CHAPTER 4

Soil Properties, Stored Carbon and Nutrients, Nutrient Recycling, and Seasonal Changes of Some Physical Environmental Factors in Fire and Non-fire DDF

Abstract

The impacts of forest fire on changes of soil physico-chemical properties, storages of carbon and nutrients, nutrient recycling through litterfall and seasonal changes of soil moisture and air temperature in dry dipterocarp forest (DDF) with and without fire were studied at Intakin Silvicultural Research Station, Chiang Mai Province. Forest fire is protected in some DDF for at least 10 years. Soil study was taken in one of two 1-ha plots used for vegetation assessment in each of fire and non-fire DDF. In each plot, three soil pits with 150 cm. width and 200 cm. depth were made, and soil samples were collected along three profiles. The soil composite samples were obtained from the same layers along three soil depths. They were layer analyzed for physical and chemical properties.

It is found that surface soil in DDF with fire had loamy sand whereas non-fire site was sandy loam. Other soil parameters in the surface soils of DDF with and without fire had some differences; bulk density: 1.26, 1.11 $Mg.m^{-3}$, pH: 5.1, 5.5 (strongly acid), contents of organic matter: 25.0, 32.1 $g.kg^{-1}$, carbon: 14.5, 18.6 $g.kg^{-1}$, nitrogen: 0.8, 1.2 $g.kg^{-1}$, available P: 13.6, 34.9 $mg.kg^{-1}$, extractable K: 282.8, 359.8 $mg.kg^{-1}$, Ca: 385.2, 621.9 $mg.kg^{-1}$, Mg: 154.7, 271.5 $mg.kg^{-1}$ and Na: 10.6, 18.9 $mg.kg^{-1}$, respectively. Average amounts of organic matter, carbon and nitrogen within 200 cm depth soil of fire site were 124, 72 and 7.9 $Mg.ha^{-1}$, respectively while the higher amounts of 212, 123 and 8.0 $Mg.ha^{-1}$ were for non-fire site. Extractable P, K, Ca, Mg and Na amounts of fire site were in the order of 50; 6,421; 3,827; 2,902 and 493 $kg.ha^{-1}$ while those of non-fire site were 156; 6,227; 4,287; 3,921 and 412 $kg.ha^{-1}$, respectively.

4.1 Introduction

The dry dipterocarp forest is widely distributed in mainland Southeast Asian countries, covering eastern region of India, central Myanmar, Thailand, Laos and Vietnam (Sukwong, 1974). In Thailand, this forest covers the most extensive area compared to other forest types. It is believed to be a fire climax forest by human influences and maintained through regular burning. The forest occurs in seasonal climate with a distinct dry season (Stott, 1990). This forest type covers an extensive area in northeastern, northern, central and western regions of the country. They found on poor soil.

Major factors that influence the effect of fire on soil temperature are fire intensity and two physical soil properties: soil heat capacity and thermal conductivity. The thermal conductivity of air, which comprises 50% of the soil volume, is several orders of magnitude lower than organic matter or mineral particles so that heat generated from fire does not penetrate very deeply into forest soils. Humphreys and Craig (1981) reported that soil temperature did not exceed 25°C at depths of about 3, 5.5, and 7 cm for the prescribed burn, wildfire, and heavy slash fire, respectively; however, soil temperatures exceeded 200°C down to 10 cm beneath a log pile fire. In general, the surface layers of dry soil reach higher temperatures than those of wet soil, but the temperature increases are propagate to greater depth on wet soil.

The objective of this chapter was to describe impacts of forest fire on changes of the soil physico-chemical properties, storages of carbon and nutrients, nutrient recycling through litterfall and seasonal changes of soil moisture and air temperature in dry dipterocarp forest (DDF) with and without fire at Intakin Silvicultural Research Station, Chiang Mai Province.

4.2 Materials and Methods

4.2.1 Soil Sampling

Soil study was taken in one of two 1-ha permanent plots used for vegetation survey in each of fire and non-fire DDF. In each plot, three soil pits with 150 cm. width and 200 cm. depth were made, and soil samples were collected along the three profiles. Soil sampling was taken from 13 depths; 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-120, 120-140, 140-160, 160-180 and 180-200 cm. The soil composite samples were obtained from the same layers along three soil depths. They were layer analyzed for physical and chemical properties in laboratory.

4.2.2 Soil Analysis

A. 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.

B. Analysis of Soil Chemical Properties

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

(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)

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

4.2.3 Nutrient Accumulations in Soils

Amounts of nutrients accumulated in soils including total C and N, extractable P, K, Ca, Mg and Na were calculated from their contents and soil mass for each layer along soil profiles.

4.2.4 Seasonal Changes of Some Physical Environmental Factors

A. Moisture Contents in Soil

The seasonal change of soil moisture contents is investigated in the same permanent plots used for vegetation survey. In each plot, sixteen soil samples (replications) were collected monthly from the depth of 0-5 cm, and totally 64 soil samples were obtained. They were later analyzed for moisture contents in laboratory.

B. Air Temperature

The air temperature in the forests had been recorded by placing two maximum-minimum thermometers at 1.3 m above ground in each plot, and recorded for temperature every week throughout a year.

4.2.5 Dry Matter and Nutrients in Litterfall

The amounts of above-ground litterfall in fire and non-fire DDF were gathered monthly throughout a year. In each plot, 30 circular litter traps (0.5 m^2 in area) were arranged systematically. The litter was separated into leaf, branch and others. The annual amounts of litter dry matter were determined. The litter samples were analyzed for nutrient composition in laboratory.

4.3 Results

4.3.1 Soil Properties in Fire and Non-fire DDF

4.3.1.1 Soil Physical Properties

Some physical properties of soils under fire and non-fire DDF including bulk density, amounts of gravel, soil particle distribution and soil texture were given in Table 4-1 and Figure 4-1 to 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).

The densities of soils under DDF with and without fire were low in the surface soils and increased with soil depth.

DDF with annual fire:

In Plot 1, the density in surface soil at 0-10 cm depth was moderately low, 1.32-1.38 Mg.m^{3}. The densities were medium in deeper soil, 1.41-1.63 Mg.m^{-3}.

In Plot 2, the density in surface soil at 0-5 cm depth was moderately low, 1.21 Mg.m^{-3}. The densities were moderately low to medium in deeper soil, 1.28-1.48 Mg.m^{-3}. The lower densities in surface soils might be influenced by the higher contents of organic matter.

DDF without fire:

In Plot 1, the density in surface soil at 0-5 cm depth was low, 1.02 Mg.m^{-3}. The densities were moderately low to medium in deeper soil, 1.28-1.44 Mg.m^{-3}.

In Plot 2, the density in surface soil at 0-5 cm depth was moderately low, 1.20 Mg.m^{-3}. They were moderately low to medium in deeper soil, 1.39-1.58 Mg.m^{-3}. The lower densities in surface soils were caused by the higher contents of organic matter.

The effect of fire on bulk density is very small in surface soil, and there was no effect in subsoil.

(2) Amounts of gravel

DDF with annual fire:

In Plot 1, the amounts of gravel in soil profiles were low, 1.37-4.94%. No change of gravel amounts along soil profile was observed.

In Plot 2, the amounts of gravel in soil profiles were low, but higher than Plot 1, 3.46-12.82%. The amounts were increased with soil depth.

DDF without fire:

In Plot 1, the amounts of gravel in soil profiles were low, 1.11-5.38%, and they were no change with soil depth.

In Plot 2, the amounts of gravel in soil profiles were also low, 1.29-6.06%, and they were no change with soil depth.

There was no effect of fire on gravel amounts in soil profile.

(3) Soil particle distribution

The combination of sand, silt and clay particles in soil is important to physical properties water potential, organic matter binding, cation exchange, and overall biotic activity.

a. Sand Particle

Soils in DDF with and without fire had the high percentages of sand in the top soil and decreased with soil depth.

DDF with annual fire:

In Plot 1, the percentage of sand particle in surface soil at 0-5 cm was high, 80.0%. They were decreased with soil depth, 51.7-77.4%.

In Plot 2, the percentage of sand particle in surface soil at 0-5 cm was also high, 80.2%. They were decreased with soil depth, 41.3-75.0%.

DDF without fire:

In Plot 1, the percentage of sand particle in surface soil at 0-5 cm was high, 74.6%, and they were decreased with soil depth, 44.2-67.2%.

In Plot 2, the percentage of sand particle in surface soil at 0-5 cm was also high, 77.3%. They were decreased with soil depth, 36.7-67.2%.

A little decrease of sand particle percentage in surface soil at 0-5 cm depth of non-fire DDF were observed.

b. Silt Particle

DDF with annual fire:

In Plot 1, the percentage of silt particle in surface soil at 0-10 cm was 11.85%. They were decreased in deeper soil, 5.3-9.6%.

In Plot 2, the percentage of silt particle in surface soil at 0-5 cm was 14.1%, and they were some small decrease with soil depth, 8.9-12.3%.

DDF without fire:

In Plot 1, the percentage of silt particle in surface soil at 0-10 cm was 17.5%, and they were decreased in deeper soil, 12.3-15.5%.

In Plot 2, the percentage of silt particle in surface soil at 0-5 cm was 13.7%. They did not change with soil depth, 7.3-16.5%.

The percentages of silt particle were some higher in the soil profiles of non-fire DDF.

c. Clay Particle

DDF with annual fire:

In Plot 1, the percentage of clay particle in surface soil at 0-5 cm was low, 8.2%. They were increased in deeper soil, up to 40%.

In Plot 2, the percentage of clay particle in surface soil at 0-5 cm was low, 5.7%, and they were increased in deeper soil, up to 49.2%.

DDF without fire:

In Plot 1, the percentage of clay particle in surface soil at 0-5 cm was low, 7.9%. They were increased in deeper soil, up to 40.9%.

In Plot 2, the percentage of clay particle in surface soil at 0-5 cm was low, 9.0%, and they were increased in deeper soil, up to 50.9%.

The forest fire might induce sheet erosion and a small extent of rill erosion in the surface soil (0-10 cm), and resulted in some losses of clay and silt particles and increase of the percentage of sand.

(4) Soil texture

Mineral soils are usually grouped into three broad textured classes – sands, silts and clays. Soil texture effects many other properties like structure, chemistry, and most notably, soil porosity, and permeability. The soil texture refers to the relative proportion of sand, silt and clay particles.

DDF with annual fire:

In Plot 1, the texture in surface soil (0-5 cm depth) was loamy sand. It was sandy loam at 5-20 cm depth, sandy clay loam at 20-40 cm, and sandy clay in deeper horizons.

In Plot 2, the texture in surface soil (0-5 cm depth) was loamy sand. It was sandy loam at 5-10 cm depth, sandy clay loam at 10-30 cm, sandy clay at 30-60 cm, and clay in deeper soil.

DDF without fire:

In Plot 1, the texture in surface soil (0-20 cm depth) soil was sandy loam. It was sandy clay loam at 20-60 cm depth, sandy clay loam at 60-180 cm, and clay in deeper soil.

In plot 2, the texture in surface soil (0-10 cm depth) was sandy loam. It was sandy clay loam at 10-30 cm depth, sandy clay at 30-40 cm, and clay in deeper soil.

The texture of surface soil in DDF with fire was loamy sand whereas that of non-fire DDF had more fine soil, sandy loam. The differences of textures in subsoils of fire and non-fire DDF are thought to be the site variation, and were not affected by forest fire.

Table 4-1 Some physical properties in soil profiles under fire and non-fire DDF

Plot	Soil depth (cm)	Bulk density ($Mg.m^{-3}$)	*	Gravel (%)	Soil particle distribution (%) Sand	Silt	Clay	Soil texture
Fire DD-1	0-5	1.32	ML	2.02	80.0	11.8	8.2	Loamy sand
	5-10	1.38	ML	1.37	77.4	11.9	10.7	Sandy loam
	10-20	1.41	M	3.75	72.3	9.4	18.3	Sandy loam
	20-30	1.49	M	2.21	62.2	9.5	28.3	Sandy clay loam
	30-40	1.50	M	3.36	59.6	9.6	30.8	Sandy clay loam
	40-60	1.53	M	1.86	57.1	5.4	37.5	Sandy clay
	60-80	1.46	M	2.03	54.7	5.3	40.0	Sandy clay
	80-100	1.51	M	2.44	54.7	7.8	37.5	Sandy clay
	100-120	1.52	M	1.64	54.7	7.8	37.5	Sandy clay
	120-140	1.47	M	3.32	54.7	7.8	37.5	Sandy clay
	140-160	1.63	M	2.13	52.1	9.6	38.3	Sandy clay
	160-180	1.56	M	4.44	52.1	9.6	38.3	Sandy clay
	180-200	1.58	M	4.94	51.7	8.3	40.0	Sandy clay
Fire DDF-2	0-5	1.21	ML	3.46	80.2	14.1	5.7	Loamy sand
	5-10	1.44	M	5.21	75.0	11.1	13.9	Sandy loam
	10-20	1.42	M	6.23	67.3	9.5	23.2	Sandy clay loam
	20-30	1.35	ML	9.66	54.7	11.3	34.0	Sandy clay loam
	30-40	1.35	ML	8.81	49.6	11.3	39.1	Sandy clay
	40-60	1.28	ML	7.59	47.0	8.9	44.1	Sandy clay
	60-80	1.39	ML	6.93	44.5	9.7	45.8	Clay
	80-100	1.35	ML	11.58	41.9	8.9	49.2	Clay
	100-120	1.43	M	8.56	41.3	10.4	48.3	Clay
	120-140	1.48	M	10.09	44.5	9.7	45.8	Clay
	140-160	1.47	M	10.54	44.5	9.7	45.8	Clay
	160-180	1.47	M	12.05	44.5	10.5	45.0	Clay
	180-200	1.42	M	12.82	41.9	12.3	45.8	Clay
Non-fire DDF-1	0-5	1.02	L	3.19	74.6	17.5	7.9	Sandy loam
	5-10	1.31	ML	1.38	67.2	15.5	17.3	Sandy loam
	10-20	1.34	ML	3.90	67.2	13.7	19.1	Sandy loam
	20-30	1.44	M	4.10	64.6	13.8	21.6	Sandy clay loam
	30-40	1.32	ML	4.50	59.5	12.2	28.3	Sandy clay loam
	40-60	1.28	ML	4.82	54.4	12.3	33.3	Sandy clay loam
	60-80	1.36	ML	1.28	51.9	12.3	35.8	Sandy clay
	80-100	1.43	M	1.62	51.9	12.3	35.8	Sandy clay
	100-120	1.35	ML	1.11	49.3	14.0	36.7	Sandy clay
	120-140	1.33	ML	1.98	51.3	12.9	35.8	Sandy clay
	140-160	1.39	ML	2.54	49.3	12.3	38.4	Sandy clay
	160-180	1.29	ML	3.32	46.8	12.3	40.9	Sandy clay
	180-200	1.39	ML	5.38	44.2	14.9	40.9	Clay
Non-fire DDF-2	0-5	1.20	ML	2.13	77.3	13.7	9.0	Sandy loam
	5-10	1.43	M	1.29	67.2	13.7	19.1	Sandy loam
	10-20	1.39	ML	3.07	62.1	13.8	24.1	Sandy clay loam
	20-30	1.50	M	1.32	54.5	12.2	33.3	Sandy clay loam
	30-40	1.46	M	2.16	46.9	12.3	40.8	Sandy clay
	40-60	1.39	ML	5.26	41.8	7.3	50.9	Clay
	60-80	1.42	M	2.38	40.0	10.7	49.3	Clay
	80-100	1.49	M	2.82	41.8	11.4	46.8	Clay
	100-120	1.42	M	3.80	41.8	12.3	45.9	Clay
	120-140	1.50	M	3.80	39.2	14.0	46.8	Clay
	140-160	1.58	M	2.56	39.2	14.0	46.8	Clay
	160-180	1.48	M	6.06	36.7	16.5	46.8	Clay
	180-200	1.56	M	2.83	38.4	14.8	46.8	Clay

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

Table 4-2 Effects of fire on some soil physical properties under DDF

Soil depth	Bulk density (Mg.m^{-3})			Gravel (%)			Sand (%)			Silt (%)			Clay (%)		
(cm)	F	WF	**EF**	F	WF	**EF**	F	WF	**EF**	F	WF	**EF**	F	WF	**EF**
0-5	1.26	1.11	**0.15**	2.7	2.7	**0.0**	80.1	76.0	**4.1**	13.0	15.6	**-2.6**	7.0	8.5	**-1.5**
5-10	1.41	1.37	**0.04**	3.3	1.3	**2.0**	76.2	67.2	**9.0**	11.5	14.6	**-3.1**	12.3	18.2	**-5.9**
10-20	1.41	1.37	**0.04**	5.0	3.5	**1.5**	69.8	64.7	**5.1**	9.5	13.8	**-4.3**	20.8	21.6	**-0.8**
20-30	1.42	1.47	**-0.05**	5.9	2.7	**3.2**	58.5	59.6	**-1.1**	10.4	13.0	**-2.6**	31.2	27.5	**3.7**
30-40	1.42	1.39	**0.03**	6.1	3.3	**2.8**	54.6	53.2	**1.4**	10.5	12.3	**-1.8**	35.0	34.6	**0.4**
40-60	1.40	1.34	**0.06**	4.7	5.0	**-0.3**	52.1	48.1	**4.0**	7.2	9.8	**-2.6**	40.8	42.1	**-1.3**
60-80	1.43	1.39	**0.04**	4.5	1.8	**2.7**	49.6	46.0	**3.6**	7.5	11.5	**-4.0**	42.9	42.6	**0.3**
80-100	1.43	1.46	**-0.03**	7.0	2.2	**4.8**	48.3	46.9	**1.4**	8.4	11.9	**-3.5**	43.4	41.3	**2.1**
100-120	1.48	1.39	**0.09**	5.1	2.5	**2.6**	48.0	45.6	**2.4**	9.1	13.2	**-4.1**	42.9	41.3	**1.6**
120-140	1.48	1.42	**0.06**	6.7	2.9	**3.8**	49.6	45.3	**4.3**	8.8	13.5	**-4.7**	41.7	41.3	**0.4**
140-160	1.55	1.49	**0.06**	6.3	2.6	**3.7**	48.3	44.3	**4.0**	9.7	13.2	**-3.5**	42.1	42.6	**-0.5**
160-180	1.51	1.39	**0.12**	8.2	4.7	**3.5**	48.3	41.8	**6.5**	10.1	14.4	**-4.3**	41.7	43.9	**-2.2**
180-200	1.50	1.48	**0.02**	8.9	4.1	**4.8**	46.8	41.3	**5.5**	10.3	14.9	**-4.6**	42.9	43.9	**-1.0**

Note: F = Fire, WF = Without fire, EF = Effects of fire

4.3.1.3 Soil Chemical Properties

Some chemical properties of soils under fire and non-fire DDF were given in Table 4-3 and Figure 4-3. Table 4-4 shows the effects of forest fire on some chemical properties.

