CHAPTER 4

Ecosystem Carbon and Nutrient Accumulations of Pine Plantations and Fragmented Forests

Abstract

Accumulations of carbon and nutrients in ecosystems of different age pine plantations and fragmented forests at Boakaew Watershed Management Station, Chiang Mai Province, were investigated including three compartments; soil, forest floor and tree biomass. Soil studies were taken in five age-class pine plantations of 17, 21, 25, 29 and 33 years old and five fragmented forests. Soil samples were analyzed for physico-chemical properties and calculated for accumulated amounts of carbon and other nutrients. More soil profile development with pine stand ages was observed. Bulk density of top soils was lower in older stands, but change of soil reaction was unclear. Soil organic matter and nutrients including carbon, nitrogen, phosphorus, calcium and magnesium has the trend of increase with stand ages. Many factors have influenced on variations of soil carbon and nutrient storages especially tree densities, species composition and density of succession trees, topographic variables and forest fire.

Amounts of organic matter and carbon in 160 cm depth soils under plantations varied between 138.65-306.30 and 80.43-276.46 $Mg.ha^{-1}$, respectively, whereas those of fragmented forest varied were 164-477 and 95-276 $Mg.ha^{-1}$. The dry matters and carbon amounts in forest floor of plantations varied between 4,122-8,379 and 1,668-3,151 $kg.ha^{-1}$. The amounts in fragmented forest were in ranges of 5,855-7,644 and 2,151-2,726 $kg.ha^{-1}$. The higher proportion of ecosystem carbon storage was occurred in soil compartment. Variations in site conditions, tree densities, growth rates and composition of succession tree species resulted in different carbon stocks in soils and forest floors.

The great variations of carbon stocks in five age-class pine plantations were observed. The carbon stored in soils varied from 40.7 to 77.5% of the total, whereas the values in tree biomass were 21.3-57.9% and 0.7-1.3% for the forest floor. In the fragmented forests, the stored carbon in soils, tree biomass and forest floor were in ranges of 41.2-72.5%, 26.8-57.7% and 0.7-1.2%.

4.1 Introduction

Nutrient cycling processes in the pine plantation ecosystem will be altered during stand development. As trees grow biomass accumulations are occurred in the various parts of stem, branch, root and needle. Litterfall will be increasing from early stage and become stable in mature stands. Carbon and other nutrients releasing from decomposing litter will be accumulated in soil profile. Carbon is important as the basis for the food and fiber that sustain and shelter human populations, as the primary energy source that fuels economies, and as a major contributor to the planetary greenhouse effect and potential climate change.

Different carbon accumulations in biomass of tree species having the high potential have been reported (Nualngam, 2001). *Acacia mangium*, *A. auriculaeformis*, *Eucalyptus camaldulensis, Xylia xylocarpa, Dalbergia cochinchinensis* and *Pterocarpus macrocarpus*, had the carbon storages of 14.8, 9.1, 8.9, 6.7, 6.1 and 4.0 $Mg.ha^{-1}$, respectively. In teak plantations, the total carbon storages in 10-, 14-, 18-, 27- and 28-year-old stands were in the order of 169.4, 83.7, 99.1, 170.1, 149.67 $Mg.ha^{-1}$. However, the variations depend on many factors such as topography, management practices, fire, etc. (Pumijumnong, 2007).

The fallen leaves are a great food source for the fungi and bacteria in the soil. These creatures slowly help the leaves to decompose, and they are eventually turned back into soil which the trees can use to grow new leaves in future seasons. The material at the top of the litter layer is newly fallen and recognizable. Towards the bottom, the older leaves are torn and usually covered with a slimy coating of microorganisms which feels gross, but it's vital to returning nutrients to the soil. Fallen leaves and indeed entire fallen trees are the soil for future forests. This organic matter is crucial because it contains the nutrients that will eventually be re-incorporated into the soil. It is also important in a partially decomposed state. Rotting leaves and wood are able to store moisture like a sponge, and help the forest soil retain rainfall.

The montane forest plays an important role in contributing organic residues to the soil and later become soil organic matter which was found in substantial amounts under both primary and secondary forest. Reforestation using a single tree species can increase the amount of organic matter at the surface. The organic layer on forest floor in the plantations may be thinner than that under natural forest. The organic layers of forest floor can reduce water erosion, which carries away fine particles including organic matter particles from soil surface, and subsequently allows organic matter to be leached downward within soil profiles as indicated by taxonomic units, namely Humults (Anusontpornperm *et al*., 2008).

The aims of this research are to assess carbon and nutrient accumulations in ecosystems of different age pine plantations and fragmented forests in the highland watershed. The data are important for improving plantation techniques.

4.2 Materials and Methods

4.2.1 Soil Sampling

Five age-class pine plantations were selected for soil study including 17, 21, 25, 29 and 33 years old. In each age-class stand, three plots were used for soil sampling. A soil pit was made for each plot/site with the depth to 1.60 meters. Soil samples were taken from 11 depths; 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-120, 120-140 and 140-160 centimeters and they were later analyzed for soil physical and chemical properties in laboratory. Soil study was also taken in five sites of fragmented forests.

4.2.2 Soil Analysis

Analysis of some soil physical properties was taken.

(1) Soil texture and analysis for particle size distribution were taken by a hydrometer method.

(2) Bulk density is determined by a core method.

Soil chemical properties were evaluated using the criteria used by National Soil Survey Center (1995, 1996).

(1) Soil reaction by using pH meter; pH (H_2O) (soil : water = 1 : 1) and pH (KCl) (soil : 1N KCl solution = 1 : 1) (Mclean, 1982)
(2) Total N by using Micro Kjedahl method (Bremner and Mulvaney, 1982)
(3) Extractable phosphorus by using Bray II and Colorimetric method and read by Atomic Absorption Spectophotometer (Bray and Kunzt, 1945)
(4) Extractable base includings potassium, calcium, magnesium and sodium extracted by Ammonium acetate solution 1N, pH 7.0 and read by Atomic Absorption Spectophotometer (Peech, 1945)
(5) Cation exchange capacity (CEC) extracted by Ammonium acetate solution 1 N, pH 7.0 (Summer and Miller, 1996)

4.2.3 Nutrient Accumulations in Soils

Amounts of nutrients accumulated in soils including total C and N, extractable P, K, Ca, Mg and Na are calculated from their contents and amounts of soil mass.

4.2.4 Biomass and Nutrients in Organic Layer

This study was carried out in the same plots of soil study. Five aged class and five sites of fragmented forests, one plot was used, and three sampling plots (replications) of 1 x 1 m^2 were made. Litter in the plot was collected and separated into leaf, branch and others. Dry matter of litter was measured. The samples were later analyzed for nutrient composition.

4.2.5 Tree Biomass

Amounts of biomass carbon and nutrients of tree species including pine and succession trees in pine plantations and fragmented forests were obtained as described in Chapter 3.

4.3 Results

4.3.1 Soil Nutrient Compartment

4.3.1.1 Soil Properties

A. Pine Plantations

(a) Physical Properties

Some physical properties including bulk density, amounts of gravel, soil particle distribution and soil texture were given in Table 4-1.

(1) Bulk Density

Bulk density is the dry mass (of 2 mm material) of a given volume of intact soil in Megagrams per cubic meter (which also equals kilograms per liter). It is found that the bulk densities of surface soils in all age-class pine plantations were low and increased with soil depth to 160 cm.

In 17-year-old plantation, the bulk densities were very low at 0-40 cm depth. It was low in the depth of 40-60 cm, and moderately low in deeper soils. For 21-year-old plantation, the densities were low at 0-40 cm depth, and moderately low in deeper soils. In 25-year-old plantation, they were low to very low at 0-20 cm depth, moderately low at 20-80 cm depth, and medium in deeper soils. In 29-year-old plantation, the values were very low at 0-30 cm depth, low at 30-60 cm depth, and moderately low in deeper soils. For 33-year-old stand, the very low densities were observed at 0-10 cm depth, and low in deeper soils.

The surface soils of all age-class plantations had low/very low bulk densities. The low densities of surface soils in pine plantations caused by annually inputs of above ground litterfall particularly needles. The decomposing needles result in humus formation which contributes to decreasing total weight of soil particles. The changes of soil bulk densities with plantation ages are not clear according to site variations.

(2) Amounts of Gravel

Gravels are rock fragments larger than 2 mm in diameter. Some differences of gravel amounts in soil profiles among five age-class pine plantations were found (Figure 4-3).

In 17-year-old plantation, gravel amounts in soil profile varied between 12.0-20.4%. The amounts of 20.9-27.9% were found for 21-year-old plantation. They were also the similar range for soil under 25-year-old plantation, 17.5-28.2%. The amounts were decreased in older plantations. In 29-year-old plantation, the amounts varied between 5.5-13.8%, and the values of 5.3-14.8%. for 33-year-old plantation.

The weathering process of parent rocks usually occurs during soil profile development. This resulted in the decreasing amounts of gravel in soil profiles of the older plantations.

(3) Soil Particle Distribution

Mineral soils are usually grouped into three broad textured classes – sands, silts and clays. The combination of sand, silt and clay particles in soil is important to physical properties water potential, organic matter binding, cation exchange capacity, and overall biotic activity.

Sand:

The sand particle percentages in soil profiles of all age-class plantations varied in the similar ranges. It was not changed with plantation ages.

In 17-, 21-, 25-, 29- and 33-year-old plantations, the percentages of sand in soil profiles varied between 44.1-76.9, 33.6-61.6, 38.9-72.0, 44.0-72.0 and 46.5-79.6%, respectively.

Silt:

The silt particle percentages in soil profiles of most age-class plantations varied in the similar ranges. It was not changed with plantation ages.

In 17-, 21-, 25-, 29- and 33-year-old plantations, the percentages of silt in soil profiles varied between 13.3-24.9, 14.9-31.8, 10.6-26.6, 18.1-30.0 and 10.7-18.9%, respectively.

Clay:

The clay particle percentages in soil profiles of most age-class plantations also varied in the similar ranges. It was not changed with plantation ages. The clay particles were low in surface soils and higher in subsoils of all age-class stands. This pattern of clay distribution along soil profile is the characteristic of Order Ultisols.

In 17-, 21-, 25-, 29- and 33-year-old plantations, the percentages of clay in soil profiles varied between 7.4-36.1, 23.5-46.4, 7.4-37.1, 9.9-33.6 and 5.8-42.8, respectively.

(4) Soil Texture

Soil texture effects many other properties like structure, chemistry, and most notably, soil porosity, and permeability. Soil texture refers to the relative proportion of sand, silt and clay particles.

In 17-year-old plantation, the texture in upper horizons (0-40 cm depth) of surface soil was sandy loam. At 40-100 cm depth, the texture varied between sandy clay loam, sandy clay and clay loam, and sandy clay loam in deeper soil.

In 21-year-old plantation, the texture in upper horizons (0-20 cm depth) of surface soil was sandy clay loam. It was clay at 20-60 cm depth, clay loam at 60-120 cm, and loam in deeper soil.

In 25-year-old plantation, the texture in upper horizons (0-20 cm depth) of surface soil was sandy loam. It was sandy clay loam at 20-40 cm depth, clay loam at 40-120 cm, and sandy clay loam in deeper soil.

In 29-year-old plantation, the texture in upper horizons (0-20 cm depth) of surface soil was sandy loam. It was sandy clay loam at 20-60 cm depth, clay loam at 60-100 cm, sandy clay loam in 100-140 cm and loam in deeper soil.

In 33-year-old plantation, the texture in upper horizons (0-30 cm depth) of surface soil was sandy loam/loamy sand. It was sandy clay loam at 30-60 cm depth, and sandy clay in deeper soil.

The texture of surface soils in five age-class plantations was mainly sandy loam/sand clay loam whereas subsoils had sandy clay loam, clay loam, sandy clay, clay and loam. In comparison to fragmented natural forests nearby plantations, the texture of surface soils was sandy loam/sandy clay, and subsoils had loam, sandy clay, clay, and loam. The change of soil texture with stand ages was not occurred in these pine plantations. The site variations have influenced on soil texture.

Figure 4-1 Soil studies in pine plantations (upper) and fragmented forests (lower)

Table 4-1 Some soil physical properties in different age pine plantations

Age (yrs))	Soil (cm)	Bulk density ($Mg.m^{-3}$)		Gravel (%)	Soil particle distribution (%)			Soil texture
					Sand	Silt	Clay	
17	0-5	0.74	VL	14.6	69.2	23.4	7.4	Sandy loam
	5-10	0.71	VL	15.0	76.9	14.0	9.1	Sandy loam
	10-20	0.75	VL	12.0	72.5	13.3	14.2	Sandy loam
	20-30	0.75	VL	12.3	64.2	18.3	17.5	Sandy loam
	30-40	0.74	LV	14.1	51.4	18.4	30.2	Sandy clay loam
	40-60	1.07	L	17.7	49.2	14.7	36.1	Sandy clay
	60-80	1.29	ML	20.4	49.2	14.7	36.1	Sandy clay
	80-100	1.32	ML	19.1	44.1	19.8	36.1	Clay loam
	100-120	1.39	ML	13.6	46.6	22.4	31.0	Sandy clay loam
	120-140	1.33	ML	17.2	51.0	23.1	25.9	Sandy clay loam
	140-160	1.41	M	12.7	51.7	24.9	23.4	Sandy clay loam
21	0-5	1.07	L	24.3	61.6	14.9	23.5	Sandy clay loam
	5-10	1.11	L	27.9	56.5	14.9	28.6	Sandy clay loam
	10-20	1.09	L	27.3	51.4	15.0	33.6	Sandy clay loam
	20-30	1.19	L	26.9	42.5	16.2	41.3	Clay
	30-40	1.13	L	26.4	37.5	16.1	46.4	Clay
	40-60	1.24	ML	27.5	33.6	20.0	46.4	Clay
	60-80	1.21	ML	25.8	36.1	24.2	39.7	Clay loam
	80-100	1.24	ML	21.3	38.7	26.7	34.6	Clay loam
	100-120	1.38	ML	21.5	41.2	31.0	27.8	Clay loam
	120-140	1.31	ML	20.9	43.8	30.9	25.3	Loam
	140-160	1.38	ML	22.1	43.8	31.8	24.4	Loam
25	0-5	1.05	L	25.2	72.0	20.6	7.4	Sandy loam
	5-10	1.08	L	20.0	71.4	19.5	9.1	Sandy loam
	10-20	0.97	VL	17.5	68.2	14.3	17.5	Sandy loam
	20-30	1.21	ML	22.5	55.9	19.0	25.1	Sandy clay loam
	30-40	1.30	ML	21.6	46.5	19.9	33.6	Sandy clay loam
	40-60	1.34	ML	27.2	41.4	21.5	37.1	Clay loam
	60-80	1.32	ML	28.2	41.4	21.5	37.1	Clay loam
	80-100	1.53	M	21.2	38.9	26.5	34.6	Clay loam
	100-120	1.45	M	22.1	41.4	26.6	32.0	Clay loam
	120-140	1.42	M	20.9	46.5	25.9	27.6	Sandy clay loam
	140-160	1.37	ML	18.3	65.0	10.6	24.4	Sandy clay loam
29	0-5	0.78	VL	5.5	66.9	21.5	11.6	Sandy loam
	5-10	0.86	VL	7.8	72.0	18.1	9.9	Sandy loam
	10-20	0.91	VL	9.6	66.9	18.1	15.0	Sandy loam
	20-30	0.96	VL	13.6	59.3	19.8	20.9	Sandy clay loam
	30-40	1.10	VL	12.7	54.2	18.2	27.6	Sandy clay loam
	40-60	1.15	VL	13.8	46.5	19.9	33.6	Sandy clay loam
	60-80	1.24	ML	13.3	44.0	22.4	33.6	Clay loam
	80-100	1.26	ML	10.5	44.0	24.9	31.1	Clay loam
	100-120	1.32	ML	12.9	46.5	23.3	30.2	Sandy clay loam
	120-140	1.34	ML	12.9	49.1	27.4	23.5	Sandy clay loam
	140-160	1.36	ML	13.2	49.1	30.0	20.9	Loam
33	0-5	0.80	VL	14.8	74.5	18.9	6.6	Sandy loam
	5-10	0.99	VL	14.0	79.6	14.6	5.8	Loamy sand
	10-20	1.02	L	13.7	77.1	15.5	7.4	Sandy loam
	20-30	1.04	L	11.4	69.4	15.6	15.0	Sandy loam
	30-40	1.04	L	10.6	59.3	16.5	24.2	Sandy clay loam
	40-60	1.13	L	8.7	54.2	11.5	34.3	Sandy clay loam
	60-80	1.16	L	7.7	46.5	10.7	42.8	Sandy clay
	80-100	1.12	L	5.3	46.5	13.2	40.3	Sandy clay
	100-120	1.04	L	8.4	46.5	15.7	37.8	Sandy clay
	120-140	1.15	L	8.5	46.5	15.7	37.8	Sandy clay
	140-160	1.14	L	7.6	46.5	15.7	37.8	Sandy clay

Note: * VL = very low, L = low, ML = moderately low, M = medium (Modified Kanchanaprasert, 1986)

(b) Chemical Properties

Soil reaction (pH), contents of organic matter, carbon, nitrogen, and extractable minerals were investigated as soil chemical properties. The data were given in Table 4-2.

(1) Soil Reaction

Soil reaction was shown by pH values. Soil acidity is important because it influences on availability of nutrients, and some plant species are sensitive to pH. Pines generally only grow well on moderately acid soils, pH 3.5-6.0, but even this genus shows variation (Evans, 1982). Soil reaction in all age-class pine plantations was mainly strongly acid to very strongly acid, either surface or subsoils.

In 17-year-old plantation, the soil was strongly acid throughout soil profile. The pH values varied between 5.18-5.47.

In 21-year-old plantation, the soil was very strongly acid (pH: 4.67-4.89) at 0-40 cm depth, strongly acid (pH: 5.17-5.55) at 40-100 cm and moderately acid (pH: 5.80-5.89) in deeper soil.

