CHAPTER 4

Carbon Storages in Plantation Forests

4.1 Introduction

Human activities are generally accepted as sources of greenhouse gases. These include burning of fossil fuels (49%), industrial processes (24%), deforestation (14%) and agriculture (13%). The greenhouse gases cause climate change and global warming. The relative contribution to global warming (percent of expected climate change) by human-caused releases of greenhouse gases over the next 100 years was reported; carbon dioxide (72.7%), methane (16.6%), nitrous oxide (7.6%), chlorofluorocarbon (2.7%) and sulfur hexafluoride (0.4%). IPCC raises estimates for average global temperature increases over the next century to 1.4 to 5.8^{o}C (Cunningham et al., 2003). Increasing CO_2 in the atmosphere is the main cause of global warming.

In the forest ecosystem, carbon begins the cycling when assimilate CO_2 through photosynthesis into reduced sugar. About half of the gross primary production (GPP) is used by plant in respiration for synthesis and maintenance of living cells, releasing CO_2 back into the atmosphere (Landsberg and Gower, 1997; Waring and Running, 2007). The remaining primary products go into net primary production (NPP) or plant biomass including stem, branch, root and reproductive organs. The above-ground and below-ground litter fall is substrate of decomposers which through their heterotrophic metabolism release CO_2 back into the atmosphere. Grazing by herbivores and carnivores is the way of carbon cycling into secondary production, and lose of CO_2 into the atmosphere is occurred through heterotrophic respiration. The carbon storages are varied with forest types, subtypes, and different forest conditions caused by human disturbance. Many activities affect on the ecosystem carbon storages such as tree cutting, forest fire, harvesting non-wood products, etc. (Phonchaluen, 2009; Naimphulthong, 2011; Wongin, 2011; Nongnuang, 2012; Wattanasuksakul, 2012).

In the past, most forests in Doi Tung area were devasted for cultivation of agricultural crops and growing opium popy. The Doi Tung development project was established in 1988 by Her Royal Highness the Princess Mother (HRH the Princess Mother)'s initiations. The project area is located in Chiang Rai province including two districts, Mae Fah Luang and Mae Sai. It covers areas of 93,515 rai (149.624 km^2) in an altitude range from 400 to 1,500 m m.s.l. The areas are the head watershed supplying water to many streams which are beneficial to 27 villages of hill tribes: Akha, Shan, Lahu, Yunanese Chinese, Lua, Tai Lu, Lisu Hmong, Karen and Mien as well as local Thais in lower land communities. The hill tribes receive more income from the labour wage, agriculture products, handicraft and commerce during the project.

The reforestation was one important activity of the project to improve the watershed environment. It was begun in 1989 as the implementation of the rehabilitation plantation to celebrate the 90th year of Somdet Phra Srinagarindra Boromarajajonani Her Royal Highness the Princess Mother (HRH the Princess Mother). The plantation area had a total area of 10,532 rai (1,685.12 ha). Many tree species were selected to plant in the areas. *Pinus kesiya* was planted in plantations in areas above 800 m m.s.l., whereas the lower area was teak (*Tectona grandis*). The other species were planted in smaller areas to study of specie trail.

The role of forest plantations on the carbon cycle is significant to reduce CO_2 in atmosphere and global warming. Few studies have been conducted on this role. The research objective is to evaluate the potential amount of water storage in the ecosystem (plant biomass and soil) of a 22-year-old teak and pine plantation underthe implementation of the rehabilitation plantation to celebrate the 90th year of Somdet Phra Srinagarindra Boromarajajonani, Her Royal Highness the Princess Mother (HRH the Princess Mother). The data are evaluated for the ecological benefit of the teak and pine plantation.

4.2 Materials and Methods

See Chapter 2, Section 2.2.1

4.3 Results

4.3.1 Carbon Storages in Plantation Forests

4.3.1.1 Carbon Storages in Standing Plant Biomass

The amounts of carbon stored in teak, pine and successional tree species in teak and pine plantations were given as following results.

A. Teak plantation

The amounts of standing biomass in five sampling plots of the 22-year-old teak plantation were described in Chapter 3, section 3.3.2. The total biomass values of all tree species varied greatly between 27.06 and 68.42 Mg plot^{-1} with the mean value of 42.24$\pm$0.65 Mg plot^{-1} (264.0$\pm$103.42 Mg ha^{-1}). The biomass amounts of teak in these plots were 15.68, 25.60, 27.77, 47.38 and 68.15 Mg plot^{-1} (mean value = 36.92$\pm$20.90 Mg plot^{-1}), whereas those of the succesional tree species were 0.27, 0.83, 1.46, 5.84 and 18.23 Mg plot^{-1} (mean value = 5.33$\pm$36.92 Mg plot^{-1}).

The amounts of carbon stored in biomass of all tree species in five sampling plots of the teak plantation were shown in **Table 4-1**. The total amounts in these plots varied between 13,379.38 and 33,843.62 Mg plot^{-1} with the mean value of 20,888.37$\pm$8189.46 Mg plot^{-1} (130.57$\pm$51.18 Mg ha^{-1}). The mean carbon amounts allocated in stem, branch, leaf and root organs were 14,196.61; 4,140.38; 1,019.37 and 1,532.01 kg plot^{-1}, respectively.

For teak, the amounts of carbon stored in biomass varied between 7,754.66 and 33,710.38 kg ha^{-1} with the mean value of 8,258.08±10,339.78 Mg $plot^{-1}$. The teak in these plots had contributed to standing biomass carbon of 46.28% to 99.61% of the all species. The high contribution to biomass carbon of successional tree species was observed in Plot 1 (53.71%), and followed by Plot 2 (17.35%). The successional tree species which had the high contribution to carbon storages in their biomass included *Cratoxylum formosum*, *Aporosa villosa*, *Dalbergia dongnaiensis*, *Lithocarpus glandifolius, Gmelina arborea*, etc.

B. Pine plantation

The amounts of standing biomass in ten sampling plots of the 22-year-old pine plantation were given in Chapter 3, section 3.3.2. The total biomass values of all tree species varied greatly between between 49.32 and 71.25 Mg $plot^{-1}$ with the mean value of 64.59±9.41 Mg $plot^{-1}$ (403.70±58.80 Mg ha^{-1}). The biomass amounts of pine in these plots were varied in a range of 46.26-82.22 Mg $plot^{-1}$ (mean value = 62.14±3.05 Mg $plot^{-1}$), whereas those of the succesional tree species varied between 0.36 and 4.98 Mg $plot^{-1}$ (mean value = 3.05±2.21 Mg $plot^{-1}$).

In **Table 4-2**, the amounts of carbon stored in biomass of all tree species in ten sampling plots of the pine plantation were given. The total amounts in these plots varied between 24,515.0 and 41,289.85 kg $plot^{-1}$ with the mean value of 32,100.0±4650.0 Mg $plot^{-1}$ (200.63±29.09 Mg ha^{-1}). The mean carbon amounts allocated in stem, branch, leaf and root organs were calculated to 21.410.0; 4500.0; 760.0 and 5,420.0 kg $plot^{-1}$, respectively.

For pine tree, the amounts of carbon stored in biomass varied between 23,000.93 and 40,764.48 kg ha^{-1} with the mean value of 30,883.17± 2,433.76 kg $plot^{-1}$. The pine in these plots had contributed to standing biomass carbon of 93.10% to 99.45% of the all species. The succession of broad-leaved tree species in the 22-year-old was occurred, but the succesional trees were still small. It needs more decades for the stand development to be the climax forest until these species are the dominant trees. Thus, the contribution of these trees to carbon storages in their biomass was rather small.

It is clear that the 22-year-old pine plantation had the higher amount of carbon storage in standing biomass than the teak plantation with the same age, because the growth rate of teak was slower than pine tree.