(1) Soil Reaction

The soil reaction is considered from pH values.

DDF with annual fire:

In Plot 1, the reaction in surface soil at 0-10 cm depth was very strongly acid, pH = 4.93-5.03. They were strongly acid to moderately acid in deeper soil, pH = 5.26-5.89.

In Plot 2, the surface soil at 0-60 cm depth had strongly acid, pH = 5.20-5.48. They were moderately acid in deeper soil, pH = 5.62-5.91.

DDF without fire:

In Plot 1, the reaction in surface soil at 0-20 cm depth had moderately acid, pH = 5.62-5.92. They were strongly acid to moderately acid in deeper soil, pH = 5.47-5.80.

In Plot 2, the surface soil at 0-40 cm depth had strongly acid, pH = 5.14-5.57. They were moderately acid in deeper soil, pH = 5.60-5.88.

The surface soils in non-fire-DDF had the small increase of pH values. This implied to the lesser acid properties. It is thought that decomposing leaf litter of broad-leaved tree species can release some bases to the soil.

(2) Soil Organic Matter

DDF with annual fire:

In Plot 1, the content of organic matter was moderately high (26.7 $g.kg^{-1}$) in surface soil (0-5 cm depth), medium (16.0 $g.kg^{-1}$) at 5-10 cm and low to very low in deeper soil.

In Plot 2, the content was medium (23.3 $g.kg^{-1}$) in surface soil (0-5 cm depth), low at 5-20 cm, and very low in deeper soil.

DDF without fire:

In Plot 1, the content of organic matter was high (37.8 $g.kg^{-1}$) in surface soil (0-5 cm depth), medium at 5-10 cm and moderately low to low in deeper soil.

In Plot 2, the content was moderately high (26.3 $g.kg^{-1}$) in surface soil (0-5 cm depth), medium at 5-10 cm and low in deeper soil.

The average contents of organic matter in soil profiles of non-fire DDF particularly the surface horizons were higher than DDF with annual fire.

(3) Soil Carbon

The effect of fire, and carbon contents in soils under fire and non-fire DDF were varied with the same trend as soil organic matter since it is assumed that organic matter consists of 58% carbon in average.

(4) Total Nitrogen and C/N Ratios

DDF with annual fire:

In Plot 1, nitrogen content was low in surface soil (0-5 cm depth), 1.3 $g.kg^{-1}$, and very low in deeper soil. The C/N ratios in surface soil varied between 11.9-24.4, and were lower in subsoil.

In Plot 2, nitrogen content was low in surface soil (0-5 cm depth), 0.2 $g.kg^{-1}$, and very low in deeper soil. The C/N ratios in surface soil varied between 7.4-67.6, and were lower in subsoil.

DDF without fire:

In Plot 1, the nitrogen content was also low in surface soil (0-5 cm depth), 1.3 $g.kg^{-1}$, and very low in deeper soil. The C/N ratios in surface soil varied between 11.6-23.4, and were lower in subsoil.

In Plot 2, the nitrogen content were very low in surface soil (0-5 cm depth), 1.1 $g.kg^{-1}$, and very low in deeper soil. The C/N ratios in surface soil varied between 13.6-25.5, and were not change with soil depth.

The surface soils of non-fire DDF had the small increase of average nitrogen contents compared to DDF with annual fire. However, the nitrogen contents in soil profiles of these DDF were still low to very low.

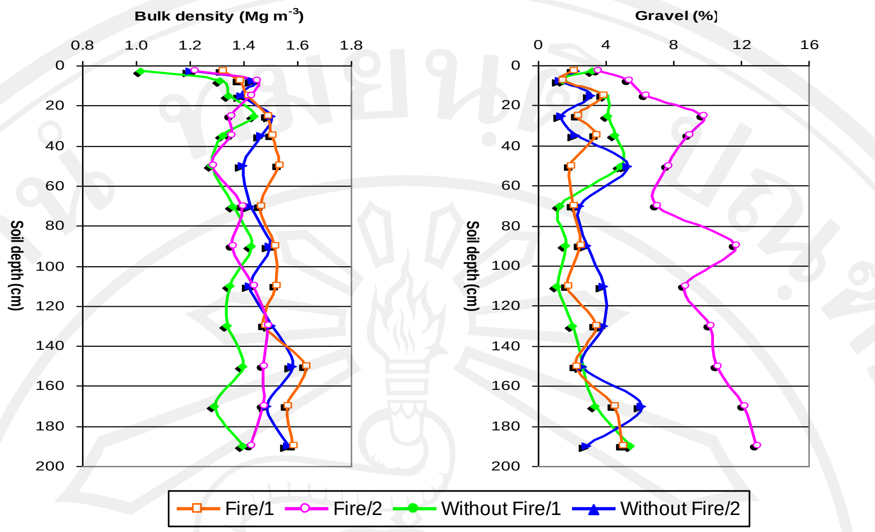

Figure 4-1 Variations of bulk densities (left) and gravel amounts (right) in soil profiles under DDF

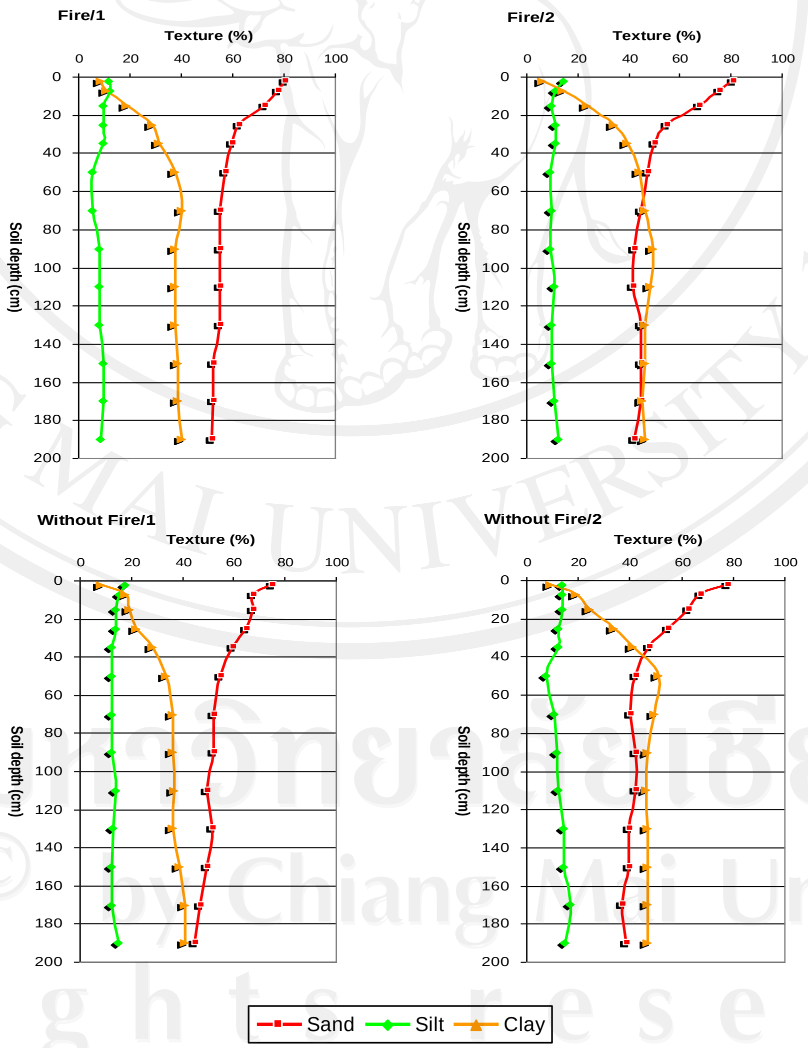

Figure 4-2 Distribution of soil particles along soil profiles under DDF

(5) Available Phosphorus

DDF with annual fire:

In Plot 1, concentration of available phosphorus in surface soil (0-5 cm depth) was medium (14.4 mg.kg^{-1}). They were moderately high (17.4-17.9 mg.kg^{-1}) at 5-20 cm, and low to very low in deeper soils.

In Plot 2, the concentration of available phosphorus in surface soil (0-5 cm depth) was medium (12.8 mg.kg^{-1}). They were low to very low in deeper soils.

DDF without fire:

In Plot 1, the concentrations of available phosphorus in surface soil (0-30 cm depth) was high to very high (39.5-79.7 mg.kg^{-1}). It was moderately low (8.5 mg.kg^{-1}) at 30-40 cm, and they were very low in deeper soils.

In Plot 2, the concentration of available phosphorus in top soil (0-5 cm depth) was high (26.6 mg.kg^{-1}). They were moderately low (6.5-9.1 mg.kg^{-1}) at 5-20 cm, and very low in deeper soils.

The concentrations of available phosphorus in the surface soil were increased for non-fire DDF. This increase might be caused by the release of phosphorus from decomposing plant litter.

(6) Extractable Potassium

DDF with annual fire:

In Plot 1, concentrations of extractable potassium were very high throughout soil profile. The values varied between 194.3-266.5 mg.kg^{-1}.

In Plot 2, the concentrations of extractable potassium were also very high throughout soil profile. The values varied between 164.0-299.0 mg.kg^{-1}.

DDF without fire:

In Plot 1, the concentrations of extractable potassium were also very high throughout soil profile. The values varied between 166.8-365.3 mg.kg^{-1}.

In Plot 2, the concentrations of extractable potassium were also very high throughout soil profile. The values varied between 191.5-354.3 mg.kg^{-1}.

The surface soil under non-fire DDF contained the higher concentrations of extractable potassium than DDF with annual fire.

(7) Extractable Calcium, Magnesium and Sodium

(7.1) Extractable Calcium

DDF with annual fire:

In Plot 1, concentrations of extractable calcium were very low throughout soil profile. The values varied between 48.5-321.8 mg.kg^{-1}.

In Plot 2, the concentration of extractable calcium were low in surface soil (0-5 cm depth), 448.6 mg.kg^{-1}, and very low in deeper soil.

DDF without fire:

In Plot 1, the concentration of extractable calcium were low in surface soil (0-5 cm depth), 785.3 mg.kg^{-1}, and very low in deeper soil.

In Plot 2, the concentration of extractable calcium were low in surface soil (0-5 cm depth), 458.5 mg.kg^{-1}, and very low in deeper soil.

(7.2) Extractable Magnesium

DDF with annual fire:

In Plot 1, concentrations of extractable magnesium were medium (139.1-168.1 mg.kg^{-1}) in surface soil at 0-60 cm depth, and low in subsoil.

In Plot 2, the concentration of extractable magnesium was medium in surface soil at 0-5 cm depth, 170.3 mg.kg^{-1}, and low in deeper soil.

DDF without fire:

In Plot 1, concentrations of extractable magnesium were medium throughout soil profile. The values varied between 125.7-319.9 mg.kg^{-1}.

In Plot 2, the concentrations of extractable magnesium were low to medium in surface soil and subsoil, and were not change with soil depth.

The concentrations of extractable magnesium in soil profile under non-fire DDF were higher than DDF with annual fire.

(7.3) Extractable Sodium

In DDF with and without fire, the concentrations of extractable sodium in soil profiles were low to very low (9.8-31.0 mg.kg^{-1}) throughout soil profiles.

The extractable sodium in the surface soil at 0-5 cm of non-fire DDF was some small higher than DDF with annual fire. They were decreased with soil depth.

(8) Cation Exchange Capacity (CEC)

The CEC is expressed as the number of centimoles of positive charge cmol.kg^{-1} that can be absorbed per unit mass. Soils with a high cation exchange capacity are more fertile than those with a low exchange capacity. (Figure 4-4).

DDF with annual fire:

In Plot 1, the CEC in surface soil at 0-40 cm depth varied between 9.4-11.9 cmol.kg^{-1}. In subsoil, they were 8.5-14.8 cmol.kg^{-1}.

In Plot 2, the CEC in surface soil at 0-40 cm depth varied between 9.6-14.8 cmol.kg^{-1}. In subsoil, they were 8.8-14.9 cmol.kg^{-1}.

DDF without fire:

In Plot 1, the CEC in surface soil at 0-40 cm depth varied between 10.5-15.9 cmol.kg^{-1}. In subsoil, they were 6.8-18.5 cmol.kg^{-1}.

In Plot 2, the CEC in surface soil at 0-40 cm depth varied between 11.2-14.2 cmol.kg^{-1}. In subsoil, they were 9.6-14.2 cmol.kg^{-1}.

(9) Base Saturation (BS)

The values of extractable bases including potassium, calcium, magnesium and sodium and base saturation were shown in Table 4-5.

DDF with annual fire:

In Plot 1, the base saturation was low throughout the soil profile. The values varied between 12.89-29.35%.

In Plot 2, the base saturation was also low throughout the soil profile. The values varied between 8.40-34.04%.

DDF without fire:

In Plot 1, the base saturation was higher as 48.10% at 0-5 cm depth, and 41.26% at 180-200 cm depth. Most soil profile at 5-180 cm depth had the low base saturation, 13.73-25.53%.

In Plot 2, the base saturation was also higher as 37.29 at 0-5 cm depth, and low in deeper horizons, 14.26-28.57%.

These soils were classified in Order Ultisols which are the soils having the low base saturation, less than 35%. The higher BS at 0-5 cm depth of non-fire DDF was influenced by the release from decomposing leaf litter on the forest floor.

(10) Fertile Assessment Using Soil Chemical Properties

Soil fertility assessment was based on Soil Survey Division (1980). The five parameters including organic matter, available phosphorus, extractable potassium, cation exchange capacity and base saturation were used (Table 4-6). The total points were used for identify soil fertility levels.

DDF with annual fire:

In Plot 1, the soil fertility level at 0-20 cm depth was medium. They were medium to low in deeper soil.

In Plot 2, the soil fertility level at 0-10 cm depth was medium, and they were medium to low in deeper horizons.

DDF without fire:

In Plot 1, the soil fertility level in surface soil (0-5 cm depth) was high. They were medium at 5-80 cm depth, and medium to low in deeper soil.

In Plot 2, most soil profile had the soil fertility level of medium. It was low at 180-200 cm depth.

The soil fertility level was increased in surface soil under non-fire DDF.