In 25-year-old plantation, the soil was strongly acid (pH: 5.18) at 0-5 cm depth, very strongly acid (pH: 4.65-5.08) at 5-80 cm and strongly acid (pH: 5.21-5.25) at 80-120 cm and strongly acid to very strongly acid in deeper soil.

In 29-year-old plantation, the soil was strongly acid (pH: 5.25-5.50) at 0-20 cm depth, very strongly acid (pH: 4.92-4.96) at 20-40 cm and strongly acid (pH: 5.13-5.22) in deeper soil. For 33-year-old plantation, the soil was almost strongly acid (pH: 5.08-5.39) throughout soil profiles of 160 cm depth.

(2) Soil Organic Matter, Carbon and Nitrogen

Soil Organic Matter:

Soil organic matter, although it forms only a small fraction of most forest soils, 0-12%, has a profound impact on the soil physical and chemical properties as well as soil biology.

In 17-year-old plantation, the contents of soil organic matter were very high (45.4-126.7 $g.kg^{-1}$) in surface soils (0-40 cm depth), moderately high at 40-60 cm, and moderately low to low/very low in deeper soil.

In 21-year-old plantation, the contents were very high (54.9 $g.kg^{-1}$) in surface soils (0-5 cm depth), moderately high at 5-10 cm, medium at 10-30 cm and low to very low in deeper soil.

In 25-year-old plantation, the contents were very high (48.0-82.6 $g.kg^{-1}$) in surface soils (0-20 cm depth), moderately high at 20-30 cm, medium at 30-40 cm and moderately low to low/very low in deeper soil.

In 29-year-old plantation, the contents were very high (56.1-115.1 $g.kg^{-1}$) in surface soils (0-20 cm depth), moderately high at 20-30 cm, medium at 30-40 cm and moderately low to low in deeper soil.

In 33-year-old plantation, the contents were very high (47.0-77.0 $g.kg^{-1}$) in surface soils (0-10 cm depth), moderately high at 10-20 cm, medium at 20-60 cm and moderately low to low in deeper soil.

The contents of organic matter in the top soil depth (0-10 cm) of total age-class samplings had rather moderately high to very high as 27.8-115.1 $g.kg^{-1}$. There were decreased with soil depth. The change of soil organic matter was not clear because of site variations.

Soil Carbon:

The carbon contents in soils under pine plantations were similar to soil organic matter since it is assumed that the carbon is 58% in average of organic matter. The contents of carbon in the top soil depth (0-10 cm) of total age-class plantations were moderately high to very high, 16.1-73.5 $g.kg^{-1}$. They were decreased with soil depth. The change of soil carbon was not clear according site variations.

Total Nitrogen:

Nitrogen has a major effect on productivity of forest trees (van den Driessche, 1898). The trend in total nitrogen distribution within the soil profiles was similar to that of soil organic matter/carbon according to carbon/nitrogen ratio. The C/N ratios in soils particularly surface soils under pine plantations were in the same range. In 17-, 21-, 25-, 29- and 33-year-old plantation, the C/N ratios in surface soils (0-40 cm depth) were varied between 7.5-10.5, 5.2-13.5, 7.9-14.7, 5.3-11.6 and 8.8-12.6.

(3) Available Phosphorus

Most phosphorus in soils is unavailable forms. Therefore, mineralization of phosphorus from soil organic matter is an important source of available phosphorus for plant growth.

In 17-year-old plantation, concentration of phosphorus in top soil (0-5 cm depth) was high (25.6 $mg.kg^{-1}$), moderately high at 5-10 cm depth (16.3 $mg.kg^{-1}$), moderately low to low/very low in lower horizons.

In 21- and 25-year-old plantations, the concentrations were moderately low (7.5 and 7.4 $mg.kg^{-1}$) in top soil (0-5 cm depth), moderately low to low/very low in lower horizons.

In 29-year-old plantation, the concentration in top soil (0-5 cm depth) was medium (12.4 $mg.kg^{-1}$), moderately low at 5-20 cm depth, and very low in lower horizons.

For 33-year-old plantation, the concentration in top soil (0-5 cm depth) was moderately high (15.2 $mg.kg^{-1}$), moderately low at 5-20 cm depth, and low to very low in lower horizons.

The concentrations of available phosphorus in the top soils (0-5 cm depth) of five plantations varied between moderately low to high whereas those in lower horizons were moderately low to low/very low. Some available phosphorus in top soils may be mineralized from decomposing/burned pine needles. No change of soil available phosphorus with plantation ages was observed.

(4) Extractable Potassium

The concentrations of extractable potassium in soils under all age-class pine plantations were very high throughout soil profiles, and no change with stand ages.

In 17-, 21-, 25-, 29- and 33-year-old plantations, the concentrations in soil profiles varied between 206.7-352.6, 226.9-453.2, 221.8-413.0, 236.9-498.5 and 201.7-372.7 $mg.kg^{-1}$.

The extractable potassium had very high in soil profiles of total age-class samplings (201.7-498.5 $mg.kg^{-1}$) and they varied among age-class pine plantations.

(5) Extractable Calcium

The concentrations of extractable calcium in soils are indicated to mineral composition of parent rocks and decomposing plant litter. The parent rock in this area is granite.

In 17-year-old plantation, concentration of calcium in top soil (0-5 cm depth) was medium (1,570.7 $mg.kg^{-1}$), low at 5-30 cm depth and very low in deeper horizons. For 21- and 25-year-old plantations, the concentrations were low to very low throughout soil profiles.

In 29-year-old plantation, the concentration in top soil (0-5 cm depth) was medium (1,594.7 $mg.kg^{-1}$), low at 5-20 cm depth and low/very low in deeper horizons.

For 33-year-old plantation, the concentration in top soil (0-5, 5-10 cm depth) was medium (1,187.1-1,714.6 $mg.kg^{-1}$), low at 10-80 cm depth and very low in deeper horizons.

The extractable calcium in soils under pine plantations was low to very low, and no change with stand ages. It is assumed that minerals in the granitic rock compose of a small fraction of calcium.

(6) Extractable Magnesium

In 17-year-old plantation, concentration of magnesium in top soil (0-5 cm depth) was medium (223.7 $mg.kg^{-1}$), low at 5-30 cm depth and low to very low in deeper horizons. For 21-year-old plantation, the concentrations were low at 0-10 cm depth and very low in lower horizons.

In 25- and 29-year-old plantations, the concentration in top soil (0-5 cm depth) were medium (142.5 and 259.5 $mg.kg^{-1}$), and low to very low in deeper soil.

In 33-year-old plantation, the concentration in top soil (0-5, 5-10 cm depth) was medium (130.6-187.9 $mg.kg^{-1}$), and low in deeper soil.

The extractable magnesium in soils under pine plantations is similar to calcium. The concentrations in top soils were low to medium, and low to very low in lower horizons.

(7) Extractable Sodium

The concentrations of extractable sodium in soils under pine plantations of all age-class were low to very low throughout soil profiles (15.0-67.2 $mg.kg^{-1}$).

(8) Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) is dependent upon the amount of organic matter and clay in soils and on the types of clay. In general, the higher organic matter and clay contents, the higher the cation exchange capacity (CEC). The CEC values in surface soils of five age-class plantations were moderately high to high and very high, and medium to moderately low in subsoils.

In 17-year-old plantation, CEC in top soil (0-5 cm depth) was very high (34.6 $mg.kg^{-1}$), high at 5-30 cm depth, moderately high at 30-60 cm depth and medium to moderately low in deeper horizons.

In 21-year-old plantation, CEC in surface soil (0-5, 5-10 and 10-20 cm depth) was moderately high (17.4-19.2 $mg.kg^{-1}$), and medium to moderately low in deeper horizons.

In 25-year-old plantation, CEC in surface soil (0-5, 5-10 and 10-20 cm depth) was high (22.5-25.0 $mg.kg^{-1}$), moderately high at 20-40 cm depth and medium to moderately low in deeper horizons.

In 29-year-old plantation, CEC in top soil (0-5 cm depth) was very high (36.6 $mg.kg^{-1}$), high at 5-20 cm depth, moderately high at 20-40 cm depth and medium to moderately low in deeper horizons.

For 33-year-old plantation, CEC values in surface soils at 0-40 cm depth were high (20.9-27.7 $mg.kg^{-1}$), and medium to moderately high in deeper horizons.

Table 4-2 Some soil chemical properties in different age pine plantations

Age (yrs)	Soil depth (cm)	pH		O.M. (g.kg^{-1})	C (g.kg^{-1})	Total N (g.kg^{-1})	Available P (mg.kg^{-1})	Extractable (mg.kg^{-1})			
								K	Ca	Mg	Na
17	0 - 5	5.33	strongly acid	126.7	73.5	8.3	25.6	352.6	1570.7	223.7	18.8
	5 - 10	5.47	strongly acid	91.7	53.2	5.5	16.3	302.3	899.3	106.7	15.5
	10 - 20	5.46	strongly acid	64.2	37.2	4.6	9.6	287.2	619.0	92.4	15.7
	20 - 30	5.42	strongly acid	58.2	33.8	3.2	8.1	262.1	403.2	50.3	21.2
	30 - 40	5.42	strongly acid	45.4	26.3	3.5	7.8	252.0	241.3	33.6	15.4
	40 - 60	5.18	strongly acid	27.2	15.8	1.9	7.9	236.9	157.4	36.0	25.8
	60 - 80	5.25	strongly acid	14.5	8.4	1.0	7.0	242.0	94.4	35.1	17.2
	80 - 100	5.34	strongly acid	7.0	4.1	1.0	3.3	247.0	43.5	28.5	17.2
	100 - 120	5.33	strongly acid	5.4	3.1	0.4	3.3	206.7	40.5	17.8	16.1
	120 - 140	5.26	strongly acid	5.3	3.1	0.2	2.8	221.8	31.5	12.4	16.0
	140 - 160	5.37	strongly acid	1.7	1.0	0.1	2.0	226.9	40.5	10.7	18.8
21	0 - 5	4.77	very strongly acid	54.9	31.8	2.8	7.5	392.9	172.4	106.7	18.1
	5 - 10	4.81	very strongly acid	27.8	16.1	2.0	3.5	453.2	73.4	62.0	19.3
	10 - 20	4.67	very strongly acid	19.9	11.5	2.2	2.2	377.8	28.5	28.0	18.0
	20 - 30	4.89	very strongly acid	15.8	9.2	0.9	1.7	372.7	22.5	24.1	16.3
	30 - 40	4.88	very strongly acid	9.3	5.4	0.4	1.2	327.5	10.5	17.5	16.2
	40 - 60	5.17	strongly acid	6.1	3.5	0.3	1.0	317.4	22.5	18.7	17.8
	60 - 80	5.41	strongly acid	3.8	2.2	0.2	0.9	297.3	16.5	13.3	20.0
	80 - 100	5.55	strongly acid	2.3	1.3	0.3	1.1	252.0	12.1	12.1	17.8
	100 - 120	5.80	moderately acid	2.9	1.7	0.3	1.2	282.2	16.5	11.6	15.0
	120 - 140	5.87	moderately acid	0.7	0.4	0.2	1.0	272.1	10.5	9.5	15.2
	140 - 160	5.89	moderately acid	1.0	0.6	0.1	1.0	226.9	7.5	5.9	17.0
25	0 - 5	5.18	strongly acid	82.6	47.9	3.9	7.4	352.6	511.1	142.5	16.9
	5 - 10	5.02	very strongly acid	74.1	43.0	3.3	5.7	413.0	259.3	92.4	24.3
	10 - 20	4.71	very strongly acid	48.0	27.8	1.9	3.4	292.3	142.4	30.9	21.9
	20 - 30	4.65	very strongly acid	34.5	20.0	1.6	2.7	257.0	94.4	24.7	26.6
	30 - 40	4.87	very strongly acid	16.4	9.5	1.2	1.2	287.2	64.5	21.7	17.6
	40 - 60	4.99	very strongly acid	10.2	5.9	1.2	1.0	231.9	58.5	18.7	16.7
	60 - 80	5.08	very strongly acid	6.5	3.8	0.9	0.9	221.8	55.5	16.3	17.4
	80 - 100	5.25	strongly acid	4.9	2.8	1.0	1.1	257.0	22.5	15.4	20.4
	100 - 120	5.21	strongly acid	4.2	2.4	0.2	0.9	362.7	19.5	14.5	17.7
	120 - 140	5.03	very strongly acid	4.0	2.3	0.1	0.9	267.1	16.5	13.0	18.7
	140 - 160	5.16	strongly acid	4.0	2.3	0.1	1.0	307.3	13.5	11.0	18.3
29	0 - 5	5.50	strongly acid	115.1	66.8	6.5	12.4	498.5	1594.7	259.5	23.2
	5 - 10	5.34	strongly acid	78.2	45.4	3.9	7.9	352.6	448.1	94.8	23.5
	10 - 20	5.25	strongly acid	56.1	32.5	3.3	6.5	342.6	436.2	59.9	17.7
	20 - 30	4.96	very strongly acid	30.5	17.7	2.3	2.8	252.0	256.3	40.5	19.3
	30 - 40	4.92	very strongly acid	18.4	10.7	2.0	2.1	327.5	448.1	72.7	17.4
	40 - 60	5.13	strongly acid	12.0	7.0	1.4	1.7	307.3	283.3	51.5	16.9
	60 - 80	5.22	strongly acid	9.6	5.6	0.5	1.6	236.9	202.3	52.4	43.4
	80 - 100	5.18	strongly acid	8.5	4.9	0.3	1.6	252.0	136.4	70.6	17.4
	100 - 120	5.13	strongly acid	6.5	3.8	0.1	1.9	257.0	82.4	58.7	18.5
	120 - 140	5.15	strongly acid	7.8	4.5	0.1	1.8	327.5	166.4	37.8	17.6
	140 - 160	5.21	strongly acid	6.0	3.5	0.1	1.8	307.3	52.5	24.1	18.5
33	0 - 5	5.25	strongly acid	77.0	44.7	4.7	15.2	372.7	1714.6	187.9	16.3
	5 - 10	5.37	strongly acid	47.0	27.3	2.9	7.3	337.5	1187.1	130.6	18.0
	10 - 20	5.39	strongly acid	34.7	20.1	1.6	6.3	322.4	879.8	85.2	16.7
	20 - 30	5.23	strongly acid	23.6	13.7	1.4	5.1	277.2	589.0	57.5	25.6
	30 - 40	5.23	strongly acid	21.2	12.3	1.4	5.9	317.4	586.0	59.3	18.4
	40 - 60	5.20	strongly acid	16.8	9.7	1.3	4.8	257.0	457.1	60.2	17.5
	60 - 80	5.27	strongly acid	11.3	6.6	0.9	2.8	201.7	400.2	78.1	18.4
	80 - 100	5.31	strongly acid	11.7	6.8	0.4	3.7	267.1	388.2	87.6	67.2
	100 - 120	5.11	strongly acid	8.8	5.1	0.3	4.8	302.3	367.2	59.9	22.4
	120 - 140	5.08	very strongly acid	7.7	4.5	0.1	5.9	272.1	304.3	54.8	20.3
	140 - 160	5.27	strongly acid	7.8	4.5	0.1	3.7	292.3	226.3	43.8	21.1

(c) Carbon and Nutrient Storages

Carbon and nutrient accumulations within 160 cm depth soils under five age-class pine plantations were given in Table 4-3 and Figure 4-2. Total organic matter, carbon and nitrogen were described. For other nutrients, the extractable forms were determined.

(1) Amounts of organic matter

Amounts of organic matter in soil profiles (0-160 cm depth) under 17-, 21-, 25-, 29- and 33-year-old plantations were 353, 139, 287, 306 and 280 Mg ha^{-1}, respectively. Inputs of above-ground and below-ground litter would be larger in the older plantations, and result in increasing soil organic matter. However, the amounts did not increase with stand ages. The site variations are thought to be the main factor.

(2) Carbon amounts

The amounts of soil carbon in soil profiles under 17-, 21-, 25-, 29- and 33-year-old plantations were 205, 80, 166, 178 and 162 Mg ha^{-1}, respectively. They were in the same trend as soil organic matter since this calculation used the mean content of carbon in organic matter as 58%.

(3) Nitrogen amounts

The amounts of total nitrogen in soil profiles under 17-, 21-, 25-, 29- and 33-year-old plantations were in the order of 24,679; 10,145; 18,935; 17,658 and 14,856 $kg.ha^{-1}$. The amounts did not increase with stand ages.

(4) Amounts of Available Phosphorus

The amounts of available phosphorus in soil profiles under 17-, 21-, 25-, 29- and 33-year-old plantations were 101, 28, 31, 46 and 85 $kg.ha^{-1}$, respectively. They did not increase with stand ages.

(5) Amounts of extractable potassium

The amounts of extractable potassium in soil profiles under 17-, 21-, 25-, 29- and 33-year-old plantations were 4,423; 5,942; 6,021; 5,582 and 4,828 $kg.ha^{-1}$, respectively. The amounts did not increase with stand ages.

(6) Amounts of extractable calcium

The amounts of extractable calcium in soil profiles under 17-, 21-, 25-, 29- and 33-year-old plantations were 2,852; 423; 1,255; 4,256 and 8,198 $kg.ha^{-1}$, respectively. The amounts were higher in the older stands.

(7) Amounts of extractable magnesium

The amounts of extractable magnesium in soil profiles under 17-, 21-, 25-, 29- and 33-year-old plantations were 608, 353, 462, 1,064 and 1,211 $kg.ha^{-1}$, respectively. The amounts were higher in the older stands.

(8) Amounts of extractable sodium

The amounts of extractable sodium in soil profiles under 17-, 21-, 25-, 29- and 33-year-old plantations were in the order 336, 343, 406, 410 and 451 kg.ha^{-1}, respectively. There were some small differences among the plantations.