Table 4-1 Amounts of carbon storages in biomass of teak and successional species in the 22-year-old teak plantation

Plot No.	Tree Species	**Carbon storages in plant biomass** (kg/plot)					
		Stem	Branch	Leaf	Root	Total	%
1	**Teak**	5,242.40	1,545.36	439.25	527.65	7,754.66	46.28
	Successional species						
	1. *C. formosum*	2,512.35	743.20	64.71	511.99	3,832.26	22.87
	2. *A. villosa*	1,938.79	552.08	59.15	426.46	2,976.47	17.76
	3. *E. candollei*	472.65	150.51	8.68	82.92	714.76	4.27
	4. *L. glandifolius*	426.52	115.97	15.89	102.75	661.13	3.95
	5. *P. serratum*	237.79	72.51	5.26	45.43	361.00	2.15
	6. *A. gomezianus*	147.47	43.63	3.72	29.89	224.71	1.34
	7. *F. hispida*	56.24	15.02	2.21	13.96	87.43	0.52
	8. *L. glutinosa*	40.55	10.60	1.75	10.50	63.39	0.38
	9. *M. pierrei*	15.06	3.79	0.78	4.23	23.85	0.14
	10. *D. cultrate*	14.74	3.62	0.83	4.31	23.50	0.14
	11. *A. odoratissima*	8.44	2.09	0.46	2.44	13.43	0.08
	12. *D. ehretioides*	6.85	1.67	0.40	2.03	10.95	0.07
	13. *S. aqueum*	5.64	1.36	0.35	1.72	9.06	0.05
	Sum (excluding teak)	5,883.10	1,716.04	164.18	1,238.62	9,001.93	53.72
	Total	**11,125.49**	**3,261.40**	**603.43**	**1,766.27**	**16,756.60**	**100**
2	**Teak**	9,322.97	2,737.31	759.29	914.37	13,733.94	82.65
	Successional species						
	1. *D. dongnaiensis*	612.31	189.72	12.65	113.36	928.05	5.58
	2. *G. arboreas*	484.52	147.95	10.66	92.31	735.44	4.43
	3. *S. pinnata*	292.81	90.47	6.12	54.51	443.92	2.67
	4. *P. emblica*	256.86	75.69	6.63	52.56	391.74	2.36
	5. *C. formosum*	159.75	47.51	3.94	32.06	243.26	1.46
	6. *B. anceps*	56.83	15.83	1.86	12.97	87.49	0.53
	7. *M. pierrei*	34.64	9.35	1.29	8.40	53.69	0.32
	Sum (excluding teak)	1,897.73	576.53	43.14	366.19	2,883.59	17.35
	Total	**11,220.69**	**3,313.84**	**802.43**	**1,280.56**	**16,617.53**	**100**
3	**Teak**	8,571.25	2,524.10	710.82	854.83	12,660.99	94.63
	Successional species						
	1. *C. formosum*	220.96	64.83	5.84	45.67	337.30	2.52
	2. *D. dongnaiensis*	203.89	57.47	6.34	45.48	313.17	2.34
	3. *P. emblica*	36.85	9.99	1.35	8.87	57.06	0.43
	4. *S. cumini*	6.80	1.66	0.40	2.02	10.87	0.08
	Sum (excluding teak)	468.49	133.94	13.93	102.03	718.39	5.37
	Total	**9,039.74**	**2,658.04**	**724.74**	**956.86**	**13,379.38**	**100**
4	**Teak**	23,248.24	6,700.36	1,699.25	2,062.54	33,710.38	99.61
	Successional species						
	1. *G. pinnata*	86.99	24.90	2.53	18.83	133.24	0.39
	Sum (excluding teak)	86.99	24.90	2.53	18.83	133.24	0.39
	Total	**23,335.23**	**6,725.25**	**1,701.78**	**2,081.37**	**33,843.62**	**100**
5	**Teak**	15,992.50	4,666.61	1,255.37	1,515.95	23,430.44	98.27
	Successional species						
	1. *C. formosum*	146.29	40.73	4.84	33.50	225.37	0.95
	2. *D. dongnaiensis*	123.07	36.00	3.26	25.51	187.85	0.79
	Sum (excluding teak)	269.37	76.73	8.10	59.01	413.21	1.73
	Total	16,261.87	4,743.35	1,263.47	1,574.97	23,843.66	100
Mean (kg rai^{-1}) **± S.D.**		**14,196.61 ± 5,758.92**	**4,140.38 ± 1,635.41**	**1,019.37 ± 456.11**	**1,532.01 ± 433.75**	**20,888.37 ± 8189.46**	

Table 4-2 Amounts of carbon storages in biomass of pine and successional species in the 22-year-old pine plantation

Plot No.	Tree species	Carbon storage in plant biomass (kg/plot)					
		Stem	Branch	Leaf	Root	Total	%
1	**Pine**	17,685.31	3,414.64	615.08	4,614.47	26,329.50	94.74
	Successional species						
	1. *L. glutinosa*	403.01	116.02	22.78	86.48	628.30	2.26
	2. *D. glandulosa*	398.38	115.63	22.02	84.00	620.03	2.23
	3. *G. usitata*	99.90	27.62	6.21	23.14	156.87	0.56
	4. *F. ribes*	35.07	9.48	2.31	8.50	55.35	0.20
	Sum (excluding pine)	936.36	268.75	53.32	202.12	1,460.56	5.26
	Total	18,621.67	3,683.40	668.40	4,816.59	27,790.06	100
2	**Pine**	19,552.10	3,963.82	679.23	5,020.96	29,216.11	93.80
	Successional species						
	1. *L. glandifolius*	504.63	151.13	25.78	100.00	781.54	2.51
	2. *A. odoratissima*	234.18	71.34	11.45	44.82	361.79	1.16
	3. *W. tomentosa*	217.40	64.55	11.41	43.99	337.36	1.08
	4. *D. glandulosa*	186.07	54.89	9.93	38.14	289.03	0.93
	5. *G. pinnata*	60.91	17.04	3.68	13.78	95.41	0.31
	6. *F. ribes*	42.50	11.63	2.71	10.05	66.90	0.21
	Sum (excluding pine)	1,245.70	370.58	64.97	250.78	1,932.03	6.20
	Total	20,797.79	4,334.41	744.20	5,271.74	31,148.14	100
3	**Pine**	19,591.62	3,879.23	680.99	5,071.27	29,223.10	99.00
	Successional species						
	1. *A. odoratissima*	130.87	38.43	7.01	26.92	203.23	0.69
	2. *M. indica*	36.22	9.39	2.64	9.52	57.77	0.20
	3. *D.cultrata*	22.28	5.85	1.57	5.71	35.41	0.12
	Sum (excluding pine)	189.37	53.67	11.23	42.15	296.42	1.00
	Total	19,780.99	3,932.90	692.22	5,113.42	29,519.53	100
4	**Pine**	19,654.47	3,873.73	683.22	5,091.66	29,303.08	97.18
	Successional species						
	1. *B. variegata*	323.26	96.55	16.63	64.40	500.85	1.66
	2. *A. odoratissima*	197.59	59.55	9.92	38.63	305.69	1.01
	3. *L. glandifolius*	28.22	7.52	1.92	7.02	44.69	0.15
	Sum (excluding pine)	549.08	163.63	28.47	110.05	851.23	2.82
	Total	20,203.55	4,037.36	711.69	5,201.70	30,154.31	100
5	**Pine**	22,065.40	4,807.59	765.22	5,530.32	33,168.53	95.37
	Successional species						
	1. *F. ribes*	188.31	54.16	10.62	40.36	293.45	0.84
	2. *L. durperreanum*	159.75	47.51	8.29	32.06	247.61	0.71
	3. *A. villosa*	152.08	45.09	7.96	30.71	235.84	0.68
	4. *D. cultrata*	139.45	39.39	8.23	30.98	218.05	0.63
	5. *A. odoratissima*	122.99	35.98	6.65	25.50	191.12	0.55
	6. *Fcus* sp.	98.30	27.14	6.14	22.84	154.41	0.44
	7. *D. glandulosa*	63.09	17.69	3.79	14.21	98.78	0.28
	8. *S. wallichii*	42.07	11.50	2.69	9.96	66.23	0.19
	9. *G. pinnata*	34.40	9.28	2.27	8.35	54.30	0.16
	10. *P. serratum*	31.59	8.48	2.11	7.75	49.94	0.14
	Sum (excluding pine)	1,032.04	296.21	58.75	222.73	1,609.72	4.63
	Total	23,097.44	5,103.80	823.97	5,753.05	34,778.26	100

Table 4-2 (Continued)

