CHAPTER 5

Ecosystem Carbon Stocks in Two-series Para Rubber Plantations

5.1 Introduction

Nong Kai province has the largest area of rubber plantations (102,052 ha) in the northeastern region, and the large area of 238,394 ha has potential for planting rubber. The rubber plantation in this province has been promoted since 1978. Nowadays, most plantations have age between 1-20 years old. Soil types are mainly the Phon Phisai and Chakkarat soil series. However, this research focuses only on rubber growths, biomass production and carbon storages in plantations on Chakkarat soil. The data are useful for improving management practices as well as extension information for increasing production and improving environment.

The carbon cycle in rubber plantations altered during the stand development. As rubber trees grow the biomass accumulations are allocated in the organs of stem, branch, root and needle. The litterfall is increasing with plantation age. Carbon and other nutrients releasing from decomposing litter are stored in the soil system. Carbon is important as the basis for the food and fiber that sustain and shelter human populations, as the primary energy source that fuels economies, and as a major contributor to the planetary greenhouse effect and potential climate change.

The different amounts of carbon in biomass of tree species were reported. *Acacia mangium*, *A. auriculaeformis*, *Eucalyptus camaldulensis, Xilia xylocarpa*, *Dalbergia cochinchinensis* and *Pterocarpus macroparpus*, had the carbon storages of 14.8, 9.1, 8.9, 6.7, 6.1 and 4.0 Mg/ha, respectively (Nualngam, 2001). In teak plantations, the total carbon storages in 10, 14, 18, 27 and 28 years old stands were in the order of 169.4, 83.7, 99.1, 170.1, 149.67 Mg/ha. However, the variations depend on many factors such as topography, management practices, fire, etc. (Pumijumnong, 2007).

The litterfall is the process of carbon and nutrient recycling into the soil. The fallen leaves are a great food source for the fungi and bacteria in the soil. These organisms help the leaves to decompose, and they are eventually turned back into soil which the trees can use to grow new leaves in future seasons. The material at the top of the litter layer is newly fallen and recognizable. Towards the bottom, the older leaves are torn and usually covered with a slimy coating of microorganisms which feels gross, but it's vital to returning nutrients to the soil. The organic matter on the soil is crucial because it contains the nutrients that will eventually be re-incorporated into the soil. It is also important in a partially decomposed state. Rotting leaves and wood are able to store moisture like a sponge, and help the forest soil retain rainfall. Without the organic matter from trees and other forest plants, the soil would become nothing but rocks and sand.

The aims of this research are to assess the carbon accumulation in biomass and soils in rubber plantations and adjacent fragmented forests on Phon Phisai and Chakkarat soil series.The data are useful as guide line to improve thepractices and management of rubber plantations.

5.2 Results

5.2.1 Carbon Stocks in Rubber Plantations and Natural Forest

5.2.1.1 Biomass carbon storages

(1) Rubber plantations

Through a process of photosynthesis, rubber trees absorb carbon dioxide to produce carbohydrate. This results in carbon accumulation in organic forms in various tissues of plant organs. The carbon storages in rubber trees can be estimated from the dry matter (biomass). The amount of biomass is depended on the growth rate and density of rubber tree in each aged class plantation.

Phon Phisai Soil Series:

The carbon amounts stored in rubber trees were calculated from biomass and carbon contents in various organs. The carbon contents in stem varied a little among the 1 to 20 years old trees, 56.0-57.5%. For branch, leaf and root components, the average contents were 56.75, 54.89 and 57.08%, respectively. As shown in **Table 3-5**, the biomass amounts of 1, 5, 10, 15 and 20 years old plantations were 1.50, 17.66, 42.07, 122.64 and 123.07 Mg/ha, respectively. The carbon amounts stored in the biomass of these plantations were the order: 0.85, 10.11, 24.01, 70.12 and 70.13 Mg/ha (**Table 5-1**).

The amounts of biomass carbon were increased with plantation age. In 1 year old plantation, the amount was 136.56 kg/rai (0.85 Mg/ha); divided into stem, branch, leaf and root organs to 57.41, 9.41, 22.16 and 47.57 Mg/rai, respectively. The amount in 5 years old plantation was 1,618.01 kg/rai (10.11 Mg/ha); 648.40, 405.95, 111.62 and 452.04 kg/rai in the four organs. The amount in 10 years old plantation was 3,842.21 kg/rai (24.01 Mg/ha); 1403.54, 1302.50, 195.07 and 941.09 kg/rai in these organs. The amount in 15 years old plantation was 11,129.96 kg/rai (70.12 Mg/ha); 3492.07, 5157.30, 364.81 and 2205.79 kg/rai in these organs. The amount as 11,220.51 kg/rai (70.13Mg/ha) was found in the 20 years old plantation; separated into the four components of 3535.26, 5058.05, 376.54 and 2250.67 kg/rai.

The carbon storages in biomass of rubber plantations increased with plantation age. The rates of accumulation were very rapid for 1 to 15 years old plantations and slow down for the older. The carbon allocation in various organs of different age plantations was the same trend to the biomass.

Compared to the 25 years old plantation of RRIM 600 in the eastern region, the rubber trees of 20 years old stand in this study area had the carbon stock of only 58% of rubber grown in the East. The Northeast has the lower amount of rainfall, and longer dry period. The site moisture conditionwas lower and had the poor soil.

Chakkarat Soil Series:

In **Table 3-6**, the biomass amounts of 1, 5, 10, 15 and 20 years old plantations were 3.75, 27.07, 100.46, 184.97 and 406.13 Mg/ha, respectively. The carbon

amounts stored in the biomass of these plantations were in the order : 2.13, 15.52, 57.38, 105.78 and 231.52 Mg/ha (**Table 5-2**).