Table 4-3 Stored carbon and nutrients in soils under different age pine plantations

Age (yrs)	Soil Depth (cm)	OM (Mg.ha^{-1})	C (Mg.ha^{-1})	Total N (kg.ha^{-1})	Available P (kg.ha^{-1})	Extractable (kg.ha^{-1})			
						K	Ca	Mg	Na
17	0 - 5	46.9	27.2	3,072.3	9.5	130.5	581.4	82.8	6.9
	5 - 10	32.7	19.0	1,960.8	5.8	107.8	320.6	38.0	5.5
	10 - 20	48.2	28.0	3,454.0	7.2	215.7	464.8	69.4	11.8
	20 - 30	43.5	25.2	2,392.8	6.0	196.0	301.5	37.6	15.8
	30 - 40	33.8	19.6	2,606.8	5.8	187.7	179.7	25.0	11.5
	40 - 60	58.0	33.7	4,052.6	16.9	505.3	335.7	76.8	54.9
	60 - 80	37.4	21.7	2,580.1	18.1	624.2	243.6	90.6	44.3
	80 - 100	18.4	10.7	2,631.0	8.7	649.8	114.4	75.0	45.1
	100 - 120	15.0	8.7	1,114.3	9.3	575.9	112.7	49.6	44.7
	120 - 140	14.1	8.2	531.7	7.5	589.7	83.7	33.1	42.6
	140 - 160	4.8	2.8	282.3	5.8	640.4	114.2	30.1	53.1
	Total	**353**	**205**	**24,679**	**101**	**4,423**	**2,852**	**608**	**336**
21	0 - 5	29.4	17.0	1,499.1	4.0	210.3	92.3	57.1	9.7
	5 - 10	15.5	9.0	1,112.4	1.9	252.1	40.8	34.5	10.7
	10 - 20	21.7	12.6	2,403.4	2.4	412.7	31.1	30.5	19.6
	20 - 30	18.9	10.9	1,074.9	2.0	445.2	26.8	28.8	19.5
	30 - 40	10.5	6.1	452.9	1.3	370.8	11.9	19.8	18.3
	40 - 60	15.2	8.8	745.4	2.6	788.6	55.9	46.5	44.3
	60 - 80	9.2	5.3	484.3	2.2	719.9	39.9	32.3	48.5
	80 - 100	5.7	3.3	745.6	2.8	626.3	30.2	30.2	44.1
	100 - 120	8.0	4.6	827.0	3.2	777.9	45.5	31.8	41.4
	120 - 140	1.8	1.1	524.5	2.5	713.7	27.5	24.8	39.9
	140 - 160	2.8	1.6	275.2	2.7	624.4	20.6	16.2	46.7
	Total	**139**	**80**	**10,145**	**28**	**5,942**	**423**	**353**	**343**
25	0 - 5	43.2	25.1	2,040.0	3.9	184.4	267.3	74.5	8.9
	5 - 10	40.0	23.2	1,783.2	3.1	223.2	140.1	49.9	13.2
	10 - 20	46.5	27.0	1,842.5	3.2	283.4	138.1	30.0	21.2
	20 - 30	41.6	24.1	1,930.1	3.2	310.1	113.9	29.8	32.1
	30 - 40	21.2	12.3	1,554.8	1.5	372.1	83.5	28.1	22.8
	40 - 60	27.3	15.8	3,206.3	2.8	619.6	156.2	50.0	44.5
	60 - 80	17.2	10.0	2,378.6	2.4	586.3	146.6	43.1	46.1
	80 - 100	15.0	8.7	3,060.4	3.4	786.6	68.8	47.2	62.3
	100 - 120	12.2	7.1	580.8	2.6	1,053.3	56.6	42.2	51.3
	120 - 140	11.4	6.6	284.9	2.7	761.1	47.0	37.2	53.2
	140 - 160	10.9	6.3	273.7	2.6	841.1	36.9	30.0	50.2
	Total	**287**	**166**	**18,935**	**31**	**6,021**	**1,255**	**462**	**406**
29	0 - 5	44.8	26.0	2,528.1	4.8	193.9	620.3	100.9	9.0
	5 - 10	33.6	19.5	1,674.3	3.4	151.4	192.4	40.7	10.1
	10 - 20	51.0	29.6	2,998.0	5.9	311.2	396.2	54.4	16.1
	20 - 30	29.4	17.0	2,216.6	2.7	242.9	247.0	39.0	18.6
	30 - 40	20.3	11.8	2,209.3	2.4	361.7	495.0	80.3	19.2
	40 - 60	27.7	16.1	3,229.6	4.0	709.0	653.5	118.9	39.0
	60 - 80	23.9	13.8	1,243.3	3.9	589.1	503.1	130.4	107.8
	80 - 100	21.4	12.4	756.3	4.1	635.3	343.8	178.0	43.9
	100 - 120	17.1	9.9	263.8	5.0	678.0	217.4	154.8	48.8
	120 - 140	20.9	12.1	267.5	4.9	876.1	445.1	101.2	47.0
	140 - 160	16.3	9.4	271.4	4.9	834.0	142.4	65.3	50.3
	Total	**306**	**178**	**17,658**	**46**	**5,582**	**4,256**	**1,064**	**410**
33	0 - 5	30.9	17.9	1,885.0	6.1	149.5	687.7	75.3	6.5
	5 - 10	23.3	13.5	1,439.2	3.6	167.5	589.1	64.8	8.9
	10 - 20	35.4	20.5	1,633.4	6.4	329.2	898.1	87.0	17.0
	20 - 30	24.5	14.2	1,454.1	5.3	287.9	611.8	59.7	26.6
	30 - 40	22.0	12.8	1,452.3	6.1	329.3	607.9	61.5	19.1
	40 - 60	37.9	22.0	2,934.7	10.9	580.3	1,032.0	135.9	39.5
	60 - 80	26.2	15.2	2,082.9	6.4	466.8	926.2	180.7	42.6
	80 - 100	26.1	15.2	893.5	8.3	596.6	867.1	195.7	150.0
	100 - 120	18.3	10.6	623.0	9.9	627.8	762.6	124.4	46.5
	120 - 140	17.7	10.2	229.2	13.5	623.8	697.5	125.7	46.6
	140 - 160	17.9	10.4	229.0	8.5	669.2	518.2	100.2	48.2
	Total	**280**	**162**	**14,856**	**85**	**4,828**	**8,198**	**1,211**	**451**

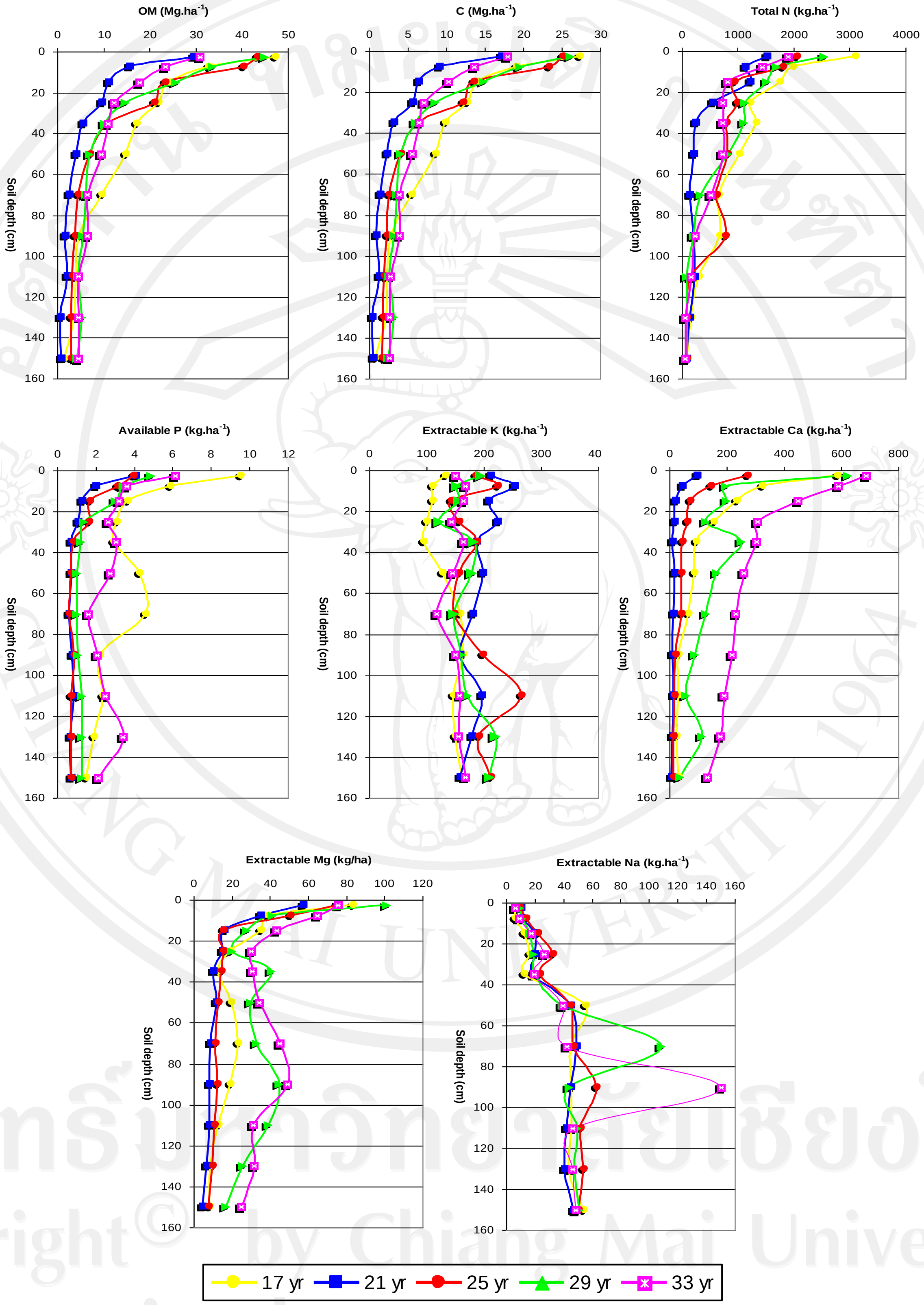

Figure 4-2 Storages of organic matter and nutrients in soils under pine plantations

B. Fragmented Forests

(a) Soil Profile Development

The soils in fragmented forests were classified in Order Ultisols, Suborder Humults, Great group Palehumults, Subgroup Typic Palehumults, except for pedon 3 was in Order Alfisols, Typic Paleudalf. The soils were more than 200 cm in depth with highly weathered from granitic rocks. All pedon were well developed soils. Most profiles of pedon 1, 2, 4 and 5 had low base saturation (< 35%), but pedon 3 had adversely high base saturation. It was found that they had a somewhat similar profile model. The soil profiles were developed as A-Bt-BC with 10-15 cm thickness of organic layers and high clay mineral in subsoils. Topography and development of soil profile under fragmented forests were summarized in Table 4-4.

Table 4-4 Topography and development of soil profile under fragmented forests

FF	Pedon	Topography			Forest type	Profile Development
		Altitude (m)	Slope (%)	Aspect		
1	1	1,414	26	S 20^0 W	Conservation forest	A-AB-Bt1-Bt2-Bt3-Bt4-Bt5-BC1-BC2-BC3
2	2	1,261	38	E 10^0 W	Conservation forest	A-BA-Bt1-Bt2-Bt3-BC1-BC2-BC3
3	3	1,427	42	S 25^0 W	Conservation forest	A1-A2-AB-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6
4	4	1,571	49	S 75^0 W	Conservation forest	A1-A2-AB-Bt1-Bt2-Bt3-Bt4-BC1-BC2-BC3
5	5	1,546	32	N 20^0 E	Conservation forest	A1-A2-AB-Bt1-Bt2-Bt3-Bt4-BC1-BC2-BC3

This indicated mechanical migration of small particles from A to B horizons to produce a relative enrichment of clay in subhorizons (Bt). The number of this horizon depends on the depth of each profile and the appearance of parent material at depth. Morphology of the fragmented forest soils were depicted below (Figure 4-3 - 4-7).

Pedon 1

I Information on the Site

Profile symbol	: Pedon 1
Soil name	: Boakaew Samoeng series 1 (tentative)
Classification	: Typic Palehumult
Date of examination	: June 05, 2009
Described by	: Niwat Anongrak, Soontorn Khamyong, Ampai Pornleesangsuwan, Somchai Nongnuang, Taparat Seeloy-ounkeaw
Location	: Approximately 82 km north from Chiang Mai City. Samoemg District. Chiang Mai Province. Grid Reference: 2087485 N, 0450005 E (Sheet: 4746 IV)
Elevation	: 1,414 m (MSL)
Land form	
1. Physiographic position	: On straight slope
2. Surrounding land form	: High mountainous
3. Slope on which profile site	: Steep (26%), S 20^0 W aspect
Vegetation and land use	: Under lower montane forest. Land is used for watershed forest (protected forest). Dominant tree is *Pinus kesiya*
Annual rainfall	: Approximately 1,894 mm/yr
Mean temperature	: Approximately 20.9 ^{0}C
Other	: Nil

II General Information on the Soil

Parent material	: Derived "*in situ*" from granitic rocks in Triassic period
Drainage	: Well drained
Moisture condition in profile	: Moist throughout
Depth of ground water table	: Nil
Surface stones and rock outcrops	: No stones and no rocks
Evidence of erosion	: Moderate sheet erosion
Human influence	: Nil

III Profile Description :

Horizon	Depth (cm)	Description
A	0-8	Very dark gray (2.5Y3/1) moist; sandy loam; moderate fine and weak medium granular structure; many fine and medium, few coarse pores; common fine, medium and coarse roots; slightly acid (pH 6.13); clear and smooth boundary to AB
AB	8-19	Dark yellowish brown (10YR3/6) moist; sandy clay loam; moderate fine and weak medium subangular blocky structure; common fine and medium pores; common fine, medium and coarse roots; moderately acid (pH 5.86); clear and smooth boundary to Bt1
Bt1	19-31	Dark yellowish brown (10YR4/6) moist; sandy clay loam; moderate medium and strong medium subangular blocky structure; common fine and medium pores; few fine and medium roots; strongly acid (pH 5.51); clear and smooth boundary to Bt2
Bt2	31-47	Brown (7.5YR4/4) moist; sandy clay loam; strong medium subandular blocky structure; few fine and medium pores; few fine, common medium and few coarse roots; moderately acid (pH 5.88); clear and smooth boundary to Bt3
Bt3	47-73	Yellowish red (5YR5/6) moist; loam; strong fine and medium subangular blocky structure; few fine and medium pores; few fine and medium roots; moderately acid (pH 6.05); clear and smooth boundary to Bt4
Bt4	73-102	Red (2.5YR5/6) moist; loam; strong fine and medium subangular blocky structure; few fine and medium pores; few fine and medium roots;

		moderately acid (pH 6.07); clear and smooth boundary to Bt5
Bt5	102-132	Red (2.5RY5/6) moist; loam; strong fine and medium subangular blocky structure; few fine and medium pores; few fine and medium roots; moderately acid (pH 5.96); clear and smooth boundary to BC1
BC1	132-167	Reddish yellow (5YR6/6) moist; sandy loam; strong fine and medium subangular blocky structure; few very fine and fine pores; few fine and medium roots; few rounded boulded of granitic rocks; moderately acid (pH 6.01); clear and smooth boundary to BC2
BC2	167-192	Reddish yellow (5YR6/6) moist; sandy loam; strong fine and medium subangular blocky structure; few very fine and fine pores; few fine roots; few rounded stones of granitic rocks; moderately acid (pH 6.01); clear and smooth boundary to BC3
BC3	192-212+	Light red (2.5YR7/8) moist; sandy loam; strong fine and medium subangular blocky structure; few very fine and fine pores; few fine roots; few rounded stones of granitic rocks; moderately acid (pH 6.01)

Pedon 2

I Information on the Site

Profile symbol : Pedon 2
Soil name : Boakaew Samoeng series 2 (tentative)
Classification : Typic Palehumult
Date of examination : May 16, 2010
Described by : Niwat Anongrak, Soontorn Khamyong, Ampai Pornleesangsuwan, Somchai Nongnuang, Taparat Seeloy-ounkeaw
Location : Approximately 82 km north from Chiang Mai City. Samoemg District. Chiang Mai Province. Grid Reference: 2090586 N, 0447589 E (Sheet: 4746 IV)
Elevation : 1,261 m (MSL)
Land form
1. Physiographic position : On straight slope
2. Surrounding land form : High mountainous
3. Slope on which profile site : Steep (38%), E 10^0 W aspect
Vegetation and land use : Under lower montane forest. Land is used for watershed forest (protected area). Dominant trees are *Castanopsis acuminatissima*, *Quercus brandisiana*
Annual rainfall : Approximately 1,894 mm/yr
Mean temperature : Approximately 20.9 ^{0}C
Other : Nil

II General Information on the Soil

Parent material : Derived "*in situ*" from granitic rocks in Triassic period
Drainage : Well drained
Moisture condition in profile : Moist throughout
Depth of ground water table : Nil
Surface stones and rock outcrops : No stones and no rocks
Evidence of erosion : Moderate sheet erosion
Human influence : Some disturbed by human through tree cutting

III Profile Description :