Plot No.	Tree Species	Carbon storage in plant biomass (kg/plot)					
		Stem	**Branch**	**Leaf**	**Root**	**Total**	**%**
6	**Pine**	22,757.49	4,773.36	789.94	5,776.63	34,097.41	96.33
	Successional species						
	1. *A. odoratissima*	481.89	147.08	23.45	91.90	744.31	2.10
	2. *M. dentriculata*	219.28	66.53	10.83	42.32	338.96	0.96
	3. *F. ribes*	89.21	25.57	5.07	19.25	139.10	0.39
	4. *D. glandulosa*	49.54	13.68	3.09	11.50	77.82	0.22
	Sum (excluding pine)	839.92	252.86	42.44	164.96	1,300.18	3.67
	Total	23,597.41	5,026.22	832.38	5,941.59	35,397.60	100
7	**Pine**	21,313.47	4,347.68	740.30	5,460.15	31,861.60	99.43
	Successional species						
	1. *P. serratum*	43.45	11.90	2.77	10.25	68.37	0.21
	2. *P. macrocarpus*	38.37	10.43	2.49	9.19	60.47	0.19
	3. *F. ribes*	33.13	8.92	2.20	8.08	52.33	0.16
	Sum (excluding pine)	114.95	31.25	7.46	27.52	181.18	0.57
	Total	21,428.41	4,378.93	747.76	5,487.67	32,042.78	100
8	**Pine**	27,097.10	5,955.39	939.53	6,772.46	40,764.48	98.73
	Successional species						
	1. *F. ribes*	172.21	51.45	8.83	34.24	266.74	0.65
	2. *G. usitata*	166.93	49.78	8.61	33.32	258.63	0.63
	Sum (excluding pine)	339.14	101.23	17.44	67.57	525.38	1.27
	Total	27,436.24	6,056.62	956.97	6,840.03	41,289.85	100
9	**Pine**	21,197.80	4,615.86	735.18	5,318.12	31,866.96	92.83
	Successional species						
	1. *B. variegate*	449.13	124.48	27.90	103.85	705.36	2.05
	2. *D. gladulosa*	298.37	92.30	14.04	55.42	460.13	1.34
	3. *L. duperreanum*	298.37	92.30	14.04	55.42	460.13	1.34
	4. *P. tomentosa*	156.42	43.40	9.65	36.00	245.47	0.72
	5. *G. arborea*	117.18	32.92	7.02	26.35	183.48	0.53
	6. *D. cultrate*	95.35	26.11	6.11	22.59	150.15	0.44
	7. *F. ribes*	60.56	16.94	3.66	13.71	94.87	0.28
	8. *Ficus* sp.	41.86	11.44	2.68	9.92	65.89	0.19
	9. *A. odoratissima*	29.29	7.83	1.98	7.26	46.36	0.14
	10. *C. pruniflorum*	18.45	4.79	1.34	4.84	29.42	0.09
	11. *S. wallichii*	7.92	1.95	0.66	2.31	12.84	0.04
	12. *M. pierrei*	4.25	1.01	0.39	1.34	6.99	0.02
	Sum (excluding pine)	1,577.16	455.44	89.48	339.00	2,461.08	7.17
	Total	22,774.96	5,071.31	824.66	5,657.12	34,328.04	100
10	**Pine**	15,397.76	3,110.71	534.95	3,957.51	23,000.93	93.82
	Successional species						
	1. *G. arborea*	521.39	160.03	25.03	98.36	804.80	3.28
	2. *D. cultrate*	215.69	65.37	10.68	41.71	333.45	1.36
	3. *A. odoratissima*	102.39	28.37	6.34	23.63	160.73	0.66
	4. *L.gutinosa*	51.05	13.51	3.57	12.95	81.08	0.33
	5. *G. usitata*	35.69	9.66	2.34	8.63	56.32	0.23
	6. *M. pierrei*	16.33	4.11	1.29	4.56	26.30	0.11
	7. *Sterculia* sp.	13.45	3.42	1.03	3.67	21.56	0.09
	8. *V. pinnata*	9.15	2.10	0.91	3.07	15.22	0.06
	9. *S. wallichii*	9.04	2.24	0.74	2.59	14.60	0.06
	Sum (excluding pine)	974.17	288.80	51.92	199.17	1,514.07	6.18
	Total	16,371.93	3,399.51	586.87	4,156.69	24,515.00	100
Mean (Mg/plot)		21,410 **± 3,050**	4,500 **± 810**	760 **± 100**	5,420 **± 710**	32,100 **± 4,650**	

4.3.1.2 Carbon Storages in Soils

4.3.1.2.1 Soil Characteristics

Soil characteristics in the teak plantation, pine plantation and opened site include soil profile development, physical properties and some chemical properties as following results.

A. Teak plantation

Some soil physical properties in the 22-year-old teak plantation were given (**Pedon 1**) in **Table 4-3**. These included soil bulk densities, gravel contents, soil particle size distribution and texture.

The bulk densities at different depths within 2 m soil profiles were almost moderately low, except the low values at 120-160 m. The moderately low values varied in a range of 1.25-1.38 Mg m^{-3}, wheras that of the low values was 1.07-1.19 Mg m^{-3}. The high contents of gravel caused the low bulk density. At the depth of 0-100 cm, the gravel contents were rather low, 4.50-12.65% by weight. The gravel contents were increased at the deeper horizons.

The percents of sand particle within 2 m soil profiles were not high, varying 34.0-71.70%. The percents of silt particle varied between 18.0 and 31.70%. At the depth of 0-20 cm, the percents of clay particle were 23.30-25.10%. They were increased to 29.30-35.30% at the depth of 20-120 cm, and then declined at the deeper horizons.

The soil in teak plantation had loamy texture: 0-10 cm depth, loam; 10-20 cm, sandy clay loam; 20-140 cm, clay loam; 120-140 cm, loam, 140-160, snady clay loam, and 160-200 cm, sandy loam.

B. Pine plantation

Soil physical properties in the teak plantation, pine plantation and opened site were given as following results.

(1) Physical properties

In **Table 4-4, s**ome soil physical properties in the 22-year-old pine plantation (**Pedon 2**) and opened site nearby the plantation (**Pedon 3**). These included soil bulk densities, gravel contents, soil particle size distribution and texture.

The bulk densities at different depths within 2 m soil profiles of Pedon 2 and Pedon 3 were low. The values varied between 0.74-1.17 Mg m^{-3} for Pedon2, and 0.79-1.18 Mg m^{-3} for Pedon 3. In Pedon 2, the bulk densities were quite low at the depth of 0-40 cm, 0.74-0.95 Mg m^{-3} caused the high organic matter contents which has the low mass. They increased at the depth of 40-160 cm, 1.01-1.17 Mg m^{-3} as the contents of organic matter were decreased. However, the lower bulk densities at the deeper horizons were caused by the high gravel contents. As for Pedon 3, the low bulk densities were observed at the depth of 0-10 cm, 0.79-0.92 Mg m^{-3}, and then increased in the deeper horizons.

In the pine plantation (Pedon 2), the percents of sand particle within 2 m soil profiles were low, varying 3.2-36.50%%. The percents of silt particle were rather high, varying 23.0-41.2%. At the depth of 0-10 cm, the percents of clay particle were 35.3-37.0%. They were increased to 40.1-58.2% at the depth of 20-200 cm. For the opened site (Pedon 3), the percents of sand particle within 2 m soil profiles were higher than Pedon 2, varying 21.60-69.60%%. The percents of silt particle varied between 20.6% and 49.10%. The percents of clay particle were rather high at the depth of 0-80 cm, 22.40-31.0%, and lower, 9.80-23.30% at the depth of 80-200 cm. The pine plantation had more developed soil than the opened site. The high clay aacumulation throughout the soil profile under pine plantation was observed.

The soil in pine plantation (Pedon 2) had almost clayey texture: 0-10 cm depth, clay loam; 10-120 cm, clay; 120-140 cm, silty clay; 140-180 cm, clay, and 180-200 cm, silty clay. In the opened site, the soil (Pedon 3) had loamy texture: 0-5 cm depth, sandy clay loam; 5-20 cm, clay loam; 20-30 cm, loam; 30-40 cm, clay loam; 40-120 cm, loam; 120-140 cm, sandy loam and 140-200 cm, loam.

