

CHAPTER 4

RESULTS

4.1 Meteorology data

4.1.1 Soil temperature

The mean soil temperature at 0.05 m depth was similar year to year (Figure 4.1). The mean soil temperatures from 2008-2011 were 26.30, 26.19, 26.82, and 25.13 °C, respectively. The soil temperature increased at the end of the dry season (February - April) and decreased at the beginning of the dry season or winter season (November - December). The mean soil temperature ranged during a year from 18.98 to 37.10 °C. The annual average of soil temperature at the study site on wet season and dry season for 4 years were 27.38 and 29.62 °C, respectively. In addition, the soil temperature was not significant change between trenching and non-trenching plots at p -value ≤ 0.05 . The mean soil temperature on trenching and non-trenching from 2010 – 2011 were 26.50 and 26.65 °C (Figure 4.1).

Figure 4.2 shows the temperature throughout the soil profile at 2.5 m, measured during July 2011-August 2012. Generally, high temporal variations were found for the upper layers where it tended to be hotter during dry season and cooler during the period between the end of wet and beginning of dry seasons.

The daily patterns of soil temperature in five soil layers were shown in figure 4.3. Normally, the diurnal patterns of soil temperature could be expressed as one-humped curves at all of the layers (Figure 4.3). There gradually increased from midday to evening (10.00 a.m. – 5.00 p.m.) and gradually decreased throughout the night. The measured means soil temperature change in during a day was highest variable at 0.05 – 0.25 m soil depth (27.00 to 35.20 °C) The means soil temperature change at 75, 150, and 250 cm soil depths were 27.59-29.88, 27.43-28.39, and 28.26-27.18 °C, respectively.

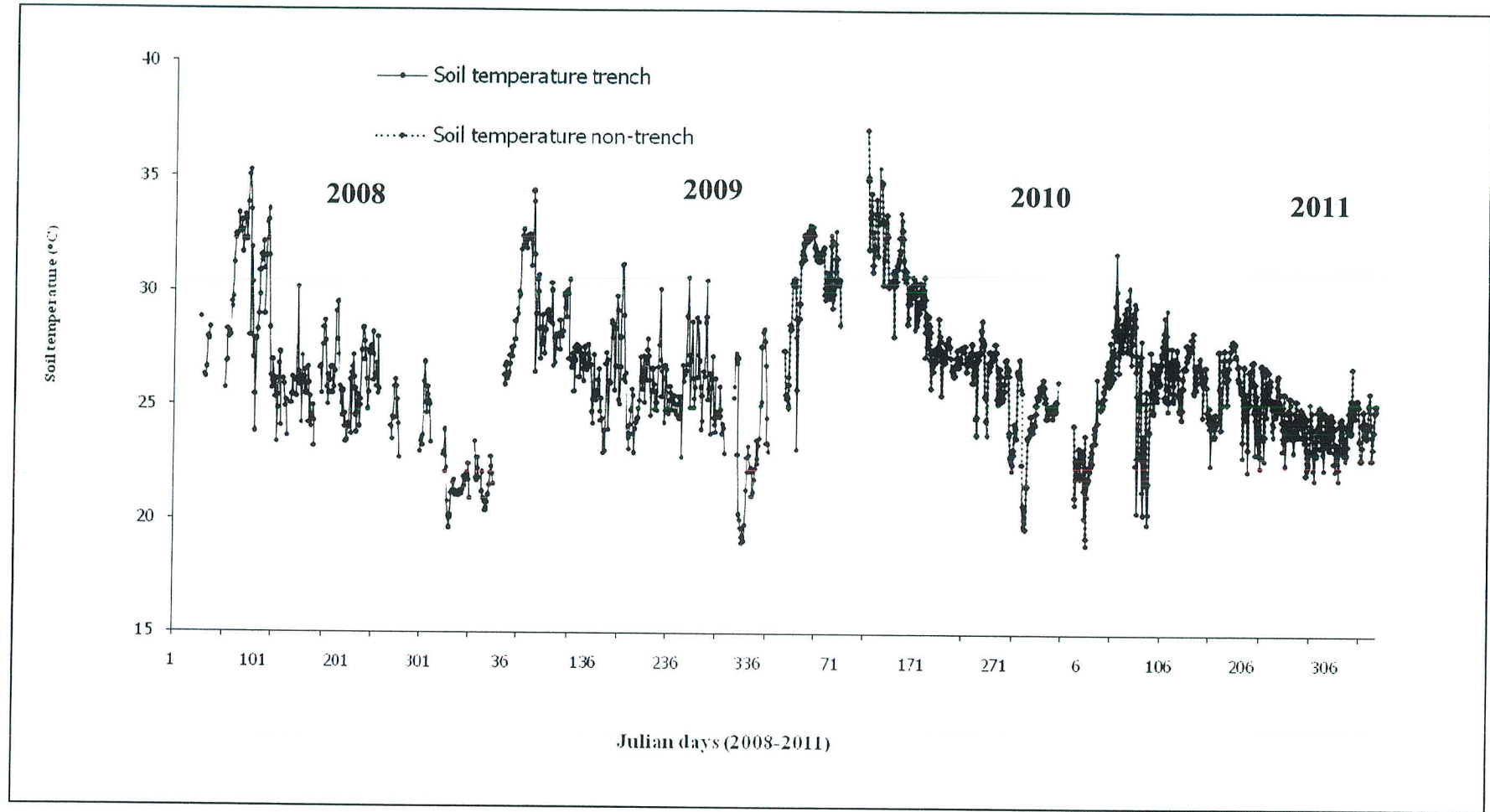


Figure 4.1 Variation of soil temperature on trenching and non-trenching plots at 0.05 m soil depth during 2008 – 2011.

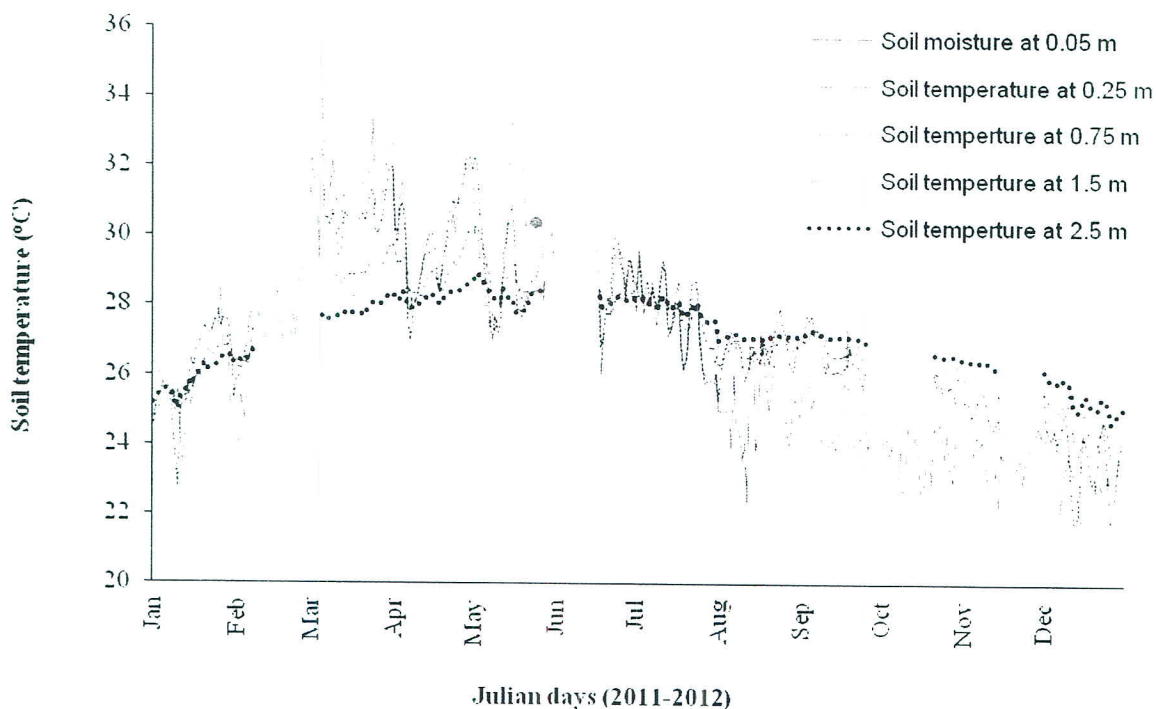


Figure 4.2 Long-term time series of measured soil temperature in soil profiles in dry dipterocarp forest during August 2011 – July 2012.

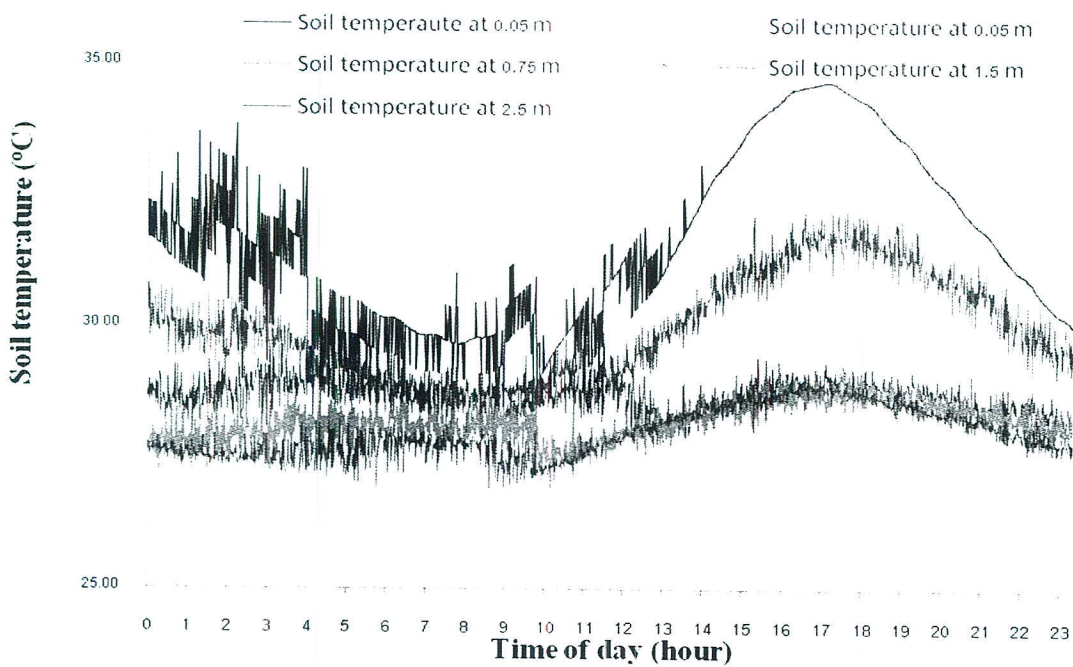


Figure 4.3 Mean diurnal patterns of soil temperature at five depths of 0.05, 0.25, 0.75, 1.5, and 2.5 m during 14 – 20 March 2012.

4.1.2 Soil moisture

Soil moisture gradually increased at the beginning of the wet season (April - October) and decreased during the dry season or winter season (November - March). The annual averages of soil moisture during 2008 – 2011 were 13.10, 14.87, 13.67, and 14.21% water filled pore space (%WFPS), respectively (Figure 4.4). The annual average soil moisture at the study site during the wet seasons and the dry seasons for 4 years were 10.47 and, 4.14 %WFPS, respectively. However, during year 2009-2010 was occurred long dry periods around 7 months (November - May). It had an impact on soil moisture and soil temperature pattern. For example, the average soil moisture value for 2010 was lower and higher of soil temperature than other years. Hence, the number of higher soil moisture days at higher than the mean value in the wet season was lower than other years. The numbers of higher soil moisture days (≥ 10 %WFPS) during 2008-2011 were 178, 215, 203, 221 days of a year, respectively. This was due to variations in the rainfall days in each year. Comparing between trenched and untrenched plots, the soil moisture was not significant different (p -value ≤ 0.05).

The seasonal variations of soil moisture in five soil layers during July 2011-August 2012 are shown in Figure 4.5. The highest peak at 30 %WFPS was the soil moisture at 2.5 m soil depth during wet season, especially October while soil depth at 0.25 m was lowest value during dry season (November - February). However, the soil moisture at top soil (0.05-0.75 m) rapidly increased after the rain come at the beginning of wet season while the soil moisture at 1.5 and 2.5 m were relatively slow but later followed the change pattern of at 0.05 m. The means soil moisture at 0.05, 0.25, 0.75, 1.5, and 2.5 m were 11.73 ± 7.98 , 7.01 ± 4.61 , 6.46 ± 5.18 , 11.49 ± 3.70 , and 16.20 ± 6.13 , respectively.

The daily patterns of soil moisture in the four soil profiles are shown in Figure 4.6. Normally, no significant changes in soil moisture at all depth at the diurnal time scale. Soil moisture increased along the soil profile depths.

