CHAPTER 4

Changes of Soil Properties under a Series of *Pinus kesiya* Plantations

Abstract

Soil physico-chemical properties and nutrient contents under *Pinus kesiya* plantations at Boakaew Watershed Management Station, Chiang Mai province were investigated. The soil study was taken in five sites of pine plantations at the ages of 17, 21, 25, 29 and 33 years old. The soil samples were analyzed for physical and chemical properties in laboratory. It is found that soil properties including soil physical and chemical properties had improved by *Pinus kesiya* plantations. Bulk density was decreased with plantation ages. Soil pH varied between moderately acid to very strongly acid. The surface layers contained high organic matter and had a trend of increase with stand ages. This tendency was the same for total nitrogen, available phosphorus, calcium and magnesium. Cation exchange capacity and base saturation percentage were increased with stand ages. Assessment of the soil fertility level revealed that all surface soil layers were moderately fertile. The succession broad-leaved tree species contributes to available phosphorus, cation exchange capacity and base saturation. Thus, the natural succession in pine plantations by many broad-leaved tree species is very important for improving soil properties and fertility.

4.1 Introduction

Many forest types and subtypes with variable floristic composition cover highland areas in northern Thailand with different altitudinal levels (Santisuk, 1988; Khamyong *et al*., 2004). The montane forest usually has moist cool weather and deep fertile soil, upper 1,000 m msl. Pine-dry dipterocarp forest occurs on the dry site and poor soil between 1,000-1,300 m. The pine-lower montane forest and lower montane forest distribute in areas of 1,000-1,600 m. These forests have been disturbed by local people for shifting cultivation and rotational agriculture because of fertile soil and suitable climate for highland agriculture. These result in deforestation and forest fragmentation. The size and abundant of remnant plant communities in fragmented forests depend on the degrees of deforestation. However the fragmented forests play the key role as sources of mother trees for restoration on highland watershed areas particularly plantations and disturbed areas.

Soils under different forests usually have different physical, chemical and biological properties influenced by parent materials, vegetations, climate, topography and time. The soils can be enormously complex systems of organic and inorganic components. They tend to show a strong geographical correlation with climate, especially at the global scale. Climate determines vegetation cover which in turn influences soil development. As time passes, climate tends to be a prime influence on soil properties while the influence of parent material is less. 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).

Soil chemical properties affecting nutrient availability are important factors to provide plant species diversity, in the same way litterfall of plant species diversity affect the biological processes controlling nutrient cycling availability (Pritchett and Fisher, 1987). Forest cover improves soil nutrient levels through the accumulation of litter and organic matter at the surface. The litterfall provides sustainable nutrients to the soil. Soil organic matter, carbon and nitrogen accumulations in soils were quite different among dry evergreen forest, mixed deciduous forest, montane forest, pine forest and dry dipterocarp forest (Khamyong, 2009).

The soil fertility is not important in forestry as in agriculture. The nutritional demands of most tree species are only moderate though there is variation. Forest tree species can grow on variable soil properties. Araucarias require more fertile soils than pines, especially in nitrogen status (Evans, 1982). Pine forests tend to dominate in cool, humid climates. Decomposing pine needles in the presence of water creates a weak acid that strips soluble bases from the soil leaving it in an acidic state. Additionally, pine trees have low nutrient demands so smaller amounts of soil nutrients are taken by the trees and later recycled by decaying needle litter. Broadleaf deciduous trees have the higher nutrient demands and thus continually recycling soil nutrients keeping soils high in soluble bases.

The fragmented forests distributed in different areas, and may have different soils which are the important factor on the spatial distribution of various plants. The investigation on soil characteristics in a series of pine plantation, fragmented forests and opened areas will provide the basic information involving ecological needs of plant species and their diversity. The soil data imply the stages of forest succession and ecosystem recovery.

4.2 Materials and Methods

4.2.1 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. A soil pit was made for each plot/site with the depth to 1.60 meters. Soil samples were taken from 11 depths; 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-120, 120-140 and 140-160 centimeters. The soil samples were later analyzed for soil physical and chemical properties in laboratory. The soil study was also taken in five sites of fragmented forests and one site for abandoned land after shifting cultivation. The five fragmented forests were randomly selected and studied the development of soil profiles. The analysis for physico-chemical properties were conducted along the soil profile.

4.2.2 Analysis of Soil Physical Properties

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

4.2.3 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)

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

4.3 Results

The soil characteristics including physico-chemical properties and nutrient status of soils in *Pinus kesiya* plantations, fragmented lower montane forests and opened areas were described. The changes in soil properties in plantations were compared to the fragmented forests and opened sites, and considered from many parameters.

4.3.1 Soil Properties in a Series of *Pinus kesiya* Plantations

4.3.1.1 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 given in Table 4-1 and Figure 4-1 - 4-2.

(1) Bulk Density

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

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

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

(2) Amounts of Gravel

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

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

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

(3) Soil Particle Distribution

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

Sand:

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

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

Silt:

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

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

Clay:

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

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

(4) Soil Texture

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

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

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

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

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

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

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

Table 4-1 Some physical properties in soil profiles under pine plantations

Age (year)	Soil (cm)	Bulk density (Mg.m^{-3})	*	Gravel (%)	Soil particle distribution (%)			Soil texture
					Sand	Silt	Clay	
17	0-5	0.74	VL	14.6	69.2	23.4	7.4	Sandy loam
	5-10	0.71	VL	15.0	76.9	14.0	9.1	Sandy loam
	10-20	0.75	VL	12.0	72.5	13.3	14.2	Sandy loam
	20-30	0.75	VL	12.3	64.2	18.3	17.5	Sandy loam
	30-40	0.74	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 Kanchanaprasert, 1986)

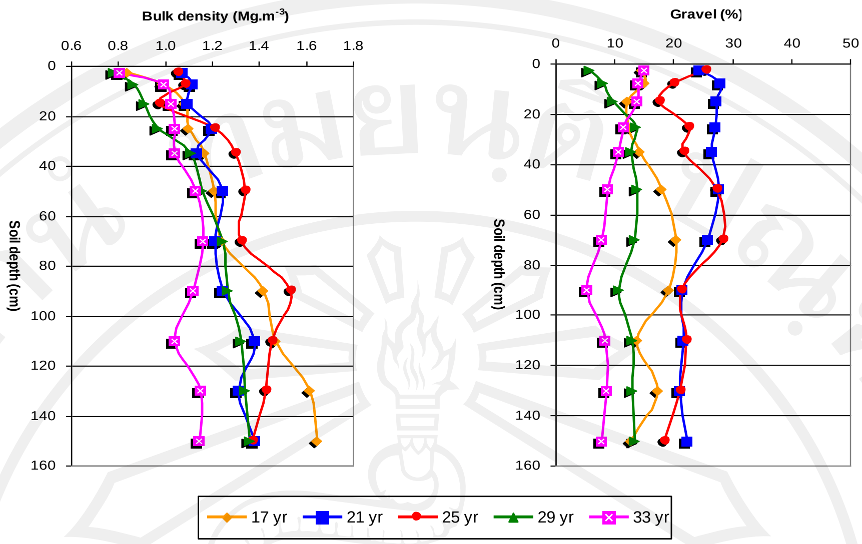

Figure 4-1 Variations of bulk densities (left) and gravel amounts (right) along soil profiles under pine plantations

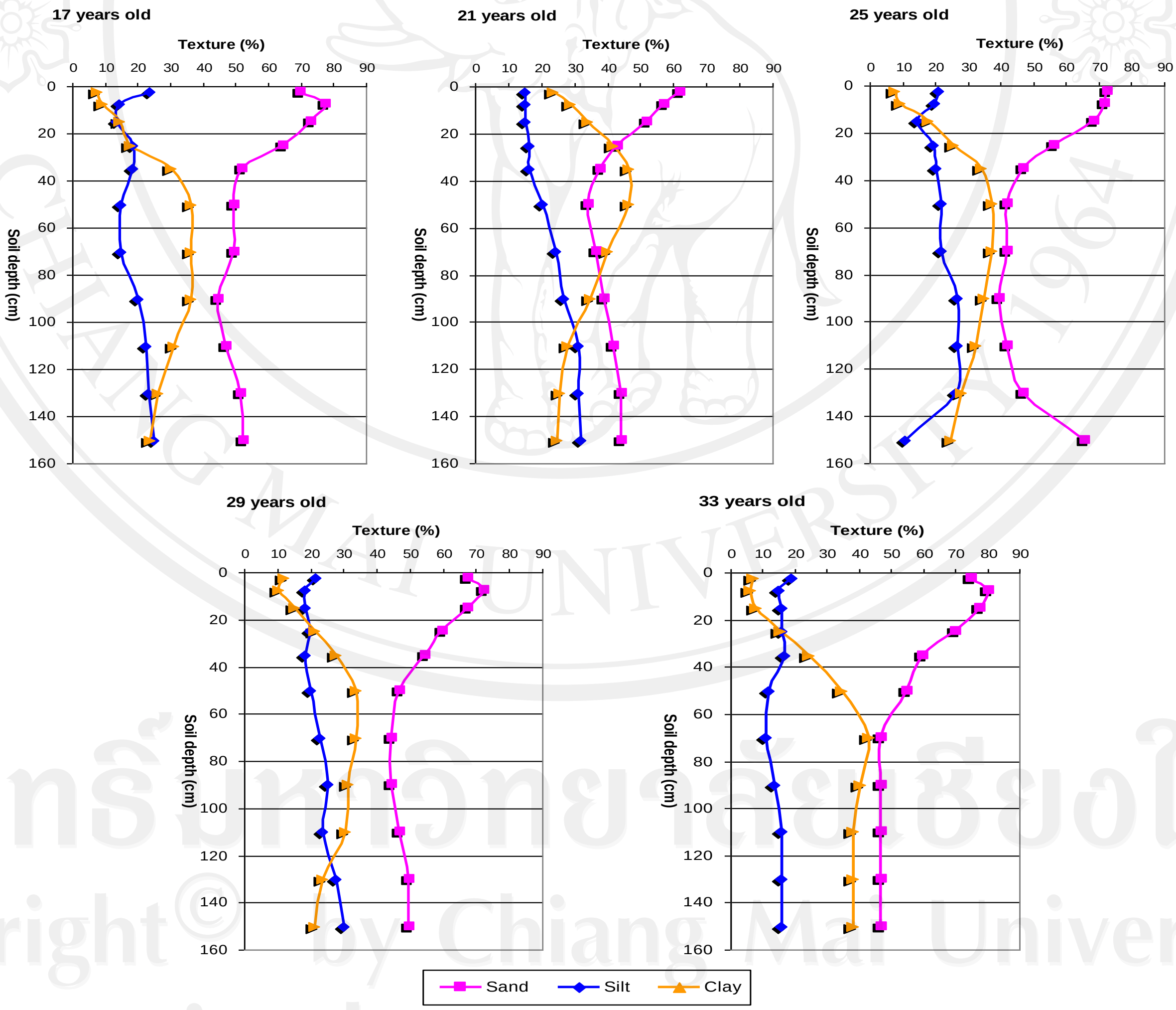

Figure 4-2 Distribution of soil particles along soil profiles under pine plantations