Horizon	Depth (cm)	Description
A	0-10/17	Dark grayish brown (10YR4/2) moist; gravelly sandy clay loam; strong fine and medium subangular blocky structure; common fine and few medium pores; common and many fine, few medium roots; strongly acid (pH 5.30); clear and smooth boundary to BA
BA	10/17-33	Yellowish red (5YR4/6) moist; very gravelly clay; strong fine subangular blocky structure; common fine pores; few fine and medium roots; moderately acid (pH 5.75); clear and smooth boundary to Bt1
Bt1	33-59	Red (2.5YR4/8) moist; gravelly clay; strong fine and moderate medium subangular blocky structure; few fine and medium pores; few coarse roots; moderately acid (pH 5.77); clear and smooth boundary to Bt2
Bt2	59-104	Red (2.5YR5/8) moist; gravelly clay; moderate medium subangular blocky structure; few fine and medium pores; few medium roots; moderately acid (pH 5.88); clear and smooth boundary to Bt3
Bt3	104-140	Red (2.5YR5/8) moist; gravelly clay loam; moderate medium subangular blocky structure; few fine and medium pores; few medium roots; very strongly acid (pH 4.82); clear and smooth boundary to Bt4
BC1	140-162	Brownish yellow (10YR6/6) moist; gravelly clay loam; moderate medium subangular blocky structure; few fine and medium pores; no roots; very strongly acid (pH 5.00); gradual and smooth boundary to BC1
BC2	162-199	Yellow (10YR7/6) moist; gravelly clay loam; moderate medium subangular blocky structure; few fine and medium pores; no roots; very

		strongly acid (pH 5.00); gradual and smooth boundary to BC2
BC3	199-225+	Pale yellow (2.5Y8/4) moist; gravelly clay loam; moderate medium subangular blocky structure; few fine and medium pores; no roots; very strongly acid (pH 5.00)

Pedon 3

I Information on the Site

Profile symbol	:	Pedon 3
Soil name	:	Boakaew Samoeng series 3 (tentative)
Classification	:	Typic Paleudalf
Date of examination	:	June 06, 2009
Described by	:	Niwat Anongrak, Soontorn Khamyong, Ampai Pornleesangsuwan, Somchai Nongnuang, Taparat Seeloy-ounkeaw
Location	:	Approximately 82 km north from Chiang Mai City. Samoemg District. Chiang Mai Province. Grid Reference: 2081200 N, 0451579 E (Sheet: 4746 IV)
Elevation	:	1,427 m (MSL)
Land form		
1. Physiographic position	:	On straight slope
2. Surrounding land form	:	High mountainous
3. Slope on which profile site	:	Steep (42%), S 25^0 W aspect
Vegetation and land use	:	Under lower montane forest. Land is used for watershed forest (protected area). Dominant tree is *Castanopsis acuminatissima*
Annual rainfall	:	Approximately 1,894 mm/yr
Mean temperature	:	Approximately 20.9 ^{0}C
Other	:	Nil

II General Information on the Soil

Parent material	:	Derived "*in situ*" from granitic rocks in Triassic period
Drainage	:	Well drained
Moisture condition in profile	:	Moist throughout
Depth of ground water table	:	Nil
Surface stones and rock outcrops	:	No stones and no rocks
Evidence of erosion	:	Moderate sheet erosion
Human influence	:	Nil

III Profile Description :

Horizon	**Depth (cm)**	**Description**
A1	0-10	Very dark gray (5YR3/1) moist; gravelly sandy loam; moderate fine and medium granular structure; many fine, medium and common coarse pores; comon fine and medium roots; strongly acid (pH 5.55); clear and smooth boundary to A2
A2	10-21	Very dark gray (5YR3/1) moist; sandy loam; moderate fine and medium granular structure; common fine, medium and few coarse pores; comon fine and medium roots; moderately acid (pH 5.83); abrupt and smooth boundary to AB
AB	21-34	Very dark gray (5YR3/1) moist; sandy clay loam; weak medium moderate fine and subangular blocky structure; common fine and medium pores; few fine and medium roots; moderately acid (pH 6.03); clear and smooth boundary to Bt1
Bt1	34-62	Dark reddish brown (2.5YR2.5/3) moist; sandy clay loam; weak fine and medium subangular blocky structure; few fine and medium pores; few fine and medium roots; strongly acid (pH 5.58); clear and smooth boundary to Bt2
Bt2	62-90	Dark reddish brown (2.5YR3/3) moist; sandy clay loam; strong fine and medium subangular blocky structure; few fine and medium pores; few fine, medium and coarse roots; moderately acid (pH 5.86); clear and smooth boundary to Bt3
Bt3	90-123	Dark red (2.5YR3/6) moist; sandy clay loam; strong fine and medium

		subangular blocky structure; few fine and medium pores; few fine, medium and coarse roots; moderately acid (pH 5.86); clear and smooth boundary to Bt4
Bt4	123-159	Red (10R4/6) moist; gravelly sandy clay loam; strong fine and medium subangular blocky structure; few fine and medium pores; few fine and medium roots; moderately acid (pH 5.73); clear and smooth boundary to Bt5
Bt5	159-192	Weak red (10R4/4) moist; gravelly sandy clay loam; strong fine and medium subangular blocky structure; few fine and medium pores; few fine and medium roots; strongly acid (pH 5.57); gradual and smooth boundary to Bt6
Bt6	192-210+	Weak red (10R4/4) moist; gravelly sandy clay loam; strong fine and medium subangular blocky structure; few fine and medium pores; few fine and medium roots; strongly acid (pH 5.57)

Pedon 4

I Information on the Site

Profile symbol : Pedon 4
Soil name : Boakaew Samoeng series 4 (tentative)
Classification : Typic Palehumult
Date of examination : May 07, 2009
Described by : Niwat Anongrak, Soontorn Khamyong, Ampai Pornleesangsuwan, Somchai Nongnuang, Taparat Seeloy-ounkeaw
Location : Approximately 82 km north from Chiang Mai City. Samoemg District. Chiang Mai Province. Grid Reference: 2082803 N, 0450647 E (Sheet: 4746 IV)
Elevation : 1,571 m (MSL)
Land form
1. Physiographic position : On straight slope
2. Surrounding land form : High mountainous
3. Slope on which profile site : Very steep (49%), S 75^0 W aspect
Vegetation and land use : Under lower montane forest. Land is used for watershed forest (protected area). Dominant tree is *Castanopsis diversifolia*
Annual rainfall : Approximately 1,894 mm/yr
Mean temperature : Approximately 20.9 ^{0}C
Other : Nil

II General Information on the Soil

Parent material : Derived "*in situ*" from granitic rocks in Triassic period
Drainage : Well drained and somewhat excessively drained
Moisture condition in profile : Moist throughout
Depth of ground water table : Nil
Surface stones and rock outcrops : No stones and no rocks
Evidence of erosion : Moderate sheet erosion
Human influence : Nil

III Profile Description :

Horizon	Depth (cm)	Description
A1	0-5	Black (5YR2.5/1) and dark gray (5YR4/1) moist; sandy loam; moderate fine subangular blocky structure; many fine, medium and common coarse pores; many very fine, common fine, medium and few coarse roots; strongly acid (pH 5.25); clear and smooth boundary to A2
A2	5-14	Black (5YR2.5/1) moist; gravelly sandy clay loam; moderate fine and medium subangular blocky structure; common fine, medium and few coarse pores; many very fine, common fine, medium and few coarse roots; strongly acid (pH 5.14); clear and smooth boundary to AB
AB	14-34	Very dark gray (5YR3/1) moist; gravelly sandy clay loam; strong fine and medium subangular blocky structure; common fine and medium pores; common fine and medium roots; very strongly acid (pH 5.01); clear and smooth boundary to Bt1
Bt1	34-64	Dark reddish brown (5YR3/2) moist; sandy clay loam; strong fine and medium subangular blocky structure; few fine and medium pores; common fine and few medium roots; strongly acid (pH 5.18); clear and smooth boundary to Bt2
Bt2	64-86	Dark brown (7.5YR3/3) moist; clay loam; strong medium subangular blocky structure; few fine and medium pores; few fine and medium roots; strongly acid (pH 5.50); clear and smooth boundary to Bt3
Bt3	86-102	Reddish brown (2.5YR4/4) moist; clay loam; strong medium subangular blocky structure; few fine and medium pores; few fine and coarse roots; strongly acid (pH 5.56); clear and smooth boundary to Bt4

Bt4	102-131	Reddish brown (2.5YR4/4) moist; clay loam; strong medium subangular blocky structure; few fine and medium pores; few fine roots; moderately acid (pH 5.67); gradual and smooth boundary to BC1
BC1	131-164	Yellowish red (5YR5/8) moist; loam; strong medium subangular blocky structure; few fine and medium pores; few fine roots; strongly acid (pH 5.47); gradual and smooth boundary to BC2
BC2	164-191	Reddish brown (5YR5/3) moist; loam; strong medium subangular blocky structure; few fine and medium pores; few fine roots; strongly acid (pH 5.47); gradual and smooth boundary to BC3
BC3	191-210+	Pinkish gray (5YR7/2) moist; gravelly loam; strong medium subangular blocky structure; few fine and medium pores; few fine roots; strongly acid (pH 5.47)

Pedon 5

I Information on the Site

Profile symbol : Pedon 5
Soil name : Boakaew Samoeng series 5 (tentative)
Classification : Typic Palehumult
Date of examination : May 08, 2009
Described by : Niwat Anongrak, Soontorn Khamyong, Ampai Pornleesangsuwan, Somchai Nongnuang, Taparat Seeloy-ounkeaw
Location : Approximately 82 km north from Chiang Mai City. Samoemg District. Chiang Mai Province. Grid Reference: 2083478 N, 0450800 E (Sheet: 4746 IV)
Elevation : 1,546 m (MSL)
Land form
1. Physiographic position : On convex slope near ridge
2. Surrounding land form : High mountainous
3. Slope on which profile site : Steep (32%), N 20^0 E aspect
Vegetation and land use : Under lower montane forest. Land is used for watershed forest (protected area). Dominant tree is *Schima wallichii*
Annual rainfall : Approximately 1,894 mm/yr
Mean temperature : Approximately 20.9 ^{0}C
Other : Nil

II General Information on the Soil

Parent material : Derived "*in situ*" from granitic rocks in Triassic period
Drainage : Well drained and somewhat excessively drained
Moisture condition in profile : Moist throughout
Depth of ground water table : Nil
Surface stones and rock outcrops : No stones and no rocks
Evidence of erosion : Moderate to severe sheet erosion
Human influence : Nil

III Profile Description :

Horizon	Depth (cm)	Description
A1	0-5	Black (5YR2.5/1) moist; sandy loam; moderate fine granular structure; many fine, medium and few coarse pores; many very fine, many fine, common medium and few coarse roots; strongly acid (pH 5.26); clear and smooth boundary to A2
A2	5-20	Very dark gray (5YR3/1) moist; sandy clay loam; moderate fine and medium subangular blocky structure; common fine, medium and few coarse pores; many fine, common fine, medium and few coarse roots; strongly acid (pH 5.56); clear and smooth boundary to AB
AB	20-36	Very dark gray (5YR3/1) moist; sandy clay loam; strong fine and medium subangular blocky structure; common fine and medium pores; common fine, medium and few coarse roots; moderately acid (pH 5.65); clear and smooth boundary to Bt1
Bt1	36-50	Reddish brown (5YR4/4) moist; sandy clay loam; strong fine and medium subangular blocky structure; few fine and medium pores; few fine, medium and coarse roots; moderately acid (pH 5.61); clear and smooth boundary to Bt2
Bt2	50-66	Yellowish red (5YR4/6) moist; clay loam; strong medium subangular blocky structure; few fine and medium pores; few fine, medium and coarse roots; strongly acid (pH 5.46); clear and smooth boundary to Bt3
Bt3	66-92	Yellowish red (5YR4/6) moist; sandy clay loam; strong medium subangular blocky structure; few fine and medium pores; few fine, medium and coarse roots; few stone rounded stones; strongly acid (pH

		5.52); clear and smooth boundary to Bt4
Bt4	92-115/124	Yellowish red (5YR4/6) moist; loam; strong medium subangular blocky structure; few fine and medium pores; few fine and medium roots; moderately acid (pH 5.64); wavy and smooth boundary to BC1
BC1	115/124-145	Pinkish gray (5YR6/2) moist; loam; strong medium subangular blocky structure; few fine and medium pores; few fine and medium roots; strongly acid (pH 5.52); clear and smooth boundary to BC2
BC2	145-185	Pinkish gray (5YR6/2) moist; loam; strong medium subangular blocky structure; few fine and medium pores; few fine and medium roots; slightly acid (pH 6.11); gradual and smooth boundary to BC3
BC3	185-210+	Pinkish gray (7.5YR5/2) moist; gravelly loam; strong medium subangular blocky structure; few fine and medium pores; no roots; slightly acid (pH 6.11)

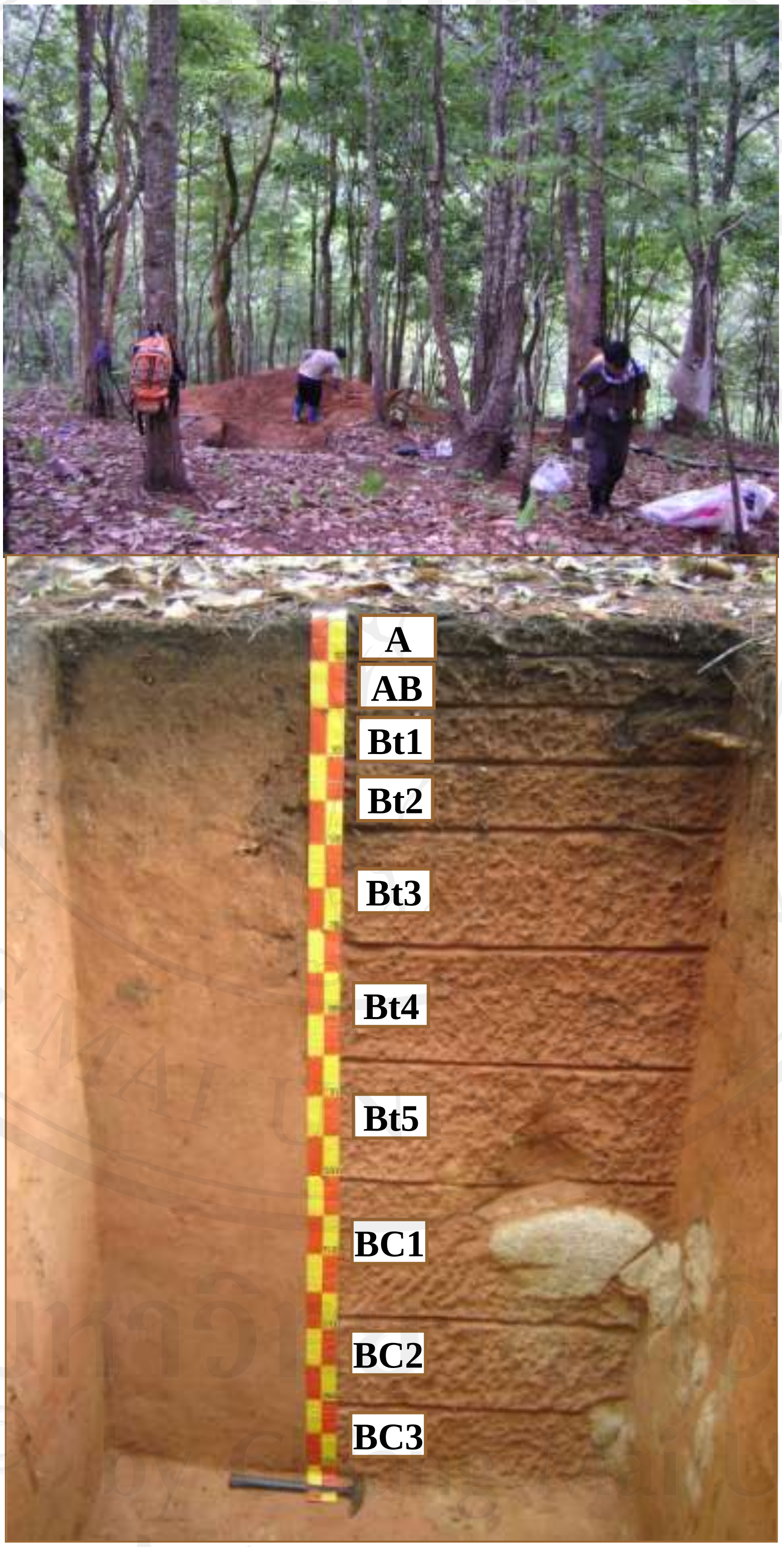

Figure 4-7 Study site and soil profile of pedon 1 (The 1st fragmented forest)

