CHAPTER 3

Carbon and Nutrient Accumulations in Ecosystems of *Pinus kesiya* Plantations, Adjacent Fragmented Forests and Climax Montane Forest

Abstract

Accumulations of carbon and nutrients in ecosystems of different age pine plantations and adjacent fragmented forests at the Boakaew Watershed Management Station, and climax montane forest at Doi Inthanon national park, Chiang Mai province, were investigated including three compartments; plant biomass, organics layer on forest floor and soil system. The storages in forest biomass were given in chapter 2. This chapter focuses on forest floor and soil compartment. Soil studies were taken in five age-class pine plantations of 17, 21, 25, 29 and 33 years old, five adjacent fragmented forests and three subplot within a 15 ha permanent plot . Soil samples were analyzed for physico-chemical properties and calculated for accumulated amounts of carbon and other nutrients. It was found that soil properties including soil physical and chemical properties had been altered by *Pinus kesiya* plantations. Bulk density was decreased with plantation age. Soil pH varied between moderately acid to very strongly acid. The surface layers contained high organic matter content and had a trend of increase with stand age. This tendency was the same for total nitrogen, available phosphorus, calcium and magnesium. 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. 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}, whereas those of adjacent fragmented forest had low to very low bulk densities in the surface soils. Soil pH in surface soils was strongly acid. The surface layers contained high organic matter as well as amounts of organic matter and carbon in 160 cm were varied between 164-477 and 95-276 Mg.ha^{-1}, respectively. The dry matters and carbon amounts in forest floor 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. In the climax montane forest, the soil reactions in surface soils was very strongly acid to extremely acid. The bulk densities in the top soil were low to very low. The contents of organic matter in the top soils were very high. The average amount of organic matter and carbon in 160 cm depth soils were 215.27 and 124.9 Mg.ha^{-1}, respectively. Also, the high content of total nitrogen was found in surface soils with the average amount of total nitrogen in soil profiles as 17,641.85 kg.ha^{-1}.

3.1 Introduction

Forest ecosystems are consider as the major reserve of terrestrial carbon stock. They about 4.1 billion hectares globally (Dixon and Wisniewski, 1995). There are three principle forest biomes: boreal, temperate and tropical. The global forest cover was decreased at the net rate of about 9.4 million hectares per year mostly due to deforestation of the tropical rainforest. The deforestation and conversion of the tropical rainforest into agricultural ecosystems results in emission of 1.6-1.7 PgC year^{-1} into the atmosphere (IPCC, 2000). Forests are the most important carbon pool on land. Approximately 60%-70% of carbon in forests is stored as organic material in the soil (Janssens *et al.*, 1999; Dixon *et al.*, 1994). Accordingly, the conversion of forests to agricultural land not only reduces C stocks in vegetation but also causes significant losses of soil organic carbon (Post and Kwon, 2000).

In Thailand, forest degradation has been identified as a major contributing factor to carbon stock losses. FAO (2003) estimated that Thailand's annual forest loss was at 112 million hectares per year, during the period 1990–2000 (0.7% annually). Over the period 2000-2004, Thailand lost an average of 60,475 hectares of natural forest per year (National Park, Wildlife and Plant Conservation Department, 2005). The deforestation rate has declined slightly since the period 1990–1995 due to already diminished forest cover as well as increasing public and governmental ecological interest (FAO, 2003). Estimates of Thailand's CO_2 emissions in 1994 were 241 Tg, and the projected level of CO_2 emissions in 2020 were approximately 583 - 777 Tg. Total CO_2 emissions would continue to increase because of a more than two fold increase in energy consumption between the years 2000 and 2020. The average increase of CO_2 emission from the energy and forestry sectors is about 5% annually (OEPP, 2000). Based on current information, reforestation is believed to have the potential to contribute to carbon storage directly through accumulation of carbon in biomass and soil (Richter *et al.*, 1999; Silver *et al.*, 2000).

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 forests. Reforestation using a single tree species can increase the amount of organic matter at the surface soil. The organic layer on forest floor in the plantations may be thinner than that under natural forest. The organic layers on 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 eluviated downward within soil profiles as indicated by taxonomic units, namely Humults (Anusontpornperm *et al.*, 2008). In addition, the adjacent fragmented forests distributed in different areas, and may have different soils which are the important factor on the spatial distribution of various plants. The nature of the soil parent material is usually the most important determinant of soil physical, chemical and biological characteristics, and this is often the main parameter used in the selection of sites for plantation forestry (Nakos, 1979). The soil parent material influences on particle size distribution in the soils, partly having and impact on the bulk density of the top soil, while being more influential in the lower part of the soil profile. Soil chemical properties such as pH and exchangeable acidity, and basic cations were initially reflected by the parent rock types (Anusontpornperm, *et al.*, 2008). Therefore, it is necessary to investigate on soil characteristics in a series of pine plantations, adjacent fragmented forests and climax montane forest will provide the basic information required for decision-making on reforestation, silvicultural selection and for forest management and forest utilization planning.

3.2 Materials and Methods

3.2.1 Soil Sampling

Five age-class plantations were selected for the soil study including 17, 21, 25, 29 and 33 years old. In each age-class, three plots were used for the soil sampling. The soil study was also taken in five sites of adjacent fragmented forests and three sites of climax montane forest. The five adjacent fragmented forests were randomly selected and studied the development of soil profiles. A soil pit was made for each plot/site in pine plantation and adjacent fragmented forest 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. Soil pits of the climax montane forest with the depth to 2.00 meters are 14 depths; 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-120, 120-140, 140-160, 160-180, 180-200 and 200-220 centimeters. The soil samples were later analyzed for soil physical and chemical properties in laboratory. The analysis for physico-chemical properties were conducted along the soil profile.

3.2.2 Soil Analysis

1) Analysis of Soil Physical Properties

(1) Soil texture and analysis for particle size distribution were taken by a hydrometer method. (Gee and Bauder, 1986)
(2) Bulk density is determined by a core method. (Blake and Hartge, 1986)

2) Analysis of Soil Chemical Properties

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) Extractable acidity (EA) extracted by Barium chloride-triethanolamine, pH 8.2 (Peech, 1965)
(6) Cation exchange capacity (CEC) extracted by Ammonium acetate solution 1 N, pH 7.0 (Summer and Miller, 1996)
(7) Base saturation percentage (BS%) can be defined as the amount of basic cations that occupy the cation exchange sites, divided by the total cation exchange capacity (CEC) (Coleman and Thomas, 1964; Soil Survey Staff, 1972)

$$\text{Base saturation percentage} = \frac{\text{Sum bases}}{\text{Sum bases + EA}} \times 100$$

3.2.3 Nutrient Accumulations in Soils

Amounts of nutrients accumulated in soils including organic matter, carbon and nitrogen, available phosphorus, extractable potassium, calcium, magnesium and sodium were calculated from their contents and amounts of soil mass.

3.2.4 Biomass and Nutrients in Organic Layers

This study was carried out in the same plots of soil study. Five age-class and five sites of adjacent fragmented forests, one plot was used, and three sampling plots (replications) of 1 x 1 m were placed in each plot was collect litter on the forest floor.

In the climax forest, three plots were used for the sampling. In each plot, litterfall was determined from ten litter traps via 0.6 m diameter circular traps placed in the forest. The accumulated litter in each trap was collected at monthly interval for one year. Three sampling plots of 1 x 1 m were placed in each plot, collect litter on the forest floor at 4-month interval from May 2010 to April 2011

The litter was collected, separated into leaf, branch and others, and oven-dried at 70 ^{0}C to constant weight in laboratory and then dry matter of litter was measured. The litter samples were analyzed for nutrient contents.

3.3 Results

The soil characteristics including physico-chemical properties and nutrient status of soils in *Pinus kesiya* plantations, adjacent fragmented forests and climax montane forest were described. The changes in soil properties in plantations were compared to the adjacent fragmented forests and climax montane forest using many parameters.

3.3.1 Soil Characteristics

3.3.1.1 *Pinus kesiya* Plantations

1) Soil Physical Properties

Soil structure affects retention and movement of water in the profile, aeration, fertility (cation exchange capacity; CEC), and penetrability for roots. Some soil physical properties including bulk density, amounts of gravel, soil particle distribution and texture were shown in Table 3-1.

(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 in all sites were increased with soil depth.

In 17-year-old plantation, the bulk densities were very low at 0-40 cm depth (0.71-0.75 $Mg.m^{-3}$). It was low at the depth of 40-60 cm (1.07 $Mg.m^{-3}$), and moderately low in deeper soils (1.29-1.39 $Mg.m^{-3}$).

In 21-year-old plantation, the densities were low at 0-40 cm depth (1.07-1.19 $Mg.m^{-3}$), and moderately low in deeper soils (1.21-1.38 $Mg.m^{-3}$).

In 25-year-old plantation, they were low to very low at 0-20 cm depth (0.97-1.05 $Mg.m^{-3}$), moderately low at 20-80 cm depth (1.21-1.34 $Mg.m^{-3}$), and medium in deeper soils.

In 29-year-old plantation, the values were very low at 0-30 cm depth (0.78-0.96 $Mg.m^{-3}$), low at 30-60 cm depth (1.10-1.15 $Mg.m^{-3}$), and moderately low in deeper soils (1.24-1.36 $Mg.m^{-3}$).

In 33-year-old stand, the very low densities were observed at 0-10 cm depth (0.80-0.99 $Mg.m^{-3}$), and low in deeper soils (1.02-1.16 $Mg.m^{-3}$).

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 were 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.

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 with adjacent fragmented 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 had contributed to the trend of soil texture in the soil profile.

Table 3-1 Some physical properties in soil profiles under pine plantations

Age (year)	Soil depth (cm)	Bulk density ($Mg.m^{-3}$)	*	Gravel (%)	Soil particle distribution (%) Sand	Silt	Clay	Soil texture
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	VL	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	L	12.7	54.2	18.2	27.6	Sandy clay loam
	40-60	1.15	L	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 from Kanchanaprasert, 1986)

2) Soil Chemical Properties

Soil reaction (pH), contents of organic matter, total carbon, total nitrogen, and extractable minerals, cation exchange capacity, and base saturation percentage were investigated as soil chemical properties. The data were given in Table 3-2.

(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 5.6-6.0, 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 horizons.

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 horizons.

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 and Soil carbon

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. The carbon contents in soils were similar to soil organic matter since it is assumed that the carbon is 58% in average of organic matter.

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 horizons.

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 horizons.

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 horizons.

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 horizons.

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 horizons.

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. Also 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 organic matter and soil carbon was not clear according site variations.

(3) Total Nitrogen and C/N Ratios

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.

In 17-year-old plantation, the content of total nitrogen in surface soils (0-5, 5-10 cm depth) were high (5.5-8.3 $g.kg^{-1}$). It were medium at 10-20, 20-30 and 30-40 cm depth (3.2-4.6 $g.kg^{-1}$), and low to very low in deeper horizons.

In 21-year-old plantation, the content of total nitrogen in top soils (0-5, 5-10, 10-20 cm depth) were low (2.0-2.8 $g.kg^{-1}$) and very low in deeper horizons.

In 25 and 33-year-old plantation, the content of total nitrogen in surface soils (0-5, 5-10 cm depth) were medium (2.9-4.7 $g.kg^{-1}$). It were low at 10-20, 20-30 and 30-40 cm depth (1.2-1.9 $g.kg^{-1}$), and very low in deeper horizons.

For 29-year-old plantation, the content of total nitrogen in surface soils (0-5 cm depth) were high (6.5 $g.kg^{-1}$). It were medium at 5-10,10-20and 20-30 cm depth (2.3-3.9 $g.kg^{-1}$), and low to very low in deeper horizons.

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, respectively.

(4) 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 surface 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 deeper 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 deeper 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 deeper 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 deeper 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 deeper 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.

(5) Extractable Potassium

Potassium is required by plants in amounts of 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.

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 $mg.kg^{-1}$, respectively.

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.

(6) Extractable Calcium, Magnesium and Sodium

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. 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.

Extractable Calcium :

In 17-year-old plantation, concentration of calcium in surface 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.

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 deeper 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 horizons.

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 horizons.

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 deeper horizons.

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 $mg.kg^{-1}$).

(7) 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 surface 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 surface 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 3-2 Some chemical properties in soil profiles under pine plantations

Age (year)	Soil depth (cm)	pH		O.M.		C		Total N		C/N ratio	Available P		Extractable (mg.kg^{-1})								CEC	
				(g.kg^{-1})	*	(g.kg^{-1})	*	(g.kg^{-1})	*		(mg.kg^{-1})	*	K	*	Ca	*	Mg	*	Na	*	(cmol.kg^{-1})	*
17	0 - 5	5.33	strongly acid	126.7	VH	73.5	VH	8.3	H	8.9	25.6	H	352.6	VH	1570.7	M	223.7	M	18.8	VL	34.6	VH
	5 - 10	5.47	strongly acid	91.7	VH	53.2	VH	5.5	H	9.7	16.3	MH	302.3	VH	899.3	L	106.7	L	15.5	VL	28.7	H
	10 - 20	5.46	strongly acid	64.2	VH	37.2	VH	4.6	M	8.1	9.6	ML	287.2	VH	619.0	L	92.4	L	15.7	VL	25.6	H
	20 - 30	5.42	strongly acid	58.2	VH	33.8	VH	3.2	M	10.5	8.1	ML	262.1	VH	403.2	L	50.3	L	21.2	VL	23.0	H
	30 - 40	5.42	strongly acid	45.4	VH	26.3	VH	3.5	M	7.5	7.8	ML	252.0	VH	241.3	VL	33.6	VL	15.4	VL	19.7	MH
	40 - 60	5.18	strongly acid	27.2	MH	15.8	MH	1.9	L	8.3	7.9	ML	236.9	VH	157.4	VL	36.0	L	25.8	L	17.7	MH
	60 - 80	5.25	strongly acid	14.5	ML	8.4	ML	1.0	L	8.4	7.0	ML	242.0	VH	94.4	VL	35.1	VL	17.2	VL	13.1	M
	80 - 100	5.34	strongly acid	7.0	L	4.1	L	1.0	L	4.1	3.3	L	247.0	VH	43.5	VL	28.5	VL	17.2	VL	8.2	ML
	100 - 120	5.33	strongly acid	5.4	L	3.1	L	0.4	VL	7.8	3.3	L	206.7	VH	40.5	VL	17.8	VL	16.1	VL	10.2	M
	120 - 140	5.26	strongly acid	5.3	L	3.1	L	0.2	VL	15.4	2.8	VL	221.8	VH	31.5	VL	12.4	VL	16.0	VL	9.8	ML
	140 - 160	5.37	strongly acid	1.7	VL	1.0	VL	0.1	VL	9.9	2.0	VL	226.9	VH	40.5	VL	10.7	VL	18.8	VL	7.5	ML
21	0 - 5	4.77	very strongly acid	54.9	VH	31.8	VH	2.8	L	11.4	7.5	ML	392.9	VH	172.4	VL	106.7	L	18.1	VL	19.2	MH
	5 - 10	4.81	very strongly acid	27.8	MH	16.1	MH	2.0	L	8.1	3.5	L	453.2	VH	73.4	VL	62.0	L	19.3	VL	17.4	MH
	10 - 20	4.67	very strongly acid	19.9	M	11.5	M	2.2	L	5.2	2.2	VL	377.8	VH	28.5	VL	28.0	VL	18.0	VL	17.8	MH
	20 - 30	4.89	very strongly acid	15.8	M	9.2	M	0.9	VL	10.2	1.7	VL	372.7	VH	22.5	VL	24.1	VL	16.3	VL	12.7	M
	30 - 40	4.88	very strongly acid	9.3	L	5.4	L	0.4	VL	13.5	1.2	VL	327.5	VH	10.5	VL	17.5	VL	16.2	VL	10.5	M
	40 - 60	5.17	strongly acid	6.1	L	3.5	L	0.3	VL	11.8	1.0	VL	317.4	VH	22.5	VL	18.7	VL	17.8	VL	10.0	M
	60 - 80	5.41	strongly acid	3.8	VL	2.2	VL	0.2	VL	11.0	0.9	VL	297.3	VH	16.5	VL	13.3	VL	20.0	VL	10.7	M
	80 - 100	5.55	strongly acid	2.3	VL	1.3	VL	0.3	VL	4.4	1.1	VL	252.0	VH	12.1	VL	12.1	VL	17.8	VL	7.9	ML
	100 - 120	5.80	moderately acid	2.9	VL	1.7	VL	0.3	VL	5.6	1.2	VL	282.2	VH	16.5	VL	11.6	VL	15.0	VL	10.7	M
	120 - 140	5.87	moderately acid	0.7	VL	0.4	VL	0.2	VL	2.0	1.0	VL	272.1	VH	10.5	VL	9.5	VL	15.2	VL	9.2	ML
	140 - 160	5.89	moderately acid	1.0	VL	0.6	VL	0.1	VL	5.8	1.0	VL	226.9	VH	7.5	VL	5.9	VL	17.0	VL	11.4	M
25	0 - 5	5.18	strongly acid	82.6	VH	47.9	VH	3.9	M	12.3	7.4	ML	352.6	VH	511.1	L	142.5	M	16.9	VL	25.0	H
	5 - 10	5.02	very strongly acid	74.1	VH	43.0	VH	3.3	M	13.0	5.7	L	413.0	VH	259.3	VL	92.4	L	24.3	L	23.5	H
	10 - 20	4.71	very strongly acid	48.0	VH	27.8	VH	1.9	L	14.7	3.4	L	292.3	VH	142.4	VL	30.9	VL	21.9	VL	22.5	H
	20 - 30	4.65	very strongly acid	34.5	MH	20.0	MH	1.6	L	12.5	2.7	VL	257.0	VH	94.4	VL	24.7	VL	26.6	L	17.9	MH
	30 - 40	4.87	very strongly acid	16.4	M	9.5	M	1.2	L	7.9	1.2	VL	287.2	VH	64.5	VL	21.7	VL	17.6	VL	15.5	MH
	40 - 60	4.99	very strongly acid	10.2	ML	5.9	ML	1.2	L	4.9	1.0	VL	231.9	VH	58.5	VL	18.7	VL	16.7	VL	11.1	M
	60 - 80	5.08	very strongly acid	6.5	L	3.8	L	0.9	VL	4.2	0.9	VL	221.8	VH	55.5	VL	16.3	VL	17.4	VL	8.9	ML
	80 - 100	5.25	strongly acid	4.9	VL	2.8	VL	1.0	VL	2.8	1.1	VL	257.0	VH	22.5	VL	15.4	VL	20.4	VL	11.3	M
	100 - 120	5.21	strongly acid	4.2	VL	2.4	VL	0.2	VL	12.2	0.9	VL	362.7	VH	19.5	VL	14.5	VL	17.7	VL	11.6	M
	120 - 140	5.03	very strongly acid	4.0	VL	2.3	VL	0.1	VL	23.2	0.9	VL	267.1	VH	16.5	VL	13.0	VL	18.7	VL	7.9	ML
	140 - 160	5.16	strongly acid	4.0	VL	2.3	VL	0.1	VL	23.2	1.0	VL	307.3	VH	13.5	VL	11.0	VL	18.3	VL	9.1	ML
29	0 - 5	5.50	strongly acid	115.1	VH	66.8	VH	6.5	H	10.3	12.4	M	498.5	VH	1594.7	M	259.5	M	23.2	L	36.6	VH
	5 - 10	5.34	strongly acid	78.2	VH	45.4	VH	3.9	M	11.6	7.9	ML	352.6	VH	448.1	L	94.8	L	23.5	L	26.0	H
	10 - 20	5.25	strongly acid	56.1	VH	32.5	VH	3.3	M	9.9	6.5	ML	342.6	VH	436.2	L	59.9	L	17.7	VL	23.8	H
	20 - 30	4.96	very strongly acid	30.5	MH	17.7	MH	2.3	M	7.7	2.8	VL	252.0	VH	256.3	VL	40.5	L	19.3	VL	18.7	MH
	30 - 40	4.92	very strongly acid	18.4	M	10.7	M	2.0	L	5.3	2.1	VL	327.5	VH	448.1	L	72.7	L	17.4	VL	16.3	MH
	40 - 60	5.13	strongly acid	12.0	ML	7.0	ML	1.4	L	5.0	1.7	VL	307.3	VH	283.3	VL	51.5	L	16.9	VL	13.4	M
	60 - 80	5.22	strongly acid	9.6	L	5.6	L	0.5	VL	11.1	1.6	VL	236.9	VH	202.3	VL	52.4	L	43.4	L	11.5	M
	80 - 100	5.18	strongly acid	8.5	L	4.9	L	0.3	VL	16.4	1.6	VL	252.0	VH	136.4	VL	70.6	L	17.4	VL	12.4	M
	100 - 120	5.13	strongly acid	6.5	L	3.8	L	0.1	VL	37.7	1.9	VL	257.0	VH	82.4	VL	58.7	L	18.5	VL	8.8	ML
	120 - 140	5.15	strongly acid	7.8	L	4.5	L	0.1	VL	45.2	1.8	VL	327.5	VH	166.4	VL	37.8	L	17.6	VL	14.1	M
	140 - 160	5.21	strongly acid	6.0	L	3.5	L	0.1	VL	34.8	1.8	VL	307.3	VH	52.5	VL	24.1	VL	18.5	VL	10.4	M
33	0 - 5	5.25	strongly acid	77.0	VH	44.7	VH	4.7	M	9.5	15.2	MH	372.7	VH	1714.6	M	187.9	M	16.3	VL	27.7	H
	5 - 10	5.37	strongly acid	47.0	VH	27.3	VH	2.9	M	9.4	7.3	ML	337.5	VH	1187.1	M	130.6	M	18.0	VL	21.1	H
	10 - 20	5.39	strongly acid	34.7	MH	20.1	MH	1.6	L	12.6	6.3	ML	322.4	VH	879.8	L	85.2	L	16.7	VL	22.8	H
	20 - 30	5.23	strongly acid	23.6	M	13.7	M	1.4	L	9.8	5.1	L	277.2	VH	589.0	L	57.5	L	25.6	L	23.4	H
	30 - 40	5.23	strongly acid	21.2	M	12.3	M	1.4	L	8.8	5.9	L	317.4	VH	586.0	L	59.3	L	18.4	VL	20.9	H
	40 - 60	5.20	strongly acid	16.8	M	9.7	M	1.3	L	7.5	4.8	L	257.0	VH	457.1	L	60.2	L	17.5	VL	17.3	MH
	60 - 80	5.27	strongly acid	11.3	ML	6.6	ML	0.9	VL	7.3	2.8	VL	201.7	VH	400.2	L	78.1	L	18.4	VL	12.9	M
	80 - 100	5.31	strongly acid	11.7	ML	6.8	ML	0.4	VL	17.0	3.7	L	267.1	VH	388.2	VL	87.6	L	67.2	L	21.2	MH
	100 - 120	5.11	strongly acid	8.8	L	5.1	L	0.3	VL	17.0	4.8	L	302.3	VH	367.2	VL	59.9	L	22.4	VL	12.2	M
	120 - 140	5.08	very strongly acid	7.7	L	4.5	L	0.1	VL	44.7	5.9	L	272.1	VH	304.3	VL	54.8	L	20.3	VL	12.3	M
	140 - 160	5.27	strongly acid	7.8	L	4.5	L	0.1	VL	45.2	3.7	L	292.3	VH	226.3	VL	43.8	L	21.1	VL	12.5	M

Note: * VL = very low, L = low, ML = moderately low, M = medium, MH = moderately high, H = high, VH = very high (Land Classification and FAO Project Staff, 1973; Soil Survey Division Staff, 1993; Land Use Planning Division, 1993

(8) Base Saturation (BS)

The values of extractable bases including potassium, calcium, magnesium and sodium were shown in Table 3-3. The base saturation values imply to percent of the exchange sites are occupied by the basic cations.