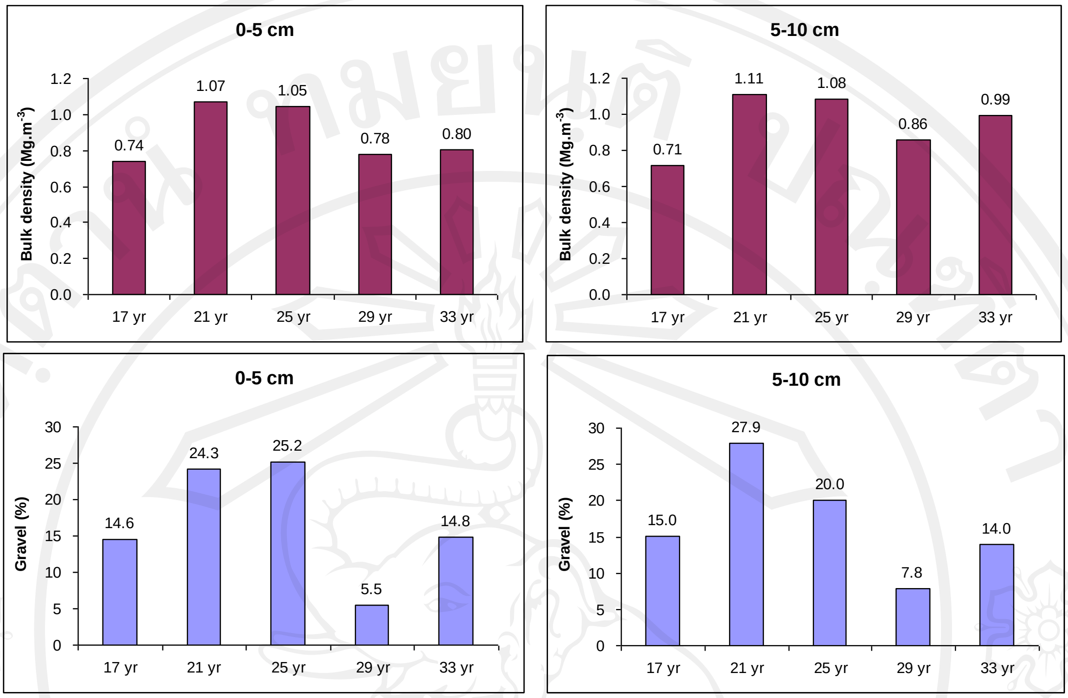

Figure 4-3 Comparison of bulk densities and gravel amounts in surface soils (0-10 cm) of five age-class pine plantations

4.3.1.2 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 4-2 and Figure 4-4.

(1) Soil Reaction

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

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

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

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

In 29-year-old plantation, the soil was strongly acid (pH: 5.25-5.50) at 0-20 cm depth, very strongly acid (pH: 4.92-4.96) at 20-40 cm and strongly acid (pH: 5.13-

5.22) in deeper soil. For 33-year-old plantation, the soil was almost strongly acid (pH: 5.08-5.39) throughout soil profiles of 160 cm depth.

(2) Soil Organic Matter, Carbon and Nitrogen

Soil Organic Matter:

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

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

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

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

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

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

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

Soil Carbon:

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

Total Nitrogen:

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

(3) Available Phosphorus

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

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

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

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

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

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

(4) Extractable Potassium

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

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

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

(5) Extractable Calcium

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

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

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

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

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

(6) Extractable Magnesium

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

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

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

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

(7) Extractable Sodium

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

(8) Cation Exchange Capacity (CEC)

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

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

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

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

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

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

(9) Base Saturation (BS)

The values of extractable bases including potassium, calcium, magnesium and sodium are shown in Table 4-3. 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 to Order Ultisols.

(10) Assessment of Soil Fertility Levels

According to soil fertility assessment of Soil Survey Division (1980), the soils under five age-class pine plantations were evaluated based on five parameters; organic matter, available phosphorus, extractable potassium, cation exchange capacity and base saturation percentage (Table 4-4). The total points were used for identify soil fertility levels.

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.

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.

Table 4-2 Some chemical properties in soil profiles under pine plantations

Age (year)	Soil depth (cm)	pH		O.M.		C		Total N		C/N	Available P		Extractable (mg.kg^{-1})								CEC	
				(g.kg^{-1})	*	(g.kg^{-1})	*	(g.kg^{-1})	*	ratio	(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)

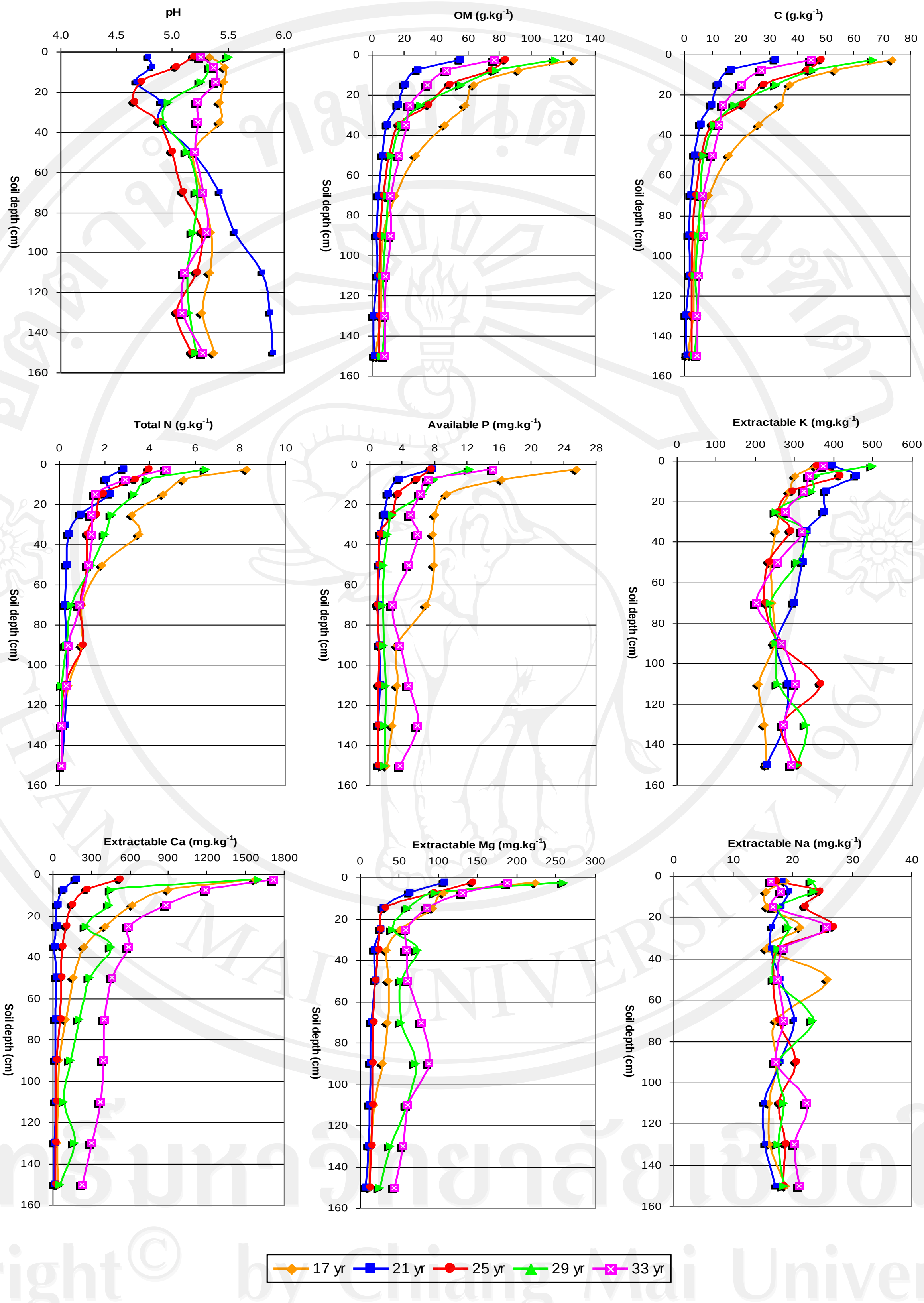

Figure 4-4 The pH values and contents of soil organic matter, carbon, nitrogen and other extractable nutrients in soil profiles under pine plantations

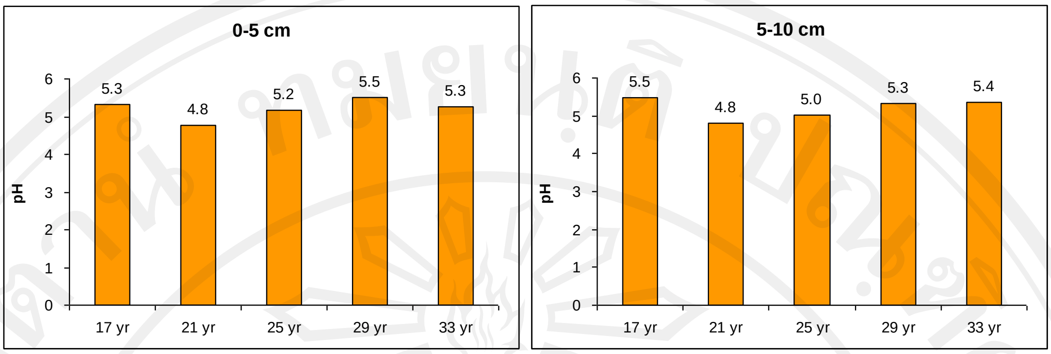

Figure 4-5 Comparison of soil reaction in surface soils (0-10 cm) among different age-class pine plantations

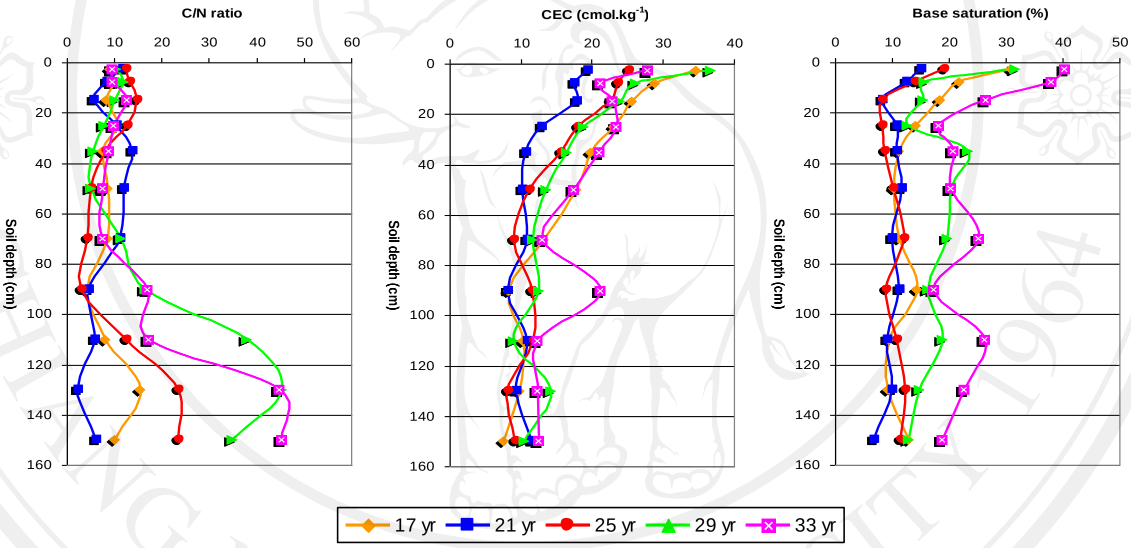

Figure 4-6 C/N ratios, cation exchange capacity (CEC) and base saturation percentages (BS) in soil profiles under pine plantations

Table 4-3 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 4-4 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)

4.3.1.3 Roles of Plant Communities in Pine Plantations

In Table 4-15, plant succession has occurred in all age-class of pine plantations including, 17, 21 25, 29 and 33 years old. The species richness were 61, 41, 39, 32 and 53 species, respectively. Tree densities were in the order of 2,256; 1,350; 963; 598 and 1,119 trees/ha. These included densities of *P. kesiya* as 106, 406, 429, 233 and 329 trees/ha, and broad-leaved trees as 2,150; 944; 533; 365 and 790 trees/ha. The succession tree species consisted of mainly the families of Leguminosae, Fagaceae, Euphorbiaceae, Lauraceae and Theaceae.

