9 VSA	2.7	VL	1.56	0.10	VL	1	VL	44	L	35	VL	12	VL	7.3	7.14
BCv2	145-185	4.9 VSA	2.0	VL	1.16	0.10	VL	1	VL	36	L	23	VL	8	VL	6.9	6.50
BCv3	185-203+	4.6 VSA	1.7	VL	0.98	0.10	VL	1	VL	36	L	34	VL	6	VL	6.3	6.00

Table 4-4 Soil chemical properties in rubber plantations and DEF on Chakkarat soil series

Horizon	Depth (cm)	pH	OM		C	N	Extratable nutrients P		K		Ca		Mg		CEC	BS
			g/kg				mg/kg								cmol /kg	%
Dry evergreen forest																
A	0-11	4.2 EA	28.4	MH	16.5	1.03 L	6	L	51	L	19	VL	10	VL	5.6	11.0
Bt1	11-30	4.4 EA	3.5	VL	2.0	0.35 VL	2	VL	15	VL	8	VL	3	VL	2.4	7.0
Bt2	30-55	4.4 EA	2.0	VL	1.2	0.19 VL	1	VL	18	VL	11	VL	2	VL	2.6	8.0
Bt3	55-75/90	4.4 EA	2.0	VL	1.2	0.21 VL	1	VL	11	VL	12	VL	3	VL	2.6	8.0
Btc1	75/90-104/130	4.8 VSA	2.7	VL	1.6	0.20 VL	1	VL	26	VL	16	VL	4	VL	2.9	10.0
Btc2	104/130-129/150	5.0 VSA	1.0	VL	0.6	-	0	VL	23	VL	19	VL	10	VL	2.9	13.0
Btc3	129/150-170	4.9 VSA	1.3	VL	0.8	-	0	VL	49	L	43	VL	8	VL	3.1	19.0
Btc4	170-193	4.7 VSA	0.6	VL	0.3	-	0	VL	16	VL	36	VL	7	VL	3.1	12.0
Bt4	193-210+	4.5 VSA	0.6	VL	0.3	-	1	VL	52	L	30	VL	4	VL	3.3	17.0
1-year-old plantation																
Ap1	0-20	4.1 EA	12.4	ML	7.2	0.57 VL	4	L	14	VL	25	VL	2	VL	2.2	15.0
Ap2	20-47	4.4 EA	3.7	VL	2.1	0.28 VL	2	VL	20	VL	16	VL	2	VL	1.7	18.0
Bt1	40-89/96	4.6 VSA	2.7	VL	1.6	0.16 VL	1	VL	18	VL	19	VL	2	VL	2.1	18.0
Btc1	89/96-144	4.7 VSA	2.4	VL	1.4	0.10 VL	1	VL	14	VL	25	VL	3	VL	2.1	15.0
Btc2	144-183	5.1 VSA	1.3	VL	0.8	-	1	VL	28	VL	32	VL	7	VL	1.9	29.0
Btc3	183-210+	5.1 VSA	1.0	VL	0.6	-	1	VL	15	VL	17	VL	9	VL	1.9	19.0
5-year-old																
Ap1	0-11	5.0 VSA	7.4	L	4.3	0.40 VL	4	L	16	VL	22	VL	12	VL	1.5	19.0
Ap2	11-26/31	4.6 VSA	9.1	L	5.3	0.34 VL	3	L	78	M	10	VL	39	L	1.9	33.0
Bt1	26/31-60	4.7 VSA	5.4	L	3.1	0.25 VL	2	VL	14	VL	10	VL	14	VL	1.8	11.0