In 17, 21, 25, 29 and 33-year-old pine plantations, BS values in soil profiles varied between 9.22-30.91%, 6.52-14.80%, 8.06-18.86%, 12.59-31.50%, and 17.24-40.31%, respectively.

Most BS values were below 35% which implied to the low base soils. The soils under these pine plantations had high clay accumulations in subsoils. Therefore, they were classified into Order Ultisols.

(9) Assessment of Soil Fertility Levels

Soil fertility assessment was carried out using data from chemical analyses comprising organic matter content, available phosphorus and potassium, cation exchange capacity and base saturation percentage (Soil Survey Division, 1980). The total points were used for identify soil fertility levels. The soils under five age-class pine plantations was found that soil in 17-year-old plantation, fertility level in top soil (0-5 cm depth) was high, medium in 5-80 cm depth, and medium to low in deeper horizons. (Table 3-4)

In 21-year-old plantation, the fertility level at 0-80 cm depth was medium, and medium to low in deeper horizons.

In 25-year-old plantation, the fertility level at 0-60 cm depth was medium, and medium to low in deeper horizons.

In 29-year-old plantation, the fertility level at 0-100 cm depth was medium, and medium to low in deeper horizons.

For 33-year-old plantation, fertility level in top soil (0-5 cm depth) was high and medium in deeper horizons.

The fertility levels of surface soils under five age-class pine plantations were medium to high. They were medium to low in subsoils. Generally, high organic matter content and high available potassium of soils contribute to soil fertility (Foth, 1990), particularly in the top 30 cm layer.

Table 3-3 Extractable bases and acidity, cation exchange capacity and base saturation in soil profiles under pine plantations

Age (year)	Soil depth (cm)	K	Ca	Mg	Na	sum of base	Extr. acidity	CEC by sum	B.S. by sum (%)
		(-------------			------cmol.kg^{-1}------			-------------)	
17	0 - 5	0.90	7.85	1.86	0.08	10.70	23.93	34.6	30.91
	5 - 10	0.78	4.50	0.89	0.07	6.23	22.47	28.7	21.70
	10 - 20	0.74	3.10	0.77	0.07	4.67	20.93	25.6	18.24
	20 - 30	0.67	2.02	0.42	0.09	3.20	19.75	23.0	13.94
	30 - 40	0.65	1.21	0.28	0.07	2.20	17.51	19.7	11.16
	40 - 60	0.61	0.79	0.30	0.11	1.81	15.90	17.7	10.20
	60 - 80	0.62	0.47	0.29	0.07	1.46	11.65	13.1	11.14
	80 - 100	0.63	0.22	0.24	0.07	1.16	6.99	8.2	14.27
	100 - 120	0.53	0.20	0.15	0.07	0.95	9.29	10.2	9.28
	120 - 140	0.57	0.16	0.10	0.07	0.90	8.86	9.8	9.22
	140 - 160	0.58	0.20	0.09	0.08	0.95	6.55	7.5	12.73
21	0 - 5	1.01	0.86	0.89	0.08	2.84	16.33	19.2	14.80
	5 - 10	1.16	0.37	0.52	0.08	2.13	15.25	17.4	12.25
	10 - 20	0.97	0.14	0.23	0.08	1.42	16.36	17.8	8.00
	20 - 30	0.96	0.11	0.20	0.07	1.34	11.36	12.7	10.55
	30 - 40	0.84	0.05	0.15	0.07	1.11	9.38	10.5	10.57
	40 - 60	0.81	0.11	0.16	0.08	1.16	8.87	10.0	11.56
	60 - 80	0.76	0.08	0.11	0.09	1.04	9.67	10.7	9.74
	80 - 100	0.65	0.06	0.10	0.08	0.89	7.04	7.9	11.16
	100 - 120	0.72	0.08	0.10	0.07	0.97	9.75	10.7	9.03
	120 - 140	0.70	0.05	0.08	0.07	0.90	8.32	9.2	9.71
	140 - 160	0.58	0.04	0.05	0.07	0.74	10.63	11.4	6.52
25	0 - 5	0.90	2.56	1.19	0.07	4.72	20.31	25.0	18.86
	5 - 10	1.06	1.30	0.77	0.11	3.23	20.22	23.5	13.78
	10 - 20	0.75	0.71	0.26	0.10	1.81	20.69	22.5	8.06
	20 - 30	0.66	0.47	0.21	0.12	1.45	16.44	17.9	8.12
	30 - 40	0.74	0.32	0.18	0.08	1.32	14.21	15.5	8.47
	40 - 60	0.59	0.29	0.16	0.07	1.12	9.95	11.1	10.07
	60 - 80	0.57	0.28	0.14	0.08	1.06	7.86	8.9	11.86
	80 - 100	0.66	0.11	0.13	0.09	0.99	10.34	11.3	8.73
	100 - 120	0.93	0.10	0.12	0.08	1.23	10.37	11.6	10.56
	120 - 140	0.68	0.08	0.11	0.08	0.96	6.97	7.9	12.07
	140 - 160	0.79	0.07	0.09	0.08	1.03	8.03	9.1	11.33
29	0 - 5	1.28	7.97	2.16	0.10	11.52	25.04	36.6	31.50
	5 - 10	0.90	2.24	0.79	0.10	4.04	21.99	26.0	15.51
	10 - 20	0.88	2.18	0.50	0.08	3.64	20.20	23.8	15.25
	20 - 30	0.65	1.28	0.34	0.08	2.35	16.31	18.7	12.59
	30 - 40	0.84	2.24	0.61	0.08	3.76	12.51	16.3	23.12
	40 - 60	0.79	1.42	0.43	0.07	2.71	10.72	13.4	20.16
	60 - 80	0.61	1.01	0.44	0.19	2.24	9.26	11.5	19.52
	80 - 100	0.65	0.68	0.59	0.08	1.99	10.39	12.4	16.09
	100 - 120	0.66	0.41	0.49	0.08	1.64	7.17	8.8	18.63
	120 - 140	0.84	0.83	0.32	0.08	2.06	12.00	14.1	14.67
	140 - 160	0.79	0.26	0.20	0.08	1.33	9.09	10.4	12.78
33	0 - 5	0.96	8.57	1.57	0.07	11.17	16.53	27.7	40.31
	5 - 10	0.87	5.94	1.09	0.08	7.97	13.11	21.1	37.79
	10 - 20	0.83	4.40	0.71	0.07	6.01	16.79	22.8	26.35
	20 - 30	0.71	2.95	0.48	0.11	4.25	19.13	23.4	18.16
	30 - 40	0.81	2.93	0.49	0.08	4.32	16.57	20.9	20.67
	40 - 60	0.66	2.29	0.50	0.08	3.52	13.82	17.3	20.31
	60 - 80	0.52	2.00	0.65	0.08	3.25	9.64	12.9	25.20
	80 - 100	0.68	1.94	0.73	0.29	3.65	17.51	21.2	17.24
	100 - 120	0.78	1.84	0.50	0.10	3.21	9.01	12.2	26.25
	120 - 140	0.70	1.52	0.46	0.09	2.76	9.54	12.3	22.47
	140 - 160	0.75	1.13	0.36	0.09	2.34	10.15	12.5	18.71

Table 3-4 Assessment of fertility levels in soil profiles under pine plantations

Age (year)	Soil depth (cm)	OM ($g.kg^{-1}$)	*	Available P ($mg.kg^{-1}$)	*	Extractable K ($mg.kg^{-1}$)	*	CEC ($cmol.kg^{-1}$)	*	B.S. (%)	*	Total Points**	Ferity assessment
17	0 - 5	126.7	(3)	25.6	(3)	352.6	(3)	34.6	(3)	30.91	(1)	13	high
	5 - 10	91.7	(3)	16.3	(2)	302.3	(3)	28.7	(3)	21.70	(1)	12	medium
	10 - 20	64.2	(3)	9.6	(1)	287.2	(3)	25.6	(3)	18.24	(1)	11	medium
	20 - 30	58.2	(3)	8.1	(1)	262.1	(3)	23.0	(3)	13.94	(1)	11	medium
	30 - 40	45.4	(3)	7.8	(1)	252.0	(3)	19.7	(2)	11.16	(1)	10	medium
	40 - 60	27.2	(2)	7.9	(1)	236.9	(3)	17.7	(2)	10.20	(1)	9	medium
	60 - 80	14.5	(1)	7.0	(1)	242.0	(3)	13.1	(2)	11.14	(1)	8	medium
	80 - 100	7.0	(1)	3.3	(1)	247.0	(3)	8.2	(1)	14.27	(1)	7	low
	100 - 120	5.4	(1)	3.3	(1)	206.7	(3)	10.2	(2)	9.28	(1)	8	medium
	120 - 140	5.3	(1)	2.8	(1)	221.8	(3)	9.8	(1)	9.22	(1)	7	low
	140 - 160	1.7	(1)	2.0	(1)	226.9	(3)	7.5	(1)	12.73	(1)	7	low
21	0 - 5	54.9	(3)	7.5	(1)	392.9	(3)	19.2	(2)	14.80	(1)	10	medium
	5 - 10	27.8	(2)	3.5	(1)	453.2	(3)	17.4	(2)	12.25	(1)	9	medium
	10 - 20	19.9	(2)	2.2	(1)	377.8	(3)	17.8	(2)	8.00	(1)	9	medium
	20 - 30	15.8	(2)	1.7	(1)	372.7	(3)	12.7	(2)	10.55	(1)	9	medium
	30 - 40	9.3	(1)	1.2	(1)	327.5	(3)	10.5	(2)	10.57	(1)	8	medium
	40 - 60	6.1	(1)	1.0	(1)	317.4	(3)	10.0	(2)	11.56	(1)	8	medium
	60 - 80	3.8	(1)	0.9	(1)	297.3	(3)	10.7	(2)	9.74	(1)	8	medium
	80 - 100	2.3	(1)	1.1	(1)	252.0	(3)	7.9	(1)	11.16	(1)	7	low
	100 - 120	2.9	(1)	1.2	(1)	282.2	(3)	10.7	(2)	9.03	(1)	8	medium
	120 - 140	0.7	(1)	1.0	(1)	272.1	(3)	9.2	(1)	9.71	(1)	7	low
	140 - 160	1.0	(1)	1.0	(1)	226.9	(3)	11.4	(2)	6.52	(1)	8	medium
25	0 - 5	82.6	(3)	7.4	(1)	352.6	(3)	25.0	(3)	18.86	(1)	11	medium
	5 - 10	74.1	(3)	5.7	(1)	413.0	(3)	23.5	(3)	13.78	(1)	11	medium
	10 - 20	48.0	(3)	3.4	(1)	292.3	(3)	22.5	(3)	8.06	(1)	11	medium
	20 - 30	34.5	(2)	2.7	(1)	257.0	(3)	17.9	(2)	8.12	(1)	9	medium
	30 - 40	16.4	(2)	1.2	(1)	287.2	(3)	15.5	(2)	8.47	(1)	9	medium
	40 - 60	10.2	(1)	1.0	(1)	231.9	(3)	11.1	(2)	10.07	(1)	8	medium
	60 - 80	6.5	(1)	0.9	(1)	221.8	(3)	8.9	(1)	11.86	(1)	7	low
	80 - 100	4.9	(1)	1.1	(1)	257.0	(3)	11.3	(2)	8.73	(1)	8	medium
	100 - 120	4.2	(1)	0.9	(1)	362.7	(3)	11.6	(2)	10.56	(1)	8	medium
	120 - 140	4.0	(1)	0.9	(1)	267.1	(3)	7.9	(1)	12.07	(1)	7	low
	140 - 160	4.0	(1)	1.0	(1)	307.3	(3)	9.1	(1)	11.33	(1)	7	low
29	0 - 5	115.1	(3)	12.4	(2)	498.5	(3)	36.6	(3)	31.50	(1)	12	medium
	5 - 10	78.2	(3)	7.9	(1)	352.6	(3)	26.0	(3)	15.51	(1)	11	medium
	10 - 20	56.1	(3)	6.5	(1)	342.6	(3)	23.8	(3)	15.25	(1)	11	medium
	20 - 30	30.5	(2)	2.8	(1)	252.0	(3)	18.7	(2)	12.59	(1)	9	medium
	30 - 40	18.4	(2)	2.1	(1)	327.5	(3)	16.3	(2)	23.12	(1)	9	medium
	40 - 60	12.0	(1)	1.7	(1)	307.3	(3)	13.4	(2)	20.16	(1)	8	medium
	60 - 80	9.6	(1)	1.6	(1)	236.9	(3)	11.5	(2)	19.52	(1)	8	medium
	80 - 100	8.5	(1)	1.6	(1)	252.0	(3)	12.4	(2)	16.09	(1)	8	medium
	100 - 120	6.5	(1)	1.9	(1)	257.0	(3)	8.8	(1)	18.63	(1)	7	low
	120 - 140	7.8	(1)	1.8	(1)	327.5	(3)	14.1	(2)	14.67	(1)	8	medium
	140 - 160	6.0	(1)	1.8	(1)	307.3	(3)	10.4	(2)	12.78	(1)	8	medium
33	0 - 5	77.0	(3)	15.2	(2)	372.7	(3)	27.7	(3)	40.31	(2)	13	high
	5 - 10	47.0	(3)	7.3	(1)	337.5	(3)	21.1	(3)	37.79	(2)	12	medium
	10 - 20	34.7	(2)	6.3	(1)	322.4	(3)	22.8	(3)	26.35	(1)	10	medium
	20 - 30	23.6	(2)	5.1	(1)	277.2	(3)	23.4	(3)	18.16	(1)	10	medium
	30 - 40	21.2	(2)	5.9	(1)	317.4	(3)	20.9	(3)	20.67	(1)	10	medium
	40 - 60	16.8	(2)	4.8	(1)	257.0	(3)	17.3	(2)	20.31	(1)	9	medium
	60 - 80	11.3	(1)	2.8	(1)	201.7	(3)	12.9	(2)	25.20	(1)	8	medium
	80 - 100	11.7	(1)	3.7	(1)	267.1	(3)	21.2	(3)	17.24	(1)	9	medium
	100 - 120	8.8	(1)	4.8	(1)	302.3	(3)	12.2	(2)	26.25	(1)	8	medium
	120 - 140	7.7	(1)	5.9	(1)	272.1	(3)	12.3	(2)	22.47	(1)	8	medium
	140 - 160	7.8	(1)	3.7	(1)	292.3	(3)	12.5	(2)	18.71	(1)	8	medium

Note: * 1 = low, 2 = medium, 3 = high
** <7 = low, 7-12 = medium, >12 = high (Soil Survey Division, 1980)

3.3.1.2 Adjacent Fragmented Forests

1) Soil Profile Development

Soil profiles in each study site were described fully in Appendix 3.1. The photographs of all soil profiles were shown in Figure 3-1 to 3-5.

Soils in most adjacent 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 had more than 200 cm in depth with highly weathered granitic rock. 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 had the horizons as A-AB-Bt with 10-15 cm thickness of organic layers on the forest floor. Topography and development of soil profiles under the adjacent fragmented forests were summarized in Table 3-5.

Table 3-5 Topography and soil profile development in five adjacent fragmented forests

No.	Pedon	Topography			Forest type	Profile Development
		Altitude (m)	Slope (%)	Aspect		
1	1	1,414	26	S 20^0 W	Lower montane forest	A-AB-Bt1-Bt2-Bt3-Bt4-Bt5-BC1-BC2-BC3
2	2	1,261	38	E 10^0 W	Lower montane forest	A-BA-Bt1-Bt2-Bt3-BC1-BC2-BC3
3	3	1,427	42	S 25^0 W	Lower montane forest	A1-A2-AB-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6
4	4	1,571	49	S 75^0 W	Lower montane forest	A1-A2-AB-Bt1-Bt2-Bt3-Bt4-BC1-BC2-BC3
5	5	1,546	32	N 20^0 E	Lower montane forest	A1-A2-AB-Bt1-Bt2-Bt3-Bt4-BC1-BC2-BC3

Note: No.1 (3rd FF), No.2 (5th FF), No.3 (11th FF), No.4 (13th FF) and No.5 (14th FF)

Some differences were occurred among soil profiles under five adjacent fragmented forests. Pedon 1 had a well developed soil compared to Pedon 2. However, Pedon 3 to 5 had more developed soil horizons as A horizon was divided into A1-A2-AB. Movement of soil particles from A to B horizon and highly weathered parent rock resulted in a relative enrichment of clay mineral in subsoils (Bt). The number of sub-horizons of Bt implied to more developed profiles according to some differences of color, texture and other morphological features.

The profile of soil under the adjacent fragmented forests (Figure 3-1 to 3-5) at the altitude about 1,200-1,600 m asl were deep, and moderate to well drainage. The surface color of the 1st, 3rd, 4th and 5th pedon were black to very dark gray with hue of 5 YR and 2.5 Y, and the soil colors are different in the subsurface. The surface color of 2nd pedon was dark grayish brown to yellowish red with hue of 10 YR and 5 YR. The subsurface soil color was yellowish red to red with hue of 5 YR and 2.5 YR. Structure was moderate fine and medium granular structure in surface horizon and moderate medium subangular blocky structure in subsoils.