The teak plantation (Pedon 1) and the opened site (Pedon 3) had the medium to moderately fine-textured soil whereas the pine plantation (Pedon 2) had the fine-textured soil. Therfore, the pine plantation had the more developed soil profile than the teak plantation.

Table 4-3 Changes in some physical properties along soil profile in the 22-year-old teak plantation (Pedon 1)

Pedon	Soil depth	Bulk density (Mg m^{-3})	*	Gravel (%)	Particle size distribution (%)			Soil texture
					Sand	Silt	Clay	
1	0-5	1.23±0.18	ML	4.50±2.54	46.70	30.00	23.30	Loam
	5-10	1.24±0.08	ML	5.79±3.29	44.20	30.70	25.10	Loam
	10-20	1.30±0.04	ML	7.85±3.01	47.70	27.20	25.10	Sandy clay loam
	20-30	1.33±0.06	ML	12.65±3.92	39.10	30.70	30.20	Clay loam
	30-40	1.37±0.04	ML	9.28±5.10	36.50	28.20	35.30	Clay loam
	40-60	1.38±0.08	ML	7.12±3.26	34.00	30.70	35.30	Clay loam
	60-80	1.36±0.07	ML	5.48±0.95	36.50	28.20	35.30	Clay loam
	80-100	1.42±0.01	M	7.87±1.86	36.50	30.70	32.80	Clay loam
	100-120	1.25±0.12	ML	21.58±5.30	41.60	29.10	29.30	Clay loam
	120-140	1.19±0.16	L	22.60±5.77	46.70	31.70	21.60	Loam
	140-160	1.07±0.19	L	28.05±9.78	53.70	23.80	22.50	Sandy clay loam
	160-180	1.26±0.06	ML	21.87±10.17	71.50	21.20	7.30	Sandy loam
	180-200	1.25±0.10	ML	22.67±12.17	74.70	18.00	7.30	Sandy loam

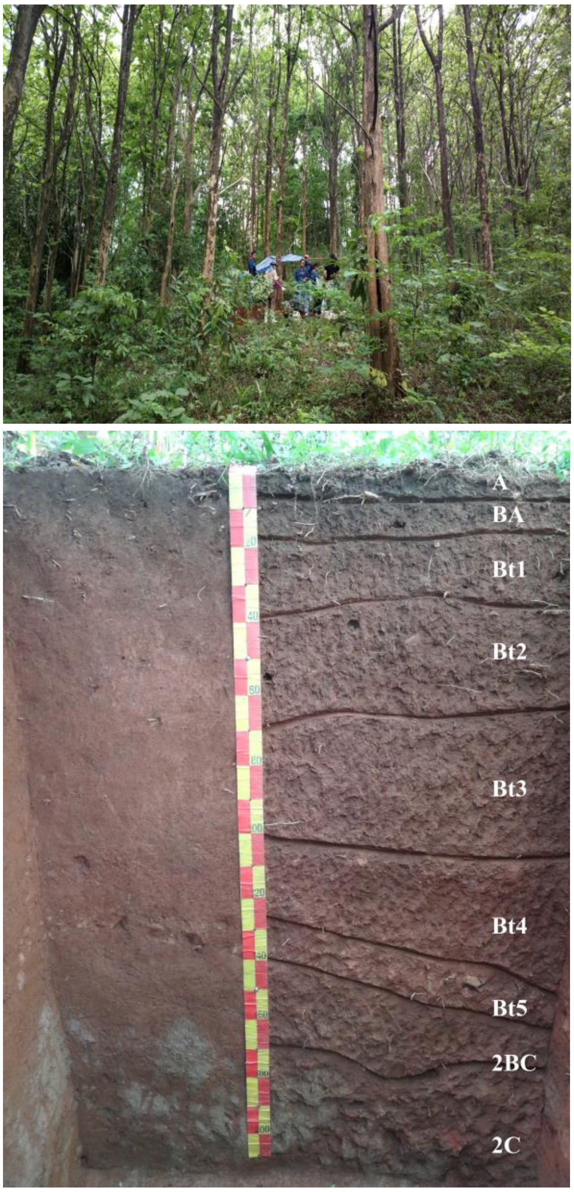

Figure 4-1 Site study and soil profile of pedon 1 (Teak plantation)

Pedon 1

I Information on the Site

Profile symbol	**:**	Pedon 1 (Map No. 4949I)
Soil name	**:**	Doi tung series 1 (Tentative)
Classification	**:**	Typic Palehumult
Date of examination	**:**	August 17, 2013
Described by	**:**	Niwat Anongrak, Samart Sumaochitraporn
Location	**:**	Doi Tung area, Mae Fa Luang Ddistrict, Chiang Rai Province
Elevation	**:**	690/654 m (MSL)
Land form		
1. Physiographic position	**:**	On straight slope
2. Surrounding land form	**:**	Mountainous
3. Slope on which profile site	**:**	Hilly (18º, 33%), S 50^0 W Aspect
Vegetation and land use	**:**	Teak plantatiom
Annual rainfall	**:**	Approximately 1,894 mm/yr
Mean temperature	**:**	Approximately 20.9 ^{0}C
Other	**:**	Nil

II General Information on the Soil

Parent material	**:**	Residuum from granite and chorite
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	0-6	Dark reddish brown (5YR3/4) moist; loam; moderate fine and weak medium granular structure; common fine and medium roots; moderagely acid (pH 5.6); clear and smooth boundary to BA
BA	6-17/22	Yellowish red (5YR4/6) moist; sandy clay loam; moderate fine and weak medium subangular blocky structure ; common fine, medium and coarse roots; strongly acid (pH 5.2); clear and smooth boundary to Bt1
Bt1	17/22-36/40	Yellowish red (5YR4/8) moist; clay loam; moderate medium and strong medium subangular blocky structure; few fine, medium roots; strongly acid (pH 5.4); clear and smooth boundary to Bt2
Bt2	36/40-68/72	Red (2.5YR4/6) moist; clay loam; strong medium subandular blocky structure; few fine, common medium and few coarse roots; moderately acid (pH 5.8); clear and smooth boundary to Bt3
Bt3	68/72-102	Red (2.5YR4/6) moist; clay loam; strong fine and medium subangular blocky structure; few fine and medium roots; slightly acid (pH 6.2); gradual and smooth boundary to Bt4
Bt4	102-127/132	Red (2.5YR4/6) moist; clay loam; strong fine and medium subangular blocky structure; few fine and medium roots; few rounded boulded of granite and weathered diorite; slightly acid (pH 6.2); gradual and smooth boundary to Bt5
Bt5	127/132-142/145	Red (2.5YR4/6) moist; clay loam; strong fine and medium subangular blocky structure; few fine roots; few rounded boulded of granite and weathered diorite; moderately acid (pH 5.8); gradual and smooth boundary to 2BC
2BC	142/145-168/175	Red (2.5YR4/6) moist; sandy loam; strong fine and medium subangular blocky structure; few fine roots; few stone rounded stones of granite and weathered diorite; moderately acid (pH 5.8); gradual and wavy to 2C
2C	168/175-200+	Yellowish red (2.5YR4/7) moist; sandy loam; strong fine and medium subangular blocky structure; few fine roots; few stone rounded stones of granite and weathered diorite; slightly acid (pH 6.2)