The amounts of biomass carbon were increased with the plantation age. In the 1 year old plantation, the amount was 340.89 kg/rai (2.13 Mg/ha). It was divided into the stem, branch, leaf and root components of 173.57, 42.25, 39.39 and 85.68 kg/rai, respectively. The amount in 5 years old plantation was 2,482.68 kg/rai (15.52 Mg/ha); 1162.73, 587.78, 139.67 and 592.50 kg/rai in the four organs. The amount in 10 years old plantation was 9,180.56 kg/rai (57.38 Mg/ha); 3830.48, 3055.45, 312.67 and2003.95kg/rai in these organs. The amount in 15 years old plantation was 16,924.15 kg/rai (105.78 Mg/ha); 6593.12, 6369.41, 462.24 and 3499.37 kg/rai in these organs. The amount as 37,043.23 kg/rai (231.52 Mg/ha) was found in the 20 years old plantation; separated into the four components of 13190.92, 15960.73, 773.67 and 7117.90 ka/rai, respectively.

The carbon storages in biomass of rubber plantations on Chakkarat soil series increased with the plantation age. The rates of accumulation were very rapid for the 1 to 15 years old plantations and slow down for the older. The carbon allocation in various organs of different age plantations was the same trend to the biomass. The amounts of carbon storages in rubber plantations on Chakkarat soils were more rapid than the Phon Phisai soils because of the more rapid growth.

(2) Natural forest

Phon Phisai Soil Series:

The dry dipterocarp forest consisted of 76 tree species with the high density, 1,119 trees/*rai* (**Table 3-7**). *S. obtusa* had highest density, and followed by *S. siamensis* and *C. subulatum*. The species having the highest ecological important value index was *S. obtusa* (18.05% of all species). The lower values were found for *S. siamensis, C. subulatum*, *C. formosum* and *M. edule*; 15.86, 10.23, 3.61 and 2.77%, respectively. These five species had the sum important value of 50.52%.

The original condition of this forest was very poor. It has been protected as recovery forest for about 20 years as the same period as the 20 years old plantation. In **Table 3-8**, the estimated biomass amount was 92.48 Mg/ha; 60.21, 15.54, 2.84 and 13.89 Mg/ha in stem, branch, leaf and root organs, respectively. The high value of 53.20% was the biomass of three species; *S. obtusa, S. siamensis* and *C. subulatum*. The value of 46.80% was biomass of the remained 73 tree species. The biomass was lower than those in the 15 and 20 years old rubber plantations

In **Table 5-3**, the carbon storages in the forest biomass was calculated to 45.68 Mg/ha; separated into stem, branch, leaf and root of 30.04, 7.57, 1.37 and 6.70 Mg /ha. *S. siamensis* had the highest amount of biomass carbon, and lower amounts were observed for *S. obtusa, C. subulatum, T. alta*and *D. obtusifolius*.

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Chakkarat Soil Series:

The dry evergreen forestcomposed of 66 tree species with the high density, 528 trees/ra i (**Table 3-9**), lower than the DDF. *Diospyros* sp. had highest density, and followed by *Quercus elegans* and *Lithocarpus* sp.. The tree species having the highest ecological important value index was *Q. elegans* (13.30% of all species). The lower

values were found for *Diospyros* sp., *Schima wallichii*, *Lithocarpus* sp. and *Dalbergia* sp.; 12.60, 6.88, 6.83 and 5.73%, respectively. These five species had the sum important value of 45.34%. The forest biomass was calculated as 251.47 Mg/ha; 161.98, 47.44, 5.18 and 36.87 Mg/ha in stem, branch, leaf and root, respectively (**Table 3-10**).

In **Table 5-4**, the biomass carbon storages in the DEF was calculated to 124.20 Mg/ha; separated into stem, branch, leaf and root of 80.83, 23.10, 2.50 and 17.77 Mg/ha. *Q. elegans* had the highest amount of biomass carbon, and the lower amounts were observed for *S. wallichii*, *C. accuminatissima*, *Parinari anamense* and *Terminalia chebula*. The DEF had the higher biomass carbon storage than the DDF.

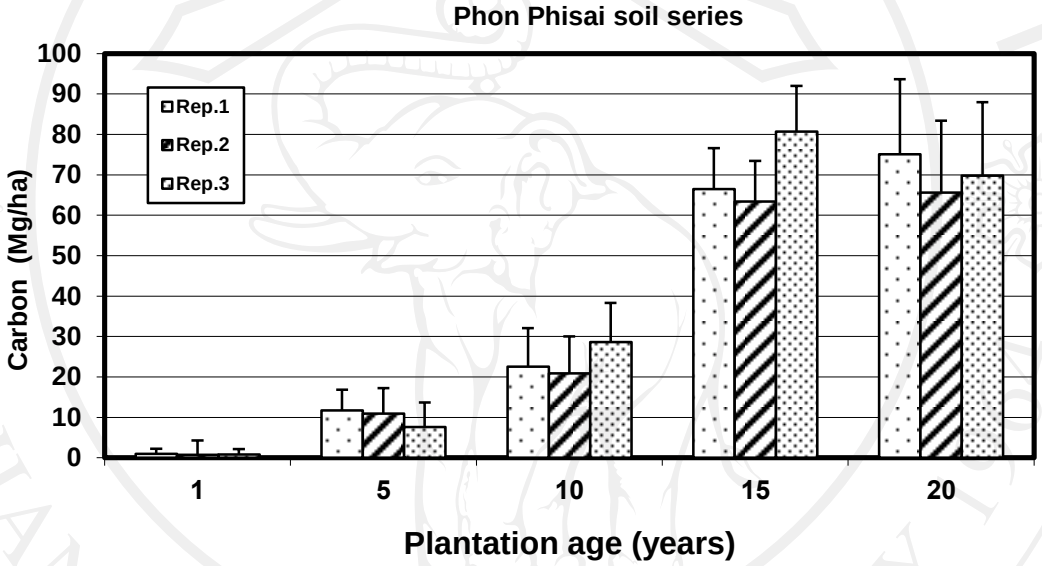

Figure5-1. Biomass carbon stocks in rubber plantations on Phon Phisai soil series

