CHAPTER 4

Results

4.1 Rainfall and average soil moisture

The relationship between rainfall and average soil moisture in each month during June 2009 – January 2012 is shown in Figs. 4.1a – e. Rainfall ranged from 0 – 323.3 mm. Maximum soil moisture (%) of all study sites were ranged from 34.05 – 37.63 % during rainy season. While minimum soil moisture (%) of all study sites were ranged from 6.46 – 16.48 %.

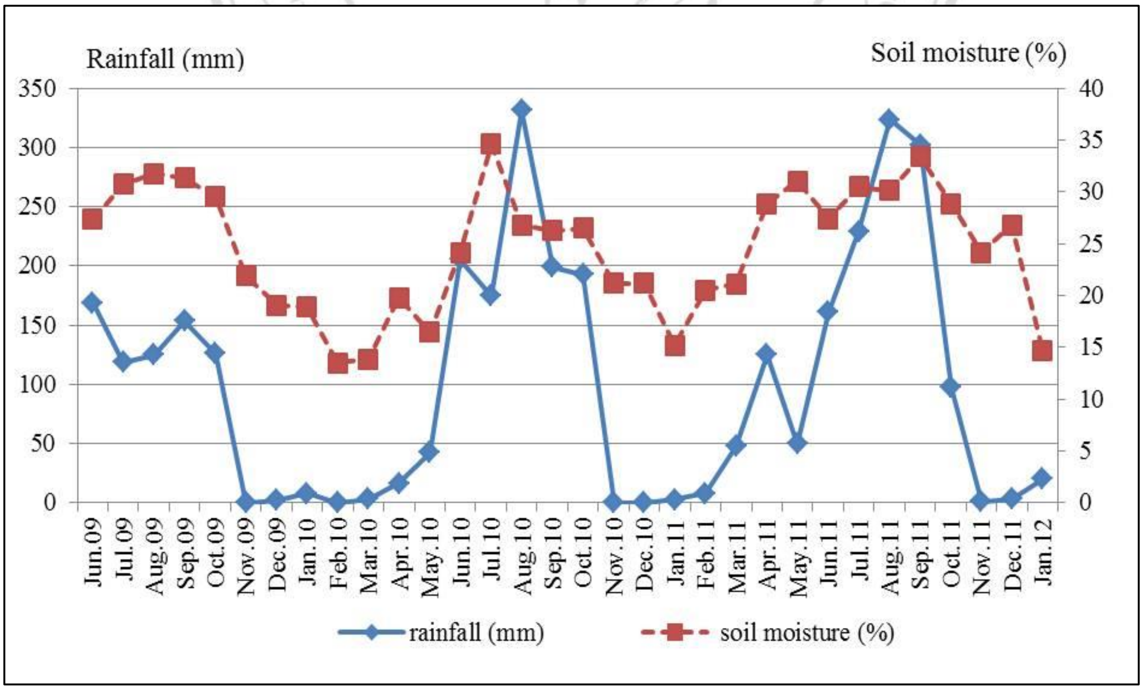


Figure 4.1a Rainfall (mm) and average soil moisture (%)
during June 2009 – January 2012 in control site

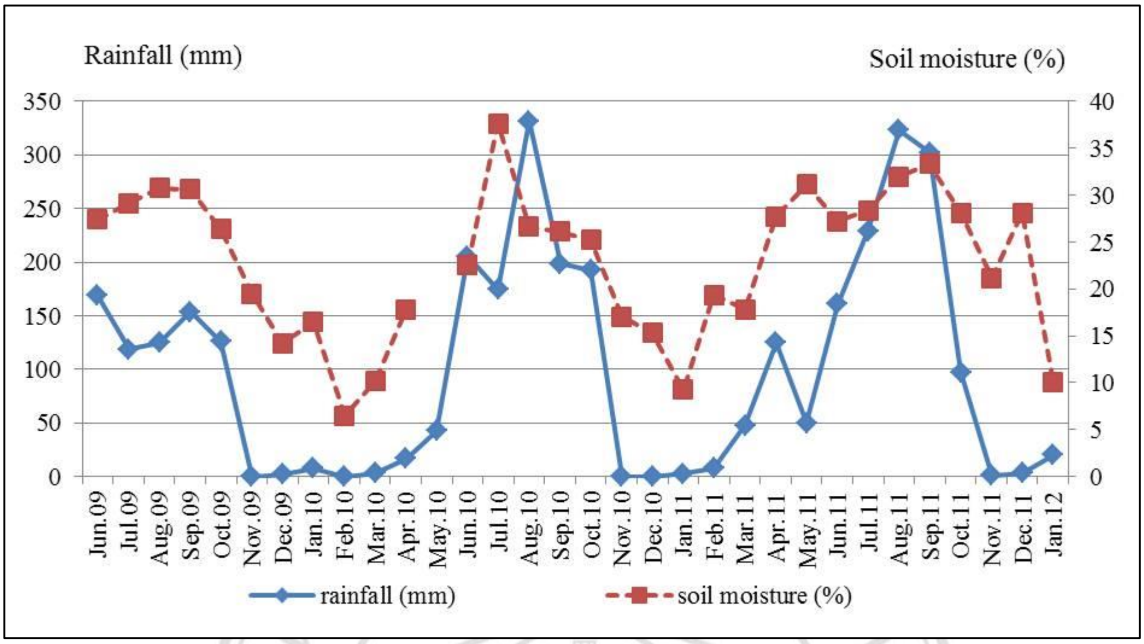


Figure 4.1b Rainfall (mm) and average soil moisture (%)

during June 2009 – January 2012 in 2-year-old site

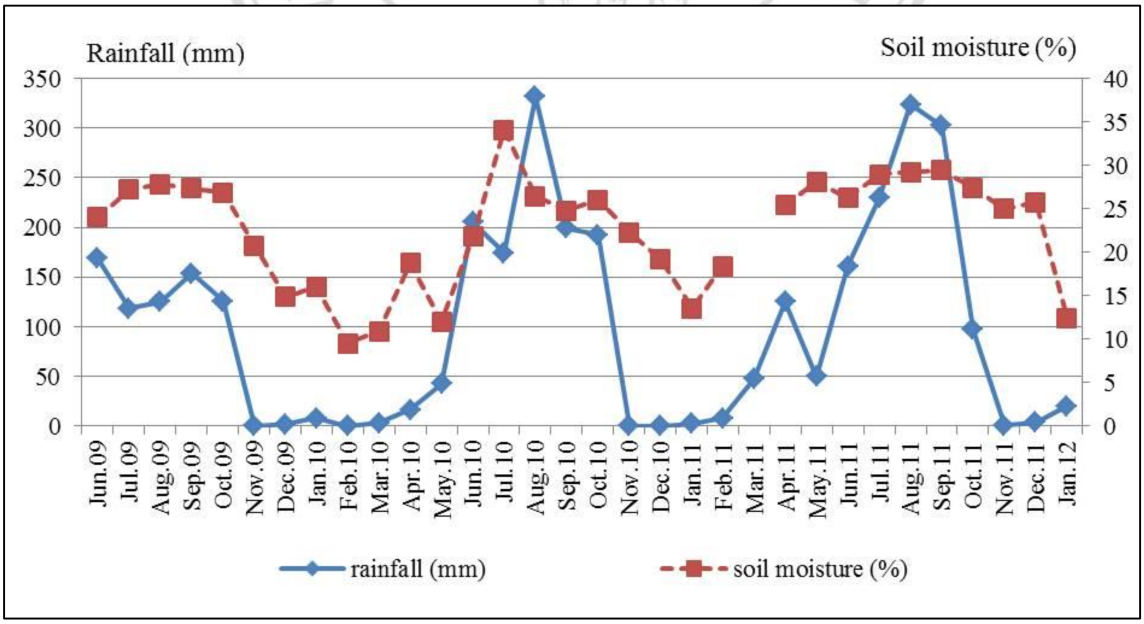


Figure 4.1c Rainfall (mm) and average soil moisture (%)

during June 2009 – January 2012 in 7-year-old site

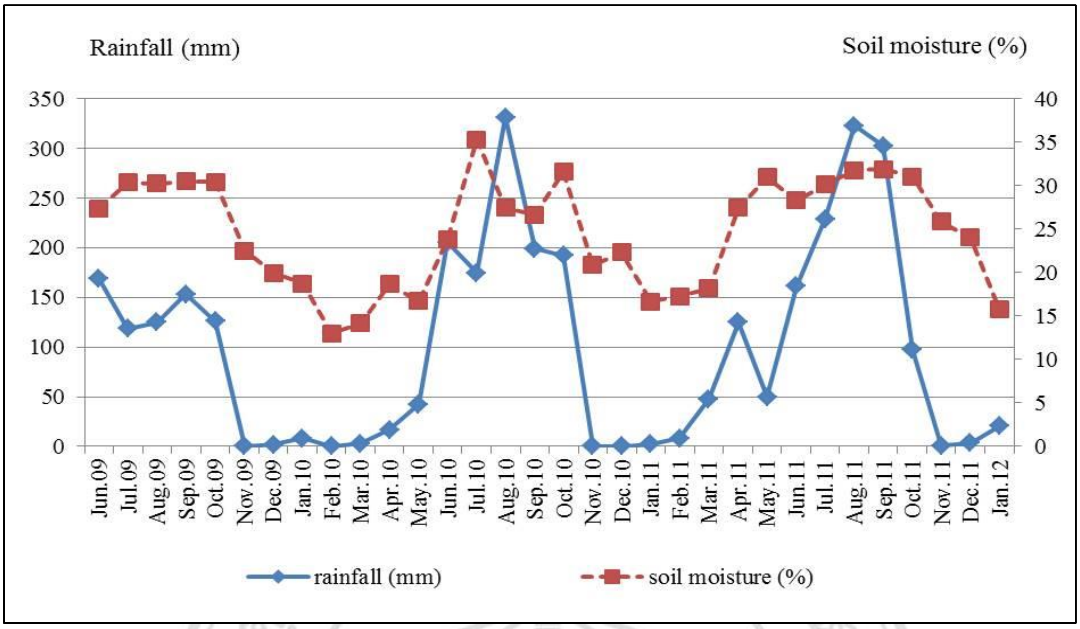


Figure 4.1d Rainfall (mm) and average soil moisture (%)

during June 2009 – January 2012 in 11-year-old site

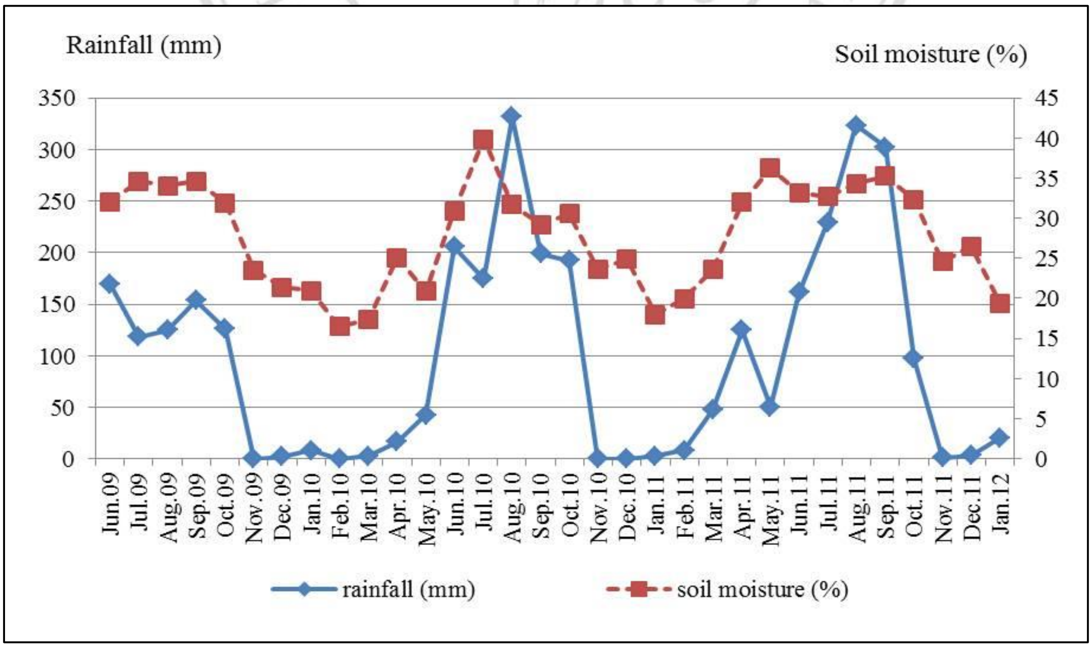


Figure 4.1e Rainfall (mm) and average soil moisture (%)

during June 2009 – January 2012 in natural site

4.2 Litterfall and rainfall

The highest amount of litterfall was found in the natural forest site followed by 11-year-old, 7-year-old, control, and 2-year-old site. The pattern of litterfall dry mass and rainfall in 32 months (June 2009 –January 2012) is shown in Fig.4.2. The amount of litterfall increased at the beginning of cool-dry season from November until March. In the second year (June 2010 – May 2011), the natural forest site had the highest peak in February 2011 and tended to produce more litterfall, but in the other study sites tended to be the same pattern of litterfall. The pattern of the litterfall in two years in restored forest site was quite similar, except in the 2-year-old site. Data from the 2-year-old site from April – September 2010 are drop to zero, because a forest fire occurred around the second week of March 2010.