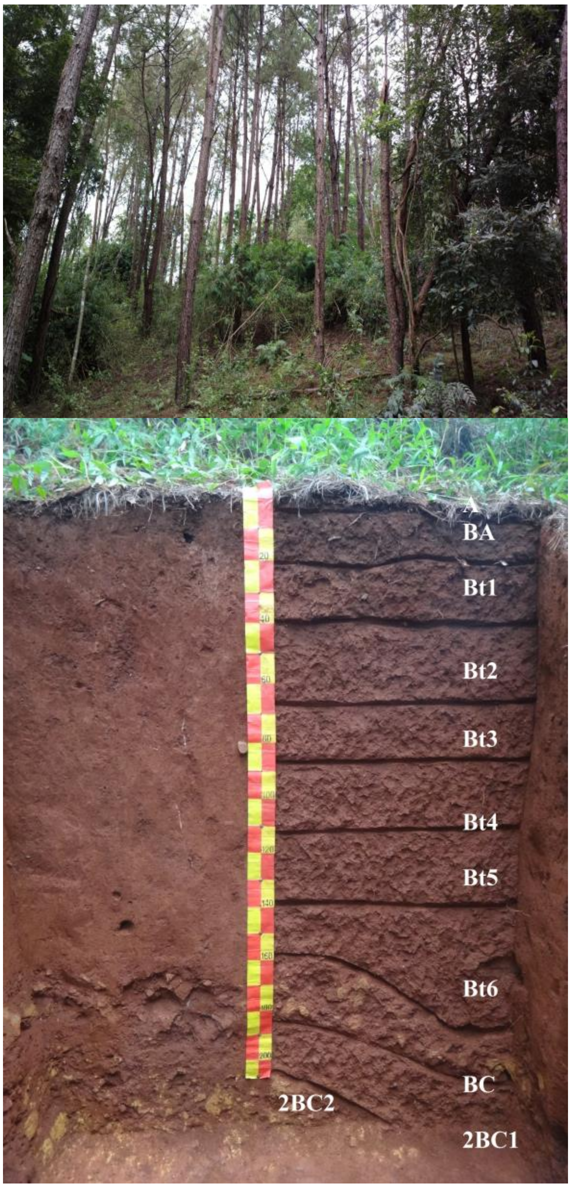

Figure 4-2 Site study and soil profile of pedon 2 (Pine plantation)

Pedon 2

I Information on the Site

Profile symbol	**:** Pedon 2
Soil name	**:** Doi Tung series 2 (Tentative)
Classification	**:** Typic Palehumult
Date of examination	**:** August 17, 2013
Described by	**:** Niwat Anongrak, Samart Sumaochitraporn
Location	**:** Doi Tung area, Mae Fa Luang District, Chiang Rai Province
Elevation	**:** 920 m (MSL)

Land form

1. Physiographic position	**:** On straight slope
2. Surrounding land form	**:** Mountainous
3. Slope on which profile site	**:** Very steep (27^{o}, 55%), S 20^{0} W aspect
Vegetation and land use	**:** Pine plantatiom
Annual rainfall	**:** Approximately 1,894 mm/yr
Mean temperature	**:** Approximately 20.9 ^{0}C
Other	**:** Nil

II General Information on the Soil

Parent material	**:** Residuum from granite
Drainage	**:** Well drained
Moisture condition in profile	**:** Moist throughout
Depth of ground water table	**:** Nil
Surface stones and rock outcrops	**:** No stone and no rocks
Evidence of erosion	**:** Slight sheet erosion
Human influence	**:** Nil

III Profile Description :

Horizon	Depth (cm)	Description
A	0-3/5	Yellowish red (5YR4/6 moist; clay loam; granular structure; common fine and medium roots; strongly acid (pH 5.2); abrupt and smooth boundary to BA
BA	3/5-17/21	Reddish brown (2.5YR4/4) moist; clay; moderate fine and weak medium subangular blocky structure ; common fine, medium and coarse roots; strongly acid (pH 5.4); abrupt and smooth boundary to Bt1
Bt1	17/21-38/40	Red (2.5YR4/6) moist; clay; moderate medium and strong medium subangular blocky structure; few fine, medium roots; moderately acid (pH 5.8); clear and smooth boundary to Bt2
Bt2	38/40-66	Red (2.5YR4/6) moist; clay; strong medium subandular blocky structure; few fine, common medium and few coarse roots; moderately acid (pH 5.6); clear and smooth boundary to Bt3
Bt3	66-86	Dark red (2.5RY3/6) moist; Clay; strong fine and medium subangular blocky structure; few fine and medium roots; moderately acid (pH 5.8); clear and smooth boundary to Bt4
Bt4	86-113	Dark red (2.5YR3/6) moist; clay; strong fine and medium subangular blocky structure; few fine and medium roots; few boulded rounded stones of granite and weathered diorite; slightly acid (pH 6.2); clear and smooth boundary to Bt5
Bt5	113-138	Red (2.5YR4/6) moist; clay; strong fine and medium subangular blocky structure; few fine and medium roots; few boulded rounded stones; slightly acid (pH 6.2); clear and smooth boundary to Bt6
Bt6	138-158/174	Red (2.5YR4/6) moist; sandy loam; strong fine and medium subangular blocky structure; few fine and medium roots; few boulded rounded stones of granite and weathered diorite; slightly acid (pH 6.2); gradual and wavy boundary to BC
BC	158/174-185/196	Red (2.5YR4/6) moist; clay loam; strong fine and medium subangular blocky structure; few fine roots; slightly acid (pH 6.01); gradual and broden to 2BC1
2BC1	185/196-204/228	Red (2.5YR4/6) moist; clay loam; strong fine and medium subangular blocky structure; few fine roots; slightly acid (pH 6.01); gradual and broden to 2BC2
2BC2	204/228-228+	Red (2.5YR4/6) moist; clay loam; strong fine and medium subangular blocky structure; few fine roots; slightly acid (pH 6.01)

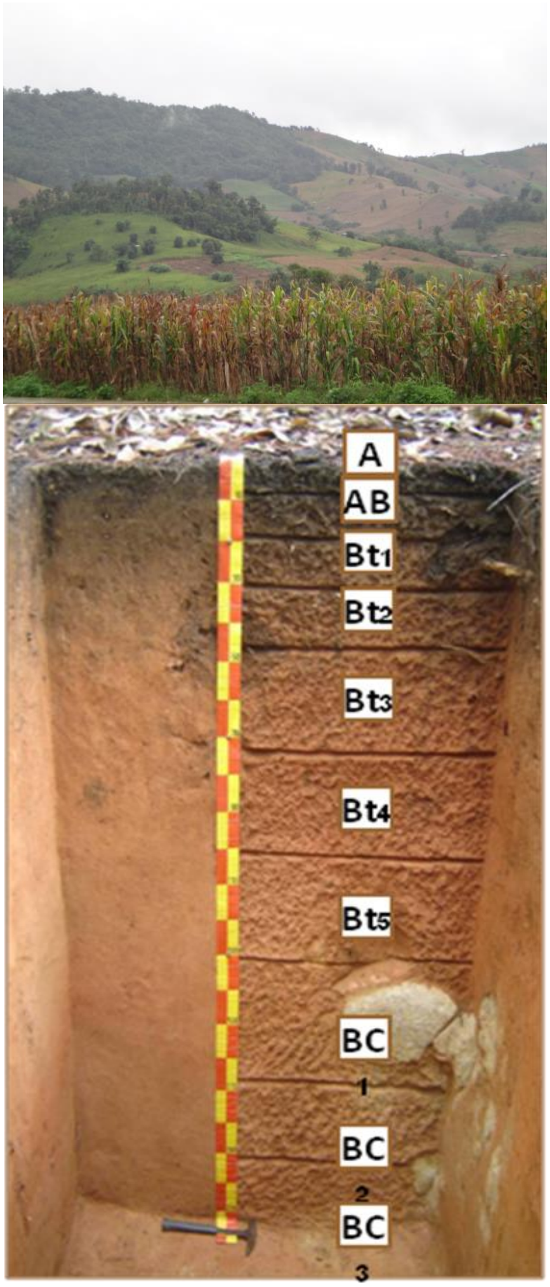

Figure 4-3 Site study and soil profile of pedon 3 (Opened site)

Pedon 3

I Information on the Site

Profile symbol	**:** Pedon 3
Soil name	**:** Doi Tung series 3 (Tentative)
Classification	**:** Typic Dystrudept
Date of examination	**:** August 17, 2013
Described by	**:** Niwat Anongrak, Samart Sumanochitraporn
Location	**:** Doi Tung area, Mae Sai District, Chiang Rai Province
Elevation	**:** 1,430 m (MSL)

Land form

1. Physiographic position	**:** On straight slope, near summit
2. Surrounding land form	**:** Mountainous
3. Slope on which profile site	**:** Very steep (27^{o}, 55%), N 60^{0} W aspect
Vegetation and land use	**:** Opened site
Annual rainfall	**:** Approximately 1,894 mm/yr
Mean temperature	**:** Approximately 20.9 ^{0}C
Other	**:** Nil