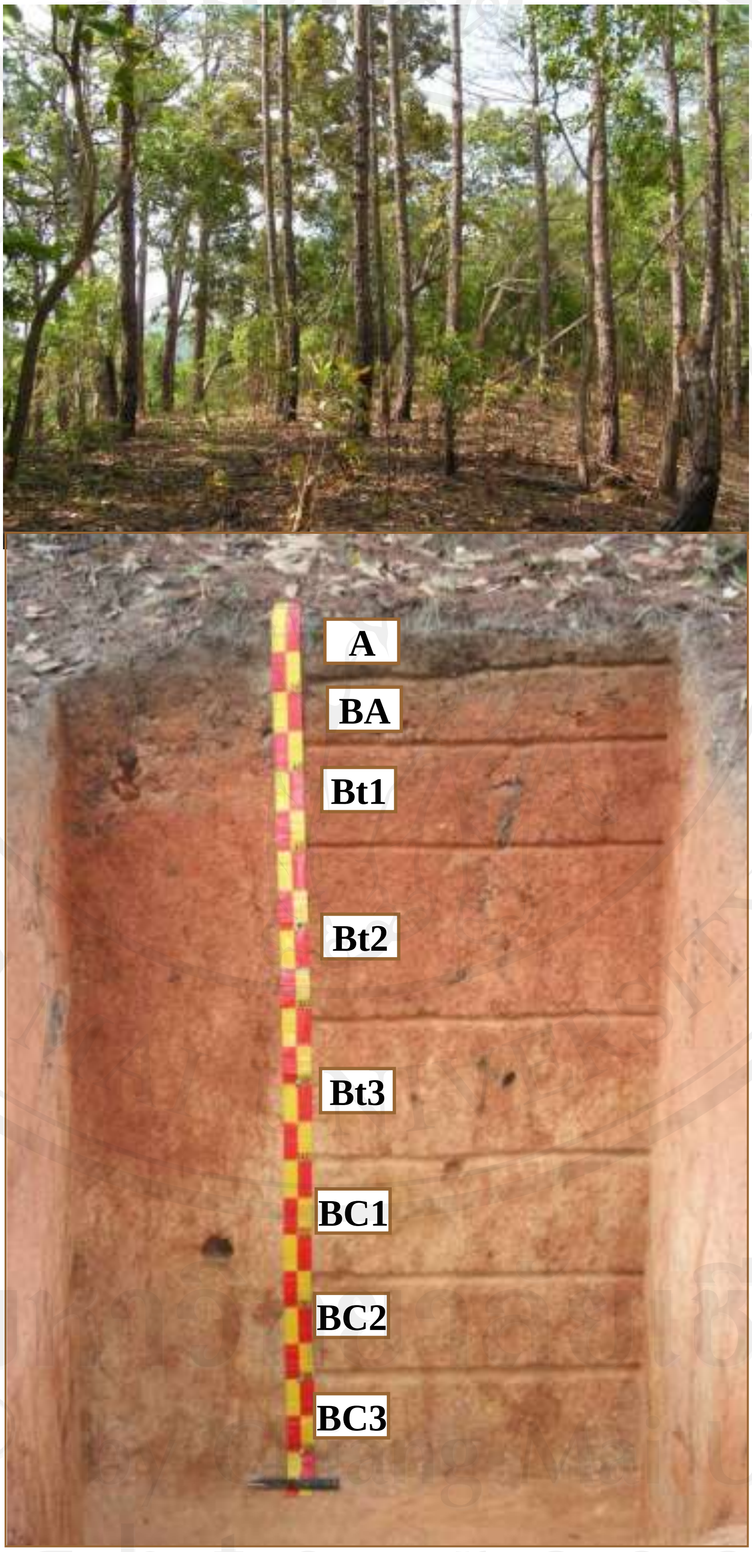

Figure 4-8 Study site and soil profile of pedon 2 (The 2nd fragmented forest)

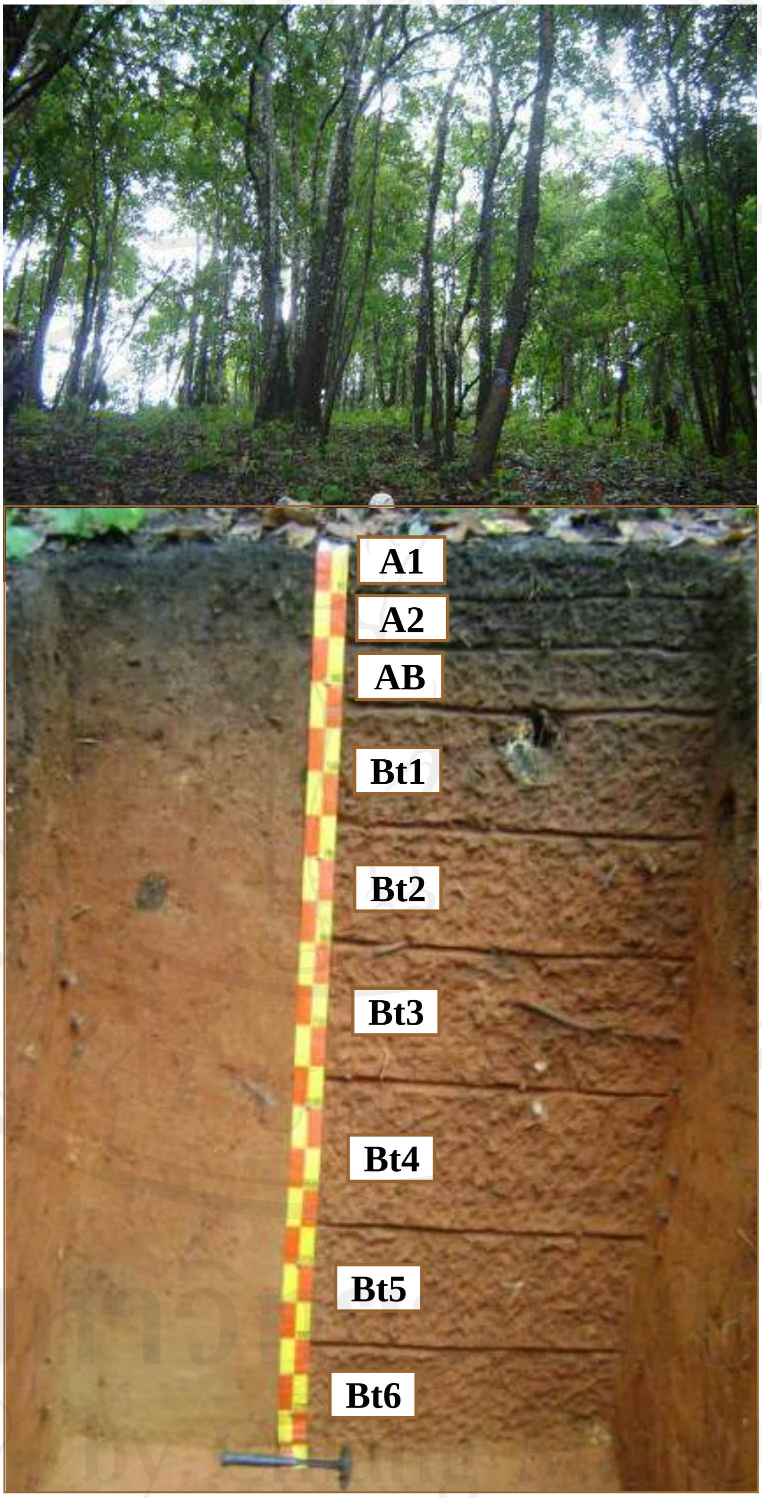

Figure 4-9 Study site and soil profile of pedon 3 (The 3rd fragmented forest)

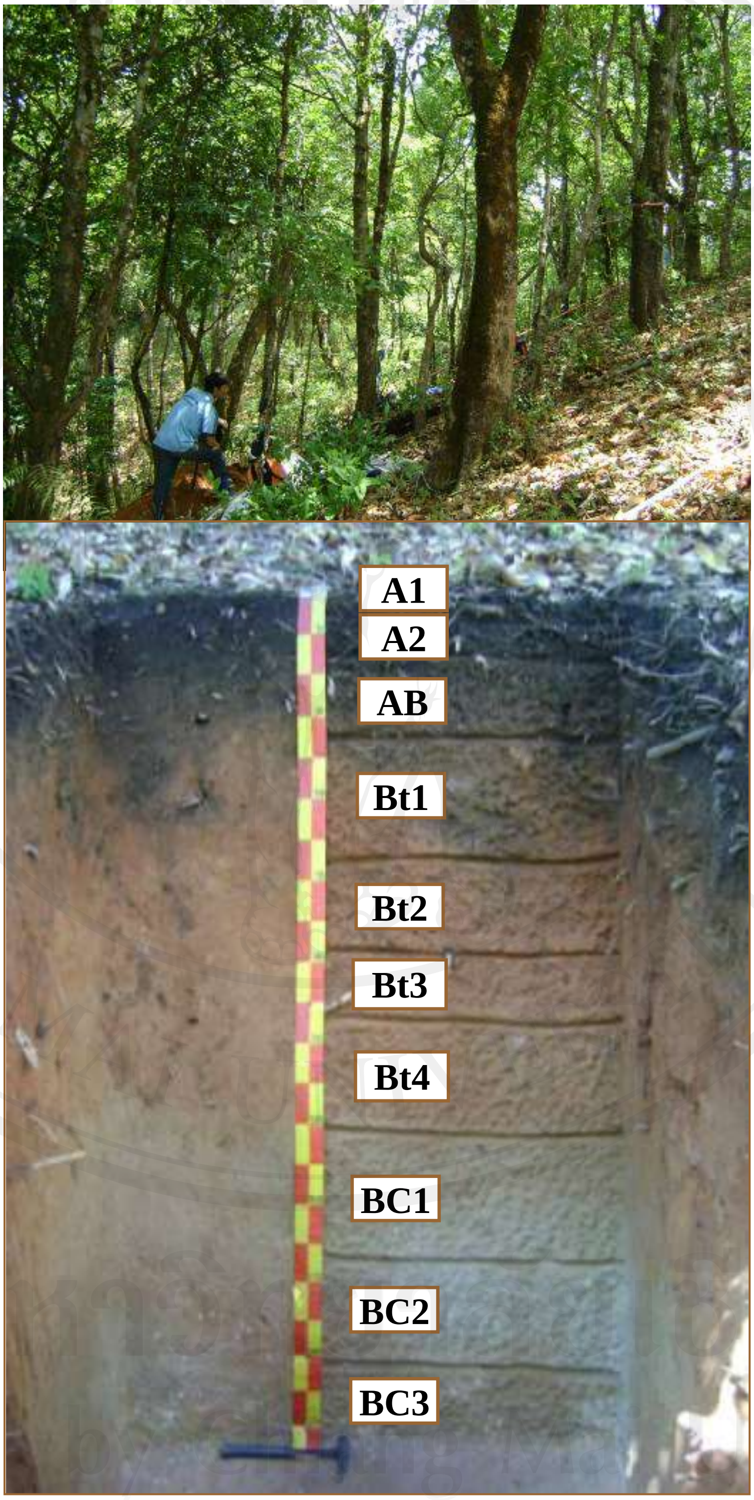

Figure 4-10 Study site and soil profile of pedon 4 (The 4th fragmented forest)

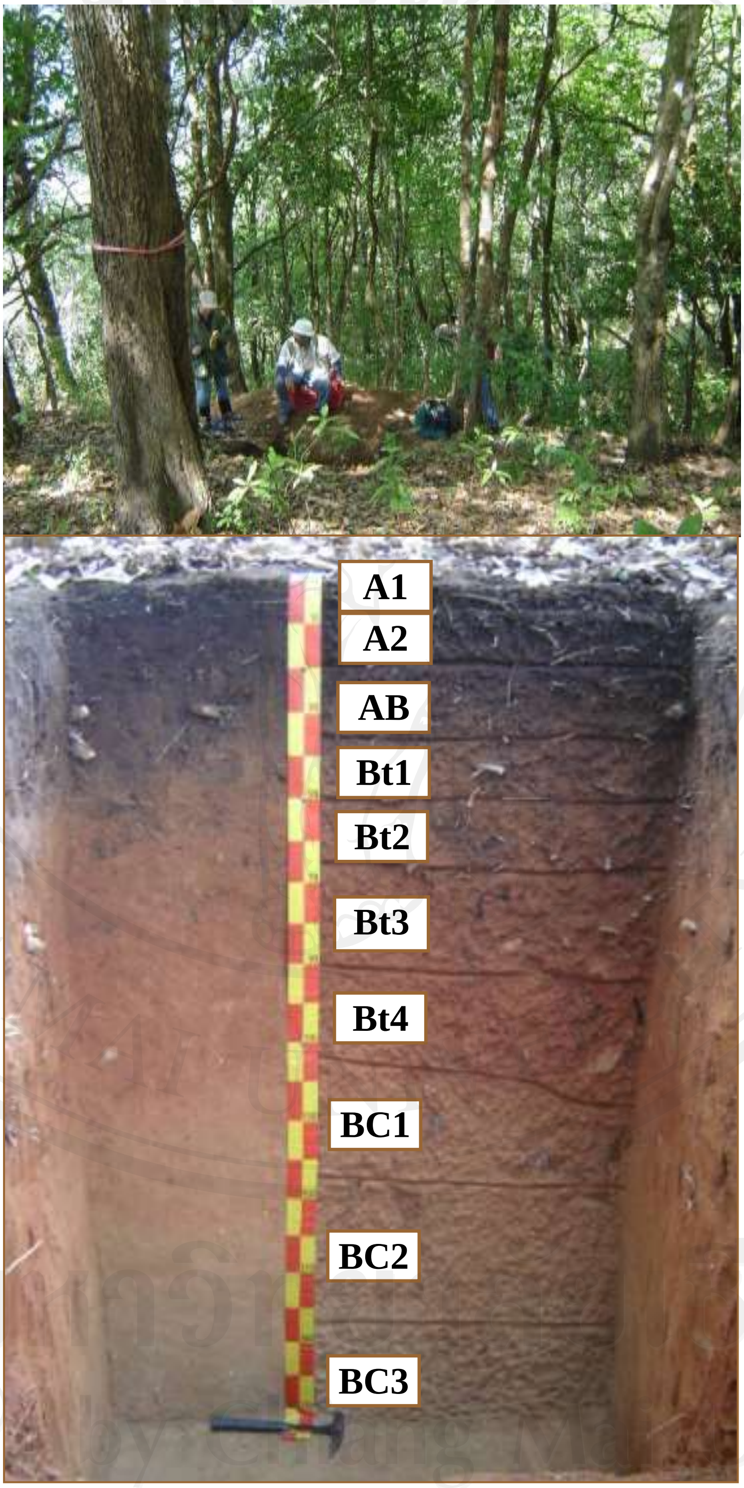

Figure 4-11 Study site and soil profile of pedon 5 (The 5th fragmented forest)

(b) Physical Properties

Some physical properties including bulk density, amounts of gravel, soil particle distribution and soil texture were given in Table 4-5.

(1) Bulk density

Some differences of soil bulk densities under five fragmented forests were observed.

In the 1st fragmented forest, bulk densities in surface soils (0-8, 8-19 cm depth) were very low (0.96-0.97 $Mg.m^{-3}$) and low in the deeper horizons (1.03-1.21 $Mg.m^{-3}$).

In the 2nd fragmented forest, the density in surface soils (0-10/17 cm depth) was very low (0.86 $Mg.m^{-3}$) and moderately low to low in the deeper horizons (1.07-1.29 $Mg.m^{-3}$).

In the 3rd fragmented forest, the density in surface soils (0-10 cm depth) was very low (0.89 $Mg.m^{-3}$), low at 10-34 cm depth, moderately low at 34-90 cm and medium in the deeper horizons (1.42-1.56 $Mg.m^{-3}$).

In the 4th fragmented forest, the densities in surface soils (0-5, 5-14 and 14-34 cm depth) were very low (0.70-0.96 $Mg.m^{-3}$), and moderately low in the deeper horizons (1.31-1.37 $Mg.m^{-3}$).

In the 5th fragmented forest, the density in surface soil at 0-5 cm depth was very low (0.83 $Mg.m^{-3}$), low at 5-50 cm depth (1.03-1.19 $Mg.m^{-3}$), moderately low at 50-92 cm depth (1.22-1.32 $Mg.m^{-3}$) and medium to high in the deeper horizons (1.44-1.65 $Mg.m^{-3}$).

All fragmented forests had low to very low bulk densities (<1.2 $Mg.m^{-3}$) in the surface soils and low/moderately low to medium in subsoils. The values of bulk density in the surface soil of lower montane forests usually low to very low because of the high accumulation of soil organic matter decomposed from litterfall and dead root either big trees or ground-covered species.

Bulk density increases with the clay content and is considered a measure of the compactness of the soil. The greater bulk density, the more compact the soils. Compact soils have low permeability, inhibiting the movement of water. Soil compaction results in reduced infiltration and increase runoff and erosion. In fragmented lower montane forests, surface soils had very low densities. Thus, these are good for water infiltration and reducing soil erosion.

(2) Amounts of Gravel

The amounts of gravel in soil profiles varied among five fragmented forests (Figure 4-12).

In the 1st, 2nd, 3rd, 4th and 5th fragmented forest, the gravel amounts in soil profile varied between 2.77-11.78%, 19.85-42.90%, 12.93-24.86%, 9.60-16.97% and 1.17-5.14%, respectively.

The 2nd fragmented forest had the high amounts of gravel in surface soils. This implies to the poor weathering of parent rock.

(3) Soil Particle Distribution

Sand:

There were some differences of sand percentages in soil profiles of five fragmented forests.

In the 1st, 2nd, 3rd, 4th and 5th fragmented forests, the percentages of sand in soil profiles varied between 46.8-62.0, 26.5-59.7, 49.3-72.2, 41.6-75.0 and 44.2-59.5%, respectively.

The percentages of sand in soil profiles varied from 26.5-75.0%. They were rather high in top soils and decreased in subsoils (Figure 4-13).

Silt:

Some small differences of silt percentages in soil profiles of five fragmented forests were occurred.

In the 1st, 2nd, 3rd, 4th and 5th fragmented forests, the percentages of silt in soil profiles varied between 17.6-32.6, 17.3-36.9, 15.7-21.3, 7.7-34.3 and 18.2-37.7%, respectively. The silt particles in soil profiles varied from 7.7-37.7%.

Clay:

The clay distribution in soil profiles of five fragmented forests had some differences.

In the 1st, 2nd, 3rd, 4th and 5th fragmented forests, the percentages of clay in soil profiles varied between 10.3-30.8, 22.3-56.1, 9.7-33.4, 17.3-35.1 and 13.0-30.8%, respectively. The clay particles in soil profiles varied from 9.7-56.1%.

The 3rd and 4th fragmented forests had the high sand particles, whereas the 2nd fragmented forest had the high clay particle. The high clay contents in soil profiles can reduce water infiltration into deeper soils as well as movement of soil organic matter, carbon and nitrogen.

(4) Soil Texture

The top soils of almost fragmented forests were sandy loam whereas subsoils were sandy clay loam, loam and clay loam. The 2nd fragmented forest had sandy clay loam in top soil and clay to clay loam in subsoil.