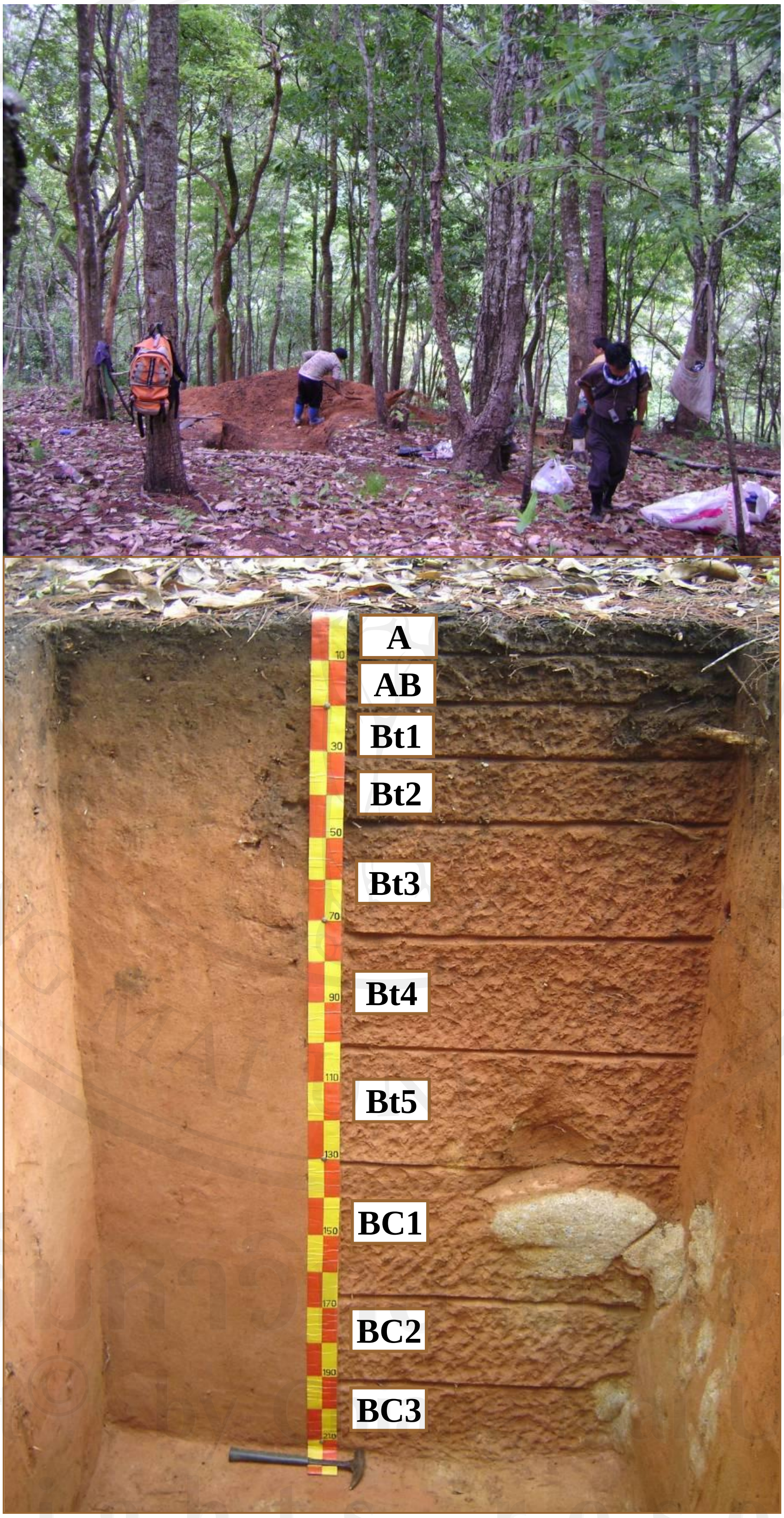

Figure 3-1 Study site and soil profile of pedon 1 in the adjacent fragmented forest

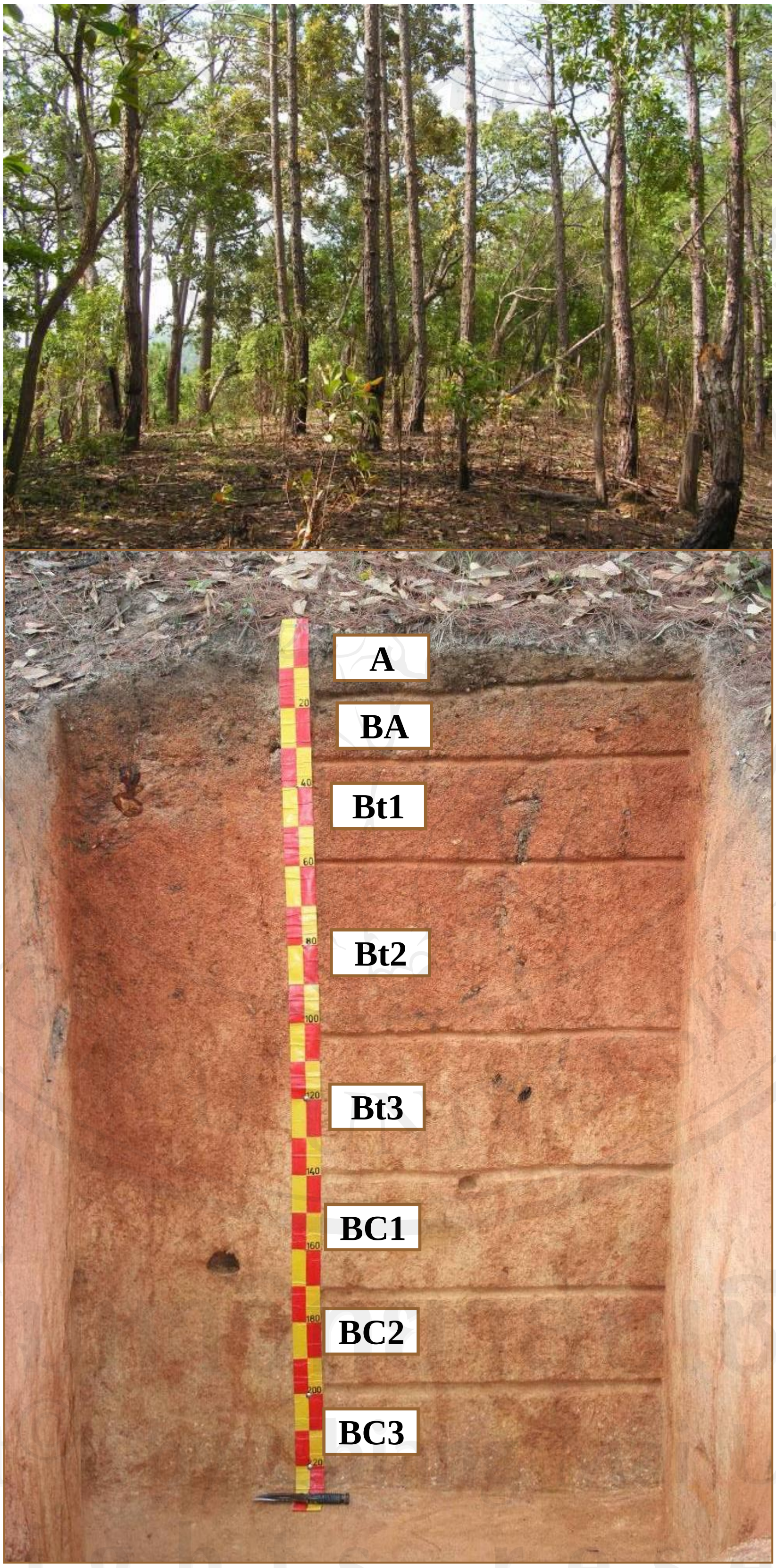

Figure 3-2 Study site and soil profile of pedon 2 in the adjacent fragmented forest

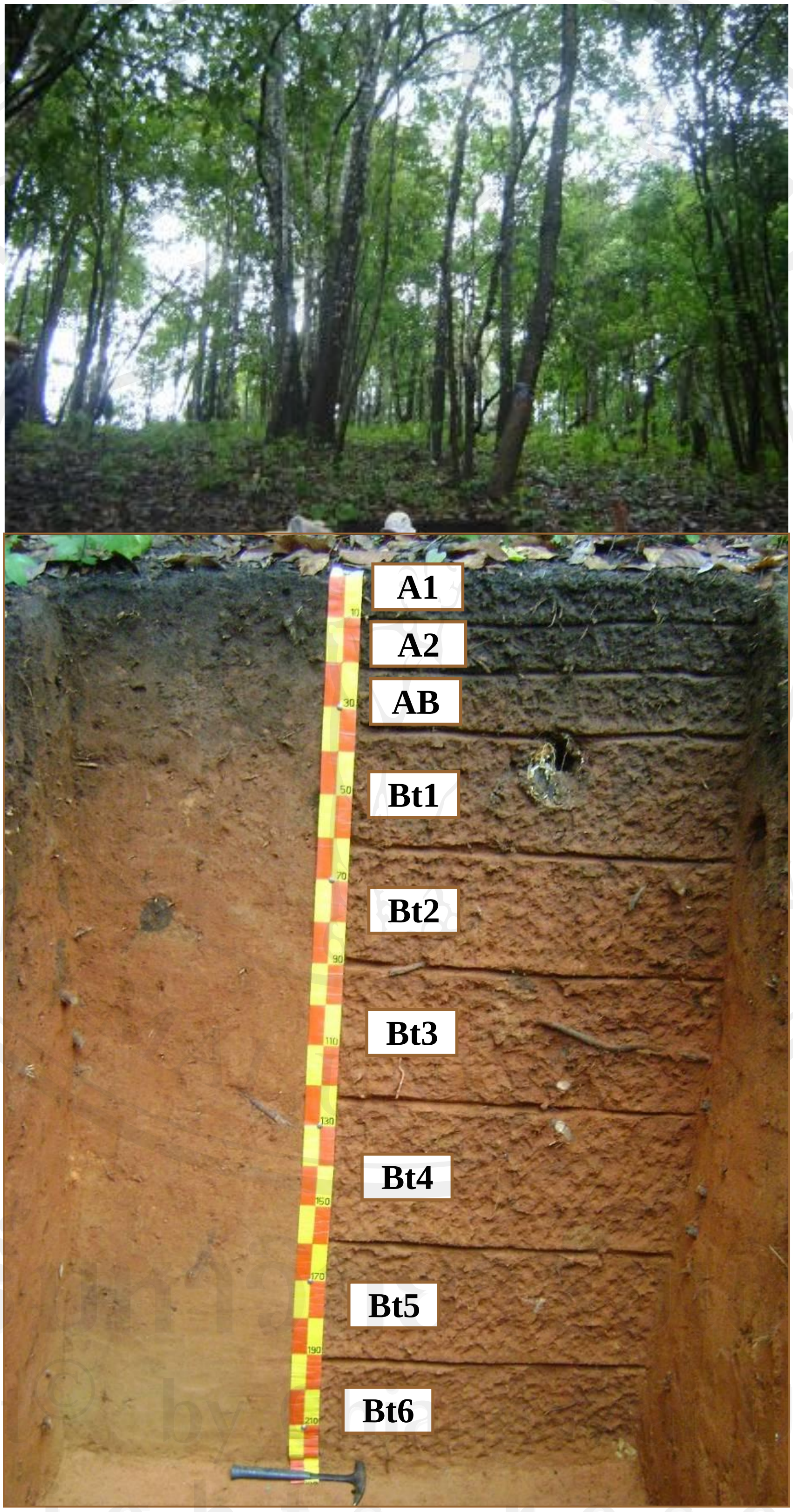

Figure 3-3 Study site and soil profile of pedon 3 in the adjacent fragmented forest

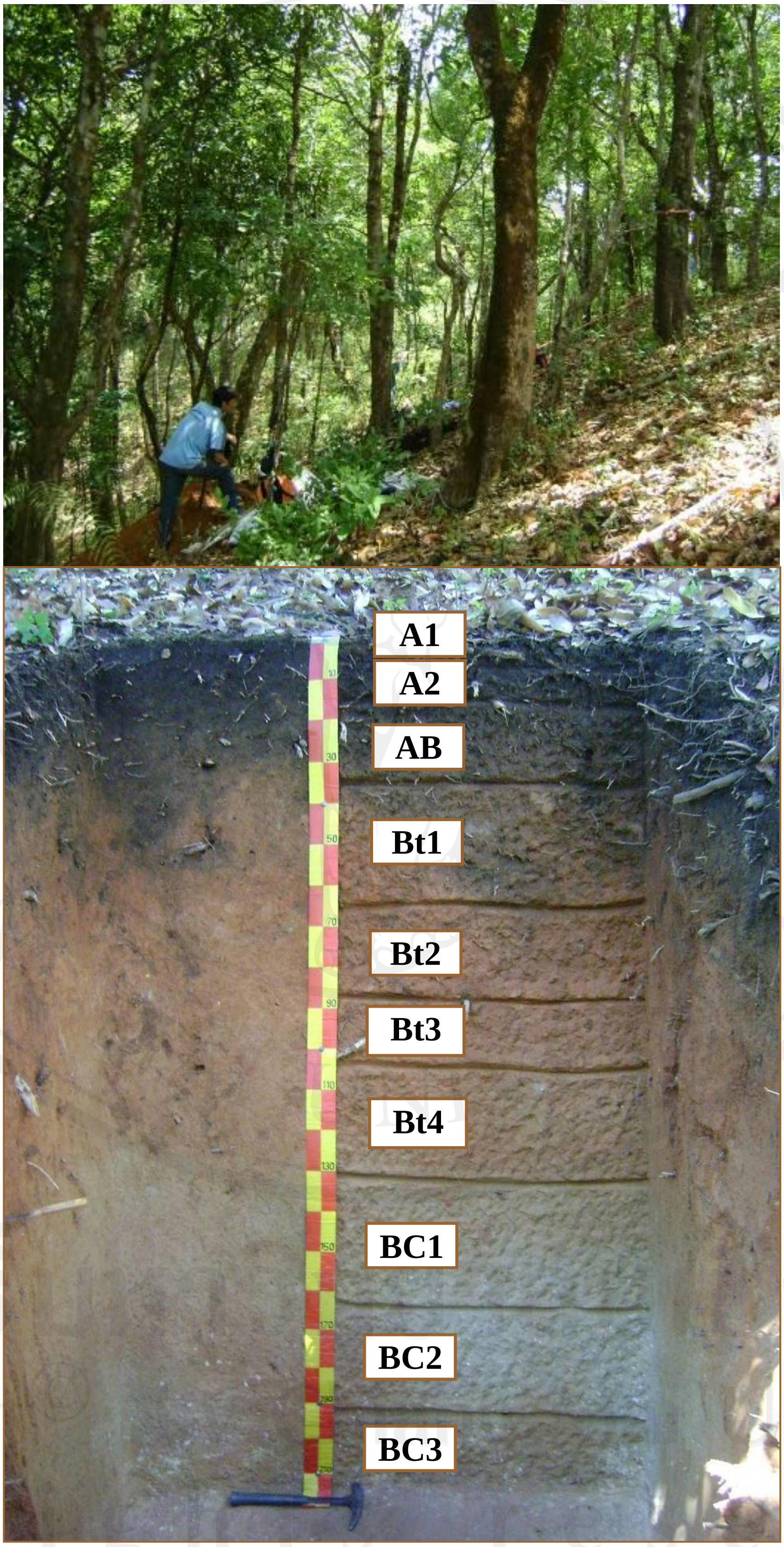

Figure 3-4 Study site and soil profile of pedon 4 in the adjacent fragmented forest

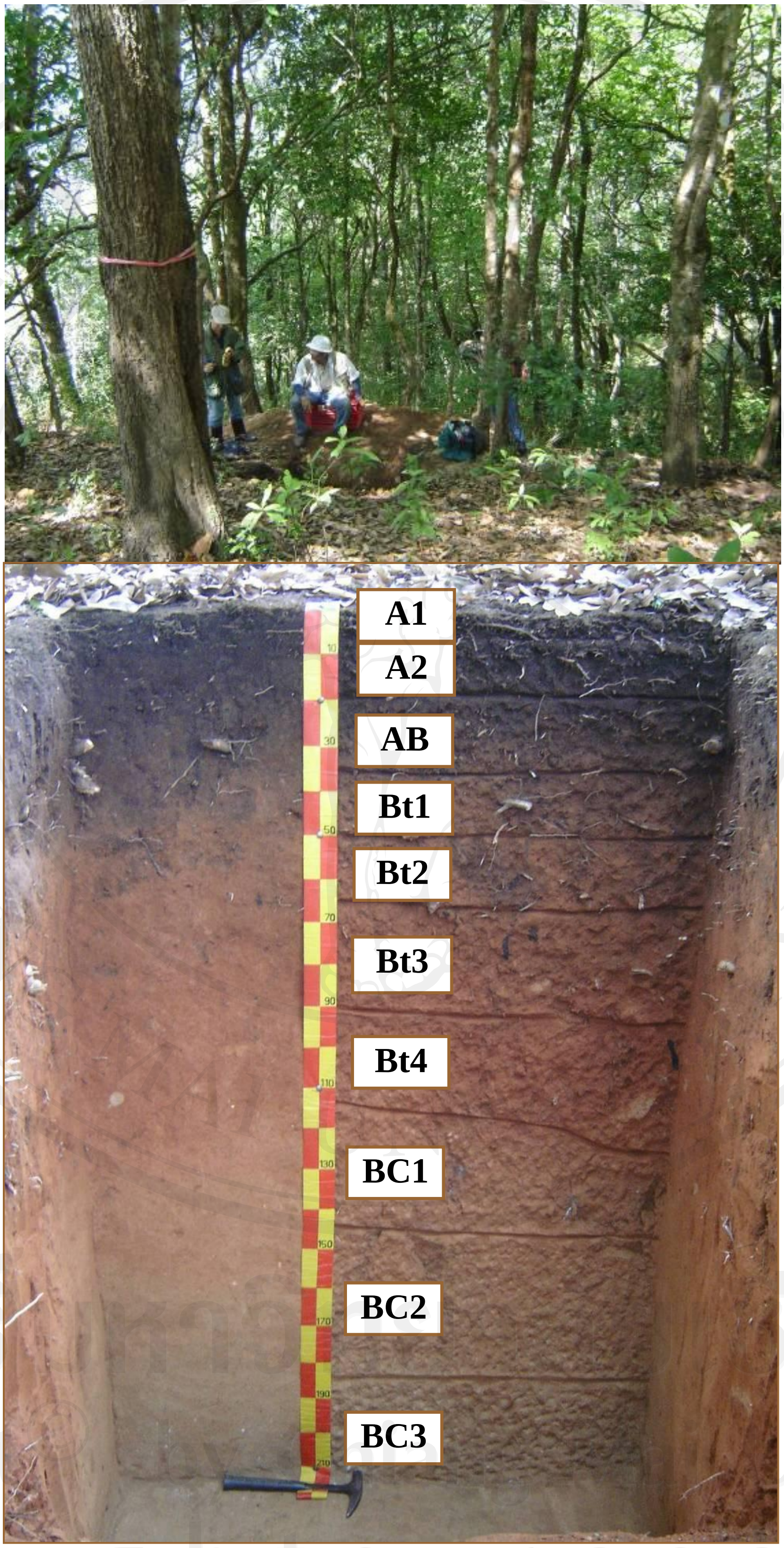

Figure 3-5 Study site and soil profile of pedon 5 in the adjacent fragmented forest

2) Soil Physical Properties

Soil structure affects retention and movement of water in the profile, aeration, fertility (cation exchange capacity; CEC), and penetrability for roots. Some soil physical properties including bulk density, amounts of gravel, soil particle distribution and texture are shown in Table 3-6.

(1) Bulk Density

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

In the 2nd pedon, 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 pedon, 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 pedon, 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 pedon, 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 adjacent fragmented forest 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 montane forests, surface soils had very low densities. Thus, these are good for water infiltration and reducing soil erosion.

(2) Amounts of Gravel

In the 1st, 2nd, 3rd, 4th and 5th pedon, 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 pedon 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 adjacent fragmented forests.

In the 1st, 2nd, 3rd, 4th and 5th pedon, 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.

Silt:

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

In the 1st, 2nd, 3rd, 4th and 5th pedon, 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 adjacent fragmented forests had some differences.

In the 1st, 2nd, 3rd, 4th and 5th pedon, 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 pedon had the high sand particles, whereas the 5th pedon 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 soil texture of adjacent fragmented forests showed different texture. There were range varying from sandy loam to sandy clay loam on the surface soils and sandy clay loam to clay loam in the subsurface soils. Soil along the profile the 2nd pedon shown high clay as compare to other sites.

Table 3-6 Some physical properties in soil profiles under adjacent fragmented forests

Pedon	Profile	Soil depth (cm)	Bulk density ($Mg.m^{-3}$)	*	Gravel (%)	Soil particle distribution (%) Sand	Silt	Clay	Soil texture
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 from Kanchanaprasert, 1986)

2) Soil Chemical Properties

Soil chemical properties including soil reaction (pH), contents of organic matter, total carbon, total nitrogen, and extractable minerals, cation exchange capacity, and base saturation percentage were investigated. The data were given in Table 3-7.

(1) Soil Reaction

In the 1st pedon, 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 horizons (pH = 5.88-6.07).

In the 2nd pedon, 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 horizons (pH = 4.82-5.00).

In the 3rd pedon, 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 horizons (pH = 5.57).

In the 4th pedon, 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 horizons (pH = 5.47).

For the 5th pedon, 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 horizons (pH = 6.11).

Soil reaction in surface soils of almost adjacent fragmented forests was strongly acid. (pH = 5.25-5.55), except for that the 1st pedon 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 and Soil carbon

In the 1st pedon, 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 horizons.

In the 2nd pedon, 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 horizons.

In the 3rd pedon, 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 horizons.

In the 4th pedon, 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 horizons.

For the 5th pedon, 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 horizons.

The contents of organic matter in the top soils under five adjacent fragmented forests were very high as 60.9 to 129.6 g.kg^{-1}. They were decreased with soil depth. The soil under the 2nd pedon contained the lower contents of organic matter compared to the others. Also the carbon contents in the top soils of five adjacent fragmented forests were very high, varying 35.3-75.2 g.kg^{-1}. There were decreased with soil depth.

(3) Total Nitrogen and C/N Ratios

In the 1st , 2nd and 3rd pedon, 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 horizons.

In the 4th pedon, 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 horizons.

In the 5th pedon, 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 horizons.

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

The C/N rations in soil profiles under the 1st, 2nd, 3rd, 4th and 5th pedon 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.

(4) Available Phosphorus

In the 1st pedon, 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 horizons.

In the 2nd pedon, 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 horizons.

In the 3rd pedon, 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 horizons.

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

For the 5th pedon, 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 horizons.

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

(5) Extractable Potassium

The concentrations of the extractable potassium in soil profiles of all adjacent fragmented forest were very high throughout soil profiles In the 1st, 2nd, 3rd, 4th and 5th pedon, the concentrations in soil profiles varied between 144.74-210.53, 142.05-437.43 and 138.02-454.89 mg.kg^{-1}, respectively.

(6) Extractable Calcium, Magnesium and Sodium

Extractable Calcium :

Soils derived from granitic rock under adjacent fragmented forests in this area contained low concentrations of extractable calcium and magnesium.

In the 1st, 2nd and 4th pedon, 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 horizons. For the 3rd and 5th pedon, 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 horizons.

Extractable Magnesium :

In the 1st pedon, the concentration of extractable magnesium in surface soil (0-8 cm depth) was medium (171.3 mg.kg^{-1}). It was low in deeper horizons. In the 2nd pedon, the concentrations were low throughout soil profile. In the 3rd pedon, 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 horizons. In the 4th pedon, the concentrations were low to very low throughout soil profiles. In the 5th pedon, the concentration in surface soil (0-5 cm depth) was medium (293.3 mg.kg^{-1}). They were low to very low in deeper horizons.

Extractable Sodium :

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

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

(7) Cation Exchange Capacity (CEC)

The 1st pedon, CEC in surface soil (0-8 cm depth) was high (26.00 mg.kg^{-1}), moderately high at 8-19 cm depth (16.7mg.kg^{-1}), and moderately low in deeper horizons.