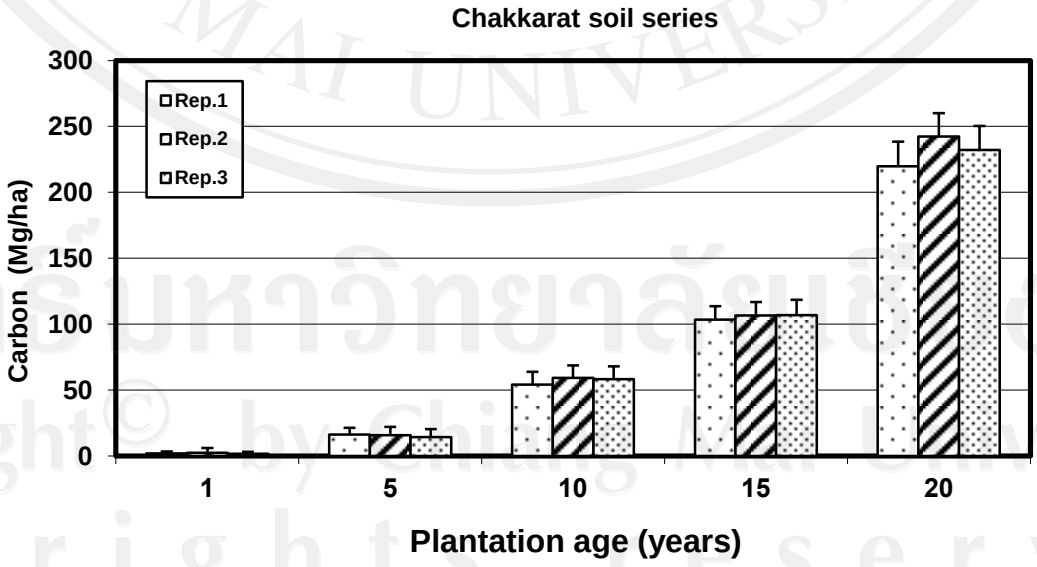

Figure 5-2 Biomass carbon stocks in rubber plantations on Chakkarat soil series

Table 5-1 Biomass carbon storages in rubber plantations on Phon Phisai soil series

Plantation Age (years)	Plot No.	Carbon amounts (kg/rai)					Total biomass carbon	
		Stem	Branch	Leaf	Root	Total	(kg/ha)	kg/tree
1	1	66.44	11.54	24.66	54.62	157.25	982.83	1.99
	2	50.54	7.56	20.46	42.31	120.87	755.44	1.55
	3	55.26	9.13	21.37	45.78	131.55	822.17	1.71
	Mean	**57.41**	**9.41**	**22.16**	**47.57**	**136.56**	**853.48**	**1.75**
	S.D.	8.16	2.00	2.21	6.35	18.70	116.88	0.22
	%	42.04	6.89	16.23	34.84	100		
5	1	743.59	491.75	123.16	514.50	1,873.00	11,706.23	26.38
	2	700.65	451.87	118.07	486.45	1,757.04	10,981.51	24.75
	3	500.97	274.23	93.61	355.18	1,223.99	7,649.92	17.24
	Mean	**648.40**	**405.95**	**111.62**	**452.04**	**1,618.01**	**10,112.55**	**22.79**
	S.D.	129.47	115.80	15.80	85.05	346.12	2,163.27	4.87
	%	40.07	25.09	6.90	27.94	100.00		
10	1	1,309.50	1,230.45	185.61	880.62	3,606.18	22,538.60	45.08
	2	1,253.15	1,058.84	181.58	848.03	3,341.59	20,884.95	42.30
	3	1,647.98	1,618.22	218.03	1,094.62	4,578.86	28,617.85	58.70
	Mean	**1,403.54**	**1,302.50**	**195.07**	**941.09**	**3,842.21**	**24,013.80**	**48.69**
	S.D.	213.56	286.57	19.98	133.96	651.53	4,072.05	8.78
	%	36.53	33.90	5.08	24.49	100.00		
15	1	3,383.70	4,725.03	364.88	2,151.54	10,625.15	66,407.16	123.55
	2	3,181.69	4,600.55	337.07	2,015.40	10,134.71	63,341.93	131.62
	3	3,910.81	6,146.31	392.47	2,450.42	12,900.02	80,625.11	163.29
	Mean	**3,492.07**	**5,157.30**	**364.81**	**2,205.79**	**11,219.96**	**70,124.73**	**139.49**
	S.D.	376.45	858.77	27.70	222.53	1,475.49	9,221.84	21.01
	%	31.12	45.97	3.25	19.66	100.00		
20	1	3,729.19	5,522.08	389.75	2,364.63	12,005.64	75,035.24	141.24
	2	3,360.51	4,615.32	365.86	2,149.42	10,491.12	65,569.51	121.99
	3	3,516.09	5,036.74	374.00	2,237.95	11,164.78	69,779.87	132.91
	Mean	**3,535.26**	**5,058.05**	**376.54**	**2,250.67**	**11,220.51**	**70,128.20**	**132.05**
	S.D.	185.08	453.75	12.14	108.16	758.80	4,742.47	9.66
	%	31.51	45.08	3.36	20.06	100.00		