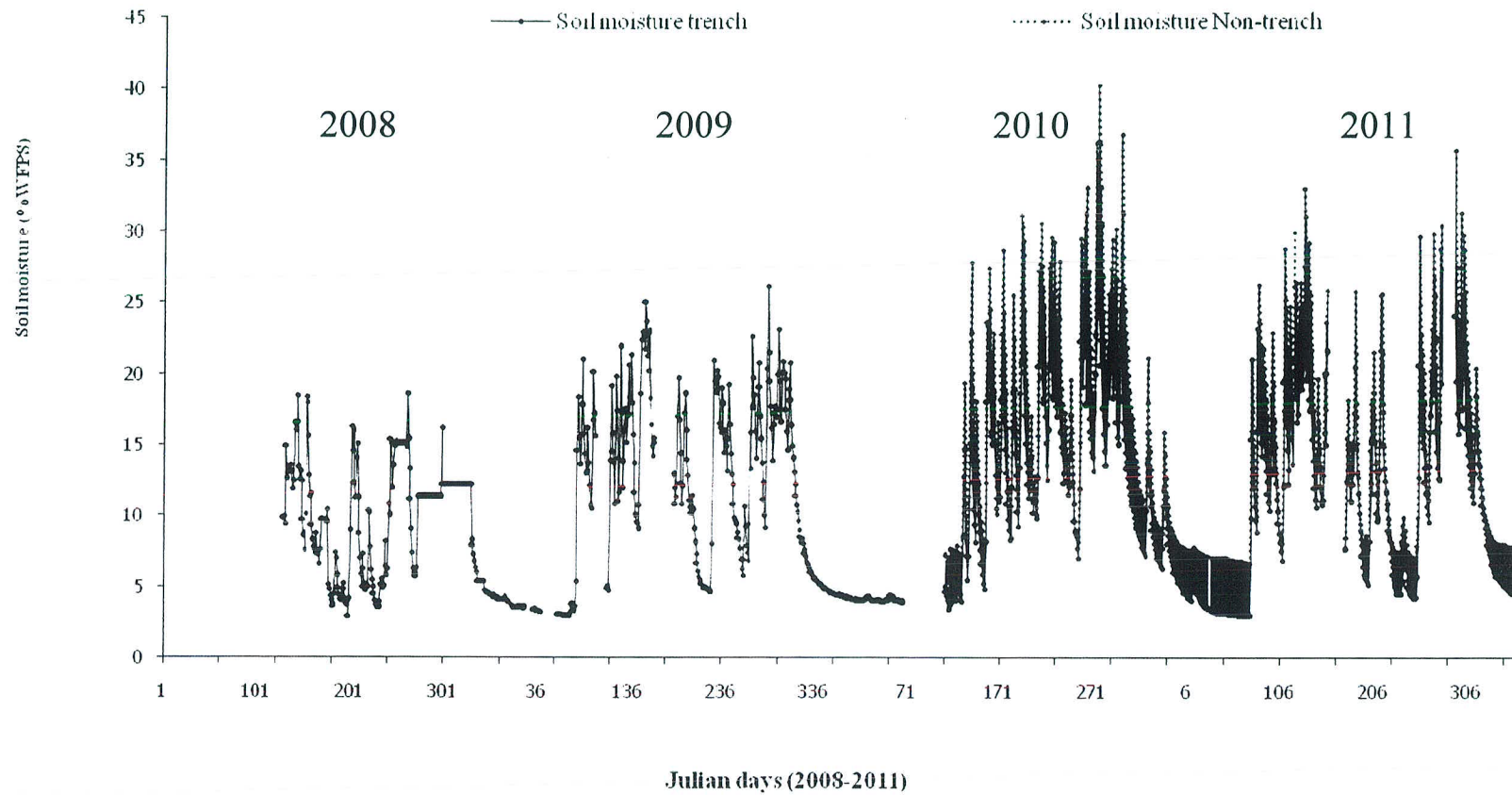


Figure 4.4 Seasonal variation of soil moisture in trenching and non-trenching at 0.05 m soil depth.

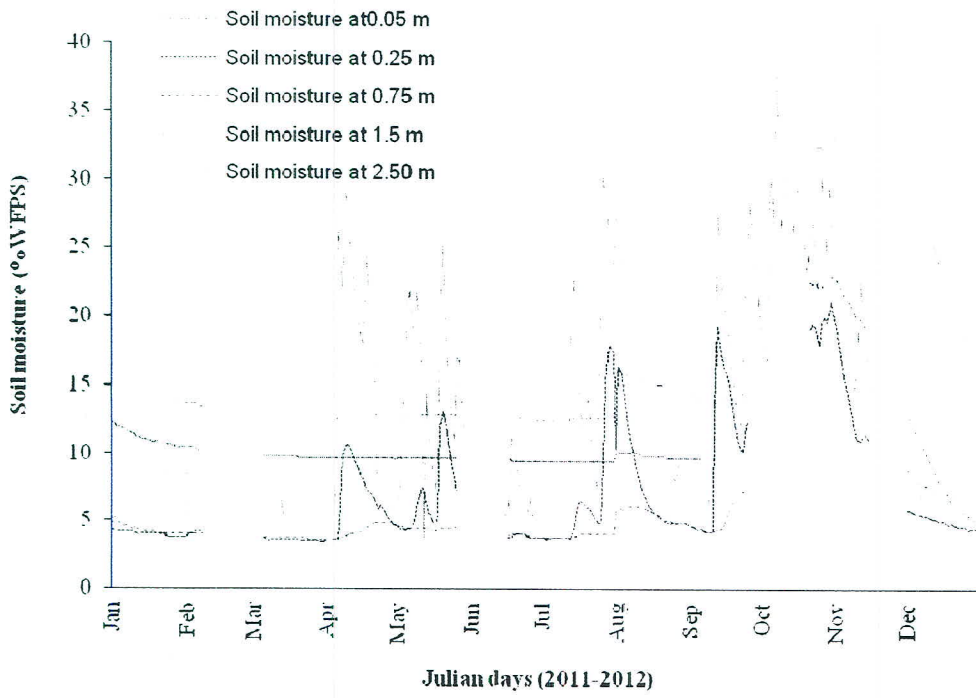


Figure 4.5 Long-term time series of measured soil moisture in five soil layers in dry dipterocarp forest during August 2011 – July 2012.

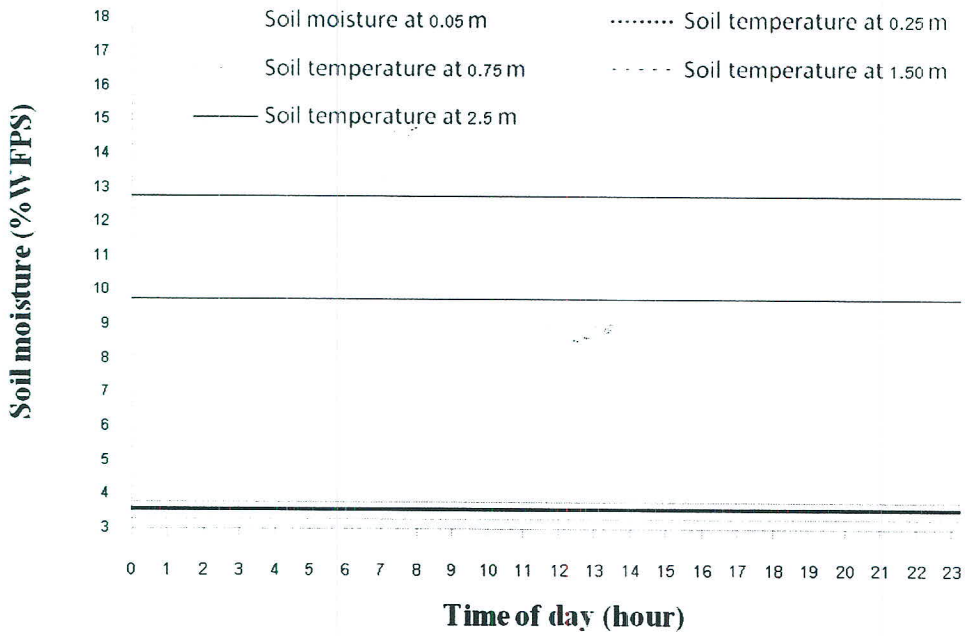


Figure 4.6 Mean diurnal patterns of soil temperature at five depths of 0.05, 0.25, 0.75, 1.5, and 2.5 cm during 14 – 20 March 2012.

4.1.3 Precipitation

The seasonal variation of the soil moisture at a depth of 0.05 m was a response to the rainfall pattern during the year (Figure 4.7). Normally, the rainfall pattern at the site consisted of heavy rain in beginning and/or ending of the wet season and a little rainfall in middle of the wet season. The precipitations during 2009-2011 were 1,164.20, 1,330.10, and 1,007.70 mm, respectively. However, the rainfall quantity in 2011 was less than in other years, but the number of rainy days about 135 days was the highest. Hence, the numbers of higher soil moisture days for 2011 was higher than in other years (2008-2011 were 178, 215, 203, 221 days of a year, respectively). Thus, the number of higher soil moisture days was also according to the distribution of rainfall days in each year also.

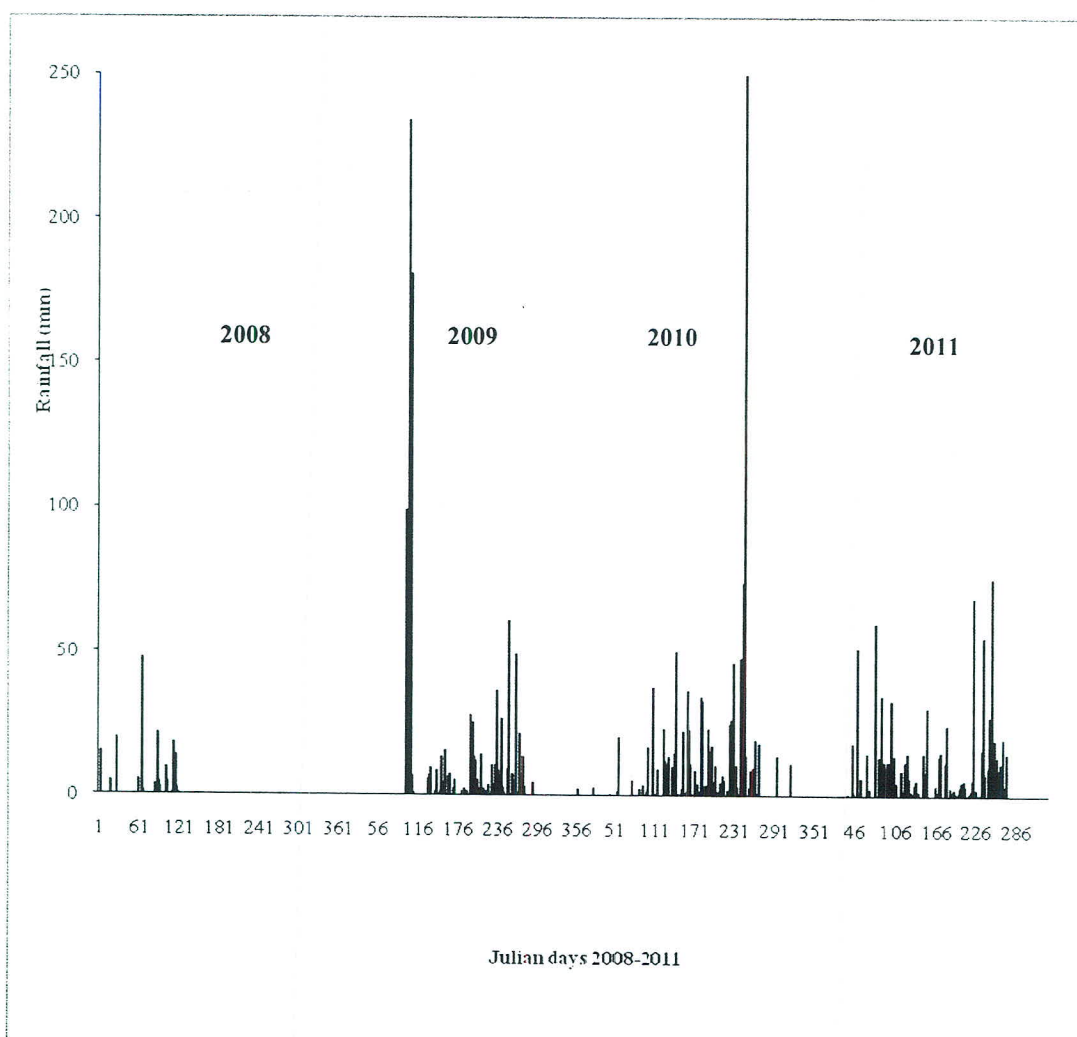


Figure 4.7 Seasonal variation of precipitation in dry dipterocarp forest

4.1.4 Soil property

Soil was sampled on 8 July, 2008, and analyzed for pH, bulk density, organic matter and organic carbon content (Table 4.1).