Bt2	60-99	4.6 VSA	3.0	VL	1.7	0.14 VL	2	VL	7	VL	26	VL	13	VL	1.4	18.0
Btc1	99/116	4.8 VSA	3.3	VL	1.9	-	3	VL	7	VL	31	VL	11	VL	1.4	21.0
Btc2	116-170/177	5.1 SA	2.7	VL	1.6	-	2	VL	12	VL	55	VL	30	VL	1.4	44.0
Btc3	170/177-215+	5.3 SA	1.0	VL	0.6	-	1	VL	10	VL	43	VL	15	VL	1.4	30.0
10-year-old																
Ap1	0-8	4.6 VSA	13.7	ML	7.9	0.65 VL	4	L	49	L	27	VL	6	VL	2.4	27.0
Ap2	8-24	4.7 VSA	11.2	L	6.5	0.49 VL	2	VL	18	VL	10	VL	3	VL	2.2	11.0
Bt1	24-44	4.7 VSA	5.0	VL	2.9	0.34 VL	2	VL	10	VL	23	VL	3	VL	1.9	14.0
Bt2	44-60/71	4.7 VSA	3.4	VL	2.0	0.20 VL	3	VL	9	VL	7	VL	2	VL	2.9	8.0
Btc1	60/71-133	4.7 VSA	3.5	VL	2.0	0.16 VL	2	VL	11	VL	19	VL	3	VL	2.6	12.0
Btc2	133-175	4.8 VSA	2.3	VL	1.3	-	2	VL	20	VL	34	VL	3	VL	2.8	23.0
BC	175-210+	5.0 VSA	1.3	VL	0.8	-	1	VL	9	VL	31	VL	5	VL	2.1	17.0
15-year-old																
Ap1	0-10	4.4 EA	13.1	ML	7.6	0.72 VL	4	L	47	L	19	VL	5	VL	2.4	22.0
Ap2	10-23	4.4 EA	9.4	L	5.5	0.45 VL	2	VL	25	VL	18	VL	3	VL	2.3	17.0
Bt1	23-50	4.4 EA	4.2	L	2.4	0.22 VL	2	VL	18	VL	12	VL	2	VL	2.0	15.0
Bt2	50-82	4.5 VSA	2.8	VL	1.6	0.18 VL	2	VL	13	VL	15	VL	2	VL	1.8	13.0
Btc	82-161	4.5 VSA	3.2	VL	1.9	0.19 VL	2	VL	15	VL	34	VL	3	VL	2.0	21.0
BC	161-210+	4.8 VSA	1.3	VL	0.8	-	1	VL	14	VL	24	VL	4	VL	2.1	18.0
20-year-old																
Ap1	0-13	4.2 EA	14.3	ML	8.3	0.80 VL	8	ML	55	L	66	VL	11	VL	2.3	40.0
Ap2	13-28	4.3 EA	9.4	L	5.5	0.59 VL	9	ML	32	L	15	VL	4	VL	2.8	12.0
Bt1	28-60	4.4 EA	5.0	L	2.9	0.29 VL	3	L	30	L	11	VL	4	VL	3.1	9.0
Bt2	60-110	4.3 EA	2.8	VL	1.6	0.22 VL	2	VL	33	L	15	VL	3	VL	3.1	10.0
Btc	110-144/165	4.6 VSA	2.2	VL	1.3	-	2	VL	20	L	22	VL	2	VL	3.3	10.0
BC1	144/165-/196	4.6 VSA	1.3	VL	0.8	-	2	VL	19	VL	7	VL	2	VL	3.2	6.0
BC2	196-210+	4.6 VSA	2.2	VL	1.3	-	3	L	21	VL	39	VL	5	VL	3.6	11.0