Table 4-3 Some chemical properties in soil profiles under fire and non-fire DDF

Plot	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})
Fire DDF-1	0 - 5	4.93	very strongly acid	26.7	MH	15.5	MH	1.3	L	11.9	14.4	M	266.5	VH	321.8	VL	139.1	M	10.2	VL	11.9
	5 - 10	5.03	very strongly acid	16.0	M	9.3	M	0.4	VL	23.2	17.4	MH	222.8	VH	88.2	VL	90.0	L	10.7	VL	10.4
	10 - 20	5.26	strongly acid	9.9	L	5.7	L	0.3	VL	19.1	17.9	MH	243.3	VH	53.4	VL	127.9	M	10.8	VL	9.7
	20 - 30	5.36	strongly acid	8.4	L	4.9	L	0.2	VL	24.4	5.9	L	253.8	VH	48.5	VL	139.2	M	15.8	VL	9.4
	30 - 40	5.31	strongly acid	8.2	L	4.8	L	0.3	VL	15.9	2.3	VL	233.3	VH	58.4	VL	168.1	M	12.4	VL	9.7
	40 - 60	5.41	strongly acid	7.7	L	4.5	L	0.3	VL	14.9	1.3	VL	240.0	VH	78.3	VL	159.2	M	11.9	VL	13.8
	60 - 80	5.50	strongly acid	6.9	L	4.0	L	0.3	VL	13.3	0.8	VL	236.8	VH	80.8	VL	112.3	L	19.3	VL	10.4
	80 - 100	5.47	strongly acid	2.5	VL	1.5	VL	0.4	VL	3.6	0.5	VL	234.3	VH	98.2	VL	101.1	L	11.9	VL	11.8
	100 - 120	5.55	strongly acid	2.4	VL	1.4	VL	0.3	VL	4.6	0.7	VL	167.5	VH	85.7	VL	76.6	L	12.5	VL	11.9
	120 - 140	5.61	moderately acid	2.5	VL	1.5	VL	0.2	VL	7.3	0.5	VL	194.3	VH	53.4	VL	94.4	L	12.7	VL	12.4
	140 - 160	5.62	moderately acid	2.0	VL	1.2	VL	0.2	VL	5.8	0.5	VL	221.5	VH	108.1	VL	90.0	L	11.0	VL	14.8
	160 - 180	5.72	moderately acid	2.3	VL	1.3	VL	0.2	VL	6.7	0.4	VL	203.5	VH	147.9	VL	114.5	L	12.9	VL	9.5
	180 - 200	5.89	moderately acid	1.3	VL	0.8	VL	0.3	VL	2.5	0.3	VL	207.5	VH	145.4	VL	114.5	L	10.7	VL	8.5
Fire DDF-2	0 - 5	5.20	strongly acid	23.3	M	13.5	M	0.2	VL	67.6	12.8	M	299.0	VH	448.6	L	170.3	M	11.0	VL	13.2
	5 - 10	5.47	strongly acid	9.5	L	5.5	L	0.4	VL	13.8	3.4	L	267.8	VH	31.1	VL	60.9	L	11.8	VL	10.3
	10 - 20	5.31	strongly acid	5.1	L	3.0	L	0.4	VL	7.4	1.5	VL	254.5	VH	16.2	VL	69.9	L	15.5	VL	9.6
	20 - 30	5.25	strongly acid	4.6	VL	2.7	VL	0.3	VL	8.9	1.3	VL	230.5	VH	31.1	VL	78.8	L	20.5	VL	12.3
	30 - 40	5.48	strongly acid	3.9	VL	2.3	VL	0.4	VL	5.7	1.1	VL	209.0	VH	18.6	VL	63.2	L	20.2	VL	14.8
	40 - 60	5.46	strongly acid	3.6	VL	2.1	VL	0.3	VL	7.0	0.7	VL	232.3	VH	18.6	VL	45.3	L	18.7	VL	9.3
	60 - 80	5.64	moderately acid	3.0	VL	1.7	VL	0.2	VL	8.7	0.2	VL	222.8	VH	142.9	VL	54.2	L	24.6	L	13.7
	80 - 100	5.62	moderately acid	3.0	VL	1.7	VL	0.3	VL	5.8	0.4	VL	164.0	VH	133.0	VL	65.4	L	18.0	VL	14.0
	100 - 120	5.72	moderately acid	2.5	VL	1.5	VL	0.3	VL	4.8	0.5	VL	216.5	VH	182.7	VL	78.8	L	21.1	VL	10.7
	120 - 140	5.79	moderately acid	2.3	VL	1.3	VL	0.2	VL	6.7	0.4	VL	209.8	VH	177.7	VL	90.0	L	20.8	VL	12.4
	140 - 160	5.82	moderately acid	2.3	VL	1.3	VL	0.2	VL	6.7	0.6	VL	186.5	VH	254.7	VL	114.5	L	16.8	VL	8.8
	160 - 180	5.83	moderately acid	2.0	VL	1.2	VL	0.1	VL	11.6	0.5	VL	245.0	VH	244.8	VL	94.4	L	31.0	L	14.9
	180 - 200	5.91	moderately acid	1.6	VL	0.9	VL	0.1	VL	9.3	0.4	VL	254.5	VH	344.2	VL	141.3	M	28.3	L	12.4
Non-fire DDF-1	0 - 5	5.92	moderately acid	37.8	H	21.9	H	1.3	L	16.9	43.2	H	365.3	VH	785.3	L	319.9	M	25.1	L	15.9
	5 - 10	5.62	moderately acid	15.1	M	8.8	M	0.6	VL	14.6	79.7	VH	253.8	VH	205.0	VL	141.3	M	15.4	VL	14.1
	10 - 20	5.63	moderately acid	12.1	ML	7.0	ML	0.3	VL	23.4	78.7	VH	220.5	VH	123.0	VL	125.7	M	12.6	VL	10.5
	20 - 30	5.47	strongly acid	8.0	L	4.6	L	0.4	VL	11.6	39.5	H	236.3	VH	147.9	VL	134.6	M	11.8	VL	12.3
	30 - 40	5.60	moderately acid	7.4	L	4.3	L	0.2	VL	21.5	8.5	ML	280.8	VH	137.9	VL	132.4	M	12.2	VL	12.5
	40 - 60	5.54	strongly acid	6.4	L	3.7	L	0.3	VL	12.4	1.1	VL	186.5	VH	157.8	VL	145.8	M	14.5	VL	18.5
	60 - 80	5.68	moderately acid	6.2	L	3.6	L	0.4	VL	9.0	0.7	VL	217.8	VH	180.2	VL	208.3	M	11.0	VL	14.2
	80 - 100	5.72	moderately acid	7.4	L	4.3	L	0.4	VL	10.7	0.6	VL	178.8	VH	145.4	VL	150.2	M	12.4	VL	13.6
	100 - 120	5.73	moderately acid	6.4	L	3.7	L	0.2	VL	18.6	0.6	VL	196.5	VH	142.9	VL	143.5	M	13.1	VL	9.9
	120 - 140	5.72	moderately acid	5.9	L	3.4	L	0.3	VL	11.4	0.6	VL	260.3	VH	135.4	VL	130.1	M	16.4	VL	11.5
	140 - 160	5.74	moderately acid	5.7	L	3.3	L	0.1	VL	33.1	0.5	VL	166.8	VH	160.3	VL	148.0	M	10.0	VL	10.3
	160 - 180	5.80	moderately acid	6.0	L	3.5	L	0.3	VL	11.6	0.2	VL	166.8	VH	145.4	VL	143.5	M	11.3	VL	9.4
	180 - 200	5.73	moderately acid	5.4	L	3.1	L	0.2	VL	15.7	0.3	VL	205.3	VH	180.2	VL	150.2	M	28.2	L	6.8
Non-fire DDF-2	0 - 5	5.14	strongly acid	26.3	MH	15.3	MH	1.1	L	13.9	26.6	H	354.3	VH	458.5	L	223.2	M	12.7	VL	13.7
	5 - 10	5.46	strongly acid	15.5	M	9.0	M	0.4	VL	22.5	9.1	ML	223.5	VH	120.5	VL	94.4	L	13.7	VL	12.3
	10 - 20	5.48	strongly acid	9.4	L	5.5	L	0.4	VL	13.6	6.5	ML	228.0	VH	75.8	VL	98.9	L	15.9	VL	13.8
	20 - 30	5.57	strongly acid	6.8	L	3.9	L	0.2	VL	19.7	2.9	VL	215.5	VH	55.9	VL	136.8	M	10.6	VL	14.2
	30 - 40	5.44	strongly acid	8.8	L	5.1	L	0.2	VL	25.5	1.4	VL	244.5	VH	68.3	VL	150.2	M	14.4	VL	11.2
	40 - 60	5.66	moderately acid	7.6	L	4.4	L	0.3	VL	14.7	0.9	VL	205.5	VH	65.9	VL	168.7	M	14.7	VL	14.2
	60 - 80	5.70	moderately acid	7.1	L	4.1	L	0.2	VL	20.6	0.7	VL	211.3	VH	133.0	VL	150.2	M	10.7	VL	11.7
	80 - 100	5.60	moderately acid	6.6	L	3.8	L	0.2	VL	19.1	0.5	VL	222.5	VH	108.1	VL	121.2	L	9.8	VL	12.0
	100 - 120	5.77	moderately acid	6.5	L	3.8	L	0.2	VL	18.9	0.4	VL	191.5	VH	135.4	VL	114.5	L	10.8	VL	11.0
	120 - 140	5.66	moderately acid	7.0	L	4.1	L	0.2	VL	20.3	1.5	VL	286.8	VH	185.1	VL	125.7	M	10.2	VL	11.6
	140 - 160	5.65	moderately acid	6.8	L	3.9	L	0.4	VL	9.9	0.4	VL	216.8	VH	152.8	VL	101.1	L	23.2	L	10.9
	160 - 180	5.81	moderately acid	6.5	L	3.8	L	0.2	VL	18.9	0.4	VL	295.3	VH	234.8	VL	134.6	M	14.1	VL	10.9
	180 - 200	5.88	moderately acid	6.3	L	3.7	L	0.2	VL	18.3	0.3	VL	208.3	VH	142.9	VL	96.5	L	25.6	L	9.6

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 4-4 Effects of fire on chemical properties in soil profiles under DDF

Soil depth	pH			O.M. ($g.kg^{-1}$)			C ($g.kg^{-1}$)			Total N ($g.kg^{-1}$)			Available P ($mg.kg^{-1}$)			K ($mg.kg^{-1}$)			Ca ($mg.kg^{-1}$)			Mg ($mg.kg^{-1}$)			Na ($mg.kg^{-1}$)		
(cm)	F	WF	**EF**	F	WF	**EF**	F	WF	**EF**	F	W	**EF**	F	WF	**EF**	F	WF	**EF**	F	WF	**EF**	F	WF	**EF**	F	WF	**EF**
0 - 5	5.1	5.5	**-0.5**	25.0	32.1	**-7.1**	14.5	18.6	**-4.1**	0.8	1.2	**-0.5**	13.6	34.9	**-21.2**	282.	359.8	**-77.0**	385	621.9	**-236.7**	154.	271.5	**-116.9**	10.6	18.9	**-8.3**
5 - 10	5.3	5.5	**-0.3**	12.8	15.3	**-2.6**	7.4	8.9	**-1.5**	0.4	0.5	**-0.1**	10.4	44.4	**-34.0**	245.	238.6	**6.6**	59.	162.8	**-103.1**	75.5	117.9	**-42.4**	11.3	14.5	**-3.2**
10 - 20	5.3	5.6	**-0.3**	7.5	10.8	**-3.3**	4.4	6.2	**-1.9**	0.4	0.4	**0.0**	9.7	42.6	**-32.9**	248.	224.3	**24.6**	34.	99.4	**-64.6**	98.9	112.3	**-13.4**	13.1	14.3	**-1.2**
20 - 30	5.3	5.5	**-0.2**	6.5	7.4	**-0.9**	3.8	4.3	**-0.5**	0.3	0.3	**-0.1**	3.6	21.2	**-17.6**	242.	225.9	**16.3**	39.	101.9	**-62.1**	109.	135.7	**-26.7**	18.1	11.2	**6.9**
30 - 40	5.4	5.5	**-0.1**	6.1	8.1	**-2.1**	3.5	4.7	**-1.2**	0.4	0.2	**0.2**	1.7	4.9	**-3.2**	221.	262.6	**-41.5**	38.	103.1	**-64.6**	115.	141.3	**-25.7**	16.3	13.3	**3.0**
40 - 60	5.4	5.6	**-0.2**	5.7	7.0	**-1.4**	3.3	4.1	**-0.8**	0.3	0.3	**0.0**	1.0	1.0	**0.1**	236.	196.0	**40.1**	48.	111.8	**-63.4**	102.	157.2	**-55.0**	15.3	14.6	**0.7**
60 - 80	5.6	5.7	**-0.1**	5.0	6.7	**-1.7**	2.9	3.9	**-1.0**	0.3	0.3	**-0.1**	0.5	0.7	**-0.2**	229.	214.5	**15.3**	111	156.6	**-44.7**	83.3	179.2	**-96.0**	22.0	10.9	**11.1**
80 - 100	5.5	5.7	**-0.1**	2.8	7.0	**-4.3**	1.6	4.1	**-2.5**	0.4	0.3	**0.1**	0.5	0.5	**-0.1**	199.	200.6	**-1.5**	115	126.7	**-11.2**	83.3	135.7	**-52.5**	14.9	11.1	**3.9**
100 - 120	5.6	5.8	**-0.1**	2.5	6.5	**-4.0**	1.4	3.7	**-2.3**	0.3	0.2	**0.1**	0.6	0.5	**0.1**	192.	194.0	**-2.0**	134	139.2	**-5.0**	77.7	129.0	**-51.3**	16.8	12.0	**4.9**
120 - 140	5.7	5.7	**0.0**	2.4	6.5	**-4.1**	1.4	3.7	**-2.3**	0.2	0.3	**-0.1**	0.5	1.1	**-0.6**	202.	273.5	**-71.5**	115	160.3	**-44.7**	92.2	127.9	**-35.7**	16.7	13.3	**3.4**
140 - 160	5.7	5.7	**0.0**	2.2	6.3	**-4.1**	1.2	3.6	**-2.4**	0.2	0.3	**-0.1**	0.5	0.4	**0.1**	204.	191.8	**12.3**	181	156.6	**24.9**	102.	124.6	**-22.3**	13.9	16.6	**-2.7**
160 - 180	5.8	5.8	**0.0**	2.2	6.3	**-4.1**	1.2	3.6	**-2.4**	0.2	0.3	**-0.1**	0.4	0.3	**0.1**	224.	231.0	**-6.8**	196	190.1	**6.2**	104.	139.1	**-34.6**	22.0	12.7	**9.3**
180 - 200	5.9	5.8	**0.1**	1.5	5.9	**-4.4**	0.8	3.4	**-2.6**	0.2	0.2	**0.0**	0.4	0.3	**0.1**	231.	206.8	**24.3**	244	161.5	**83.3**	127.	123.4	**4.5**	19.5	26.9	**-7.4**