Table 4.1 General characteristics of soil samples in dry dipterocarp forest

Sampling depth (cm)	pH	Bulk density (g cm ⁻³)	% Organic matter	% Organic carbon	Texture	Present separate (%)		
						Sand	Silt	Clay
0-10	5.10	1.48	0.85	0.49	loamy sand	78.00	19.50	2.50
10-20	5.00	1.46	0.86	0.50	loamy sand	77.40	19.60	3.00
20-30	4.80	1.40	0.85	0.49	loamy sand	78.60	17.90	3.50
30-40	4.80	1.44	1.06	0.61	loamy sand	76.80	20.20	3.00
40-50	4.80	1.40	1.02	0.59	loamy sand	76.20	20.30	3.50
50-60	4.80	1.34	0.36	0.21	loamy sand	74.70	22.30	3.00
60-70	4.90	1.38	0.53	0.31	sandy loam	73.00	23.50	3.50
70-80	4.90	1.43	0.63	0.37	loamy sand	78.50	18.50	3.00
80-90	4.90	1.37	0.69	0.40	loamy sand	77.80	18.20	4.00
90-100	4.90	1.42	0.54	0.31	sandy loam	66.90	28.60	4.50

Soil pH at the site was acidic, being highest in the surface layer and decreasing with increasing depth. However, the pH difference within the 100 cm depth was quite small. This may indicate the limited influence of an immature forest canopy on soil when compared to a mature forest. For example, in the old-growth forests in Thailand, pH at the top layer is usually significantly higher than at the layers beneath, because of the active supply of litter fall and the existence of a litter layer at the surface (Ogawa, *et al.*, 1961).

Janmahasatien, *et al.* (2005) studied the soil properties of the Maeklong mixed deciduous forest, Thailand. The pH value in the top layer was higher than in the subsoil as 5.76 (0-20 cm), second layer as 5.34 (20-45 cm), third layer as 5.26 (45-60 cm) and last layer as 5.33 (> 60 cm). On the other hand, dense roots and their activity usually cause forest soil acidity (Sanchez, 1976). It means that phosphorous, iron, and certain other nutrients have limited availability, and levels of calcium, magnesium, and potassium would normally be low (Milo, *et al.*, 2001). Similar to soil pH, soil bulk density of dry dipterocarp forest was constant with depth, which ranged from 1.3-1.4 g cm⁻³. The bulk density tended to decrease as the soil depth increased. Moreover, soil texture at the surface

of the study site was loamy sand, and soil texture was sandy loam at the depth of 90-100 cm.

Organic matter and organic carbon content are important soil characteristics such that, if high enough, they can increase the availability of nutrients. The organic matter and organic carbon trends at the study site decreased when the soil depth increased, ranging from 0.36 - 1.06 % and 0.21 - 0.61 %, respectively. Compared to other forest ecosystem in Thailand, these are quite low; compared to the Sakaerat dry evergreen forest (SDEF) and Maeklong mixed deciduous forest (MMDF), which contain OM and OC in their top layers of about 4.48% and 2.60%, and 5.05% and 2.93%, respectively (Janmahasatien, *et al.*, 2005). MMDF and SDEF are native and mature tropical forests, and thus are expected to contain a higher amount of soil carbon. On the other hand, the dry dipterocarp forest in this study could be considered a degraded forest, where only young trees are growing. Burning was also a common phenomenon in the past. These may be the reasons why soil carbon in this forest is quite low compared to others.

4.2 Vegetation data

4.2.1 Plant growth rate

The equations 3.9-3.11 were applied to evaluate the biomass in this forest. The measurement of diameter (D) and height (H) of 26 trees were carried out for every 3 months during May 2009 to February 2012 by using diameter tape. The growth rates of the trees in this forest were 0.62 m year⁻¹ for height and 0.51 cm year⁻¹ for trunk diameter. The means height and diameter at the beginning of measurement in 2009 were 4.81±0.73 m and 5.44±1.11 cm, and at the end in 2012 was 6.56±0.95 m and 6.93±1.28 cm, respectively (Table 4.2). Generally, the rate in the wet season (May-November) was higher than in the dry season (November-May) approximately 60%. The monthly means rate of height and diameter increases were 7.45 x 10⁻² m month⁻¹ and 7.72 x 10⁻² cm month⁻¹ during the wet season, and 3.0x10⁻² m month⁻¹ and 1.08 x 10⁻² cm month⁻¹ during the dry season.

Table 4.2 Mean diameter and height of trees growth in dry dipterocarp forest during February 2009 to February 2012.

Year		February		May		August		November	
		mean	sd	mean	sd	mean	sd	mean	sd
2009	High (m)			4.81	± 0.73	5.05	±	5.27	± 0.73
	Diameter (cm)			5.44	± 1.11	5.76	0.74	6.01	± 1.08
2010	High (m)	5.33	± 0.80	5.42	± 0.69	5.72	±	5.90	± 0.89
	Diameter (cm)	6.05	± 1.09	6.08	± 1.10	6.18	0.83	6.59	± 1.17
2011	High (m)	5.97	± 0.89	6.03	± 0.88	6.35	±	6.43	± 0.87
	Diameter (cm)	6.60	± 1.15	6.59	± 1.17	6.80	0.86	6.90	± 1.24
2012	High (m)	6.56	± 0.95				±		
	Diameter (cm)	6.93	± 1.28				1.13		

The aboveground and belowground biomass were then calculated (kg dry mass of tree per three month) by the allometric equations (Figure 3.12). The biomass stock of stems and branches (W_{S+B}), leaves (W_L), and roots (W_R) at the beginning and the ending dates were 9.26 ± 4.43 , 4.65 ± 1.23 , 24.49 ± 7.49 kg biomass tree⁻¹, and 19.84 ± 9.35 , 7.06 ± 1.78 , 39.72 ± 11.64 kg biomass tree⁻¹, respectively (Table 4.3). Biomass W_L , W_{S+B} , and W_R increase rates were 0.85, 3.77, and 5.37 kg biomass tree⁻¹ yr⁻¹, respectively. The annually average of W_L , W_{S+B} , and W_R during the wet season were 0.11, 0.50, 0.72, and in the dry season were 0.02, 0.13, 0.17 kg biomass tree⁻¹ month⁻¹, respectively. Thus, biomass stock during the wet season was higher than in the dry season, approximately 74-77%. Moreover, the total biomass stocks from May, 2009 to February 2012 were gradually increased from 38.37 ± 4.36 to 66.62 ± 6.71 kg tree⁻¹ or 165.37 ± 18.79 to 287.13 ± 28.92 ton dry matter ha⁻¹ (density of plant at DDF was $1,724 \pm 167$ tree ha⁻¹). The annually means biomass increasing rate resulting from plant growth in the DDF was 16.2 ± 0.29 ton dry matter ha⁻¹ yr⁻¹. In terms of carbon using the IPCC default factor of 0.5 (50% of dry weight biomass) (Kurz *et al.*, 1992), the total carbon stock at in February, 2012 were 8.12 ± 0.15 ton C ha⁻¹ yr⁻¹.

Table 4.3 Measurement results of biomass stock in W_{s+b} , W_L , and W_R (kg/tree) during May, 2009 to February, 2012. (mean \pm S.D, 26 samples).

Year	Month	W_{s+b} (kg/tree)		W_L (kg/tree)		W_R (kg/tree)		Total (kg/tree)	
		mean	sd	mean	sd	mean	sd	mean	sd
2009	May	9.26	± 7.49	4.65	± 1.23	24.46	± 4.43	38.37	± 4.36
	August	10.77	± 7.81	5.06	± 1.26	27.01	± 4.95	42.84	± 4.54
	November	12.11	± 7.96	5.41	± 1.28	29.15	± 5.21	46.67	± 4.62
2010	February	12.42	± 8.35	5.48	± 1.33	29.60	± 5.55	47.5	± 4.84
	May	12.68	± 8.15	5.55	± 1.30	30.04	± 5.49	48.27	± 4.73
	August	13.79	± 8.75	5.81	± 1.38	31.65	± 6.10	51.25	± 5.07
2011	November	16.16	± 9.79	6.32	± 1.52	34.95	± 7.25	57.43	± 5.66
	February	16.28	± 9.49	6.36	± 1.48	35.17	± 7.00	57.81	± 5.49
	May	16.51	± 9.88	6.40	± 1.54	35.44	± 7.32	58.35	± 5.71
2011	August	18.38	± 10.57	6.78	± 1.63	37.93	± 8.16	63.09	± 6.10
	November	19.14	± 10.86	6.93	± 1.67	38.90	± 8.54	64.97	± 6.27
2012	February	19.84	± 11.64	7.06	± 1.78	39.72	± 9.35	66.62	± 6.71

4.2.2 Root biomass and fine root activity

Root biomass from soil core sample

The average root biomass with diameter less than 10 mm from 0-60 cm soil depth during September, 2010 – August, 2011 were 518 ± 55 , 786 ± 121 , 415 ± 102 , 551 ± 93 , 388 ± 26 , 492 ± 156 , 531 ± 82 , 459 ± 160 , 390 ± 40 , 409 ± 55 , 419 ± 120 , and 496 ± 89 kg m⁻², respectively (Figure 4.8). The mean root biomass in dry dipterocarp forest was 488 ± 91 kg m⁻² or 4.88 ton ha⁻¹, while the means in wet season was 503 ± 148 kg m⁻² and 473 ± 64 kg m⁻² in the dry season. The mean root biomass did not differ significantly between the wet and the dry season ($p < 0.05$). Moreover, total root mass of different soil layers did not differ between the first soil layer 0-20 and 20-40 cm but significantly higher in layer 40-60 cm ($p < 0.05$). The means root biomass in 0-20, 20-40, and 40-60 cm were 1.88 ± 0.28 , 1.91 ± 0.74 , and 1.29 ± 0.76 ton ha⁻¹ during the wet season and 1.83 ± 0.65 , 1.66 ± 0.21 , and 1.19 ± 0.36 ton ha⁻¹ during the dry season, respectively.

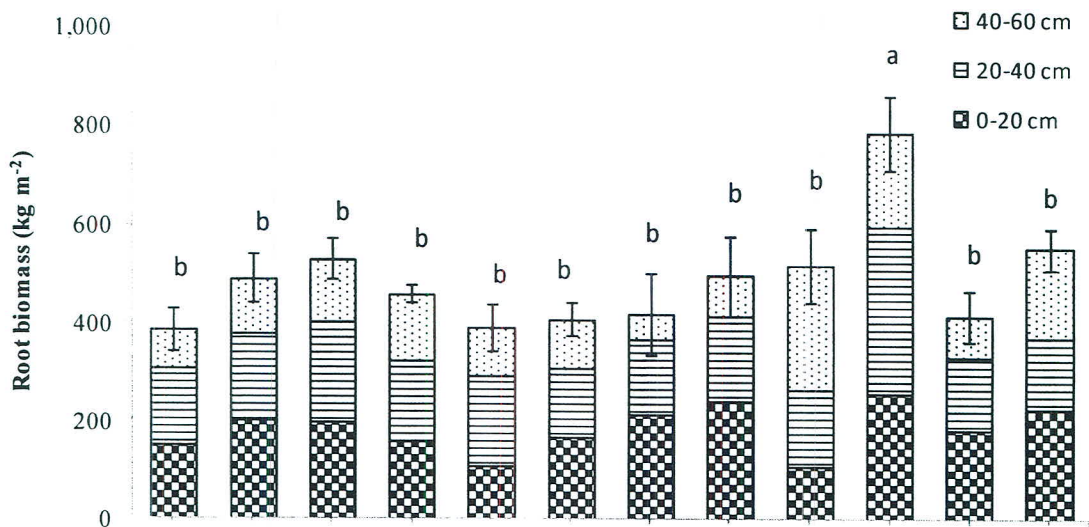


Figure 4.8 Root biomass for three different soil layers during September 2010–August 2011. The bar refers to standard deviations ($N=3$).

Fine root growth and senescence from root window

Most of the fine roots that grew along the root windows during one - year observation period (January – December 2011) were fine roots less than 2 mm in diameter, most likely tertiary and quaternary axes. The total lengths of fine roots growth and branching in different soil depths at 0.15, 0.75, 1.5, and 2.5 m during a year were 66.10 ± 2.31 , 46.55 ± 1.31 , 45.0 ± 1.98 , and 29.85 ± 1.85 m m⁻², respectively (Figure 4.13a). The total fine root growth of soil profiles did not significantly differ between the second and third soil layers (0.75 and 1.5 m) but differed significantly in the first layer and the fourth layer ($p < 0.05$). Moreover, the root senescence (disappearance from the scanned photos) and was presumably decayed was observed in all of soil layers every month. The total root senescence and disappearance in four soil profiles were 38.36 ± 1.34 , 40.30 ± 0.81 , 32.09 ± 1.12 , and 26.68 ± 1.08 m m⁻², respectively (Figure 4.13a) The highest active layer of fine root growth at DDF was the top soil profile while the root senescence was quite similar in layers 1-3 (Figure 4.9-10).