The 2nd pedon, CEC in all soil profile were moderately low (5.7-7.7 mg.kg^{-1}).

The 3rd pedon, CEC in surface soil (0-10 cm depth) was moderately high (16.1 mg.kg^{-1}), medium at 10-21 cm depth (11.7 mg.kg^{-1}), and moderately low to low in deeper horizons.

The 4th pedon, CEC in surface soil (0-5 cm depth) was high (29.6 mg.kg^{-1}), moderately high at 5-14 cm depth (18.6 mg.kg^{-1}), medium at 14-34 cm depth (13.1 mg.kg^{-1}), and moderately low to low in deeper horizons.

The 5th pedon, CEC in surface soil (0-5 cm depth) was medium (13.6 $mg.kg^{-1}$), very low at 20-36 cm depth (2.00 $mg.kg^{-1}$), and moderately low in deeper horizons.

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

(8) Base Saturation (BS)

The percent of base saturation in the surface soil (0-10 cm depth) of five adjacent fragmented forests varied between 7.58-84.45%. %. The 2nd pedon had the lowest of CEC (Table 3-8).

In the 1st, 2nd, 3rd, 4th and 5th pedon, BS values in soil profiles varied between 18.28-32.79%, 25.21-61.70%, 33-34-96.24%, 7.58-31.20%, and 16.35-84.45%, respectively.

(9) Assessment of Soil Fertility Levels

In the 1st pedon, the fertility levels of soils at 0-8 and 8-19 cm depth were medium. It was low in deeper horizons.

In the 2nd pedon, the fertility level of soil at 0-10/17 cm depth was medium. It was low at 10/17 cm depth, medium at 13-59 cm depth, low at 59-140 cm depth and medium in deeper horizons.

In the 3rd pedon, the soil fertility levels were medium throughout soil profile.

In the 4th pedon, the fertility level of soil at 0-34 cm depth was medium. It was low in deeper horizons.

In the 5th pedon, the fertility level of soil at 0-5 cm depth was high. It was medium at 5-66 cm depth and low in deeper horizons.

The fertility levels of soils under five adjacent fragmented forests were different. In most adjacent fragmented forests, the fertility levels in surface soils were medium. Only top soil (0-5 cm depth) in the 5th pedon had the high level, and the depth of 5-66 cm had the medium level (Table 3-9).

Table 3-7 Some chemical properties in soil profiles under adjacent fragmented forests

Pedon	Profile	Soil depth (cm)	pH		O.M. (g.kg^{-1})	*	C (g.kg^{-1})	*	Total N (g.kg^{-1})	*	C/N ratio	Available P (mg.kg^{-1})	*	Extractable (mg.kg^{-1}) K	*	Ca	*	Mg	*	Na	*	CEC (cmol.kg^{-1})	*
1	A	0-8	6.13	slightly acid	73.5	VH	42.6	VH	4.3	M	9.9	12.2	M	745.5	VH	894.2	L	171.3	M	26.0	L	26.0	H
	AB	8-19	5.86	moderately acid	25.6	MH	14.8	MH	1.9	L	7.8	7.7	ML	548.7	VH	192.7	VL	69.6	L	21.7	VL	16.7	MH
	Bt1	19-31	5.51	strongly acid	14.0	ML	8.1	ML	0.7	VL	11.6	2.6	VL	243.4	VH	219.4	VL	49.2	L	20.1	VL	9.6	ML
	Bt2	31-47	5.88	moderately acid	7.0	L	4.0	L	0.5	VL	9.0	1.9	VL	208.4	VH	301.3	VL	50.3	L	19.9	VL	8.0	ML
	Bt3	47-73	6.05	moderately acid	6.2	L	3.6	L	0.3	VL	11.9	1.8	VL	147.9	VH	276.4	VL	58.9	L	21.2	VL	7.3	ML
	Bt4	73-102	6.07	moderately acid	4.4	VL	2.6	VL	0.3	VL	10.2	1.9	VL	140.9	VH	283.5	VL	68.5	L	21.6	VL	7.5	ML
	Bt5	102-132	5.96	moderately acid	3.2	VL	1.9	VL	0.3	VL	7.4	2.7	VL	125.4	VH	208.7	VL	54.6	L	24.4	L	7.5	ML
	BC1	132+	6.01	moderately acid	1.7	VL	1.0	VL	0.3	VL	3.9	3.1	L	143.7	VH	198.0	VL	46.0	L	21.0	VL	7.3	ML
2	A	0-10/17	5.30	strongly acid	79.1	VH	45.9	VH	2.5	M	18.7	12.8	M	384.1	VH	543.4	L	118.8	L	19.8	VL	7.7	ML
	BA	10/17-33	5.75	moderately acid	14.0	ML	8.1	ML	0.9	VL	9.0	3.1	L	294.2	VH	137.5	VL	80.3	L	20.6	VL	7.4	ML
	Bt1	33-59	5.77	moderately acid	5.7	L	3.3	L	0.4	VL	8.2	1.3	VL	309.6	VH	116.1	VL	74.9	L	22.0	VL	5.7	ML
	Bt2	59-104	5.88	moderately acid	3.4	VL	2.0	VL	0.2	VL	9.9	1.3	VL	257.6	VH	116.1	VL	52.5	L	20.7	VL	7.0	ML
	Bt3	104-140	4.82	very strongly acid	3.9	VL	2.3	VL	0.3	VL	7.5	1.5	VL	237.9	VH	148.2	VL	51.4	L	23.0	L	6.4	ML
	BC1	140+	5.00	very strongly acid	2.1	VL	1.2	VL	0.2	VL	6.1	1.3	VL	222.4	VH	148.2	VL	53.5	L	19.8	VL	4.8	L
3	A1	0-10	5.55	strongly acid	60.9	VH	35.3	VH	2.7	M	13.3	16.0	MH	527.6	VH	1195.2	M	357.5	M	20.1	VL	16.1	MH
	A2	10-21	5.83	moderately acid	33.7	MH	19.5	MH	1.5	L	13.0	4.5	L	593.6	VH	354.7	VL	224.8	M	23.6	L	11.7	M
	AB	21-34	6.03	moderately acid	31.1	MH	18.0	MH	0.8	VL	22.5	5.5	L	545.8	VH	183.8	VL	92.1	L	24.3	L	9.6	ML
	Bt1	34-62	5.58	strongly acid	17.1	M	9.9	M	1.3	L	7.9	2.5	VL	468.5	VH	262.1	VL	86.7	L	19.9	VL	6.6	ML
	Bt2	62-90	5.86	moderately acid	8.1	L	4.7	L	0.7	VL	6.7	2.0	VL	457.3	VH	276.4	VL	79.2	L	23.5	L	5.5	ML
	Bt3	90-123	5.86	moderately acid	6.4	L	3.7	L	0.6	VL	6.7	2.0	VL	398.2	VH	272.8	VL	68.5	L	21.2	VL	4.7	L
	Bt4	123-159	5.73	moderately acid	3.0	VL	1.7	VL	0.6	VL	2.9	1.8	VL	152.1	VH	336.9	VL	85.6	L	21.8	VL	3.0	L
	Bt5	159+	5.57	strongly acid	2.2	VL	1.3	VL	0.3	VL	4.3	1.9	VL	146.5	VH	361.8	VL	89.9	L	20.0	VL	4.5	L
4	A1	0-5	5.25	strongly acid	127.1	VH	73.7	VH	5.9	H	12.5	14.7	M	298.4	VH	425.9	L	89.9	L	25.5	L	29.6	H
	A2	5-14	5.14	strongly acid	54.4	VH	31.5	VH	4.3	M	7.3	3.9	L	221.1	VH	101.9	L	28.9	VL	21.7	VL	18.6	MH
	AB	14-34	5.01	very strongly acid	27.3	MH	15.8	MH	2.6	M	6.1	2.4	VL	301.3	VH	41.3	VL	18.2	VL	20.3	VL	13.1	M
	Bt1	34-64	5.18	strongly acid	9.7	L	5.6	L	1.1	L	5.4	2.7	VL	256.2	VH	73.4	VL	28.9	VL	19.2	VL	8.7	ML
	Bt2	64-86	5.50	strongly acid	4.0	VL	2.3	VL	0.5	VL	4.6	1.3	VL	292.7	VH	55.6	VL	36.4	L	19.9	VL	6.8	ML
	Bt3	86-102	5.56	strongly acid	4.2	VL	2.4	VL	0.5	VL	4.9	1.6	VL	287.1	VH	76.9	VL	40.7	L	20.8	VL	5.0	ML
	Bt4	102-131	5.67	moderately acid	1.8	VL	1.0	VL	0.4	VL	2.5	2.3	VL	273.1	VH	55.6	VL	25.7	VL	20.7	VL	4.2	L
	BC1	131+	5.47	strongly acid	0.9	VL	0.5	VL	0.3	VL	1.7	2.3	VL	264.6	VH	52.0	VL	22.5	VL	21.0	VL	3.9	L
5	A1	0-5	5.26	strongly acid	129.6	VH	75.2	VH	6.9	H	10.9	22.0	MH	422.1	VH	1572.7	M	293.3	M	19.9	VL	13.6	M
	A2	5-20	5.56	strongly acid	102.9	VH	59.7	VH	4.3	M	14.0	11.5	M	249.2	VH	301.3	VL	70.7	L	21.0	VL	8.8	ML
	AB	20-36	5.65	moderately acid	51.8	VH	30.0	VH	1.3	L	24.0	2.7	VL	279.0	VH	116.1	VL	37.5	L	20.5	VL	2.0	VL
	Bt1	36-50	5.61	moderately acid	33.4	MH	19.3	MH	0.6	VL	32.2	1.7	VL	315.2	VH	105.4	VL	33.2	VL	21.1	VL	5.9	ML
	Bt2	50-66	5.46	strongly acid	15.9	M	9.2	M	0.5	VL	20.5	1.5	VL	252.0	VH	87.6	VL	17.1	VL	24.7	L	5.7	ML
	Bt3	66-92	5.52	strongly acid	10.4	ML	6.0	ML	0.5	VL	13.3	1.6	VL	197.1	VH	69.8	VL	20.3	VL	19.6	VL	5.8	ML
	Bt4	92-115/124	5.64	moderately acid	7.2	L	4.1	L	0.5	VL	8.3	1.5	VL	206.4	VH	52.0	VL	24.0	VL	19.2	VL	6.4	ML
	BC1	115/124-145	5.52	strongly acid	3.4	VL	2.0	VL	0.3	VL	6.6	1.8	VL	180.3	VH	62.7	VL	30.0	VL	20.1	VL	6.1	ML
	BC2	145+	6.11	slightly acid	2.6	VL	1.5	VL	0.3	VL	5.0	1.4	VL	101.5	H	69.8	VL	25.7	VL	19.5	VL	5.6	ML

Note: * VL = very low, L = low, ML = moderately low, M = medium, MH = moderately high, H = high, VH = very high
(Land Classification and FAO Project Staff, 1973; Soil Survey Division Staff, 1993; Land Use Planning Division, 1993)

Table 3-8 Extractable bases and acidity, cation exchange capacity and base saturation in soil profiles under adjacent fragmented forests

Pedon	Profile	Soil depth (cm)	K	Ca	Mg	Na	sum of base	Extr. acidity	CEC by sum	B.S. by sum (%)
			(---cmol.kg^{-1}---						)	
1	A	0-8	1.91	4.47	1.43	0.11	7.92	18.09	26.0	30.46
	AB	8-19	1.41	0.96	0.58	0.09	3.04	13.61	16.7	18.28
	Bt1	19-31	0.62	1.10	0.41	0.09	2.22	7.35	9.6	23.18
	Bt2	31-47	0.53	1.51	0.42	0.09	2.55	5.42	8.0	31.97
	Bt3	47-73	0.38	1.38	0.49	0.09	2.34	4.96	7.3	32.08
	Bt4	73-102	0.36	1.42	0.57	0.09	2.44	5.01	7.5	32.79
	Bt5	102-132	0.32	1.04	0.45	0.11	1.93	5.53	7.5	25.85
	BC1	132+	0.37	0.99	0.38	0.09	1.83	5.47	7.3	25.09
2	A	0-10/17	0.98	2.72	0.99	0.09	4.78	2.97	7.7	61.70
	BA	10/17-33	0.75	0.69	0.67	0.09	2.20	5.18	7.4	29.81
	Bt1	33-59	0.79	0.58	0.62	0.10	2.09	3.60	5.7	36.75
	Bt2	59-104	0.66	0.58	0.44	0.09	1.77	5.25	7.0	25.21
	Bt3	104-140	0.61	0.74	0.43	0.10	1.88	4.48	6.4	29.56
	BC1	140+	0.57	0.74	0.45	0.09	1.84	2.98	4.8	38.22
3	A1	0-10	1.35	5.98	2.98	0.09	10.40	5.68	16.1	64.67
	A2	10-21	1.52	1.77	1.87	0.10	5.27	6.42	11.7	45.09
	AB	21-34	1.40	0.92	0.77	0.11	3.19	6.38	9.6	33.34
	Bt1	34-62	1.20	1.31	0.72	0.09	3.32	3.25	6.6	50.50
	Bt2	62-90	1.17	1.38	0.66	0.10	3.32	2.16	5.5	60.52
	Bt3	90-123	1.02	1.36	0.57	0.09	3.05	1.70	4.7	64.18
	Bt4	123-159	0.39	1.68	0.71	0.09	2.88	0.11	3.0	96.24
	Bt5	159+	0.38	1.81	0.75	0.09	3.02	1.44	4.5	67.78
4	A1	0-5	0.77	2.13	0.75	0.11	3.75	25.84	29.6	12.69
	A2	5-14	0.57	0.51	0.24	0.09	1.41	17.22	18.6	7.58
	AB	14-34	0.77	0.21	0.15	0.09	1.22	11.86	13.1	9.32
	Bt1	34-64	0.66	0.37	0.24	0.08	1.35	7.35	8.7	15.50
	Bt2	64-86	0.75	0.28	0.30	0.09	1.42	5.38	6.8	20.87
	Bt3	86-102	0.74	0.38	0.34	0.09	1.55	3.42	5.0	31.20
	Bt4	102-131	0.70	0.28	0.21	0.09	1.28	2.88	4.2	30.79
	BC1	131+	0.68	0.26	0.19	0.09	1.22	2.73	3.9	30.85
5	A1	0-5	1.08	7.86	2.44	0.09	11.48	2.11	13.6	84.45
	A2	5-20	0.64	1.51	0.59	0.09	2.83	5.94	8.8	32.22
	AB	20-36	0.72	0.58	0.31	0.09	1.70	0.35	2.0	82.96
	Bt1	36-50	0.81	0.53	0.28	0.09	1.70	4.21	5.9	28.78
	Bt2	50-66	0.65	0.44	0.14	0.11	1.33	4.36	5.7	23.41
	Bt3	66-92	0.51	0.35	0.17	0.09	1.11	4.74	5.8	18.98
	Bt4	92-115/124	0.53	0.26	0.20	0.08	1.07	5.36	6.4	16.68
	BC1	115/124-145	0.46	0.31	0.25	0.09	1.11	5.02	6.1	18.13
	BC2	145+	0.26	0.35	0.21	0.08	0.91	4.64	5.6	16.35

Table 3-9 Assessment of fertility levels in soil profiles under adjacent fragmented forests

Pedon	Horizon	Soil depth (cm)	OM ($g.kg^{-1}$)	*	Available P ($mg.kg^{-1}$)	*	Extractable K ($mg.kg^{-1}$)	*	CEC ($cmol.kg^{-1}$)	*	B.S. (%)	*	Total Points**	Ferity Levels
1	A	0-8	73.5	(3)	12.2	(2)	745.5	(3)	26.0	(3)	30.46	(1)	12	medium
	AB	8-19	25.6	(2)	7.7	(1)	548.7	(3)	16.7	(2)	18.28	(1)	9	medium
	Bt1	19-31	14.0	(1)	2.6	(1)	243.4	(3)	9.6	(1)	23.18	(1)	7	low
	Bt2	31-47	7.0	(1)	1.9	(1)	208.4	(3)	8.0	(1)	31.97	(1)	7	low
	Bt3	47-73	6.2	(1)	1.8	(1)	147.9	(3)	7.3	(1)	32.08	(1)	7	low
	Bt4	73-102	4.4	(1)	1.9	(1)	140.9	(3)	7.5	(1)	32.79	(1)	7	low
	Bt5	102-132	3.2	(1)	2.7	(1)	125.4	(3)	7.5	(1)	25.85	(1)	7	low
	BC1	132+	1.7	(1)	3.1	(1)	143.7	(3)	7.3	(1)	25.09	(1)	7	low
2	A	0-10/17	79.1	(3)	12.8	(2)	384.1	(3)	7.7	(1)	61.70	(2)	11	medium
	BA	10/17-33	14.0	(1)	3.1	(1)	294.2	(3)	7.4	(1)	29.81	(1)	7	low
	Bt1	33-59	5.7	(1)	1.3	(1)	309.6	(3)	5.7	(1)	36.75	(2)	8	medium
	Bt2	59-104	3.4	(1)	1.3	(1)	257.6	(3)	7.0	(1)	25.21	(1)	7	low
	Bt3	104-140	3.9	(1)	1.5	(1)	237.9	(3)	6.4	(1)	29.56	(1)	7	low
	BC1	140+	2.1	(1)	1.3	(1)	222.4	(3)	4.8	(1)	38.22	(2)	8	medium
3	A1	0-10	60.9	(3)	16.0	(2)	527.6	(3)	16.1	(2)	64.67	(2)	12	medium
	A2	10-21	33.7	(2)	4.5	(1)	593.6	(3)	11.7	(2)	45.09	(2)	10	medium
	AB	21-34	31.1	(2)	5.5	(1)	545.8	(3)	9.6	(1)	33.34	(1)	8	medium
	Bt1	34-62	17.1	(2)	2.5	(1)	468.5	(3)	6.6	(1)	50.50	(2)	9	medium
	Bt2	62-90	8.1	(1)	2.0	(1)	457.3	(3)	5.5	(1)	60.52	(2)	8	medium
	Bt3	90-123	6.4	(1)	2.0	(1)	398.2	(3)	4.7	(1)	64.18	(2)	8	medium
	Bt4	123-159	3.0	(1)	1.8	(1)	152.1	(3)	3.0	(1)	96.24	(3)	9	medium
	Bt5	159+	2.2	(1)	1.9	(1)	146.5	(3)	4.5	(1)	67.78	(2)	8	medium
4	A1	0-5	127.1	(3)	14.7	(2)	298.4	(3)	29.6	(3)	12.69	(1)	12	medium
	A2	5-14	54.4	(3)	3.9	(1)	221.1	(3)	18.6	(2)	7.58	(1)	10	medium
	AB	14-34	27.3	(2)	2.4	(1)	301.3	(3)	13.1	(2)	9.32	(1)	9	medium
	Bt1	34-64	9.7	(1)	2.7	(1)	256.2	(3)	8.7	(1)	15.50	(1)	7	low
	Bt2	64-86	4.0	(1)	1.3	(1)	292.7	(3)	6.8	(1)	20.87	(1)	7	low
	Bt3	86-102	4.2	(1)	1.6	(1)	287.1	(3)	5.0	(1)	31.20	(1)	7	low
	Bt4	102-131	1.8	(1)	2.3	(1)	273.1	(3)	4.2	(1)	30.79	(1)	7	low
	BC1	131+	0.9	(1)	2.3	(1)	264.6	(3)	3.9	(1)	30.85	(1)	7	low
5	A1	0-5	129.6	(3)	22.0	(2)	422.1	(3)	13.6	(2)	84.45	(3)	13	high
	A2	5-20	102.9	(3)	11.5	(2)	249.2	(3)	8.8	(1)	32.22	(1)	10	medium
	AB	20-36	51.8	(3)	2.7	(1)	279.0	(3)	2.0	(1)	82.96	(3)	11	medium
	Bt1	36-50	33.4	(2)	1.7	(1)	315.2	(3)	5.9	(1)	28.78	(1)	8	medium
	Bt2	50-66	15.9	(2)	1.5	(1)	252.0	(3)	5.7	(1)	23.41	(1)	8	medium
	Bt3	66-92	10.4	(1)	1.6	(1)	197.1	(3)	5.8	(1)	18.98	(1)	7	low
	Bt4	92-115/124	7.2	(1)	1.5	(1)	206.4	(3)	6.4	(1)	16.68	(1)	7	low
	BC1	115/124-145	3.4	(1)	1.8	(1)	180.3	(3)	6.1	(1)	18.13	(1)	7	low
	BC2	145+	2.6	(1)	1.4	(1)	101.5	(3)	5.6	(1)	16.35	(1)	7	low

Note: * 1 = low, 2 = medium, 3 = high
** <7 = low, 7-12 = medium, >12 = high (Soil Survey Division, 1980)

3.3.1.3 Climax Montane Forest

1) Soil Profile Development

Soil profiles in each study site were described fully in Appendix 3.2. The photographs of all soil profiles were shown in Figure 3-6 to 3-8.

Soils in most climax montane forests were classified in Order Ultisols, Suborder Humults, Great group Palehumults, Subgroup Typic Palehumults. The soils had more than 200 cm in depth with highly weathered gneissic granitic rock. All pedon were well developed soils. All soil profiles of pedon 6, 7 and 8 had low base saturation (< 35%). It was found that they had a somewhat similar profile model. The soil profiles had the horizons as A-AB-Bt with 10-20 cm thickness of organic layers on the forest floor. Topography and development of soil profiles under climax montane forests were summarized in Table 3-10.