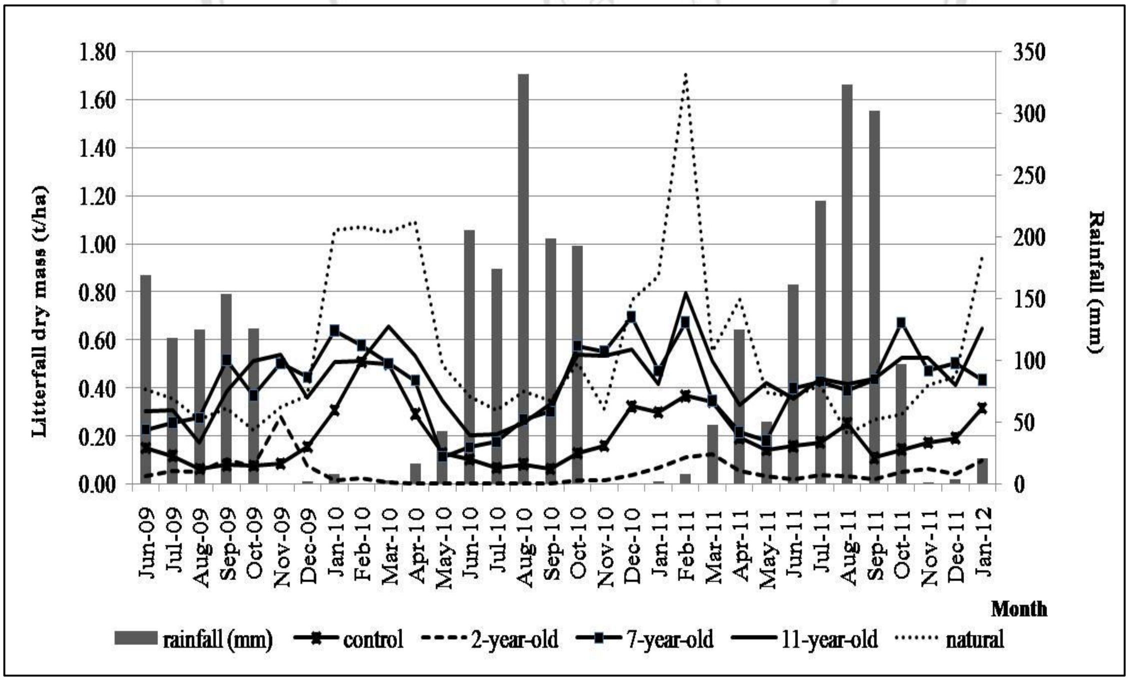


Figure 4.2 The total litterfall (t/ha/month) of all study sites with rainfall (mm) during June 2009 – January 2012

In the first year of collection from June 2009 to May 2010, the ranged of litterfall in the control, 2, 7, 11-year-old and the natural site were 0.06 – 0.51, 0 – 0.13, 0.11 – 0.64, 0.17 – 0.65 and 0.27 – 1.07 t/ha/month, respectively (Table 4.1a). In the second year of collection from June 2010 to May 2011 the ranges were 0.06 – 0.34, 0 - 0.13, 0.17 – 0.69, 0.20 – 0.80, and 0.31 – 1.71 t/ha/month, respectively (Table 4.1b). The annual litterfall in the first year of 2, 7, 11-year-old and the natural site 2.46, 0.71, 4.85, 5.13 and 7.01 (t/ha/yr), respectively, and in the second year were 2.27, 0.46, 4.60, 5.09 and 7.26 (t/ha/yr), respectively. Moreover, additional data in the third year were collected from June 2011 to January 2012. High amounts of litter in most study sites (control, 2, 11-year-old and natural sites) were found in January 2012: 0.32, 0.11, 0.65 and 0.95 t/ha, respectively, except in the 7-year-old site in October (Table 4.1c). However, there was a fire in the 2-year-old plot in early March 2010, so the amount of the litterfall in this plot was low from February to September 2010. Moreover, total litterfall collected from June 2009 until January 2012 (32 months) in control, 2, 7, 11-year-old and natural site were 6.24, 1.54, 13.18, 13.98 and 17.62 t/ha, respectively.

Table 4.1a The amount of litterfall dry mass in year1 during June 2009 – May 2010

Study site	Amount of litter (t/ha)												Total
	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	
	2009							2010					
control	0.15 cd	0.12 cd	0.06 b	0.08 c	0.08 d	0.09 d	0.16 b	0.31 c	0.51 b	0.50 b	0.29 bc	0.13 b	2.46
2-year-old	0.03 d	0.06 d	0.05 b	0.10 c	0.07 d	0.28 c	0.08 b	0.02 d	0.02 c	0.00 c	0.00 c	0.00 c	0.71
7-year-old	0.23 bc	0.26 bc	0.28 a	0.52 a	0.37 b	0.50 ab	0.44 a	0.64 b	0.58 b	0.50 b	0.43 b	0.11 b	4.85
11-year-old	0.30 ab	0.31 ab	0.17 ab	0.39 b	0.51 a	0.54 a	0.36 a	0.51 bc	0.51 b	0.65 b	0.53 b	0.35 b	5.13
natural	0.39 a	0.35 a	0.27 a	0.31 b	0.23 c	0.32 bc	0.37 a	1.05 a	1.07 a	1.05 a	1.09 a	0.49 a	7.01

Note: Value are means± SD (n=18). Means followed by different letters on the same column indicate significant differences among study sites at *P*<0.05 based on Tukey's test

Table 4.1b The amount of litterfall dry mass in year2 during June 2010 – May 2011

Study site	Amount of litter (t/ha)												
	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Total
	2010							2011					
control	0.10 b	0.07 c	0.08 c	0.06 b	0.13 b	0.16 bc	0.32 b	0.30 b	0.37 cd	0.34 ab	0.19 bc	0.14 c	2.27
2-year-old	0.00 c	0.00 c	0.00 c	0.00 b	0.02 b	0.02 c	0.04 c	0.07 c	0.11 d	0.13 b	0.05 c	0.03 c	0.46
7-year-old	0.15 b	0.17 b	0.27 ab	0.30 a	0.57 a	0.55 a	0.69 a	0.47 b	0.67 bc	0.35 ab	0.22 b	0.18 bc	4.60
11-year-old	0.20 b	0.20 ab	0.25 b	0.33 a	0.54 a	0.53 a	0.56 ab	0.42 b	0.80 b	0.51 a	0.33 b	0.42 a	5.09
natural	0.37 a	0.31 a	0.39 a	0.35 a	0.50 a	0.31 b	0.77 a	0.87 a	1.71 a	0.55 a	0.77 a	0.38 ab	7.26

Note: Value are means± SD (n=18). Means followed by different letters on the same column indicate significant differences among study sites at *P*<0.05 based on Tukey's test.

Table 4.1c The amount of litterfall dry mass in year3 during June 2011 – January 2012

Study site	Amount of litter (t/ha)							
	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.
	2011							2012
control	0.16 c	0.17 b	0.25 bc	0.11 c	0.14 bc	0.17 b	0.19 bc	0.32 de
2-year-old	0.02 c	0.04 b	0.03 d	0.02 c	0.05 c	0.06 b	0.04 c	0.11 e
7-year-old	0.40 b	0.43 a	0.39 ab	0.44 a	0.67 a	0.47 a	0.50 a	0.43 cd
11-year-old	0.35 a	0.44 a	0.42 a	0.44 a	0.53 a	0.52 a	0.41 ab	0.65 bc
natural	0.36 b	0.41 a	0.21 c	0.27 b	0.29 b	0.41 a	0.45 a	0.95 a

Note: Value are means± SD (n=18). Means followed by different letters on the same column indicate significant differences among study sites at *P*<0.05 based on Tukey's test.

4.3 Litter component

The average different components of litter: leaf, branch, flower/fruit and the others (t/ha/yr) in the study sites, and percentage of litter component are shown in Table 4.2. Leaf litter was the major component of all study sites overall the year. (Fig.4.3). Leaf component in control, 2, 7 and 11-year-old and natural site were 2.10, 0.47, 4.07, 4.27 and 4.51 t/ha/yr, respectively.

Percentage of leaf tended to be lower from control site to natural site. In contrast, other component such as fruit/flower, branch and small fractions in natural site higher than other site followed by 11, 7, 2-year-old and control site.

Table 4.2 Litter in different component (t/ha/yr) and percentage

Site	Leaf (%)	Branch (%)	Flower/fruit (%)	Other (%)	Total (%)
control	2.1 (89.4)	0.1 (5.5)	0.1 (4.3)	0.02 (0.8)	2.4 (100)
2-year-old	0.5 (81.4)	0.1 (15.2)	0.01 (2.6)	0.005 (0.8)	0.6 (100)
7-year-old	4.1 (81.2)	0.6 (12.4)	0.2 (4.7)	0.08 (1.7)	5.0 (100)
11-year-old	4.3 (80.8)	0.7 (14.0)	0.2 (4.2)	0.05 (1.0)	5.3 (100)
natural	4.5 (70.1)	1.2 (19.3)	0.6 (8.5)	0.13 (2.1)	6.4 (100)

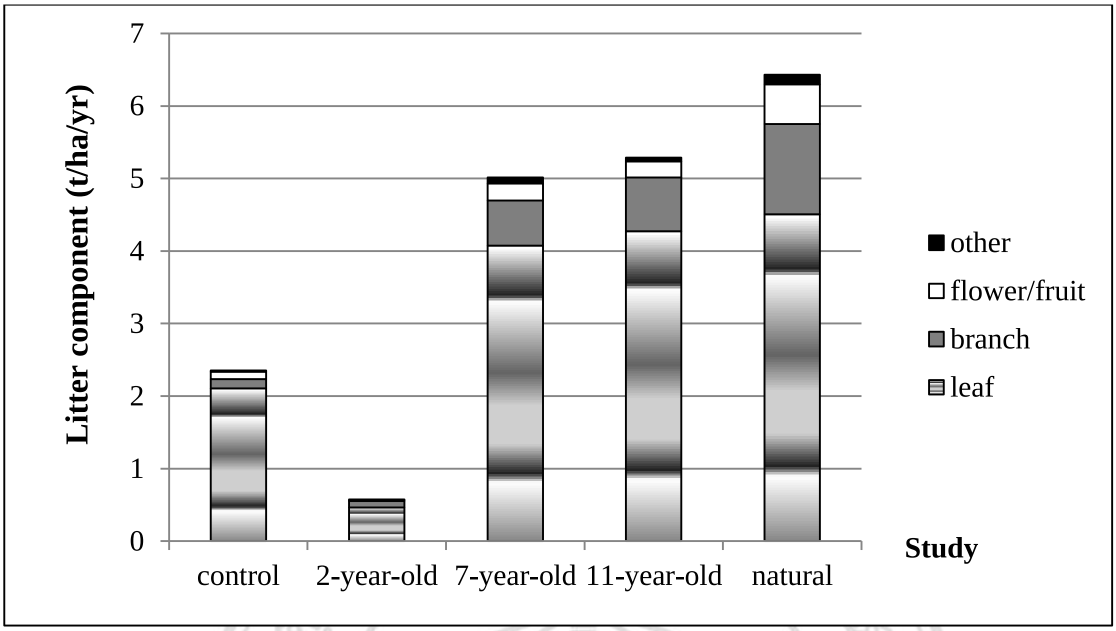


Figure 4.3 Mean litter of 3 years in different component (t/ha/yr)

4.4 Carbon through litterfall

The highest amount of organic carbon was found in natural site (38.72 g/100g), in contrast lowest amount of organic carbon was found in 7-year-old site (32.97 g/100g) (Table 4.3).

Litter carbon (litterC) in Year1 and Year2 ranged from 0.25 – 2.71 tC/ha/yr and 0.16 – 2.81 tC/ha/yr, respectively. LitterC in natural site was higher than other sites significantly. Among restored forest site, the high value of litter carbon was found in oldest site (11-year-old) next to 7-year-old, control and 2-year-old site (Table 4.3). The pattern of litter in terms of carbon similar to the pattern of litterfall which was collected in the study sites (Fig. 4.5).

Moreover, in the third year of collection from June 2011 – January 2013 (8 months), the total litterfall and litter carbon ranged from 0.55 – 5.63 t/ha and 0.19 – 2.00 tC/ha. However, in the third collection was not covered in one year. So, annual litter and litterC in the third year were calculated by multiplying average litterfall with 12. Mean annual litterfall over 3 years are shown in Table 4.4. The amount of litterfall was highest in the natural forest but not different significantly with the old restored forest sites (7 and 11-year-old). LitterC was the same trend as litterfall which ranged from 0.20 to 2.49 tC/ha.

Table 4.3 Annual litterfall (t/ha/yr) and litterC (tC/ha/yr)

Study site	OC g/100g	Year1		Year2		Year3	
		Litter (t/ha/yr)	LitterC (tC/ha/yr)	Litter (t/ha/yr)	LitterC (tC/ha/yr)	Litter (t/ha/yr)	LitterC (tC/ha/yr)
control	33.29±1.95 **b**	2.46	0.82 **cd**	2.27	0.75 **cd**	2.27	0.76
2-year-old	34.74±2.13 **ab**	0.71	0.25 **d**	0.46	0.16 **d**	0.55	0.19
7-year-old	32.97±2.74 **b**	4.85	1.60 **bc**	4.60	1.52 **bc**	5.59	1.84
11-year-old	35.50±1.50 **ab**	5.13	1.82 **ab**	5.09	1.81 **b**	5.63	2.00
natural	38.72±0.39 **a**	7.01	2.71 **a**	7.26	2.81 **a**	5.02	1.94

Note: Values in column 1 is mean of OC± SD (n= 3). In Column 3 and 5 are means of carbon in litter in year1 and year2 followed by different letters on the same column indicate significant differences at *P*<0.05 among study sites.

Table 4.4 Mean litterfall (t/ha/yr) in all study sites over 3 years and litterC (tC/ha/yr)

Site	Mean annual litterfall (t/ha/yr)	LitterC (tC/ha/yr)
control	2.33 ± 0.11 **b**	0.78 ± 0.04 **c**
2-year-old	0.57 ± 0.13 **c**	0.20 ± 0.05 **d**
7-year-old	5.01 ± 0.51 **a**	1.65 ± 0.17 **b**
11-year-old	5.28 ± 0.30 **a**	1.88 ± 0.11 **b**
natural	6.43 ± 1.23 **a**	2.49 ± 0.48 **a**

Note: Values are mean ± SD (n = 3) with different superscripts within columns are significantly different among study site at *P*<0.05 based on Tukey's test.

4.5 Litter accumulation and carbon in litter

Highest amount of litter accumulation was highest in natural forest (5.89 t/ha) but not significantly higher than 7-year-old (5.26 t/ha) and 11-year-old (4.89 t/ha). While the lowest amount of litter accumulation was found in 2-year-old site (1.94 t/ha). Carbon in litter was highest in natural forest next to 11, 7, control and 2-year-old were 2.28, 1.74, 1.73, 1.09 and 0.67 tC/ha (Table 4.5).

Table 4.5 Litter accumulation (t/ha) and carbon in litter (tC/ha)

Site	Litter accumulation (t/ha)	Carbon in litter (tC/ha)
control	3.27 ±1.6 **b**	1.09 ± 0.53 **c**
2-year-old	1.94 ± 1.4 **c**	0.67 ± 0.50 **d**
7-year-old	5.26 ± 1.5 **a**	1.73 ± 0.49 **b**
11-year-old	4.89 ± 1.5 **a**	1.74 ± 0.53 **b**
natural	5.89 ± 1.8 **a**	2.28 ± 0.78 **a**

Note: Values are mean ± SD (n = 27) with different superscripts within columns are significantly different among study site at *P*<0.05 based on Tukey's test.

4.6 Relationship between total litterC (tC/ha) and age since planted

The relationship between total litterC and age since planted was determined and are shown in Fig. 4.4. The equation derived from the data to describe the relationship was y = 0.90741ln(x) – 0.3187 (R^2 = 0.9757).