The annual mean weight of fine root growth and branching along the 2.5-m soil profile in the dry dipterocarp forest was 15.62 ± 3.70 m m⁻², while the mean root length in wet season (May-October) was 18.45 ± 2.81 m m⁻² and in the dry season was 12.80 ± 1.77 m m⁻² (November-April). The mean root growth did differ significantly between the wet and the dry season ($p < 0.05$). Moreover, the annual mean of fine root senescence and

disappearance along the 3-m soil profile was $11.45 \pm 2.28 \text{ m m}^{-2}$, while the mean root length in the wet season was $12.46 \pm 1.87 \text{ m m}^{-2}$ and in the dry season was $10.98 \pm 2.76 \text{ m m}^{-2}$. The mean root senescence did not differ significantly between the wet and the dry season ($p < 0.05$).

The relationship between fine root lengths (m) and dry weights of fine root (g) were developed for further study. There was significant correlation between this two parameters ($p \leq 0.02$), (Figure 4.11) followed Equation 4.1:

$$Y = 0.7518X - 1.2845 \quad R^2 = 0.86; \quad (\text{Eq. 4.1})$$

Where: Y = Dry weight of fine root (g)

X = Fine root lengths (m)

Equation 4.1 was applied to evaluate the fine root biomass for each soil layer. The mean weight find root growth and senescence along the 2.5-m soil profile in dry dipterocarp forest were 10.46 ± 2.78 and $7.33 \pm 1.90 \text{ g m}^{-2} \text{ month}^{-1}$, respectively (Figure 4.12). The highest root growth in monthly variation occurred during beginning of wet season on April about $16.22 \pm 7.61 \text{ g m}^{-2}$, while the lowest root growth shown on March about $5.77 \pm 0.84 \text{ g m}^{-2}$. Moreover, the highest carbon release from root senescence occurred on February about $7.04 \pm 1.49 \text{ g m}^{-2}$, while the lowest shown on November about $4.93 \pm 1.0 \text{ g m}^{-2}$. Moreover, during the seasonal variation of root growth did differ significantly variations between wet season ($12.09 \pm 2.70 \text{ g m}^{-2}$) and dry season ($8.18 \pm 0.64 \text{ g m}^{-2}$) (p -value 0.05), while did not differ significantly variation of root senescence between wet season ($7.62 \pm 2.31 \text{ g m}^{-2}$) and dry season ($7.04 \pm 1.49 \text{ g m}^{-2}$).

The accumulated fine root dry biomass along the 2.5-m deep soil profile in DDF was $1.36 \pm 0.07 \text{ ton dry matter ha}^{-1}$ and $0.98 \pm 0.04 \text{ ton dry matter ha}^{-1}$ of fine root senescence (Figure 4.13 b). Assuming the organic carbon content of approximately 47% (Wauters *et al.*, 2008), the amount of carbon stored in fine root biomass was $0.72 \text{ ton C ha}^{-1} \text{ yr}^{-1}$ or in terms of CO_2 equivalent this was about $2.64 \text{ ton CO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$, while CO_2 emission by fine root decomposition (assumed that all carbon resulting from the disappearance of find root is converted to CO_2) was $0.52 \text{ tonC ha}^{-1} \text{ yr}^{-1}$ or $1.91 \text{ tonCO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$. Thus, carbon remained in fine root biomass in DDF was about $0.73 \text{ tonCO}_2 \text{ ha}^{-1} \text{ yr}^{-1}$ or 28% of total carbon stock in the fine root biomass of the dry dipterocarp forest.

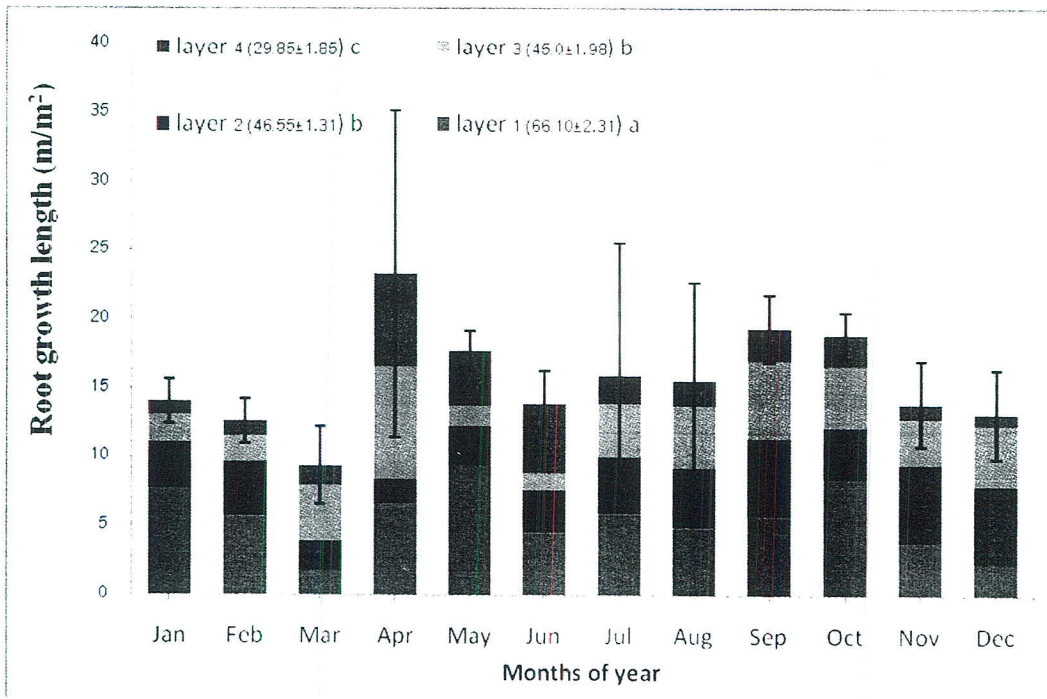


Figure 4.9 Seasonal variation of fine root growth of different soil layers during January – December 2011. The bar refers to standard deviations ($N=2$).

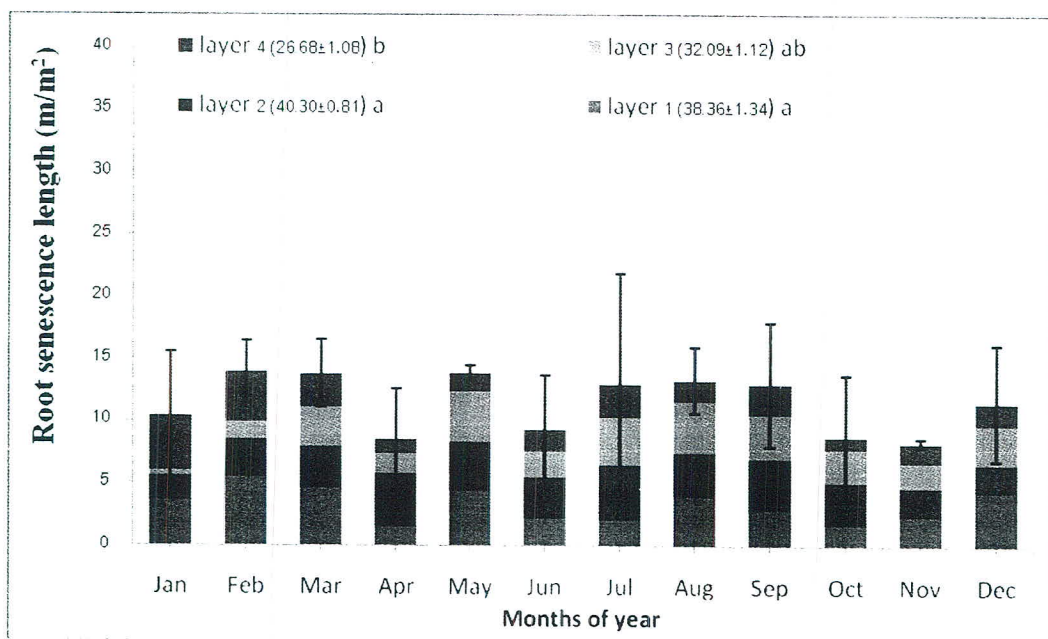


Figure 4.10 Seasonal variation of fine root senescence of different soil layers during January – December 2011. The bar refers to standard deviations ($N=2$).

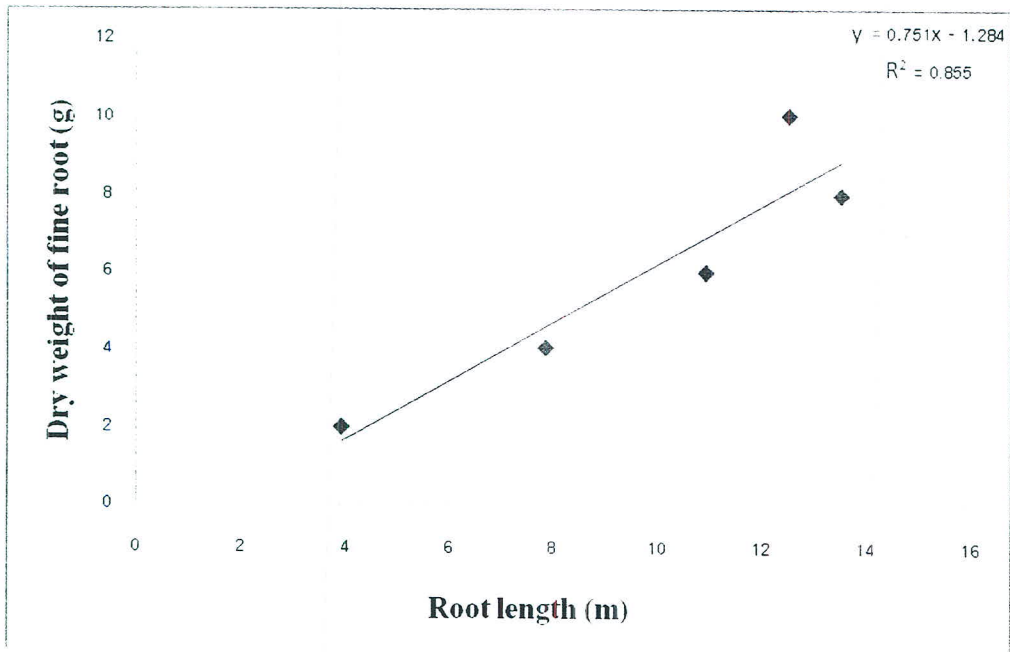


Figure 4.11 Relationship between fine root length and weight

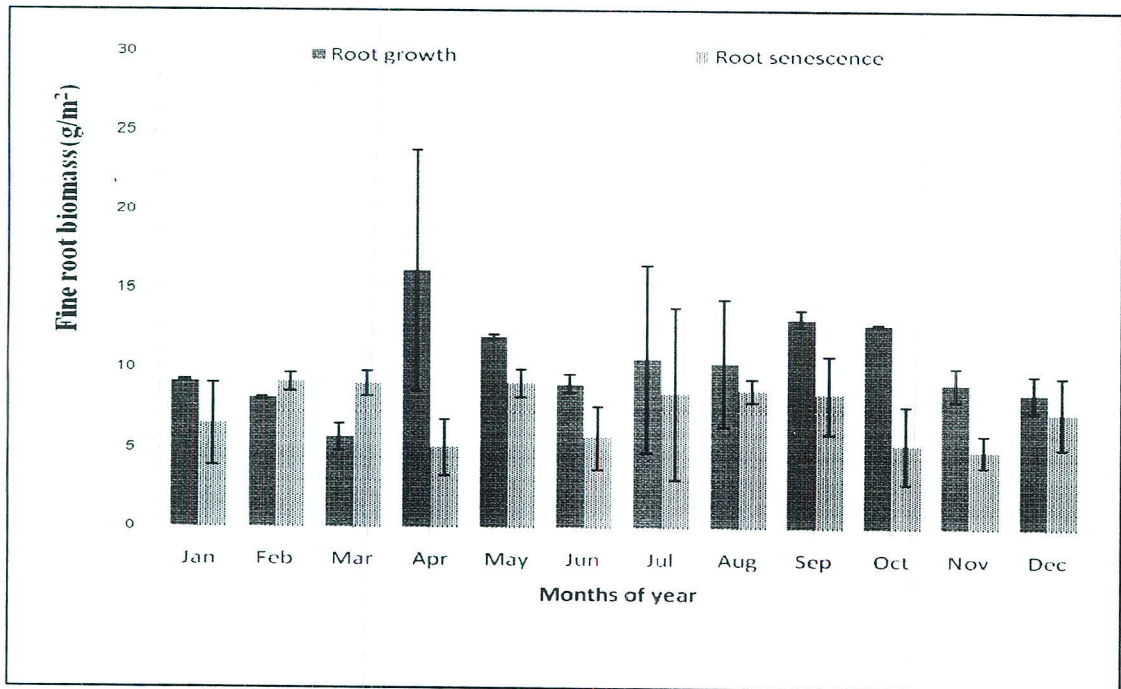


Figure 4.12 Monthly changes in root biomass growth and senescence from January to December. The bar refers to standard deviations ($N=2$)