Table 4-5 Some soil physical properties in fragmented forests

FF	Profile	Soil depth (cm)	Bulk density ($Mg.m^{-3}$)	*	Gravel (%)	Soil particle distribution (%)			Soil texture
						Sand	Silt	Clay	
1	A	0-8	0.97	VL	11.78	62.0	18.2	19.8	Sandy loam
	AB	8-19	0.96	VL	8.79	57.5	17.6	24.9	Sandy clay loam
	Bt1	19-31	1.15	L	11.16	46.8	22.4	30.8	Sandy clay loam
	Bt2	31-47	1.03	L	9.72	46.9	24.2	28.9	Sandy clay loam
	Bt3	47-73	1.07	L	11.27	48.9	29.8	21.3	Loam
	Bt4	73-102	1.16	L	10.66	49.5	30.0	20.5	Loam
	Bt5	102-132	1.18	L	3.99	52.0	32.6	15.4	Loam
	BC1	132+	1.21	ML	2.77	59.7	30.0	10.3	Sandy loam
2	A	0-10/17	0.86	VL	23.40	59.7	18.0	22.3	Sandy clay loam
	BA	10/17-33	1.23	ML	42.90	34.2	17.3	48.5	Clay
	Bt1	33-59	1.07	L	29.32	26.5	17.4	56.1	Clay
	Bt2	59-104	1.15	L	23.22	26.5	26.7	46.8	Clay
	Bt3	104-140	1.21	ML	21.38	31.6	34.4	34.0	Clay loam
	BC1	140+	1.29	ML	19.85	34.2	36.9	28.9	Clay loam
3	A1	0-10	0.89	VL	16.71	72.2	18.1	9.7	Sandy loam
	A2	10-21	1.06	L	14.55	62.0	18.1	19.9	Sandy loam
	AB	21-34	1.17	L	14.83	54.4	18.1	27.5	Sandy clay loam
	Bt1	34-62	1.27	ML	14.88	51.8	15.7	32.5	Sandy clay loam
	Bt2	62-90	1.34	ML	12.93	49.3	17.3	33.4	Sandy clay loam
	Bt3	90-123	1.42	M	14.60	49.3	20.7	30.0	Sandy clay loam
	Bt4	123-159	1.50	M	24.09	54.4	20.7	24.9	Sandy clay loam
	Bt5	159+	1.56	M	24.86	56.3	21.3	22.4	Sandy clay loam
4	A1	0-5	0.70	VL	13.51	75.0	7.7	17.3	Sandy loam
	A2	5-14	0.85	VL	15.34	59.5	18.1	22.4	Sandy clay loam
	AB	14-34	0.96	VL	16.97	49.3	19.9	30.8	Sandy clay loam
	Bt1	34-64	1.35	ML	14.53	46.7	19.9	33.4	Sandy clay loam
	Bt2	64-86	1.34	ML	14.25	44.2	20.7	35.1	Clay loam
	Bt3	86-102	1.31	ML	9.60	44.2	20.7	35.1	Clay loam
	Bt4	102-131	1.37	ML	10.47	41.6	25.0	33.4	Clay loam
	BC1	131+	1.34	ML	10.26	41.7	34.3	24.0	Loam
5	A1	0-5	0.83	VL	1.59	59.5	20.7	19.8	Sandy loam
	A2	5-20	1.03	L	1.17	54.4	18.2	27.4	Sandy clay loam
	AB	20-36	1.13	L	3.09	51.9	20.7	27.4	Sandy clay loam
	Bt1	36-50	1.19	L	4.80	46.8	20.7	32.5	Sandy clay loam
	Bt2	50-66	1.22	ML	5.14	44.2	25.0	30.8	Clay loam
	Bt3	66-92	1.32	ML	3.34	46.8	27.5	25.7	Sandy clay loam
	Bt4	92-115/124	1.44	M	2.52	49.3	28.3	22.4	Loam
	BC1	115/124-145	1.54	M	4.08	49.3	35.9	14.8	Loam
	BC2	145+	1.65	MH	4.50	49.3	37.7	13.0	Loam

Note: * VL = very low, L = low, ML = moderately low, M = medium, MH = moderately high
(Modified Kanchanaprasert, 1986)

(c) Chemical Properties

Soil reaction (pH), contents of organic matter, carbon, nitrogen, and extractable minerals were investigated as soil chemical properties. The data were given in Table 4-6.

(1) Soil Reaction

Soil reaction is expressed in term of pH value.

In the 1st fragmented forest, the soil reaction in top soil (0-8 cm depth) was slightly acid (pH = 6.13). It was moderately acid at 8-19 cm depth (pH = 5.86), strongly acid at 19-31 cm depth (pH = 5.51) and moderately acid in deeper soil (pH = 5.88-6.07).

In the 2nd fragmented forest, the soil reaction in surface soil (0-10/17 cm depth) was strongly acid (pH = 5.30). It was moderately acid at 10/17-104 cm depth (pH = 5.75-5.88) and very strongly acid in deeper soil (pH = 4.82-5.00).

In the 3rd fragmented forest, the soil reaction in surface soil (0-10 cm depth) was strongly acid (pH = 5.55). It was moderately acid at 10-34 cm depth (pH = 5.83-6.03), strongly acid at 34-62 cm depth (pH = 5.58), moderately acid at 62-159 cm depth (pH = 5.73-5.86) and strongly acid in deeper soil (pH = 5.57).

In the 4th fragmented forest, the soil reactions in surface soil (0-5, 5-14 cm depth) were strongly acid (pH = 5.14-5.25). It was very strongly acid at 14-34 cm depth (pH = 5.01), strongly acid at 34-102 cm depth (pH = 5.18-5.56), moderately acid at 102-131 cm depth (pH = 5.67) and strongly acid in deeper soil (pH = 5.47).

For the 5th fragmented forest, the soil reactions in surface soil (0-5, 5-20 cm depth) were strongly acid (pH = 5.26-5.56). It was moderately at 20-50 cm depth (pH = 5.61-5.65), strongly acid at 50-92 cm depth (pH = 5.46-5.52), moderately acid at 92-115/124 cm depth (pH = 5.64) and strongly acid (pH = 5.52) at 115/124-145 cm depth and slightly acid in deeper soil (pH = 6.11).

Soil reaction in surface soils of almost fragmented forests was strongly acid. (pH = 5.25-5.55), except for that of the 1st fragmented forest had slightly acid (pH = 6.13). Their subsoils had moderately to strongly and very strongly acid. Differences in plant species composition and diversity as well as variable mineral composition of parent rock are considered as the main factor affecting soil pH through processes of litter decomposition and rock weathering.

(2) Soil Organic Matter

The soil under lower montane forest usually contains the high content of organic matter.

In the 1st fragmented forest, the content of organic matter in top soil (0-8 cm depth) was very high (73.5 $g.kg^{-1}$). It was moderately high at 8-19 cm depth (25.6 $g.kg^{-1}$), and moderately low to low and very low in deeper soils.

In the 2nd fragmented forest, the content in top soil (0-10/17 cm depth) was very high (79.1 $g.kg^{-1}$). It was moderately low to low and very low in deeper soils.

In the 3rd fragmented forest, the content in top soil (0-10 cm depth) was very high (60.9 $g.kg^{-1}$). It was moderately high at 10-34 cm depth (31.1-33.7 $g.kg^{-1}$), medium at 34-62 cm depth (17.1 $g.kg^{-1}$), and low to very low in deeper soils.

In the 4th fragmented forest, the contents in top soil (0-5, 5-14 cm depth) were very high (54.4-127.1 $g.kg^{-1}$). It was moderately high at 14-34 cm depth (27.3 $g.kg^{-1}$), and low to very low in deeper soils.

For the 5th fragmented forest, the contents in surface soil (0-5, 5-20 and 20-36 cm depth) were very high (51.8-129.6 g.kg^{-1}). It was moderately high at 36-50 cm depth (33.4 g.kg^{-1}), and moderately low to low and very low in deeper soils.

The contents of organic matter in the top soils under five fragmented forests were very high as 60.9 to 129.6 g/kg. They were decreased with soil depth. The soil under the 2nd fragmented forest contained the lower contents of organic matter compared to the others.

The organic matter influences on soil physical, chemical and biological characteristics. It improves water holding capacity and supplies energy and body-building constituents for soil organisms, increases microbial populations and their activities as well as source and sink for nutrients.

(3) Soil Carbon

The contents of organic carbon in soils under five fragmented forests varied in the same pattern as organic matter since it is assumed that carbon is 58% in average of organic matter. The carbon contents in the top soils of five fragmented forests were very high, varying 35.3-75.2 g.kg^{-1}. They were decreased with soil depth. The 2nd fragmented forest contained the lower carbon contents in soil profile compared to the others.

(4) Total Nitrogen and C/N Ratios

In the 1st, 2nd and 3rd fragmented forest, the contents of total nitrogen in top soil were medium (2.5-4.3 g.kg^{-1}). It was low to very low in deeper soils.

In the 4th fragmented forest, the content in top soil (0-5 cm depth) was high (5.9 g.kg^{-1}). It was medium at 5-34 cm depth (2.6-4.3 g.kg^{-1}), and low to very low in deeper soils.

In the 5th fragmented forest, the content in top soil (0-5 cm depth) was high (6.9 g.kg^{-1}). It was medium at 5-20 cm depth (4.3 g.kg^{-1}), and low to very low in deeper soils.

The nitrogen contents in the top soils under the 4th and 5th fragmented forests were high as 5.9-6.9 g.kg^{-1} whereas those in the 1st, 2nd and 3rd fragmented forests were medium (4.3, 2.5 and 2.7 g.kg^{-1}, respectively).

The C/N rations in soil profiles under the 1st to the 5th fragmented forests were in ranges of 3.9-11.9, 6.1-18.7, 2.9-13.3, 1.7-12.5 and 5.0-32.2, respectively. In surface soils, the values were in the order of 9.9, 18.7, 13.3, 12.5 and 10.9. The values were low in subsoils according to low carbon contents.

(5) Available Phosphorus

In the 1st fragmented forest, the concentration of available phosphorus in top soil (0-8 cm depth) was medium (12.2 mg.kg^{-1}). It was moderately low and low to very low in deeper soils.

In the 2nd fragmented forest, the concentration in top soil (0-10/17 cm depth) was medium (12.8 mg.kg^{-1}). It was low to very low in deeper soils.

In the 3rd fragmented forest, the concentration in top soil (0-10 cm depth) was moderately high (16.0 $mg.kg^{-1}$). It was low to very low in deeper soils.

In the 4th fragmented forest, the concentration in top soil (0-5 cm depth) was medium (14.7 $mg.kg^{-1}$). It was low to very low in deeper soils.

For the 5th fragmented forest, the concentration in top soil (0-5 cm depth) was moderately high (22.0 $mg.kg^{-1}$). It was medium at 5-20 cm depth, and very low in deeper soils.

The available phosphorus concentrations in the top soils under the 3rd and 5th fragmented forests were moderately high as 16.0 and 22.0 $mg.kg^{-1}$whereas the 1st, 2nd and 4th fragmented forests were medium as 12.2, 12.8 and 14.7 $mg.kg^{-1}$, respectively.

(6) Extractable Potassium

Potassium is required by plants in amounts second only to nitrogen. Unlike nitrogen and phosphorus, potassium is not organically combined in soil organic matter. Acid, weathered soils are those most likely to be deficient in available potassium.

However, concentrations of the extractable potassium in soil profiles of all fragmented montane forests were very high (101.5-745.5 $mg.kg^{-1}$). Potassium in plant litter and weathered rock are the main sources. The extractable potassium in subsoils was influenced by amounts of clay accumulations. This nutrient could be moved easily from surface soil and absorbed by clay minerals. The high concentrations of exchangeable potassium were also implied that the soil profiles had well developed.

(7) Extractable Calcium, Magnesium and Sodium

Calcium is the predominant exchangeable cation in soils, even in the majority of acid soils, followed by magnesium. This occurs because of the large number of minerals in soils that contain calcium and/or magnesium. Actual plant deficiencies of these elements are infrequent because problems associated with soil acidity, such as aluminum toxicity. The cations of calcium, magnesium, potassium, and sodium produce an alkaline reaction in water and are termed bases or basic cations.

However, soils derived from granitic rock under fragmented montane forests in this area contained low concentrations of extractable calcium and magnesium.

In the 1st 2nd and 4th fragmented forests, the concentrations of extractable calcium in top soil (0-8, 0-10/17 and 0-14 cm depth) were low (425.9-894.2 $mg.kg^{-1}$). It was very low in deeper soils. For the 3rd and 5th fragmented forests, the concentrations in top soil (0-10 and 0-5 cm depth) were medium (1,195.2 and 1,572.7 $mg.kg^{-1}$). It was very low in deeper soils.

In the 1st fragmented forest, the concentration of extractable magnesium in top soil (0-8 cm depth) was medium (171.3 $mg.kg^{-1}$). It was low in deeper soils. In the 2nd fragmented forest, the concentrations were low throughout soil profile. In the 3rd fragmented forest, the concentrations in top soil (0-10, 10-21 cm depth) were medium (224.8-357.5 $mg.kg^{-1}$). They were low in deeper soils. In the 4th fragmented forest, the concentrations were low to very low throughout soil profiles. In the 5th fragmented forest, the concentrations in top soil (0-5 cm depth) was medium (293.3 $mg.kg^{-1}$). They were low to very low in deeper soils.

The concentrations of extractable sodium in soil profiles of all fragmented forests were low to very low (19.2-26.0 mg.kg^{-1}).

Most soils under fragmented montane forests in this watershed derived from granitic rock. They were low base soils.

(8) Cation Exchange Capacity (CEC)

Cations such as calcium, magnesium, sodium, and potassium are attracted and held to humus. These cations are rather weakly held to the humus and can be replaced by metallic ions like iron and aluminum, releasing them into the soil for plants to use. Soils with the ability to absorb and retain exchangeable cations have a high cation exchange capacity. Soils with a high cation exchange capacity are more fertile than those with a low cation exchange capacity.

Cation exchange capacity (CEC) in the top soil depth of total fragmented forests had range from 7.7-29.6 cmol.kg^{-1} and had lower in subsoil. The 2nd fragmented forest had the lowest of CEC.

Table 4-6 Some soil chemical properties in fragmented forests

Fragmented forest	Soil depth (cm)	pH		O.M. ($g.kg^{-1}$)	C ($g.kg^{-1}$)	Total N ($g.kg^{-1}$)	Available P ($mg.kg^{-1}$)	Extractable ($mg.kg^{-1}$)			
								K	Ca	Mg	Na
FF 1	0 - 5	6.13	slightly acid	73.5	42.6	4.3	12.2	745.5	894.2	171.3	26.0
	5 - 10	6.05	moderately acid	32.9	19.1	2.8	9.4	866.4	173.1	94.2	23.9
	10 - 20	5.67	moderately acid	18.3	10.6	1.0	6.1	230.9	212.3	45.0	21.7
	20 - 30	5.51	strongly acid	14.0	8.1	0.7	2.6	243.4	219.4	49.2	20.1
	30 - 40	5.73	moderately acid	7.5	4.4	0.5	1.9	275.9	369.0	47.1	20.0
	40 - 60	6.03	moderately acid	6.4	3.7	0.4	1.9	140.9	233.6	53.5	20.5
	60 - 80	6.06	moderately acid	5.9	3.4	0.2	1.7	155.0	319.1	64.2	21.4
	80 - 100	6.07	moderately acid	2.9	1.7	0.3	2.1	126.8	247.9	72.8	21.6
	100 - 120	5.86	moderately acid	4.7	2.7	0.2	2.3	115.6	233.6	62.1	23.0
	120 - 140	6.05	moderately acid	1.7	1.0	0.3	3.1	135.3	183.8	47.1	22.7
	140 - 160	5.97	moderately acid	1.7	1.0	0.2	3.2	152.1	212.3	45.0	21.0
FF 2	0 - 5	5.24	strongly acid	79.8	46.3	2.5	16.0	419.3	639.6	128.5	19.5
	5 - 10	5.36	strongly acid	78.3	45.4	2.4	9.6	349.0	447.3	109.2	19.8
	10 - 20	5.65	moderately acid	20.2	11.7	1.2	4.4	273.1	148.2	81.4	20.2
	20 - 30	5.85	moderately acid	7.7	4.5	0.6	1.9	315.2	126.8	79.2	21.3
	30 - 40	5.52	strongly acid	6.5	3.8	0.5	1.2	247.8	119.7	77.1	21.6
	40 - 60	6.01	moderately acid	4.8	2.8	0.3	1.3	371.5	112.5	72.8	21.8
	60 - 80	6.18	slightly acid	3.9	2.3	0.2	1.2	298.4	119.7	59.9	21.3
	80 - 100	5.57	strongly acid	2.9	1.7	0.2	1.5	216.8	112.5	45.0	21.0
	100 - 120	4.90	very strongly	3.9	2.3	0.3	1.4	295.6	155.3	51.4	20.3
	120 - 140	4.74	very strongly	3.9	2.3	0.3	1.7	180.3	141.0	51.4	19.8
	140 - 160	5.00	very strongly	2.1	1.2	0.2	1.3	222.4	148.2	53.5	19.8
FF 3	0 - 5	5.35	strongly acid	79.9	46.3	3.1	26.7	498.0	1501.4	359.7	20.1
	5 - 10	5.75	moderately acid	41.8	24.2	2.2	5.4	557.1	888.9	355.4	20.1
	10 - 20	5.83	moderately acid	33.7	19.5	1.5	4.5	593.6	354.7	224.8	23.6
	20 - 30	6.03	moderately acid	31.1	18.0	0.8	5.5	545.8	183.8	92.1	21.7
	30 - 40	5.50	strongly acid	21.8	12.6	1.1	2.9	484.0	297.7	85.6	22.7
	40 - 60	5.65	moderately acid	12.4	7.2	1.4	2.1	453.0	226.5	87.8	22.2
	60 - 80	5.88	moderately acid	8.5	4.9	0.8	2.1	484.0	297.7	89.9	21.7
	80 - 100	5.84	moderately acid	7.6	4.4	0.6	1.9	430.6	255.0	68.5	22.3
	100 - 120	5.87	moderately acid	5.1	3.0	0.5	2.1	365.9	290.6	68.5	21.5
	120 - 140	5.89	moderately acid	3.7	2.1	0.9	1.7	157.8	312.0	81.4	21.7
	140 - 160	5.57	strongly acid	2.2	1.3	0.3	1.9	146.5	361.8	89.9	20.0
FF 4	0 - 5	5.25	strongly acid	127.1	73.7	5.9	14.7	298.4	425.9	89.9	25.5
	5 - 10	5.13	strongly acid	69.8	40.5	4.4	5.1	188.7	162.4	38.5	23.6
	10 - 20	5.15	strongly acid	38.9	22.6	4.2	2.7	253.6	41.3	19.3	21.0
	20 - 30	4.86	very strongly	15.7	9.1	1.0	2.1	349.0	41.3	17.1	19.8
	30 - 40	4.82	very strongly	13.3	7.7	1.2	3.8	228.1	69.8	21.4	20.0
	40 - 60	5.54	strongly acid	6.1	3.5	0.9	1.5	284.3	76.9	36.4	20.0
	60 - 80	5.50	strongly acid	4.0	2.3	0.5	1.3	292.7	55.6	36.4	19.9
	80 - 100	5.56	strongly acid	4.2	2.4	0.5	1.6	287.1	76.9	40.7	20.8
	100 - 120	5.59	strongly acid	2.5	1.5	0.5	2.3	264.6	48.4	25.7	20.8
	120 - 140	5.75	moderately acid	1.0	0.6	0.3	2.3	281.5	62.7	25.7	20.9
	140 - 160	5.18	strongly acid	0.8	0.5	0.3	2.3	247.8	41.3	19.3	20.9
FF 5	0 - 5	5.26	strongly acid	129.6	75.2	6.9	22.0	422.1	1572.7	293.3	19.9
	5 - 10	5.54	strongly acid	129.2	74.9	5.6	15.3	273.1	518.5	119.9	20.4
	10 - 20	5.58	strongly acid	76.6	44.4	2.9	7.7	225.3	84.1	21.4	20.7
	20 - 30	5.63	moderately acid	56.0	32.5	1.8	3.5	262.4	112.5	25.7	20.7
	30 - 40	5.66	moderately acid	47.5	27.6	0.7	1.9	295.6	119.7	49.2	20.8
	40 - 60	5.55	strongly acid	19.2	11.1	0.5	1.5	334.9	91.2	17.1	22.9
	60 - 80	5.37	strongly acid	12.6	7.3	0.4	1.4	169.0	84.1	17.1	22.2
	80 - 100	5.67	moderately acid	8.1	4.7	0.5	1.7	225.3	55.6	23.6	19.4
	100 - 120	5.60	moderately acid	6.2	3.6	0.5	1.3	187.5	48.4	24.4	19.7
	120 - 140	5.52	strongly acid	3.4	2.0	0.3	1.8	180.3	62.7	30.0	20.1
	140 - 160	6.11	slightly acid	2.6	1.5	0.3	1.4	101.5	69.8	25.7	19.5