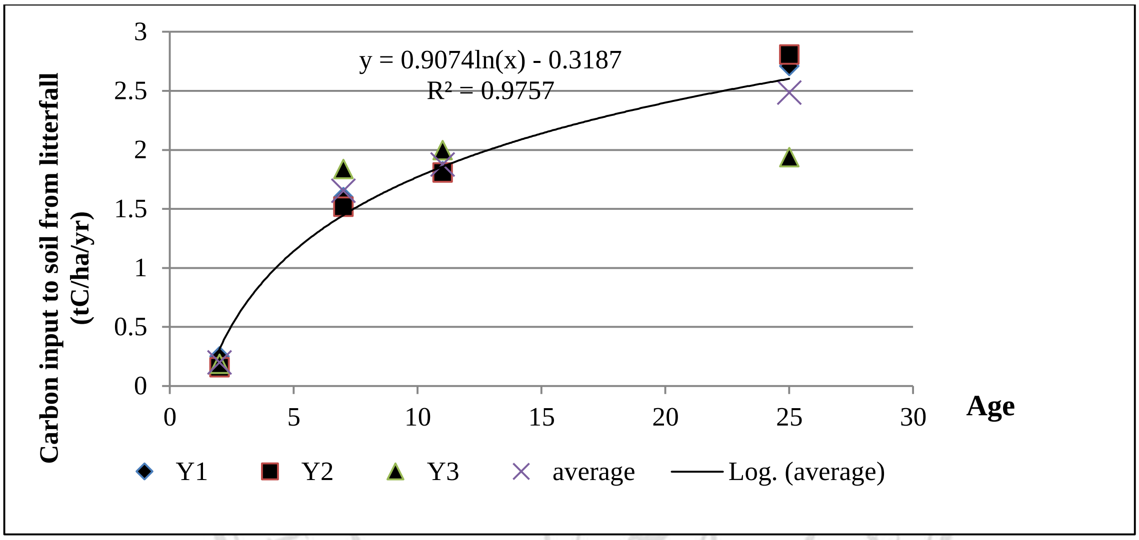


Figure 4.4 Relationship between total litterC (tC/ha/yr) and age since planted

4.7 Leaf litter decomposition of mixed three species

Ficus subincisa leaves decomposed the fastest (c80% in 5 months), *Erythrina subumbrans* leaves decomposed at a moderate rate (c50% in 5 months) and *Castanopsis diversifolia* leaves decomposed the slowest (c20% in 5 months) (Figs. 4.5a – d).

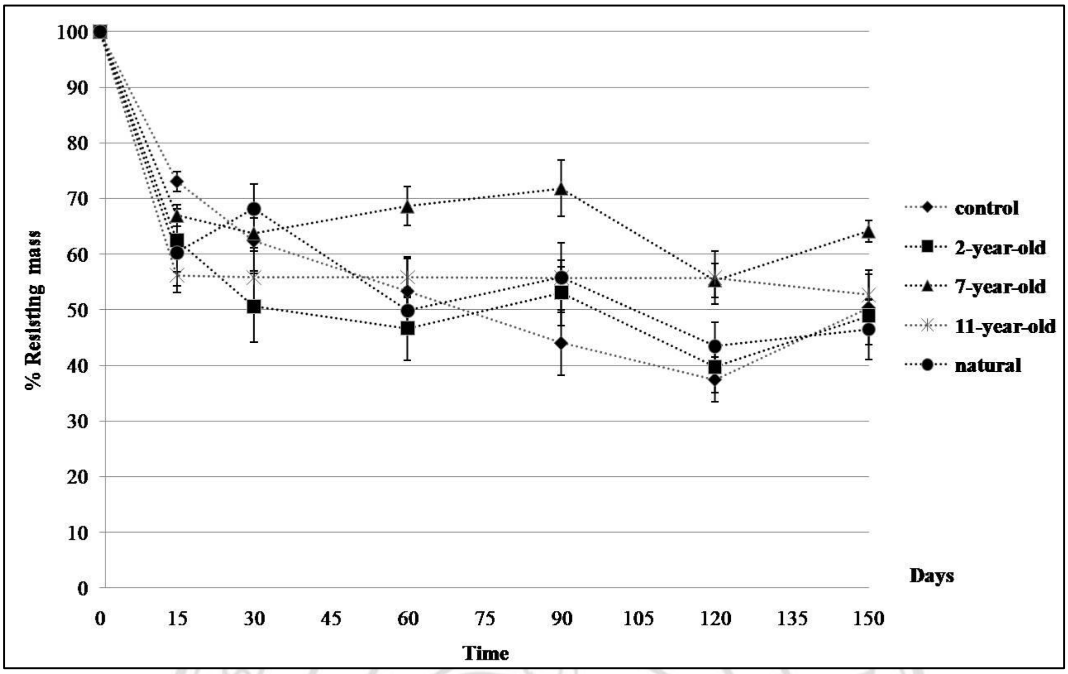


Figure 4.5a Percentage of resisting mass of *Erythrina subumbrans*

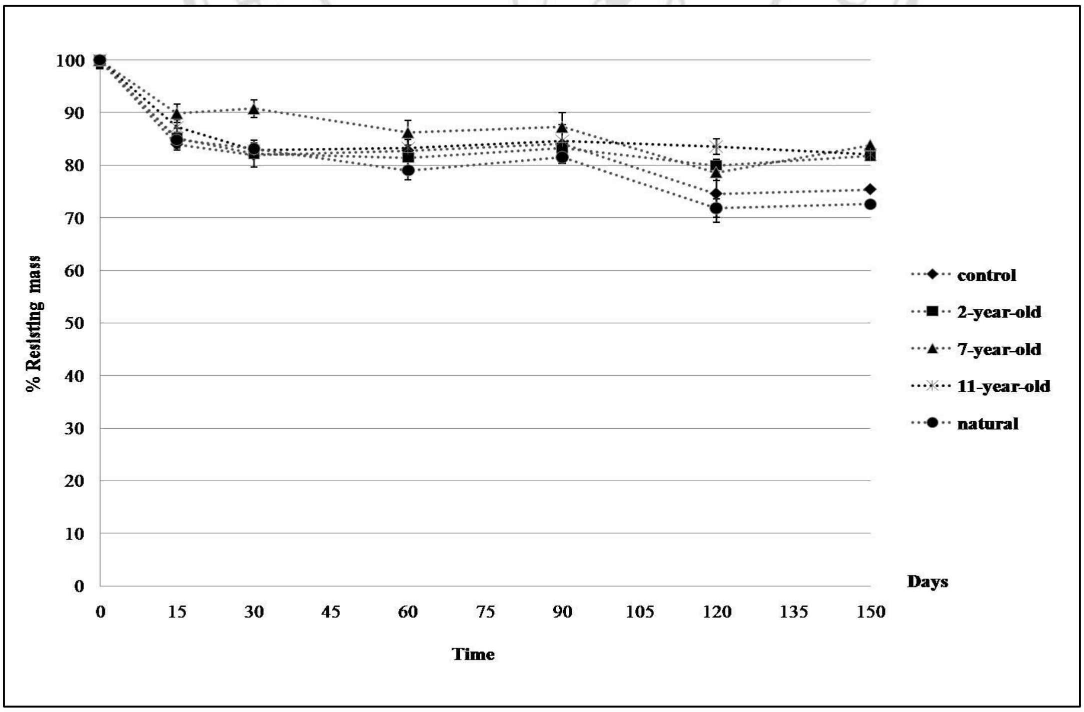


Figure 4.5b Percentage of resisting mass of *Castanopsis diversifolia*

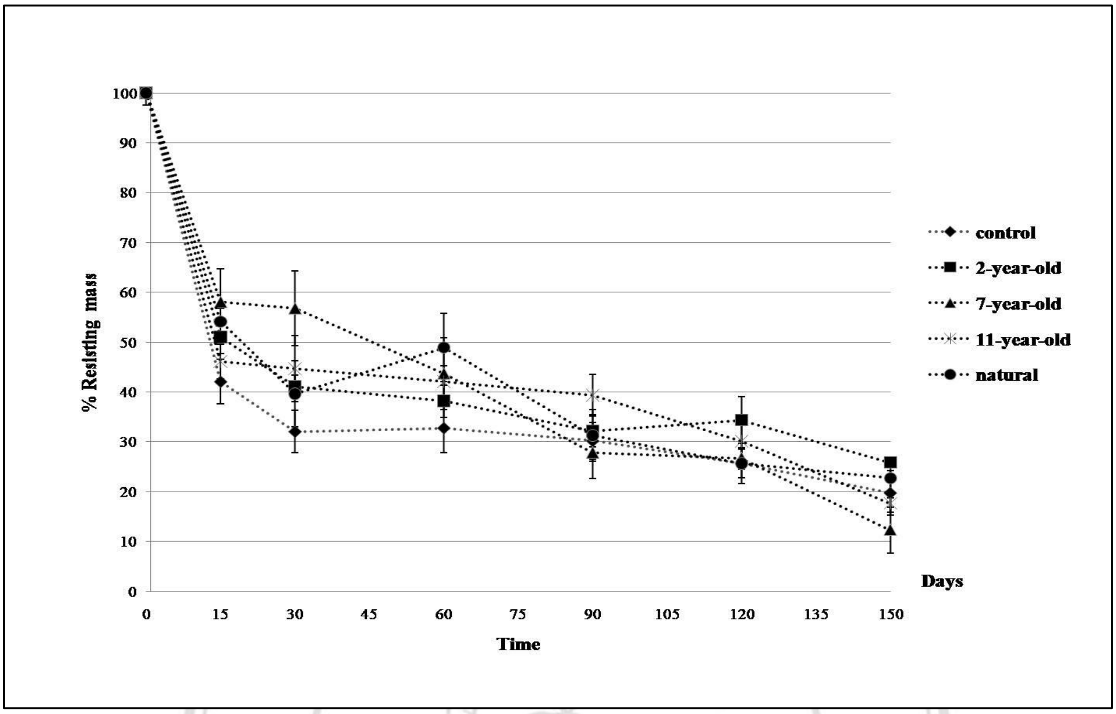


Figure 4.5c Percentage of resisting mass of *Ficus subincis*

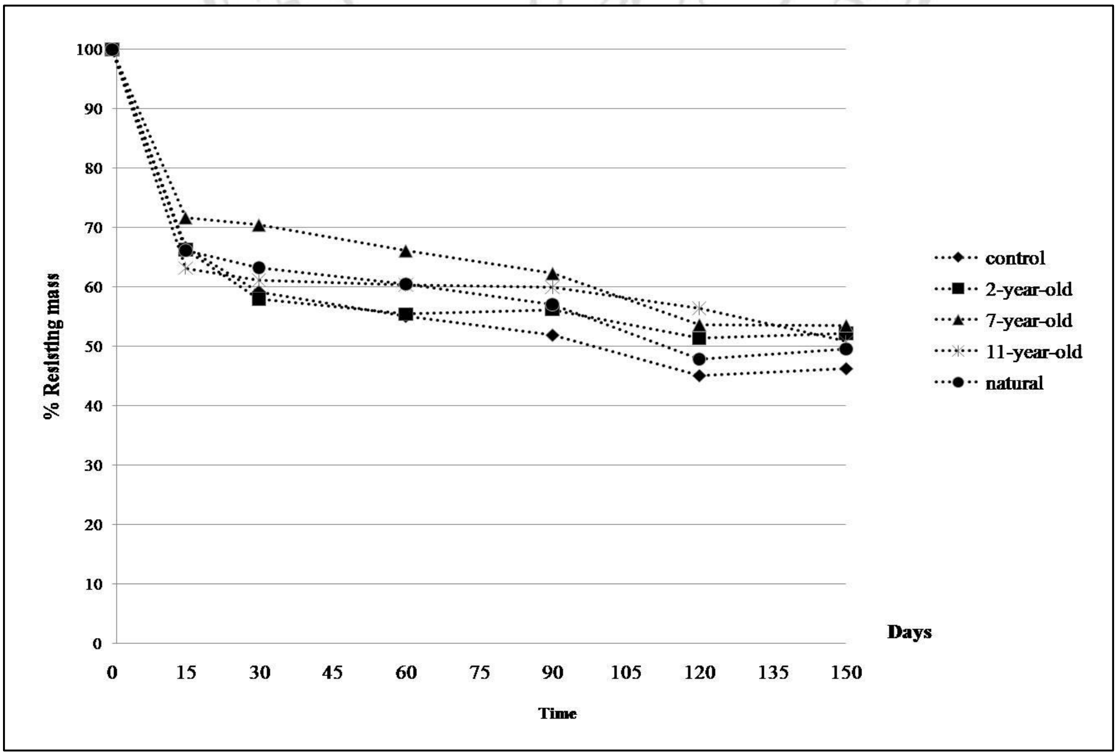


Figure 4.5d Percentage of resisting mass of mix three species

K values of three species in all study sites were shown in Table 4.6. *K* value of *Erythrina subumbrans* ranged 1.05 – 2.12, *Castanopsis diversifolia* ranged 0.41 – 0.87, *Ficus subincisa* ranged 1.21 – 4.15 and mix species ranged 1.46 – 1.87. *K* value in each species were not significantly different among study sites but high *k* value was found in *Ficus subincisa* compared with *Erythrina subumbrans* and *Castanopsis diversifolia*. The highest *k* value was found in 11-year-old site (4.15) site whereas the lowest *k* value was found in 7-year-old site (0.41). Moreover, *k* value of mix species ranged 1.46 – 1.87 and were not differ among study sites at $P<0.05$.

Table 4.6 *K* values of three species in all study sites

Study site	*k*			
	Erythrina subumbrans	*Castanopsis diversifolia*	*Ficus subincisa*	Mix species
control	AB 2.12±0.48 **a**	C 0.87±0.27 **a**	A 3.27±0.69 **a**	AB 1.87±0.21 **a**
2-year-old	AB 1.67±0.09 **a**	C 0.47±0.03 **a**	A 2.42±0.44 **ab**	B 1.51±0.05 **a**
7-year-old	AB 1.05±0.11 **a**	B 0.41±0.04 **a**	AB 1.21±0.45 **b**	A 1.46±0.07 **a**
11-year-old	B 1.88±0.50 **a**	C 0.46±0.04 **a**	A 4.15±0.25 **a**	B1.59±0.10 **a**
natural	B 1.66±0.19 **a**	B 0.66±0.06 **a**	A 3.27±0.49 **a**	B 1.63±0.07 **a**

Note: Value are means± SD (n= 12). Means followed by different letters on the same column on the right indicate significant differences at $p < 0.05$ among study sites and different letters on the same row on the left indicate significant differences at $P<0.05$ among three species.