Note: EA = extremely acid, VSA = very strongly acid, SA = strongly acid, M = medium, L = low, VL = very low

4.2.3 Amounts of Organic Matter, Carbon and Nutrients

Table 4-7 and **Table 4-8** shows amounts per area of organic matter, carbon, nitrogen and extractable nutrients in soils under rubber plantations and natural forests of Phon Phisai and Chakkarat soil series.

(1) Amounts oforganic matter

Phon Phisai Soil Series:

The DDF stored organic matter amount in the soil profile (1.0 m depth) of 57.81 Mg/ha. The amounts of soil organic matter under the 1 to 20 years old rubberplantations were37.37, 64.41, 49.37, 53.85 and 20.74 Mg/ha, respectively. The amounts were not increased with the plantation age. The soil erosion might be the main factor. The manure application was applied to soils under the plantations, but the applied amounts might be different among the farmers and different age of plantations. The Phon Phisai soils also had clayey texture in subsoils, and it was difficult for movement of organic matter into the deeper soils.

Table 4-5 Amounts of organic matter, total C and N, and extractable nutrients in rubber plantations and DDF on Phon Phisai soil series

Horizon	Depth (cm)	Soil mass ($kg.m^2$)	OM (Mg/ha)	C (Mg/ha)	N (kg/ha)	Avail. P (kg/ha)	Ext. K (kg/ha)	Ext. Ca (kg/ha)	Ext. Mg (kg/ha)
1-year-old									
Ap	0-18	45.0	20.97	12.16	868.50	0.41	6.72	16.61	5.27
Btcv1	18-40	70.4	7.89	4.57	549.12	0.15	12.70	6.97	9.14
Btcv2	40-82/88	112.5	6.53	3.79	281.25	1.00	38.55	24.53	34.04
Btv	82/88-100	79.5	1.99	1.15	103.35	0.12	12.32	4.07	2.83
	Total		**37.37**	**21.67**	**1,802.22**	**1.68**	**70.29**	**52.17**	**51.28**
5-year-old									
Ap	0-19	68.4	8.28	4.80	492.48	0.39	6.11	5.85	2.47
Btcv1	19-36	73.1	7.75	4.49	533.63	0.25	8.57	7.58	2.11
Btcv2	36-100	896.0	48.38	28.06	3,136.00	5.64	349.98	293.53	141.12
	Total		**64.41**	**37.36**	**4,162.11**	**6.28**	**364.66**	**306.96**	**145.70**
10-year-old									
Ap	0-19	53.2	9.36	5.43	686.28	0.30	8.69	6.77	3.74
Btcv1	19-46	132.3	14.16	8.21	979.02	0.36	31.43	8.93	11.79
Btcv2	46-92/100	453.6	25.86	15.00	1,315.44	2.45	215.55	39.19	80.83
	Total		**49.37**	**28.64**	**2,980.74**	**3.11**	**255.68**	**54.89**	**96.36**
15-year-old									
Ap	0-20	50.0	14.25	8.27	550.00	0.40	10.00	13.10	4.10
Btc1	20-40	50.0	6.80	3.94	355.00	0.10	8.70	4.40	5.40
Btc2	40-80	500.0	31.00	17.98	1,850.00	2.00	206.00	136.00	146.00
Btv3	80-100	60.0	1.80	1.04	162.00	0.12	10.20	2.28	4.32
	Total		**53.85**	**31.23**	**2,917.00**	**2.62**	**234.90**	**155.78**	**159.82**
20-year-old									
Ap	0-17	49.3	7.44	4.32	433.84	0.25	9.22	3.69	1.26
Btcv1	17-40	20.7	2.61	1.51	120.06	0.10	2.71	1.29	0.38
Btcv2	40-100	198.0	10.69	6.20	752.40	1.19	52.27	106.92	22.57
	Total		**20.74**	**12.03**	**1,306.30**	**1.53**	**64.20**	**111.89**	**24.21**
Dry dipterocarp forest									
A	0-5	9.0	2.96	1.72	162.00	0.03	0.50	1.57	0.88
BA	5-18	59.4	10.63	6.17	629.64	0.39	7.49	12.59	15.06
Btcv1	18-50	86.4	8.81	5.11	552.96	1.11	31.24	44.51	52.81
Btcv2	50-100	590.0	35.40	20.53	1,534.00	8.85	333.35	256.65	548.70
	Total		**57.81**	**33.53**	**2,878.60**	**10.37**	**372.58**	**315.32**	**617.44**

Chakkarat Soil Series:

The DEF could store the organic matter amount in the soil profile (1.0 m depth) of only 23.06 Mg/ha.The amounts of organic matter in 1.0 m soil profile in the 1 to 20 years old rubberplantations were 24.59, 29.01, 31.93, 27.68 and 23.06 Mg/ha. The amounts were not increased with the plantation age. The reasons were the same as PhonPhisai soil series. It is assumed that organic matters on the forest floor might be decomposed rapidly during rainy season and dissolved in water. Some of them might be uptaken by plants, and the remaining amount was leached out to ground water and through surface runoff. Sine the soil texture was mainly fine sandy, the organic matter could not accumulate in the soil profile. The amounts of soil organic matter in Chakkarat soil series were lower than Phon Phisai soil series.