Table 5-2 Biomass carbon storages in rubber plantations on Chakkarat soil series

Plantation Age (years)	Plot No.	Carbon amounts (kg/rai)					Total biomass carbon	
		Stem	Branch	Leaf	Root	Total	(kg/ha)	kg/tree
1	1	167.46	39.23	38.66	82.55	327.90	2,049.35	4.10
	2	201.35	52.71	43.53	99.73	397.32	2,483.23	4.97
	3	151.90	34.82	35.97	74.77	297.46	1,859.13	3.72
	Mean	**173.57**	**42.25**	**39.39**	**85.68**	**340.89**	**2,130.57**	**4.26**
	S.D.	25.28	9.32	3.83	12.77	51.18	319.88	0.64
	%	50.92	12.39	11.55	25.14	100		
5	1	1,224.09	626.90	144.96	624.28	2,620.24	16,376.49	32.75
	2	1,178.78	602.36	140.69	600.98	2,522.81	15,767.56	31.54
	3	1,085.32	534.06	133.37	552.25	2,305.00	14,406.26	28.81
	Mean	**1,162.73**	**587.78**	**139.67**	**592.50**	**2,482.68**	**15,516.77**	**31.03**
	S.D.	70.77	48.11	5.86	36.75	161.40	1,008.77	2.02
	%	46.83	23.68	5.63	23.87	100		
10	1	3,630.77	2,851.85	303.31	1,908.29	8,694.22	54,338.87	103.50
	2	3,928.95	3,197.81	318.57	2,068.96	9,514.29	59,464.32	114.63
	3	3,865.72	3,116.71	316.14	2,034.58	9,333.16	58,332.25	111.11
	Mean	**3,808.48**	**3,055.45**	**312.67**	**2,003.95**	**9,180.56**	**57,378.48**	**109.75**
	S.D.	157.11	180.93	8.20	84.61	430.81	2,692.55	5.69
	%	41.48	33.28	3.41	21.83	100.00		
15	1	6,472.49	6,205.19	456.51	3,433.99	16,568.19	103,551.17	182.07
	2	6,647.77	6,438.59	465.24	3,528.78	17,080.38	106,752.37	187.70
	3	6,659.12	6,464.46	464.95	3,535.35	17,123.87	107,024.21	188.17
	Mean	**6,593.12**	**6,369.41**	**462.24**	**3,499.37**	**16,924.15**	**105,775.92**	**185.98**
	S.D.	104.63	142.81	4.96	56.72	309.04	1,931.48	3.40
	%	38.96	37.64	2.73	20.68	100.00		
20	1	12,426.39	15,330.57	716.26	6,712.60	35,185.81	219,911.33	362.74
	2	13,839.05	16,661.36	815.67	7,465.41	38,781.48	242,384.28	334.32
	3	13,307.34	15,890.26	789.09	7,175.69	37,162.38	232,264.86	325.99
	Mean	**13,190.92**	**15,960.73**	**773.67**	**7,117.90**	**37,043.23**	**231,520.16**	**341.02**
	S.D.	713.49	668.19	51.47	379.72	1,800.79	11,254.97	19.27
	%	35.61	43.09	2.09	19.22	100.00		

Table 5-3 Carbon storages in tree biomass in the dry dipterocarp forest

Species No.	Plant name	Biomass Carbon				
		Stem	Branch	Leaf	Root	Total
		kg/rai				
1	*Shoreasiamensis*	1,006.77	232.7625	49.98116	229.797	1,519.32
2	*Shoreaobtusa*	912.29	207.2073	46.44858	212.3778	1,378.32
3	*Canariumsubulatum*	653.64	172.3998	26.7556	138.2349	991.03
4	*Terminaliaalata*	405.07	166.9533	6.565862	64.71458	643.30
5	*Dipterocarpusobtusifolius*	357.34	92.9636	14.79587	75.20499	540.30
6	*Syzygiumcumini*	232.55	57.33505	10.64413	51.97803	352.51
7	*Careyasphaerica*	116.51	32.9359	4.103232	23.06325	176.61
8	*Ulmuslancaefolia*	101.98	26.70888	4.149266	21.18202	154.02
9	*Irvingiamalayana*	90.65	19.43306	4.969958	22.32803	137.38
10	*Bombaxanceps*	86.72	30.29821	1.713537	14.67929	133.41
11	*Quercuskerrii*	83.30	20.07172	3.900394	18.50887	125.78
12	*Walsurarobusta*	72.10	17.5394	3.327114	15.96767	108.93
13	*Stereospermumfimbriatum*	64.63	15.79787	2.961339	14.24007	97.63
14	*Dalbergiavelutina*	60.77	11.33827	3.819067	16.0013	91.92
15	*Spondiaspinnata*	38.56	9.987194	1.613094	8.265305	58.43
16	*Cratoxylumpruniflorum*	36.90	5.562423	2.758679	11.61181	56.83
17	*Flemingiamacrophylla*	36.37	8.962849	1.662597	8.31536	55.31
18	*Zizyphusoenoplia*	35.07	8.704733	1.572595	7.738956	53.09
19	*Strychnosnux-vomica*	32.75	7.746399	1.57074	7.290428	49.36
20	*Buchananialatifolia*	31.53	5.729612	2.035808	8.623143	47.92
21	*Pterocarpusmacrocarpus*	27.56	7.14656	1.141945	5.789003	41.64
22	*Sindorasiamensis*	23.20	3.877831	1.605819	6.767095	35.45
23	*Litseaglutinosa*	23.35	4.906418	1.307327	5.789779	35.35
24	*Memecylon sp.*	21.37	2.850456	1.717209	7.201149	33.13
25	*Aporosavillosa*	19.95	3.128594	1.438433	5.944953	30.46
26	*Zizyphusmauritiana*	19.32	4.165525	1.048171	4.627629	29.17
27	*Macarangadenticulata*	18.91	3.119647	1.319896	5.509714	28.86
28	*Schoepfiafragrans*	16.47	2.825589	1.110127	4.607342	25.01
29	*Symplocosrecemosa*	14.73	2.831356	0.903846	3.845152	22.32
30	*Oleasalicifolia*	13.75	2.308386	0.942674	3.894101	20.89
31	*Mimusopselengi*	11.92	1.702117	0.913936	3.782743	18.32
32	*Mitragynarotundifolia*	10.07	1.509527	0.749186	3.097539	15.43
33	*Ampelocissusmartinii*	10.10	1.576626	0.728916	2.996283	15.41
34	*Garugapinnata*	9.48	2.067498	0.507796	2.241222	14.30
35	*Tristaniopsisburmanica*	9.33	2.046373	0.495131	2.188198	14.06
36	*Wendlandiatinctoria*	8.48	1.632107	0.517077	2.172374	12.80
37	*Garciniasootepensis*	8.05	1.482626	0.513043	2.142423	12.19
38	*Phyllanthusemblica*	7.27	1.0319	0.560606	2.328596	11.19
39	*Garciniamerguensis*	6.96	0.76074	0.621759	2.65883	11.00
40	*Memecylonscutellatum*	5.91	0.761687	0.485036	2.040108	9.20
41	*Macalangadenticulata*	4.72	0.835322	0.310317	1.28797	7.15
42	*Antidesmaacidum*	4.29	0.459364	0.386565	1.655269	6.79
43	*Vitexpinnata*	4.16	0.533183	0.344406	1.45627	6.50
44	*Croton roxburghii*	4.14	0.719539	0.276211	1.144493	6.28
45	*Dalbergiaoliverli*	3.72	0.465895	0.307716	1.287903	5.78