Growths of *P. kesiya* trees in pine plantations at Boakaew Watershed Management Station were not increased with stand ages. Many factors influenced on the pine growths. The average growth increment in 17 year-old stand was the highest (0.93 m/yr in height and 1.56 cm/yr in stem diameter), whereas 29 year-old stand was the lowest (0.52 m/yr in height and 0.98 cm/yr in diameter). For broad-leaved tree species, the average growth increment was the highest in 17 year-old stand (0.75 m/yr in height and 1.24 cm/yr in diameter), whereas that of 29 year-old stand was the lowest (0.40 m/yr in height and 0.75 cm/yr in diameter).

Plant communities in these *Pinus kesiya* plantations could improve soil properties including soil physical, chemical and biological properties through above-ground and below-ground litterfall. The litter decomposition resulted in increase in soil organic matter, acidity and nutrients. The bulk densities tended to be decreased with stand ages of pine plantations. These affected on water infiltration and aeration as well as other biological processes in soils. The surface soils were rich in organic matter and tended to be increased with stand ages. The similar trend was observed for carbon and nitrogen. The values of cation exchange capacity in these plantations were high to very high in surface soils and medium to moderately low in subsoils. The extractable potassium concentrations of all age-class stands were very high throughout soil profiles. The fertility levels of surface soils under five age-class pine plantations were medium to high, and medium to low in subsoils. The soil under 17 year-old plantation had high fertility influenced by forest cover and good site factors. In this plantation, broad-leaved tree species were abundant with the highest IVI value of broad-leaved trees as 89.35%, whereas the other age-class plantations had the vales between 58.60-67.58%. Thus, the changes of soil properties with plantation ages were not clear.

Table 4-5 Overall data of plant communities in pine plantations

	Quantitative characteristics	The age of pine plantations (year)				
		17	21	25	29	33
1	Alitude (m)	1,561	1,314	1,362	1,606	1,453
2	Number of Species	61	41	39	32	53
3	Number of Genus	51	34	33	30	48
4	Number of Families	34	23	23	16	31
5	Basal area (m^2/ha)	19.66	36.52	28.13	22.54	34.92
6	Dominant tree (%)					
	6.1 *Pinus kesiya*	24.51	62.89	68.22	65.07	90.89
	6.2 Other broad-leaved trees	75.49	37.11	31.78	34.93	9.11
7	IVI (%)					
	7.1 *Pinus kesiya*	10.65	32.42	39.17	36.74	41.40
	7.2 Other broad-leaved trees	89.35	67.58	60.83	63.26	58.60
8	Density (trees/ha)	2,256	1,350	963	598	1,119
	8.1 *Pinus kesiya*	106	406	429	233	329
	(1) gbh < 30 cm	15	4	10	0	0
	(2) gbh 30-50 cm	8	30	64	15	0
	(3) gbh 50-100 cm	73	277	330	140	93
	(4) gbh 100-150 cm	10	95	25	79	228
	(5) gbh > 150 cm	0	0	0	0	8
	8.2 Other broad-leaved trees	2,150	944	533	365	790
	(1) gbh < 30 cm	1,793	584	296	198	690
	(2) gbh 30-50 cm	225	196	152	66	88
	(3) gbh 50-100 cm	108	139	73	83	8
	(4) gbh 100-150 cm	16	19	6	13	4
	(5) gbh > 150 cm	8	6	6	4	0
9	Species diversity (SWI)	4.50	3.94	3.29	3.35	3.51
10	Growth					
	10.1 *Pinus kesiya*					
	H (m)	15.87	19.01	18.47	15.13	23.30
	DBH (cm)	26.44	26.98	25.25	28.53	34.52
	10.2 Other broad-leaved trees					
	H (m)	12.76	13.61	12.91	11.66	16.63
	DBH (cm)	21.14	18.81	18.72	21.68	26.23
11	Annual growth increment					
	11.1 *Pinus kesiya*					
	H (m/yr)	0.93	0.91	0.74	0.52	0.71
	DBH (cm/yr)	1.56	1.28	1.01	0.98	1.05
	11.2 Other broad-leaved trees					
	H (m/yr)	0.75	0.65	0.52	0.40	0.50
	DBH (cm/yr)	1.24	0.90	0.75	0.75	0.79

4.3.2 Soils Properties in Fragmented Forests

4.3.2.1 Soil Profile Development

Soils in most 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-Bt-BC with 10-15 cm thickness of organic layers on the forest floor. Topography and development of soil profiles under fragmented forests were summarized in Table 4-6.

Table 4-6 Topography and soil profile development in five fragmented forests

FF	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

Some differences were occurred among soil profiles under five 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 morphological characteristics of soil profiles under the fragmented forests were depicted below (Figure 4-5 to 4-9).

Pedon 1

I Information on the Site

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

II General Information on the Soil

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

III Profile Description :

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

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

Pedon 2

I Information on the Site

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

II General Information on the Soil

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

III Profile Description :

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

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

Pedon 3

I <u>Information on the Site</u>

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

II <u>General Information on the Soil</u>

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

III <u>Profile Description</u> :

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

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

Pedon 4

I Information on the Site

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

II General Information on the Soil

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

III Profile Description :

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

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

Pedon 5

I Information on the Site

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

II General Information on the Soil

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

III Profile Description :

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

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

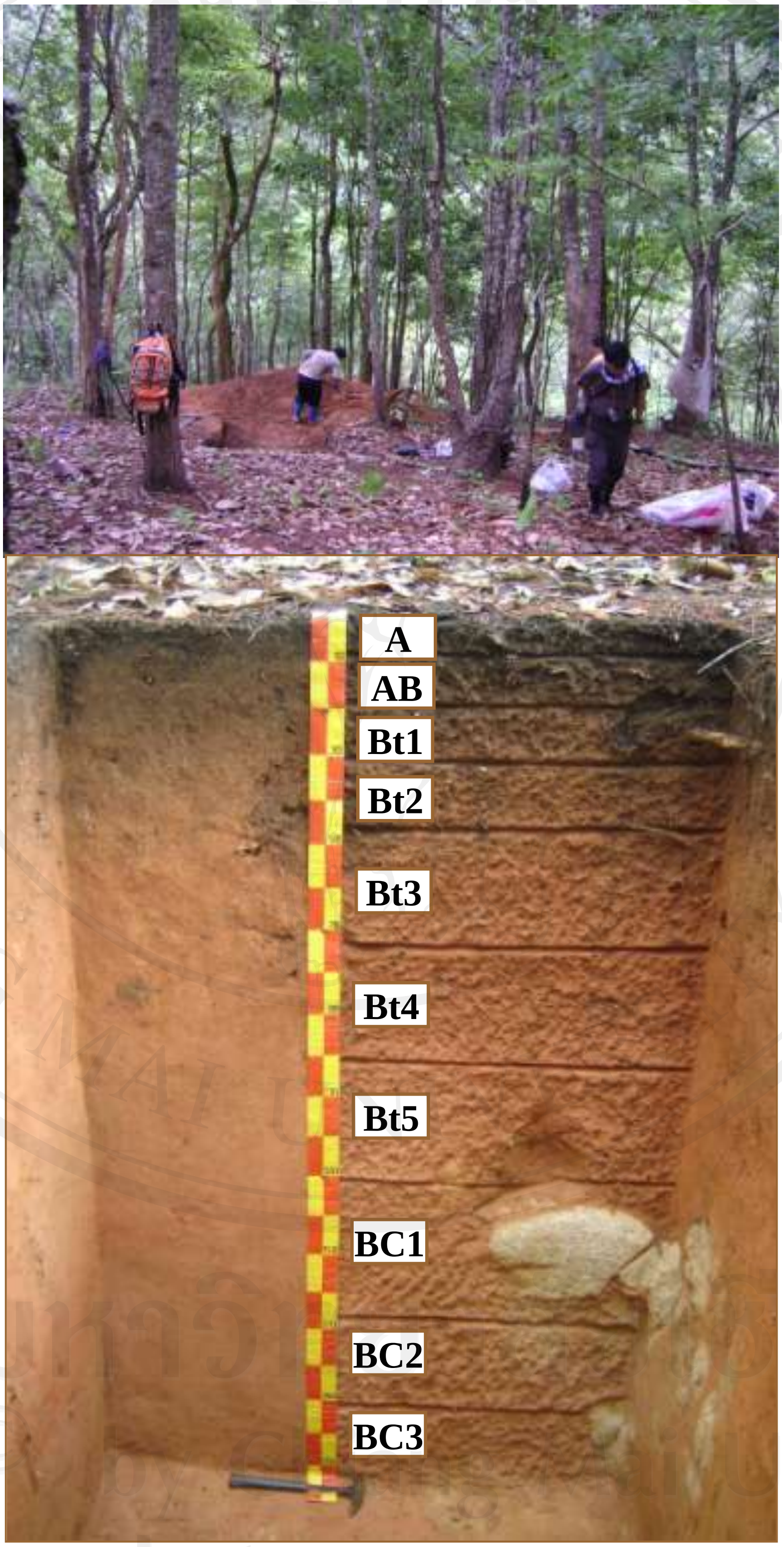

Figure 4-7 Study site and soil profile of pedon 1 (The 1st fragmented forest)

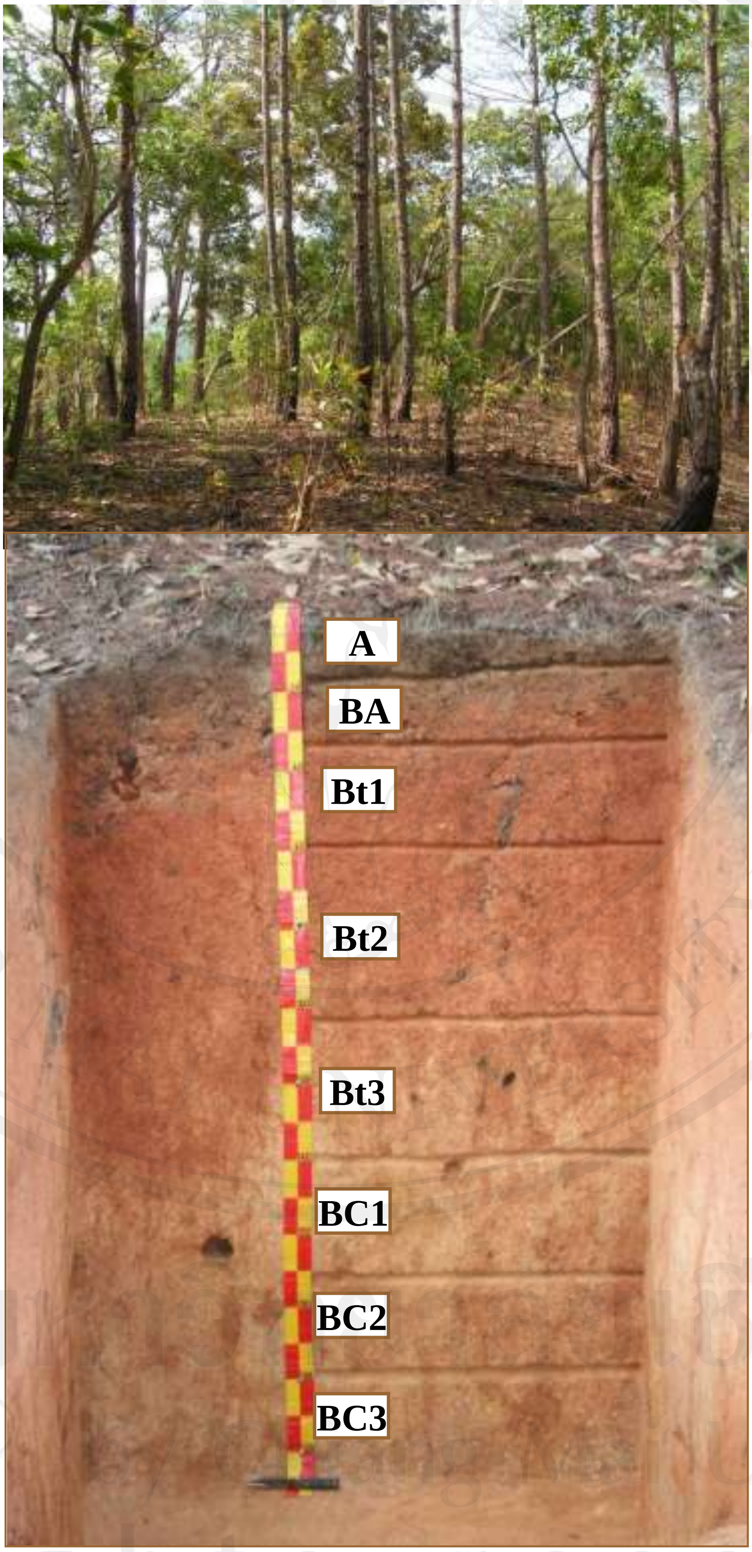

Figure 4-8 Study site and soil profile of pedon 2 (The 2nd fragmented forest)