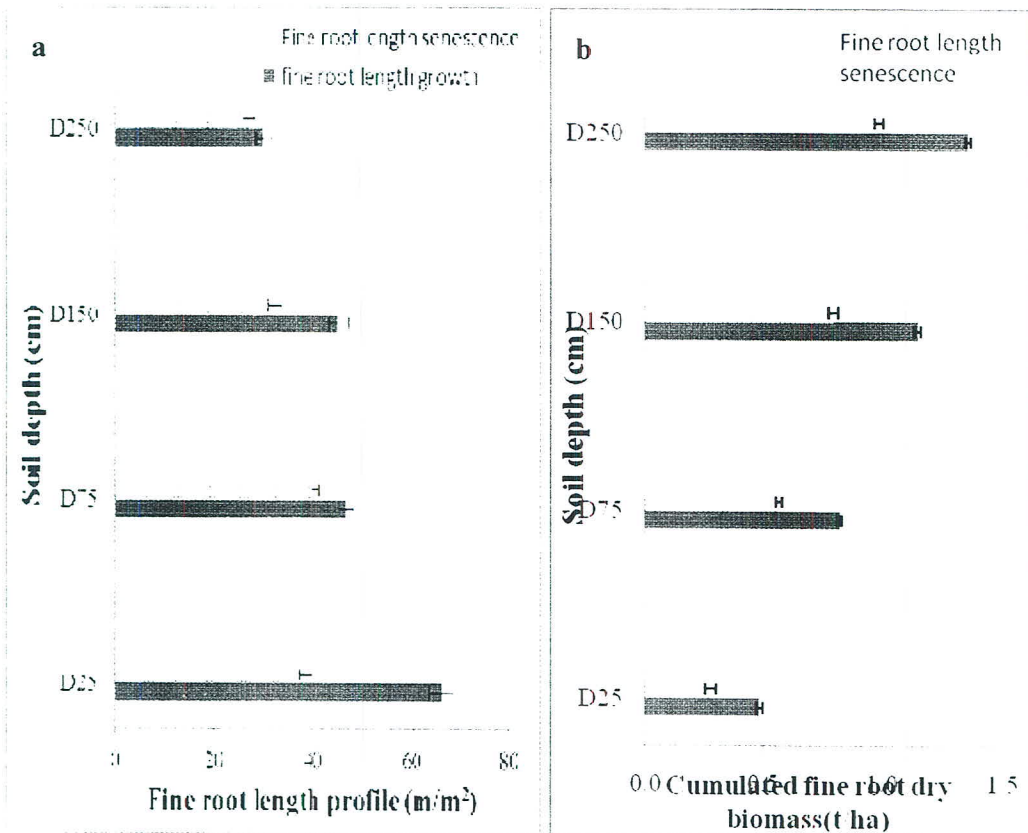


Figure 4.13 (a) Rate of fine root growth and senescence, and (b) the amount of fine roots throughout the soil profile. The bar refers to standard deviations ($N=2$)

4.2.3 Litter production

Seasonal variation of litterfall production at the dry dipterocarp forest is shown in Figure 4.14. Litterfall occurred throughout the year but the maximum rate of leaf shedding occurred in the cool and dry period (November - April), about 76% of total litterfall occurred during these periods. The litterfall production during June – May from 2009-2012 were 668.79 ± 79.85 , 645.22 ± 64.50 , $807.14 \pm 62.79 \text{ g m}^{-2} \text{ yr}^{-1}$, respectively. Annual minimum and maximum of litterfall during June 2009 to May 2012 at the forest varied from 11.42 ± 0.55 to $298.56 \pm 6.46 \text{ g m}^{-2} \text{ month}^{-1}$. The mean maximum and minimum litter fall occurred in January around $156.13 \text{ g m}^{-2} \text{ month}^{-1}$ or 26% of total litter and $27.23 \text{ g m}^{-2} \text{ month}^{-1}$ or 3% of total litterfall on October. In addition, the mean annual litterfall at this forest was $7,070.51 \pm 67.73 \text{ g m}^{-2} \text{ yr}^{-1}$ or $7.07 \text{ ton dry matter ha}^{-1} \text{ year}^{-1}$.

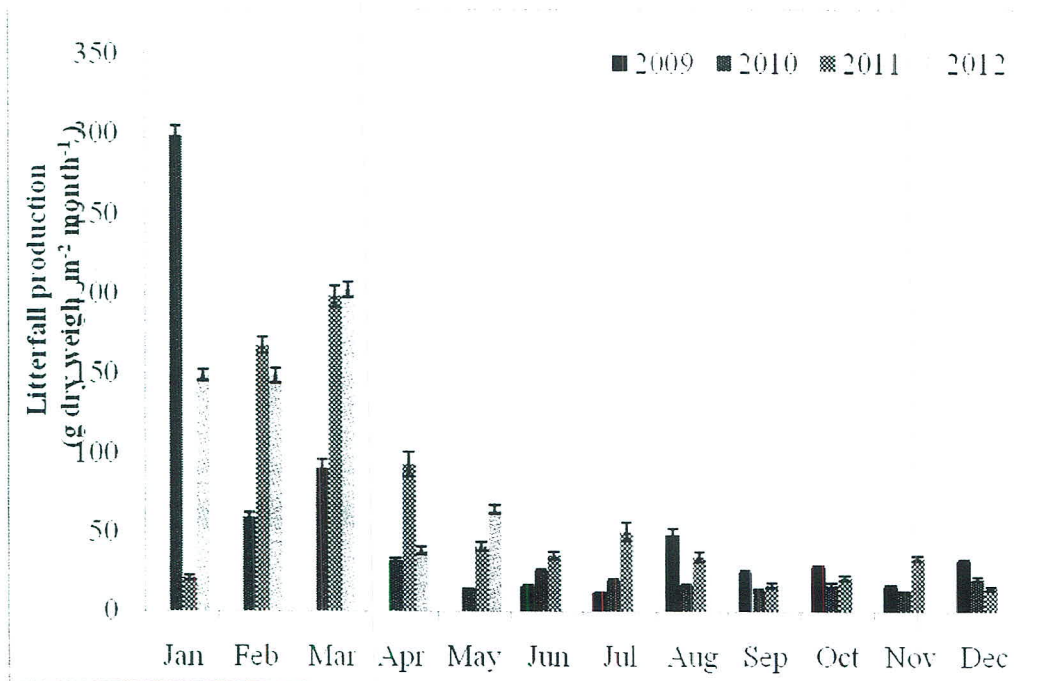


Figure 4.14 Monthly litterfall measured in DDF during June 2009-May 2012.

The litterfall was comprised of different fractions, which can be separated into 87% or 6.12 ± 0.87 ton dry matter ha^{-1} year⁻¹ of leaf, 11% or 0.79 ± 0.11 ton dry matter ha^{-1} year⁻¹ of branch, and 0.16 ton dry matter ha^{-1} year⁻¹ of others or 2%, including flowers and fruits (Figure 4.15).

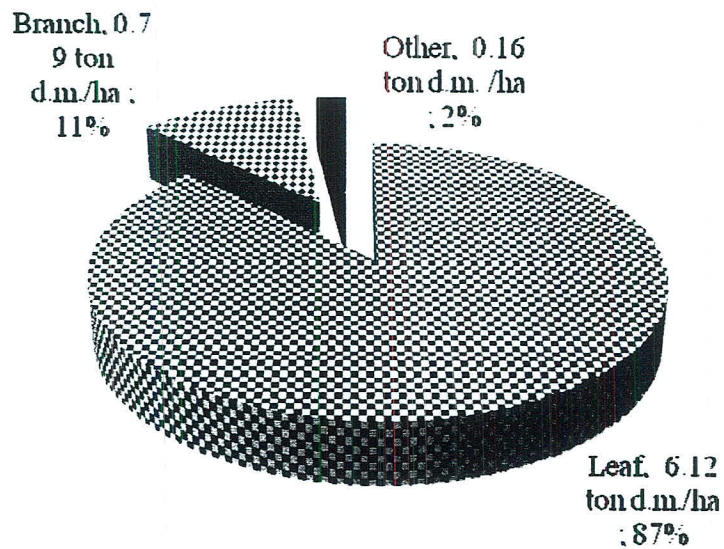


Figure 4.15 Litterfall components in DDF from June, 2009 to May, 2012

4.2.4 Litter decomposition

Mass losses of leaves and branches were significantly positively correlated ($r^2 > 0.93$, p -value < 0.05) with the time elapsed in months (Figure 4.16-4.17). The decomposition rate of leaf litter on ground floor in the dry dipterocarp forest was increased in the order: *Dipterocarpus tuberculatns* (DT) $<$ *Dipterocarpus obtusifolius* (DO) $<$ *Barringtonia acutangula* (BA) $<$ *Afzelia xylocarpa* (AX) while *D. tuberculatns* was fastest decomposed at 10 cm soil depth but *A. xylocarpa* was slowest decomposed. However, the branch litter decomposition rates at both layers were increased in the order: *A. xylocarpa* $<$ *D. tuberculatns* $<$ *B. acutangula* and *D. Obtusifolius*. The leaf and branch litter disappearance was 13-16% during the first month.

Rapid decline in leaf residual weights were noticed during the rainy months of July-October, nearly 55% in *B. acutangula* and *A. Xylocarpa*, 40% of *D. Obtusifolius* and 25% of *D. Tuberculatns* were lost. In addition branch residual weights losses were noticed during the rainy season, nearly 50% of *D. Obtusifolius*, 30% of *B. acutangula* and *D. Tuberculatns*, and 20% of *A. Xylocarpa*. The leaf litter was decomposed faster than branch litter for all plant species (Table 4.4). The relative mass loss of litter in the dry dipterocarp forest was observed during 13-month period, but some species were decomposed completely before a year. In addition, litter decomposition at 10 cm soil depth was faster than ground floor decomposition. The means decomposition rate constants (k -value) of leaf and branch in the forest were 0.26 and 0.14 at 0 cm and 0.86 and 0.25 at 10 cm soil depth, respectively.

Table 4.4 Decomposition rate constant (k) of four species of leaf and branch litter

<i>Scientific name</i>	k value of litter at 0 cm		k value of litter at 10 cm	
	(per month)		(per month)	
	<i>Leaf</i>	<i>Branch</i>	<i>Leaf</i>	<i>Branch</i>
<i>Afzelia xylocarpa</i> (AX)	0.36	0.10	0.75	0.17
<i>Dipterocarpus Obtusifolius</i> (DO)	0.29	0.17	0.80	0.28
<i>Barringtonia acutangula</i> (BA)	0.21	0.17	0.76	0.29
<i>Dipterocarpus tuberculatns</i> (DT)	0.17	0.13	0.86	0.25
<i>Average</i>	0.26	0.14	0.79	0.25