Table 5-3 (Continued)

Species No.	Plant name	Biomass Carbon				
		Stem	Branch	Leaf	Root	Total
		kg/rai				
46	*Mitrephoravandaeflora*	3.35	0.41526	0.279254	1.174734	5.21
47	*Climber*	3.41	0.503608	0.254642	1.048317	5.21
48	*Catunaregamspathulifolia*	3.27	0.387728	0.279796	1.182165	5.12
49	*Vitexpeduncularis*	3.22	0.462529	0.249247	1.049682	4.98
50	*Terminaliachebula*	3.13	0.556321	0.205279	0.846819	4.74
51	*Artocarpuslakoocha*	3.04	0.394926	0.245748	1.022186	4.70
52	*Hymenodictyonorixense*	2.54	0.432835	0.172317	0.707951	3.86
53	*Garciniacowa*	2.48	0.346178	0.192603	0.796206	3.82
54	*Lithocarpuselegans*	2.42	0.322458	0.193775	0.807856	3.74
55	*Brideliaaffinis*	2.02	0.218005	0.181855	0.777476	3.20
56	*Antidesmaghaesembilla*	2.03	0.325214	0.14429	0.593563	3.09
57	*Antidesmavelutinosum*	1.88	0.258609	0.146922	0.609568	2.89
58	*Colona floribunda*	1.47	0.223648	0.107767	0.441944	2.24
59	*Pavetta sp.*	1.07	0.126832	0.090818	0.382454	1.67
60	*Aryteralittoralis*	1.05	0.149422	0.080522	0.331418	1.61
61	*Ochnaintergerima*	0.97	0.097822	0.089465	0.385513	1.54
62	*Ilex umbellata*	0.95	0.132458	0.073768	0.304108	1.46
63	*Artabotrysvanprukii*	0.95	0.132458	0.073768	0.304108	1.46
64	*Rhusjavanica*	0.70	0.080549	0.061009	0.257741	1.10
65	*Pavettatomentosa*	0.68	0.068917	0.063104	0.272269	1.09
66	*Flacourtiaindica*	0.66	0.085662	0.053648	0.222815	1.02
67	*Aganosmamarginata*	0.63	0.080849	0.05142	0.213808	0.98
68	*Dalbergiacultrata*	0.53	0.053749	0.048685	0.209951	0.84
69	*Euodiaroxburghiana*	0.42	0.049628	0.035904	0.150928	0.66
70	*Bruceajavanica*	0.34	0.031128	0.032739	0.143577	0.54
71	*Annesleafragrans*	0.27	0.028497	0.023819	0.101587	0.42
72	*Gnetummontanum*	0.23	0.023896	0.020904	0.089593	0.36
73	*Lepisanthesrubiginosa*	0.19	0.016924	0.019258	0.085133	0.31
74	*Brideliaaffinis*	0.19	0.018754	0.017462	0.075365	0.30
75	*Mitragynahirsuta*	0.12	0.011257	0.011947	0.052357	0.20
76	*Antidesma sp.*	0.07	0.005441	0.00695	0.031164	0.11
	Total (kg/rai)	**4,806.98**	**1,211.22**	**219.11**	**1,071.25**	**7,308.57**
	Total (Mg/ha)	**30.04**	**7.57**	**1.37**	**6.70**	**45.68**