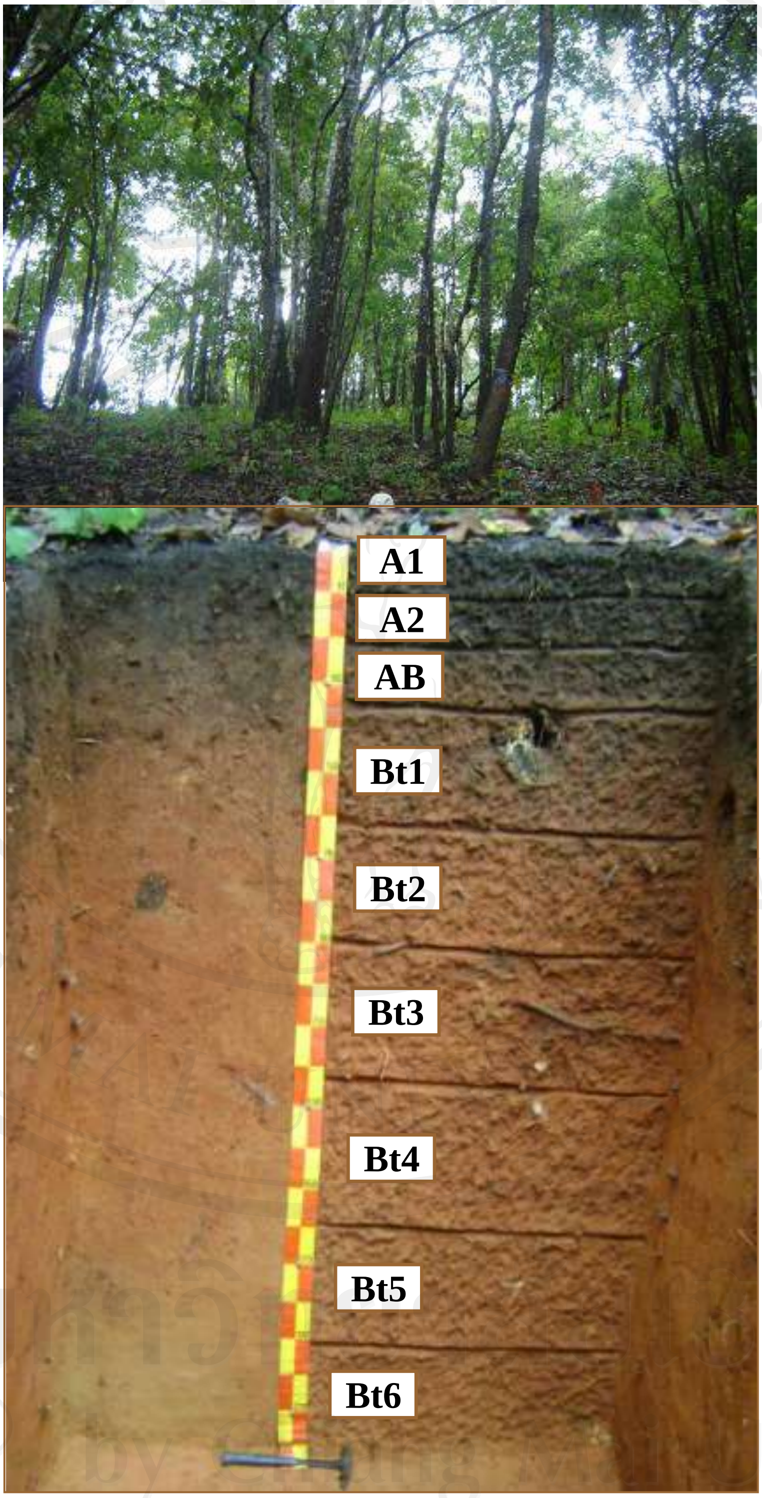

Figure 4-9 Study site and soil profile of pedon 3 (The 3rd fragmented forest)

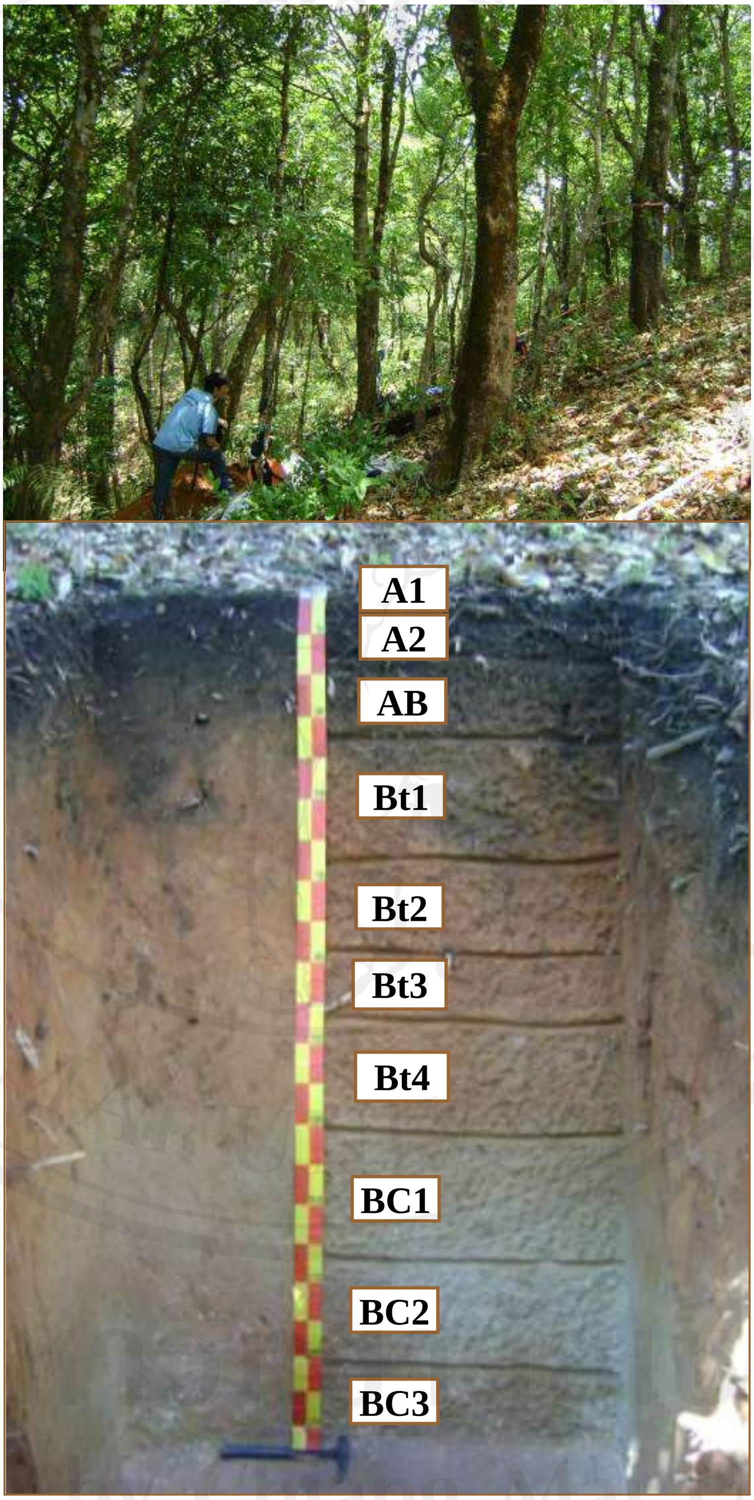

Figure 4-10 Study site and soil profile of pedon 4 (The 4th fragmented forest)

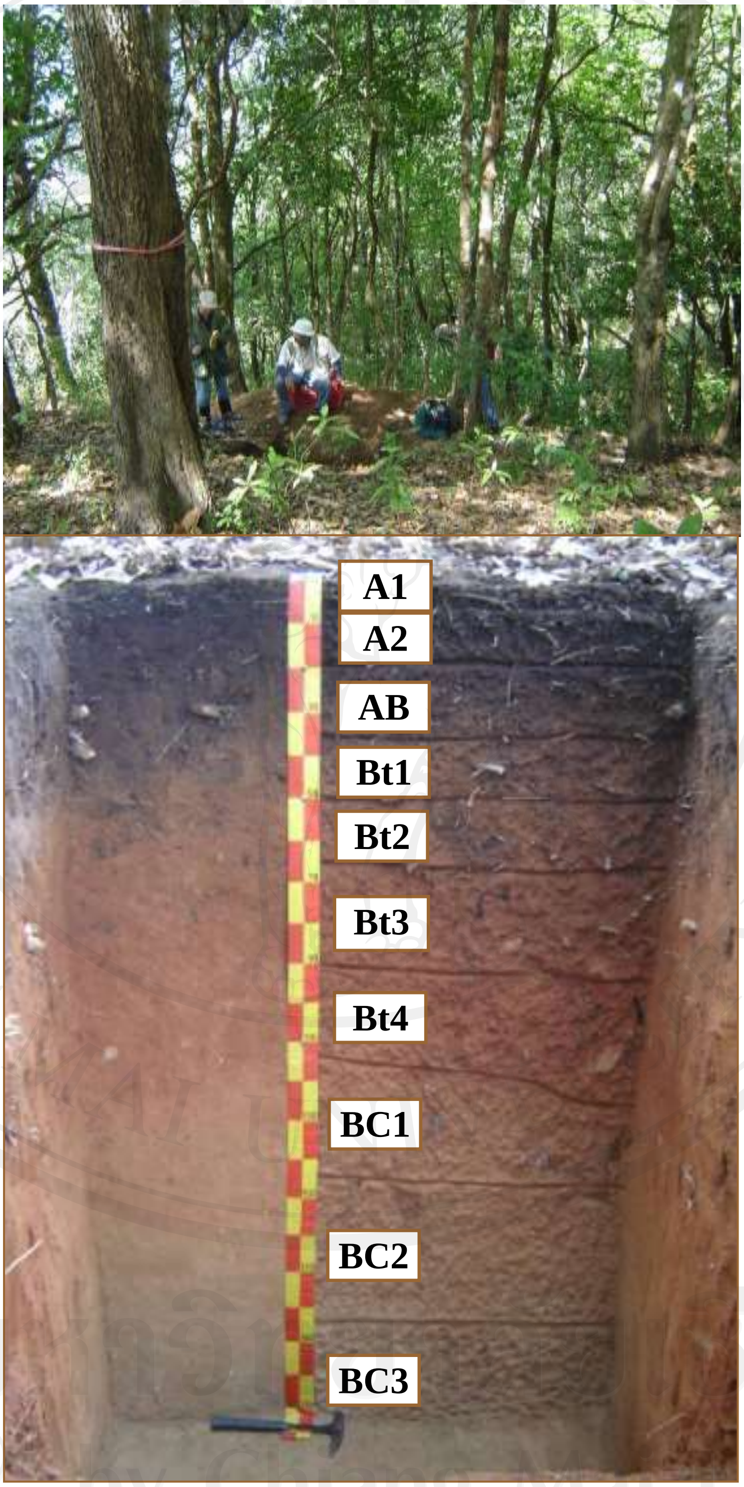

Figure 4-11 Study site and soil profile of pedon 5 (The 5^{th} fragmented forest)

4.3.2.2 Soil Physical Properties

Some physical properties including bulk density, amounts of gravel, soil particle distribution and soil texture were given in Table 4-7.