II General Information on the Soil

Parent material	**:** Residuum from granite
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	0-13	Dark brown (10YR3/3) moist; clay loam; granular structure; common fine and medium roots; very strongly acid (pH 5.0); abrupt and smooth boundary to BA
BA	13-25	Yellowish brown (10YR5/8) moist; clay loam; moderate fine and weak medium subangular blocky structure ; common fine, medium and coarse roots; very strongly acid (pH 5.0) ; clear and smooth boundary to Bw1
Bw1	25-53	Yellowish brown (10YR5/8) 70%, bruwn (7.5YR5/4) 30% moist; loam; moderate medium and strong medium subangular blocky structure; few fine, medium roots; strongly acid (pH 5.2) ; clear and smooth boundary to Bw2
Bw2	53-80/83	Reddish yellow (7.5YR7/8) moist; loam; strong medium subandular blocky structure; few fine, common medium and few coarse roots; strongly acid (pH 5.2) ; gradual and smooth boundary to Bw3
Bw3	80/83-108/110	Reddish yellow (2.5YR6/8) moist; loam; strong fine and medium subangular blocky structure; few fine and medium roots; strongly acid (pH 5.4); gradual and smooth boundary to Bw4
Bw4	108/110-153/158	Strong brown (7.5YR5/8) moist; loam; strong fine and medium subangular blocky structure; few fine and medium roots; few boulded rounded stones of granite and weathered diorite; moderately acid (pH 5.8); clear and smooth boundary to Bw5
Bw5	153/158-170/176	Strong brown (7.5YR5/6) moist; loam; strong fine and medium subangular blocky structure; few fine and medium roots; few boulded rounded stones; moderately acid (pH 5.6); clear and smooth boundary to Bw6
Bw6	170/176-190/196	Strong brown (7.5YR5/6) moist; loam; strong fine and medium subangular blocky structure; few fine and medium roots; few boulded rounded stones of granite and weathered diorite; moderately acid (pH 5.6); clear and smooth boundary to Bw7
Bw7	190/196-210+	Reddish yellow (2.5YR6/8) moist; loam; strong fine and medium subangular blocky structure; few fine roots; few stone rounded stones; strongly acid (pH 5.4)

Table 4-4 Changes in some physical properties along soil profile in the 22-year-old pine plantation (Pedon 2) and opened site (Pedon 3)

Pedon	Soil depth	Bulk density (Mg m^{-3})	*	Gravel (%)	Texture (%) Sand	Silt	Clay	Soil texture
P-2	0-5	0.74±0.14	L	14.06±10.58	28.80	35.90	35.30	Clay loam
	5-10	0.90±0.03	L	5.34±0.75	26.30	36.70	37.00	Clay loam
	10-20	0.85±0.01	L	10.54±1.62	36.50	23.00	40.50	Clay
	20-30	0.90±0.04	L	8.44±2.86	18.60	37.30	44.10	Clay
	30-40	0.95±0.02	L	7.45±3.77	16.10	38.20	45.70	Clay
	40-60	1.01±0.02	L	7.62±0.40	13.50	37.20	49.30	Clay
	60-80	1.03±0.06	L	6.46±3.05	8.40	37.00	54.60	Clay
	80-100	1.09±0.04	L	5.82±2.20	3.20	38.60	58.20	Clay
	100-120	1.07±0.01	L	6.41±1.00	5.80	38.60	55.60	Clay
	120-140	1.17±0.02	L	7.10±0.10	3.20	41.20	55.60	Silty clay
	140-160	1.17±0.02	L	6.37±3.05	5.80	39.60	54.60	Clay
	160-180	0.89±0.38	L	28.16±25.35	5.80	39.60	54.60	Clay
	180-200	0.98±0.10	L	21.95±6.41	5.80	43.90	50.30	Silty clay
P-3	0-5	0.79±0.06	L	13.41±5.47	49.20	23.20	27.60	Sandy clay loam
	5-10	0.92±0.10	L	19.14±10.39	39.00	30.00	31.00	Clay loam
	10-20	1.11±0.18	L	11.12±4.61	33.90	35.10	31.00	Clay loam
	20-30	1.10±0.25	L	10.81±4.86	33.90	40.30	25.80	Loam
	30-40	1.16±0.23	L	11.51±4.79	28.80	42.80	28.40	Clay loam
	40-60	1.13±0.19	L	10.32±4.33	41.60	36.00	22.40	Loam
	60-80	1.18±0.22	L	8.07±2.66	28.80	47.90	23.30	Loam
	80-100	1.09±0.02	L	16.05±11.51	41.60	38.50	19.90	Loam
	100-120	1.15±0.08	L	13.28±9.69	35.40	43.90	20.70	Loam
	120-140	1.17±0.13	L	10.90±7.01	69.60	20.60	9.80	Sandy loam
	140-160	1.04±0.20	L	22.81±18.29	51.00	35.90	13.10	Loam
	160-180	1.08±0.05	L	12.21±2.27	51.00	38.40	10.60	Loam
	180-200	1.03±0.11	L	15.47±8.78	27.60	49.10	23.30	Loam

(2) Chemical properties

Soil chemical properties in the teak plantation, pine plantation and opened site include soil reaction, contents of organic matter, carbon and nitrogen, and C/N ratios as following results.

A. Teak plantation

Some soil chemical properties in the 22-year-old teak plantation were given (**Pedon 1**) in **Table 4-5**. These included soil pH, contents of organic matter, total organic carbon and total nitrogen.

The soil reaction at 0-5 cm depth was moderately acid, pH = 5.56. It was varied with soil depth: 5-30 cm, strongly acid (pH = 5.05-5.48); 30-60 cm, moderately acid (pH = 5.50-5.68); 60-120 cm, slightly acid (pH = 6.10-6.19); 120-180 cm, moderately acid (pH = 5.62-5.86) and 180-200 cm, slightly acid (pH = 6.29).

Contents of organic matter were very high at 0-10 cm depth, 4.61-5.23% by weight. They decreased in deeper soil: 10-20 cm, moderately high; 20-40 cm, medium; 40-60 cm, moderately low, and low to very low in the deeper horizons. The contents of carbon were in the same trend as organic matter. The contents of total nitrogen were medium at 0-10 cm depth, 0.23-0.26% by weight. They were low to very low in deeper soil.

B. Pine plantation

Table 4-6 shows some soil chemical properties in the 22-year-old pine plantation (**Pedon 2**) and opened site (**Pedon 3**). These included soil pH, contents of organic matter, total organic carbon and total nitrogen.

In Pedon 2, the soil reaction at 0-20 cm depth was strongly acid, pH = 5.21-5.35. It was varied with soil depth: 30-80 cm, moderately acid (pH = 5.32-5.90); 80-100 cm, slightly acid (pH = 6.44); 100-120 cm, moderately acid (pH = 5.94); 140-160 cm, moderately acid (pH = 5.90) and 160-200 cm, slightly acid (pH = 6.14-6.23). In Pedon3, the soil reaction at 0-5 cm depth was strongly acid, pH = 5.21. It was varied with soil depth: 5-10 cm, very strongly acid (pH = 4.57); 10-100 cm, strongly acid (pH = 5.05-5.44); 100-180 cm, moderately acid (pH = 5.59-5.96) and 180-200 cm, strongly acid (pH = 5.46).

As for Pedon 2, the contents of organic matter were very high at 0-10 cm depth, 6.27-7.72% by weight. They decreased in deeper soil: 10-30 cm, high; 30-40 cm, moderately high; 40-80 cm, medium; 80-120 cm, moderately low, and low in the deeper horizons. In Pedon 3, the contents of organic matter were very high at 0-10 cm depth, 4.57-5.96% by weight. They decreased in deeper soil: 10-20 cm, medium; 20-40 cm, moderately low and low to very low in the deeper horizons. The contents of carbon were in the same trend as the organic matter. In Pedon 2, the contents of total nitrogen were modium at 0-10 cm depth, varying 0.31-0.39% by weight. They were low to very low in the deeper horizons. As for Pedon 2, the contents of total nitrogen were medium at 0-10 cm depth, 0.23-0.30% by weight, and low to very low in the deeper soil.