Note: F = Fire, WF = Without fire, EF = Effect of fire

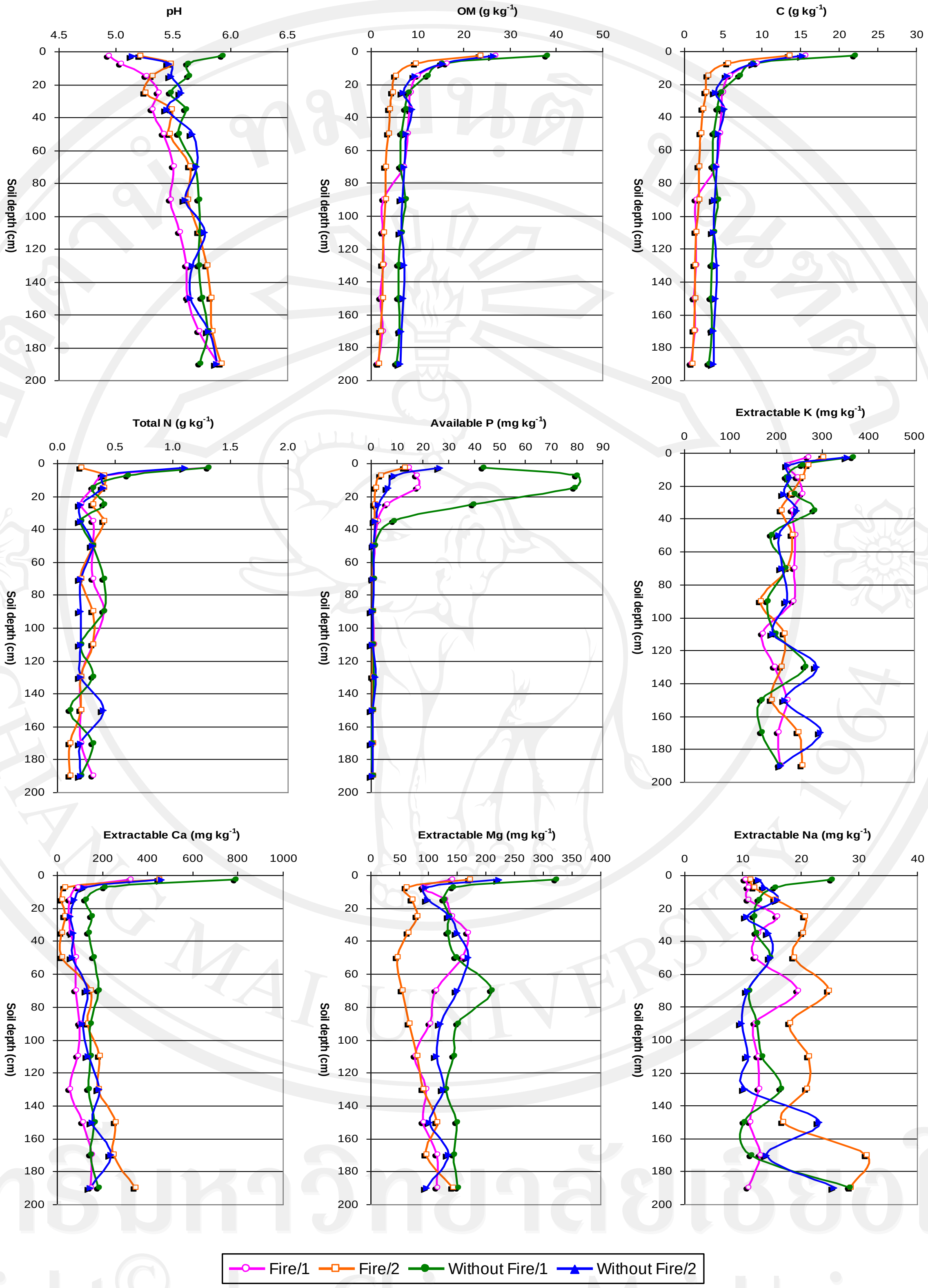

Figure 4-3 Changes of some chemical properties along soil profiles under fire and non-fire DDF

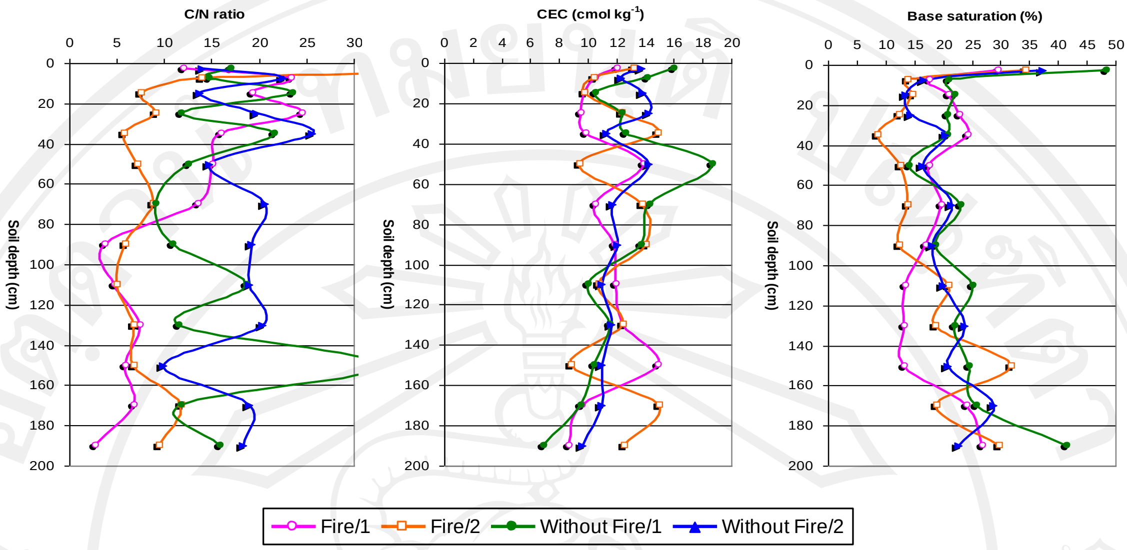

Figure 4-4 C/N ratios, cation exchange capacity and base saturation in soil profiles under fire and non-fire DDF

Table 4-5 Extractable bases and acidity, CEC and BS in soil profiles under fire and non-fire DDF

Plot	Soil depth (cm)	K	Ca	Mg	Na	sum of base	Extr. acidity	CEC by sum	B.S. by sum (%)
		(---cmol.kg^{-1}---)							
Fire DDF-1	0 - 5	0.68	1.61	1.16	0.04	3.50	8.41	11.9	29.35
	5 - 10	0.57	0.44	0.75	0.05	1.81	8.63	10.4	17.32
	10 - 20	0.62	0.27	1.07	0.05	2.00	7.66	9.7	20.74
	20 - 30	0.65	0.24	1.16	0.07	2.12	7.27	9.4	22.59
	30 - 40	0.60	0.29	1.40	0.05	2.34	7.40	9.7	24.07
	40 - 60	0.62	0.39	1.33	0.05	2.38	11.38	13.8	17.33
	60 - 80	0.61	0.40	0.94	0.08	2.03	8.40	10.4	19.47
	80 - 100	0.60	0.49	0.84	0.05	1.99	9.81	11.8	16.83
	100 - 120	0.43	0.43	0.64	0.05	1.55	10.30	11.9	13.08
	120 - 140	0.50	0.27	0.79	0.06	1.61	10.74	12.4	13.01
	140 - 160	0.57	0.54	0.75	0.05	1.91	12.88	14.8	12.89
	160 - 180	0.52	0.74	0.95	0.06	2.27	7.22	9.5	23.94
	180 - 200	0.53	0.73	0.95	0.05	2.26	6.27	8.5	26.49
Fire DDF-2	0 - 5	0.77	2.24	1.42	0.05	4.48	8.67	13.2	34.04
	5 - 10	0.69	0.16	0.51	0.05	1.40	8.91	10.3	13.59
	10 - 20	0.65	0.08	0.58	0.07	1.38	8.26	9.6	14.34
	20 - 30	0.59	0.16	0.66	0.09	1.49	10.82	12.3	12.12
	30 - 40	0.54	0.09	0.53	0.09	1.24	13.57	14.8	8.40
	40 - 60	0.60	0.09	0.38	0.08	1.15	8.15	9.3	12.34
	60 - 80	0.57	0.71	0.45	0.11	1.84	11.83	13.7	13.49
	80 - 100	0.42	0.66	0.55	0.08	1.71	12.27	14.0	12.22
	100 - 120	0.56	0.91	0.66	0.09	2.22	8.48	10.7	20.72
	120 - 140	0.54	0.89	0.75	0.09	2.27	10.08	12.4	18.35
	140 - 160	0.48	1.27	0.95	0.07	2.78	6.00	8.8	31.65
	160 - 180	0.63	1.22	0.79	0.13	2.77	12.10	14.9	18.65
	180 - 200	0.65	1.72	1.18	0.12	3.67	8.75	12.4	29.58
Non-fire DDF-1	0 - 5	0.94	3.93	2.67	0.11	7.64	8.24	15.9	48.10
	5 - 10	0.65	1.03	1.18	0.07	2.92	11.13	14.1	20.78
	10 - 20	0.57	0.62	1.05	0.05	2.28	8.18	10.5	21.82
	20 - 30	0.61	0.74	1.12	0.05	2.52	9.75	12.3	20.52
	30 - 40	0.72	0.69	1.10	0.05	2.57	9.96	12.5	20.47
	40 - 60	0.48	0.79	1.21	0.06	2.54	16.00	18.5	13.73
	60 - 80	0.56	0.90	1.74	0.05	3.24	10.95	14.2	22.85
	80 - 100	0.46	0.73	1.25	0.05	2.49	11.09	13.6	18.34
	100 - 120	0.50	0.71	1.20	0.06	2.47	7.45	9.9	24.91
	120 - 140	0.67	0.68	1.08	0.07	2.50	8.97	11.5	21.80
	140 - 160	0.43	0.80	1.23	0.04	2.51	7.81	10.3	24.28
	160 - 180	0.43	0.73	1.20	0.05	2.40	7.00	9.4	25.53
	180 - 200	0.53	0.90	1.25	0.12	2.80	3.99	6.8	41.26
Non-fire DDF-2	0 - 5	0.91	2.29	1.86	0.06	5.12	8.60	13.7	37.29
	5 - 10	0.57	0.60	0.79	0.06	2.02	10.25	12.3	16.48
	10 - 20	0.58	0.38	0.82	0.07	1.86	11.96	13.8	13.44
	20 - 30	0.55	0.28	1.14	0.05	2.02	12.14	14.2	14.26
	30 - 40	0.63	0.34	1.25	0.06	2.28	8.96	11.2	20.31
	40 - 60	0.53	0.33	1.41	0.06	2.33	11.86	14.2	16.39
	60 - 80	0.54	0.66	1.25	0.05	2.50	9.21	11.7	21.39
	80 - 100	0.57	0.54	1.01	0.04	2.16	9.83	12.0	18.04
	100 - 120	0.49	0.68	0.95	0.05	2.17	8.79	11.0	19.79
	120 - 140	0.74	0.93	1.05	0.04	2.75	8.88	11.6	23.67
	140 - 160	0.56	0.76	0.84	0.10	2.26	8.65	10.9	20.74
	160 - 180	0.76	1.17	1.12	0.06	3.11	7.79	10.9	28.57
	180 - 200	0.53	0.71	0.80	0.11	2.16	7.40	9.6	22.64

Table 4-6 Fertility assessment along soil profiles under fire and non-fire DDF

Plot	Soil depth	OM		Available P		Extractable K		CEC		B.S.		Total	Ferity
	(cm)	(g.kg^{-1})	*	(mg.kg^{-1})	*	(mg.kg^{-1})	*	(cmol.kg^{-1})	*	(%)	*	points**	assessment
Fire	0 - 5	26.7	(2)	14.4	(2)	266.5	(3)	11.9	(2)	29.35	(1)	10	medium
DDF-1	5 - 10	16.0	(2)	17.4	(2)	222.8	(3)	10.4	(2)	17.32	(1)	10	medium
	10 - 20	9.9	(1)	17.9	(2)	243.3	(3)	9.7	(1)	20.74	(1)	8	medium
	20 - 30	8.4	(1)	5.9	(1)	253.8	(3)	9.4	(1)	22.59	(1)	7	low
	30 - 40	8.2	(1)	2.3	(1)	233.3	(3)	9.7	(1)	24.07	(1)	7	low
	40 - 60	7.7	(1)	1.3	(1)	240.0	(3)	13.8	(2)	17.33	(1)	8	medium
	60 - 80	6.9	(1)	0.8	(1)	236.8	(3)	10.4	(2)	19.47	(1)	8	medium
	80 - 100	2.5	(1)	0.5	(1)	234.3	(3)	11.8	(2)	16.83	(1)	8	medium
	100 - 120	2.4	(1)	0.7	(1)	167.5	(3)	11.9	(2)	13.08	(1)	8	medium
	120 - 140	2.5	(1)	0.5	(1)	194.3	(3)	12.4	(2)	13.01	(1)	8	medium
	140 - 160	2.0	(1)	0.5	(1)	221.5	(3)	14.8	(2)	12.89	(1)	8	medium
	160 - 180	2.3	(1)	0.4	(1)	203.5	(3)	9.5	(1)	23.94	(1)	7	low
	180 - 200	1.3	(1)	0.3	(1)	207.5	(3)	8.5	(1)	26.49	(1)	7	low
Fire	0 - 5	23.3	(2)	12.8	(2)	299.0	(3)	13.2	(2)	34.04	(1)	10	medium
DDF-2	5 - 10	9.5	(1)	3.4	(1)	267.8	(3)	10.3	(2)	13.59	(1)	8	medium
	10 - 20	5.1	(1)	1.5	(1)	254.5	(3)	9.6	(1)	14.34	(1)	7	low
	20 - 30	4.6	(1)	1.3	(1)	230.5	(3)	12.3	(2)	12.12	(1)	8	medium
	30 - 40	3.9	(1)	1.1	(1)	209.0	(3)	14.8	(2)	8.40	(1)	8	medium
	40 - 60	3.6	(1)	0.7	(1)	232.3	(3)	9.3	(1)	12.34	(1)	7	low
	60 - 80	3.0	(1)	0.2	(1)	222.8	(3)	13.7	(2)	13.49	(1)	8	medium
	80 - 100	3.0	(1)	0.4	(1)	164.0	(3)	14.0	(2)	12.22	(1)	8	medium
	100 - 120	2.5	(1)	0.5	(1)	216.5	(3)	10.7	(2)	20.72	(1)	8	medium
	120 - 140	2.3	(1)	0.4	(1)	209.8	(3)	12.4	(2)	18.35	(1)	8	medium
	140 - 160	2.3	(1)	0.6	(1)	186.5	(3)	8.8	(1)	31.65	(1)	7	low
	160 - 180	2.0	(1)	0.5	(1)	245.0	(3)	14.9	(2)	18.65	(1)	8	medium
	180 - 200	1.6	(1)	0.4	(1)	254.5	(3)	12.4	(2)	29.58	(1)	8	medium
Non-fire	0 - 5	37.8	(3)	43.2	(3)	365.3	(3)	15.9	(2)	48.10	(2)	13	high
	5 - 10	15.1	(2)	79.7	(3)	253.8	(3)	14.1	(2)	20.78	(1)	11	medium
DDF-1	10 - 20	12.1	(1)	78.7	(3)	220.5	(3)	10.5	(2)	21.82	(1)	10	medium
	20 - 30	8.0	(1)	39.5	(3)	236.3	(3)	12.3	(2)	20.52	(1)	10	medium
	30 - 40	7.4	(1)	8.5	(1)	280.8	(3)	12.5	(2)	20.47	(1)	8	medium
	40 - 60	6.4	(1)	1.1	(1)	186.5	(3)	18.5	(2)	13.73	(1)	8	medium
	60 - 80	6.2	(1)	0.7	(1)	217.8	(3)	14.2	(2)	22.85	(2)	9	medium
	80 - 100	7.4	(1)	0.6	(1)	178.8	(3)	13.6	(2)	18.34	(1)	8	medium
	100 - 120	6.4	(1)	0.6	(1)	196.5	(3)	9.9	(1)	24.91	(1)	7	low
	120 - 140	5.9	(1)	0.6	(1)	260.3	(3)	11.5	(2)	21.80	(1)	8	medium
	140 - 160	5.7	(1)	0.5	(1)	166.8	(3)	10.3	(2)	24.28	(1)	8	medium
	160 - 180	6.0	(1)	0.2	(1)	166.8	(3)	9.4	(1)	25.53	(1)	7	low
	180 - 200	5.4	(1)	0.3	(1)	205.3	(3)	6.8	(1)	41.26	(2)	8	medium
Non-fire	0 - 5	26.3	(2)	26.6	(3)	354.3	(3)	13.7	(2)	37.29	(2)	12	medium
	5 - 10	15.5	(2)	9.1	(2)	223.5	(3)	12.3	(2)	16.48	(1)	10	medium
DDF-2	10 - 20	9.4	(1)	6.5	(2)	228.0	(3)	13.8	(2)	13.44	(1)	9	medium
	20 - 30	6.8	(1)	2.9	(1)	215.5	(3)	14.2	(2)	14.26	(1)	8	medium
	30 - 40	8.8	(1)	1.4	(1)	244.5	(3)	11.2	(2)	20.31	(1)	8	medium
	40 - 60	7.6	(1)	0.9	(1)	205.5	(3)	14.2	(2)	16.39	(1)	8	medium
	60 - 80	7.1	(1)	0.7	(1)	211.3	(3)	11.7	(2)	21.39	(1)	8	medium
	80 - 100	6.6	(1)	0.5	(1)	222.5	(3)	12.0	(2)	18.04	(1)	8	medium
	100 - 120	6.5	(1)	0.4	(1)	191.5	(3)	11.0	(2)	19.79	(1)	8	medium
	120 - 140	7.0	(1)	1.5	(1)	286.8	(3)	11.6	(2)	23.67	(1)	8	medium
	140 - 160	6.8	(1)	0.4	(1)	216.8	(3)	10.9	(2)	20.74	(1)	8	medium
	160 - 180	6.5	(1)	0.4	(1)	295.3	(3)	10.9	(2)	28.57	(1)	8	medium
	180 - 200	6.3	(1)	0.3	(1)	208.3	(3)	9.6	(1)	22.64	(1)	7	low

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

4.3.2 Soil Carbon and Nutrient Storages in Fire and Non-fire DDF

Carbon sinks and nutrient accumulations in soils with 200 cm depth in DDF with fire and without fire were shown in Table 4-7.and Figure 4-5.