(1) Bulk Density

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

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

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

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

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

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

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

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

(2) Amounts of Gravel

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

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

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

(3) Soil Particle Distribution

Sand:

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

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

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

Silt:

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

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

Clay:

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

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

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

(4) Soil Texture

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

Table 4-7 Some physical properties in soil profiles under fragmented forests

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

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

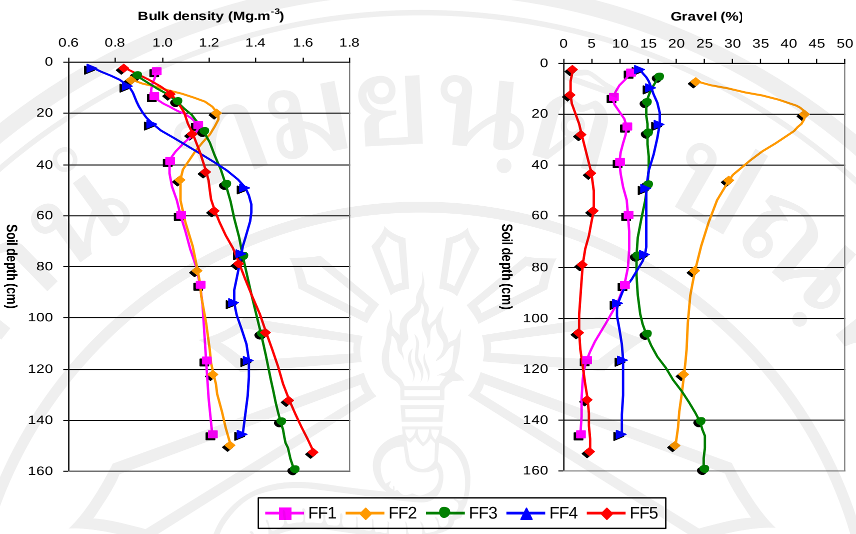

Figure 4-12 Variations of bulk densities (left) and gravel amounts (right) in soil profiles under fragmented forests

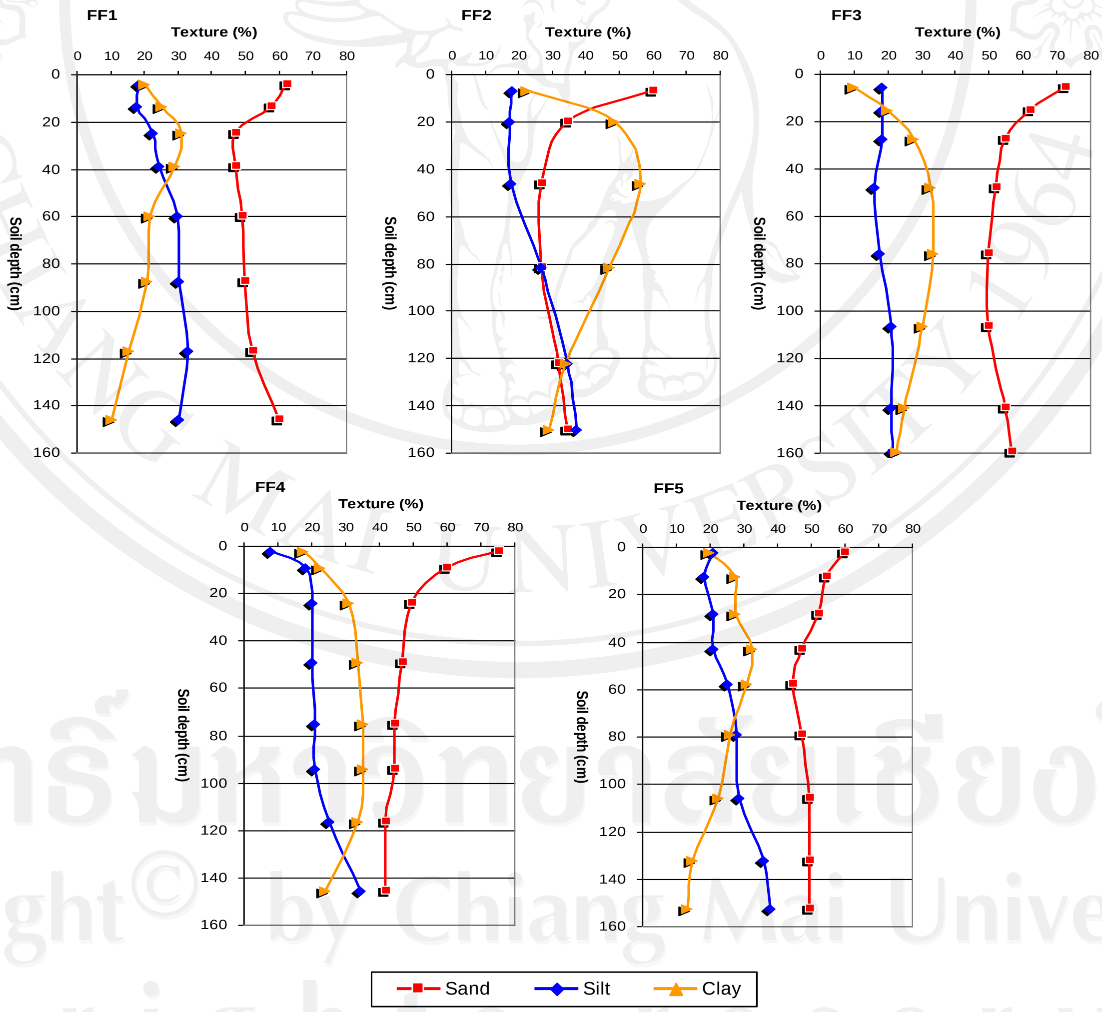

Figure 4-13 Distribution of soil particles in soil profiles under fragmented forests

4.3.2.3 Soil Chemical Properties

Soil chemical properties involve soil reaction (pH), contents of organic matter, total carbon, total nitrogen, extractable minerals, cation exchange capacity (CEC) and base saturation percentage. The data were given in Table 4-8 and Figure 4-14.

(1) Soil Reaction

Soil reaction is expressed in term of pH value.

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

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

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

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

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

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

Soils become acidic properties by the natural processes as well as human activities. The parent material of soils initially influences soil pH, for example, granitic rock is acidic. The decay of organic matter by soil microorganisms increases soil acidity. Soils which covered with pine trees had more acidic reaction than other broad-leaved trees. However, forest fire is usually occurred in dry season and causes decrease in acidic reaction in surface soils (Pritchett and Fisher, 1987; Seanchantong, 2005).

(2) Soil Organic Matter

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

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

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

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

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

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

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

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

Soils derived from slate, phyllite and quartzite under secondary lower montane forest in Ang Khang area, Chiang Mai province, contained a range of organic matter contents in surface soils between 38.67-85.52 $g.kg^{-1}$. Within the same area, the organic matter content in surface soil under a 25-year-old *Liquidambar formosana* plantation was considerably high (72.41 g,kg^{-1}) whereas a range of 26.34-50.96 $g.kg^{-1}$ was found in soils derived from gneiss under montane forest in Doi Inthanon area (Tongsiri, *et al*., 2007).

(3) Soil Carbon

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

(4) Total Nitrogen and C/N Ratios

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

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

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

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

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

(5) Available Phosphorus

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

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

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

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

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

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

(6) Extractable Potassium

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

However, concentrations of the extractable potassium in soil profiles of all fragmented montane forests were very high (101.5-745.5 $mg.kg^{-1}$). Potassium in plant litter and weathered rock are the main sources. The extractable potassium in subsoils was influenced by amounts of clay accumulations. This nutrient could be moved easily from surface soil and absorbed by clay minerals. The high concentrations of exchangeable potassium were also implied that the soil profiles had well developed (Wiklander, 1950; Khamyong *et al.*, 1999).

(7) Extractable Calcium, Magnesium and Sodium

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

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

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

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

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

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

(8) Cation Exchange Capacity (CEC)

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

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

(9) Base Saturation (BS)

The values of extractable bases including potassium, calcium, magnesium and sodium are shown in Table 4-9. The percents of base saturation in the top soils (0-10 cm) of five fragmented forests varied between 7.58-84.45%. The 5th fragmented forest had the highest of the base saturation percentage (Figure 4-15).

(10) Assessment of Soil Fertility Levels

According to soil fertility assessment of Soil Survey Division (1980), the soils under five fragmented montane forests were evaluated based on five parameters;

organic matter, available phosphorus, extractable potassium, cation exchange capacity and base saturation (Table 4-10). The total points were used for identify soil fertility levels.

In the 1st fragmented forest, the fertility levels of soils at 0-8 and 8-19 cm depth were medium. It was low in deeper soils. In the 2nd fragmented forest, 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 soil. In the 3rd fragmented forest, the soil fertility levels were medium throughout soil profile. In the 4th fragmented forest, the fertility level of soil at 0-34 cm depth was medium. It was low in deeper soils. In the 5th fragmented forest, the fertility level of soil at 0-5 cm depth was high. It was medium at 5-66 cm depth and low in deeper soils.

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

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 4-8 Some chemical properties in soil profiles under fragmented forests

Pedon	Profile	Soil depth	pH		O.M.		C		Total N		C/N	Available P		Extractable (mg.kg^{-1})								CEC	
		(cm)			(g.kg^{-1})	*	(g.kg^{-1})	*	(g.kg^{-1})	*	ratio	(mg.kg^{-1})	*	K	*	Ca	*	Mg	*	Na	*	(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)