Table 4-5 Changes in some chemical properties along soil profile in the 22-year-old teak plantation (Pedon 1)

Pedon	Soil depth	pH		O.M. (%)	*	O.C. (%)	*	Nitrogen (%)	*	C/N
P-1	0-5	5.56±0.31	Moderately acid	5.23±0.37	VH	3.03	VH	0.26±0.02	M	11.67
	5-10	5.26±0.13	Strongly acid	4.61±0.30	VH	2.67	VH	0.23±0.01	M	11.63
	10-20	5.05±0.17	Strongly acid	2.80±0.20	MH	1.63	MH	0.14±0.01	L	11.61
	20-30	5.48±0.33	Strongly acid	2.32±0.14	M	1.34	M	0.12±0.01	L	11.52
	30-40	5.50±0.06	Moderately acid	1.70±0.28	M	0.99	M	0.09±0.02	VL	11.38
	40-60	5.68±0.19	Moderately acid	1.41±0.10	ML	0.82	ML	0.07±0.01	VL	11.15
	60-80	6.10±0.22	Slightly acid	0.75±0.42	L	0.43	L	0.04±0.02	VL	11.81
	80-100	6.10±0.27	Slightly acid	0.79±0.01	L	0.46	L	0.04±0.01	VL	11.46
	100-120	6.19±0.43	Slightly acid	0.84±0.04	L	0.49	L	0.04±0.01	VL	12.13
	120-140	5.62±0.24	Moderately acid	0.73±0.07	L	0.42	L	0.04±0.01	VL	11.49
	140-160	5.86±0.37	Moderately acid	0.69±0.08	L	0.40	L	0.04±0.01	VL	10.86
	160-180	5.83±0.15	Moderately acid	0.53±0.20	L	0.31	L	0.03±0.01	VL	10.25
	180-200	6.29±0.76	Slightly acid	0.35±0.10	VL	0.20	VL	0.02±0.01	VL	12.18

4.3.1.2.2 Carbon Storages in Soils

A. Teak plantation

As shown in **Table 4-7,** the amount of organic matter in 1 m and 2 m soil profile in the 22-year-old teak plantation (Pedon 1) were 133.95 and 186.34 Mg ha^{-1}, respectively. The accumulated amount within 1 m soil depth was 71.88% of the total 2 m soil profiles. The carbon amounts stored in 1 m and 2 m soil depths were 77.69 and 108.08 Mg ha^{-1}. The total amounts of nitrogen storages in 1 m and 2 m soil depths were in the following order: 6,745.08 and 9,426.54 Mg ha^{-1}.

B. Pine plantation

In **Table 4-8,** the amounts of organic matter in 1 m and 2 m soil profile in the 22-year-old pine plantation (Pedon 2) were 308.04 and 399.18 Mg ha^{-1}, respectively. The accumulated amount within 1 m soil depth was 77.88% of the total 2 m soil profiles. The carbon amounts stored in 1 m and 2 m soil depths were 178.66 and 231.48 Mg ha^{-1}. The total amounts of nitrogen storages in 1 m and 2 m soil depths were in the following order: 15,499.12 and 19,977.49 Mg ha^{-1}. In the opened site (Pedon 3), the amounts of organic matter in 1 m and 2 m soil profile were 145.45 and 197.09 Mg ha^{-1}, respectively. The accumulated amount within 1 m soil depth was 73.80% of the total 2 m soil profiles. The carbon amounts stored in 1 m and 2 m soil depths were 84.36 and 114.31 Mg ha^{-1}. The total amounts of nitrogen storages in 1 m and 2 m soil depths were in the following order: 7,500.80 and 10,226.55 Mg ha^{-1}.

Table 4-6 Changes in some chemical properties along soil profile in the 22-year-old pine plantation (Pedon 2) and opened site (Pedon 3)

Pedon	Depth (cm.)	pH		O.M. (%)		O.C. %		Nitrogen		C/N
P-2	0-5	5.21±0.20	Strongly acid	7.72±1.52	VH	4.48	VH	0.39±0.08	M	11.59
	5-10	5.35±0.08	Strongly acid	6.27±0.73	VH	3.64	VH	0.31±0.04	M	11.61
	10-20	5.32±0.21	Strongly acid	3.88±3.15	H	2.25	H	0.19±0.16	L	11.64
	20-30	5.66±0.31	Moderately acid	4.35±0.88	H	2.52	H	0.22±0.04	M	11.46
	30-40	5.79±0.38	Moderately acid	3.20±0.33	MH	1.86	MH	0.16±0.02	L	11.61
	40-60	5.62±0.05	Moderately acid	2.23±0.31	M	1.29	M	0.11±0.02	L	11.41
	60-80	5.90±0.21	Moderately acid	1.57±0.04	M	0.91	M	0.08±0.01	VL	11.36
	80-100	6.44±0.99	Slightly acid	1.06±0.29	ML	0.61	ML	0.05±0.02	VL	11.53
	100-120	5.94±0.17	Moderately acid	1.17±0.10	ML	0.68	ML	0.06±0.01	VL	11.98
	120-140	6.18±0.32	Slightly acid	0.86±0.07	L	0.50	L	0.04±0.01	VL	11.51
	140-160	5.90±0.70	Moderately acid	0.86±0.07	L	0.50	L	0.04±0.01	VL	11.51
	160-180	6.14±0.41	Slightly acid	1.01±0.33	ML	0.59	ML	0.05±0.02	VL	11.75
	180-200	6.23±0.10	Slightly acid	0.84±0.17	L	0.49	L	0.04±0.01	VL	12.13
P-3	0-5	5.21	Strongly acid	5.96	VH	3.46	VH	0.30	M	11.52
	5-10	4.79	Very strongly acid	4.57	VH	2.65	VH	0.23	M	11.52
	10-20	5.05	Strongly acid	2.12	M	1.23	M	0.11	L	11.18
	20-30	5.19	Strongly acid	1.39	ML	0.81	ML	0.07	VL	11.52
	30-40	5.36	Strongly acid	1.32	ML	0.77	ML	0.07	VL	10.94
	40-60	5.29	Strongly acid	0.79	L	0.46	L	0.04	VL	11.46
	60-80	5.28	Strongly acid	0.73	L	0.42	L	0.04	VL	10.59
	80-100	5.44	Strongly acid	0.73	L	0.42	L	0.04	VL	10.59
	100-120	5.96	Moderately acid	0.79	L	0.46	L	0.04	VL	11.46
	120-140	5.77	Moderately acid	0.53	L	0.31	L	0.03	VL	10.25
	140-160	5.60	Moderately acid	0.46	VL	0.27	VL	0.02	VL	13.34
	160-180	5.59	Moderately acid	0.53	L	0.31	L	0.03	VL	10.25
	180-200	5.46	Strongly acid	0.53	L	0.31	L	0.03	VL	10.25

Table 4-7 Changes in amounts of carbon and nitrogen storages along soil profile in the 22-year-old teak plantation (Pedon 1)

Pedon	Soil depth	O.M.	O.C.	Total N
		(Mg ha^{-1})		(kg ha^{-1})
P-1 (Teak plantation)	0-5	21.21	12.30	1,054.47
	5-10	18.60	10.79	928.22
	10-20	21.64	12.55	1,080.53
	20-30	17.47	10.13	879.98
	30-40	12.40	7.19	632.34
	40-60	20.51	11.89	1,066.63
	60-80	10.96	6.35	537.99
	80-100	11.16	6.47	564.92
	100-120	13.41	7.78	640.90
	120-140	12.19	7.07	615.06
	140-160	12.79	7.42	683.11
	160-180	8.42	4.88	476.64
	180-200	5.58	3.24	265.74
	Total 1m	133.95	77.69	6,745.08
	Total 2m	186.34	108.08	9,426.54

Table 4-8 Changes in amounts of carbon and nitrogen storages along soil profile in the 22-year-old pine plantation (Pedon 2) and opened site (Pedon 3)