(d) Carbon and Nutrient Accumulations

Accumulations of soil carbon and nutrients within 160 cm depth under five fragmented forests were given in Table 4-7 and Figure 4-3. The total amounts of organic matter, carbon and nitrogen were described. The extractable nutrients were considered for other nutrients.

(1) Amounts of Soil Organic Matter

The amounts of organic matter in soil profiles (0-160 cm depth) under five fragmented forests varied between 164-477 $Mg.ha^{-1}$, respectively. The highest amount was implied to the good forest condition, and the lowest amount should be the deteriorated forest caused by selective tree cutting by local people. The amounts were high in surface soils, and decrease to subsoils.

(2) Amounts of Total Carbon and Nitrogen

The amounts of organic carbon in soil profiles (0-160 cm depth) under these fragmented forests were in range of 95-276 Mg ha^{-1}. They were in the same trend as soil organic matter since this calculation used the mean content of carbon in organic matter as 58%.

The amounts of total nitrogen in soil profiles of five fragmented forests varied between 9,048-19,845 $kg.ha^{-1}$. The amounts were high in surface soils, and decrease to subsoils.

(4) Amounts of Available Phosphorus

The total amounts of available phosphorus in soil profiles (0-160 cm depth) under these fragmented forests were 43-63 $kg.ha^{-1}$. The amounts were varied with soil depths.

(5) Extractable Potassium, Calcium, Magnesium and Sodium

The amounts of extractable potassium, calcium, magnesium and sodium in soil profiles (0-160 cm depth) under these fragmented forests were in ranges of 3,656-8,078; 1,349-6,872, 587-2,121 and 392-461 $kg.ha^{-1}$.

In some fragmented forests, the amounts of potassium were not different along soil profiles whereas some forests had the higher amounts in subsoils. For calcium and magnesium, the amounts in some forests were not different along soil profiles. However, some forests had the higher amounts in subsoils, but surface soils in the others had the higher amounts than subsoils. The amounts of sodium were higher in subsoils of these forests.

Table 4-7 Stored soil carbon and nutrients in fragmented forests

FF	Profile	Soil Depth (cm)	OM ($Mg.ha^{-1}$)	C ($Mg.ha^{-1}$)	Total N ($kg.ha^{-1}$)	Available P ($kg.ha^{-1}$)	Extractable ($kg.ha^{-1}$)			
							K	Ca	Mg	Na
1	A	0-8	57.1	33.1	3,341.1	9.5	579.3	694.8	133.1	20.2
	AB	8-19	27.1	15.7	2,008.6	8.2	580.0	203.7	73.6	23.0
	Bt1	19-31	19.3	11.2	964.1	3.6	335.2	302.1	67.8	27.6
	Bt2	31-47	11.4	6.6	741.3	3.1	343.3	496.3	82.9	32.8
	Bt3	47-73	17.2	10.0	837.4	5.1	412.9	771.4	164.3	59.0
	Bt4	73-102	14.8	8.6	841.3	6.4	474.1	953.9	230.5	72.6
	Bt5	102-132	11.3	6.6	886.5	9.5	444.8	740.0	193.6	86.6
	BC1	132-160	5.8	3.3	847.3	10.6	487.0	671.1	156.0	71.1
	Total		**164**	**95**	**10,468**	**56**	**3,656**	**4,833**	**1,102**	**393**
2	A	0-10/17	95.7	55.5	2,965.1	15.4	464.9	657.7	143.8	24.0
	BA	10/17-33	32.6	18.9	2,104.3	7.3	687.7	321.4	187.7	48.1
	Bt1	33-59	15.8	9.2	1,117.4	3.5	864.9	324.3	209.3	61.4
	Bt2	59-104	17.6	10.2	1,032.5	6.9	1,329.8	599.4	270.8	107.0
	Bt3	104-140	17.1	9.9	1,312.2	6.7	1,040.6	648.0	224.7	100.6
	BC1	140-160	5.4	3.1	516.4	3.5	574.3	382.5	138.2	51.1
	Total		**184**	**107**	**9,048**	**43**	**4,962**	**2,933**	**1,174**	**392**
3	A1	0-10	53.9	31.3	2,348.0	14.2	467.4	1,059.0	316.8	17.8
	A2	10-21	39.3	22.8	1,747.3	5.2	691.5	413.2	261.8	27.5
	AB	21-34	47.5	27.5	1,221.6	8.4	833.5	280.6	140.6	37.2
	Bt1	34-62	60.7	35.2	4,433.5	8.8	1,661.7	929.7	307.5	70.5
	Bt2	62-90	30.2	17.5	2,630.1	7.4	1,718.1	1,038.4	297.6	88.3
	Bt3	90-123	29.7	17.2	2,571.2	9.4	1,861.6	1,275.3	320.3	98.9
	Bt4	123-159	15.9	9.2	3,240.3	9.7	821.6	1,819.4	462.5	117.8
	Bt5	159-160	0.3	0.2	46.9	0.3	22.9	56.5	14.0	3.1
	Total		**278**	**161**	**18,239**	**63**	**8,078**	**6,872**	**2,121**	**461**
4	A1	0-5	44.3	25.7	2,055.9	5.1	104.0	148.4	31.3	8.9
	A2	5-14	41.5	24.1	3,284.7	3.0	168.9	77.8	22.1	16.6
	AB	14-34	52.2	30.3	4,975.0	4.6	576.5	79.0	34.8	38.9
	Bt1	34-64	39.4	22.8	4,263.7	10.8	1,040.3	297.9	117.4	78.0
	Bt2	64-86	11.8	6.8	1,471.2	3.7	861.4	163.5	107.1	58.5
	Bt3	86-102	8.8	5.1	1,044.8	3.4	599.9	160.7	85.0	43.5
	Bt4	102-131	6.9	4.0	1,585.3	9.1	1,082.2	220.2	101.8	82.2
	BC1	131-160	3.5	2.0	1,164.5	8.9	1,027.2	201.8	87.3	81.4
	Total		**208**	**121**	**19,845**	**49**	**5,460**	**1,349**	**587**	**408**
5	A1	0-5	53.9	31.3	2,871.9	9.2	175.7	654.6	122.1	8.3
	A2	5-20	159.3	92.4	6,580.7	17.8	385.8	466.5	109.4	32.5
	AB	20-36	93.4	54.2	2,256.6	4.9	503.7	209.6	67.6	37.0
	Bt1	36-50	55.3	32.1	995.7	2.8	523.2	174.9	55.1	35.0
	Bt2	50-66	31.1	18.0	880.4	2.8	493.0	171.4	33.5	48.3
	Bt3	66-92	35.7	20.7	1,550.2	5.4	679.1	240.5	70.1	67.7
	Bt4	92-115/124	27.8	16.1	1,943.0	5.8	801.9	202.0	93.2	74.7
	BC1	115/124-145	13.6	7.9	1,201.0	7.1	721.6	250.9	120.0	80.6
	BC2	145-160	6.4	3.7	740.4	3.5	250.6	172.3	63.4	48.1
	Total		**477**	**276**	**19,020**	**59**	**4,534**	**2,543**	**734**	**432**

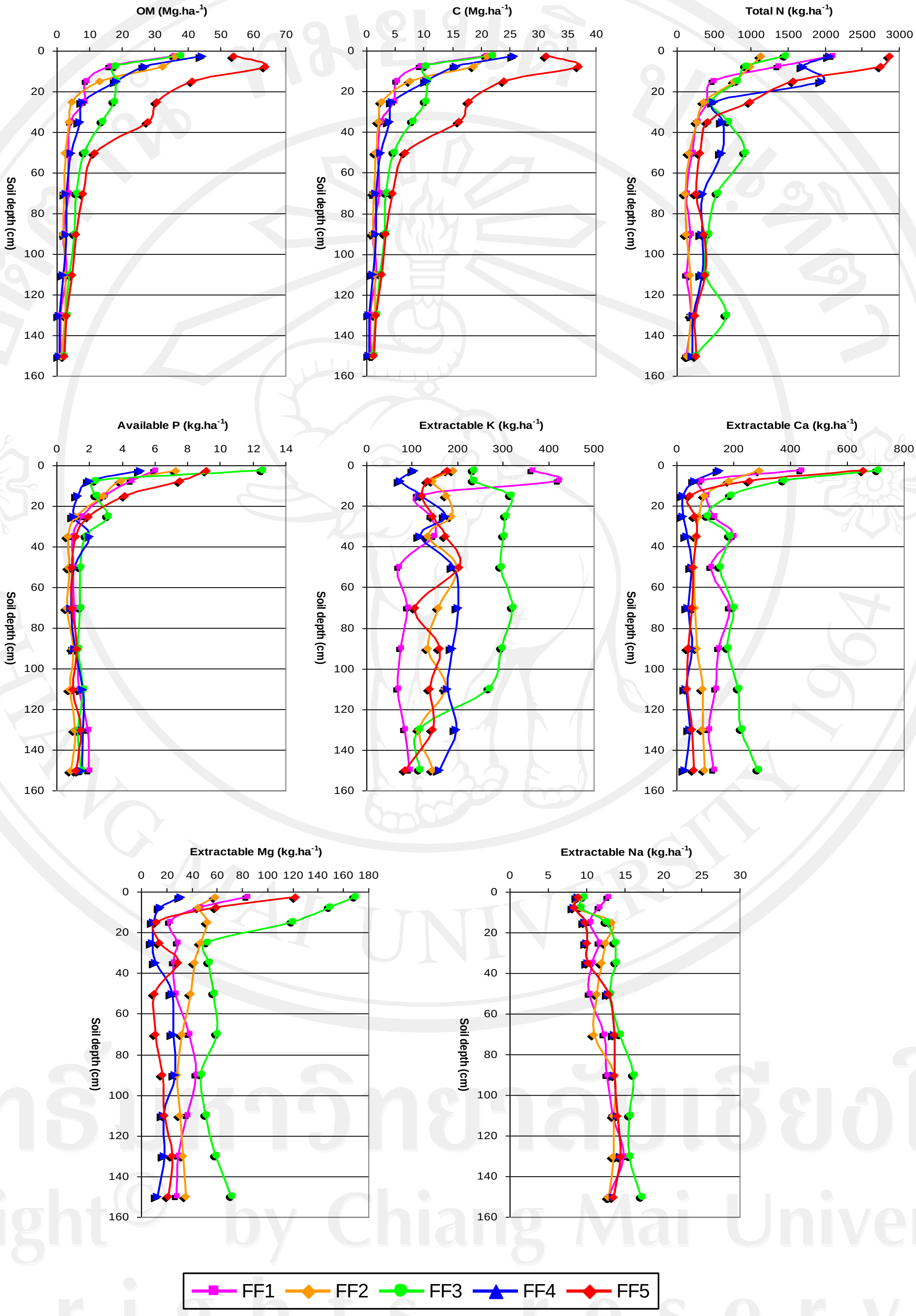

Figure 4-8 Stored nutrients along soil profiles under fragmented forests

4.3.2 Forest Floor Compartment

This nutrient compartment involves organic layers (Ao layers) accumulated on the forest floor in pine plantations and fragmented forests. The organic layers include litter (L), fragmented (F) and humus (H) layers.

A. Pine Plantations

Most litterfall in pine plantations is occurred during dry season. The fresh litter on the forest floor was collected, and analyzed for nutrients. The carbon and nutrient contents in litter of pine needle, leaves of succession broad-leaved species, and tree species in fragmented forests were analyzed as Table 4-8. The carbon content in pine needle was higher than broad-leaved trees, but nitrogen content was adversely lower. The leaves of succession broad-leaved trees had the higher contents of potassium and calcium.

Table 4-8 Carbon and nutrient contents in Ao layers

Nutrient	Leaf (%)		Branch (%)	Others (%)
	P. kesiya	Succession trees		
1 Carbon (C)	41.61	33.27	44.60	35.71
2 Total Nitrogen (N)	0.690	1.040	0.44	0.58
3 Phosphorus (P)	0.006	0.006	0.003	0.004
4 Potassium (K)	0.038	0.149	0.012	0.024
5 Calcium (Ca)	0.050	0.083	0.053	0.059
6 Magnesium (Mg)	0.010	0.013	0.008	0.013

Dry matters of Ao layers in different age pine plantations were shown in Table 4-9. The total dry matters in 17-, 21-, 25-, 29- and 33-year-old stands were 8,379; 6,427; 4,122; 6,678 and 7,017 $kg.ha^{-1}$, respectively (in range of 4,122-8,379 $kg.ha^{-1}$). The succession trees had the different contribution to leaf litter, 6.63-63.37%. However, this study did not separate the litter of branch and other organs between pine and succession tree species.

The carbon and nutrient amounts accumulated in Ao layers of five age-class pine plantations were shown in Table 4-10. The carbon amounts varied between 1,668-3,151 $kg.ha^{-1}$. The amounts were different for each nutrient: nitrogen, 28.95-69.89 $kg.ha^{-1}$; phosphorus, 0.22-0.46 $kg.ha^{-1}$; potassium, 2.12-7.73 $kg.ha^{-1}$; calcium, 2.32-5.70 $kg.ha^{-1}$, and magnesium, 0.42-0.95 $kg.ha^{-1}$.

Table 4-9 Dry matter of Ao layers in different age pine plantations

Age (yrs)	Dry weight of Ao layers ($kg.ha^{-1}$)						
	Leaf				Branch	Others	Total
	P. kesiya		Succession trees				
17	2,553	36.63%	4,417	63.37%	1,306	102	8,379
21	3,273	83.56%	644	16.44%	2,082	428	6,427
25	2,596	79.25%	680	20.75%	668	178	4,122
29	2,554	53.66%	2,252	46.34%	1,562	311	6,678
33	3,520	93.37%	250	6.63%	2,380	868	7,017

Table 4-10 Accumulated carbon and nutrients in Ao layers of pine plantations

Age (yrs)	Nutrients	Ao layers (kg.ha^{-1})				
		Leaf		Branch	Others	Total
		P. kesiya	Succession trees			
17	OC	1,062	1,470	583	36	3,151
	N	17.62	45.94	5.75	0.59	69.89
	P	0.15	0.27	0.04	0.00	0.46
	K	0.97	6.58	0.16	0.02	7.73
	Ca	1.28	3.67	0.69	0.06	5.70
	Mg	0.26	0.57	0.10	0.01	0.95
21	OC	1,362	214	928	153	2,657
	N	22.58	6.69	9.16	2.48	40.92
	P	0.20	0.04	0.06	0.02	0.31
	K	1.24	0.96	0.25	0.10	2.56
	Ca	1.64	0.53	1.10	0.25	3.53
	Mg	0.33	0.08	0.17	0.06	0.63
25	OC	1,080	226	298	63	1,668
	N	17.91	7.07	2.94	1.03	28.95
	P	0.16	0.04	0.02	0.01	0.22
	K	0.99	1.01	0.08	0.04	2.12
	Ca	1.30	0.56	0.35	0.10	2.32
	Mg	0.26	0.09	0.05	0.02	0.42
29	OC	1,063	749	696	111	2,619
	N	17.62	23.42	6.87	1.80	49.71
	P	0.15	0.14	0.05	0.01	0.35
	K	0.97	3.36	0.19	0.07	4.59
	Ca	1.28	1.87	0.83	0.18	4.16
	Mg	0.26	0.29	0.12	0.04	0.71
33	OC	1,464	83	1,061	310	2,919
	N	24.28	2.60	10.47	5.03	42.39
	P	0.21	0.02	0.07	0.03	0.33
	K	1.34	0.37	0.29	0.21	2.20
	Ca	1.76	0.21	1.26	0.51	3.74
	Mg	0.35	0.03	0.19	0.11	0.69

B. Fragmented Forests

Dry matters of forest floor in fragmented forests were shown in Table 4-11. The dry matters in these fragmented forests varied between 5,855-7,644 kg.ha^{-1}. The carbon and nutrient amounts were shown in Table 4-12. Carbon amounts in organic layers varied between 2,151-2,726 kg.ha^{-1}. The amounts of nutrients were different: nitrogen; 42.57-69.39 kg.ha^{-1}, phosphorus; 0.30-0.41 kg.ha^{-1}, potassium; 3.68-9.05 kg.ha^{-1}, calcium; 3.64-5.84 kg.ha^{-1}, and magnesium; 0.64-0.91 kg.ha^{-1}.