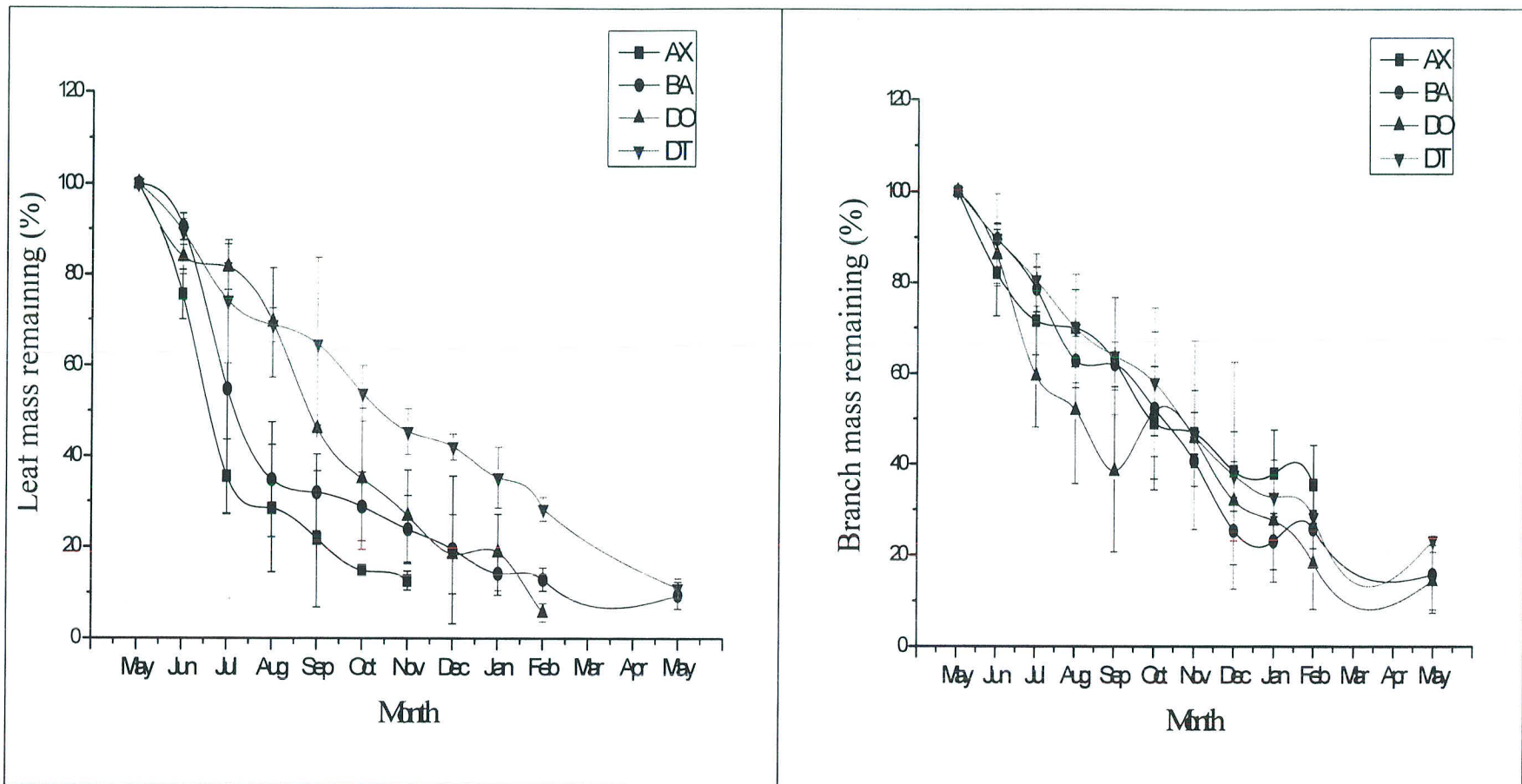


Figure 4.16 Monthly weight loss in dry dipterocarp biomass from litter bags placed on forest floor (0 cm).
The bar refers to standard deviations ($N=3$)

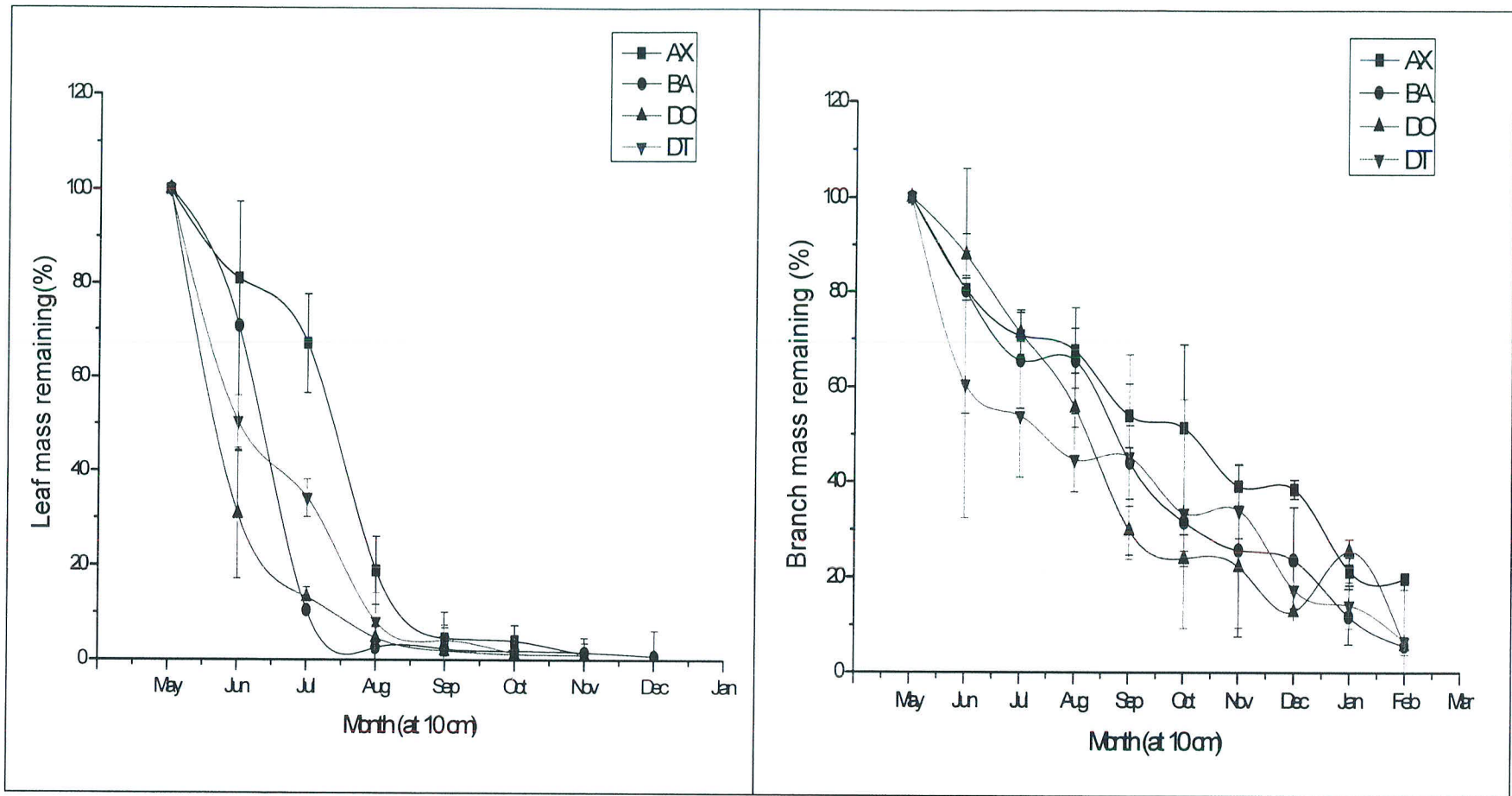


Figure 4.17 Monthly weight loss in dry dipterocarp biomass from litter bags placed on forest floor (10 cm).

The bar refers to standard deviations ($N=3$)

4.2.5 Microbial biomass

The amount of microbial biomass was quite varied for each month (Fig. 4.18). The average microbial biomass from 0 - 60 cm soil depth during September, 2010 – August, 2011 were 119.30 ± 46.95 , 758.70 ± 46.95 , 405.51 ± 107.91 , 22.60 ± 1.19 , 61.86 ± 57.81 , 15.02 ± 2.68 , 17.64 ± 7.61 , 266.56 ± 80.69 , 259.26 ± 29.45 , 273 ± 81.00 , 111.90 ± 34.06 , and 532.79 ± 191.44 g C_{mic} m⁻². The annual mean microbial biomass in dry dipterocarp forest was 237.03 ± 16.83 g C_{mic} m⁻², while the means in wet season was 331.67 ± 23.72 g C_{mic} m⁻² and in dry season was 104.52 ± 7.19 g C_{mic} m⁻². The mean microbial biomass differed significantly between wet season and dry season ($p < 0.05$). Microbial mass did not differ between layer 0-20 and 20-40 cm but significantly lower for the soil layer 40-60 cm ($p < 0.05$). The means microbial biomass in 0-20, 20-40, and 40-60 cm were 113.09 ± 82.08 , 123.39 ± 87.69 , and 106.05 ± 91.99 g C_{mic} m⁻² in wet season and 5.76 ± 4.02 , 10.44 ± 10.18 , and 13.07 ± 10.90 g C_{mic} m⁻² in dry season, respectively. In addition, the microbial biomass during October and August were highest among months while microbial biomass during December until March was the lowest of the year (Figure 4.18).

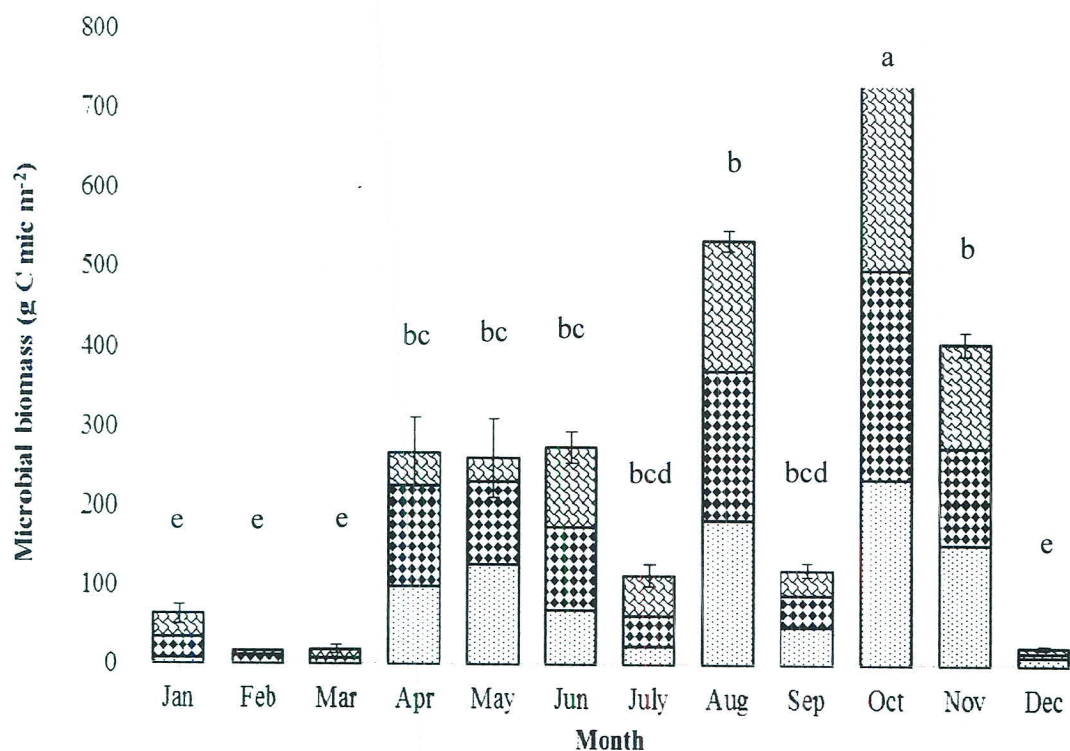


Figure 4.18 Microbial biomass for three different soil layers during September, 2010 – August, 2011. The bar refers to standard deviations ($N=3$). Different letters indicate significant differences in total microbial biomass among the months.

4.3 Temporal variations of soil respiration and its components

4.3.1 Diurnal variations of R_s , R_m , and R_b

Besides seasonal variations diurnal variations are also common characteristics of soil respiration. Diurnal variations of soil respiration, microbial respiration, and root respiration in this study were measured and compared between dry season (November – April) and wet season (May – October) during 2008 - 2011, as shown in Figure 4.19. Normally, the diurnal patterns of soil respiration could be expressed as one-humped curves all both seasons except R_b in dry season (Figure 4.19 e). All of the soil CO_2 flux during the wet season gradually increased from early morning to afternoon and gradually decreased throughout the night. However, the diurnal pattern of R_b in wet season gradually increased from early morning to afternoon and remained relatively stable throughout the night (Figure 4.19 f).

The highest CO_2 flux occurred in the afternoon. The measured average rates of R_s during the wet season were between 415.49 and 491.41 $\text{mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$. For R_m , these were 304.58 and 370.30 $\text{mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$, and for R_b were between 147.76 and 196.78 $\text{mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$. Daily CO_2 peaks during the wet season were found during 10:00 until 16:00 h. The diurnal patterns were corresponded to soil temperature rather than to soil moisture. However, the soil CO_2 flux during dry season was different from that of wet season: it increased from midday to afternoon and gradually decreased from afternoon to morning. The highest CO_2 flux occurred in the afternoon. The measured average of CO_2 flux during the dry season was 245.35 to 283.51, 118.69 to 155.16, and 113.15 to 133.54 $\text{mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$ for R_s , R_m , and R_b , respectively. Daily CO_2 peaks in dry season of all soil respiration components were found around 12:00 to 17:00 h.

The daily patterns of CO_2 flux variation mirrors changes in soil temperature. The measured average of soil temperature change during a day was 26.06 to 31.08 °C during the dry season and 24.06 to 28.39 °C during the wet season (Figure 4.19 g-h). However, the mean soil moisture during the day was relatively stable. It was 8.94 to 9.03 %WFPS in the dry season and 19.41 to 19.27 %WFPS in the wet season (Figure 4.19 g-h).