Carbon nitrogen ratio (C:N) in three species were determined and showed in Table 4.7.
C:N ratio was much higher for *C. diversifolia* than for the other 2 species.
F. subincisa and *E. subumbrans* had similar C:N ratios

Table 4.7 Carbon nitrogen ratio in three species at beginning, middle (2 months) and late phase (5 months)

Study site	Species	Beginning phase C:N	Middle phase C:N	Late phase C:N
control	*Erythrina subumbrans*	20:1	15:1	15:1
	Castanopsis diversifolia	35:1	21:1	23:1
	Ficus subincisa	22:1	15:1	15:1
2-year-old	*Erythrina subumbrans*	20:1	13:1	13:1
	Castanopsis diversifolia	35:1	22:1	24:1
	Ficus subincisa	22:1	15:1	14:1
7-year-old	*Erythrina subumbrans*	20:1	16:1	14:1
	Castanopsis diversifolia	35:1	23:1	21:1
	Ficus subincisa	22:1	17:1	14:1
11-year-old	*Erythrina subumbrans*	20:1	16:1	14:1
	Castanopsis diversifolia	35:1	-	21:1
	Ficus subincisa	22:1	16:1	15:1
natural	*Erythrina subumbrans*	20:1	14:1	14:1
	Castanopsis diversifolia	35:1	20:1	21:1
	Ficus subincisa	22:1	15:1	15:1

4.8 Litter decomposition of mixed species using big bag

Decomposition of natural leaf litter in each study site was investigated during May 2011 to February 2012 over 4 periods were conducted. The early rainy season (May 2011), rainy season (August 2011), cool season (November 2011) and cool dry season (February 2012) from the starting date: 0, 103, 187 and 286 days. In each period, 10% of wet weight of each litter bag from all study sites was sub-sampled. The mass remaining of all study sites decreased rapidly from the beginning period to rainy season (Aug. 2011). The mass decreased around 20 – 30 % over 103 days in all study sites. From rainy season (Aug. 2011) to cool season (Nov. 2011) mass remaining (%) was increased in the 11-year-old and natural site (Table 4.8). In contrast, litter mass of in the 2 and 7-year-old sites decreased. In the last period, litter mass decreased in all study sites. Especially in 7-year-old site, the mass decreased rapidly in all periods (Fig.4.6). Moreover, mass remaining (%) of 7-year-old site in the last period of was 30.57% significantly and less than that at other sites (*P*<0.05). Moreover mass remaining with trend line was also shown in Fig.4.6 and predicted mass remaining (%) in 1 year using equation from linear regression is also shown in Table 4.9.

Table 4.8 Mass remaining (%) in different periods

Period / Site	1	2	3	4
	0 day Early rainy (May.11)	103 days Rainy (Aug.11)	187 days Cool (Nov.11)	286 days Cool dry (Feb.12)
control	100	A 76.12±14.85 **a**	A 71.43±27.97 **a**	A 67.42±22.59 **a**
2-year-old	100	A 75.09±13.76 **a**	A 66.65±22.36 **a**	A 68.18±21.58 **a**
7-year-old	100	A 79.50±14.42 **a**	AB 57.55±18.52 **a**	B 30.57±25.75 **b**
11-year-old	100	A 69.13±20.66 **a**	A 71.51±34.69 **a**	A 61.66±18.46 **a**
natural	100	A 75.36±13.07 **a**	A 79.82±24.45 **a**	B 53.06±11.11 **ab**

Note: Value are means± SD (n= 12). Means followed by different letters on the same column on the right indicate significant differences at *P*<0.05 among study sites and different capital letters on the same row on the left indicate significant differences at *P*<0.05 among periods.

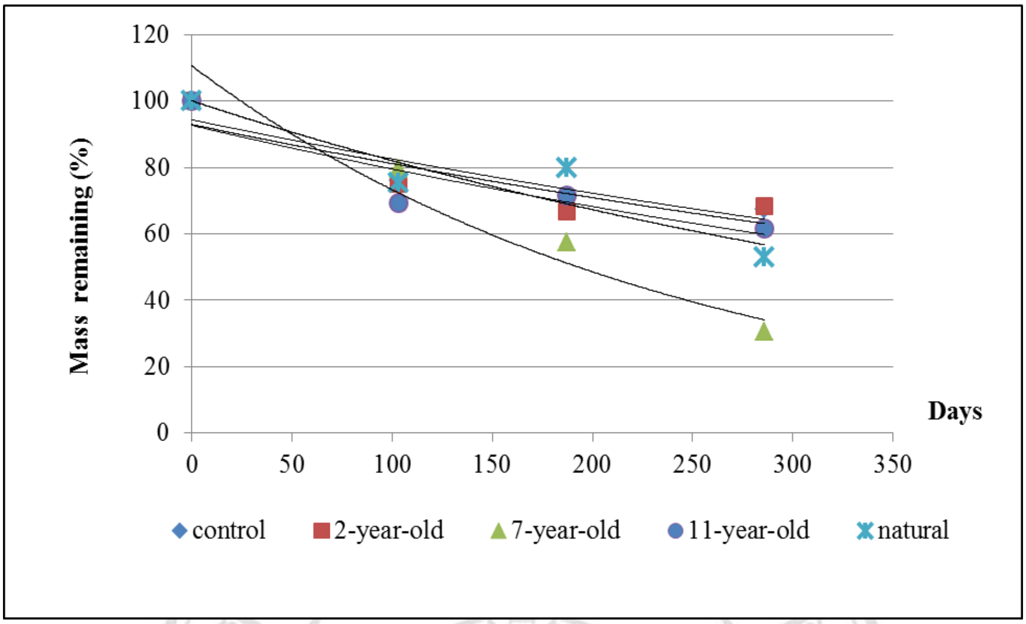


Figure 4.6 Litter mass remaining with trend line in different periods

Table 4.9 Linear regression equation and R^2 of all study sites

site	Equation	R^2	Predicted mass remaining (%) in 1 year
control	$y = 94.287^{e-0.001x}$	0.87	65.45
2-year-old	$y = 92.863^{e-0.001x}$	0.78	64.47
7-year-old	$y = 110.53^{e-0.004x}$	0.94	25.67
11-year-old	$y = 92.608^{e-0.002x}$	0.80	44.63
natural	$y = 99.996^{e-0.002x}$	0.85	48.19

Remaining mass in control, 2, 7, 11-year-old and natural site was calculated as 1.53, 0.37, 1.29, 2.36 and 3.10 t/ha/yr, respectively. In contrast, mass loss in control, 2, 7, 11-year-old and natural site were 0.81, 0.20, 3.73, 2.93 and 3.33 t/ha/yr, respectively (Fig.4.7). And percentage of remaining and loss per year were shown in Fig. 4.8. Percentage of remaining and loss mass in control and the youngest sites were around 65:35. In 11-year-old and natural site were 50:50. But in 7-year-old site, percentage of loss mass was 74.33 while percentage of remaining mass was just 25.67.

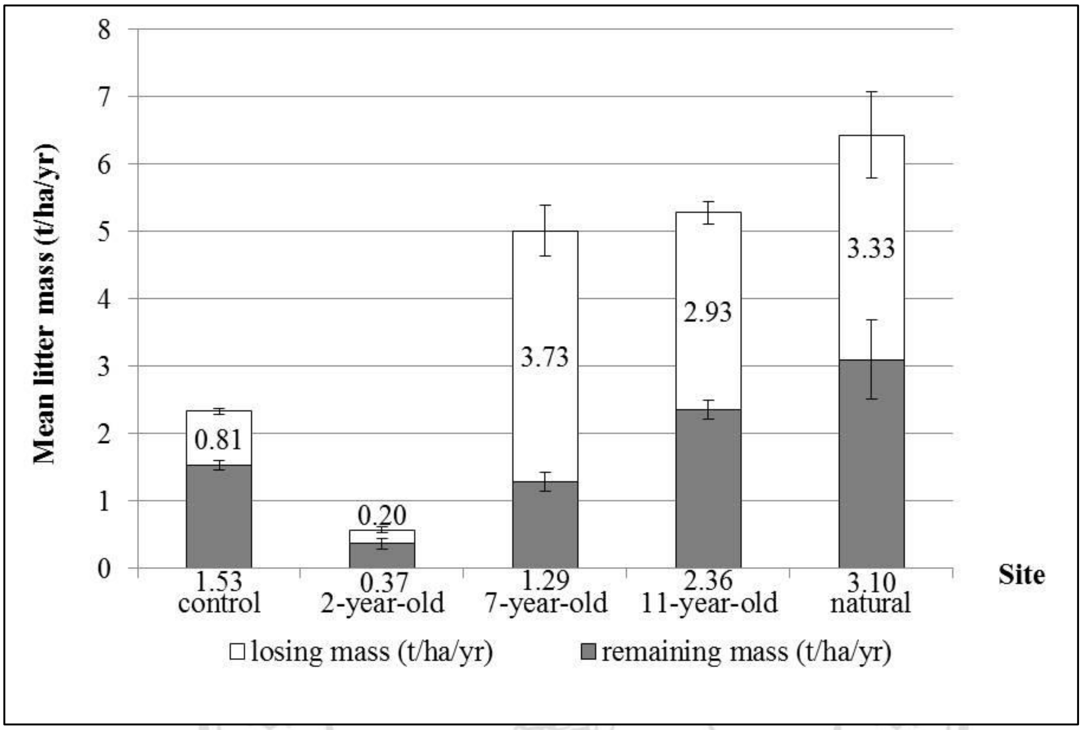


Figure 4.7 Litter mass remaining and loss (t/ha/yr)

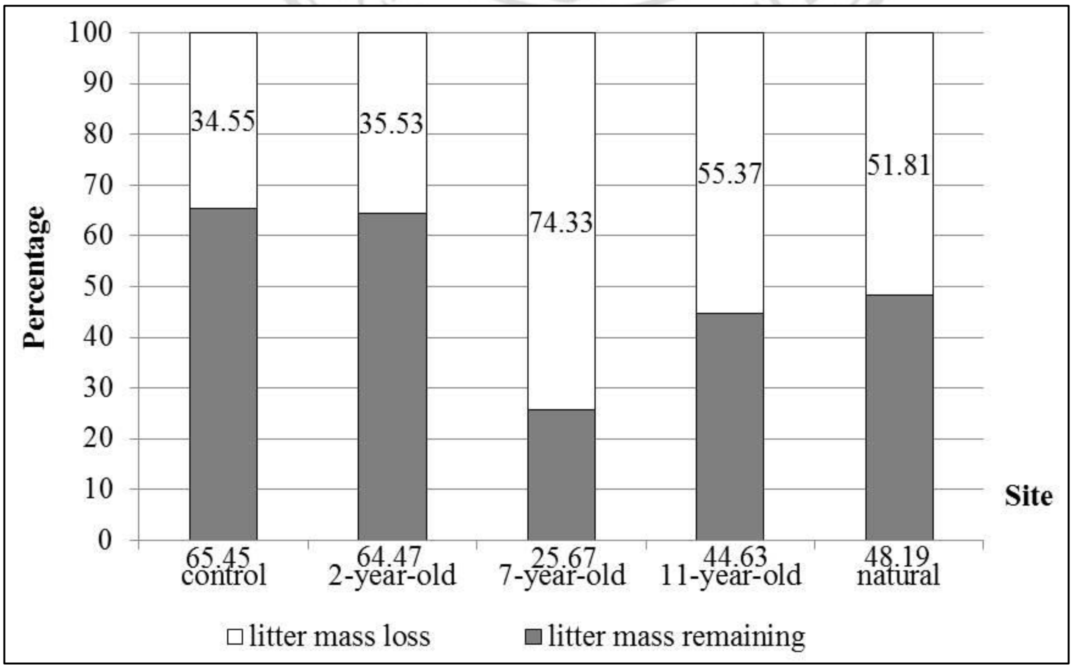


Figure 4.8 Percentage of mass remaining and loss

4.9 Carbon

Carbon content in litter was determined after collected in each period. Duration times were 0, 103, 187 and 286 days. Organic matter was determined and converted to organic carbon using 0.58. Carbon in litter decreased gradually from the beginning period to the last period. Significant differences among period were shown in Table 4.10. Highest carbon in litter of the beginning period was found in natural site next to 11, 2-year-old, control and 7-year-old were 38.72, 35.50, 34.74, 33.29 and 32.97 g/100g, respectively. After 286 days, highest carbon was also found in the natural site compared with 7, 2-year-old, control and 11-year-old site were 30.79, 29.54, 26.25, 25.70 and 25.37 g/100g, respectively.

Table 4.10 Carbon content (%) in litter in different periods

Period / Site	1	2	3	4
	0 day Early rainy (May.11)	103 days Rainy (Aug.11)	187 days Cool (Nov.11)	286 days Cool dry (Feb.12)
control	A 33.29±1.95 **b**	AB 31.79±4.90 **a**	AB 25.89±1.98 **ab**	B 25.37±1.16 **c**
2-year-old	A 34.74±2.13 **ab**	A 32.92±4.18 **a**	B 25.55±1.93 **ab**	B 25.70±0.82 **c**
7-year-old	A 32.97±2.74 **b**	AB 25.52±3.95 **a**	B 22.39±4.02 **b**	AB 29.54±3.27 **ab**
11-year-old	A 35.50±1.50 **ab**	AB 29.97±3.71 **a**	B 26.33±2.16 **ab**	B 26.25±0.38 **bc**
natural	A 38.72±0.39 **a**	AB 35.21±2.92 **a**	B 31.72±3.89 **a**	B 30.79±0.90 **a**

Note: Value are means± SD (n= 12). Means followed by different letters on the same column on the right indicate significant differences at $p < 0.05$ among study sites and different capital letters on the same row on the left indicate significant differences at $P < 0.05$ among periods.

4.10 Carbon remaining (%) in different period

Carbon remaining (%) from period by period was calculated using equation below.

$$\text{Carbon remaining (\%)} = (X_t/X_0) \times (C_t/C_0) \times 100$$

X_0 = initial dry mass of litter

X_t = remaining litter mass after time t

C_0 = initial carbon in litter

C_t = remaining carbon in litter after time t

Percentage of carbon remaining dropped from beginning period around 30 %. In restored forest and control site were not different among period of times (p < 0.05) but carbon remaining in natural site was quit fluctuated. After 103 days, carbon remaining was not different among study sites. After 187 days, carbon remaining in natural site was significantly higher than other sites. Highest carbon remaining in 2-year-old site next to control, 11-year-old, natural and 7-year-old site were 68.15, 66.08, 61.66, 51.48 and 40.36 %, respectively after 286 days (Table 4.11). Carbon remaining in different period and trend line was shown in Fig.4.10 and predicted mass remaining in 1 year of control, 2, 7, 11-year-old and natural site using regression equation were 63.46, 43.55, 31.17, 41.26 and 46.22 % , respectively (Table 4.12).