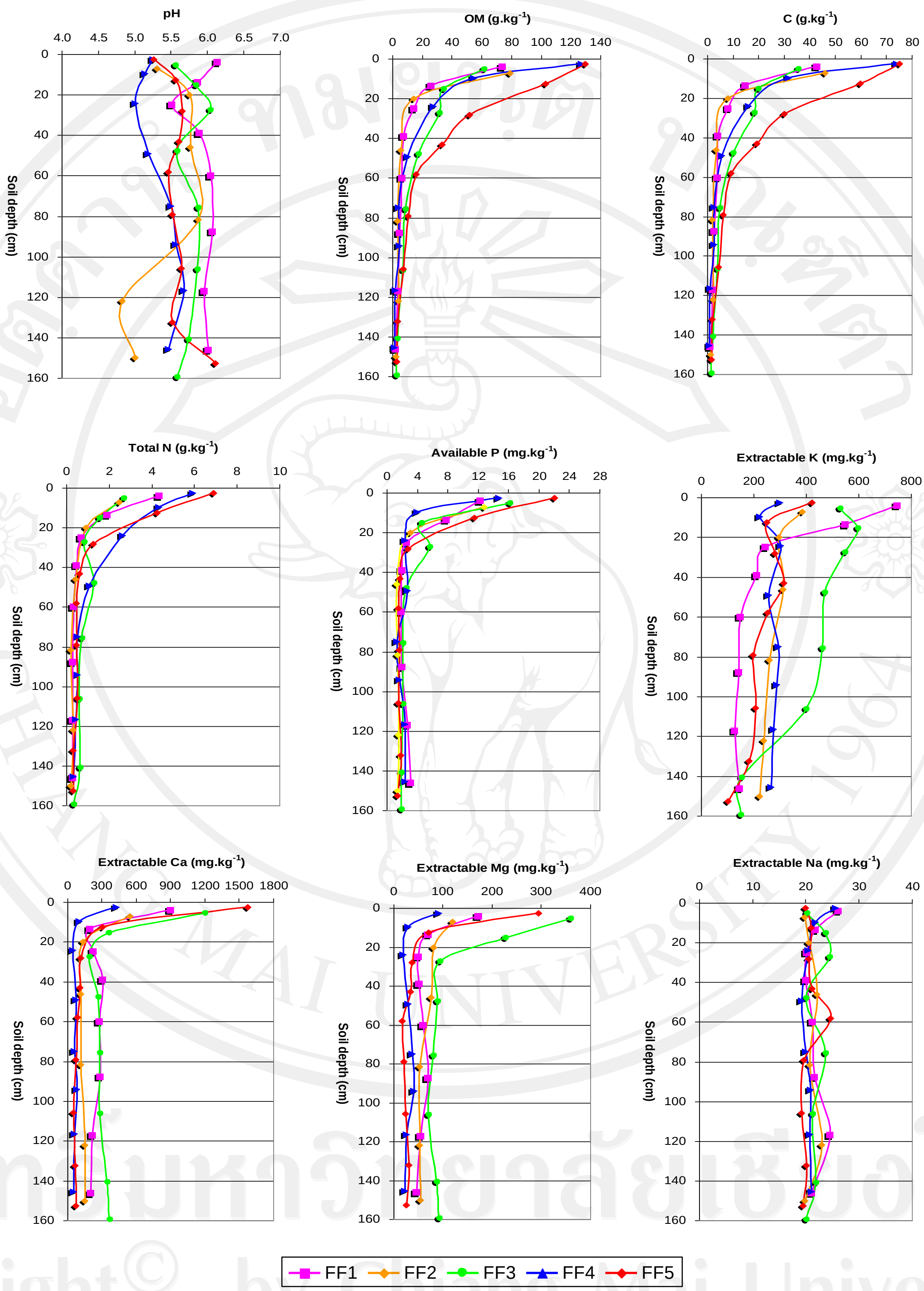

Figure 4-14 The pH values and contents of organic matter, carbon, nitrogen, and other extractable nutrients in soil profiles under fragmented forests

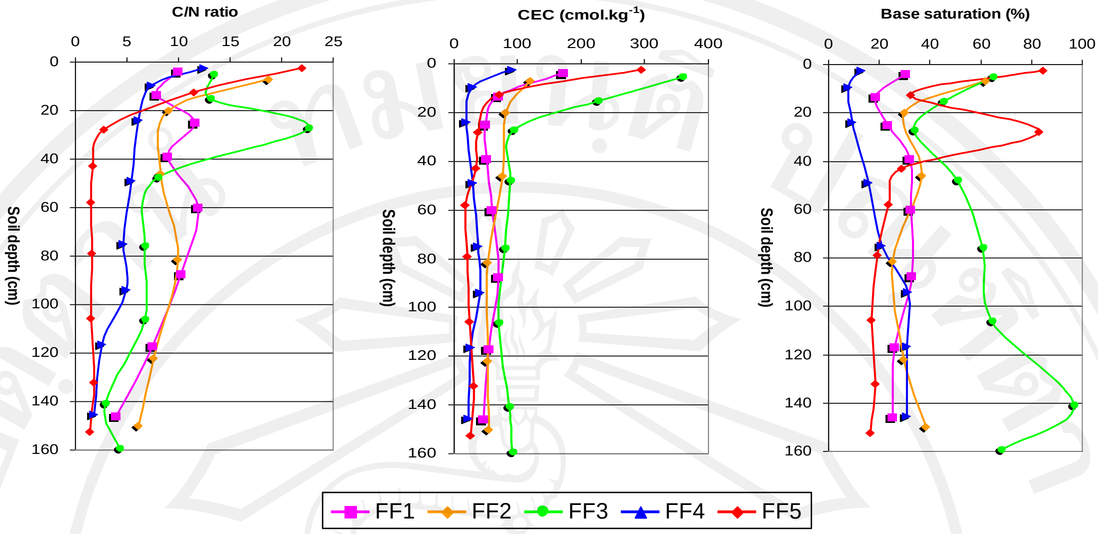

Figure 4-15 C/N ratios, cation exchange capacity (CEC) and base saturation percentages (BS) in soil profiles under fragmented forests

Table 4-9 Extractable bases and acidity, cation exchange capacity and base saturation in soil profiles under 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 4-10 Assessment of fertility levels in soil profiles under 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)

4.3.2.4 Roles of Plant Communities in Fragmented Forests

The plant species composition and diversity in fragmented forests have influenced on soil characteristics. Decomposition of above-ground and below-ground litter may be the key process. Decomposing litter of various broad-leaved species provides variable contents of nutrients, organic acids and other chemical substances. The pine needles usually give more acid to soil with low nutrients whereas broad-leaved species provide more bases and nutrients.

Overall data of plant communities in five fragmented forests where the soils were investigated are summarized in Table 4-11. The species richness, dominant tree species and species diversity index (SWI) were varied among the forests. The combined effects of these species affect on soil properties.

FF 1: It was located at 1,395 m msl altitude with species richness of 42 species (35 genus in 21 families). The forest was dominated by *P. kesiya*, *C. purpurea*, *S. wallichii* and *L. elegans*; and had Shannon-Wiener Index of species diversity of 4.65.

FF 2 : The forest was situated at 1,300 m msl and had species richness of 21 species (18 genus in 12 families). The dominant trees were *C. acuminatissima*, *Q. brandisiana*, *P. kesiya* and *C. purpurea*. The Shannon-Wiener Index of species diversity was 3.65.

FF 3 : Its attitude was 1,390 m msl. The forest had species richness of 40 species (35 genus in 22 families) dominated by *C. acuminatissima*, *C. diversifolia*, *L. elegans* and *C. purpurea*, *Schima wallichii* and had the Shannon-Wiener Index of species diversity of 4.15.

FF 4 : The forest was located at the higher altitude, 1,556 m msl. Its species richness was 37 species (33 genus in 24 families) and dominant trees were *C. diversifolia*, *S. wallichii*, *Helicia nilagirica* and *T. gymnanthera*. The Shannon-Wiener Index of species diversity was 4.51.

FF 5 : At altitude 1,545 m msl, the forest consisted of 32 species (28 genus in 18 families). It was dominated by *S. wallichii*, *Helicia nilagirica*, *T. gymnanthera* and *C. acuminatissima*; and had the Shannon-Wiener Index of species diversity of 4.23.

Table 4-11 Overall data of plant communities in five fragmented forests

	Parameters	Fragmented forests				
		1	2	3	4	5
1	Altitude (m)	1,395	1,300	1,390	1,556	1,545
2	Slope (%)	36	38	42	49	45
3	Number of Species	42	21	40	37	32
4	Number of Genus	35	18	35	33	28
5	Number of Families	21	12	22	24	18
6	Basal area (m^2/ha)	32.88	27.96	31.01	36.58	27.02
7	Dominant tree (%)					
	(1) *Pinus kesiya*	25.67	16.51	-	0.91	7.00
	(2) *Castanopsis acuminatissima*	1.61	30.80	17.37	-	7.78
	(3) *Castanopsis purpurea*	16.24	2.96	9.61	-	-
	(4) *Lithocarpus elegans*	5.80	0.25	10.22	-	-
	(5) *Schima wallichii*	9.36	0.79	5.96	9.77	21.90
	(6) *Quercus brandisiana*	-	19.34	-	-	-
	(7) *Castanopsis diversifolia*	0.09	-	10.80	33.22	-
	(8) *Ternstroemia gymnanthera*	3.19	0.51	2.62	9.55	5.56
	(9) *Helicia nilagirica*	0.91	-	1.17	9.71	10.90
8	IVI (%)					
	(1) *Pinus kesiya*	17.61	9.44	-	1.64	3.69
	(2) *Castanopsis acuminatissima*	1.31	22.80	9.39	-	4.47
	(3) *Castanopsis purpurea*	9.88	3.26	5.87	-	-
	(4) *Lithocarpus elegans*	5.41	0.42	8.11	-	-
	(5) *Schima wallichii*	8.95	0.99	4.04	8.14	17.00
	(6) *Quercus brandisiana*	-	13.22	-	-	-
	(7) *Castanopsis diversifolia*	0.30	-	7.34	20.16	-
	(8) *Ternstroemia gymnanthera*	4.11	0.85	2.72	10.39	5.12
	(9) *Helicia nilagirica*	0.71	-	1.29	7.52	6.62
9	Density (trees/ha)	1244	1056	1769	1056	1600
	(1) gbh < 50 cm	898	694	1447	733	1319
	(2) gbh 50-100 cm	254	278	268	235	217
	(3) gbh 100-150 cm	79	66	40	31	43
	(4) gbh 150-200 cm	13	13	15	31	22
	(5) gbh 200-250 cm	-	6	-	13	-
	(6) gbh 250-300 cm	-	-	-	13	-
10	Species diversity (SWI)	4.65	3.65	4.15	4.51	4.23

4.3.3 Soil Properties in Opened Area

4.3.3.1 Soil Physical Properties

Some physical properties including bulk density, amounts of gravel, soil particle distribution and soil texture are given in Table 4-12.

(1) Bulk Density and Amounts of Gravel

Bulk densities in opened area was very low at 0-40 cm depth (0.80-0.99 $Mg.m^{-3}$, low at 40-100 cm depth (1.12-1.18 $Mg.m^{-3}$), and increased to moderately low in deeper soil (1.27-1.38 $Mg.m^{-3}$). The amounts of gravel were varied with soil depth, 10.52-23.08%.

The comparison of bulk densities and amounts of gravel in *Pinus kesiya* plantations, fragmented forest and opened area are shown in Figure 4-16 and 4-17.

(2) Soil Particle Distribution and Soil Texture

The percentages of sand in soil profiles varied between 57.0-72.2%. It was rather high in top soils and decreased to subsoils. Silt particles in soil profiles varied between 18.5-30.0%, whereas the clay particles were 7.2-20.7%. The surface soil of opened area was sandy loam. The texture of subsoil was sandy loam to sandy clay loam (Figure 4-18).