Table 5-4 Carbon storages in plant biomass of the dry evergreen forest

Species No.	Plant name	Density (trees/rai)	Biomass carbon (kg/rai)				
			Cs	Cb	Cl	Cr	Total
1	*Quercuselegans*	41	2,673.49	772.69	76.20	570.50	4,092.89
2	*Schimawallichii*	10	1,663.17	500.58	39.31	326.77	2,529.83
3	*Castanopsisaccuminatissima*	29	1,117.83	316.94	34.99	248.34	1,718.11
4	*Parinarianamense*	24	905.19	250.25	31.13	210.61	1,397.18
5	*Terminaliachebula*	14	815.18	232.00	24.59	178.87	1,250.64
6	*Pterocarpusmacrocarpus*	7	561.03	164.40	14.91	116.21	856.56
7	*Garciniacowa*	23	499.88	137.93	17.47	116.92	772.19
8	*Lithocarpus* sp.1	5	408.80	120.71	10.76	83.90	624.18
9	*Sindorasiamensis*	22	380.32	102.46	14.87	93.48	591.12
10	*Xerospermumnoronhianum*	21	383.72	109.64	11.87	84.32	589.55
11	*Syzygiumalbiflorum*	7	331.63	95.89	9.50	70.78	507.79
12	*Lithocarpus* sp.2	4	326.03	99.14	7.70	63.36	496.23
13	*Dipterocarpusintricatus*	2	321.28	96.02	7.80	63.95	489.04
14	*Syzygium* sp.	11	308.81	88.28	9.40	67.58	474.07
15	*Melodorumfruticosum*	8	259.89	75.98	7.07	54.18	397.12
16	*Cananriumsubulatum*	9	247.57	69.03	8.31	56.80	381.72
17	*Casaeriagrewiifolia*	1	224.41	68.18	5.04	43.18	340.82
18	*Cratoxylumpruniflorum*	31	205.93	52.69	10.27	56.31	325.20
19	*Dalbergianigrescens*	1	146.80	43.42	3.70	29.77	223.70
20	*Aporosavillosa*	23	134.56	33.76	7.17	38.06	213.56
21	*Diospyros*sp.1	122	120.10	28.27	9.24	39.46	197.08
22	*Dalbergia* sp.	2	117.80	34.03	3.36	25.15	180.35
23	*Dilleniaobovata*	16	108.88	27.14	5.85	31.05	172.92
24	*Diospyros* sp.2	2	101.31	28.94	3.04	22.12	155.41
25	*Symplocos* sp.	4	74.06	19.51	3.12	18.92	115.60
26	*Quercuskerii*	2	64.94	18.20	2.09	14.68	99.91
27	*Artocarpus* sp.	2	50.96	13.72	1.96	12.49	79.13
28	*Syzygiumcumini*	1	48.83	13.47	1.66	11.35	75.32
29	*Gardenia coronaria*	2	40.75	10.76	1.70	10.36	63.57
30	*Irvingiamalayana*	4	28.01	6.86	1.60	8.23	44.70
31	*Schouteniaovata*	1	25.83	6.85	1.05	6.50	40.21
32	*Colona flagrocarpa*	1	25.83	6.85	1.05	6.50	40.21
33	*Mitrephoravandaeflora*	1	25.75	6.82	1.04	6.48	40.10
34	*Dalbergiavelutina*	3	23.66	5.87	1.29	6.80	37.62
35	*Symplocosrecemosa*	1	20.00	5.22	0.87	5.19	31.28
36	*Dalbergiavolubilis*	2	17.70	4.40	0.95	5.05	28.10
37	*Memecylonscutellatum*	3	13.60	3.27	0.85	4.16	21.88
38	*Vitexpeduncularis*	2	13.37	3.40	0.66	3.66	21.09
39	*Oleasalicifolia*	7	12.06	2.78	0.91	4.01	19.75
40	*Ficusprostrata*	1	12.13	3.06	0.60	3.35	19.15
41	*Memecylon* sp.	3	9.79	2.29	0.68	3.16	15.93
42	*Dalbergiafoliacea*	1	6.92	1.69	0.40	2.05	11.06
43	Climber-1	1	6.81	1.66	0.40	2.02	10.89
44	Climber-1	1	6.40	1.55	0.38	1.91	10.24
45	*Mimusopselengi*	2	6.25	1.51	0.39	1.90	10.05
46	*Catunaregumspathulifolia*	2	5.79	1.38	0.38	1.80	9.34
47	*Diospyrosglandulosa*	2	5.49	1.29	0.38	1.77	8.93
48	*Aporosawallichii*	5	5.13	1.18	0.41	1.72	8.44
49	*Ardisia* sp.	17	3.98	0.79	0.56	1.76	7.09
50	*Croton roxburghii*	1	2.52	0.58	0.19	0.85	4.14
51	*Engelhardtiaspicata*	1	2.33	0.53	0.18	0.79	3.83
52	*Gnetummontanum*	1	2.01	0.45	0.16	0.70	3.33

Table 5-4 (Continued)

Species No.	Plant name	Density (trees/rai)	Biomass carbon (kg/rai)				
			Cs	Cb	Cl	Cr	Total
53	*Lagerstroemia duperreana*	1	1.79	0.40	0.15	0.63	2.97
54	*Wendlandiatinctoria*	1	1.77	0.40	0.15	0.62	2.93
55	*Elaeocarpussphaericus*	3	1.41	0.29	0.17	0.58	2.44
56	*Dalbergiacochinchinensis*	1	1.11	0.24	0.11	0.41	1.86
57	*Dalbergialanceolaria*	2	0.92	0.19	0.10	0.36	1.57
58	*Schoefiafragrans*	1	0.62	0.13	0.07	0.25	1.07
59	*Antidesmavelutinosum*	1	0.30	0.06	0.04	0.13	0.53
60	*Goniothalamuslaoticus*	1	0.16	0.03	0.03	0.08	0.30
61	*Lophopetalumduperreanum*	1	0.09	0.02	0.02	0.05	0.17
62	*Catunaregumlogispina*	2	0.09	0.02	0.02	0.05	0.17
63	*Pavettawallichiana*	2	0.08	0.01	0.02	0.05	0.17
64	*Euodiaroxburghiana*	1	0.07	0.01	0.01	0.04	0.14
65	*Litseaglutinosa*	1	0.07	0.01	0.01	0.04	0.14
66	*Buchananialatifolia*	1	0.04	0.01	0.01	0.02	0.09
	Total (kg/rai)	**528**	**12,933.03**	**3,696.15**	**400.38**	**2,843.14**	**19,872.70**
	Total (Mg/ha)	**3,300**	**80.83**	**23.10**	**2.50**	**17.77**	**124.20**