Table 4.11 Carbon remaining (%) in different period

Site \ Period	1	2	3	4
	0 day Early rainy (May.11)	103 days Rainy (Aug.11)	187 days Cool (Nov.11)	286 days Cool dry (Feb.12)
control	100	A 71.19±14.11 **a**	A 64.06±9.88 **b**	A 66.08±22.13 **ab**
2-year-old	100	A 71.24±13.06 **a**	A 55.58±14.72 **b**	A 68.15±21.69 **a**
7-year-old	100	A 61.21±11.10 **a**	A 50.62±16.28 **b**	A 40.36±25.22 **b**
11-year-old	100	A 58.07±17.36 **a**	A 62.93±15.20 **b**	A 61.66±18.46 **ab**
natural	100	B 68.57±11.89 **a**	A 91.29±2.03 **a**	B 51.48±10.78 **ab**

Note: Value are means± SD (n= 12). Means followed by different letters on the same column on the right indicate significant differences at $p < 0.05$ among study sites and different capital letters on the same row on the left indicate significant differences at $p < 0.05$ among periods.

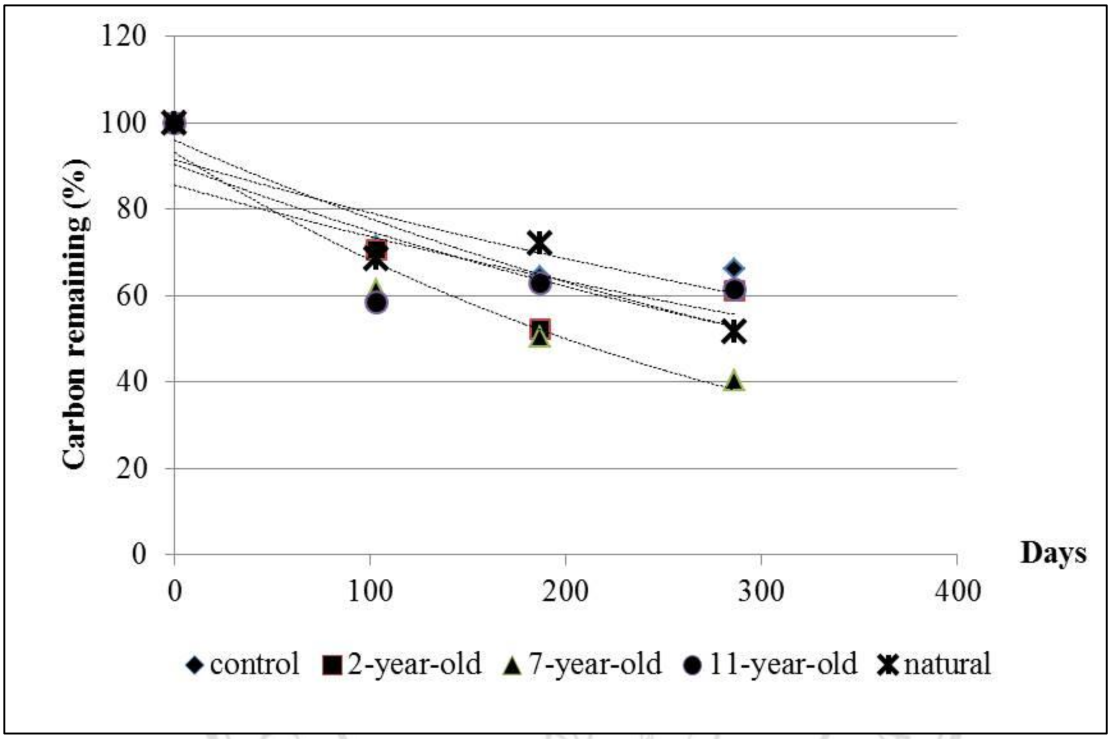


Figure 4.9 Carbon remaining with trend line in different periods

Table 4.12 Regression equation and R^2 of all study sites

site	Equation	R^2	Predicted carbon remaining (%) in 1 year
Control	$y = 91.421e^{-0.001x}$	0.75	63.46
2-year-old	$y = 90.368e^{-0.002x}$	0.68	43.55
7-year-old	$y = 93.18e^{-0.003x}$	0.96	31.17
11-year-old	$y = 85.615e^{-0.002x}$	0.54	41.26
natural	$y = 95.919e^{-0.002x}$	0.86	46.22

4.11 Nitrogen

Nitrogen of mixed litter mass at the different times was determined. At the beginning time, highest of nitrogen was found in 7-year-old next to natural, 11, 2-year-old and control site were 1.67, 1.66, 1.62, 1.30 and 1.24 (g/100g), respectively (Table 4.13). Among period of times, after 103 days nitrogen was decreased from beginning period in 11 and 7-year-old sites. In 2-year-old, control and natural sites nitrogen was not different among periods.

After 103 days, nitrogen in litter was not different among study sites. The negative relationship between nitrogen and duration times (R^2 = 0.90) was found and shown in Fig. 4.10.

Table 4.13 Nitrogen (g/100 g) in litter in different periods

Period / Site	1	2	3	4
	0 day Early rainy (May.11)	103 days Rainy (Aug.11)	187 days Cool (Nov.11)	286 days Cool dry (Feb.12)
control	A 1.24±0.11 **c**	A 1.14±0.17 **a**	A 1.03±0.03 **b**	A 1.01±0.03 a
2-year-old	A 1.30±0.14 **bc**	A 1.28±0.32 **a**	A 1.06±0.12 **b**	A 1.05±0.05 a
7-year-old	A 1.67±0.09 **a**	B 1.15±0.19 **a**	B 0.95±0.18 b	B 1.02±0.21 a
11-year-old	A 1.62±0.16 **ab**	B 1.22±0.11 **a**	B 1.03±0.11 b	B 1.04±0.01 a
natural	A 1.66±0.22 **ab**	A1.48±0.23 **a**	A 1.54±0.36 a	A 1.33±0.27 a

Note: Value are means± SD (n= 12). Means followed by different letters on the same column on the right indicate significant differences at P<0.05 among study sites and different letters on the same row on the left indicate significant differences at P<0.05 among periods.

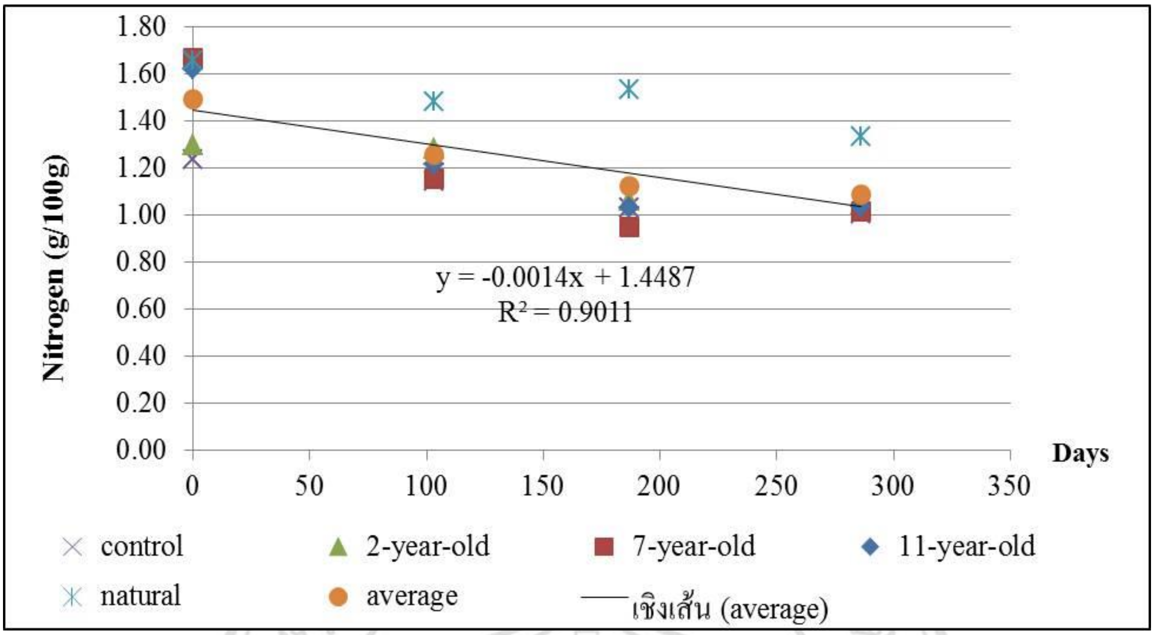


Figure 4.10 Relationship between nitrogen in litter and duration times

4.12 Carbon:Nitrogen

Carbon:nitrogen was determined during period of times. The positive relationship between carbon:nitrogen and duration times (R^2 = 0.43). Carbon:nitrogen from the first to the last period ranged from 19.79 – 26.90, 22.10 – 27.80, 20.65 – 25.51 and 23.11 – 29.03, respectively (Table 4.14 and Fig. 4.11).

Table 4.14 Carbon nitrogen ratio in different periods

Period / Site	1	2	3	4
	0 day Early rainy (May.11)	103 days Rainy (Aug.11)	187 days Cool (Nov.11)	286 days Cool dry (Feb.12)
control	26.90	27.80	25.04	25.24
2-year-old	26.72	25.67	24.04	24.50
7-year-old	19.79	22.10	23.55	29.03
11-year-old	21.91	24.64	25.51	25.24
natural	23.35	23.74	20.65	23.11

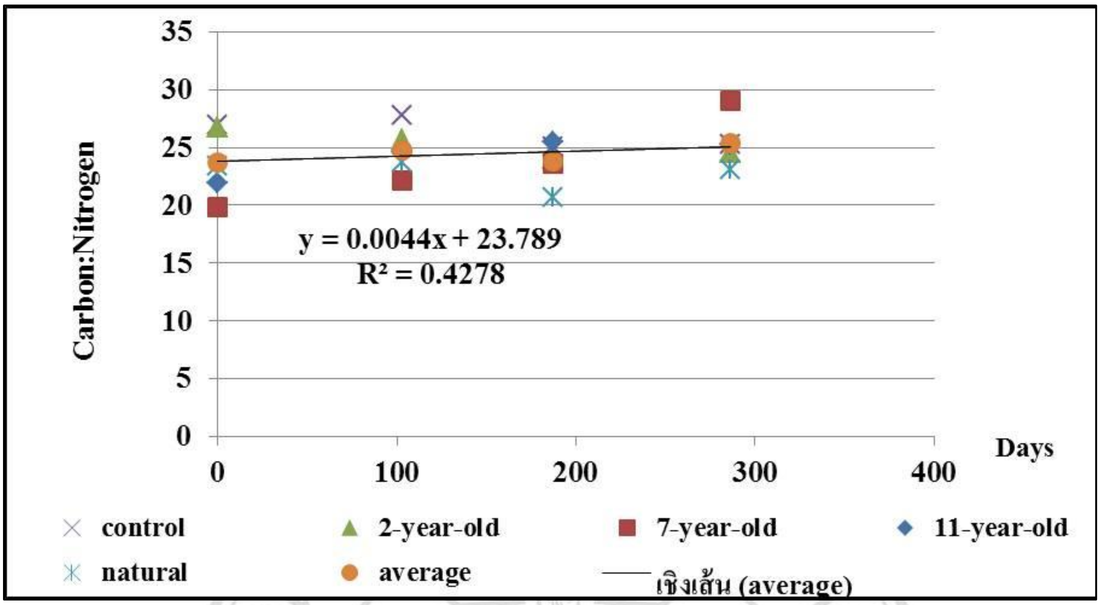


Figure 4.11 The relationship between carbon nitrogen ratio in litter and duration times

4.13 *K* value

K value was calculated. Over 286 days *k* value ranged from 1.08 – 2.85. *K* value in 7-year-old was higher significantly from other sites (Table 4.13).

Table 4.15 *K* value

Site	*k*
control	1.20 ± 0.88 b
2-year-old	1.08 ± 0.78 b
7-year-old	2.85 ± 1.10 a
11-year-old	1.27 ± 0.40 b
natural	1.12 ± 0.29 b

Note: Value are means± SD (n= 12). Means followed by different letters on the same column on the right indicate significant differences at $P<0.05$ among study sites.

4.14 Soil profiles

Soil profile of each study site was dig from top soil down to 200 cm in depth. Topography of study site was recorded (Table 4.16). Each layer of soil was collected and analyzed (Fig. 4.12). Then the results from laboratory comprised with observed data using for described soil profile descriptions. Soil classification of each soil profile was determined using soil taxonomy USDA 11th edition, 2010 and also shown in Table 4.17.

Table 4.16 Summary of study site topography

Pedon	site	Elevation (m.asl.)	Slope (%)	Slope aspect	GPS		
1	control	1,332	10	ESE 99^0	N18^0 E098^0	51’ 50’	410” 881”
2	2-year-old	1,311	16	ENE 60^0	N18^0 E098^0	51’ 50’	410” 931”
3	7-year-old	1,228	22	ENE 86^0	N18^0 E098^0	51’ 50’	569” 968”
4	11-year-old	1,332	9	NNW 352^0	N18^0 E098^0	51’ 50’	410” 881”
5	natural	1,288	14	WSW 266^0	N18^0 E098^0	51’ 51’	893” 717”

Table 4.17 Soil classification

Pedon	Site	Order	Suborder	Great group	Sub group	Soil family
1	control	Ultisols	Ustults	Haplustults	Typic Haplustults	Fine loamy
2	2-year-old	Ultisols	Ustults	Haplustults	Typic Haplustults	Fine
3	7-year-old	Ultisols	Ustults	Haplustults	Typic Haplustults	Fine loamy
4	11-year-old	Ultisols	Ustults	Haplustults	Typic Haplustults	Fine loamy
5	natural	Ultisols	Ustults	Haplustults	Typic Haplustults	Fine

Control **2-year-old** **7-year-old** **11-year-old** **Natural**

Figure 4.12 Soil profiles of each study site

4.14.1 Soil physical properties

4.14.1.1 Bulk density

Soil bulk density increased with depth but not significantly different among study sites. Soil bulk density from 0 – 200 cm. in depth in pedon 1 - 5 (control, 2, 7. 11-year-old and natural sites) were 0.78 – 1.12, 0.68 – 1.07, 0.75 – 1.14, 0.78 – 1.12 and 0.62 – 1.06 g/cm^3, respectively. According to appendix C, soil bulk density among study sites were low (< 1.2 g/cm^3) (Tables 4.18a-b).