Table 3-10 Topography and soil profile development in climax montane forest

Soil pit No.	Pedon	Topography			Forest type	Profile Development
		Altitude (m)	Slope (%)	Aspect		
1	6	1,720	26	S 30^0 W	Lower montane forest	A1-A2-AB-Bt1-Bt2-Bt3-Bt4-Bt5-CB
2	7	1,674	38	S 10^0 W	Lower montane forest	A1-A2-AB-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6
3	8	1,640	37	S 20^0 W	Lower montane forest	A1-A2-AB-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6

Note: Pedon 6 (upper slope site), Pedon 7 (middle slope site) and Pedon 8 (lower slope site)

The profiles of soils in climax montane forest (Figure 3-6 to 3-8) were deep, in the effective soil depth having moderate to well drainage characteristics. The color of surface horizon of these soils was very dark brown to dark brown with hue of 7.5 YR. The subsurface soil color was yellowish red to dark reddish brown with hue of 5 YR, and the subsoil color was strong brown to red with hue of 7.5 YR and 2.5 YR. The accumulation of organic matters in subsurface horizon was dominantly represented in this soil group causing a characteristic of dark soil color particularly in surface soil. Structure was weak in surface horizon and moderate in subsurface, having granular structure. Consistency was very friable when moist and sticky when wet.

2) Soil Physical Properties

Soil structure affects retention and movement of water in the profile, aeration, fertility (cation exchange capacity; CEC), and penetrability for roots. Some soil physical properties including bulk density, amounts of gravel, soil particle distribution and texture were shown in Table 3-11.

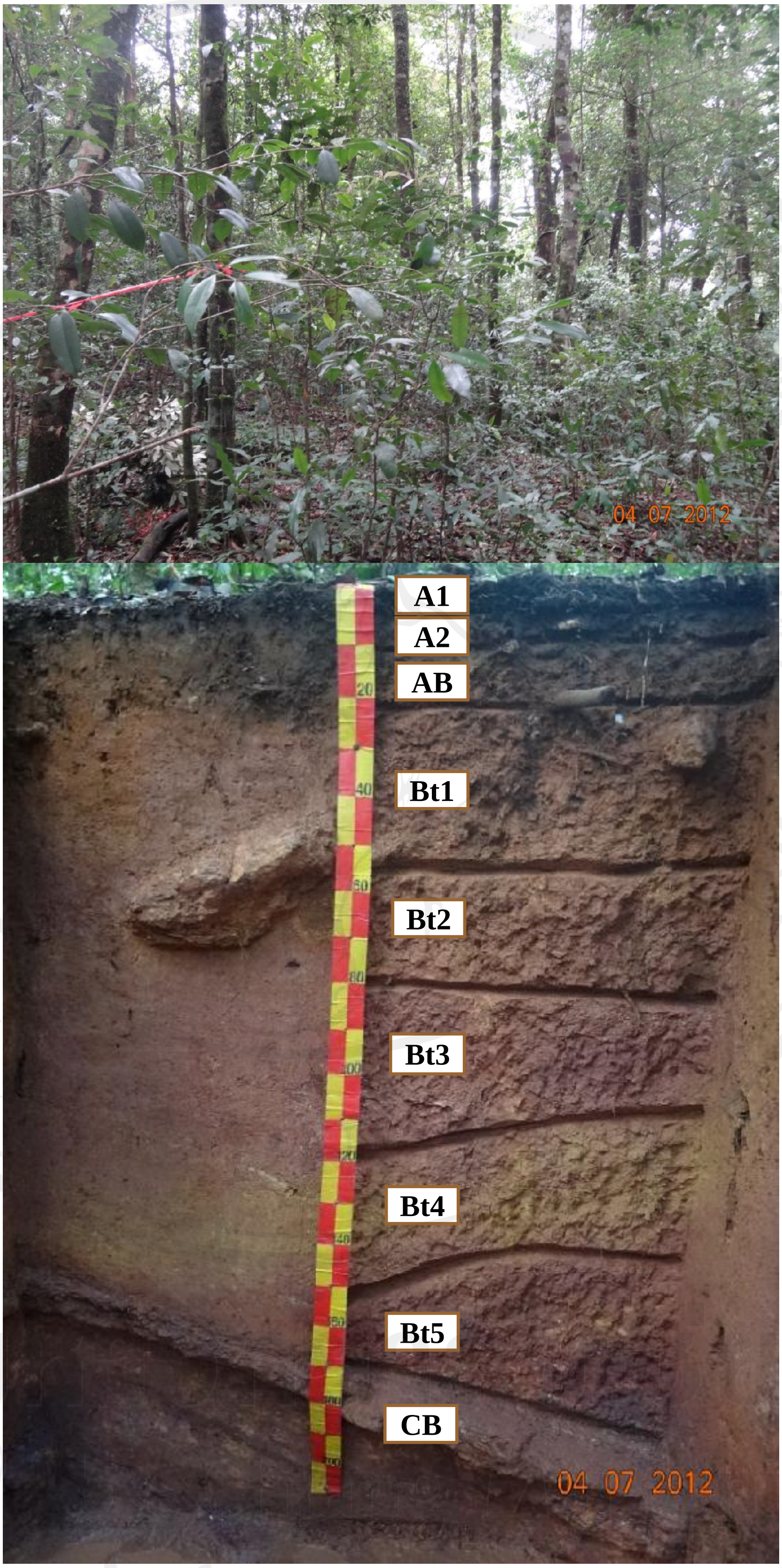

Figure 3-6 Study site and soil profile of pedon 6 at upper slope site in the climax montane forest

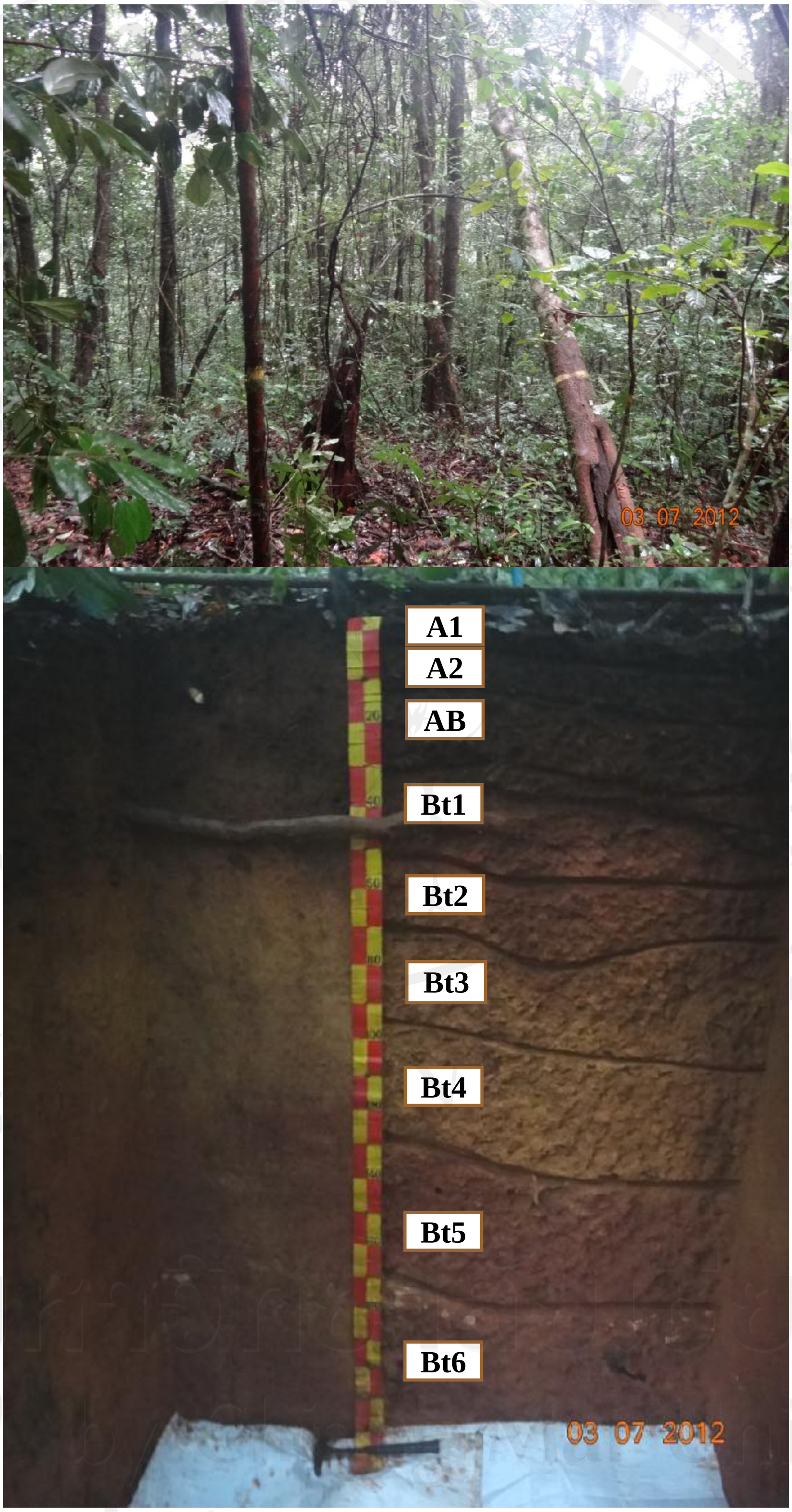

Figure 3-7 Study site and soil profile of pedon 7 at middle slope site in the climax montane forest

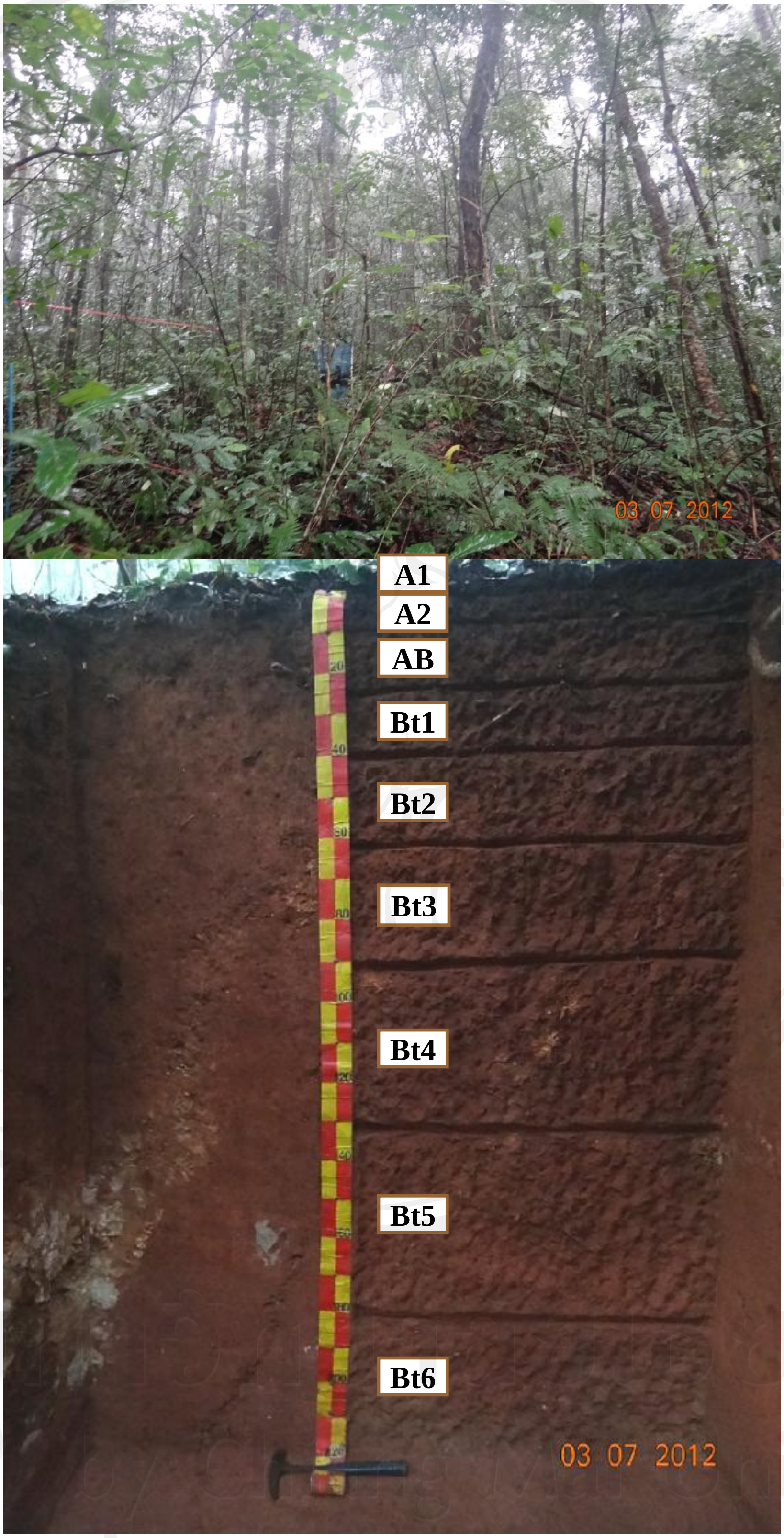

Figure 3-8 Study site and soil profile of pedon 8 at lower slope site in the climax montane forest

(1) Bulk Density

In the upper slope, the bulk densities were very low at 0-5, 5-9/11, and 9/11-25/27 cm depth (0.43-0.90 $mg.m^{-3}$), low at 25/27-58 cm depth (1.14 $mg.m^{-3}$) and moderately low in the deeper horizons (1.22-1.35 $mg.m^{-3}$).

In the middle slope, the density in top soils (0-5/8, 5/8-15/19 and 15/18-30/33 cm depth) were very low (0.61-0.80 $mg.m^{-3}$), low at 30/33-54/58 cm depth (1.09 $mg.m^{-3}$) and moderately low in the deeper horizons (1.22-1.36 $mg.m^{-3}$).

In the lower slope, the density were very low at 0-5, 5-10, 10-25, 25-40 and 40-60 cm depth (0.51-0.91 $mg.m^{-3}$) and low in the deeper horizons (1.11-1.15 $mg.m^{-3}$).

The bulk density in the top soil at 0-40/60 cm depth were low to very low, especially in 0-10 cm depth had varying 0.43-0.65 $mg.m^{-3}$ and increasing in the deeper horizons. Parent material and content of organic matter mainly affects particle density. Soil parent material in Doi Inthanon national park are mainly derived from weathered granite and gneiss rocks.

(2) Amounts of Gravel

The gravel amount of soil in three site, they were increased to subsurface soils and decreased with soil depth. However within three site there was a similar amount of gravel in the soil profile. The highest amount of gravel was found in soils of middle slope in surface soils (0-5/8, 5/8-15/19 cm depth) between 9.37-9.85%. However, the gravel amount of soil in the montane forest was low and varied between 0.07-17.30%, because the soil under montane forest usually contains the high content of organic matter.

(3) Soil Particle Distribution

Sand:
The sand particle percentages in soil profiles of all site varied in the similar ranges. In upper, middle and lower slope, the percentages of sand in soil profiles varied between 51.70-69.60, 50.55-72.15 and 59.40-74.70%, respectively.

Silt:
The silt particle percentages in soil profiles of all site varied in the similar ranges. There were low in surface soils and higher in subsoils. In upper, middle and lower slope, the percentages of silt in soil profiles varied between 16.15-24.95, 15.50-27.80 and 11.20-16.00%, respectively.

Clay:
The clay particle percentages in soil profiles of all site also varied in the similar ranges. There were low in surface soils, higher in subsurface soil and low in deeper soils. This pattern of clay distribution along soil profile is the characteristic of Order Ultisols.

(4) Soil Texture

The soil texture of climax montane forest showed similar texture on all site, varying from sandy loam on surface soils and sandy clay loam to loam in subsoils.

Table 3-11 Some physical properties in soil profiles under climax montane forest

Pedon	Profile	Soil depth	Bulk Density		Gravel	Soil particle distribution (%)			Texture
		(cm)	(Mg m^{-3})	*	(%)	Sand	Silt	Clay	
6	A1	0-5	0.43	VL	0.00	69.60	16.30	14.10	Sandy loam
	A2	5-9/11	0.44	VL	0.07	67.00	15.50	17.50	Sandy loam
	AB	9/11-25/27	0.90	VL	1.54	58.10	19.40	22.50	Sandy clay loam
	Bt1	25/27-58	1.14	L	0.36	52.57	22.67	24.77	Sandy clay loam
	Bt2	58-84/88	1.24	ML	0.03	51.70	17.90	30.40	Sandy clay loam
	Bt3	84/88-114/122	1.31	ML	0.08	51.70	16.60	31.70	Sandy clay loam
	Bt4	114/122-152/159	1.35	ML	0.01	55.60	16.15	28.25	Sandy clay loam
	Bt5	152/159-174/195	1.26	ML	0.00	57.77	18.47	23.77	Sandy clay loam
	CB	195-220+	1.22	ML	0.00	60.75	24.95	14.30	Sandy loam
7	A1	0-5/8	0.61	VL	9.37	72.15	15.50	12.35	Sandy loam
	A2	5/8-15-19	0.73	VL	9.85	67.10	16.35	16.55	Sandy loam
	AB	15/19-30/33	0.80	VL	3.07	60.33	18.10	21.57	Sandy clay loam
	Bt1	30/33-54/58	1.09	L	2.90	55.65	19.40	24.95	Sandy clay loam
	Bt2	54/58-67/76	1.36	ML	1.39	53.10	22.80	24.10	Sandy clay loam
	Bt3	67/76-98/103	1.38	ML	1.34	50.55	25.35	24.10	Sandy clay loam
	Bt4	98/103-130/138	1.33	ML	0.38	53.10	23.65	23.25	Sandy clay loam
	Bt5	130/138-171/179	1.24	ML	0.34	52.67	26.07	21.27	Sandy clay loam
	Bt6	171/179-225+	1.22	ML	0.42	55.20	27.80	17.00	Sandy loam
8	A1	0-5	0.51	VL	2.63	74.70	11.20	14.10	Sandy loam
	A2	5-10	0.65	VL	1.03	72.10	13.80	14.10	Sandy loam
	AB	10-25	0.69	VL	3.25	64.50	16.40	19.10	Sandy loam
	Bt1	25-40	0.72	VL	2.68	64.50	16.00	19.50	Sandy loam
	Bt2	40-60	0.91	VL	2.32	59.40	19.80	20.80	Sandy clay loam
	Bt3	60-90	1.15	L	0.84	63.25	14.85	21.90	Sandy clay loam
	Bt4	90-130	1.14	L	1.06	61.60	14.60	23.80	Sandy clay loam
	Bt5	130-180	1.11	L	0.80	60.10	14.03	25.87	Sandy clay loam
	Bt6	180-220+	1.15	L	0.24	61.95	13.25	24.80	Sandy clay loam

Note: Pedon 6 (upper slope site), Pedon 7 (middle slope site) and Pedon 8 (lower slope site)
* VL = very low, L = low, ML = moderately low, M = medium, MH = moderately high
(Modified from Kanchanaprasert, 1986)

2) Soil Chemical Properties

Soil chemical properties including soil reaction (pH), contents of organic matter, total carbon, total nitrogen, and extractable minerals, cation exchange capacity, and base saturation percentage were investigated. The data were given in Table 3-12.

(1) Soil Reaction

In the upper slope, the soil reaction in surface soils and subsurface soils (0-5, 9/11-25/27, 25/27-58 and 58-84/88 cm depth) were strongly acid (pH = 4.38-5.09) ,except soil depth at 5-9/11 was extremely acid (pH = 4.12) and strongly acid in deeper horizons (pH = 5.16-5.38).

In the middle slope, the soil reaction in surface soil and subsurface soil (0-5/8, 5/8-15/19, 15/19-30/33 and 30/33-54/58 cm depth) were very strongly acid (pH = 4.44-4.87) and strongly acid in deeper horizons (pH = 5.06-5.36).

In the lower slope, the surface soils and subsurface soil (0-5, 5-10 and 10-25 cm depth) were extremely acid with pH of about 3.53, 3.58 and 4.05, respectively. It was very strongly acid at 25-40 cm depth (pH = 4.38), strongly acid at 40-60 cm depth (pH = 5.19), moderately acid at 60-90, 90-130 and 130-180 cm depth (pH = 5.59-5.81) and strongly acid at 180-220 cm depth (pH = 5.58).

It is known that forest soil pH is regulated by several factors such as mineralogy, plant types and decomposition of organic matter (Boruvka *et al.*, 2005)

(2) Soil Organic Matter and Soil carbon

In the upper slope, the content of organic matter in surface and subsurface soils (0-5, 5-9/11, cm depth) were very high (60.40-130.20 $g.kg^{-1}$). It was high at 9/11-25/27 cm depth (36.15 $g.kg^{-1}$), moderately low to low and very low in deeper horizons.

In the middle slope, the content of organic matter in surface soils (0-5/8, 5/8-15/19 cm depth) were very high (73.30-104.05 $g.kg^{-1}$). It was high at 15/19-30/33 cm depth (41.23 $g.kg^{-1}$), medium at 54/58 cm depth (19.35 $g.kg^{-1}$). moderately low to low and very low in deeper horizons.

For the lower slope, the contents in surface soil (0-5, 5-10 and 10-25 cm depth) were very high (49.20-110.50 $g.kg^{-1}$). It was moderately high at 20-45 cm depth (23.40 $g.kg^{-1}$), and moderately low to low and very low in deeper horizons.

The contents of organic matter in the surface soils under climax montane forest were very high as 49.20 to 130.20 g/kg. There were decreased with soil depth. Also the carbon contents in the top soils were very high, varying 28.54-75.52 $g.kg^{-1}$ and decreased with soil depth.