5.3.2 Carbon Storages in Soils

Phon Phisai Soil Series:

Most soil organic carbon is accumulated in the form of organic matter. In **Table 5-5**, the soil organic matter in the dry dipterocarp forest was 57.81 Mg/ha, and calculated to carbon amount of 33.53 Mg/ha. In the 1, 5, 10, 15 and 20 years old rubber plantations, the amounts of organic matter in 100 cm soil profiles were 37.37, 64.41, 49.37, 53.85 and 20.74 Mg/ha, respectively. They were calculated to carbon amounts of 21.67, 37.36, 28.64, 31.23 and 12.03 Mg/ha.

Chakkarat Soil Series:

The organic matter and carbon storages in soils should be increased with plantation ages as increasing litterfall. However, the highest amount was found in the soil under the 5 years old plantation, and the lowest for 20 years old (**Table 5-6**). Different management practices by the farmers are considered as the important factor. Some farmers might apply a large amount of manure in some plantations and resulted in the high amount of organic matter in the 5 years old plantation, whereas the 20 years old stand might has the high soil erosion and no or little manure application.

Table 5-5 Carbon storages in Phon Phisai soils under rubber plantations and dry dipterocarp forest

Horizon	Depth (cm)	Soil Mass (kg/m^2)	Organic matter		Org. Carbon	
			(kg/rai)	(kg/ha)	(kg/rai)	(kg/ha)
1-year-old						
Ap1	0-18	40.0	3,355.2	20,970.00	1,946.0	12,162.60
Ap2	18-40	70.0	1,261.6	7,884.80	731.7	4,573.18
Bt1	40-82/88	110.0	1,044.0	6,525.00	605.5	3,784.50
Btc1	82/88-100	70.0	318.0	1,987.50	184.4	1,152.75
			5,978.8	**37,367.30**	**3,467.7**	**21,673.03**

Table 5-5 (Continued)

Horizon	Depth (cm)	Soil Mass (kg/m^2)	Organic matter		Org. Carbon	
			(kg/rai)	(kg/ha)	(kg/rai)	(kg/ha)
5-year-old						
Ap1	0-19	60.0	1,324.2	8,276.40	768.0	4,800.31
Ap2	19-36	70.0	1,239.8	7,748.60	719.1	4,494.19
Bt1	36-100	890.0	7,741.4	48,384.00	4,490.0	28,062.72
			10,305.4	**64,409.00**	**5,977.2**	**37,357.22**
Horizon	**Depth (cm)**	**Soil Mass (kg/m^2)**	**Organic matter**		**Org. Carbon**	
			(kg/rai)	**(kg/ha)**	**(kg/rai)**	**(kg/ha)**
10-year-old						
Ap1	0-19	50.0	1,498.1	9,363.20	868.9	5,430.66
Ap2	19-46	130.0	2,265.0	14,156.10	1,313.7	8,210.54
Bt1	46-100	450.0	4,136.8	25,855.20	2,399.4	14,996.02
			7,899.9	**49,374.50**	**4,582.0**	**28,637.21**
15-year-old						
Ap1	0-20	50.0	2,280.0	14,250.00	1,322.4	8,265.00
Ap2	20-40	50.0	1,088.0	6,800.00	631.0	3,944.00
Bt1	40-80	500.0	4,960.0	31,000.00	2,876.8	17,980.00
Bt2	80-100	60.0	288.0	1,800.00	167.0	1,044.00
			8,616.0	**53,850.00**	**4,997.3**	**31,233.00**
20-year-old						
Ap1	0-17	40.0	1,191.1	7,444.30	690.8	4,317.69
Ap2	17-40	20.7	417.3	2,608.20	242.0	1,512.76
Bt1	40-100	198.0	1,710.7	10,692.00	992.2	6,201.36
			3,319.1	**20,744.50**	**1,925.1**	**12,031.81**
Dry dipterocarp forest						
A	0-5	9.0	473.8	2,961.00	274.8	1,717.38
Bt1	5-18	59.4	1,701.2	10,632.60	986.7	6,166.91
Bt2	18-50	80.0	1,410.0	8,812.80	817.8	5,111.42
Bt3	50-100	590.0	5,664.0	35,400.00	3,285.1	20,532.00
			9,249.0	**57,806.40**	**5,364.4**	**33,527.71**

Table 5-6 Carbon storages in Chakkarat soils under rubber plantations and dry evergreen forest

Horizon	Depth (cm)	Soil Mass (kg/m^2)	Organic matter (kg)		Org. Carbon (kg)	
			(per rai)	(per ha)	(per rai)	(per ha)
1-year-old						
Ap1	0-20	100.0	2,023.68	12,648.00	1,173.73	7,335.84
Ap2	20-47	140.0	847.15	5,294.70	491.35	3,070.93
Bt1	40-89/96	230.0	1,033.34	6,458.40	599.34	3,745.87
Btc1	89/96-100	7.5	30.72	192.00	17.82	111.36
Total			3,934.90	24,593.10	2,282.24	14,264.00
5-year-old						
Ap1	0-11	60.0	716.32	4,477.00	415.47	2,596.66
Ap2	11-26/31	90.0	1,415.23	8,845.20	820.83	5,130.22
Bt1	26/31-60	90.0	1,492.99	9,331.20	865.94	5,412.10
Bt2	60-100	210.0	1,017.60	6,360.00	590.21	3,688.80
Total			4,642.14	29,013.40	2,692.44	16,827.77
10-year-old						
Ap1	0-8	40.0	929.41	5,808.80	539.06	3,369.10
Ap2	8-24	80.0	1,548.29	9,676.80	898.01	5,612.54
Bt1	24-44	110.0	880.00	5,500.00	510.40	3,190.00
Bt2	44-60/71	110.0	634.30	3,964.40	367.90	2,299.35
Btc1	60/71-100	190.0	1,117.20	6,982.50	647.98	4,049.85
Total			5,109.20	31,932.50	2963.34	18,520.85