(1) Organic matter

DDF with annual fire:

In Plot 1, the amount of organic matter in soil profile was 151.0 $Mg.ha^{-1}$. In Plot 2, the amount was lower, 97.0 $Mg.ha^{-1}$. The average amount in soil under fire DDF was 124.0 $Mg.ha^{-1}$.

DDF without fire:

In Plot 1, the amount of organic matter in soil profile was 200.0 $Mg.ha^{-1}$. It was higher in Plot 2, 224.0 $Mg.ha^{-1}$. The average amount in soil for non-fire DDF was 212.0 $Mg.ha^{-1}$.

The average amount of organic matter in soil profile of non-fire DDF was higher than fire DDF.

(2) Organic Carbon

DDF with annual fire:

In Plot 1, the amount of organic carbon in soil profile was calculated as 88.0 $Mg.ha^{-1}$. In Plot 2, the amount was lower, 56.0 $Mg.ha^{-1}$. The average amount in soil under fire DDF was 72.0 $Mg.ha^{-1}$.

DDF without fire:

In Plot 1, the amount of organic carbon accumulated in soil profile was 116.0 $Mg.ha^{-1}$. It was higher in Plot 2, 130.0 $Mg.ha^{-1}$. The average amount in soil for non-fire DDF was 123.0 $Mg.ha^{-1}$.

The average amount of organic carbon in soil profile of non-fire DDF was higher than fire DDF.

(3) Total Nitrogen

DDF with annual fire:

In Plot 1, the amount of total nitrogen in soil profile was estimated as 9,024 $kg.ha^{-1}$. In Plot 2, the amount was lower, 6,677 $kg.ha^{-1}$. The average amount in soil under fire DDF was 7,850 $kg.ha^{-1}$.

DDF without fire:

In Plot 1, the amount of total nitrogen accumulated in soil profile was 8,239 $kg.ha^{-1}$. It was lower in Plot 2, 7,749 $kg.ha^{-1}$. The average amount in soil for non-fire DDF was 7,994 $kg.ha^{-1}$.

The average amount of total nitrogen in soil profile of non-fire DDF was higher than fire DDF.

(4) Available Phosphorus

DDF with annual fire:

In Plot 1, the amount of available phosphorus in soil profile was 74 $kg.ha^{-1}$. In Plot 2, the amount was lower, 26 $kg.ha^{-1}$. The average amount in soil under fire DDF was 50 $kg.ha^{-1}$.

DDF without fire:

In Plot 1, the amount of available phosphorus in soil profile was high, 259 $kg.ha^{-1}$. It was lower in Plot 2, 52 $kg.ha^{-1}$. The average amount in soil for non-fire DDF was 156 $kg.ha^{-1}$.

The average amount of available phosphorus in soil profile of non-fire DDF was about three times higher than fire DDF.

(5) Extractable Potassium

DDF with annual fire:

In Plot 1, the amount of extractable potassium in soil profile was 6,623 $kg.ha^{-1}$. It was 6,220 $kg.ha^{-1}$ for Plot 2. The average amount in soil for non-fire DDF was 6,421 $kg.ha^{-1}$.

DDF without fire:

In Plot 1, the amount of extractable potassium in soil profile was 5,628 $kg.ha^{-1}$. It was 6,827 $kg.ha^{-1}$ for Plot 2. The average amount in soil for non-fire DDF was 6,227 $kg.ha^{-1}$.

The average amount of extractable potassium in soil profile of non-fire DDF was not different from fire DDF.

(6) Extractable Calcium

DDF with annual fire:

In Plot 1, the amount of extractable calcium in soil profile was 2,969 $kg.ha^{-1}$. It was higher as 4,685 $kg.ha^{-1}$ for Plot 2. The average amount in soil for non-fire DDF was 3,827 $kg.ha^{-1}$.

DDF without fire:

In Plot 1, the amount of extractable calcium in soil profile was 4,471 $kg.ha^{-1}$. It was 4,103 $kg.ha^{-1}$ for Plot 2. The average amount in soil for non-fire DDF was 4,287 $kg.ha^{-1}$.

The average amount of extractable calcium in soil profile of non-fire DDF was higher than fire DDF.

(7) Extractable Magnesium

DDF with annual fire:

In Plot 1, the extractable magnesium amount in soil profile was 3,435 $kg.ha^{-1}$. It was lower as 2,389 $kg.ha^{-1}$ for Plot 2. The average amount in soil for non-fire DDF was 2,912 $kg.ha^{-1}$.

DDF without fire:

In Plot 1, the extractable magnesium amount in soil profile was 4,094 $kg.ha^{-1}$. It was lower as 3,748 $kg.ha^{-1}$ for Plot 2. The average amount in soil for non-fire DDF was 3,921 $kg.ha^{-1}$.

The average amount of extractable magnesium in soil profile of non-fire DDF was higher than fire DDF.

(8) Extractable Sodium

DDF with annual fire:

In Plot 1, the extractable sodium amount in soil profile was 385 $kg.ha^{-1}$. It was higher as 600 $kg.ha^{-1}$ for Plot 2. The average amount in soil for non-fire DDF was 493 $kg.ha^{-1}$.

DDF without fire:

In Plot 1, the extractable sodium amount in soil profile was 390 $kg.ha^{-1}$. It was higher as 434 $kg.ha^{-1}$ for Plot 2. The average amount in soil for non-fire DDF was 412 $kg.ha^{-1}$.

The average amount of extractable sodium in soil profile of non-fire DDF was not different from fire DDF.

Table 4-7 Soil carbon and nutrient storages in fire and non-fire DDF

Plot	Soil Depth (cm)	OM (Mg.ha^{-1})	C (Mg.ha^{-1})	Total N (kg.ha^{-1})	Available P (kg.ha^{-1})	Extractable (kg.ha^{-1}) K	Ca	Mg	Na
Fire DDF-1	0 - 5	17.57	10.19	855	9.50	175.35	211.75	91.50	6.72
	5 - 10	11.04	6.40	276	12.01	153.63	60.85	62.05	7.41
	10 - 20	13.94	8.09	423	25.24	342.61	75.25	180.14	15.16
	20 - 30	12.48	7.24	297	8.77	377.09	72.02	206.79	23.47
	30 - 40	12.29	7.13	450	3.49	349.72	87.56	252.01	18.61
	40 - 60	23.53	13.65	917	4.10	733.48	239.24	486.39	36.40
	60 - 80	20.15	11.69	876	2.31	691.22	235.82	327.82	56.35
	80 - 100	7.54	4.38	1,207	1.54	706.74	296.15	305.08	35.87
	100 - 120	7.29	4.23	911	2.00	508.46	260.27	232.40	37.88
	120 - 140	7.37	4.28	590	1.56	572.78	157.55	278.41	37.30
	140 - 160	6.51	3.77	651	1.56	720.65	351.70	292.69	35.92
	160 - 180	7.17	4.16	624	1.09	634.71	461.17	357.15	40.23
	180 - 200	4.11	2.38	949	1.01	656.11	459.69	362.08	33.90
	Total	151	88	9,024	74	6,623	2,969	3,435	385
Fire DDF-2	0 - 5	14.10	8.18	121	7.77	180.97	271.49	103.08	6.68
	5 - 10	6.84	3.97	288	2.45	192.88	22.37	43.90	8.51
	10 - 20	7.25	4.21	569	2.09	361.77	22.96	99.32	21.98
	20 - 30	6.19	3.59	404	1.68	310.08	41.78	105.99	27.52
	30 - 40	5.25	3.05	539	1.48	281.53	25.11	85.09	27.21
	40 - 60	9.22	5.35	768	1.74	594.65	47.73	116.01	47.78
	60 - 80	8.35	4.84	557	0.56	619.85	397.62	150.93	68.48
	80 - 100	8.13	4.71	813	1.17	444.34	360.24	177.20	48.77
	100 - 120	7.17	4.16	860	1.29	620.67	523.63	225.88	60.61
	120 - 140	6.83	3.96	594	1.16	622.74	527.52	267.09	61.81
	140 - 160	6.76	3.92	588	1.62	548.15	748.66	336.56	49.23
	160 - 180	5.88	3.41	294	1.32	719.91	719.26	277.44	91.18
	180 - 200	4.54	2.63	284	1.22	722.04	976.47	400.85	80.37
	Total	97	56	6,677	26	6,220	4,685	2,389	600
Average Fire DDF		124	72	7,850	50	6,421	3,827	2,912	493
Non-fire DDF-1	0 - 5	19.19	11.13	660	21.90	185.39	398.58	162.35	12.75
	5 - 10	9.89	5.74	393	52.19	166.24	134.32	92.56	10.06
	10 - 20	16.25	9.42	403	105.62	296.04	165.15	168.72	16.93
	20 - 30	11.49	6.66	574	56.67	339.20	212.29	193.25	16.87
	30 - 40	9.78	5.67	264	11.21	371.10	182.30	174.97	16.07
	40 - 60	16.35	9.48	766	2.68	476.31	403.01	372.26	37.01
	60 - 80	16.82	9.76	1,085	1.82	590.83	488.86	565.08	29.77
	80 - 100	21.11	12.25	1,141	1.60	510.03	414.81	428.62	35.24
	100 - 120	17.26	10.01	539	1.51	529.91	385.34	387.06	35.30
	120 - 140	15.75	9.13	801	1.63	694.65	361.51	347.34	43.77
	140 - 160	15.88	9.21	279	1.25	464.69	446.68	412.41	27.92
	160 - 180	15.50	8.99	775	0.41	430.77	375.56	370.79	29.22
	180 - 200	15.06	8.74	558	0.75	572.50	502.54	419.00	78.63
	Total	200	116	8,239	259	5,628	4,471	4,094	390
Non-fire DDF-2	0 - 5	15.77	9.15	660	15.93	212.43	274.95	133.86	7.59
	5 - 10	11.11	6.44	287	6.49	160.13	86.36	67.65	9.80
	10 - 20	13.07	7.58	556	9.01	316.98	105.38	137.47	22.13
	20 - 30	10.21	5.92	300	4.29	323.57	83.95	205.45	15.96
	30 - 40	12.87	7.47	293	2.05	357.67	99.97	219.75	21.09
	40 - 60	21.18	12.28	836	2.42	572.56	183.47	469.97	40.82
	60 - 80	20.21	11.72	569	1.88	601.36	378.47	427.63	30.57
	80 - 100	19.72	11.44	598	1.43	664.74	322.96	362.16	29.13
	100 - 120	18.49	10.73	569	1.22	544.81	385.32	325.78	30.75
	120 - 140	21.02	12.19	601	4.50	860.98	555.89	377.33	30.72
	140 - 160	21.46	12.45	1,262	1.26	684.00	482.28	319.10	73.05
	160 - 180	19.29	11.19	594	1.04	876.40	697.09	399.54	41.82
	180 - 200	19.71	11.44	626	0.94	651.68	447.15	301.98	80.24
	Total	224	130	7,749	52	6,827	4,103	3,748	434
Average Non-fire DDF		212	123	7,994	156	6,227	4,287	3,921	412

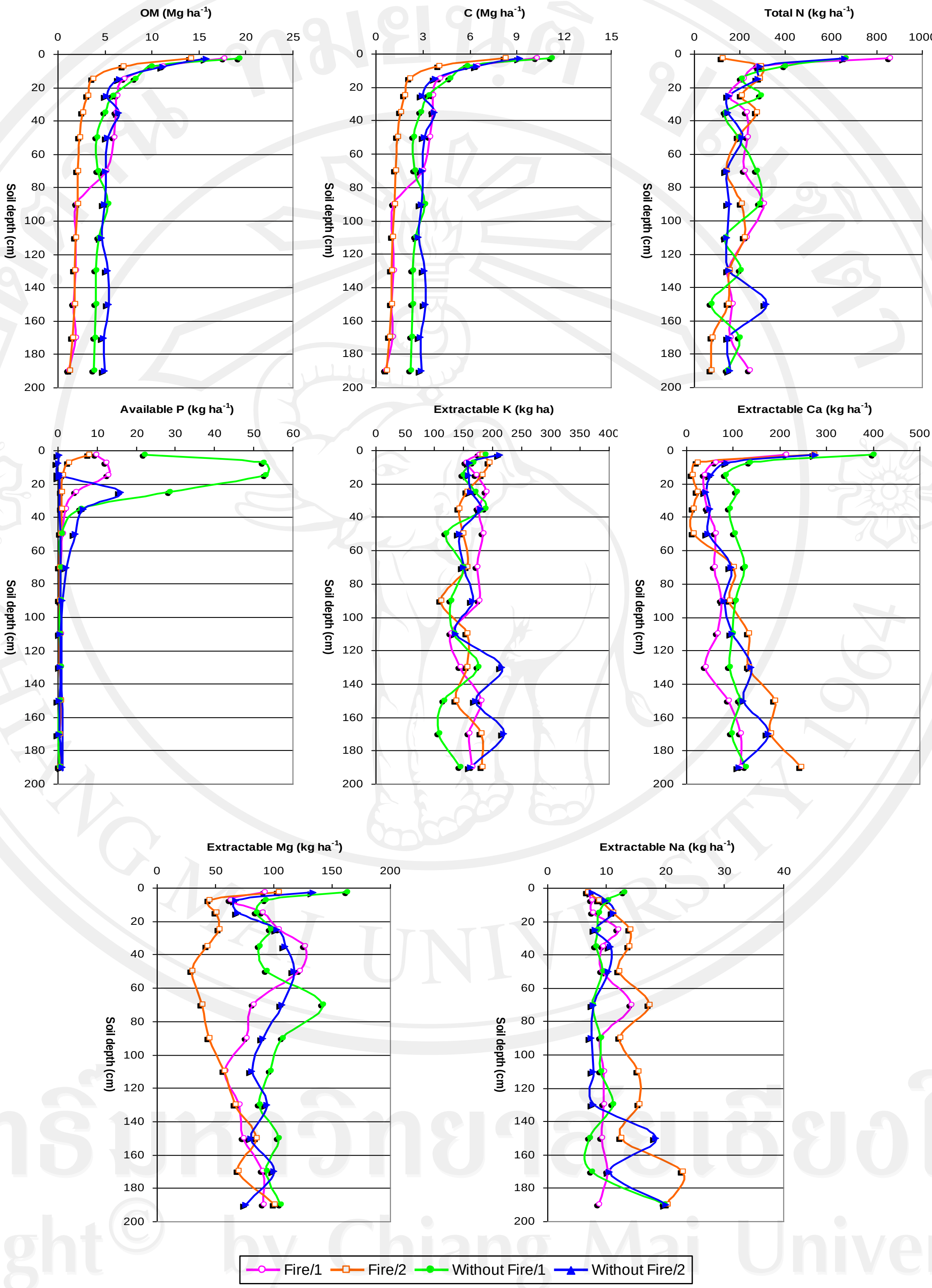

Figure 4-5 Changes in amounts of organic matter and nutrients in soil profiles under fire and non-fire DDF

4.3.2.1 Development of Soil Profiles

The soils in DDF with and without fire were classified in Order Ultisols, Suborder Ustults, Great group Paleustults, Subgroup Typic Paleustults. The soils were more than 200 cm in depth with highly weathered from granitic rocks. The former was a well developed soil with low base saturation (< 35%) while the latter had the highest base saturation. It was found that they had a somewhat similar profile model. The soil profiles were developed as A-BA-Bt with 5-10 cm thickness of organic layers and high clay mineral in subsoils. Topography and development of soil profile under DDF with and without fire were summarized in Table 4-8.

Table 4-8 Topography and development of soil profile under fire and non-fire DDF

DDF	Pedon	Topography			Forest type	Profile Development
		Altitude (m)	Slope (%)	Aspect		
Fire 1	1	400	2	S 20^{0} W	Conservation forest	A-BA-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6-Bt7
Fire 2	2	398	2	S 10^{0} W	Conservation forest	A-BA-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6-Bt7
Without fire 1	3	390	5	S 25^{0} W	Conservation forest	A-BA-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6
Without fire 2	4	395	5	S 75^{0} W	Conservation forest	A-BA-Bt1-Bt2-Bt3-Bt4-Bt5-Bt6-Bt7-Bt8

This indicated mechanical migration of small particles from A to B horizons to produce a relative enrichment of clay in subhorizons (Bt). The number of this horizon depends on the depth of each profile and the appearance of parent material at depth. Morphology of DDF soils with and without fire were depicted below (Figure 4-6 to 4-9).