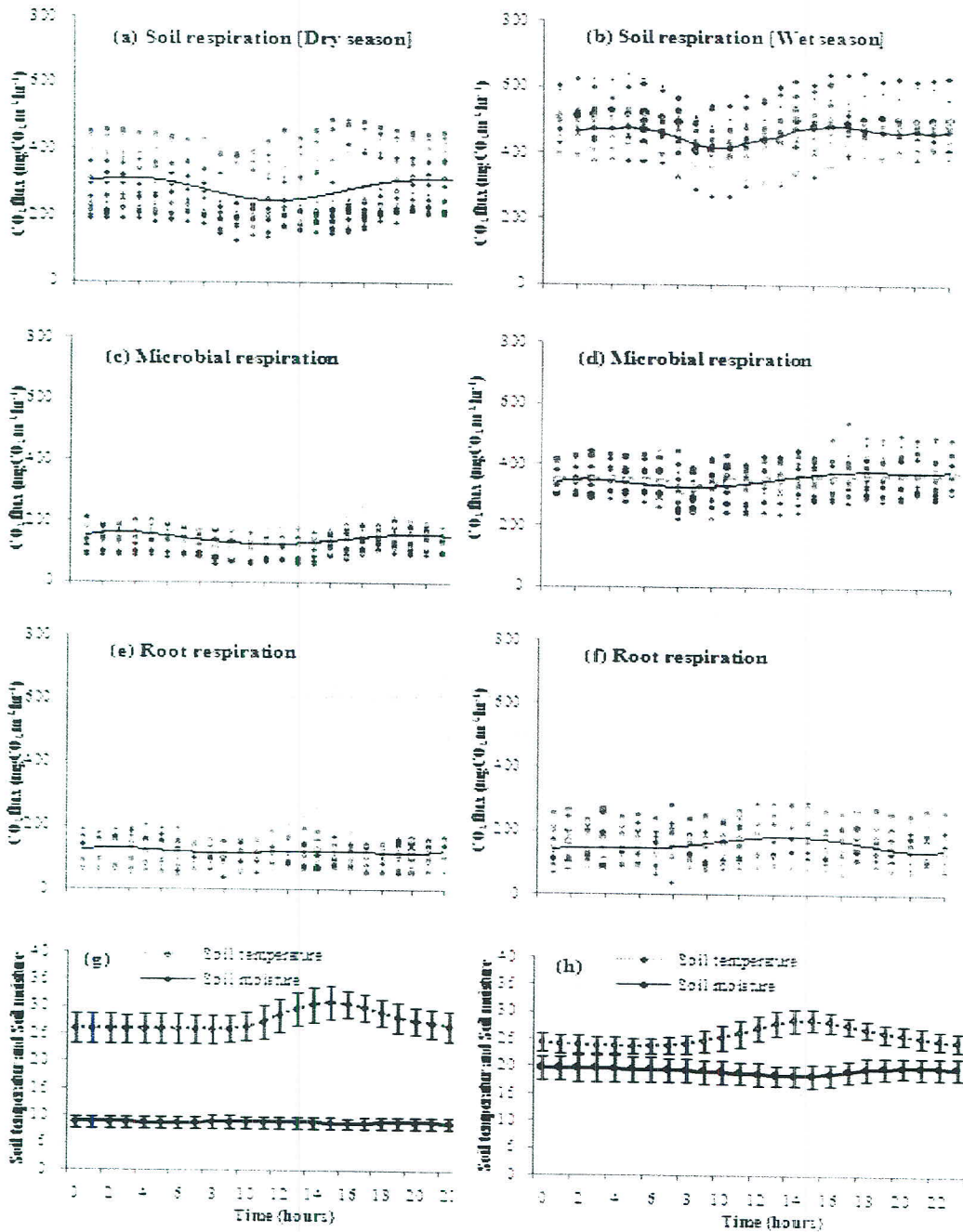


Figure 4.19 Monthly mean diurnal variations of soil respiration and its components, soil temperature and moisture during the dry (a, c, e, g) and the wet seasons (b, d, f, h). For soil respiration, the solid line is the monthly average values and the symbols show value ranges at specific time of the day. Soil respiration, microbial respiration and root respiration are shown separately for dry season (November-April) (a, c, e) and wet season (May-October) (b, d, f). Soil temperature ($^{\circ}\text{C}$) and soil moisture (%WFPS) with errors bar representing S.D. for each month are also shown (g, h).

4.3.2 Monthly variation of R_s , R_m , and R_b

The seasonal variations in R_s , R_b , and R_m were divided into dry and wet seasons. November to March was in the dry season while April to October was the wet season, based on data of soil moisture and precipitation (Figure 4.20 a,b). The monthly pattern of soil respiration during 2008-2011 was similar in every year (Figure 4.20 a). These were increasing at the beginning of the wet season and remained high until the end of the wet period but it was gradually decreasing during mid wet season. However, during the dry season, the soil respiration rate was stable. On May and June were highest CO_2 emissions from soil activities while the lowest soil respiration occurred on January.

The seasonal variations of soil moisture at a depth of 0.05 m were a response to the rainfall pattern during the year (Figure 4.20 a). Normally, the rainfall pattern at the site study consisted of heavy rain in beginning and/or ending of the wet season and a little rainfall in middle of the wet season. The means precipitations from January 2009 to December 2011 were 2.20, 1.50, 50.55, 6.41, 269.73, 86.83, 108.47, 109.57, 164.93, 330.00, 21.10, and 11.50 mm, respectively (Figure 4.20 b). Soil moisture gradually increased at the beginning of the wet season (April - October) and decreased during the dry season or winter season (November - March). The soil temperature at a depth of 0.05 m was gradually increased during the dry season and reduced at the beginning of the wet season until the winter season (April-December) (Figure 4.20 c).

The annual average of soil moisture during February 2008 to December 2011 were 5.71 ± 0.81 , 5.23 ± 0.69 , 9.31 ± 3.61 , 13.86 ± 6.49 , 18.16 ± 4.67 , 18.21 ± 5.68 , 14.48 ± 3.38 , 14.45 ± 6.54 , 16.67 ± 2.57 , 24.57 ± 2.40 , 13.37 ± 1.99 and 6.66 ± 2.53 % water fill pore space (%WFPS), respectively (Figure 4.20 b), and mean soil temperatures were 23.71 ± 2.68 , 28.70 ± 2.32 , 29.46 ± 2.19 , 29.33 ± 2.93 , 27.70 ± 2.91 , 27.22 ± 2.14 , 26.17 ± 0.67 , 25.58 ± 0.56 , 25.34 ± 0.74 , 24.22 ± 0.91 , 22.96 ± 0.61 and 22.64 ± 1.13 °C, respectively (Figure 4.20 c). The maximum soil water content was recorded during the wet season (April - October) and was at a minimum during dry season (November-March). The annual average soil temperature and soil moisture at the study site during the wet seasons and the dry seasons for 4 years were 27.38 °C, 10.47 %WFPS, and 29.62 °C, 4.14 %WFPS, respectively.

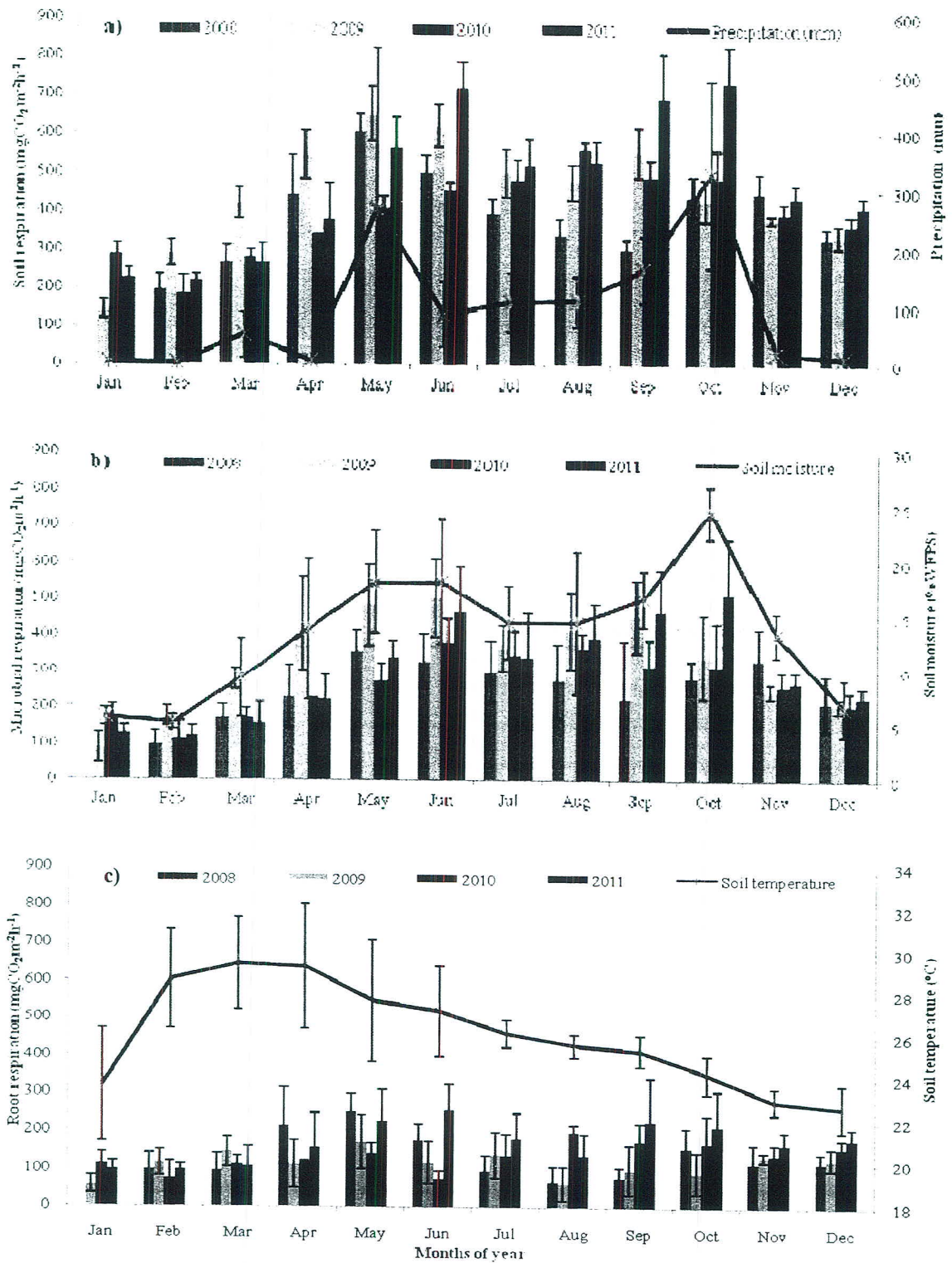


Figure 4.20 Monthly changes of: (a) mean soil respiration ($\text{mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$) and precipitation (mm), (b) mean microbial respiration and soil moisture (%WFPS) at 5 cm soil depth, (c) mean root respiration and soil temperature ($^{\circ}\text{C}$) at 5 cm soil depth for 2008-2011 in dry dipterocarp forest.

4.3.3 Seasonal variations of R_s , R_m , and R_b

The seasonal pattern of R_s was increased at the beginning of the wet season and remained high until the end of the wet period. However, during the dry season, the soil respiration rate was quite low and stable (Figure 4.21). CO_2 emission occurred during the dry season was about 37% of the total CO_2 emission from soil respiration. The daily mean CO_2 flux from soil respiration in dry season and wet season were 277.95 ± 100.91 (range; 35.06-438.16) and 515.44 ± 176.64 (range; 101.75-1027.19) $mgCO_2 m^{-2} h^{-1}$, respectively.

Seasonal patterns of R_m and R_b are presented in Figures 4.22-4.23. Results indicate that the major CO_2 production in DDF depends on the R_m rather than R_b because the quantity of CO_2 emissions from R_m increased during the wet season but R_b in a year was not quite different. The daily mean CO_2 flux from microbial and root respiration were 166.10 ± 70.99 (range; 18.40-237.52) and 115.70 ± 50.62 (range; 16.66-200.64) $mgCO_2 m^{-2} h^{-1}$ in dry season and 376.06 ± 137.34 (range; 69.33-728.36) and 139.37 ± 88.91 (range; 32.42-298.83) $mgCO_2 m^{-2} h^{-1}$ in wet season, respectively.