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) Total Nitrogen and C/N Ratios

In the upper slope, the contents of total nitrogen in surface soils (0-5 ,5-9/11 cm depth) were high (5.1-6.4 $g.kg^{-1}$). It were medium at 9/11-25/27, 25/27-58 cm depth (3.1-3.06 $g.kg^{-1}$), and low to very low in deeper horizons.

In the middle slope, the contents of total nitrogen in surface soil (0-5/8 cm depth) were high (6.1 $g.kg^{-1}$). It was medium at 5/8 cm depth (3.9 $g.kg^{-1}$), and low to very low in deeper horizons.

In the lower slope, the contents of total nitrogen in surface soils (0-5 cm depth) were high (5.2 $g.kg^{-1}$). It were medium at 5-10, 10-25 cm depth (2.35-4.00 $g.kg^{-1}$), and low to very low in deeper horizons.

The highest contents of total nitrogen were found in surface soils of the upper slope. The C/N ratios in soils particularly under climax montane forest were in the same range. In upper, middle and lower slope, the C/N ratios were varied between and 8.8-12.6, respectively.

(4) Available Phosphorus

In the upper slope, the concentration of available phosphorus in surface soil (0-5 cm depth) was low (4.33 $mg.kg^{-1}$). It was very low in deeper horizons. Also, in the middle slope at 0-5/8, 5/8-15/19 cm depth were low (3.66-4.33 $mg.kg^{-1}$), very low in deeper horizons. For, the lower slope, the concentration at 0-5 cm depth was medium (13.08 $mg.kg^{-1}$). It was moderately low and low to very low in deeper horizons.

(5) Extractable Potassium

The concentrations of the extractable potassium in soil profiles of climax montane forest were very high throughout soil profiles. In upper slope, middle slope and lower slope, the concentrations in soil profiles varied between 125.4-745.5, 222.4-384.1, 146.5-593.6, 221.1-301.3 and 101.1-422.1 $mg.kg^{-1}$, respectively.

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.

(6) Extractable Calcium, Magnesium and Sodium

Extractable Calcium :

The concentrations of extractable magnesium in soil profiles of climax montane forest were very low throughout soil profiles in upper slope and lower slope, varied between 16.67-147.14 and 9.93-172.39 $mg.kg^{-1}$, respectively. In the middle slope, the concentrations of extractable calcium in top soil (0-5/8 and 5/8-15/19 cm depth) were low (496.70 and 937.61 $mg.kg^{-1}$). It was very low in deeper horizons.

Extractable Magnesium :

The concentrations of extractable magnesium in all soil profiles of climax montane forest were very low throughout soil profiles, varied between 3.18-32.70, 3.15-78.91 and 5.11-10.54 $mg.kg^{-1}$, respectively.

Extractable Sodium :

In the upper slope, the concentration of extractable magnesium in surface soils (0-5, 5-/11 cm depth) were low (24.02-32.91 mg.kg^{-1}). It was very low in deeper soils. In the middle slope, the concentration of extractable magnesium varied low to very low with soil depth (21.31-35.48 mg.kg^{-1}). For the lower slope, the concentration of extractable magnesium at 0-5, 5-10, 10-25, 25-40, 40-60 and 60-90 cm depth were low (25.77-47.93 mg.kg^{-1}) and very low in deeper horizons.

(7) Cation Exchange Capacity (CEC)

In the upper slope, CEC in surface soil (0-5 cm depth) was very high (33.29 mg.kg^{-1}), medium at 5-9/11 and 9/11-25/27 cm depth (12.72-14.39 mg.kg^{-1}, and moderately low in deeper horizons.

In middle slope, CEC in surface soil (0-5/8 cm depth) was high (27.56 mg.kg^{-1}), moderately high at 5/8-15/19 cm depth (22.03 mg.kg^{-1}) and medium to moderately low in deeper horizons.

In lower slope, CEC in surface soil (0-5 cm depth) was very high (31.94 mg.kg^{-1}), high at 5-10 and 10-25 cm depth (21.64-27.29 mg.kg^{-1}), and medium to moderately low in deeper horizons.

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.

(8) Base Saturation (BS)

In upper slope, middle slope and lower slope of climax montane forest, The base saturation values in soil profiles varied between 4.32-8.26%, 6.63-24.18%, and 3.85-16.39%, respectively (Table 3-13).

(9) Assessment of Soil Fertility Levels

In the upper slope the fertility levels of soils at 0-5, 5-9/11 and 9/11-25/27 cm depth were medium. It was low in deeper horizons.

In the medium slope, the fertility levels of soils at 0-5/8, 5/8-15/19, 15/19-30/33 and 30/33-54/58 cm depth were medium. It was low in deeper horizons.

For the lower slope, the fertility levels of soils at 0-5, 5-10, 10-25, 25-40 and 40-60 cm depth were medium. It was low in deeper horizons (Table 3-14).

The assessment of soil fertility based on extractable nutrients may have some limitations for forest soils. In acid forest soils with the high accumulation of organic matter, most nutrients including phosphorus, calcium and magnesium may be occurred in non-available forms. Therefore, the total point maybe not increased. Forest vegetation can uptake the low concentrations of available forms of nutrients by associated mycorrhizal fungi. Unlike agricultural soils, availability of nutrients can be increased by lime application, and thus the total point indicated to fertility levels will be high.

Table 3-12 Some chemical properties in soil profiles under climax montane forest

Pedon	Soil depth	pH		O.M.		C		Total N		C/N	Available P		Exchangeable from (mg/kg)								CEC	
	(cm)			(g. kg-1)	*	(g. kg-1)	*	(g. kg-1)	*	ratio	(mg kg-1)	*	K	*	Ca	*	Mg	*	Na	*	(cmol.kg-1)	*
6	0-5	4.38	very strongly acid	130.20	VH	75.52	VH	6.40	H	11.80	4.33	L	210.53	VH	147.14	VL	32.70	VL	32.91	L	33.29	VH
	5-9/11	4.12	extremely acid	60.40	VH	35.03	VH	5.10	H	6.87	2.38	VL	197.10	VH	25.93	VL	6.25	VL	24.02	L	12.72	M
	9/11-25/27	4.75	very strongly acid	36.15	H	20.97	H	3.60	M	5.70	1.28	VL	152.79	VH	16.67	VL	7.25	VL	19.68	VL	14.39	M
	25/27-58	5.04	very strongly acid	13.03	ML	7.56	ML	3.13	M	2.36	0.97	VL	143.39	VH	17.51	VL	4.10	VL	18.91	VL	8.63	ML
	58-84/88	5.09	very strongly acid	8.60	L	4.99	L	1.05	L	4.65	0.87	VL	144.74	VH	20.04	VL	3.18	VL	21.67	VL	9.41	ML
	84/88-114/122	5.16	strongly acid	3.65	VL	2.12	VL	0.70	VL	3.34	0.89	VL	154.14	VH	17.20	VL	3.68	VL	20.89	VL	8.41	ML
	114/122-152/159	5.19	strongly acid	2.80	VL	1.62	VL	0.30	VL	5.41	0.81	VL	151.45	VH	22.56	VL	5.39	VL	19.51	VL	9.85	ML
	152/159-174/195	5.26	strongly acid	3.97	VL	2.30	VL	0.30	VL	7.67	1.02	VL	157.72	VH	22.54	VL	5.34	VL	17.47	VL	9.39	ML
	195-220+	5.38	strongly acid	3.55	VL	2.06	VL	0.20	VL	10.15	1.51	VL	164.88	VH	22.56	VL	4.18	VL	19.99	VL	7.96	ML
7	0-5/8	4.46	very strongly acid	104.05	VH	60.35	VH	6.10	H	9.83	4.33	L	264.23	VH	937.61	L	139.99	M	30.42	L	27.56	H
	5/8-15-19	4.44	very strongly acid	73.30	VH	42.52	VH	3.90	M	11.92	3.66	L	241.41	VH	496.70	L	78.91	VL	27.92	L	22.03	MH
	15/19-30/33	4.59	very strongly acid	41.23	H	23.92	H	1.33	L	20.18	1.47	VL	317.94	VH	32.10	VL	10.30	VL	22.11	VL	17.46	M
	30/33-54/58	4.87	very strongly acid	19.35	M	11.22	M	0.75	VL	14.66	1.17	VL	419.98	VH	16.67	VL	5.68	VL	35.48	L	12.09	ML
	54/58-67/76	5.06	strongly acid	10.20	ML	5.92	ML	0.60	VL	9.83	1.21	VL	437.43	VH	14.98	VL	4.53	VL	35.04	L	7.95	ML
	67/76-98/103	5.21	strongly acid	5.65	L	3.28	L	0.40	VL	7.71	1.14	VL	339.42	VH	13.30	VL	3.61	VL	20.48	VL	7.09	ML
	98/103-130/138	5.32	strongly acid	3.00	VL	1.74	VL	0.35	VL	5.05	1.56	VL	142.05	VH	14.98	VL	3.32	VL	20.98	VL	7.60	ML
	130/138-171/179	5.36	strongly acid	2.77	VL	1.60	VL	0.23	VL	8.31	1.75	VL	217.69	VH	13.02	VL	3.15	VL	21.31	VL	7.81	ML
	171/179-225+	5.28	strongly acid	2.10	VL	1.22	VL	0.10	VL	12.18	1.79	VL	172.04	VH	9.09	VL	3.29	VL	23.28	L	8.31	ML
8	0-5	3.58	extremely acid	110.50	VH	64.10	VH	5.20	H	12.33	13.08	M	280.34	VH	172.39	VL	24.98	VL	25.77	L	31.94	VH
	5-10	3.53	extremely acid	98.80	VH	57.31	VH	4.00	M	14.33	8.72	ML	296.46	VH	36.63	VL	10.54	VL	26.70	L	27.29	H
	10-25	4.05	extremely acid	49.20	VH	28.54	VH	2.35	M	14.54	2.92	VL	362.25	VH	51.18	VL	9.32	VL	52.72	L	21.64	H
	25-40	4.38	very strongly acid	23.40	MH	13.57	M	0.80	VL	16.76	2.44	VL	274.98	VH	18.35	VL	4.46	VL	47.93	L	19.31	MH
	40-60	5.19	strongly acid	13.90	ML	8.06	ML	0.60	VL	13.44	2.49	VL	454.89	VH	14.14	VL	3.53	VL	46.91	L	10.78	M
	60-90	5.59	moderately acid	3.75	VL	2.18	VL	0.50	VL	4.25	3.41	L	391.78	VH	11.62	VL	3.39	VL	40.44	L	7.73	ML
	90-130	5.74	moderately acid	2.57	VL	1.49	VL	0.33	VL	4.54	2.75	VL	280.34	VH	16.39	VL	4.20	VL	21.19	VL	8.43	ML
	130-180	5.81	moderately acid	2.13	VL	1.24	VL	0.23	VL	5.57	2.42	VL	138.02	VH	22.56	VL	4.82	VL	16.08	VL	7.92	ML
	180-220+	5.58	strongly acid	1.50	VL	0.87	VL	0.10	VL	8.70	2.32	VL	146.08	VH	9.93	VL	5.11	VL	15.89	VL	13.91	M

Note: Pedon 6 (upper slope site), Pedon 7 (middle slope site) and Pedon 8 (lower slope site)

* VL = very low, L = low, ML = moderately low, M = medium, MH = moderately high, H = high, VH = very high
(Land Classification and FAO Project Staff, 1973; Soil Survey Division Staff, 1993; Land Use Planning Division, 1993)

Table 3-13 Extractable bases and acidity, cation exchange capacity and base saturation in soil profiles under climax montane forest

Pedon	Soil depth	K	Ca	Mg	Na	sum of base	Extr. acidity	CEC by sum	B.S. by sum
	(cm)	(--cmol kg-1--)							(%)
6	0-5	0.54	0.74	0.27	0.14	1.69	31.60	33.29	5.08
	5-9/11	0.51	0.13	0.05	0.10	0.79	11.93	12.72	6.22
	9/11-25/27	0.39	0.08	0.06	0.09	0.62	13.76	14.39	4.32
	25/27-58	0.37	0.09	0.03	0.08	0.57	8.06	8.63	6.62
	58-84/88	0.37	0.10	0.03	0.09	0.59	8.82	9.41	6.29
	84/88-114/122	0.40	0.09	0.03	0.09	0.60	7.80	8.41	7.17
	114/122-152/159	0.39	0.11	0.04	0.08	0.63	9.22	9.85	6.40
	152/159-174/195	0.40	0.11	0.04	0.08	0.64	8.76	9.39	6.79
	195-220+	0.42	0.11	0.03	0.09	0.66	7.30	7.96	8.26
7	0-5/8	0.68	4.69	1.17	0.13	6.66	20.90	27.56	24.18
	5/8-15-19	0.62	2.48	0.66	0.12	3.88	18.14	22.03	17.62
	15/19-30/33	0.82	0.16	0.09	0.10	1.16	16.30	17.46	6.63
	30/33-54/58	1.08	0.08	0.05	0.15	1.36	10.72	12.09	11.27
	54/58-67/76	1.12	0.07	0.04	0.15	1.39	6.56	7.95	17.45
	67/76-98/103	0.87	0.07	0.03	0.09	1.06	6.03	7.09	14.89
	98/103-130/138	0.36	0.07	0.03	0.09	0.56	7.04	7.60	7.34
	130/138-171/179	0.56	0.07	0.03	0.09	0.74	7.07	7.81	9.50
	171/179-225+	0.44	0.05	0.03	0.10	0.62	7.69	8.31	7.40
8	0-5	0.72	0.86	0.21	0.11	1.90	30.04	31.94	5.95
	5-10	0.76	0.18	0.09	0.12	1.15	26.14	27.29	4.20
	10-25	0.93	0.26	0.08	0.23	1.49	20.14	21.64	6.89
	25-40	0.71	0.09	0.04	0.21	1.04	18.27	19.31	5.40
	40-60	1.17	0.07	0.03	0.20	1.47	9.31	10.78	13.64
	60-90	1.00	0.06	0.03	0.18	1.27	6.46	7.73	16.39
	90-130	0.72	0.08	0.03	0.09	0.93	7.51	8.43	11.00
	130-180	0.35	0.11	0.04	0.07	0.58	7.34	7.92	7.29
	180-220+	0.37	0.05	0.04	0.07	0.54	13.37	13.91	3.85

Note: Pedon 6 (upper slope site), Pedon 7 (middle slope site) and Pedon 8 (lower slope site)

Table 3-14 Assessment of fertility levels in soil profiles under climax montane forest

Pedon	Soil depth (cm)	O.M. ($g\ kg^{-1}$)	*	Available P ($mg\ kg^{-1}$)	*	Exchangeable K ($mg\ kg^{-1}$)	*	CEC ($cmol.kg^{-1}$)	*	B.S. (%)	*	Total points**	Ferity assessment
6	0-5	130.20	(3)	4.33	(1)	210.53	(3)	33.29	(3)	5.08	(1)	11	medium
	5-9/11	60.40	(3)	2.38	(1)	197.10	(3)	12.72	(2)	6.22	(1)	9	medium
	9/11-25/27	36.15	(3)	1.28	(1)	152.79	(3)	14.39	(2)	4.32	(1)	10	medium
	25/27-58	13.03	(1)	0.97	(1)	143.39	(3)	8.63	(1)	6.62	(1)	7	low
	58-84/88	8.60	(1)	0.87	(1)	144.74	(3)	9.41	(1)	6.29	(1)	7	low
	84/88-114/122	3.65	(1)	0.89	(1)	154.14	(3)	8.41	(1)	7.17	(1)	7	low
	114/122-152/159	2.80	(1)	0.81	(1)	151.45	(3)	9.85	(1)	6.40	(1)	7	low
	152/159-174/195	3.97	(1)	1.02	(1)	157.72	(3)	9.39	(1)	6.79	(1)	7	low
	195-220+	3.55	(1)	1.51	(1)	164.88	(3)	7.96	(1)	8.26	(1)	7	low
7	0-5/8	104.05	(3)	4.33	(1)	264.23	(3)	27.56	(3)	24.18	(1)	11	medium
	5/8-15-19	73.30	(3)	3.66	(1)	241.41	(3)	22.03	(3)	17.62	(1)	11	medium
	15/19-30/33	41.23	(3)	1.47	(1)	317.94	(3)	17.46	(2)	6.63	(1)	10	medium
	30/33-54/58	19.35	(2)	1.17	(1)	419.98	(3)	12.09	(2)	11.27	(1)	9	medium
	54/58-67/76	10.20	(1)	1.21	(1)	437.43	(3)	7.95	(1)	17.45	(1)	7	low
	67/76-98/103	5.65	(1)	1.14	(1)	339.42	(3)	7.09	(1)	14.89	(1)	7	low
	98/103-130/138	3.00	(1)	1.56	(1)	142.05	(3)	7.60	(1)	7.34	(1)	7	low
	130/138-171/179	2.77	(1)	1.75	(1)	217.69	(3)	7.81	(1)	9.50	(1)	7	low
	171/179-225+	2.10	(1)	1.79	(1)	172.04	(3)	8.31	(1)	7.40	(1)	7	low
8	0-5	110.50	(3)	13.08	(2)	280.34	(3)	31.94	(3)	5.95	(1)	12	medium
	5-10	98.80	(3)	8.72	(1)	296.46	(3)	27.29	(3)	4.20	(1)	11	medium
	10-25	49.20	(3)	2.92	(1)	362.25	(3)	21.64	(3)	6.89	(1)	11	medium
	25-40	23.40	(2)	2.44	(1)	274.98	(3)	19.31	(2)	5.40	(1)	9	medium
	40-60	13.90	(1)	2.49	(1)	454.89	(3)	10.78	(2)	13.64	(1)	8	medium
	60-90	3.75	(1)	3.41	(1)	391.78	(3)	7.73	(1)	16.39	(1)	7	low
	90-130	2.57	(1)	2.75	(1)	280.34	(3)	8.43	(1)	11.00	(1)	7	low
	130-180	2.13	(1)	2.42	(1)	138.02	(3)	7.92	(1)	7.29	(1)	7	low
	180-220+	1.50	(1)	2.32	(1)	146.08	(3)	13.91	(2)	3.85	(1)	8	medium

Note: Pedon 6 (upper slope site), Pedon 7 (middle slope site) and Pedon 8 (lower slope site)
***** 1 = low, 2 = medium, 3 = high
****** <7 = low, 7-12 = medium, >12 = high (Soil Survey Division, 1980)

3.3.2 Carbon and Nutrient Storages

Carbon and nutrient accumulations within 160 cm depth soils under five age-class pine plantations, five adjacent fragmented forests and climax montane forest were given in Table 3-15 to 3-17. Total organic matter, carbon and nitrogen were described. For other nutrients, the extractable forms were determined.

3.3.2.1 *Pinus kesiya* Plantations

(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.

(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 24,679; 0,145; 18,935; 17,658 and 14,856 kg.ha^{-1}, respectively. 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.

Table 3-15 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**

(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.

3.3.2.2 Adjacent Fragmented Forests

Carbon and nutrient accumulations within 160 cm depth soils under five adjacent fragmented was given in Table 3-16

(1) Amounts of Organic Matter

The amounts of organic matter in soil profiles (0-160 cm depth) under the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} pedon were 145.4, 160.5, 259.9, 186.2, and 454.9 $Mg.ha^{-1}$, 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 in subsoils.

(2) Carbon Amounts

The amounts of organic carbon in soil profiles (0-160 cm depth) under the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} pedon were 84.3, 93.1, 150.8, 108.0, and 263.9 Mg ha^{-1}, respectively.

(3) Nitrogen Amounts

The amounts of total nitrogen in soil profiles of the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} pedon were 9,364.2, 8,441.3, 18,582.7, 17,896.8 and 18,574.0 $kg.ha^{-1}$, respectively. The amounts were high in surface soils, and decrease in subsoils.

(4) Amounts of Available Phosphorus

The amounts of available phosphorus in soil profiles of the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} pedon were 54.2, 40.3, 62.3, 45.8, and 57.2 $kg.ha^{-1}$, respectively. The amounts were varied with soil depths.

(5) Amounts of Extractable Potassium

The amounts of extractable potassium in soil profiles of the 1^{st}, 2^{nd}, 3^{rd}, 4^{th} and 5^{th} pedon were 3,472.9, 5,001.4, 7,912.5, 5,433.1, and 4,512.8 $kg.ha^{-1}$, respectively. In some adjacent fragmented forests, the amounts of potassium were not different along soil profiles whereas some forests had the higher amounts in subsoils.