4.14.1.2 Soil texture

In all study sites, the pattern of percentage of sand, silt and sand seem to be similar. Percentage of sand tended to be decreased followed by soil depth in pedon 1 – 5. Percentage of silt was quite constantly. In pedon 1 – 4, percentage of silt was around 20 % but in pedon 5 (natural site) was around 15 %. Clay percentage of pedon 1 (control site) was quit constant around 25 % (Tables 4.18a-b and Fig. 4.13).

Table 4 .18a Soil physical properties

Soil depth (cm)	Bulk density (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	Texture	Texture class
Pedon 1 (control site)						
0-5	0.78	53.6	23.9	22.5	Sandy clay loam	Moderately fine-textured
5--10	0.85	51.8	22.3	25.9	Sandy clay loam	
10--20	0.90	49.2	24	26.8	Sandy clay loam	
20-30	0.90	46.7	26.5	26.8	Sandy clay loam	
30-40	0.95	44.1	26.6	29.3	Clay loam	
40-60	0.92	46.7	25.7	27.6	Sandy clay loam	
60-80	0.91	43.4	27.3	29.3	Clay loam	
80-100	1.15	39	28.2	32.8	Clay loam	
100-150	1.12	39	30.8	30.2	Clay loam	
150-200	1.12	46.7	29.1	24.2	Loam	Medium-textured
Pedon 2 (2-year-old site)						
0-5	0.68	51.8	19.8	28.4	Sandy clay loam	Moderately fine-textured
5-10	0.79	39	21.5	39.5	Clay loam	
10-20	0.76	39	21.5	39.5	Clay loam	
20-30	0.82	33.9	23.1	43	Clay	Fine-textured
30-40	0.92	31.4	24	44.6	Clay	
40-60	1.12	31.4	24	44.6	Clay	
60-80	1.14	33.9	23.1	43	Clay	
80-100	1.12	31.4	28.1	40.5	Clay	
100-150	1.21	31.4	28.1	40.5	Clay	
150-200	1.07	28.8	32.4	38.8	Clay loam	Moderately fine-textured

Table 4.18b Soil physical properties

Soil depth (cm)	Bulk density (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	Texture	Texture class
Pedon 3 (7-year-old site)						
0-5	0.75	56.9	30	13.1	Sandy loam	Moderately coarse-textured
5-10	0.81	56.2	30.7	13.1	Sandy loam	
10-20	0.82	58.8	28.9	12.3	Sandy loam	
20-30	0.89	64	26.2	9.8	Sandy loam	
30-40	0.85	44.1	27.5	28.4	Clay loam	Moderately fine-textured
40-60	0.94	55.7	13.4	30.9	Sandy clay loam	
60-80	0.98	43.2	24.2	32.6	Clay loam	
80-100	0.96	41.6	23.3	35.1	Clay loam	
100-150	0.92	39	23.3	37.7	Clay loam	
150-200	1.14	40.6	21.7	37.7	Clay loam	
Pedon 4 (11-year-old site)						
0-5	0.78	64.4	23.2	12.4	Sandy loam	Moderately coarse-textured
5-10	0.83	69	18.6	12.4	Sandy loam	
10-20	0.81	69	18.6	12.4	Sandy loam	
20-30	0.85	64.4	20.7	14.9	Sandy loam	
30-40	0.82	49.1	24.1	26.8	Sandy clay loam	Moderately fine-textured
40-60	0.93	46.6	23.3	30.1	Sandy clay loam	
60-80	1.02	44	23.3	32.7	Clay loam	
80-100	1.04	44	23.3	32.7	Clay loam	
100-150	1.09	44	23.3	32.7	Clay loam	
150-200	1.12	41.6	18.2	40.2	Clay	Fine-textured
Pedon 5 (natural site)						
0-5	0.62	56.9	20.6	22.5	Sandy clay loam	Moderately fine-textured
5--10	0.63	56.9	19.7	23.4	Sandy clay loam	
10--20	0.80	51.8	15.6	32.6	Sandy clay loam	
20-30	0.90	51.8	15.6	32.6	Sandy clay loam	
30-40	0.85	46.7	15.6	37.7	Sandy clay	Fine-textured
40-60	0.90	44.1	13.2	42.7	Clay	
60-80	0.98	41.6	14.1	44.3	Clay	
80-100	0.93	44.1	10.6	45.3	Clay	
100-150	0.97	44.1	13.2	42.7	Clay	
150-200	1.06	41.6	13.1	45.3	Clay	

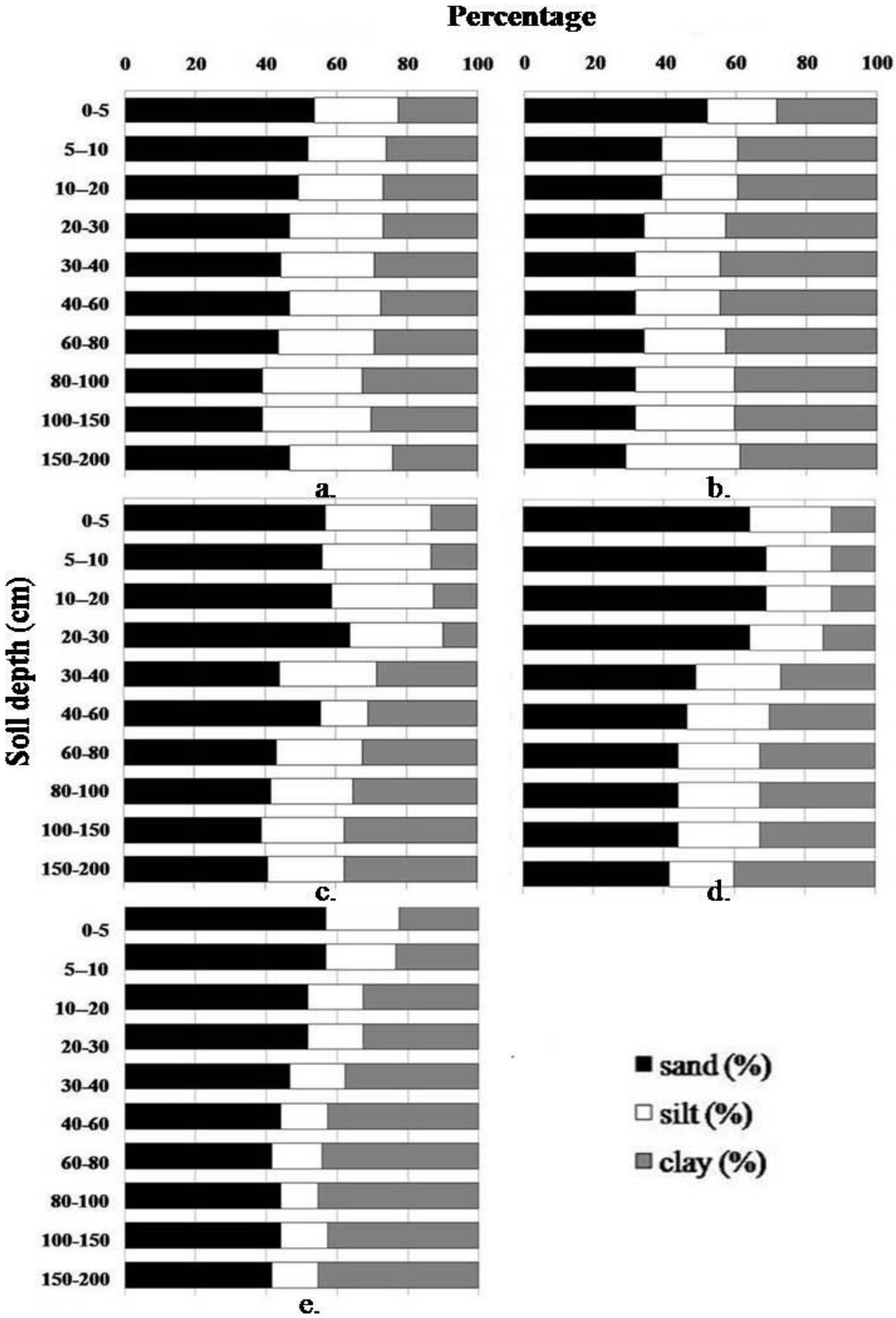


Figure 4.13 Soil texture

4.14.2 Soil chemical properties

4.14.2.1 Soil pH

According to appendix C, soil in pedon 1 (control site) and pedon 2 (2-year-old site) were very strongly acid (4.5 – 5.0). Upper soil in pedon 3 (7 – year-old site) (0- 30 cm.) was strongly acid (5.4 – 5.7) while lower than 30 cm. was very strongly acid (5.4 – 5.7). Soil pH in pedon 4 (11- year-old site) was very extremely acid (4.8 - 5.3) whereas in pedon 5 (natural site) was ranged from extremely acid to very strongly acid (Tables 4.19a –b).

4.14.2.2 OM, N, P and K

OM, N, P and K decreased with depth. According appendix C, OM of top soil (first 5cm. in depth) in all study sites was low, but in pedon 5 (natural site) was moderately low. Nitrogen in 0 – 30 cm. soil depth in old-restored plot: pedon 3 and pedon 4 (7 and 11 year-old) and pedon 5 (natural forest) were medium rate (2.0 – 5.0 g/kg). Phosphorus in first 5 cm. was indicate high in pedon 4 (32.33 g/kg), moderately high in pedon 3 (21.81 g/kg), medium in pedon 2 (13.84 g/kg), moderately low in pedon 1 (9.99 g/kg) and low in pedon 5 (4.82 g/kg) (Tables 4.19a-b).

.

Table 4.19a Soil chemical properties

Soil depth (cm)	pH 1:1	OM g/100g	OC g/100g	TotalN g/100g	P (mg/kg)	K (mg/kg)
Pedon 1 (control site)						
0-5	5.01	10.08	5.85	0.39	9.99	180.81
5-10	4.79	7.16	4.15	0.26	6.31	114.19
10-20	4.44	5.03	2.92	0.19	1.23	75.34
20-30	4.39	4.39	2.55	0.16	0.88	64.23
30-40	4.38	2.76	1.60	0.11	0.53	64.23
40-60	4.61	2.76	1.60	0.11	0.26	47.58
60-80	4.89	1.88	1.09	0.09	0.45	58.68
80-100	4.82	0.74	0.43	0.03	0.18	25.38
100-150	4.78	0.6	0.35	0.02	0.27	19.83
150-200	4.81	0.47	0.27	0.02	0.36	5.13
Pedon 2 (2-year-old site)						
0-5	4.76	6.86	3.98	0.28	13.84	286.28
5-10	4.7	5.83	3.38	0.24	3.68	164.15
10-20	4.79	5.26	3.05	0.21	2.28	103.09
20-30	4.56	3.58	2.08	0.14	0.26	47.58
30-40	4.53	2.53	1.47	0.10	0.26	42.03
40-60	4.53	1.86	1.08	0.07	0.26	19.83
60-80	4.58	1.41	0.82	0.05	0.09	13.96
80-100	4.6	0.93	0.54	0.03	0.91	3.17
100-150	4.52	0.87	0.50	0.02	0.27	8.72
150-200	4.8	0.7	0.41	0.02	0.55	3.17
Pedon 3 (7-year-old site)						
0-5	5.75	7.71	4.47	0.38	21.81	397.3
5-10	5.41	6.75	3.92	0.34	15.59	291.83
10-20	5.44	6.18	3.58	0.31	17.61	208.56
20-30	5.49	5.51	3.20	0.27	8.59	108.64
30-40	5.3	3.47	2.01	0.16	1.93	80.89
40-60	5.01	3.09	1.79	0.14	1.58	108.64
60-80	4.85	2.5	1.45	0.11	0.96	108.64
80-100	4.88	1.99	1.15	0.08	0.79	103.09
100-150	4.97	1.56	0.90	0.10	1.18	136.40
150-200	4.96	1.4	0.81	0.01	0.55	30.93

Table 4.19b Soil chemical properties

Soil depth (cm)	pH 1:1	OM g/100g	OC g/100g	TotalN g/100g	P (mg/kg)	K (mg/kg)
			Pedon 4 (11-year-old site)			
0-5	4.65	8.97	5.20	0.37	32.33	180.81
5-10	5.12	7.71	4.47	0.31	47.83	97.54
10-20	4.42	7.12	4.13	0.28	24.18	80.89
20-30	5.4	5.62	3.26	0.24	5.61	91.99
30-40	4.45	4.69	2.72	0.17	2.98	42.03
40-60	4.31	3.12	1.81	0.08	1.4	30.93
60-80	4.31	2.35	1.36	0.08	1.14	36.48
80-100	4.41	1.16	0.67	0.05	0.09	36.48
100-150	4.95	0.86	0.50	0.04	0.7	8.72
150-200	5.24	0.69	0.40	0.02	0.55	8.72
			Pedon 5 (natural site)			
0-5	4.52	11.59	6.72	0.42	4.82	158.6
5-10	4.52	9.91	5.75	0.39	4.12	75.34
10-20	4.46	6.99	4.05	0.27	1.84	42.03
20-30	6.79	5.55	3.22	0.36	15.68	119.74
30-40	4.49	3.27	1.90	0.11	0.79	42.03
40-60	4.38	2.13	1.24	0.10	0.26	14.27
60-80	4.36	1.48	0.86	0.06	0.82	14.27
80-100	4.64	1.09	0.63	0.04	0.55	19.83
100-150	4.56	0.78	0.45	0.04	0.45	3.17
150-200	4.67	0.73	0.42	0.02	0.36	3.17

4.14.2.3 CEC and percentage base saturation

According to Appendix C**,** CEC of first 5 cm. depth of soil in pedon 1, 2, 4 and 5 were moderately high (15 – 20 cmol+/kg) while in pedon 3 was high. Base saturation (%) in the same depth of pedon 1, 4 and 5 were low (< 35 %) but in pedon 2 and 3 were medium (35 – 75%) (Tables 4.20a – b).