Pedon 1

I Information on the Site

Profile symbol	:	Pedon 1
Soil name	:	Intakin series 1 (tentative)
Classification	:	Typic Paleustults
Date of examination	:	February 18, 2012
Described by	:	Niwat Anongrak, Soontorn Khamyong, Saroj Wattanasuksakul, Taparat Seeloy-ounkeaw
Location	:	Approximately 44 km north from Chiang Mai City. Mae Tang District. Chiang Mai Province. Grid Reference: 2117377 N, 0495421 E (Sheet: 4747 II)
Elevation	:	400 m (MSL)
Land form		
1. Physiographic position	:	On straight slope
2. Surrounding land form	:	Hill
3. Slope on which profile site	:	Nearly level (2%), S 20^0 W aspect
Vegetation and land use	:	Under dry dipterocarp forest with annual fire. Land is also used for the experimental area. The dominant tree is *Dipterocarpus tuberculatus*
Annual rainfall	:	Approximately 1,174 mm/yr
Mean temperature	:	Approximately 26 ^{0}C
Other	:	Nil

II General Information on the Soil

Parent material	:	Derived "*in situ*" from shale interbedded with sandstone in Tertiary period
Drainage	:	Well drained
Moisture condition in profile	:	Dry throughout
Depth of ground water table	:	Nil
Surface stones and rock outcrops	:	No stones and no rocks
Evidence of erosion	:	Slight sheet erosion
Human influence	:	Nil

III Profile Description :

Horizon	Depth (cm)	Description
A	0-4/6	Dark brown (7.5YR3/2) moist and brown (7.5YR5/4) dry; moderate fine granular structure; many fine and medium tubular pores; many vary fine and many fine roots; ; very strongly acid (pH 4.9); abrupt and smooth boundary to BA
BA	4/6-14/17	Dark reddish brown (5YR3/4) moist and reddish brown (5YR4/3) dry; moderate fine granular structure; many fine and medium tubular pores; many vary fine and many fine roots; very strongly acid (pH 5.0); abrupt and smooth boundary to Bt1
Bt1	14/17-30/32	Dark red (2.5YR3/6) moist and red (2.5YR4/6) dry; moderate fine and medium angular blocky structure; common fine tubular and medium tubular pores; many fine and common fine roots; strongly acid (pH 5.3); clear and smooth boundary to Bt2
Bt2	30/32-49/52	Dark reddish brown (2.5YR3/4) moist and reddish brown (2.5YR5/4) dry; moderate fine and medium angular blocky structure; common fine and medium tubular pores; common fine and medium roots; strongly acid (pH 5.4); clear and smooth boundary to Bt3
Bt3	49/52-73	Dark red (2.5YR3/6) moist and red (2.5YR4/6) dry; strong medium angular blocky structure; common fine tubular and medium pores; common fine and few fine roots; strongly acid (pH 5.4); clear and smooth boundary to Bt4
Bt4	73-122	Dark red (2.5YR3/6) moist and red (2.5YR4/8) dry; strong medium angular

		blocky structure; few fine and medium tubular pores; common fine and few medium roots; strongly acid (pH 5.5); clear and smooth boundary to Bt5
Bt5	122-149	Dark red (2.5YR3/6) moist and red (2.5YR4/6) dry; strong medium angular blocky structure; few fine and medium tubular pores; common fine roots; moderately acid (pH 5.6); clear and smooth boundary to Bt6
Bt6	149-180	Dark red (2.5YR3/6) moist and red (2.5YR4/6) dry; strong medium angular blocky structure; few fine and medium tubular pores; few fine roots; moderately acid (pH 5.7); clear and smooth boundary to Bt7
Bt7	180-200+	Dark reddish brown (2.5YR3/4) moist and dark red (2.5YR3/6) dry; strong medium angular blocky structure; few fine and medium tubular pores; few fine roots; moderately acid (pH 5.8)

Pedon 2

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

Profile symbol	:	Pedon 2
Soil name	:	Intakin series 1 (tentative)
Classification	:	Typic Paleustults
Date of examination	:	February 19, 2012
Described by	:	Niwat Anongrak, Soontorn Khamyong, Saroj Wattanasuksakul, Taparat Seeloy-ounkeaw
Location	:	Approximately 44 km north from Chiang Mai City. Mae Tang District. Chiang Mai Province. Grid Reference: 2117377 N, 0495421 E (Sheet: 4747 II)
Elevation	:	398 m (MSL)
Land form		
1. Physiographic position	:	On straight slope
2. Surrounding land form	:	Hill
3. Slope on which profile site	:	Nearly level (2%) S 10^0 W aspect
Vegetation and land use	:	Under dry dipterocarp forest with annual fire. Land is also used for the experimental area. The dominant tree is *Dipterocarpus tuberculatus*
Annual rainfall	:	Approximately 1,174 mm/yr
Mean temperature	:	Approximately 26 ^{0}C
Other	:	Nil

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

Parent material	:	Derived "*in situ*" from shale interbedded with sandstone in Tertiary period
Drainage	:	Well drained
Moisture condition in profile	:	Top 118 cm of profile dry, moist below
Depth of ground water table	:	Nil
Surface stones and rock outcrops	:	No stones and no rocks
Evidence of erosion	:	Slight sheet erosion
Human influence	:	Nil

III <u>Profile Description</u> :

Horizon	Depth (cm)	Description
A	0-3	Very dark grayish brown (10YR3/2) moist and dark brown (10YR3/3) dry; moderate fine subangular blocky structure; many fine and medium tubular pores; many fine and medium roots; strongly acid (pH 5.2); abrupt and smooth boundary to BA
BA	3-10	Brown to dark brown (7.5YR4/4) moist and strong brown (7.5YR5/6) dry; moderate fine and medium angular blocky structure; many fine and medium tubular pores; many fine and medium roots; strongly acid (pH 5.3); abrupt and smooth boundary to Bt1
Bt1	10-30	Dark red (2.5YR3/6) moist and red (2.5YR4/6) dry; moderate fine and medium angular blocky structure; many fine and medium tubular pores; many fine and medium roots; strongly acid (pH 5.3); clear and smooth boundary to Bt2
Bt2	30-58	Dark red (2.5YR3/6) moist and red (2.5YR4/8) dry; moderate fine and medium angular blocky structure; common medium tubular pores; common fine and medium roots; strongly acid (pH 5.4); clear and smooth boundary to Bt3
Bt3	58-80	Red (2.5YR3/6) moist and red (2.5YR4/6) dry; moderate fine and medium angular blocky structure; common medium tubular pores; common fine and medium roots; moderately acid (pH 5.6); clear and smooth boundary to Bt4
Bt4	80-118	Dark red (2.5YR3/6) moist and red (2.5YR4/8) dry; moderate fine and

		medium angular blocky structure; few fine and medium tubular pores; common fine and medium roots; moderately acid (pH 5.7); clear and smooth boundary to Bt5
Bt5	118-135	Dark red (2.5YR3/6) 80% mixed light yellowish brown (10YR6/4) 20% moist; strong fine and medium angular blocky structure; few fine tubular pores; few fine roots; moderately acid (pH 5.8); clear and smooth boundary to Bt6
Bt6	135-170	Dark red (2.5YR3/6) 70% mixed light gray (10YR7/2) 30% moist; strong fine and medium angular blocky structure; few fine tubular pores; few fine roots; moderately acid (pH 5.8); clear and smooth boundary to Bt7
Bt7	170-200+	Dark red (2.5YR3/6) 60% mixed pinkish white (5YR8/2) 40% moist ; strong fine and medium angular blocky structure; few fine tubular pores; few fine roots; moderately acid (pH 5.9)

Pedon 3

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

Profile symbol	: Pedon 3
Soil name	: Intakin series 1 (tentative)
Classification	: Typic Paleustults
Date of examination	: February 12, 2012
Described by	: Niwat Anongrak, Soontorn Khamyong, Saroj Wattanasuksakul, Taparat Seeloy-ounkeaw
Location	: Approximately 44 km north from Chiang Mai City. Mae Tang District. Chiang Mai Province. Grid Reference: 2117377 N, 0495421 E (Sheet: 4747 II)
Elevation	: 390 m (MSL)
Land form	
1. Physiographic position	: On straight slope
2. Surrounding land form	: Hill
3. Slope on which profile site	: Slightly undulating (5%), S 25^0 W aspect
Vegetation and land use	: Under dry dipterocarp forest without fire. Land is also used for the experimental area. The dominant tree is *Dipterocarpus tuberculatus*
Annual rainfall	: Approximately 1,174 mm/yr
Mean temperature	: Approximately 26 ^{0}C
Other	: Nil

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

Parent material	: Derived "*in situ*" from shale interbedded with sandstone in Tertiary period
Drainage	: Well drained
Moisture condition in profile	: Dry 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
A	0-7	Dark brown (7.5YR3/2) moist and brown (7.5YR4/4) dry; moderate fine subangular plocky structure; common medium tubular pores; many very fine and common fine roots; moderately acid (pH 5.9); abrupt and smooth boundary to BA
BA	7-11/15	Dark reddish brown (5YR3/4) moist and reddish brown (5YR4/4) dry; moderate fine subangular plocky structure; common fine and medium tubular pores; common fine and common medium roots; moderately acid (pH 5.6); clear and wavy boundary to Bt1
Bt1	11/15-27/31	Dark reddish brown (5YR3/3) moist and yellowish red (5YR4/7) dry; moderate fine and medium subangular blocky structure; common fine and common medium tubular pores; many fine, common fine and few coarse roots; moderately acid (pH 5.6); clear and wavy boundary to Bt2
Bt2	27/31-50/56	Dark reddish brown (2.5YR3/4) moist and yellowish red (5YR4/4) dry; weak and moderate find angular blocky structure; few and common medium tubular pores; common fine and few coarse roots; moderately acid (pH 5.6); clear and wavy boundary to Bt3
Bt3	50/56-98	Dark red (2.5YR3/6) moist and dark reddish brown (2.5YR3/4) dry; moderate fine and medium subangular blocky structure; few medium tubular pores; common fine and common medium roots; moderately acid (pH 5.7); gradual and smooth boundary to Bt4
Bt4	98-133	Dark red (2.5YR3/6) moist and red (2.5YR4/6) dry; moderate fine and

		medium subangular blocky structure; few medium tubular pores; many very fine and many fine roots; moderately acid (pH 5.7); clear and smooth boundary to Bt5
Bt5	133-168/174	Dark red (2.5YR3/6) moist and red (2.5YR4/6) dry; moderate fine subangular blocky structure; few fine tubular pores; common fine roots; moderately acid (pH 5.7); gradual and wavy boundary to Bt6
Bt6	168/174-200+	Dark reddish brown (2.5YR3/4) moist and red (2.5YR3/6) dry; weak and moderate very fine blocky structure; few very fine and fine tubular pores; common fine roots; moderately acid (pH 5.7)

Pedon 4

I Information on the Site

Profile symbol	:	Pedon 4
Soil name	:	Intakin series 1 (tentative)
Classification	:	Typic Paleustults
Date of examination	:	February 15, 2012
Described by	:	Niwat Anongrak, Soontorn Khamyong, Saroj Wattanasuksakul, Taparat Seeloy-ounkeaw
Location	:	Approximately 44 km north from Chiang Mai City. Mae Tang District. Chiang Mai Province. Grid Reference: 2117377 N, 0495421 E (Sheet: 4747 II)
Elevation	:	395 m (MSL)
Land form		
1. Physiographic position	:	On straight slope
2. Surrounding land form	:	Hill
3. Slope on which profile site	:	Slightly undulating (5%), S 75^0 W aspect
Vegetation and land use	:	Under dry dipterocarp forest without fire. Land is also used for the experimental area. The dominant tree is *Dipterocarpus tuberculatus*
Annual rainfall	:	Approximately 1,174 mm/yr
Mean temperature	:	Approximately 26 ^{0}C
Other	:	Nil

II General Information on the Soil

Parent material	:	Derived "*in situ*" from shale interbedded with sandstone in Tertiary period
Drainage	:	Well drained
Moisture condition in profile	:	Dry throughout
Depth of ground water table	:	Nil
Surface stones and rock outcrops	:	No stones and no rocks
Evidence of erosion	:	Slisht sheet erosion
Human influence	:	Nil

III Profile Description :

Horizon	**Depth (cm)**	**Description**
A	0-5/8	Dark brown (10YR3/3) moist and dark brown to brown (7.5YR4/4) dry; moderate fine subangular blocky structure; common medium tubular pores; many fine and common fine roots; strongly acid (pH 5.1); abrupt and smooth boundary to BA
BA	5/8-12/16	Red (2.5YR4/6) moist and yellowish red (5YR4/8) dry; moderate very fine blocky structure, common very fine tubular pores, many fine and common fine roots; strongly acid (pH 5.4); clear and wavy boundary to Bt1
Bt1	12/16-26/30	Reddish brown (2.5YR4/4) moist and red (2.5YR4/6) dry; moderate very fine blocky structure; common very fine tubular pores; common fine and few coarse roots; strongly acid (pH 5.5); clear and smooth boundary to Bt2
Bt2	26/30-38	Red (2.5YR4/6) moist and red (2.5YR5/8) dry; strong fine blocky structure; common very fine tubular pores; few fine and few coarse roots; strongly acid (pH 5.5); clear and smooth boundary to Bt3
Bt3	38-60	Red (2.5YR4/6) moist and red (2.5YR4/8) dry; strong fine blocky structure; few fine tubular pores; common fine and medium roots; moderately acid (pH 5.6); gradual and smooth boundary to Bt4
Bt4	60-102	Reddish brwon (2.5YR4/4) moist and red (2.5YR4/8) dry; strong fine and medium blocky structure; few fine tubular pores; common fine and few coarse roots; moderately acid (pH 5.7); clear and smooth boundary to Bt5
Bt5	102-130	Red (2.5YR4/6) moist and red (2.5YR4/8) dry; strong medium blocky structure; few fine and medium tubular pores; common fine and few coarse

		roots; moderately acid (pH 5.7); diffuse and smooth boundary to Bt6
Bt6	130-160	Dark reddish brown (2.5YR3/4) moist and reddish brown (2.5YR4/4) dry; strong medium blocky structure; few fine tubular pores; common fine and few coarse roots; moderately acid (pH 5.6); clear and smooth boundary to Bt7
Bt7	160-180	Dark reddish brwon (2.5YR3/4) moist and red (2.5YR4/6) dry; strong medium blocky structure; few and common medium tubular pores; few fine roots; moderately acid (pH 5.8); clear and smooth boundary to Bt8
Bt8	180-200+	Dark reddish brwon (2.5YR3/4) moist and reddish brown (2.5YR4/4) dry; strong medium blocky structure; few fine tubular pores; few fine roots; moderately acid (pH 5.8)