Table 3-16 Stored carbon and nutrients in soils under the adjacent fragmented forests

Pedon No.	Soil Depth (cm)	OM (Mg.ha^{-1})	C (Mg.ha^{-}	Total N (kg.ha^{-1})	Available P (kg.ha^{-1})	Extractable (kg.ha^{-1})			
						K	Ca	Mg	Na
1	0 - 5	35.7	20.7	2,088.2	5.9	362.0	434.3	83.2	12.6
	5 - 10	15.9	9.2	1,356.5	4.5	419.7	83.9	45.6	11.6
	10 - 20	17.4	10.1	953.2	5.8	220.1	202.3	42.9	20.7
	20 - 30	16.1	9.3	803.4	3.0	279.3	251.8	56.5	23.0
	30 - 40	8.0	4.6	532.6	2.0	293.8	393.0	50.2	21.2
	40 - 60	12.7	7.4	795.2	3.8	280.1	464.5	106.4	40.8
	60 - 80	13.6	7.9	461.3	4.0	357.4	735.9	148.1	48.8
	80 - 100	6.8	3.9	700.6	4.8	296.2	578.8	170.0	50.4
	100 - 120	10.9	6.3	464.3	5.3	268.3	542.3	144.1	53.4
	120 - 140	4.1	2.4	722.1	7.4	325.6	442.3	113.4	58.8
	140 - 160	4.1	2.4	486.9	7.7	370.4	516.7	109.5	51.1
	Total	**145.4**	**84.3**	**9,364.2**	**54.2**	**3,472.9**	**4,645.7**	**1,069.8**	**392.4**
2	0 - 5	36.2	21.0	1,133.6	7.2	190.1	290.0	58.2	9.0
	5 - 10	32.2	18.7	986.5	3.9	143.4	183.9	44.9	8.3
	10 - 20	26.0	15.1	1,543.6	5.6	351.2	190.6	104.6	26.4
	20 - 30	9.0	5.2	704.9	2.2	370.3	148.9	93.1	25.0
	30 - 40	7.1	4.1	543.3	1.3	269.2	130.0	83.7	23.9
	40 - 60	10.2	5.9	637.3	2.8	789.2	239.1	154.6	45.4
	60 - 80	8.2	4.8	422.1	2.5	629.6	252.5	126.5	43.7
	80 - 100	7.2	4.2	495.7	3.8	537.4	278.9	111.4	54.2
	100 - 120	9.1	5.3	703.7	3.2	693.3	364.2	120.5	54.0
	120 - 140	9.8	5.7	754.2	4.2	453.2	354.6	129.2	53.8
	140 - 160	5.4	3.1	516.4	3.5	574.3	382.5	138.2	51.1
	Total	**160.5**	**93.1**	**8,441.3**	**40.3**	**5,001.4**	**2,815.3**	**1,165.0**	**394.8**
3	0 - 5	37.4	21.7	1,451.0	12.5	233.1	702.8	168.4	9.4
	5 - 10	17.5	10.1	919.5	2.3	232.8	371.5	148.5	9.1
	10 - 20	35.7	20.7	1,588.4	4.7	628.6	375.6	238.0	25.0
	20 - 30	34.6	20.1	890.9	6.1	607.8	204.6	102.5	27.1
	30 - 40	26.9	15.6	1,359.2	3.5	598.0	367.9	105.8	27.3
	40 - 60	32.2	18.7	3,633.7	5.5	1,175.9	587.9	227.8	51.6
	60 - 80	22.4	13.0	2,106.8	5.5	1,274.6	784.1	236.8	57.1
	80 - 100	20.8	12.1	1,640.4	5.1	1,177.1	697.2	187.3	64.3
	100 - 120	15.0	8.7	1,466.3	6.2	1,072.9	852.2	200.9	62.0
	120 - 140	10.6	6.2	2,589.1	5.0	453.8	897.5	234.0	61.8
	140 - 160	6.9	4.0	937.1	5.8	457.7	1,130.2	280.9	68.2
	Total	**259.9**	**150.8**	**18,582.7**	**62.3**	**7,912.5**	**6,971.5**	**2,131.0**	**463.0**
4	0 - 5	44.3	25.7	2,055.9	5.1	104.0	148.4	31.3	8.9
	5 - 10	26.9	15.6	1,693.1	2.0	72.6	62.5	14.8	8.4
	10 - 20	36.1	20.9	3,897.4	2.5	235.3	38.3	17.9	19.5
	20 - 30	15.5	9.0	985.5	2.0	343.9	40.7	16.9	20.0
	30 - 40	13.7	7.9	1,233.3	3.9	234.4	71.7	22.0	20.3
	40 - 60	16.3	9.5	2,408.5	4.0	760.9	205.8	97.4	51.4
	60 - 80	11.0	6.4	1,369.0	3.4	801.5	152.1	99.6	54.5
	80 - 100	11.0	6.4	1,305.9	4.3	749.9	200.9	106.3	54.4
	100 - 120	6.7	3.9	1,341.9	6.3	710.2	130.0	68.9	55.8
	120 - 140	2.8	1.6	834.9	6.3	783.4	174.4	71.5	57.7
	140 - 160	2.1	1.2	771.3	6.0	637.0	106.2	49.5	53.9
	Total	**186.2**	**108.0**	**17,896.8**	**45.8**	**5,433.1**	**1,331.2**	**596.2**	**404.8**
5	0 - 5	53.9	31.3	2,871.9	9.2	175.7	654.6	122.1	8.9
	5 - 10	63.5	36.9	2,754.1	7.5	134.3	255.0	59.0	8.4
	10 - 20	82.8	48.0	3,134.7	8.3	243.5	90.9	23.1	19.5
	20 - 30	61.2	35.5	1,967.7	3.9	286.9	123.0	28.1	20.0
	30 - 40	55.3	32.1	814.4	2.2	343.9	139.2	57.3	20.3
	40 - 60	46.4	26.9	1,207.3	3.5	808.7	220.1	41.4	51.4
	60 - 80	31.2	18.1	990.7	3.6	418.6	208.2	42.4	54.5
	80 - 100	22.9	13.3	1,411.5	4.8	635.9	156.8	66.5	54.4
	100 - 120	18.2	10.6	1,467.0	3.8	550.0	142.1	71.6	55.8
	120 - 140	11.0	6.4	967.4	5.7	581.3	202.1	96.6	57.7
	140 - 160	8.6	5.0	987.2	4.7	334.1	229.7	84.5	53.9
	Total	**454.9**	**263.9**	**18,574.0**	**57.2**	**4,512.8**	**2,421.7**	**692.6**	**404.8**

(6) Amounts of Extractable Calcium

The amounts of extractable calcium in soil profiles of the 1st, 2nd, 3rd, 4th and 5th pedon were 4,645.7, 2,815.3, 6,971.5, 1,331.2, and 2,421.7 kg.ha^{-1}, respectively. For calcium, 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.

(7) Amounts of Extractable Magnesium

The amounts of extractable magnesium in soil profiles of the 1st, 2nd, 3rd, 4th and 5th pedon were 1,069.8, 1,165.0, 2,131.0, 596.2, and 692.6 kg.ha^{-1}, respectively. For magnesium, the amounts in some forests were not different along soil profiles.

(8) Amounts of Extractable Sodium

The amounts of extractable sodium in soil profiles of the 1st, 2nd, 3rd, 4th and 5th pedon were 392.4, 394.8, 463.0, 404.8, and 404.8 kg.ha^{-1}, respectively.The amounts of sodium were higher in subsoils of these forests.

3.2.2.3 Climax Montane Forest

Carbon and nutrient accumulations within 160 cm depth soils under climax forest was given in Table 3-17

(1) Amounts of Organic Matter

The amounts of organic matter in soil profiles (0-160 cm depth) under the climax forest in upper slope, middle slope and lower slope were 193.8, 247.6, and 204.45 Mg.ha^{-1}, respectively. The average of amount organic matter in soil profiles was 215.27 Mg.ha^{-1}.

(2) Carbon Amounts

The amounts of organic carbon in soil profiles (0-160 cm depth) under the climax forest in upper slope, middle slope and lower slope were 112.4, 143.6, and 118.6 Mg.ha^{-1}, respectively. The average of amount organic carbon in soil profiles was 124.9 Mg.ha^{-1}.

(3) Nitrogen Amounts

The amounts of total nitrogen in soil profiles under the climax forest in upper slope, middle slope and lower slope were 27,680.5, 13,553.3, and 11.691.7 kg.ha^{-1}, respectively. The average of amount total nitrogen in soil profiles was 17,641.85 kg.ha^{-1}.

(**4) Amounts of Available Phosphorus**

The amounts of available phosphorus in soil profiles under the climax forest in upper slope, middle slope and lower slope were 18.3, 28.5, and 48.9 kg.ha^{-1}. The average amounts of available phosphorus in soil profiles was 31.90 kg.ha^{-1}.

Table 3-17 Stored carbon and nutrients in soils under the climax montane forest

Pedon No.	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
6	0-5	27.75	16.09	1,363.84	0.92	44.86	31.36	6.97	7.01
	5-10	13.15	7.63	1,110.53	0.52	42.92	5.65	1.36	5.23
	10-20	37.22	21.59	2,992.86	1.20	132.71	13.44	7.43	16.41
	20-30	24.38	14.14	3,380.52	1.00	135.89	16.21	4.94	18.41
	30-40	9.84	5.71	3,619.52	1.04	137.89	21.71	4.64	22.08
	40-60	16.63	9.64	7,305.10	2.54	442.39	44.11	8.54	48.44
	60-80	30.62	17.76	2,652.10	2.00	365.15	50.34	8.51	51.76
	80-100	11.51	6.68	2,558.40	2.30	353.11	49.10	7.21	55.93
	100-120	7.52	4.36	1,074.48	2.34	457.33	40.83	12.17	53.51
	120-140	8.05	4.67	804.60	2.04	543.02	56.00	15.23	63.05
	140-160	7.09	4.12	818.58	2.35	274.03	66.14	13.92	42.29
	Total	**193.76**	**112.39**	**27,680.53**	**18.26**	**2,929.29**	**394.87**	**90.92**	**384.13**
7	0-5	32.83	19.04	1,832.60	0.94	79.17	253.71	37.38	9.02
	5-10	29.79	17.28	1,863.81	1.78	81.00	322.30	48.76	9.45
	10-20	46.00	26.68	1,830.96	1.64	189.29	45.47	12.62	21.71
	20-30	28.65	16.62	622.80	0.96	243.34	14.94	6.31	14.29
	30-40	23.18	13.45	697.28	0.90	342.65	15.26	5.45	17.01
	40-60	31.75	18.42	1,836.80	3.41	1,172.48	41.51	13.38	134.95
	60-80	23.48	13.62	1,414.60	3.17	1,210.98	40.00	11.20	52.74
	80-100	8.06	4.68	805.98	3.12	673.83	33.48	8.73	59.96
	100-120	9.05	5.25	1,168.32	3.86	403.13	41.30	9.49	64.35
	120-140	6.93	4.02	716.58	4.30	348.93	37.79	8.10	47.58
	140-160	7.89	4.58	763.56	4.40	747.70	31.71	7.18	51.31
	Total	**247.61**	**143.63**	**13,553.29**	**28.47**	**5,492.50**	**877.47**	**168.61**	**482.38**
8	0-5	28.39	16.47	1,335.88	3.36	72.02	44.29	6.42	6.62
	5-10	32.09	18.61	1,299.20	2.83	96.29	11.90	3.42	8.67
	10-20	49.54	28.74	2,697.24	2.66	271.41	60.23	9.31	44.56
	20-30	19.07	11.06	600.03	1.39	228.08	11.67	3.69	28.44
	30-40	14.11	8.18	542.57	2.16	161.10	14.87	2.63	41.23
	40-60	25.41	14.74	1,096.92	4.55	831.63	25.85	6.45	85.76
	60-80	11.73	6.81	1,436.64	8.19	729.12	25.79	8.12	114.69
	80-100	5.77	3.34	887.12	7.52	1,062.44	27.63	7.52	73.14
	100-120	7.74	4.49	725.28	6.58	580.37	42.33	11.29	34.38
	120-140	4.14	2.40	653.10	4.64	265.40	41.78	9.86	35.62
	140-160	6.48	3.76	417.76	5.08	316.35	43.61	10.07	37.70
	Total	**204.45**	**118.59**	**11,691.74**	**48.96**	**4,614.21**	**349.95**	**78.77**	**510.82**
	Average	**215.27**	**124.87**	**17,641.85**	**31.90**	**4,345.33**	**540.77**	**112.76**	**459.11**

Note: Pedon 6 (upper slope site), Pedon 7 (middle slope site) and Pedon 8 (lower slope site)

(5) Amounts of Extractable Potassium

The amounts of extractable potassium in soil profiles under the climax forest in upper slope, middle slope and lower slope were 2,929.3, 5,492.5 and 4,614.2 $kg.ha^{-1}$, respectively. The average amounts of extractable potassium in soil profiles was 4,345.33 $kg.ha^{-1}$.

(6) Amounts of Extractable Calcium

The amounts of extractable calcium in soil profiles under the climax forest in upper slope, middle slope and lower slope were 394.9, 877.5, and 349.9 $kg.ha^{-1}$, respectively. The average amounts of extractable calcium in soil profiles was 540.77 $kg.ha^{-1}$.

(7) Amounts of Extractable Magnesium

The amounts of extractable magnesium in soil profiles under the climax forest in upper slope, middle slope and lower slope were 90.9, 168.6, and 78.8 $kg.ha^{-1}$, respectively. The average amounts of extractable magnesium in soil profiles was 112.76 $kg.ha^{-1}$.

(8) Amounts of Extractable Sodium

The amounts of extractable sodium in soil profiles under the climax forest in upper slope, middle slope and lower slope were 384.1, 482.4, and 510.8 $kg.ha^{-1}$, respectively. The average amounts of extractable sodium in soil profiles was 459.11 $kg.ha^{-1}$.

3.3.3 Forest Floor Compartment

This nutrient compartment involved organic layers (Ao layers) accumulated on the forest floor in pine plantations, adjacent fragmented forests and climax montane forest.

3.3.3.1 *Pinus kesiya* Plantations

Most litter on forest floor of pine plantations was occurred during dry season. The fresh litter on the forest floor was collected, and analyzed for nutrients. The carbon and nutrient concentrations in litter of pine needle, leaves of succession broad-leaved species, and tree species in adjacent fragmented forests were analyzed as illustrated in Table 3-18. The carbon concentration in leaf of pine needle was higher than broad-leaved trees, but nitrogen concentration was adversely lower. The leaves of succession broad-leaved trees had the higher contents of potassium and calcium. Nutrient element concentration among components was highest for concentration in leaf, then other and branch.

Dry matters of Ao layers in different age pine plantations were shown in Table 3-19. 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.

Table 3-18 Nutrient concentrations (% dry weight) in litter on forest floor of pine plantations

Component	Nutrient concentrations (% dry weight)					
	OC	N	P	K	Ca	Mg
Leaf *P. kesiya*	41.61	0.690	0.006	0.038	0.050	0.010
Leaf succession trees	33.27	1.040	0.006	0.149	0.083	0.013
Branch	44.60	0.44	0.003	0.012	0.053	0.008
Other	35.71	0.58	0.004	0.024	0.059	0.013

The carbon and nutrient amounts accumulated in litter on forest floor of five age-class pine plantations were shown that 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 3-19 Distribution of dry matter and nutrient contents in litter on forest floor of pine plantations

Age (yrs)	Component	Dry matter (ka.ha^{-1})	Nutrient contents (kg. ha^{-1})					
			OC	N	P	K	Ca	Mg
17	Leaf of *P. kesiya*	2,553	1,062	17.62	0.15	0.97	1.28	0.26
	Leaf of Succession trees	4,417	1,470	45.94	0.27	6.58	3.67	0.57
	Branch	1,306	583	5.75	0.04	0.16	0.69	0.10
	Others	102	36	0.59	0.00	0.02	0.06	0.01
	Total	8,379	3,151	69.89	0.46	7.73	5.70	0.95
21	Leaf of *P. kesiya*	3,273	1,362	22.58	0.20	1.24	1.64	0.33
	Leaf of Succession trees	644	214	6.69	0.04	0.96	0.53	0.08
	Branch	2,082	928	9.16	0.06	0.25	1.10	0.17
	Others	428	153	2.48	0.02	0.10	0.25	0.06
	Total	6,427	2,657	40.92	0.31	2.56	3.53	0.63
25	Leaf of *P. kesiya*	2,596	1,080	17.91	0.16	0.99	1.30	0.26
	Leaf of Succession trees	680	226	7.07	0.04	1.01	0.56	0.09
	Branch	668	298	2.94	0.02	0.08	0.35	0.05
	Others	178	63	1.03	0.01	0.04	0.10	0.02
	Total	4,122	1,668	28.95	0.22	2.12	2.32	0.42
29	Leaf of *P. kesiya*	2,554	1,063	17.62	0.15	0.97	1.28	0.26
	Leaf of Succession trees	2,252	749	23.42	0.14	3.36	1.87	0.29
	Branch	1,562	696	6.87	0.05	0.19	0.83	0.12
	Others	311	111	1.80	0.01	0.07	0.18	0.04
	Total	6,678	2,619	49.71	0.35	4.59	4.16	0.71
33	Leaf of *P. kesiya*	3,520	1,464	24.28	0.21	1.34	1.76	0.35
	Leaf of Succession trees	250	83	2.60	0.02	0.37	0.21	0.03
	Branch	2,380	1,061	10.47	0.07	0.29	1.26	0.19
	Others	868	310	5.03	0.03	0.21	0.51	0.11
	Total	7,017	2,919	42.39	0.33	2.20	3.74	0.69

3.3.3.2 Adjacent Fragmented Forests

Dry matters of forest floor in the adjacent fragmented forests were shown in Table 3-20. The dry matters in these adjacent fragmented forests varied between 5,855-7,644 kg.ha^{-1}. 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 3-20 Distribution of dry matter and nutrient content in litter on forest floor of the adjacent fragmented forests

Pedon No.	Component	Dry matter (ka.ha^{-1})	Nutrient contents (kg. ha^{-1})					
			OC	N	P	K	Ca	Mg
1	Leaf of *P. kesiya*	303	126	2.09	0.02	0.12	0.15	0.03
	Leaf of Succession trees	3,903	1,298	40.59	0.23	5.81	3.24	0.51
	Branch	1,358	606	5.98	0.04	0.16	0.72	0.11
	Others	339	121	1.96	0.01	0.08	0.20	0.04
	Total	5,903	2,151	50.62	0.31	6.17	4.31	0.69
2	Leaf of *P. kesiya*	2,097	873	14.47	0.13	0.80	1.05	0.21
	Leaf of Succession trees	1,708	568	17.76	0.10	2.55	1.42	0.22
	Branch	1,506	672	6.63	0.05	0.18	0.80	0.12
	Others	640	228	3.71	0.03	0.15	0.38	0.08
	Total	5,951	2,341	42.57	0.30	3.68	3.64	0.64
3	Leaf of *P. kesiya*	0	0.00	0.00	0.00	0.00	0.00	0.00
	Leaf of Succession trees	5,928	1,972	61.65	0.36	8.83	4.92	0.77
	Branch	1,583	706	6.97	0.05	0.19	0.84	0.13
	Others	132	47	0.77	0.01	0.03	0.08	0.02
	Total	7,644	2,726	69.39	0.41	9.05	5.84	0.91
4	Leaf of *P. kesiya*	167	70	1.15	0.01	0.06	0.08	0.02
	Leaf of Succession trees	3,779	1,257	39.30	0.23	5.63	3.14	0.49
	Branch	1,529	682	6.73	0.05	0.18	0.81	0.12
	Others	381	136	2.21	0.02	0.09	0.22	0.05
	Total	5,855	2,145	49.39	0.30	5.97	4.25	0.68
5	Leaf of *P. kesiya*	40	17	0.28	0.00	0.02	0.02	0.00
	Leaf of Succession trees	4,928	1,640	51.25	0.30	7.34	4.09	0.64
	Branch	1,597	712	7.03	0.05	0.19	0.85	0.13
	Others	309	110	1.79	0.01	0.07	0.18	0.04
	Total	6,874	2,479	60.34	0.36	7.62	5.14	0.81

3.3.3.3 Climax Montane Forest

The nutrient contents in litterfall and forest floor were varied as shown in Table 3-21. The average of contents in litterfall including leaf, branch and other were carbon: 35.10, 36.12 and 34.04%; nitrogen: 1.28, 0.88 and 1.54%; phosphorus: 0.04, 0.01 and 0.05%; potassium: 0.39, 0.33 and 0.45%; calcium: 1.20, 1.31 and 1.10%; magnasuim: 0.25, 0.15 and 0.21%. Also, the average of contents in forest floor including leaf, branch and other were carbon: 35.08, 36.60 and 32.33%; nitrogen: 1.57, 0.98 and 1.68%; phosphorus: 0.04, 0.01 and 0.05%; potassium: 0.16, 0.09 and 0.16%; calcium: 1.52, 1.36 and 1.01%; magnasuim: 0.22, 0.50 and 0.17%.

Table 3-21 Nutrient contents (% dry weight) in litterfall and forest floor of the climax montane forest

	Season	Component	Nutrient contents (% dry weight)					
			OC	N	P	K	Ca	Mg
Litterfall	Summer	Leaf	32.62	1.17	0.02	0.42	1.27	0.25
		Branch	37.29	0.95	0.02	0.42	1.22	0.14
		Other	32.75	1.72	0.01	0.42	0.97	0.21
	Rainy	Leaf	36.47	1.42	0.03	0.32	1.19	0.23
		Branch	37.23	0.87	0.01	0.16	1.38	0.13
		Other	34.52	1.17	0.05	0.42	1.30	0.18
	Winter	Leaf	36.20	1.24	0.07	0.42	1.14	0.28
		Branch	33.85	0.81	0.01	0.42	1.32	0.18
		Other	34.84	1.72	0.10	0.50	1.03	0.23
	Average	**Leaf**	**35.10**	**1.28**	**0.04**	**0.39**	**1.20**	**0.25**
		Branch	**36.12**	**0.88**	**0.01**	**0.33**	**1.31**	**0.15**
		Other	**34.04**	**1.54**	**0.05**	**0.45**	**1.10**	**0.21**
Forest floor	Summer	Leaf	35.27	1.46	0.03	0.26	1.54	0.24
		Branch	36.84	0.85	0.01	0.11	1.27	1.24
		Other	35.54	1.69	0.05	0.15	0.11	0.12
	Rainy	Leaf	35.23	1.66	0.07	0.10	1.43	0.19
		Branch	36.74	1.01	0.01	0.05	1.41	0.13
		Other	32.14	1.58	0.04	0.10	1.38	0.17
	Winter	Leaf	34.73	1.59	0.03	0.11	1.59	0.22
		Branch	36.23	1.07	0.01	0.10	1.41	0.13
		Other	29.32	1.77	0.06	0.24	1.54	0.23
	Average	**Leaf**	**35.08**	**1.57**	**0.04**	**0.16**	**1.52**	**0.22**
		Branch	**36.60**	**0.98**	**0.01**	**0.09**	**1.36**	**0.50**
		Other	**32.33**	**1.68**	**0.05**	**0.16**	**1.01**	**0.17**

Dry matters and nutrient amounts in litterfall and forest floor litter in the climax forest were shown in Table 3-22. The dry matters in litterfall were 5,463.25 kg.ha^{-1}y^{-1}, these were lower than in forest floor litter (10,094.46 kg.ha^{-1}y^{-1}). In litterfall, carbon amounts in organic layers were 1,892.31 kg.ha^{-1}y^{-1}. The amounts of nutrients were different: nitrogen; 71.13 kg.ha^{-1}y^{-1}, phosphorus; 0.21 kg.ha^{-1}y^{-1}, potassium; 2.19 kg.ha^{-1}y^{-1}, calcium; 6.44 kg.ha^{-1}y^{-1} and magnesium; 1.27 kg.ha^{-1}y^{-1}.