Table 5-6 (Continued)

Horizon	Depth (cm)	Soil Mass (kg/m^2)	Organic matter (kg)		Org. Carbon (kg)	
			(per rai)	(per ha)	(per rai)	(per ha)
15-year-old						
Ap1	0-10	50.0	1,110.88	6,943.00	644.31	4,026.94
Ap2	10-23	70.0	1,055.81	6,598.80	612.37	3,827.30
Bt1	23-50	140.0	979.78	6,123.60	568.27	3,551.69
Bt2	50-82	170.0	802.82	5,017.60	465.63	2,910.21
Btc	82-100	90.0	479.23	2,995.20	277.95	1,737.22
Total			4,428.51	27,678.20	2568.54	16,053.36
20-year-old						
Ap1	0-13	40.0	1,130.27	7,064.20	655.56	4,097.24
Ap2	13-28	20.0	879.84	5,499.00	510.31	3,189.42
Bt1	28-60	120.0	998.40	6,240.00	579.07	3,619.20
Bt2	60-100	150.0	680.96	4,256.00	394.96	2,468.48
Total			3,689.47	23,059.20	2139.89	13,374.34
Dry evergreen forest						
A	0-11	30.0	1,699.46	10,621.60	985.68	6,160.53
Bt1	11-30	110.0	404.32	2,527.00	234.51	1,465.66
Bt2	30-55	100.0	320.00	2,000.00	185.60	1,160.00
Bt3	55-75/90	100.0	349.44	2,184.00	202.68	1,266.72
Btc1	75/90-100	20.0	101.09	631.80	58.63	366.44
			2,874.30	17,964.40	1667.10	10,419.35

5.3.3 Ecosystem carbon storages

The carbon stored in natural forest and plantation ecosystems composed of mainly two compartments; tree biomass and soil system. In the natural forest, theaccumulation of organic layers on the soil did not occurred because of forest fireand rapid decomposition.

Phon Phisai Soil Series:

In the DDF, the ecosystem carbon was estimated to 79.21 Mg/ha; 57% in the biomass and 43% in the soil. The total amounts of ecosystem carbon in the 1, 5, 10, 15 and 20 years old plantations were 22.52, 47.47, 52.65, 101.35 and 82.16 Mg/ha, respectively (**Table 5-7**).The percentages of carbon allocation in rubber biomass were increased with the plantation age.

Chakkarat Soil Series:

In the DEF, the ecosystem carbon was estimated to 134.62 Mg/ha; 92.26% in the biomass and only 7.74% in the soil. The total amounts of ecosystem carbon in the 1, 5, 10, 15 and 20 years old plantations were 18.52, 65.89, 128.27, 202.03 and 354.39 Mg/ha, respectively (**Table 5-8**).The percentages of carbon allocation in rubber biomass were aslo increased with the plantation age.

The ecosystem carbon amounts was increased with plantation age as same as the biomass. The young plantations had the high percentages of carbon in the soil and lower in biomass. In contrast, they were adversely increased in biomass and lower in the soil for the older plantations. However, the amount in the 15 years old plantation on Phon Phisai soil series was higher than the 20 years old. This might be caused by different management practices. The owner of 15 years old plantation might have better management practices such as manure application, reducing soil erosion, etc.

Differences in environmental factors particularly rainfall amounts and soil fertility resulted in the slower growth rates of rubber in the Northeast compared to southern Thailand. Improving management practices by the farmers to be the good level are considered as the important work of extension organizations. Increasing soil fertility by reducing the soil erosion and applying organic matter (manure, organic fertilizer, etc,) as well as improving the drainage system are significant to satisfy the increasing rubber yield and environmental value particularly the ecosystem carbon storage.

Table 5-7 Ecosystem carbon storages in rubber plantations on Phon Phisai soil series and DDF

Ecosystems	Biomass carbon		Soil carbon		Total
	Mg/ha	%	Mg/ha	%	Mg/ha
1 year old plantation	0.85	3.77	21.67	96.23	22.52
5years old plantation	10.11	22.30	37.36	78.70	47.47
10years old plantation	24.01	44.60	28.64	54.40	52.65
15years old plantation	70.12	69.19	31.23	30.81	101.35
20years old plantation	70.13	85.36	12.03	14.64	82.16
Dry dipterocarp forest	45.68	57.68	33.53	43.32	79.21

Table 5-8 Ecosystem carbon storages in rubber plantations and DEF on Chakkarat soil series

Ecosystems	Biomass carbon		Soil carbon		Total
	Mg/ha	%	Mg/ha	%	
1 year old plantation	4.26	23.00	14.26	77.00	18.52
5years old plantation	31.03	47.09	16.83	52.91	65.89
10years old plantation	109.75	85.56	18.52	14.44	128.27
15years old plantation	185.98	92.06	16.05	7.94	202.03
20years old plantation	341.02	96.23	13.37	3.77	354.39
Dry evergreen forest	124.20	92.23	10.42	7.77	134.62