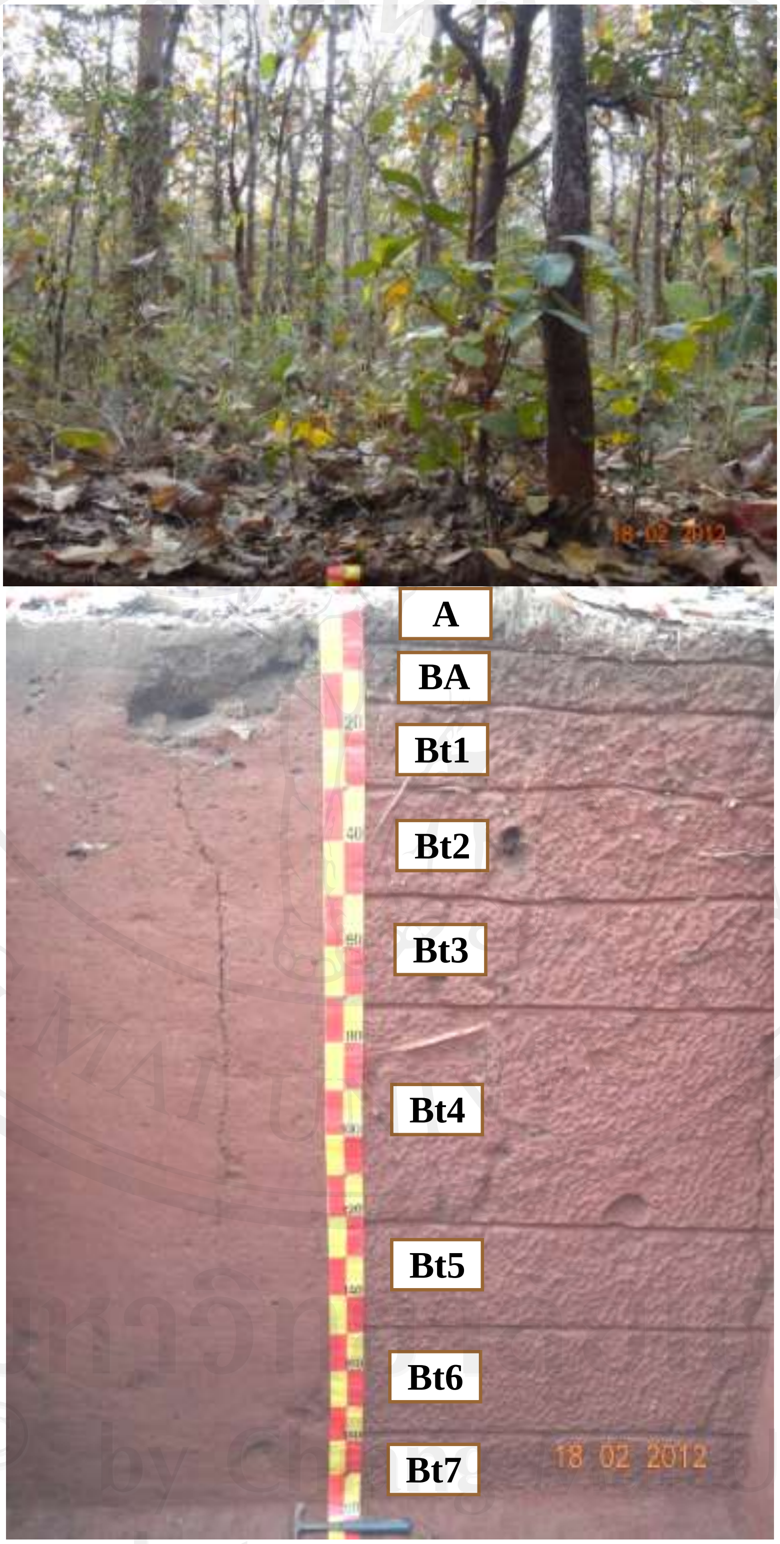

Figure 4-6 Study site and soil profile of pedon 1 (DDF with fire: Plot 1)

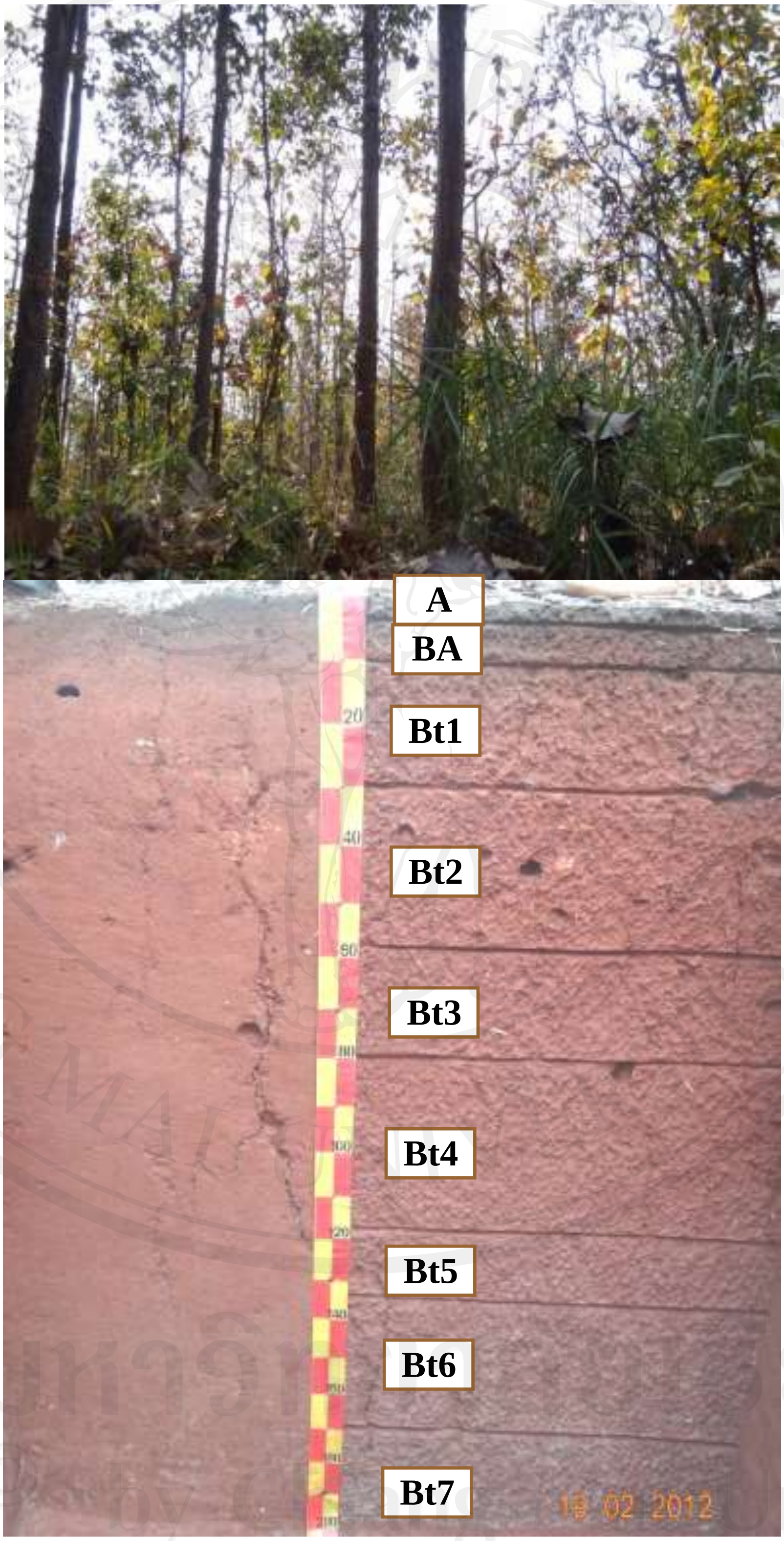

Figure 4-7 Study site and soil profile of pedon 2 (DDF with fire: Plot 2)

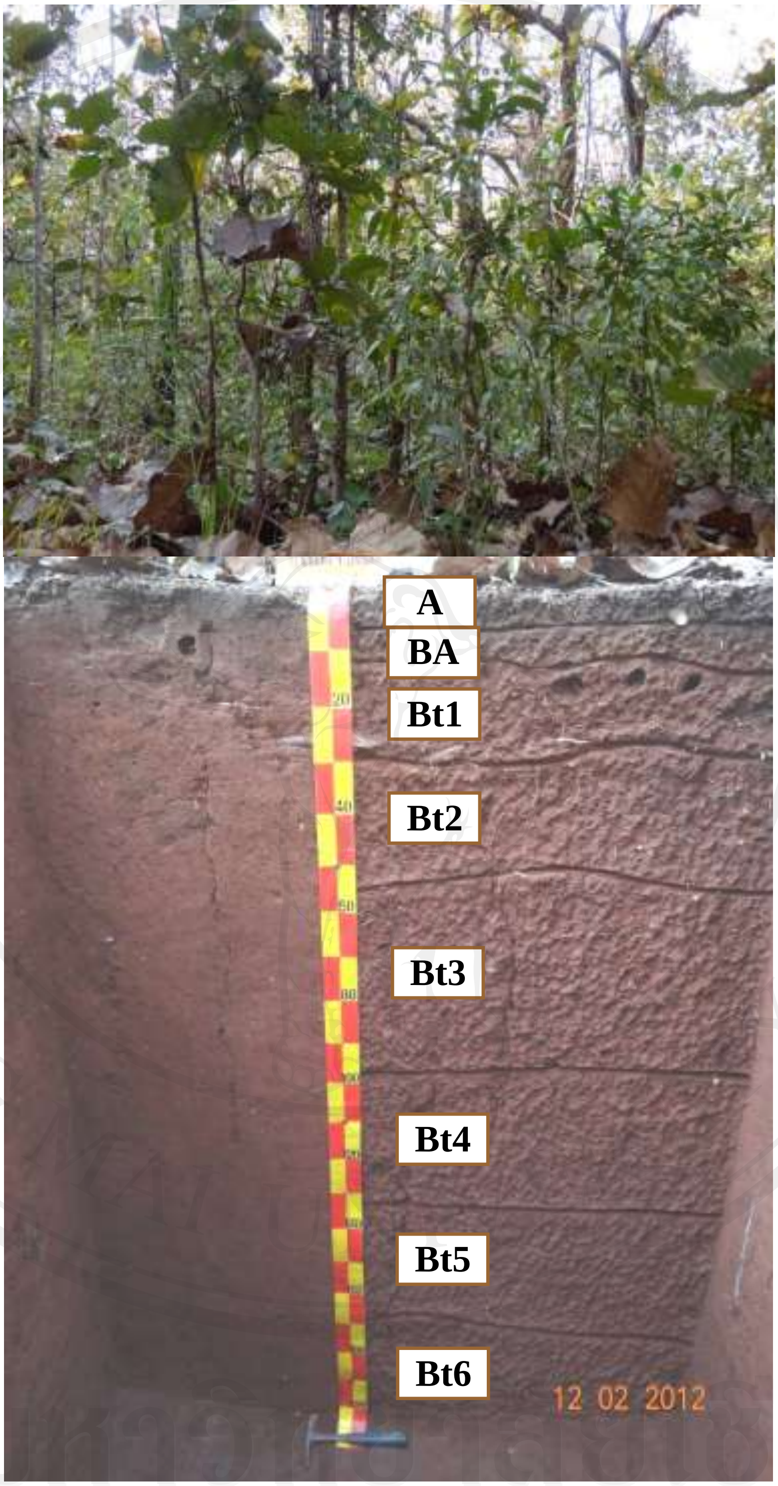

Figure 4-8 Study site and soil profile of pedon 3 (DDF without fire: Plot 1)

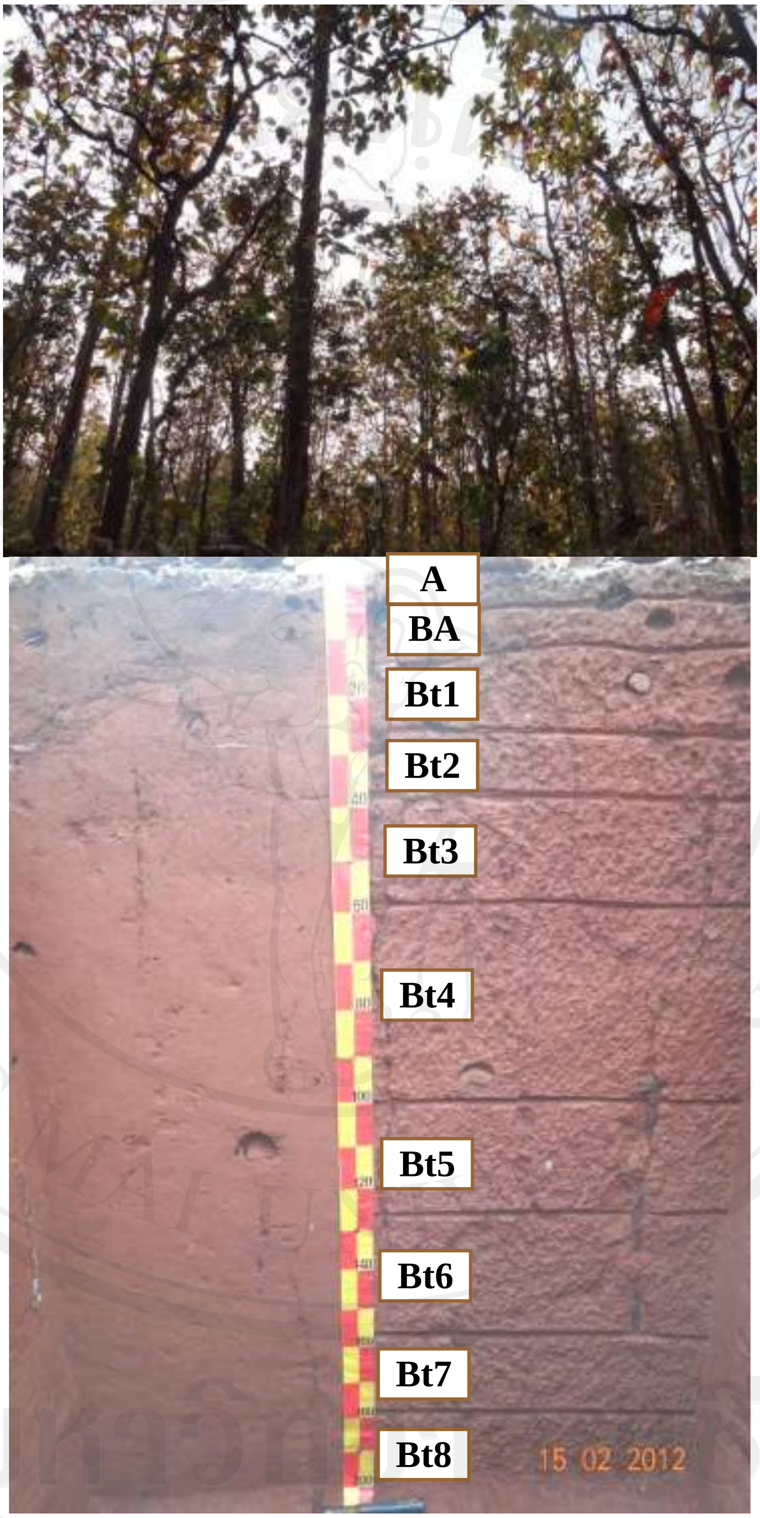

Figure 4-9 Study site and soil profile of pedon 4 (DDF without fire: Plot 2)

4.3.3 Seasonal Change of Soil Moisture Contents in DDF

In Table 4-9, the soil moisture contents at 0-5 cm depth throughout a year under DDF without fire varied in a range of 6.1-25.9%, which were a little higher than DDF with annual fire, 4.7-21.1%. The moisture contents in surface soils during five months of dry season, December-April 2011, were low as 4.7-6.9% for DDF with annual fire and higher as 6.1-9.7% for the non-fire forest (Figure 4-10). The difference of soil moisture contents between dry dipterocarp forest with and without fire was about 2.9% in average.