In forest floor litter, carbon amounts in organic layers were 3,500.02 kg.ha^{-1}y^{-1}. nitrogen contents were 153.98 kg.ha^{-1}y^{-1}, phosphorus; 0.41 kg.ha^{-1}y^{-1}, potassium; 1.39 kg.ha^{-1}y^{-1}, calcium; 14.83 kg.ha^{-1}y^{-1}, and magnesium; 1.93 kg.ha^{-1}y^{-1}.

Table 3-22 Distribution of dry matter and nutrient amounts in litterfall and forest floor of the climax montane forest

	Season	Component	Dry matter (ka.ha^{-1} y^{-1})	Nutrient amounts (kg.ha^{-1}y^{-1})					
				OC	N	P	K	Ca	Mg
Litterfall	Summer	Leaf	1,417.88	462.512	16.589	0.028	0.596	1.801	0.354
		Branch	122.54	45.697	1.164	0.002	0.051	0.150	0.017
		Other	724.22	237.181	12.457	0.007	0.304	0.702	0.152
		Total	2,264.64	745.390	30.210	0.038	0.951	2.653	0.524
	Rainy	Leaf	700.45	255.453	9.946	0.021	0.224	0.834	0.161
		Branch	257.46	95.851	2.240	0.003	0.041	0.355	0.033
		Other	350.42	120.966	4.100	0.018	0.147	0.456	0.063
		Total	1,308.33	472.270	16.286	0.041	0.413	1.644	0.258
	Winter	Leaf	1,309.53	474.049	16.238	0.092	0.550	1.493	0.367
		Branch	175.51	59.411	1.422	0.002	0.074	0.232	0.032
		Other	405.24	141.186	6.970	0.041	0.203	0.417	0.093
		Total	1,890.28	674.647	24.630	0.134	0.826	2.142	0.491
	Total		**5,463.25**	**1,892.31**	**71.13**	**0.21**	**2.19**	**6.44**	**1.27**
Forest floor	Summer	Leaf	1,308.47	461.496	19.104	0.039	0.340	2.015	0.314
		Branch	496.83	183.033	4.223	0.005	0.055	0.631	0.055
		Other	868.36	308.614	14.675	0.043	0.130	1.077	0.104
		Total	2,673.66	953.143	38.002	0.088	0.525	3.723	0.473
	Rainy	Leaf	2,260.23	796.280	37.520	0.158	0.226	3.232	0.429
		Branch	251.68	92.466	2.542	0.003	0.013	0.355	0.033
		Other	614.24	197.418	9.705	0.025	0.061	0.848	0.104
		Total	3,126.16	1,086.16	49.767	0.185	0.300	4.435	0.567
	Winter	Leaf	2,882.82	1,001.20	45.837	0.086	0.317	4.584	0.634
		Branch	659.60	238.973	7.058	0.007	0.066	0.930	0.086
		Other	752.22	220.552	13.314	0.045	0.181	1.158	0.173
		Total	4,294.64	1,460.72	66.209	0.138	0.564	6.672	0.893
	Total		**10,094.46**	**3,500.02**	**153.98**	**0.41**	**1.39**	**14.83**	**1.93**

3.3.4 Ecosystem Carbon and Nutrient Storages

3.3.4.1 *Pinus kesiya* Plantations

In the five age-class *Pinus kesiya* plantations, the carbon storages in pine plantation ecosystems including in plant biomass, forest floor and soil compartments varied between 196.66-277.92 MgC.ha^{-1}. The majority amount was stored in soils (40.7-77.5%), followed by plant biomass (21.3-57.9%) and forest floor (0.7-1.3%). The complex cycling of carbon in forest plantation ecosystems 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; 11,020.92-25,299.89 kg.ha^{-1}, phosphorus; 99.35-175.46 kg.ha^{-1}, potassium; 4,807.73-6,526.56 kg.ha^{-1}, calcium; 1,580.53-8,935.74 kg.ha^{-1}, and magnesium; 578.63-1,321.69 kg.ha^{-1} (Table 3-23 and Figure 3-9).

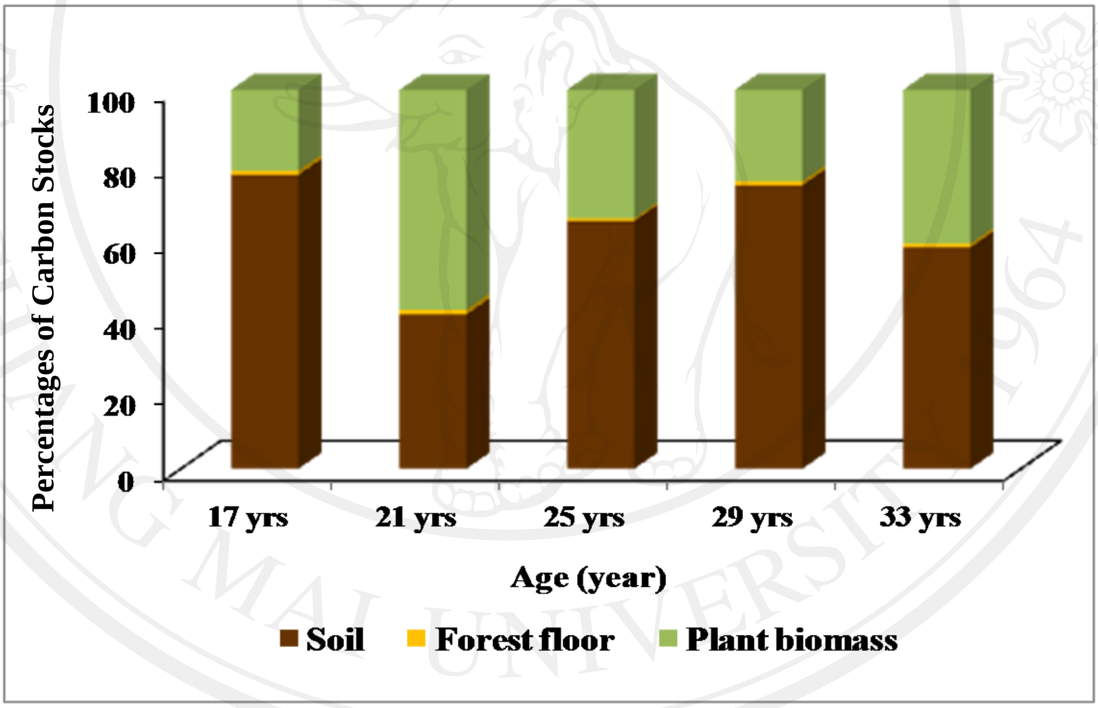

Figure 3-9 Percentages of carbon stocks in ecosystems of pine plantations

3.3.4.2 Adjacent Fragmented Forests

In five adjacent fragmented forests, the carbon stocks in ecosystems including in plant biomass, forest floor and soil compartments varied between 196.34-364.48 Mg.ha^{-1}. The majority amount was stored in soils (41.2-72.5%), followed by plants biomass (26.8-57.7%) and forest floor (0.7-1.2%). The amounts of nutrients were different: nitrogen; 9,605.57-19,787.39 kg.ha^{-1}, phosphorus; 197.30-236.31 kg.ha^{-1}, potassium; 4,375.17-8,695.05 kg.ha^{-1}, calcium; 3,218.25-8,625.84 kg.ha^{-1}, and magnesium; 1,018.68-2,501.91 kg.ha^{-1} (Table 3-23 and Figure 3-10).

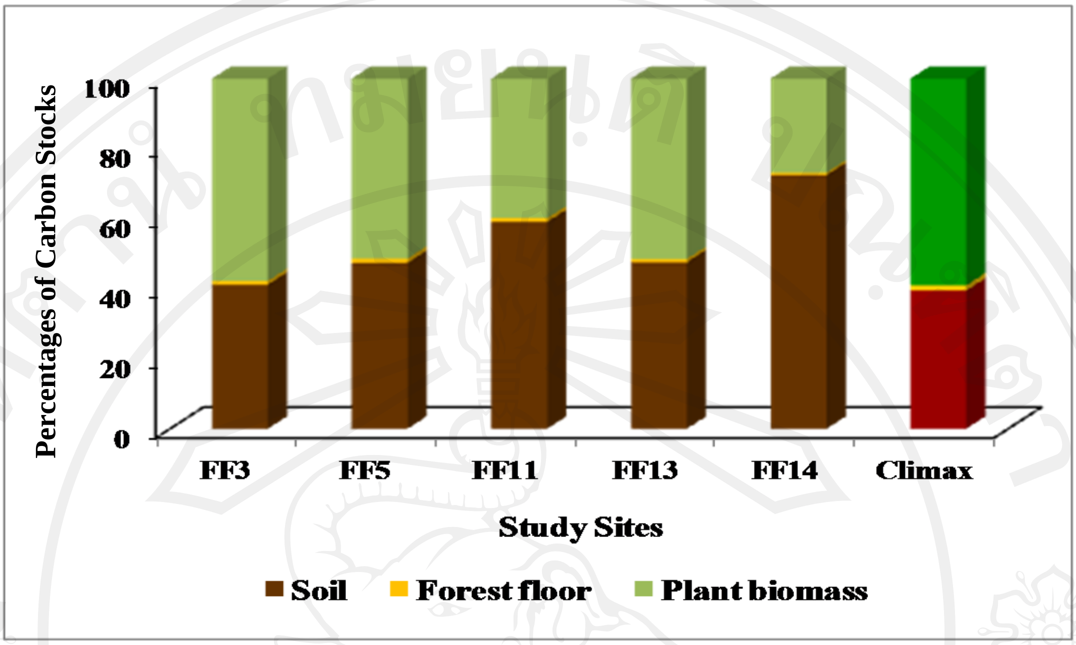

Figure 3-10 Percentages of carbon stocks in ecosystems of adjacent fragmented forests and climax montane forest

3.3.4.3 Climax Montane Forest

In the climax montane forests at Doi Inthanon national park, the carbon stocks in ecosystems including in plant biomass, forest floor and soil compartments was 316.41 $Mg.ha^{-1}$. The majority amount was stored in plant biomass (59.04%), followed by soils (39.46%) and forest floor (1.50%). The amounts of nutrients including : nitrogen; 19,904.67 $kg.ha^{-1}$, phosphorus; 310.98 $kg.ha^{-1}$, potassium; 5,737.49 $kg.ha^{-1}$, calcium; 3,562.64 $kg.ha^{-1}$, and magnesium; 768.11 $kg.ha^{-1}$ (Table 3-23 and Figure 3-10). The forest was still abundant, and had the high biomass and carbon storages.

Table 3-23 Carbon and nutrients storages in ecosystems of pine plantations , adjacent fragmented forests and climax montane forest

Type	Plot	component	OC (Mg ha^{-1})	(%)	Nutrient amounts (kg.ha^{-1}) N	(%)	P	(%)	K	(%)	Ca	(%)	Mg	(%)
Pine Plantations	**17 yrs**	Plant	56.00	21.20	551.00	2.18	74.00	42.17	377.00	7.84	789.00	21.64	172.00	22.02
		Forest Floor litter	3.15	1.19	69.89	0.28	0.46	0.26	7.73	0.16	5.70	0.16	0.95	0.12
		Soil	205.00	77.61	24,679.00	97.55	101.00	57.56	4,423.00	92.00	2,852.00	78.21	608.00	77.85
		Total	**264.15**	**100.00**	**25,299.89**	**100.00**	**175.46**	**100.00**	**4,807.73**	**100.00**	**3,646.70**	**100.00**	**780.95**	**100.00**
	21 yrs	Plant	114.00	57.97	835.00	7.58	108.00	79.23	582.00	8.92	1,154.00	73.01	225.00	38.88
		Forest Floor litter	2.66	1.35	40.92	0.37	0.31	0.23	2.56	0.04	3.53	0.22	0.63	0.11
		Soil	80.00	40.68	10,145.00	92.05	28.00	20.54	5,942.00	91.04	423.00	26.76	353.00	61.01
		Total	**196.66**	**100.00**	**11,020.92**	**100.00**	**136.31**	**100.00**	**6,526.56**	**100.00**	**1,580.53**	**100.00**	**578.63**	**100.00**
	25 yrs	Plant	86.00	33.90	595.00	3.04	76.00	70.88	414.00	6.43	814.00	39.30	155.00	25.10
		Forest Floor litter	1.67	0.66	28.95	0.15	0.22	0.21	2.12	0.03	2.32	0.11	0.42	0.07
		Soil	166.00	65.44	18,935.00	96.81	31.00	28.91	6,021.00	93.54	1,255.00	60.59	462.00	74.83
		Total	**253.67**	**100.00**	**19,558.95**	**100.00**	**107.22**	**100.00**	**6,437.12**	**100.00**	**2,071.32**	**100.00**	**617.42**	**100.00**
	29 yrs	Plant	57.00	23.99	408.00	2.25	53.00	53.35	285.00	4.85	562.00	11.65	108.00	9.21
		Forest Floor litter	2.62	1.10	49.71	0.27	0.35	0.35	4.59	0.08	4.16	0.09	0.71	0.06
		Soil	178.00	74.91	17,658.00	97.47	46.00	46.30	5,582.00	95.07	4,256.00	88.26	1,064.00	90.73
		Total	**237.62**	**100.00**	**18,115.71**	**100.00**	**99.35**	**100.00**	**5,871.59**	**100.00**	**4,822.16**	**100.00**	**1,172.71**	**100.00**
	33 yrs	Plant	113.00	40.66	564.00	3.65	68.00	44.35	412.00	7.86	734.00	8.21	110.00	8.32
		Forest Floor litter	2.92	1.05	42.39	0.27	0.33	0.22	2.20	0.04	3.74	0.04	0.69	0.05
		Soil	162.00	58.29	14,856.00	96.08	85.00	55.44	4,828.00	92.10	8,198.00	91.74	1,211.00	91.63
		Total	**277.92**	**100.00**	**15,462.39**	**100.00**	**153.33**	**100.00**	**5,242.20**	**100.00**	**8,935.74**	**100.00**	**1,321.69**	**100.00**
Adjacent Fragmented Forests	**FF 3**	Plant	118.00	57.80	1,312	12.23	182	77.02	896	20.48	1,907	29.08	428	28.56
		Forest Floor litter	2.15	1.05	50.62	0.47	0.31	0.13	6.17	0.14	4.31	0.07	0.69	0.05
		Soil	84.00	41.15	9,364	87.30	54	22.85	3,473	79.38	4,646	70.85	1,070	71.40
		Total	**204.15**	**100.00**	**10,726.62**	**100.00**	**236.31**	**100.00**	**4,375.17**	**100.00**	**6,557.31**	**100.00**	**1,498.69**	**100.00**
	FF 5	Plant	101.00	51.44	1,122	11.68	157	79.57	767	13.29	1,632	36.67	366	23.90
		Forest Floor litter	2.34	1.19	42.57	0.44	0.3	0.15	3.68	0.06	3.64	0.08	0.64	0.04
		Soil	93.00	47.37	8,441	87.88	40	20.27	5,001	86.65	2,815	63.25	1,165	76.06
		Total	**196.34**	**100.00**	**9,605.57**	**100.00**	**197.30**	**100.00**	**5,771.68**	**100.00**	**4,450.64**	**100.00**	**1,531.64**	**100.00**
	FF 11	Plant	102.00	39.89	1,135	5.74	157	71.56	774	8.90	1,649	19.12	370	14.79
		Forest Floor litter	2.73	1.07	69.39	0.35	0.41	0.19	9.05	0.10	5.84	0.07	0.91	0.04
		Soil	151.00	59.05	18,583	93.91	62	28.26	7,912	90.99	6,971	80.82	2,131	85.17
		Total	**255.73**	**100.00**	**19,787.39**	**100.00**	**219.41**	**100.00**	**8,695.05**	**100.00**	**8,625.84**	**100.00**	**2,501.91**	**100.00**
	FF 13	Plant	117.00	51.51	1,293	6.72	183	79.81	886	14.01	1,883	58.51	422	41.43
		Forest Floor litter	2.14	0.94	49.39	0.26	0.3	0.13	5.97	0.09	4.25	0.13	0.68	0.07
		Soil	108.00	47.55	17,897	93.02	46	20.06	5,433	85.90	1,331	41.36	596	58.51
		Total	**227.14**	**100.00**	**19,239.39**	**100.00**	**229.30**	**100.00**	**6,324.97**	**100.00**	**3,218.25**	**100.00**	**1,018.68**	**100.00**
	FF 14	Plant	98.00	26.89	1,083	5.49	151	72.47	740	14.07	1,574	39.34	353	33.72
		Forest Floor litter	2.48	0.68	60.34	0.31	0.36	0.17	7.62	0.14	5.14	0.13	0.81	0.08
		Soil	264.00	72.43	18,574	94.20	57	27.36	4,513	85.79	2,422	60.53	693	66.20
		Total	**364.48**	**100.00**	**19,717**	**100.00**	**208**	**100.00**	**5,261**	**100.00**	**4,001**	**100.00**	**1,047**	**100.00**
Climax Montane Forest		Plant	186.80	59.04	2,057.32	10.34	278.54	89.57	1,390.26	24.23	3,002.04	84.26	652.86	85.00
		Forest Floor litter	4.74	1.50	205.50	1.03	0.54	0.17	1.89	0.03	19.83	0.56	2.49	0.32
		Soil	124.87	39.46	17,641.85	88.63	31.90	10.26	4,345.33	75.74	540.77	15.18	112.76	14.68
		Total	**316.41**	**100.00**	**19,904.67**	**100.00**	**310.98**	**100.00**	**5,737.49**	**100.00**	**3,562.64**	**100.00**	**768.11**	**100.00**

3.4 Discussion

Reforestation in watershed areas through pine plantation could alter soil properties especially physical and chemical properties in the top soils during stand development. Annual litterfall resulted in accumulated of organic layers (Ao layers) on forest floor, and subsequently decomposed to humus and organic matter in soil. Tree roots penetrate in to soils and made the pores with allows water and air permeability. The increasing soil organic matter leads to the low bulk densities. The amounts organic matter in pine plantations did not increased with stand age. This plantation was abundant with other broad-leaved trees and ground-covered which supplied high organic residues to the soil. Plant succession in pine plantation is therefore important for soil development including physical, chemical, and biological properties.

The acidic reaction of pine plantations tended to be increased over stand age. The needle of pine needles had high acidic reaction so soils which covered with pine trees had more acidic reaction than other broad-leaved trees (Khamyong and Seremethakun, 2006). After succession occurred in pine plantations by broad-leaved trees, the acidic reaction would be reduced. However, forest fire in plantations was the important factor to increase the acidic reaction. The suitable management of pine plantation should be promoted through allowing succession of local broad-leaved tree species. According to this result, the soil acidity was very high in soil of the montane forest. The higher soil acidity and greater amount of organic matter were considered to be chemical characteristics of the tropical montane forest soil. (Veneklass, 1991; Pendry and Procter, 1996).

All the adjacent fragmented forests had the high soil organic matter due to annual litterfall and slow decomposition. Soils formed from granite were moderately fertile and rich in organic matter in the top soil layers (Anusontpornperm and Kheoruenromne, 1996). The fine-textured soils had the higher soil carbon content than coarse-textured soils (Amato and Ladd, 1992; Hassink, 1994). The 4^{th} and 5^{th} adjacent fragmented forests were abundant of succession trees, and the high rate of litterfall would be occurred combined with dense ground-covered species and resulted in the high amounts organic matter. The trend of soil nitrogen was similar to the soil organic matter. Plant diversity in the climax montane forest was high. The species richness was 122 species. This plant species had different nature and contribution in litterfall. This plant had including life-span, biomass allocation, biomass productivity and tissue chemical composition which had significant effects on soil organic carbon and soil nutrient dynamics (Vitousek *et al.*, 1987; Berendse *et al.*, 1989; Matson, 1990; Cote *et al.*, 2000).

Many factors affecting for soil nutrient contents including, plant community, parent material, climate, topography and forest fire such as organic matter and nitrogen compounds were broken down by heat of the fire (Kitur and Frye, 1983; Giovannini and Lucchesi, 1997). The climax montane forest in Doi Inthanon national park was situated at high elevation (1,700 m. msl.) where the forest sites were relatively moist and not disturb by fire, which was continuously input organic matter to the soils in the form of litterfall; then cool, humid climates and low intensity of light caused the slow decomposition process and thus resulting accumulated organic layer on the soil surface.

The assessment of soil fertility level using some chemical properties revealed that all soils in the adjacent fragmented forest were moderately fertile. Pine plantations could alter some soil chemical properties during stand development. The organic layers on forest floor were decomposed especially from succession trees, and had the high potential to increase soil fertility. The soil under forest cover can preserve their equilibrium status of nutrients.