Table 4.20a CEC and percentage base saturation

Soil depth (cm)	K (cmol+/kg)	Ca (cmol+/kg)	Mg (cmol+/kg)	Na (cmol+/kg)	Sum of base (cmol+/kg)	CEC (cmol+/kg)	Base saturation (%)
			Pedon 1 (control site)				
0-5	0.46	3.00	0.93	0.06	4.45	15.49	28.70
5-10	0.29	0.52	0.24	0.06	1.11	12.73	8.72
10-20	0.19	0.00	0.05	0.09	0.34	9.87	3.42
20-30	0.16	0.03	0.02	0.11	0.32	8.81	3.69
30-40	0.16	0.07	0.02	0.08	0.33	7.22	4.57
40-60	0.12	0.18	0.10	0.14	0.54	6.79	7.96
60-80	0.15	0.58	0.23	0.07	1.02	5.09	20.12
80-100	0.07	0.08	0.08	0.08	0.30	2.97	10.10
100-150	0.05	0.20	0.07	0.04	0.36	2.23	16.30
150-200	0.01	0.11	0.15	0.17	0.45	2.55	17.69
			Pedon 2 (2-year-old site)				
0-5	0.73	3.63	1.12	0.06	5.55	15.49	35.81
5-10	0.42	0.43	0.14	0.24	1.22	13.27	9.21
10-20	0.26	2.57	0.11	0.07	3.02	12.84	23.51
20-30	0.12	0.49	0.04	0.08	0.73	11.35	6.46
30-40	0.11	0.19	0.02	0.05	0.36	5.94	6.12
40-60	0.05	0.25	0.02	0.11	0.43	6.05	7.06
60-80	0.04	0.09	0.03	0.10	0.25	4.88	5.20
80-100	0.01	0.12	0.07	0.06	0.26	3.93	6.50
100-150	0.02	0.14	0.10	0.08	0.34	3.93	8.71
150-200	0.01	0.09	0.09	0.06	0.24	5.09	4.67
			Pedon 3 (7-year-old site)				
0-5	1.02	9.74	3.32	0.08	14.16	20.59	68.76
5-10	0.75	6.28	1.97	0.07	9.07	18.78	48.30
10-20	0.53	5.19	0.73	0.07	6.52	17.40	37.48
20-30	0.28	4.62	0.85	0.08	5.84	16.34	35.74
30-40	0.21	2.06	0.68	0.03	2.98	11.57	25.73
40-60	0.28	0.97	0.51	0.07	1.83	10.40	17.62
60-80	0.28	0.63	0.48	0.05	1.44	9.02	15.96
80-100	0.26	0.68	0.64	0.07	1.65	8.17	20.18
100-150	0.35	0.40	0.50	0.10	1.34	6.15	21.78
150-200	0.08	0.21	0.41	0.15	0.84	4.56	18.40

Table 4.20b CEC and percentage base saturation

Soil depth (cm)	K (cmol+/kg)	Ca (cmol+/kg)	Mg (cmol+/kg)	Na cmol+/kg	Sum of base (cmol+/kg)	CEC cmol+/kg	Base saturation (%)
			Pedon 4 (11-year-old site)				
0-5	0.46	2.58	0.62	0.08	3.75	19.74	19.00
5-10	0.25	0.49	0.15	0.09	0.98	16.13	6.06
10-20	0.21	0.20	0.06	0.09	0.56	14.33	3.90
20-30	0.24	0.06	0.04	0.02	0.36	13.80	2.58
30-40	0.11	0.04	0.02	0.09	0.26	13.80	1.89
40-60	0.08	0.00	0.01	0.12	0.21	11.57	1.82
60-80	0.09	0.15	0.02	0.07	0.34	8.70	3.85
80-100	0.09	0.22	0.01	0.07	0.40	7.43	5.38
100-150	0.02	0.28	0.06	0.08	0.43	4.88	8.86
150-200	0.02	0.06	0.05	0.07	0.21	3.29	6.28
			Pedon 5 (natural site)				
0-5	0.41	0.89	0.45	0.07	1.82	16.77	10.83
5-10	0.19	0.04	0.07	0.10	0.41	14.64	2.78
10-20	0.11	0.06	0.04	0.09	0.30	10.82	2.76
20-30	0.31	0.04	0.07	0.29	0.70	9.34	7.45
30-40	0.11	0.03	0.01	0.06	0.21	7.22	2.92
40-60	0.04	0.01	0.03	0.11	0.18	5.52	3.35
60-80	0.04	0.01	0.02	0.06	0.12	4.03	3.06
80-100	0.05	0.01	0.01	0.11	0.18	3.82	4.69
100-150	0.01	0.00	0.01	0.07	0.09	2.55	3.48
150-200	0.01	0.01	0.01	0.07	0.10	1.91	5.33

14.14.3 Soil fertility

Score of each parameter were defined and sum of them were used for estimating soil fertility level according to Appendix C. The first 30 cm in depth of soil in pedon 1, 2 and 5 were indicated as medium fertility and lower than 30 cm in depth was indicated as low fertility. In pedon 3, first 5 cm in depth was high, while 5 – 100 cm in depth was medium and lower than that was low (Tables 4.21a-b).

Table 4.21a Soil fertility

Soil depth (cm)	O.M. (g/kg)	P (mg/kg)	K (mg/kg)	CEC (cmol+/kg)	Base saturation (%)	Score	Fertility level
			Pedon 1 (control site)				
0-5	100.80 (3)	9.99 (1)	180.81 (3)	15.49 (2)	28.70 (1)	10	medium
5-10	71.60(3)	6.31 (1)	114.19 (3)	12.73(2)	8.72(1)	10	medium
10-20	50.30(3)	1.23 (1)	75.34 (2)	9.87(1)	3.42(1)	8	medium
20-30	43.90(3)	0.88 (1)	64.23 (2)	8.81(1)	3.69(1)	8	medium
30-40	27.60 (2)	0.53 (1)	64.23 (2)	7.22(1)	4.57(1)	7	low
40-60	27.60 (2)	0.26 (1)	47.58 (1)	6.79(1)	7.96(1)	6	low
60-80	18.80 (2)	0.45 (1)	58.68 (1)	5.09(1)	20.12(1)	6	low
80-100	7.40 (1)	0.18 (1)	25.38 (1)	2.97(1)	10.10(1)	5	low
100-150	6.00 (1)	0.27 (1)	19.83 (1)	2.23(1)	16.30(1)	5	low
150-200	4.70 (1)	0.36 (1)	5.13 (1)	2.55(1)	17.69(1)	5	low
			Pedon 2 (2-year-old site)				
0-5	68.60 (3)	13.84 (2)	286.28 (3)	15.49 (2)	35.81 (2)	12	medium
5-10	58.30 (3)	3.68 (1)	164.15(3)	13.27(2)	9.21(1)	10	medium
10-20	52.60 (3)	2.28 (1)	103.09(3)	12.84(2)	23.51(1)	10	medium
20-30	35.80 (3)	0.26 (1)	47.58 (2)	11.35(2)	6.46(1)	9	medium
30-40	25.30 (2)	0.26 (1)	42.03(2)	5.94 (1)	6.12(1)	7	low
40-60	18.60 (2)	0.26 (1)	19.83 (1)	6.05(1)	7.06(1)	6	low
60-80	14.10 (1)	0.09 (1)	13.96(1)	4.88(1)	5.20(1)	5	low
80-100	9.30 (1)	0.91 (1)	3.17(1)	3.93(1)	6.50(1)	5	low
100-150	8.70 (1)	0.27 (1)	8.72(1)	3.93(1)	8.71(1)	5	low
150-200	7.00 (1)	0.55 (1)	3.17(1)	5.09(1)	4.67(1)	5	low
			Pedon 3 (7-year-old site)				
0-5	77.10 (3)	21.81 (2)	397.30 (3)	20.59 (3)	68.76 (2)	13	high
5-10	67.50 (3)	15.59 (2)	291.83 (3)	18.78(2)	48.30(2)	12	medium
10--20	61.80 (3)	17.61 (2)	208.56 (3)	17.40(2)	37.48(2)	12	medium
20-30	55.10 (3)	8.59 (1)	108.64 (3)	16.34(2)	35.74(2)	11	medium
30-40	34.70 (2)	1.93 (1)	80.89 (2)	11.57(2)	25.73(1)	8	medium
40-60	30.90 (2)	1.58 (1)	108.64 (3)	10.40(2)	17.62(1)	9	medium
60-80	25.00 (2)	0.96 (1)	108.64 (3)	9.02 (1)	15.96(1)	8	medium
80-100	19.90 (2)	0.79 (1)	103.09 (3)	8.17(1)	20.18(1)	8	medium
100-150	15.60 (2)	1.18 (1)	136.40 (3)	6.15 (1)	21.78(1)	8	medium
150-200	14.00 (1)	0.55 (1)	30.93 (1)	4.56(1)	18.40(1)	5	low

Table 4.21b Soil fertility

Soil depth (cm)	O.M. (g/kg)	P (mg/kg)	K (mg/kg)	CEC (cmol+/kg)	Base saturation (%)	Score	Fertility level
			Pedon 4 (11-year-old site)				
0-5	89.70 (3)	32.33 (3)	180.81 (3)	19.74 (2)	19.00(1)	12	medium
5-10	77.10 (3)	47.83(3)	97.54 (3)	16.13(2)	6.06(1)	12	medium
10-20	71.20 (3)	24.18 (2)	80.89 (2)	14.33(2)	3.90(1)	10	medium
20-30	56.20 (3)	5.61 (1)	91.99 (3)	13.80(2)	2.58(1)	10	medium
30-40	46.90 (3)	2.98 (1)	42.03 (1)	13.80(2)	1.89(1)	8	medium
40-60	31.20 (2)	1.40 (1)	30.93 (1)	11.57(2)	1.82(1)	7	low
60-80	23.50 (2)	1.14 (1)	36.48 (1)	8.70 (1)	3.85(1)	7	low
80-100	11.60 (1)	0.09 (1)	36.48 (1)	7.43(1)	5.38(1)	5	low
100-150	8.60 (1)	0.70 (1)	8.72 (1)	4.88(1)	8.86(1)	5	low
150-200	6.90 (1)	0.55 (1)	8.72 (1)	3.29(1)	6.28(1)	5	low
			Pedon 5 (natural site)				
0-5	115.9 (3)	4.82 (1)	158.6 (3)	16.77 (2)	10.83 (1)	10	medium
5-10	99.1 (3)	4.12 (1)	75.34 (2)	14.64 (2)	2.78 (1)	9	medium
10-20	69.9 (3)	1.84 (1)	42.03 (1)	10.82 (2)	2.76 (1)	8	medium
20-30	55.5 (3)	15.68 (2)	119.74 (3)	9.34 (1)	7.45 (1)	10	medium
30-40	32.7 (2)	0.79 (1)	42.03 (1)	7.22 (1)	2.92 (1)	6	low
40-60	21.3 (2)	0.26 (1)	14.27 (1)	5.52 (1)	3.35 (1)	6	low
60-80	14.8 (1)	0.82 (1)	14.27 (1)	4.03 (1)	3.06 (1)	5	low
80-100	10.9 (1)	0.55 (1)	19.83 (1)	3.82 (1)	4.69 (1)	5	low
100-150	7.8 (1)	0.45 (1)	3.17 (1)	2.55 (1)	3.48 (1)	5	low
150-200	7.3 (1)	0.36 (1)	3.17 (1)	1.91 (1)	5.33 (1)	5	low

4.15 Soil sampling using soil auger

4 soil pits from each study site was conducted in July 2012. Each soil layer: 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-150 and 150 -200 cm in depth were collected soil auger. Soil samples from 4 points were mixed and sub-sampled into 3 replicates. Soil chemical parameters: pH, N, P, K, CEC and organic matter were analyzed.

4.15.1 Soil pH

Soil pH in each site from different soil depths (0 -200 cm) were determined. The differences among study sites in the same depth was investigated and shown in Table 4.22. Soil pH of 11-year-old site from 0 – 100 cm in depth tended to be lower than other sites and pH ranged from 3.97 – 4.93. In contrast, 0- 20 cm in depth pH in 7-year-old was higher than other sites significantly. Below 60 cm, pH in control site was significantly higher other sites (Table 4.22).

Table 4.22 Soil pH in different soil depth from 0 – 200 cm in all study sites

Soil depth (cm)	control	2-year-old	7-year-old	11-year-old	natural
0-5	4.79±0.02 **c**	4.96±0.03 **b**	5.16 ±0.03 **a**	4.53 ±0.03 **d**	4.50±0.06 **d**
5-10	4.55±0.15 **b**	4.68±0.03 **b**	4.99±0.02 **a**	4.03±0.02 **c**	4.53±0.03 **b**
10-20	4.57±0.03 **b**	4.54±0.01 **b**	4.74±0.03 **a**	4.17±0.10 **c**	4.31±0.05 **c**
20-30	4.43±0.01 **ab**	4.49±0.01 **a**	4.48±0.02 **a**	4.14±0.05 **c**	4.37±0.03 **b**
30-40	4.43±0.05 **a**	4.41±0.02 **a**	4.35±0.01 **a**	4.04±0.04 **b**	4.41±0.00 **a**
40-60	4.38±0.02 **b**	4.44±0.02 **ab**	4.44±0.02 **a**	3.97±0.03 **c**	4.41±0.02 **ab**
60-80	4.62±0.03 **a**	4.48±0.02 **c**	4.55±0.02 **b**	3.97±0.01 **d**	4.54±0.03 **b**
80-100	4.91±0.06 **a**	4.51±0.03 **c**	4.61±0.02 **b**	4.07±0.02 **d**	4.61±0.01 **b**
100-150	5.03±0.07 **a**	4.47±0.05 **d**	4.63±0.04 **bc**	4.52±0.06 **cd**	4.67±0.03 **b**
150-200	5.17±0.16 **a**	4.63±0.01 **a**	4.74±0.03 **a**	4.68±0.03 **a**	5.72±1.74 **a**

Note: Value are means± SD (n= 3). Means followed by different letters on the same row on the right indicate significant differences at *P*<0.05 among study sites.

4.15.2 Soil nitrogen (N)

In natural forest site, soil nitrogen (N) in 0 – 10 cm in depth was higher than other sites significantly (Table 4.23). Below 20 until 200 cm in depth, in 7-year-old site was highly significant than other sites. In all study sites, nitrogen was decreased with soil depth.

Table 4.23 Soil N (g/100g) in different soil depth from 0 – 200 cm in all study sites

Soil depth (cm)	control	2-year-old	7-year-old	11-year-old	natural
0-5	0.358±0.073 **b**	0.281±0.003 **b**	0.309±0.019 **b**	0.347 ±0.018 **b**	0.499±0.031 **a**
5-10	0.222±0.005 **c**	0.225±0.005 **c**	0.263±0.006 **b**	0.217±0.008 **c**	0.382±0.011 **a**
10-20	0.182±0.011 **b**	0.165±0.009 **b**	0.230±0.010 **a**	0.175±0.012 **b**	0.240±0.018 **a**
20-30	0.128±0.003 **b**	0.132±0.006 **b**	0.176±0.012 **a**	0.116±0.010 **b**	0.159±0.015 **a**
30-40	0.118±0.005 **bc**	0.084±0.006 **d**	0.148±0.006 **a**	0.104±0.007 **c**	0.127±0.015 **b**
40-60	0.073±0.010 **bc**	0.056±0.010 **c**	0.124±0.007 **a**	0.073±0.003 **bc**	0.082±0.003 **b**
60-80	0.042±0.005 **c**	0.029±0.003 **d**	0.108±0.008 **a**	0.053±0.003 **bc**	0.055±0.003 **b**
80-100	0.019±0.008 **c**	0.023±0.002 **bc**	0.100±0.022 **a**	0.030±0.002 **bc**	0.048±0.002 **b**
100-150	0.023±0.004 **c**	0.010±0.002 **c**	0.076±0.009 **a**	0.022±0.002 **c**	0.036±0.006 **b**
150-200	0.018±0.002 **c**	0.011±0.001 **d**	0.060±0.001 **a**	0.018±0.002 **c**	0.030±0.001 **b**

Note: Value are means± SD (n= 3). Means followed by different letters on the same row on the right indicate significant differences at *P*<0.05 among study sites.