Table 4-12 Some physical properties in a soil profile under opened area

Soil depth (cm)	Bulk density ($Mg.m^{-3}$)		Gravel (%)	Soil particle distribution (%)			Soil texture
				Sand	Silt	Clay	
0-5	0.80	VL	10.52	72.2	20.6	7.2	Sandy loam
5-10	0.82	VL	16.87	72.2	20.6	7.2	Sandy loam
10-20	0.80	VL	16.47	67.1	21.4	11.5	Sandy loam
20-30	0.87	VL	15.75	59.5	22.4	18.1	Sandy loam
30-40	0.99	VL	17.01	57.0	22.3	20.7	Sandy clay loam
40-60	1.12	L	23.08	59.5	20.6	19.9	Sandy loam
60-80	1.17	L	22.14	59.5	20.6	19.9	Sandy loam
80-100	1.18	L	20.72	61.6	18.5	19.9	Sandy loam
100-120	1.27	ML	20.11	57.0	23.1	19.9	Sandy loam
120-140	1.30	ML	16.80	59.5	23.2	17.3	Sandy loam
140-160	1.38	ML	12.14	57.0	30.0	13.0	Sandy loam

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

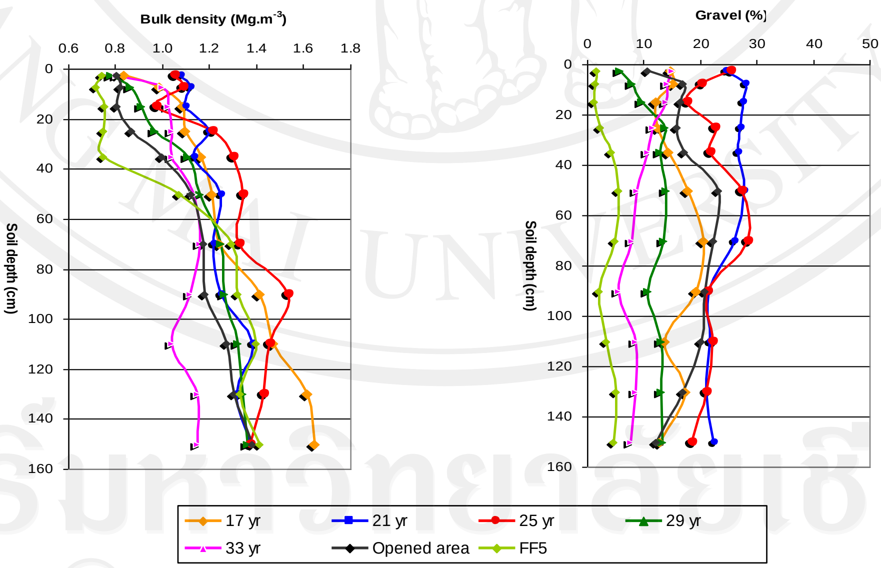

Figure 4-16 Variations of bulk densities (left) and gravel amounts (right) in soil profiles of pine plantations, opened area and the 5th fragmented forest

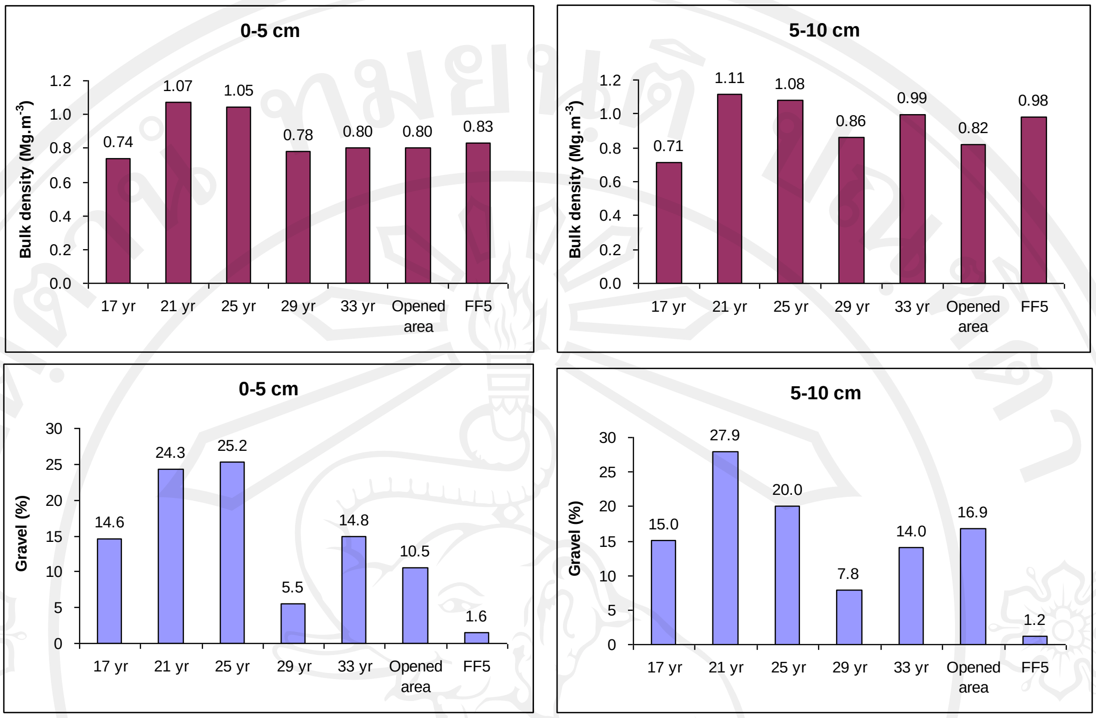

Figure 4-17 Comparison of bulk densities and gravel amounts in surface soils (0-5 and 5-10 cm) among pine plantations, opened area and the 5th fragmented forest

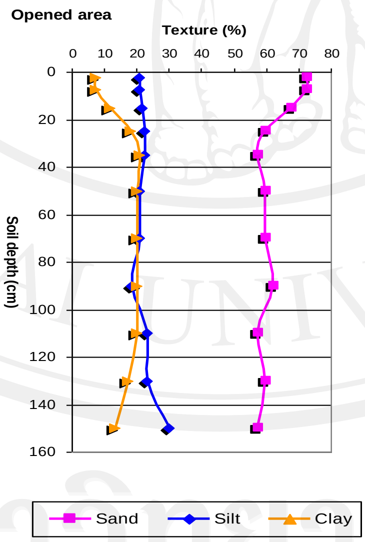

Figure 4-18 Distribution of soil particles along profile in opened area

4.3.3.2 Soil Chemical Properties

Soil reaction (pH), cation exchange capacity (CEC), base saturation percentage, contents of organic matter, carbon, nitrogen, and extractable minerals were investigated as soil chemical properties. The data are given in Table 4-13 and Figure 4-19.

(1) Soil Reaction

Soil reaction along soil profile of the opened area was mainly strongly acid. The pH values varied between 5.02-5.55.

(2) Soil Organic Matter and Soil Carbon

The contents of organic matter in surface soil at 0-20 cm depth of opened area were very high. The contents varied between 81.5-118.7 $g.kg^{-1}$ for the depth of 0-5, 5-10 and 10-20 cm. It was high at 20-30 cm depth, medium at 30-40 cm depth, and moderately low to low in deeper horizons.

The contents of carbon in the soil profile varied in the same trend as soil organic matter.

The soil in opened area consisted of very high organic matter in surface soil. This may be caused by decomposing dead materials of annual plants particularly grasses and herbs which grow densely in the opened area.

(3) Total Nitrogen

The total nitrogen content in top soil (0-10 cm depth) of opened area was high as 5.3 $g.kg^{-1}$. It was medium at 10-40 cm depth, and very low in deeper horizons.

The C/N ratios in surface soil were 11.0-13.2. The values in subsoils varied between 7.7- 32.5.

(4) Available Phosphorus

The concentration of available phosphorus was medium (12.8 $mg.kg^{-1}$) in top soil (0-5 cm depth) of opened area, and moderately low to very low in lower horizons.

(5) Extractable Potassium, Calcium, Magnesium and Sodium

The concentrations of extractable potassium were very high throughout soil profile of opened area, varying 171.5-468.3 $mg.kg^{-1}$. The concentration of extractable calcium was medium at 0-10 cm depth, and very low in deeper soil. The concentration of extractable magnesium was medium at 0-5 cm depth and low to very low in deeper soil whereas concentrations of extractable sodium were low to very low throughout soil profile.

(6) Cation Exchange Capacity (CEC)

The value of cation exchange capacity (CEC) in soil of opened area was very high 0-10 cm depth, high at 10-30 cm depth and moderately high to medium in deeper horizons. They were ranged from 10.7 to 33.5 $cmol.kg^{-1}$.

(7) Base Saturation (BS)

The values of extractable bases including potassium, calcium, magnesium and sodium in soil of opened area are shown in Table 4-14. The base saturation percentage in top soil (0-5 cm depth) was 34.74%, and decreased with soil depth. They varied between 22.67-34.74%. Therefore, it is a low base soil.

(8) Assessment of Soil Fertility Levels

Based upon soil fertility assessment of Soil Survey Division (1980), the soils in opened area was evaluated based on five parameters; organic matter, available phosphorus, extractable potassium, cation exchange capacity and base saturation (Table 4-10). The total points were used for identify soil fertility levels.

It is found that the soil fertility levels in opened area were medium throughout the soil profile. (Table 4-15).

4.3.3.3 Roles of Plant Community in Opened Areas

In opened area, herbal species which had the high densities were *Hypolepis punctata* and *Ageratina adenophora*. The other herb species included *Imperata cylindrical*, *Catimbium speciosum*. Some seedlings of tree species were observed particularly *Eurya nitida*. Few of *Melastoma sanguineum*, *Camellia pleurocarpa, Litsea cubeba, Blumea balsamifera* and *Tephrosia purpurea* were existed in the opened area.

Dense ground-covered herbs input some amounts of organic matter into surface soil, and some were moved into the deeper soil.

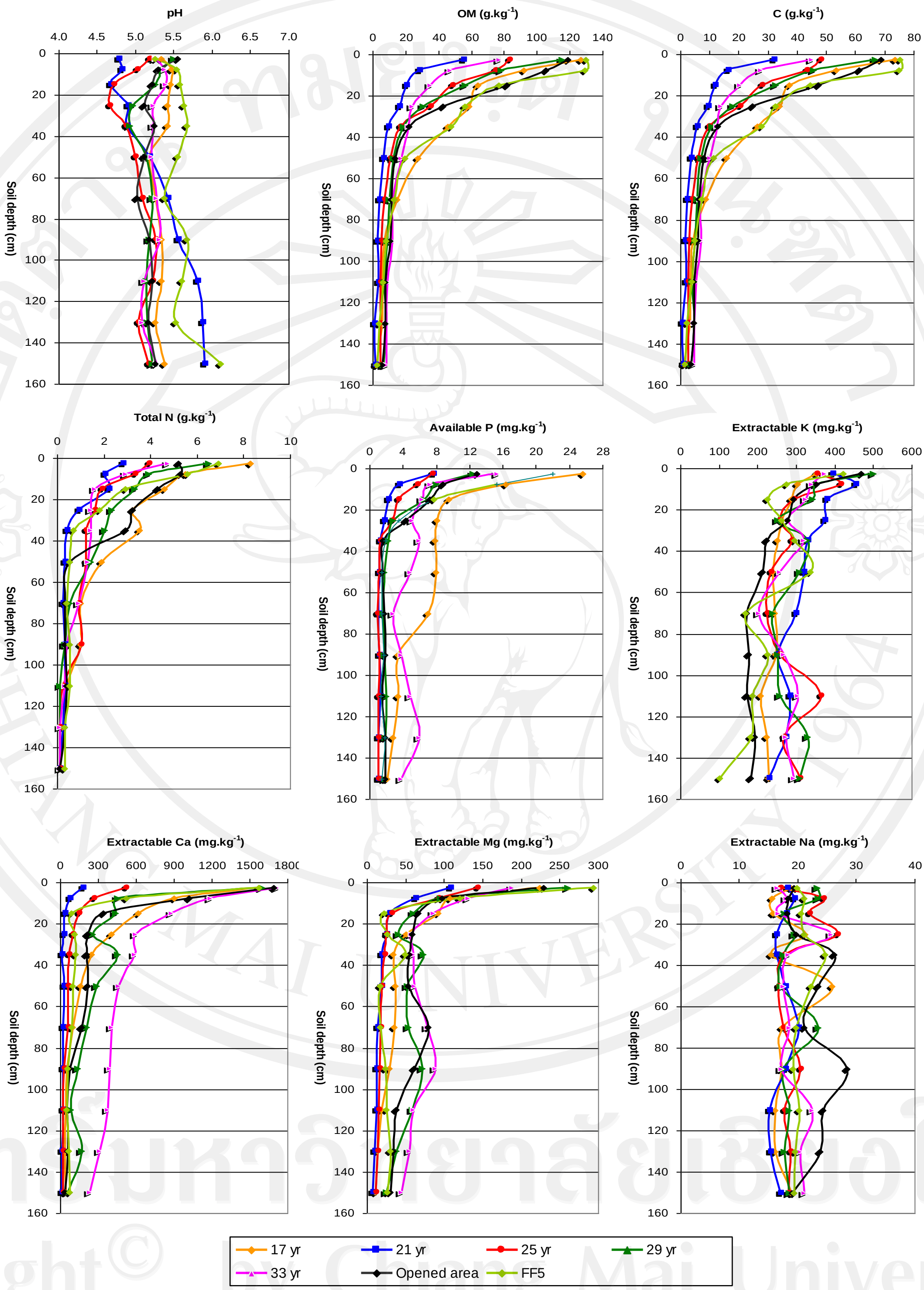

Figure 4-19 The pH values and contents of organic matter, carbon, nitrogen and extractable nutrients in soil profiles of pine plantations, opened area and the 5th fragmented forest