Table 4-9 Seasonal changes of soil moisture contents in DDF with and without fire

Month	Soil moisture contents (%)								
	DDF with fire				DDF without fire				Fire Effect
	1	2	**Avg.**	**SD**	1	2	**Avg.**	**SD**	
Year 2010									
September	21.7	20.1	**20.9**	**1.1**	27.1	24.6	**25.9**	**1.7**	5.0
October	15.6	13.7	**14.7**	**1.3**	20.6	19.1	**19.8**	**1.0**	5.2
November	18.9	17.6	**18.2**	**1.0**	23.2	21.5	**22.4**	**1.3**	4.1
December	7.8	6.0	**6.9**	**1.2**	10.3	9.0	**9.7**	**1.0**	2.7
Year 2011									
January	6.4	5.6	**6.0**	**0.6**	8.8	8.4	**8.6**	**0.3**	2.6
February	5.6	5.2	**5.4**	**0.3**	8.2	7.5	**7.8**	**0.5**	2.5
March	4.7	4.6	**4.7**	**0.1**	6.5	5.7	**6.1**	**0.6**	1.4
April	6.9	4.8	**5.8**	**1.5**	9.2	8.7	**8.9**	**0.3**	3.1
May	19.9	18.9	**19.4**	**0.7**	23.5	21.3	**22.4**	**1.6**	3.0
June	15.9	14.2	**15.0**	**1.2**	18.4	16.8	**17.6**	**1.2**	2.6
July	21.3	19.8	**20.6**	**1.1**	24.6	22.9	**23.8**	**1.2**	3.2
August	22.2	20.0	**21.1**	**1.6**	24.9	20.1	**22.5**	**3.4**	1.4
September	20.3	18.2	**19.3**	**1.5**	22.0	18.3	**20.1**	**2.6**	0.9
Average	13.4	12.2	**13.7**		16.3	14.7	**16.6**		2.9

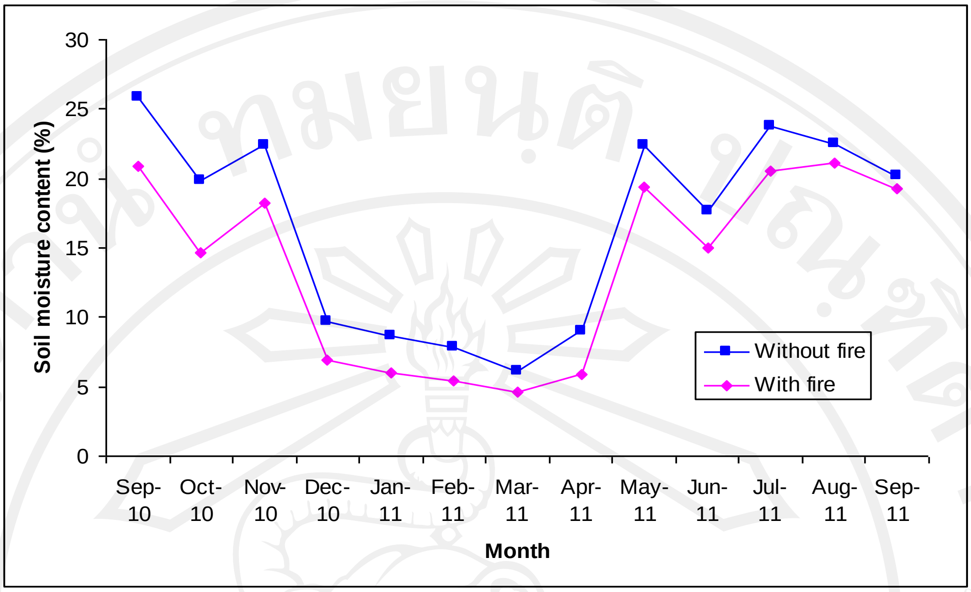

Figure 4-10 Seasonal changes of soil moisture contents at 0-5 cm depth in DDF with and without fire

4.3.4 Seasonal Change of Air Temperature in DDF

In Table 4-9 and 4-10, the air maximum temperature at 1.3 m above ground throughout a year under DDF with annual fire varied between 28.6-38.5 ^{0}C while the non-fire forest had a range of 27.9-38.1 ^{0}C. This implied that a little decrease of maximum temperature was the effect of fire. For minimum air temperature, a range of 13.5-22.9 ^{0}C was occurred in DDF with annual fire, and 12.8-23.1 ^{0}C for non-fire forest. The minimum temperature was observed during January-February 2011, and the maximum temperature was occurred during March-April 2011 (Figure 4-11). There was a little difference in air temperature between DDF with and without fire.

Table 4-10 Seasonal changes of air temperature in DDF with and without fire

Duration	Air temperature (^{0}C)					
	DDF with fire		**DDF without fire**		**Fire Effect**	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Year 2010						
September	22.0	34.4	22.2	35.2	-0.2	-0.8
October	21.3	32.1	21.4	32.1	-0.1	0.1
November	16.1	30.3	15.9	30.2	0.2	0.1
December	16.0	29.6	16.0	29.3	0.0	0.3
Year 2011						
January	13.5	28.6	12.8	27.9	0.6	0.7
February	12.6	33.9	12.3	33.4	0.3	0.5
March	15.3	38.5	15.3	37.7	0.1	0.8
April	17.7	38.5	17.8	38.1	-0.1	0.4
May	22.2	35.3	21.9	35.0	0.3	0.3
June	22.9	34.9	23.1	34.8	-0.1	0.2
July	22.8	34.4	22.8	34.3	0.0	0.1
August	22.0	32.8	21.8	33.1	0.1	-0.3
September	22.3	32.9	22.1	33.3	0.1	-0.4

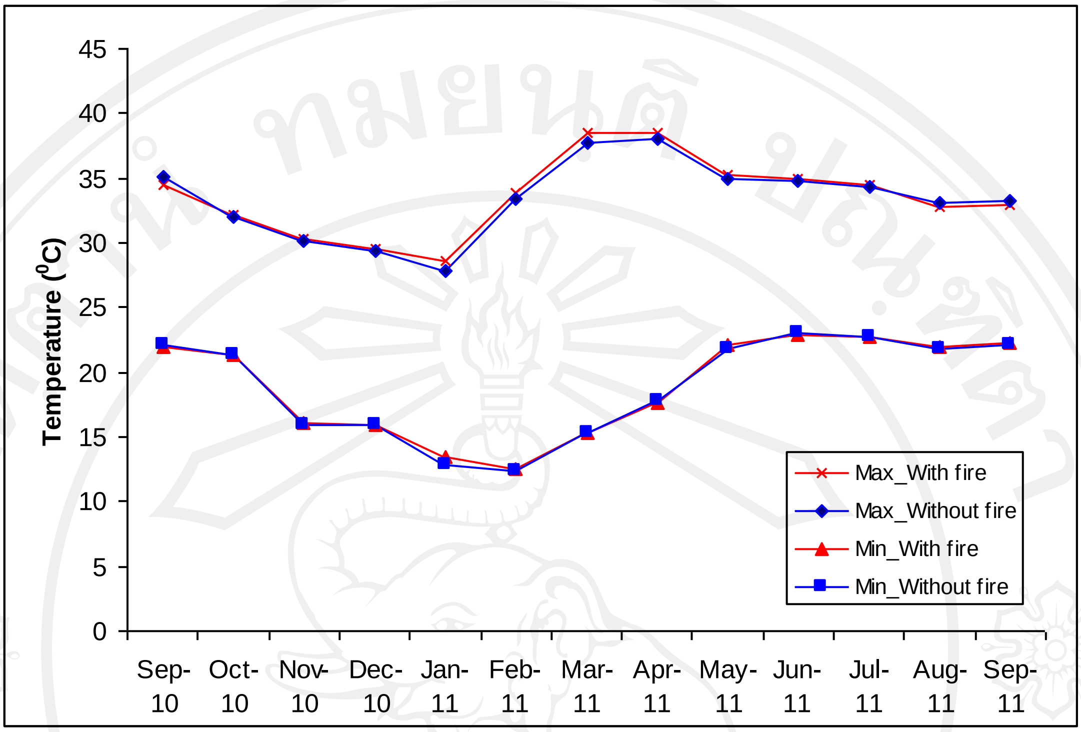

Figure 4-11 Air temperature in DDF with and without fire

4.3.5 Dry Matter and Nutrients in Litterfall

Amounts of litterfall in DDF with and without fire were given in Table 4-11 to 4-13. The total amounts were shown in Table 4-11. The annual amounts of litterfall in DDF with and without fire were 4.34 and 5.76 Mg.ha^{-1} (Table 4-11). The higher amount was found in non-fire forest.

The litterfall amounts varied with collection month throughout a year. The contribution of various organs of tree species to litterfall was also varied with collection month. The amounts were high during dry season and low in rainy season and winter (Table 4-12 and 4-13).

Table 4-11 Annual amounts of litterfall in DDF with and without fire

Species	Organs	Litterfall (Mg.ha^{-1})					
		With fire			Without fire		
		Plot 1	Plot 2	Average	Plot 1	Plot 2	Average
D. tuberculatus	Leaves	2.03	0.78	1.41	3.51	3.10	3.31
	Branches	0.02	0.00	0.01	0.13	0.33	0.23
Shorea obtusa	Leaves	0.50	0.07	0.29	0.20	0.32	0.26
	Branches	0.00	0.00	0.00	0.01	0.00	0.00
Other	Leaves	2.16	2.84	2.50	2.32	1.49	1.91
	Branches	0.11	0.16	0.14	0.06	0.05	0.05
Total		4.83	3.84	4.34	6.23	5.30	5.76

Table 4-12 Variations of litterfall throughout a year in DDF with annual fire

Month	DDF with fire. Plot 1 (g)							DDF with fire. Plot 2 (g)						
	S. obtusa		*D. tuberculatus*		Other		Total	*S. obtusa*		*D. tuberculatus*		Other		Total
	Leaf	Branch	Leaf	Branch	Leaf	Branch		Leaf	Branch	Leaf	Branch	Leaf	Branch	
May-10	3.44	0.00	220.11	0.00	467.90	0.00	**691.45**	12.64	0.00	273.87	115.29	333.28	4.05	**739.13**
Sep-10	0.00	0.00	0.00	0.00	38.04	0.00	**38.04**	0.00	0.00	0.00	0.00	26.36	1.57	**27.93**
Apr-11	85.03	0.00	873.98	14.68	1,057.69	0.00	**2,031.38**	261.72	0.00	961.62	78.13	1,020.45	0.00	**2,321.92**
Jun-10	43.55	0.00	404.22	98.27	1,014.03	65.20	**1,625.27**	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Jul-10	0.00	0.00	0.00	0.00	78.08	0.00	**78.08**	0.00	0.00	0.00	0.00	52.71	0.00	**52.71**
Aug-10	0.00	0.00	51.20	1.67	35.04	1.29	**89.20**	0.00	0.00	33.42	0.00	30.12	0.00	**63.54**
Oct-10	0.00	0.00	0.00	0.00	71.54	0.00	**71.54**	0.00	0.00	0.00	0.00	25.54	1.12	**26.66**
Nov-10	7.54	11.39	16.41	7.54	70.16	0.00	**113.04**	0.00	0.00	0.00	0.00	37.48	0.00	**37.48**
Dec-10	4.31	0.00	27.57	19.31	37.87	1.36	**90.42**	1.09	0.00	4.28	163.10	67.99	0.00	**236.46**
Jan-11	0.00	0.00	0.00	0.00	4.85	0.00	**4.85**	0.94	0.00	26.99	27.25	122.80	37.98	**215.96**
Feb-11	7.22	0.00	311.37	47.78	122.53	6.87	**495.77**	1.51	0.00	118.54	0.00	25.97	0.45	**146.47**
Mar-11	152.34	0.00	3,395.24	0.00	500.87	17.35	**4,065.80**	207.04	0.00	3,258.11	119.94	512.22	22.89	**4,120.20**
Total	**303.43**	**11.39**	**5,300.10**	**189.25**	**3,498.60**	**92.07**	**9,394.84**	**484.94**	**0.00**	**4,676.83**	**503.71**	**2,254.92**	**68.06**	**7,988.46**

Table 4-13 Variations of litterfall throughout a year in DDF without fire

Month	DDF without fire. Plot 1 (g)							DDF without fire. Plot 2 (g)						
	S. obtusa		*D. tuberculatus*		Other		**Total**	*S. obtusa*		*D. tuberculatus*		Other		**Total**
	Leaf	Branch	Leaf	Branch	Leaf	Branch		Leaf	Branch	Leaf	Branch	Leaf	Branch	
May-10	28.40	0.00	51.06	0.00	328.25	9.86	**417.57**	2.72	0.00	70.17	0.00	736.83	4.70	**814.42**
Sep-10	0.00	0.00	0.00	0.00	53.60	42.16	**95.76**	0.00	0.00	0.00	0.00	48.77	35.71	**84.48**
Apr-11	159.68	0.00	353.74	0.00	783.04	0.00	**1,296.46**	32.29	0.00	17.56	0.00	820.89	139.38	**1,010.12**
Jun-10	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Jul-10	0.00	0.00	0.00	0.00	102.18	76.96	**179.14**	0.00	0.00	0.00	0.00	228.70	12.43	**241.13**
Aug-10	0.00	0.00	34.47	0.00	42.36	0.00	**76.83**	0.00	0.00	34.54	0.00	61.95	12.20	**108.69**
Oct-10	0.00	0.00	0.00	0.00	23.32	4.89	**28.21**	0.00	0.00	0.00	0.00	209.56	2.53	**212.09**
Nov-10	0.00	0.00	12.82	23.59	87.85	16.49	**140.75**	0.00	0.00	0.00	0.00	304.08	7.46	**311.54**
Dec-10	4.62	4.00	11.55	0.00	53.73	0.00	**73.90**	0.00	0.00	0.00	0.00	255.66	11.48	**267.14**
Jan-11	14.81	0.00	7.64	4.82	69.22	1.87	**98.36**	0.00	0.00	0.00	0.00	140.45	0.00	**140.45**
Feb-11	5.55	0.00	138.70	0.00	98.45	3.11	**245.81**	0.00	0.00	114.50	0.00	78.48	9.28	**202.26**
Mar-11	545.93	0.00	2,459.71	0.00	1,617.77	15.87	**4,639.28**	72.25	0.00	934.80	0.00	1,392.37	5.47	**2,404.89**
Total	**758.99**	**4.00**	**3,069.69**	**28.41**	**3,259.77**	**171.21**	**7,292.07**	**107.26**	**0.00**	**1,171.57**	**0.00**	**4,277.74**	**240.64**	**5,797.21**

Table 4-14 shows amounts of carbon and other nutrients in litterfall and ash of litterfall in DDF with and without fire. An experiment of burning litter in laboratory was conducted. It was found that the 100 g litter was burnt to be ash of 12.9 g.

In DDF with fire, the amount in litterfall in 2010-2011 was 4.34 $Mg.ha^{-1}$, and calculated to be carbon amount of 1,474 $kg.ha^{-1}$. The amounts of nitrogen, phosphorus, potassium, calcium and magnesium were 21.45,3.86, 34.95, 41.89 and 10.17 $kg.ha^{-1}$, respectively. The loss of carbon in litterfall through fire was high as 1,425.2 $kg.ha^{-1}$ (96.68%), and the remainder 48.82 $kg.ha^{-1}$ was recycling to soil. The loss of nitrogen was 18.7 $kg.ha^{-1}$, and 11.4 $kg.ha^{-1}$ for potassium. For phosphorus, calcium and magnesium, no significant losses were observed. It the DDF without fire had forest fire in 2010-2011, the losses of carbon and nutrients might be occurred as shown in Table 4-14. However, the total amounts of carbon and nutrients in litterfall were recycling into forest floor and soil.

Table 4-14 Nutrient amounts in above-ground litterfall in DDF with and without fire

No.	Nutrient contents (%)			DDF with fire ($kg.ha^{-1}$)			DDF without fire ($kg.ha^{-1}$)		
		litter	ash	litterfall	ash	loss	litterfall	ash	loss
1	Carbon	33.97	8.96	1,474	48.82	-1,425.2	1,957	64.83	-1,892.2
2	Nitrogen	0.49	0.51	21.45	2.77	-18.7	28.49	3.67	-24.8
3	Phosphorus	0.09	0.76	3.86	4.14	+0.3	5.12	5.49	+0.4
4	Potassium	0.81	4.32	34.95	23.54	-11.4	46.41	31.26	-15.15
5	Calcium	0.97	7.99	41.89	43.54	+1.7	55.63	57.82	+2.2
6	Magnesium	0.23	2.06	10.17	11.24	+1.1	13.51	14.93	+1.4

4.4 Discussion

Forest fire has impacts on soil characteristics by many mechanisms (Kimmins, 1997; Ubeda and Outeiro, 2009). As fire occurs, the organic layers on forest floor and organic matter as well as soil fauna and flora in surface soil are destroyed. Increasing surface runoff and soil erosion are usually found in following rainy season.

In this study, the impacts of forest fire on changes of soil physico-chemical properties were occurred in the surface soil. However, some small changes were observed during ten years of fire protection. The soil physical properties included bulk density and texture, and the chemical properties were acidity and nutrient contents. Changes in the chemical properties of soils during burning are primarily related to rapid conversion, or oxidation, of nutrients contained in the organic materials of the living vegetation and litter on the soil surface.

The effects of fire on soil moisture are indirect. It the majority of organic layers on forest floor is removed by burning, water absorption and retention by the humus layer may be significant reduced (Pritchett and Fisher, 1987). In this study, the seasonal change of soil moisture contents in 0-5 cm depth of non-fire forest was a little higher than DDF with annual fire that indicated to the higher water holding capacity which was related to higher organic matter.

The nutrient cycling in forest ecosystem is considerably altered by fire (Kimmins, 1997; Raison *et al*, 2009). These effects of fire on nutrient cycling are caused by heat, ash additions, altered microclimate and changed vegetation dynamics. In this study, the cycling processes of carbon and nutrients were different between DDF with annual fire and without fire. In DDF with fire, most carbon and some amounts of nitrogen in litterfall were lost into atmosphere in the forms of CO_2 and NOx. The organic layers on forest floor and organic matter in surface soil were destroyed, and most amounts of the ash were washed out through surface runoff. In contrast, most nutrients in litterfall were recycling into forest floor, and the organic layers were decomposed with releasing available nutrients into soil. More rapid growths of tree species resulted in increasing biomass and nutrient storages were occurred in non-fire forest. The amounts of annual litterfall and stored carbon and nutrients were increased in non-fire DDF. Therefore, the annual amounts of nutrient recycling into soil in the non-fire forest will be increased year by year. The higher nutrient recycling from plant to soil, increasing uptake by plants, and decreasing losses into atmosphere and erosion are considered as the main mechanisms occurring in the non-fire DDF.