Table 4-11 Dry matter of organic layers on forest floor in five fragmented forests

Fragmented forests	Organic layers (kg.ha^{-1})				
	Leaf		Branch	Others	Total
	P. kesiya	Succession trees			
FF 1	303	3,903	1,358	339	5,903
FF 2	2,097	1,708	1,506	640	5,951
FF 3	0	5,928	1,583	132	7,644
FF 4	167	3,779	1,529	381	5,855
FF 5	40	4,928	1,597	309	6,874

Table 4-12 Stored carbon and nutrients in organic layers in fragmented forests

Fragmented forests	Nutrients	Organic layers (kg.ha^{-1})				
		Leaf		Branch	Others	Total
		P. kesiya	Succession trees			
FF 1	OC	126	1,298	606	121	2,151
	N	2.09	40.59	5.98	1.96	50.62
	P	0.02	0.23	0.04	0.01	0.31
	K	0.12	5.81	0.16	0.08	6.17
	Ca	0.15	3.24	0.72	0.20	4.31
	Mg	0.03	0.51	0.11	0.04	0.69
FF 2	OC	873	568	672	228	2,341
	N	14.47	17.76	6.63	3.71	42.57
	P	0.13	0.10	0.05	0.03	0.30
	K	0.80	2.55	0.18	0.15	3.68
	Ca	1.05	1.42	0.80	0.38	3.64
	Mg	0.21	0.22	0.12	0.08	0.64
FF 3	OC	0.00	1,972	706	47	2,726
	N	0.00	61.65	6.97	0.77	69.39
	P	0.00	0.36	0.05	0.01	0.41
	K	0.00	8.83	0.19	0.03	9.05
	Ca	0.00	4.92	0.84	0.08	5.84
	Mg	0.00	0.77	0.13	0.02	0.91
FF 4	OC	70	1,257	682	136	2,145
	N	1.15	39.30	6.73	2.21	49.39
	P	0.01	0.23	0.05	0.02	0.30
	K	0.06	5.63	0.18	0.09	5.97
	Ca	0.08	3.14	0.81	0.22	4.25
	Mg	0.02	0.49	0.12	0.05	0.68
FF 5	OC	17	1,640	712	110	2,479
	N	0.28	51.25	7.03	1.79	60.34
	P	0.00	0.30	0.05	0.01	0.36
	K	0.02	7.34	0.19	0.07	7.62
	Ca	0.02	4.09	0.85	0.18	5.14
	Mg	0.00	0.64	0.13	0.04	0.81

4.3.3 Ecosystem Carbon and Nutrient Storages

A. Pine Plantations

In the five age-class *Pinus kesiya* plantations, the carbon stocks in pine plantation ecosystems including in biomass, forest floor and soil compartments varied between 198-278 $Mg.ha^{-1}$. The majority amount was stored in soils (40.7-77.5%), followed by plants (21.3-57.9%) and litterfall (0.7-1.3%) (Table 4-13). The complex cycling of carbon in forest plantation ecosystems is involved the exchanges among pine trees, succession tree species, forest floor and soils as well as animals and microbes. The amounts of nutrients were different: nitrogen; 11,021-25,300 $kg.ha^{-1}$, phosphorus; 99-175 $kg.ha^{-1}$, potassium; 4,808-6,526 $kg.ha^{-1}$, calcium; 1,580-8,936 $kg.ha^{-1}$, and magnesium; 578-1,322 $kg.ha^{-1}$ (Table 4-14).

Table 4-13 Stored carbon in pine plantation ecosystems

Age (yrs)	Stored carbon ($Mg.ha^{-1}$)						
	Plant	%	Soil	%	Organic layers	%	Total
17	56	21.3	205	77.5	3.15	1.2	264
21	114	57.9	80	40.7	2.66	1.3	198
25	86	33.9	166	65.4	1.67	0.7	254
29	57	24.1	178	74.8	2.62	1.1	238
33	113	40.6	162	58.4	2.92	1.0	278

Figure 4-9 Percentages of carbon stocks in pine plantation ecosystems

Table 4-14 Total stored nutrients in pine plantation ecosystems

Age (yrs)	Nutrients	Nutrient amounts ($kg.ha^{-1}$)			
		Plant	Soil	Organic layers	Total
17	N	551	24,679	69.89	25,300
	P	74	101	0.46	175
	K	377	4,423	7.73	4,808
	Ca	789	2,852	5.70	3,647
	Mg	172	608	0.95	781
21	N	835	10,145	40.92	11,021
	P	108	28	0.31	136
	K	582	5,942	2.56	6,526
	Ca	1,154	423	3.53	1,580
	Mg	225	353	0.63	578
25	N	595	18,935	28.95	19,559
	P	76	31	0.22	107
	K	414	6,021	2.12	6,438
	Ca	814	1,255	2.32	2,071
	Mg	155	462	0.42	617
29	N	408	17,658	49.71	18,116
	P	53	46	0.35	99
	K	285	5,582	4.59	5,872
	Ca	562	4,256	4.16	4,823
	Mg	108	1,064	0.71	1,173
33	N	564	14,856	42.39	15,463
	P	68	85	0.33	153
	K	412	4,828	2.20	5,242
	Ca	734	8,198	3.74	8,936
	Mg	110	1,211	0.69	1,322

B. Fragmented Forests

In five fragmented forests, the carbon stocks in ecosystems including in biomass, forest floor and soil compartments varied between 197-364 $Mg.ha^{-1}$. The majority amount was stored in soils (41.2-72.5%), followed by plants (26.8-57.7%) and litterfall (0.7-1.2%) (Table 4-15). The amounts of nutrients were different: nitrogen; 9,606-19,787 $kg.ha^{-1}$, phosphorus; 197-237 $kg.ha^{-1}$, potassium; 4,375-8,695 $kg.ha^{-1}$, calcium; 3,218-8,626 $kg.ha^{-1}$, and magnesium; 1,018-2,502 $kg.ha^{-1}$ (Table 4-16).

Table 4-15 Ecosystem stored carbon in five fragmented forests

Fragmented forest	Nutrient accumulations ($Mg.ha^{-1}$)						
	Plant	%	Soil	%	Organic layers	%	Total
FF 1	118	57.7	84	41.2	2.15	1.1	205
FF 2	101	51.5	93	47.3	2.34	1.2	197
FF 3	102	39.9	151	59.0	2.73	1.1	255
FF 4	117	51.5	108	47.5	2.14	0.9	227
FF 5	98	26.8	264	72.5	2.48	0.7	364

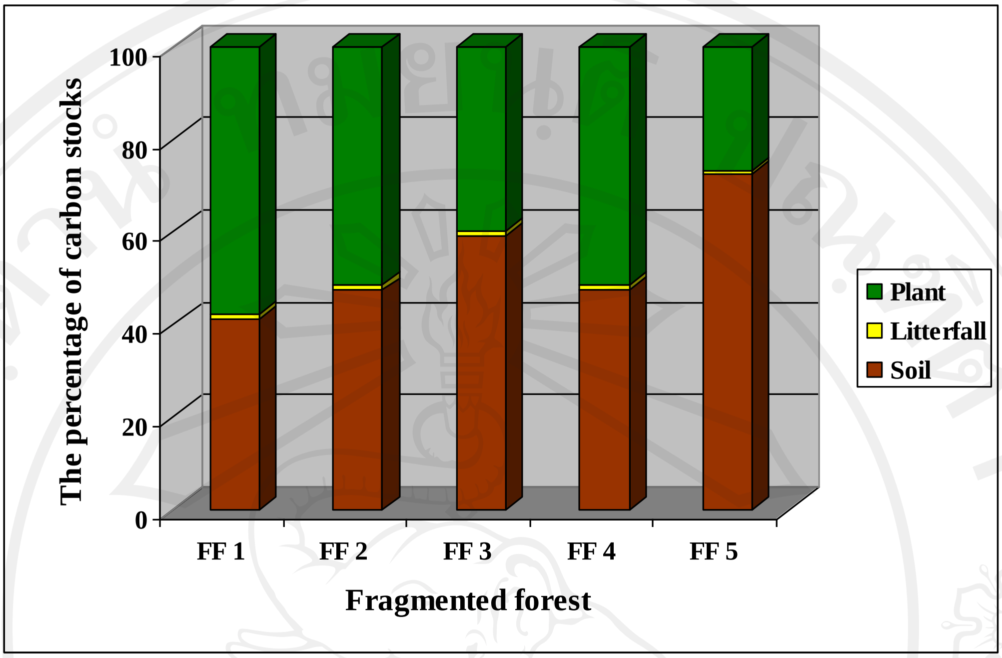

Figure 4-10 Percentages of carbon stocks in ecosystems of fragmented forests

Table 4-16 Ecosystem stored nutrients in five fragmented forests

Fragmented forest	Nutrients	Nutrient amounts (kg ha^{-1})			
		Plant	Soil	Organic layers	Total
FF 1	N	1,312	9,364	50.62	10,727
	P	182	54	0.31	237
	K	896	3,473	6.17	4,375
	Ca	1,907	4,646	4.31	6,557
	Mg	428	1,070	0.69	1,498
FF 2	N	1,122	8,441	42.57	9,606
	P	157	40	0.30	197
	K	767	5,001	3.68	5,772
	Ca	1,632	2,815	3.64	4,451
	Mg	366	1,165	0.64	1,532
FF 3	N	1,135	18,583	69.39	19,787
	P	157	62	0.41	220
	K	774	7,912	9.05	8,695
	Ca	1,649	6,971	5.84	8,626
	Mg	370	2,131	0.91	2,502
FF 4	N	1,293	17,897	49.39	19,239
	P	183	46	0.30	229
	K	886	5,433	5.97	6,325
	Ca	1,883	1,331	4.25	3,218
	Mg	422	596	0.68	1,018
FF 5	N	1,083	18,574	60.34	19,717
	P	151	57	0.36	208
	K	740	4,513	7.62	5,260
	Ca	1,574	2,422	5.14	4,001
	Mg	353	693	0.81	1,047

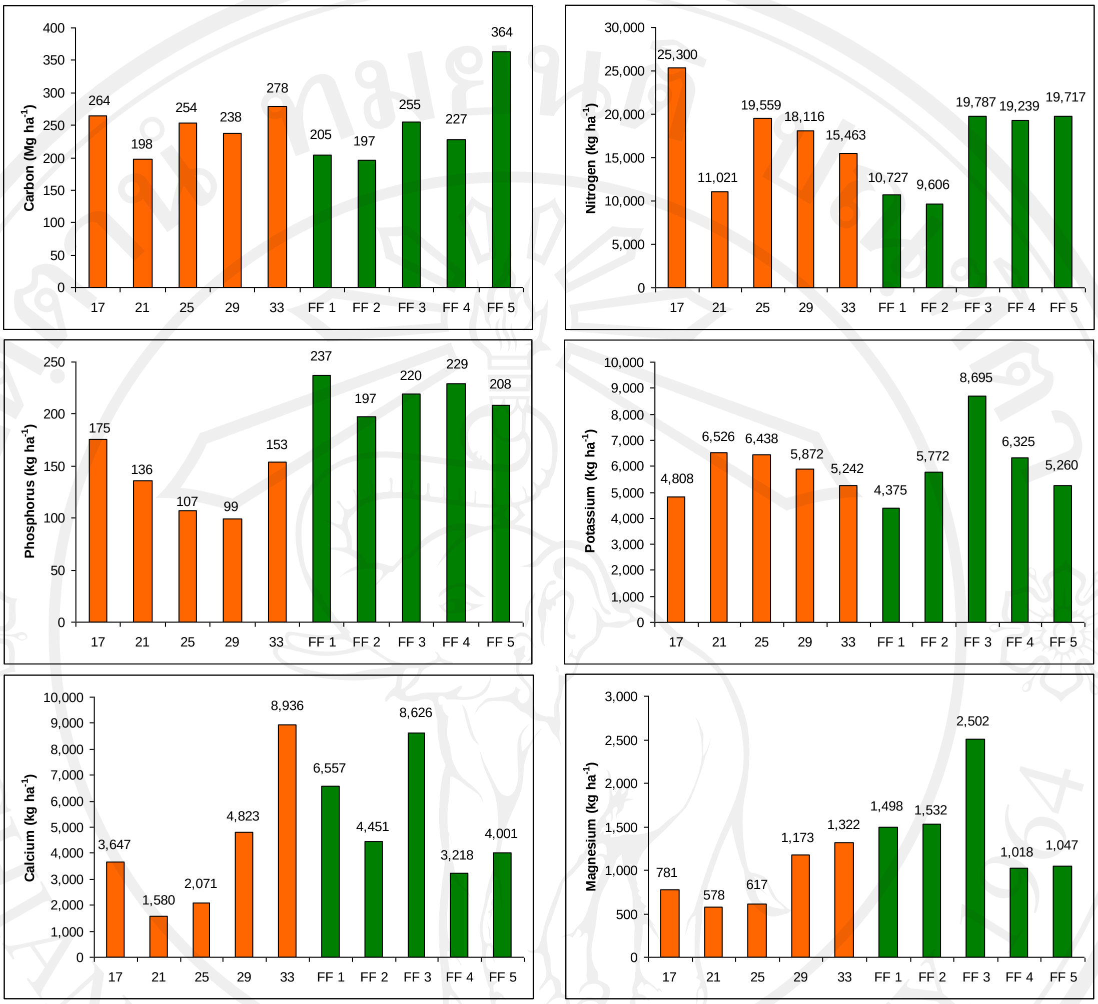

Figure 4-11 Ecosystem carbon and nutrient accumulations in pine plantations and fragmented forests

4.4 Discussion

The ecosystem carbon and nutrient storages in a series of pine plantations involved three compartments; tree biomass, forest floor and soil. The tree biomass included pine trees and succession tree species. The biomass production, and stored carbon and nutrients have been discussed in Chapter 3. In this chapter, discussion on forest floor and soil compartments as well as the ecosystem carbon and nutrient storages is taken.

Most soil carbon is stored as organic matter, with the average value of 58% by weight. Plant litter either above-ground or below-ground is the major source of soil organic matter. In the pine plantations, both pine trees and succession tree species provide litter throughout a year. The annual amounts of litterfall are thought to be increased with stand development. The data about the annual amount of litterfall for pine plantations in Thailand are not available. In natural forest, the amount was high as 11.3 $Mg.ha^{-1}$ (Tsutsumi *et al*, 1983). For this study, the dry matters and carbon amounts in organic layers on forest floor of pine plantations varied in ranges of 4,122-8,379 and 1,668-3,151 $kg.ha^{-1}$, respectively. The amounts in fragmented forest were in ranges of 5,855-7,644 and 2,151-2,726 $kg.ha^{-1}$.

Amounts of accumulated carbon in 160 cm soils under five different age plantations varied between 80.43-276.46 $Mg.ha^{-1}$, whereas those in five fragmented forests varied were 95-276 $Mg.ha^{-1}$. Since these plantations were located in different areas, soil variation might be occurred. Therefore, the carbon amounts in soils were not increased continuously with stand ages.

The total amounts of carbon storages in ecosystems of five age-class pine plantations including tree biomass, forest floor and soil were varied between 198-278 $Mg.ha^{-1}$, and 197-364 $Mg.ha^{-1}$ for five fragmented forests. The highest amount was occurred in 33-year-old pine plantation, and calculated to be 76.37% of the most abundant fragmented forest. This indicated to the highest amount of carbon storage by the pine plantation in this area which is about 25% to be approximately the same to the natural forest.

The carbon stored in soil compartment varied from 40.7 to 77.5% of the total, whereas the values in tree biomass were 21.3-57.9% and 0.7-1.3% for the forest floor. In the fragmented forests, the stored carbon in soils was in range of 41.2-72.5%, 26.8-57.9% for tree biomass and 0.7-1.3% for the forest floor. Therefore, the forest soil is considered as the major stock of ecosystem carbon.

The complex cycling of carbon and nutrients in forest plantation ecosystems is involved the exchanges among pine trees, succession tree species, forest floor and soils as well as animals and microbes. The amounts of other nutrients in ecosystems were different: nitrogen; 11,021-25,300 $kg.ha^{-1}$, phosphorus; 99-175 $kg.ha^{-1}$, potassium; 4,808-6,526 $kg.ha^{-1}$, calcium; 1,580-8,936 $kg.ha^{-1}$, and magnesium; 578-1,322 $kg.ha^{-1}$. In fragmented forests, the amounts of ecosystem nutrients were also different: nitrogen; 9,606-19,787 $kg.ha^{-1}$, phosphorus; 197-237 $kg.ha^{-1}$, potassium; 4,375-8,695 $kg.ha^{-1}$, calcium; 3,218-8,626 $kg.ha^{-1}$, and magnesium; 1,018-2,502 $kg.ha^{-1}$.