4.15.3 Soil phosphorus (P)

Soil phosphorus was tended to decrease with soil depth. The first 10 cm in depth, soil phosphorus in 11-year-old site was higher than others. Below 80 cm in depth, soil phosphorus in 7 year-old site was higher than other sites significantly (Table 4.24).

Table 4.24 Soil phosphorus (mg/kg) in 0 – 200 cm in all study sites

Soil depth (cm)	control	2-year-old	7-year-old	11-year-old	natural
0-5	8.03±0.18 **bc**	13.32±0.61 **b**	32.25±7.86 **a**	31.60±2.64 **a**	4.92±0.46 **c**
5-10	4.15±0.60 **c**	7.74±0.91 **c**	26.99±2.24 **b**	40.57±5.29 **a**	2.60±0.00 **c**
10-20	1.61±0.48 **c**	3.91±1.13 **c**	16.88±2.74 **a**	10.23±2.54 **b**	1.30±0.20 **c**
20-30	1.23±0.38 **c**	2.04±0.56 **bc**	6.46±0.34 **a**	3.13±1.28 **b**	0.87±0.06 **c**
30-40	1.06±0.06 **a**	0.91±0.13 **a**	5.71±4.28 **a**	1.71±0.39 **a**	0.73±0.21 **a**
40-60	0.87±0.15 **b**	0.73±0.27 **b**	2.84±0.31 **a**	2.32±0.42 **a**	0.47±0.15 **b**
60-80	0.67±0.06 **b**	0.58±0.18 **b**	2.47±0.49 **a**	1.26±0.19 **b**	0.63±0.06 **b**
80-100	0.67±0.35 **bc**	0.41±0.18 **c**	1.90±0.31 **a**	1.13±0.15 **b**	0.47±0.06 **c**
100-150	0.13±0.06 **b**	0.41±0.13 **ab**	0.82±0.35 **a**	0.61±0.15 **ab**	0.47±0.15 **ab**
150-200	0.10±0.00 **c**	0.53±0.15 **ab**	0.58±0.10 **a**	0.26±0.20 **bc**	0.43±0.06 **ab**

Note: Value are means± SD (n= 3). Means followed by different letters on the same row on the right indicate significant differences at P<0.05 among study sites

4.15.4 Potassium (K)

Soil potassium of all sites was tended to decrease with soil depth. In the first 10 cm was high in 7-year-old and 2-year-old sites. Below 10 cm, soil potassium in 7-year-old site was higher than other sites significantly (Table 4.25).

Table 4.25 Soil potassium (mg/kg) in 0 – 200 cm in all study sites

Soil depth (cm)	control	2-year-old	7-year-old	11-year-old	natural
0-5	170.10±11.63 **b**	247.27±10.37 **a**	245.80±4.45 **a**	159.46±0.97 **bc**	140.97±7.41 **c**
5-10	110.69±9.79 **b**	158.93±24.29 **a**	175.16±11.03 **a**	82.09±8.63 **b**	98.61±10.09 **b**
10-20	96.53±5.83 **b**	91.90±7.51 **b**	139.12±10.14 **a**	77.05±15.26 **b**	67.23±13.06 **b**
20-30	55.34±0.88 **c**	90.89±10.14 **b**	115.77±9.99 **a**	42.29±6.73 **c**	48.41±11.13 **c**
30-40	56.93±8.30 **ab**	54.33±6.87 **b**	103.07±7.51 **a**	33.81±1.79 **b**	66.71±36.77 **ab**
40-60	72.99±13.06 **b**	41.13±6.64 **c**	106.63±18.72 **a**	23.36±1.76 **c**	34.29±3.27 **c**
60-80	24.88±9.19 **b**	34.53±32.33 **b**	96.47±14.07 **a**	22.56±5.03 **b**	28.54±1.57 **b**
80-100	32.20±8.92 **b**	14.22±4.65 **c**	76.67±4.90 **a**	13.70±1.68 **c**	25.92±2.40 **bc**
100-150	11.86±0.88 **b**	12.19±5.49 **b**	39.60±4.03 **a**	17.62±1.94 **b**	12.85±4.15 **b**
150-200	6.29±0.00 **c**	11.74±3.85 **bc**	21.33±4.03 **a**	16.50±0.97 **ab**	11.28±3.14 **bc**

Note: Value are means± SD (n= 3). Means followed by different letters on the same row on the right indicate significant differences at *P*<0.05 among study sites.

4.15.5 Cation exchange capacity (CEC)

CEC in soil was decreased with soil depth. In the first 20 cm in depth, CEC from soil in natural site was significantly higher than other sites. Below 60 cm in depth, in 7-year-old site was higher than other sites. The amount of CEC in different soil depths (0 -200 cm) ranged from 1.90 – 24.23 cmol(+)/kg (Table 4.26).

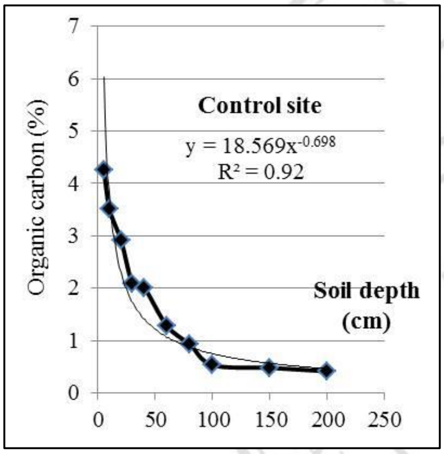
Table 4.26 Cation exchange capacity cmol(+)/kg in different sites

Site	CEC cmol(+)/kg				
	control	2-year-old	7-year-old	11-year-old	natural
0-5	17.03±0.44 **b**	16.45±0.69 **b**	17.83±0.35 **b**	18.11±0.83 **b**	24.23±0.73 **a**
5-10	14.27±0.24 **b**	14.25±0.25 **b**	15.65±0.35 **b**	11.99±0.52 **c**	18.77±0.95 **a**
10-20	10.88±2.68 **b**	11.93±0.26 **ab**	13.81±0.35 **ab**	10.51±0.64 **b**	14.50±0.70 **a**
20-30	9.78±0.18 **ab**	10.92±0.89 **a**	11.49±0.35 **a**	7.94±0.10 **b**	11.31±1.42 **a**
30-40	9.96±0.51 **ab**	7.66±1.46 **bc**	10.48±0.93 **a**	6.43±0.05 **c**	9.80±0.72 **ab**
40-60	8.03±0.40 **ab**	5.55±1.66 **bc**	9.98±0.87 **a**	5.37±0.38 **c**	7.25±0.44 **bc**
60-80	4.89±0.42 **b**	5.39±1.63 **b**	8.73±0.42 **a**	3.91±0.24 **b**	5.25±0.46 **b**
80-100	3.33±0.38 **b**	4.43±1.43 **b**	8.28±0.78 **a**	2.43±0.60 **b**	4.57±0.11 **b**
100-150	3.30±0.18 **b**	4.06±0.52 **b**	6.45±0.62 **a**	1.70±0.05 **c**	3.81±0.34 **b**
150-200	2.89±0.14 **b**	4.13±0.24 **a**	4.75±0.45 **a**	1.90±0.19 **c**	2.82±0.32 **b**

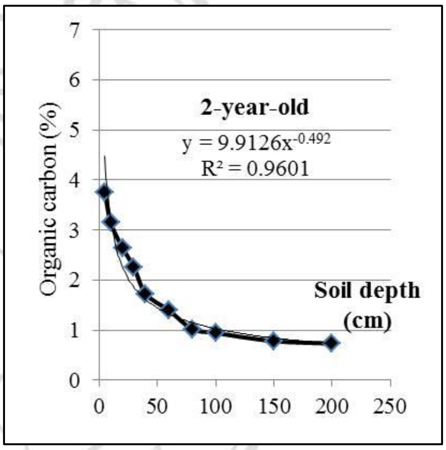
Note: Value are means± SD (n= 3). Means followed by different letters on the same row on the right indicate significant differences at *P*<0.05 among study sites.

4.15.6 Organic carbon (OC)

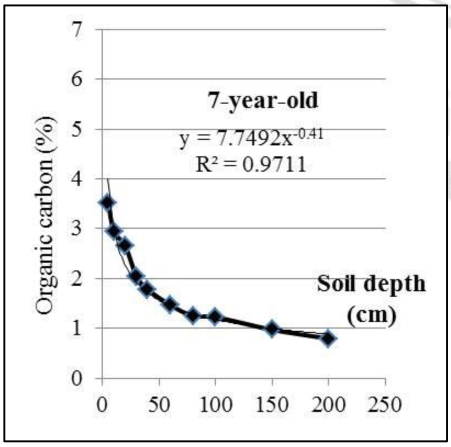
Organic carbon calculated from organic matter using 0.58. In the first 0-5 cm on top soil, natural and 11-year-old sites were higher than other sites significantly. In the top soil layer (0 – 40 cm) high amounts of organic carbon were found in the natural site, but below 40 cm in depth, high amount of carbon were found in 7-year-old site. The negative regression correlation between soil depth and organic carbon is shown in Figs 4.14 a- e.



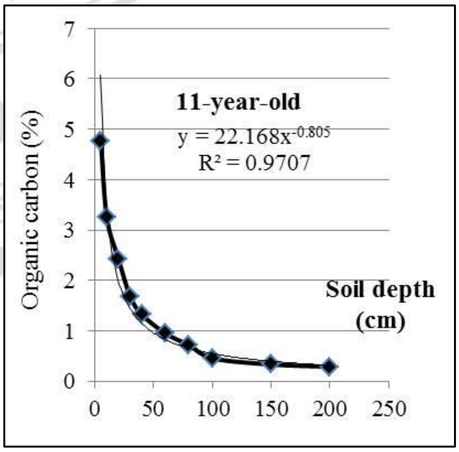
a.



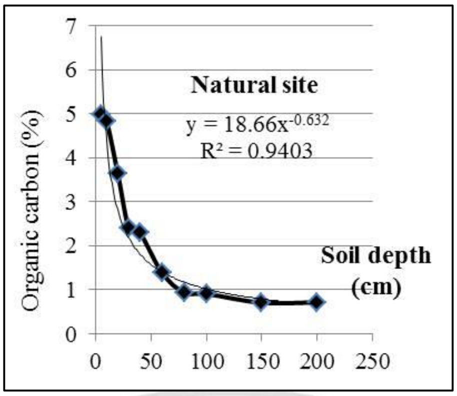
b.



c.



d.



e.

Figures 4.14 a-e. Organic carbon (%)

4.15.7 Soil organic carbon

Highest soil organic carbon in total 200 cm in depth was found in 2-year-old but it was not higher significantly than 7–year-old and natural site. Soil carbon stock in 200 cm of depth were 205.88, 254.40, 251.14, 161.82 and 244.96 tC/ha. Whereas, in 100 cm of depth were 156.10, 168.12, 160.16, 127.41 and 172.99 tC/ha., respectively (Table 4.27).

Table 4.27 Soil carbon stock in 0 – 100, 100 -200 and total 200 cm. in depth

Soil depth (cm)	Soil organic carbon (tC/ha)				
	control	2-year-old	7-year-old	11-year-old	natural
0 – 100	156.10 **c**	168.12 **ab**	160.16 **bc**	127.41**d**	172.99 **a**
100 -200	49.78 **c**	86.28 **a**	90.98 **a**	34.41**d**	71.97 **b**
0 – 200	205.88 **b**	254.40 **a**	251.14 **a**	161.82 **c**	244.96 **a**

Note: Value are means± SD (n= 3). Means followed by different letters on the same row on the right indicate significant differences at *P*<0.05 among study sites.

4.16 Model

Simulated soil carbon mass using fullCAM started from 2010 to 2020. Simulated soil carbon in control (non-planted site), restored forest site and natural forest site were increasing yearly. The high rate of carbon mass was found in natural forest next to 7, 11 year-old site and control site. The difference of C mass was quite high in the several years after starting simulation, after that it was gradually increased and then constant (Table 4.28 and Figs.4.15).

Table 4.28 Simulated C mass of soil (tC/ha) from 2010 – 2020

Year	control		7-year-old		11-year-old		natural	
	C	df	C	df	C	df	C	df
2010	0.90		1.72		1.93		3.13	
2011	1.57	0.67	3.08	1.36	2.47	0.54	5.10	1.97
2012	1.86	0.29	3.61	0.53	2.72	0.25	6.05	0.95
2013	2.07	0.21	4.01	0.4	2.98	0.26	6.75	0.7
2014	2.24	0.17	4.33	0.32	3.22	0.24	7.30	0.55
2015	2.38	0.14	4.59	0.26	3.45	0.23	7.76	0.46
2016	2.5	0.12	4.83	0.24	3.67	0.22	8.18	0.42
2017	2.62	0.12	5.04	0.21	3.88	0.21	8.56	0.38
2018	2.72	0.1	5.24	0.2	4.09	0.21	8.91	0.35
2019	2.82	0.1	5.43	0.19	4.30	0.21	9.25	0.34
2020	2.92	0.1	5.62	0.19	4.49	0.19	9.57	0.32
Min.	0.06		0.14		0.16		0.23	
Max.	2.92		5.62		4.49		9.57	

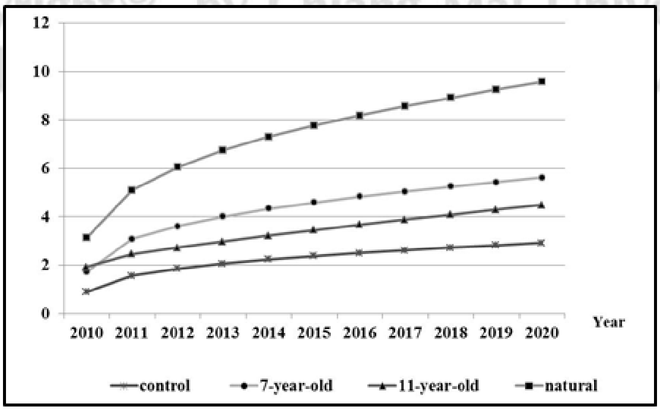


Figure 4.15 Simulated soil carbon mass (tC/ha) in all study sites