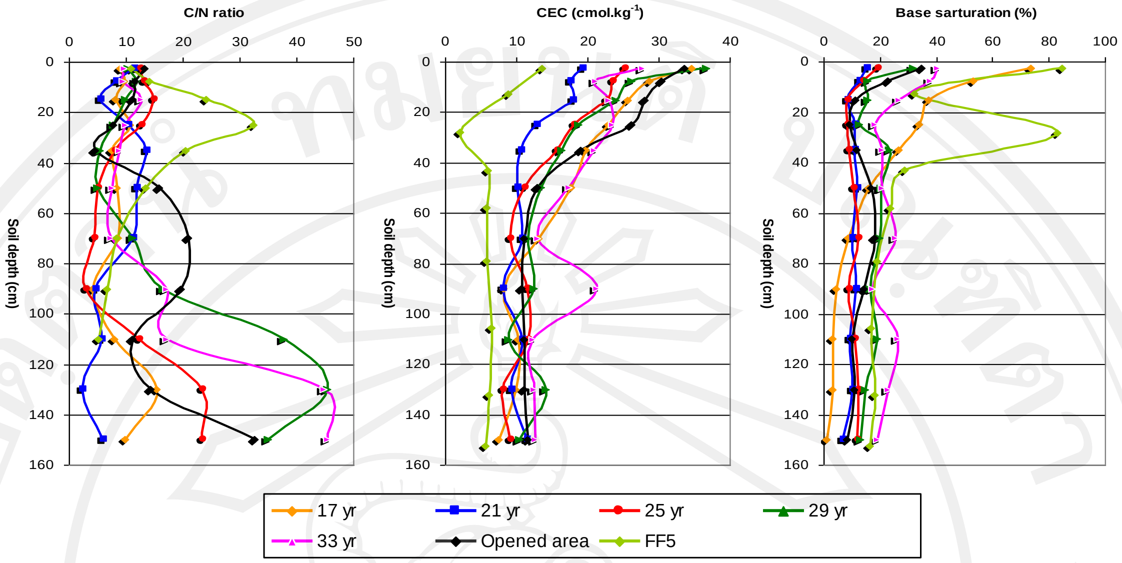

Figure 4-20 C/N ratio, cation exchange capacity (CEC) and base saturation percentage (BS) in soil profiles of pine plantations, opened area and the 5th fragmented forest

Table 4-13 Some chemical properties in a soil profile under opened area

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})	*
0 - 5	5.55	strongly acid	118.7	VH	68.9	VH	5.2	H	13.2	12.8	M	468.3	VH	1690.7	M	228.5	M	19.4	VL	33.5	VH
5 - 10	5.30	strongly acid	105.6	VH	61.3	VH	5.3	H	11.6	8.8	ML	352.6	VH	1019.2	M	97.2	L	18.2	VL	30.4	VH
10 - 20	5.22	strongly acid	81.5	VH	47.3	VH	4.3	M	11.0	7.3	ML	292.3	VH	337.2	VL	65.9	L	18.1	VL	28.0	H
20 - 30	5.11	strongly acid	42.7	H	24.8	H	3.2	M	7.7	4.3	L	277.2	VH	211.3	VL	58.1	L	19.6	VL	26.0	H
30 - 40	5.24	strongly acid	21.9	M	12.7	M	2.9	M	4.4	1.6	VL	221.8	VH	208.3	VL	54.2	L	26.1	L	18.9	MH
40 - 60	5.11	strongly acid	13.5	ML	7.8	ML	0.5	VL	15.7	1.5	VL	211.8	VH	211.3	VL	53.6	L	23.4	L	12.9	M
60 - 80	5.02	very strongly acid	10.8	ML	6.3	ML	0.3	VL	20.9	1.6	VL	171.5	VH	163.4	VL	78.4	L	21.0	VL	11.1	M
80 - 100	5.18	strongly acid	10.1	ML	5.9	ML	0.3	VL	19.5	1.8	VL	176.6	VH	73.4	VL	61.1	L	38.4	L	10.7	M
100 - 120	5.21	strongly acid	7.6	L	4.4	L	0.4	VL	11.0	1.4	VL	171.5	VH	43.5	VL	38.1	L	24.3	L	11.1	M
120 - 140	5.16	strongly acid	7.4	L	4.3	L	0.3	VL	14.3	1.8	VL	191.7	VH	58.5	VL	33.9	VL	23.7	L	11.0	M
140 - 160	5.25	strongly acid	5.6	L	3.2	L	0.1	VL	32.5	1.8	VL	181.6	VH	31.5	VL	29.2	VL	18.9	VL	11.6	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)

Table 4-14 Extractable bases and acidity, cation exchange capacity and base saturation in soil profile under opened area

Soil depth (cm)	K	Ca	Mg	Na	sum of base	Extr. acidity	CEC by sum	B.S. by sum (%)
	(cmol.kg^{-1})							
0 - 5	1.20	8.45	1.90	0.08	11.64	21.87	33.5	34.74
5 - 10	0.90	5.10	0.81	0.08	6.89	23.50	30.4	22.67
10 - 20	0.75	1.69	0.55	0.08	3.06	24.89	28.0	10.96
20 - 30	0.71	1.06	0.48	0.09	2.34	23.70	26.0	8.97
30 - 40	0.57	1.04	0.45	0.11	2.18	16.75	18.9	11.49
40 - 60	0.54	1.06	0.45	0.10	2.15	10.72	12.9	16.69
60 - 80	0.44	0.82	0.65	0.09	2.00	9.10	11.1	18.03
80 - 100	0.45	0.37	0.51	0.17	1.50	9.22	10.7	13.96
100 - 120	0.44	0.22	0.32	0.11	1.08	9.99	11.1	9.76
120 - 140	0.49	0.29	0.28	0.10	1.17	9.78	11.0	10.68
140 - 160	0.47	0.16	0.24	0.08	0.95	10.64	11.6	8.18

Table 4-15 Assessment of fertility levels in a soil profile under opened area

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
0 - 5	118.7	(3)	12.8	(2)	468.3	(3)	33.5	(3)	34.74	(1)	12	medium
5 - 10	105.6	(3)	8.8	(1)	352.6	(3)	30.4	(3)	22.67	(1)	11	medium
10 - 20	81.5	(3)	7.3	(1)	292.3	(3)	28.0	(3)	10.96	(1)	11	medium
20 - 30	42.7	(3)	4.3	(1)	277.2	(3)	26.0	(3)	8.97	(1)	11	medium
30 - 40	21.9	(2)	1.6	(1)	221.8	(3)	18.9	(2)	11.49	(1)	9	medium
40 - 60	13.5	(1)	1.5	(1)	211.8	(3)	12.9	(2)	16.69	(1)	8	medium
60 - 80	10.8	(1)	1.6	(1)	171.5	(3)	11.1	(2)	18.03	(1)	8	medium
80 - 100	10.1	(1)	1.8	(1)	176.6	(3)	10.7	(2)	13.96	(1)	8	medium
100 - 120	7.6	(1)	1.4	(1)	171.5	(3)	11.1	(2)	9.76	(1)	8	medium
120 - 140	7.4	(1)	1.8	(1)	191.7	(3)	11.0	(2)	10.68	(1)	8	medium
140 - 160	5.6	(1)	1.8	(1)	181.6	(3)	11.6	(2)	8.18	(1)	8	medium

Note: * 1 = low, 2 = medium, 3 = high
** <7 = low, 7-12 = medium, >12 = high

4.4 Discussion

Pine plantations on watershed areas could develop soil properties over stand age especially physical and chemical properties in the top soils because litterfall accumulations decomposed to humus and the root penetrate in to soils and made the pores in order to reduce bulk densities and allows water and air permeability. The content of organic matter in *P. kesiya* tended to increase over stand age except the age of 17 year-old was considered high whereas 33 year-old was low because of forest cover. The 17 year-old plantations was abundant with other broad-leaved trees and ground-covered which supplied high organic residues to the soil more than 33 year-old plantation which still had *P. kesiya* as dominat trees (90.89%) but quite low density and a litter bit with ground-covered. Reforestation using a single tree species could increase the amount of organic matter at the surface but, without or little ground-covered, this layer was much thinner than that under natural conditions.

The acidic reaction of pine plantations tended to be increased over stand age. The needle of pine leaves had high acidic reaction so soils which covered with pine trees had more acidic reaction than other broad-leaved trees. 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 of pine plantation management should promote succession of local broad-leaved tree species for long period.

All fragmented forests were found high content of organic matter because of parent materials. Soils formed from granite were moderately fertile and rich in organic matter in the top soil layers (Anusontpornperm and Kheoruenromne, 1996). Additionally, the accumulation of organic matter in these soils was influenced by forest cover too. The 4th and 5th fragmented forests were abundant of other broad-leaved species so the high rate of litter deposition combined with dense ground-covered species generated a high content of organic matter in the surface layer and leaching resulted in a high organic carbon proportion in the upper subsoil. The trend in total nitrogen distribution within the soil profiles was identical to that of soil organic matter.

The surface soil layers in fragmented forests were strongly acid which were suitable for pine growth so *P. kesiya* was found common in these areas. The 2nd fragmented forests had poorer developed than other fragmented forests due to the content of organic matter, C, N, P and K were found less than other so these cause to had lower species diversity. Extractable Mg, Ca and Na were no found different among fragmented forests. The 1st fragmented forest was slightly acid due to the highest of extractable K.

P. kesiya and *C. acuminatissima* distributed as 1,300-1,400 m msl, whereas *C. diversifolia* and *C. diversifolia* distributed as 1,500 m msl. Most of these fragmented forests had similarity in SWI except the 2nd fragmented forest had lower value. As this result, *Q. brandisiana* was dominated only in the 2nd fragmented forest which had dry site and poorer soil which was clay to sandy clay loam but *C. diversifolia* distributed in moist condition and fertile soil.

Many factors affecting for soil nutrient contents including, plant community, parent material, forest fire, climate and topography such as lower steep had nutrient contents more than higher steep slop (Handrick, 1981). The 1st and 2nd fragmented forests located on lower steep slope than other fragmented forests but had lower content of organic matter, C and N than other because of plant species covering. The 1st and 2nd fragmented forests were found *P. kesiya* as dominant trees, whereas the others abundant with other broad-leaved trees and higher species diversity. The major contribution of broad-leaved trees, which was continuously adding organic matter to the soils in the form of litter deposition, then cool, humid climates and low intensity of light due to late decomposition and found thick layer of organic matter on soil surface. The 4th and 5th fragmented forests had higher steep slop than other so Ca and Mg were reduced by surface runoff.

The assessment of soil fertility level using some chemical properties revealed that all soils in fragmented are moderately fertile. Pine plantations could develop some soil chemical properties over stand age in the top soils. Litterfall accumulations decomposed especially from other broad-leaved trees successions had a high potential to increase soil fertile. Soil under forest cover can preserve their equilibrium status. However, this result was shown no found affecting of opened area on soil properties.