Pedon	Soil depth	O.M.	O.C.	Total N
		($Mg\ ha^{-1}$)		($kg\ ha^{-1}$)
P-2	0-5	52.07	30.20	2,607.08
(Pine plantation)	5-10	34.81	20.19	1,739.48
	10-20	45.39	26.33	2,261.75
	20-30	48.19	27.95	2,439.08
	30-40	33.60	19.49	1,678.19
	40-60	44.08	25.56	2,240.07
	60-80	30.40	17.63	1,552.56
	80-100	19.50	11.31	980.91
	100-120	21.80	12.64	1,055.68
	120-140	14.67	8.51	739.39
	140-160	14.76	8.56	743.61
	160-180	22.79	13.22	1,124.60
	180-200	17.05	9.89	815.10
	Total 1m	308.04	178.66	15,499.12
	Total 2m	399.11	231.48	19,977.49
P-3	0-5	37.57	21.79	1,890.90
(Open site)	5-10	24.94	14.47	1,255.40
	10-20	19.15	11.11	993.66
	20-30	12.65	7.34	636.90
	30-40	11.33	6.57	601.01
	40-60	14.03	8.14	710.41
	60-80	12.40	7.19	679.59
	80-100	13.38	7.76	732.94
	100-120	13.69	7.94	693.12
	120-140	9.05	5.25	512.49
	140-160	8.81	5.11	383.21
	160-180	9.81	5.69	555.48
	180-200	10.27	5.96	581.45
	Total 1m	145.45	84.36	7,500.80
	Total 2m	197.09	114.31	10,226.55

4.3.1.3 Carbon Storages in Ecosystems of Plantation Forests

The carbon storage in a forest ecosystem involves mainly two compartments: plant biomass and soil system. The storage in ground-covered species was not included here.

A. Teak plantation

The total amount of carbon storage in plant biomass in the 22-year-old teak plantation was 130.57$\pm$51.18 Mg ha^{-1} (20,888.37$\pm$8189.46 kg rai^{-1}), and partitioned into stem, branch, leaf and root allocations as 88.75, 25.88, 6.38 and 9.56 Mg ha^{-1}, respectively. The total amount of carbon storage in 2 m soil depth of teak plantation was 108.08 Mg ha^{-1}. Therefore, the total carbon storage in teak plantation ecosystem was calculated to 238.65 Mg ha^{-1}. The carbon recycling in leaf litterfall was 6.38 Mg ha^{-1}

per year. The percents of carbon storage in standing plant biomass and soil system were 54.71% and 45.29%, respectively.

B. Pine plantation

The total amount of carbon storage in standing plant biomass in the 22-year-old pine plantation was 200.63±29.09 Mg ha^{-1} (32,100.0±4,650 kg rai^{-1}), and partitioned into stem, branch, leaf and root allocations as 113.81; 28.13; 4.75 and 33.88 Mg ha^{-1}, respectively. The total amount of carbon storage in 2 m soil depth of teak plantation was 231.48 Mg ha^{-1}. Therefore, the total carbon storage in pine plantation ecosystem was calculated to 432.11 Mg ha^{-1}. The carbon recycling in needle litterfall was about 4.75 Mg ha^{-1} per year. The percents of carbon storage in standing plant biomass and soil system were 46.43% and 53.57%, respectively.

The carbon storage in pine plantation ecosystem (432.11 Mg ha^{-1}) was abou two-folds higher than teak plantation (238.65 Mg ha^{-1}). In the teak plantation ecosystem, the percentage of carbon stored in standing plant biomass was higher in soil system. In the opposite, the percentage of carbon stored in soil system was higher than the standing plant biomass in the pine plantation ecosystem.

4.4 Discussion

Ideally forest plantations should grow progressively during stand development and attain the maximum possible yield per unit area as timber. However, initial spacing between trees may be a limiting factor. As trees grow rapidly until the canopy is closure, and then the growth rate of trees may be decreased caused by light competition. Thinning is needed in this stage for increasing the growth rate. Khamyong (2001) reported that pine (*Pinus kesiya*) plantations of age between 7 and 37 years old in Hot district, Chiang Mai province, did not have progressive growth rates during the stand development. Different tree densities and site quality among different age stands were the causes of the fluctuated growth rate. This was the same for pine plantations in Samoeng district, Chiang Mai (Pornleesangsuwan, 2012). The biomass accumulations of standing trees in the plantations had the trend of increase with stand ages, but were fluctuated in the older stands. The amounts of carbon stored in the plantations varied in the same trend.

No information about carbon storage in teak plantation in Thailand is available. The growth rate of teak at Doi Tung is intermediate, and this area was not the good site or poor site. The 22-year old teak plantation at Doi Tung could stored carbon amount of 130.57±51.18 Mg ha^{-1} which was lower than the 22-year-old pine plantation. This caused by the slower growth rate of teak as compared to pine.

Nongnuang et al. (2012) reported that the 21-yearold pine plantation in Sammoeng district, Chiang Mai could store carbon amount of 114 Mg ha^{-1}, which was lower than the 22-year-old pine plantation at Doi Tung (200.63±29.09 Mg ha^{-1}). No more data about carbon storage in the plantations of this pine species are vailable.

The biomass and carbon stored in biomass are higher than the natural forests. Wattanasuksakul *et al*. (2012) found that, DDF with and without fire at Intakin silvicultural research station, Chiang Mai province could carbon storage in biomass varied between 52.6-63.4 Mg ha^{-1}, whereas Seramethakun *et al.* (2012) reported that, the pine-MF and pine-DDF with defference of the dominant dipterocarp tree species: *Dipterocarpus obtusifloius*, *D. tuberculatus* and *Shorea obtusa* in Kanlay Ni Wattana district, Chiang mai province could store carbon in plant biomass at 39.38, 69.06, 51.50 and 42.13 Ma ha^{-1}, respectively. Seeloy-ounkeaw et al. (2012) found that pine-MF and MF in community forest of Nong Tao village which was divided into conservation (CF) and utilization (UF) forests can store the carbon in biomass at 126.88 and 69.66 Mg ha^{-1}, respectively. The biomass and carbon stored in tree biomass of teak and pine plantations were higher than the natural forests because each individual tree in plantations had nearly the same size with regular spacing in a unit area while the natural forests consisted of different-size tree individuals: small, intermediate and big trees.

In a forest ecosystem, carbon is stored in three compartments; plant biomass, soil and organic layers on forest floor. Satienperakul (2013) reported that the climax montane forest at Doi Inthanon national park could store carbon in ecosystem incluing in plant biomass, forest floor and soil compartment at 316.41 Mg ha^{-1}. The majority amount was stored in plant biomass (59.04%), followed by soils (39.46%) and forest floor (1.50%). Khamyong (2009) reported that in the pine-montane forest of Doi Suthep-Pui national park could store carbon in ecosystem at 281.77 Mg ha^{-1} including plant biomass (148.74 Mg ha^{-1}) and Soil (133.03 Mg ha^{-1}). Seeloy-ounkeaw (2012) studied in the conmmunity forest of Nong Tao village which was managed into two purposes, conservation (CF) and utilization (UF) forests, and found that carbon storages in biomass and soil of UF were 69.01 and 84.27 Mg ha^{-1}, and the total ecosystems stock was 153.28 Mg ha^{-1}. The CF had carbon storages in biomass and soil at 124.68 and 332.71 Mg ha^{-1}. The total ecosystem stock was 457.39 Mg ha^{-1}.

In the 22-year-old teak plantation, percents of carbon storage in the standing plant biomass and soil system were 54.71% and 45.29%, respectively. The total carbon storage in teak plantation ecosystem was calculated to 238.65 Mg ha^{-1}. As for the pine plantation, percents of carbon storage in standing plant biomass and soil system were 46.43% and 53.57%, respectively. The total carbon storage in pine plantation ecosystem was calculated to 432.11 Mg ha^{-1}.

At the present, the data about forest biomass and carbon storages in Thailand had increased because many researchers give more attention, especially the biomass of different forests. In addition, most researches on forest biomass are coupled with the carbon cycling which is realevant to the global warming problem. The research in the aspect of the roles of different forest plantations on ecosystem carbon storages is still significant since many forest areas are changed to agricultural land, and reforestation is urgently required such as in Nan province. Different tree species have different growths, and need the appropriate plant systems for restoring plant diversity as well as ecosytems in the highland watershed.