Table 4-6 Amounts of organic matter, total C and N, and extractable nutrients in rubber plantations and DEF on Chakkarat soil series

Horizon	Depth (cm)	Soil mass ($kg.m^2$)	OM (Mg/ha)	C (Mg/ha)	N (kg/ha)	Avail. P (kg/ha)	Ext. K (kg/ha)	Ext. Ca (kg/ha)	Ext. Mg (kg/ha)
1-year-old									
Ap1	0-20	102.0	12.65	7.34	581.40	0.82	2.86	5.10	0.41
Ap2	20-47	143.1	5.29	3.07	400.68	0.77	7.73	6.18	0.77
Bt1	40-89/96	239.2	6.46	3.75	382.72	1.26	22.60	23.86	2.51
Btc1	89/96-100	8.0	0.19	0.11	8.00	0.01	0.08	0.15	0.02
	Total		**24.59**	**14.26**	**1,372.80**	**2.85**	**33.27**	**35.29**	**3.71**
5-year-old									
Ap1	0-11	60.5	4.48	2.60	242.00	0.27	1.06	1.46	0.80
Ap2	11-26/31	97.2	8.85	5.13	330.48	0.51	13.27	1.70	6.63
Bt1	26/31-60	172.8	9.33	5.41	432.00	1.09	7.62	5.44	7.62
Bt2	60-100	212.0	6.36	3.69	296.80	1.70	5.94	22.05	11.02
	Total		**29.01**	**16.83**	**1,301.28**	**3.56**	**27.89**	**30.66**	**26.08**
10-year-old									
Ap1	0-8	42.4	5.81	3.37	275.60	0.14	1.66	0.92	0.20
Ap2	8-24	86.4	9.68	5.61	423.36	0.28	2.49	1.38	0.41
Bt1	24-44	110.0	5.50	3.19	374.00	0.44	2.20	5.06	0.66
Bt2	44-60/71	116.6	3.96	2.30	233.20	0.75	2.26	1.75	0.50
Btc1	60/71-133	199.5	6.98	4.05	319.20	1.38	7.57	13.08	2.06
	Total		**31.93**	**18.52**	**1,625.36**	**2.98**	**16.18**	**22.19**	**3.84**
15-year-old									
Ap1	0-10	53.0	6.94	4.03	381.60	0.21	2.49	1.01	0.27
Ap2	10-23	70.2	6.60	3.83	315.90	0.18	2.28	1.64	0.27
Bt1	23-50	145.8	6.12	3.55	320.76	0.79	7.09	4.72	0.79
Bt2	50-82	179.2	5.02	2.91	322.56	1.15	7.45	8.60	1.15
Btc	82-161	93.6	3.00	1.74	177.84	0.34	2.53	5.73	0.51
	Total		**27.68**	**16.05**	**1,518.66**	**2.67**	**21.84**	**21.70**	**2.98**
20-year-old									
Ap1	0-13	49.4	7.06	4.10	395.20	0.51	3.53	4.24	0.71
Ap2	13-28	58.5	5.50	3.19	345.15	0.79	2.81	1.32	0.35
Bt1	28-60	124.8	6.24	3.62	361.92	1.20	11.98	4.39	1.60
Bt2	60-110	152.0	4.26	2.47	334.40	1.22	20.06	9.12	1.82
	Total		**23.06**	**13.37**	**1,436.67**	**3.72**	**38.38**	**19.07**	**4.48**
Dry evergreen forest									
A	0-11	37.4	10.62	6,16	385.22	0.25	2.10	0.78	0.41
Bt1	11-30	72.2	2.53	1,47	252.70	0.27	2.06	1.10	0.41
Bt2	30-55	100.0	2.00	1,16	190.00	0.25	4.50	2.75	0.50
Bt3	55-75/90	109.2	2.18	1,27	229.32	0.30	3.30	3.60	0.90
Btc1	75/90-104/130	23.4	0.63	0.37	46.80	0.04	1.06	0.66	0.16
	Total		**17.96**	**10.42**	**1,104.04**	**1.11**	**13.02**	**8.89**	**2.39**

(2) Amounts ofcarbon

PhonPhisai Soil Series:

The DDF stored carbon amount in the soil profile (1.0 m depth) of 33.53 Mg/ha. The amounts of soil carbonunder the 1 to 20 years old rubberplantations were 21.67, 37.36, 28.64, 31.23 and 12.03 Mg/ha, respectively. The amounts were not increased with the plantation age. The reasons were the same as organic matter.

ChakkaratSoil Series:

The DEF could store the carbon amount in the soil profile (1.0 m depth) of only 10.42 Mg/ha. The amounts of soil carbonunder the 1 to 20 years old rubberplantations were 14.26, 16.83, 18.52, 16.05 and 13.37 Mg/ha, respectively. The amounts were not increased with the plantation age. The reasons were the same as organic matter. The amounts of soil carbon in Chakkarat soil series were lower than PhonPhisai soil series.

(3) Amounts of nitrogen

PhonPhisai Soil Series:

The DDF stored total nitrogen amount in the soil profile (1.0 m depth) of 2,878.60 kg/ha. The amounts of soil nitrogenunder the 1 to 20 years old rubberplantations were 1802.22, 4162.11, 2980.74, 2917.0 and 1306.3 kg/ha, respectively. The amounts were not increased with the plantation age. The reasons were the same as organic matter and carbon

ChakkaratSoil Series:

The DEF could store the nitrogen amount in the soil profile (1.0 m depth) of 1,104.04 kg/ha. The amounts of soil organic matter under the 1 to 20 years old rubberplantations were 1372.80, 1301.28, 1625.36, 1518.66 and 1436.67 kg/ha, respectively. The amounts were not increased with the plantation age. The reasons were the same as organic matter and carbon. The amounts of soil nitrogen in Chakkarat soil series were lower than PhonPhisai soil series.

(4) Amounts ofextractable nutrients

(4-1) Available phosphorus

Phon Phisai Soil Series:

The DDF stored available phosphorus amount in the soil profile (1.0 m depth) of 10.37 kg/ha. The amounts of soil available phosphorus under the 1 to 20 years old rubberplantations were 1.68, 6.28, 3.11, 2.62 and 1.53 kg/ha, respectively. The amounts were not increased with the plantation age.

ChakkaratSoil Series:

The DEF could store the available phosphorus amount in the soil profile (1.0 m depth) of 1.11 kg/ha. The amounts of soil available phosphorus amount under the 1 to 20 years old rubberplantations were 2.85, 3.56, 2.98, 2.67 and 3.72 kg/ha, respectively. The amounts were not increased with the plantation age. The amounts of soil available phosphorus in Chakkarat soil series were similar to Phon Phisai soil series.

(4-1) Extractable potassium

Phon Phisai Soil Series:

The DDF stored total extractable potassium amount in the soil profile (1.0 m depth) of 372.58 kg/ha. The amounts of soil extractable potassium under the 1 to 20 years old rubberplantations were 70.29, 364.66, 255.68, 234.90 and 64.20 kg/ha, respectively. The amounts were not increased with the plantation age.

Chakkarat Soil Series:

The DEF could store the extractable potassium amount in the soil profile (1.0 m depth) of 13.02 kg/ha. The amounts of soil extractable potassium under the 1 to 20 years old rubberplantations were 33.27, 27.89, 16.18, 21.84 and 38.38 kg/ha, respectively. The amounts were not increased with the plantation age. The amounts of soil extractable potassium in Chakkarat soil series were lower than Phon Phisai soil series.

(4-1) Extractable calcium

Phon Phisai Soil Series:

The DDF stored total extractable calcium amount in the soil profile (1.0 m depth) of 315.32 kg/ha. The amounts of soil extractable calcium under the 1 to 20 years old rubberplantations were 52.17, 306.96, 54.89, 155.78 and 111.89 kg/ha, respectively. The amounts were not increased with the plantation age.

Chakkarat Soil Series:

The DEF could store the extractable calcium amount in the soil profile (1.0 m depth) of 8.89 kg/ha. The amounts of soil extractable calcium under the 1 to 20 years old rubberplantations were 35.29, 30.66, 22.19, 21.70 and 19.07 kg/ha, respectively. The amounts were not increased with the plantation age. The amounts of extractable calcium in Chakkarat soil series were lower than Phon Phisai soil series.

(4-1) Extractable magnesium

Phon Phisai Soil Series:

The DDF stored extractable magnesium amount in the soil profile (1.0 m depth) of 617.44 kg/ha. The amounts of soil extractable magnesium under the 1 to 20 years old rubberplantations were 51.28, 145.70, 96.36, 159.82 and 24.21 kg/ha, respectively. The amounts were not increased with the plantation age.

ChakkaratSoil Series:

The DEF could store the extractable magnesium amount in the soil profile (1.0 m depth) of 2.39 kg/ha. The amounts of soil extractable magnesium under the 1 to 20 years old rubberplantations were 3.71, 26.08, 3.84, 2.98 and 4.48 kg/ha, respectively. The amounts were not increased with the plantation age. The amounts of soil extractable magnesium in Chakkarat soil series were lower than PhonPhisai soil series.