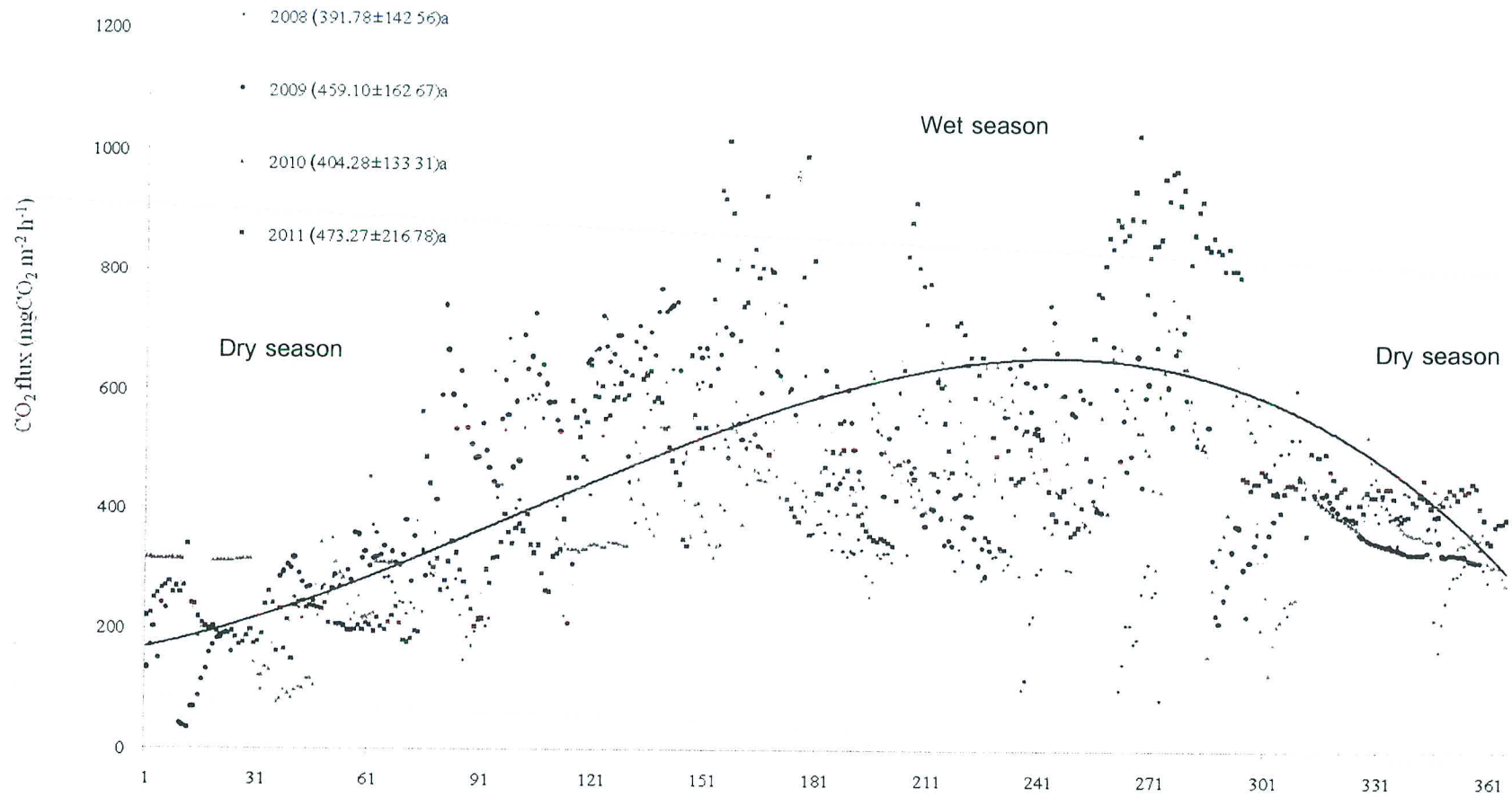


Figure 4.21 Daily mean soil respiration at DDF by using automated-chamber method from 2008-2011

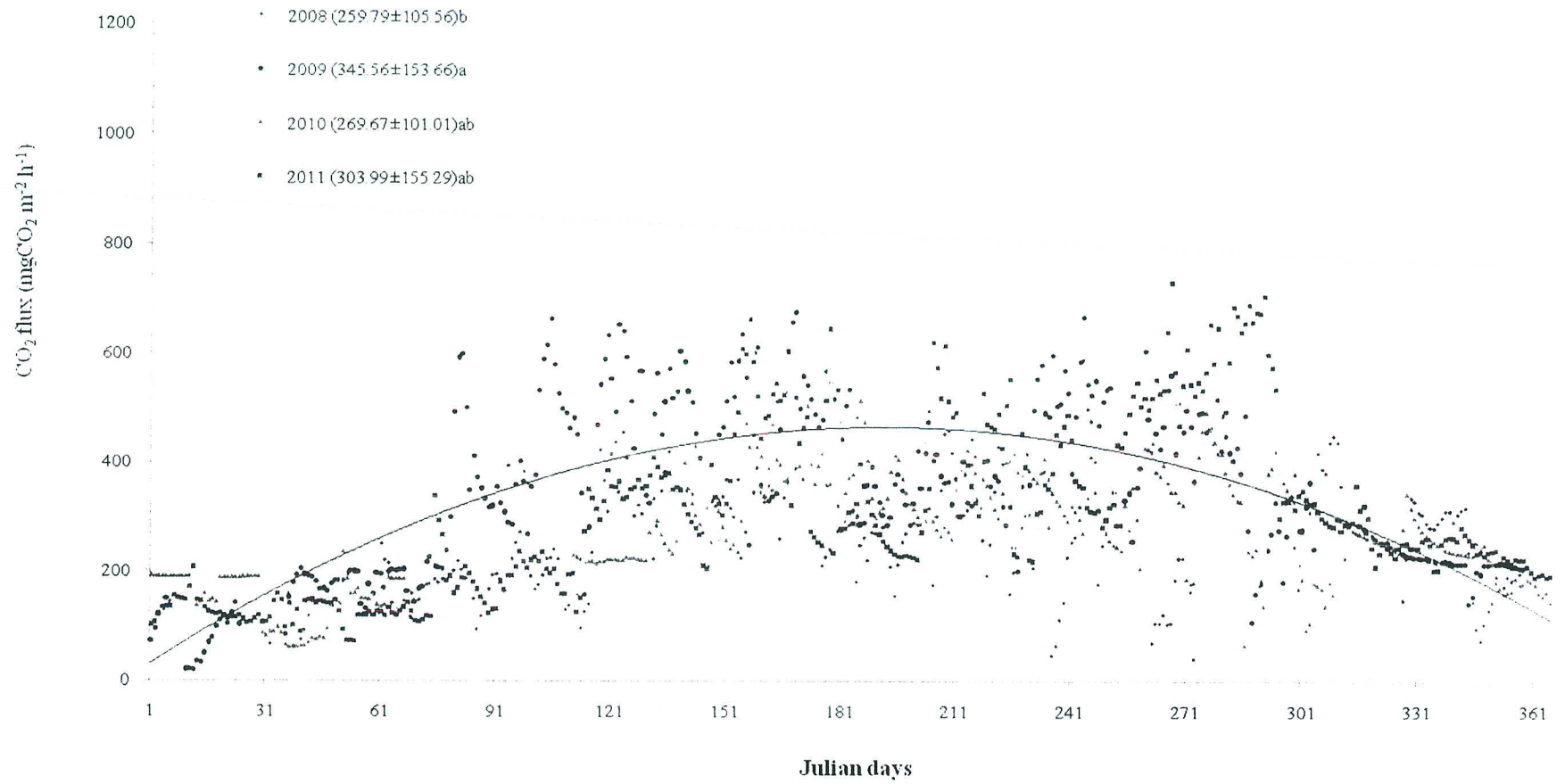


Figure 4.22 Daily mean microbial respiration at DDF by using automated-chamber method from 2008-2011

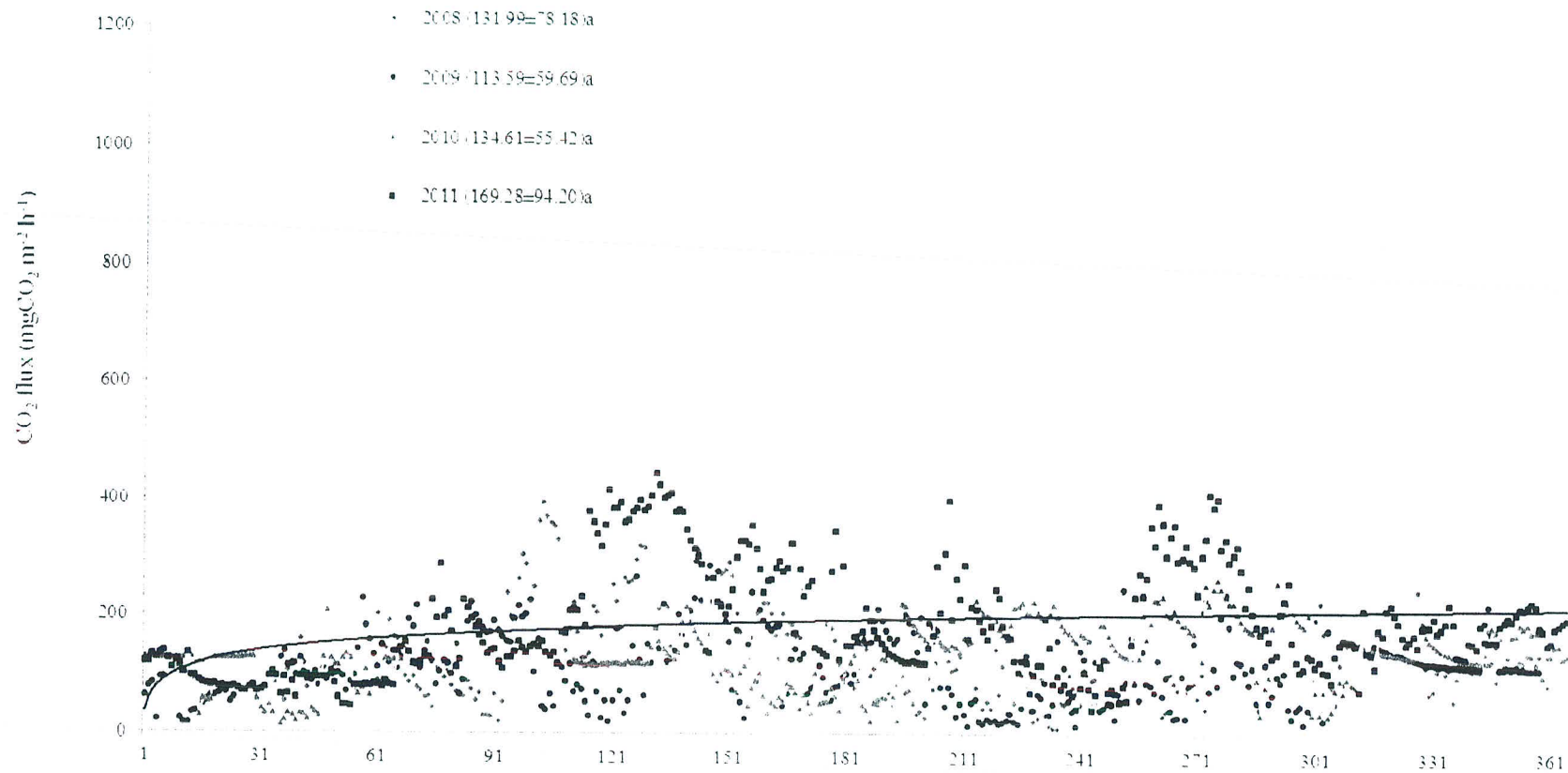


Figure 4.23 Daily mean root respiration at DDF by using automated-chamber method from 2008-2011

4.3.4 Annual variation of R_s , R_m , and R_b

Yearly variations of R_s during 2008-2011 were 391.78 ± 142.56 , 459.10 ± 162.67 , 404.28 ± 133.31 , and 473.27 ± 216.78 $\text{mgCO}_2 \text{ m}^{-2} \text{ hr}^{-1}$, respectively. In addition, cumulative total CO_2 emissions from soil respiration during 2008-2011 in a dry dipterocarp forest were 3.20, 3.89, 3.52, 4.14 $\text{kgCO}_2 \text{ m}^{-2} \text{ yr}^{-1}$, respectively. In addition, the average of R_m during 2008-2011 were 259.79 ± 105.56 , 345.56 ± 153.66 , 269.67 ± 101.01 , and 303.99 ± 155.29 $\text{mgCO}_2 \text{ m}^{-2} \text{ hr}^{-1}$ and average of R_b were 131.99 ± 78.18 , 113.59 ± 59.69 , 134.61 ± 55.42 , and 169.28 ± 94.20 $\text{mgCO}_2 \text{ m}^{-2} \text{ hr}^{-1}$, respectively. In addition, cumulative total CO_2 emissions from root respiration (R_b) during 2008-2011 were 1.12, 0.96, 1.19, and 1.52 $\text{kgCO}_2 \text{ m}^{-2} \text{ yr}^{-1}$ and microbial respiration (R_m) in the same years were 2.08, 2.95, 2.33, and 2.66 $\text{kgCO}_2 \text{ m}^{-2} \text{ yr}^{-1}$, respectively. Throughout four years measurements, R_m was always higher than R_b . The mean soil respiration and root respiration did not differ significantly in each year at ($p < 0.05$). However, the mean microbial respiration differed significantly during 2008-2011 at $p < 0.05$ (Figure 4.24).

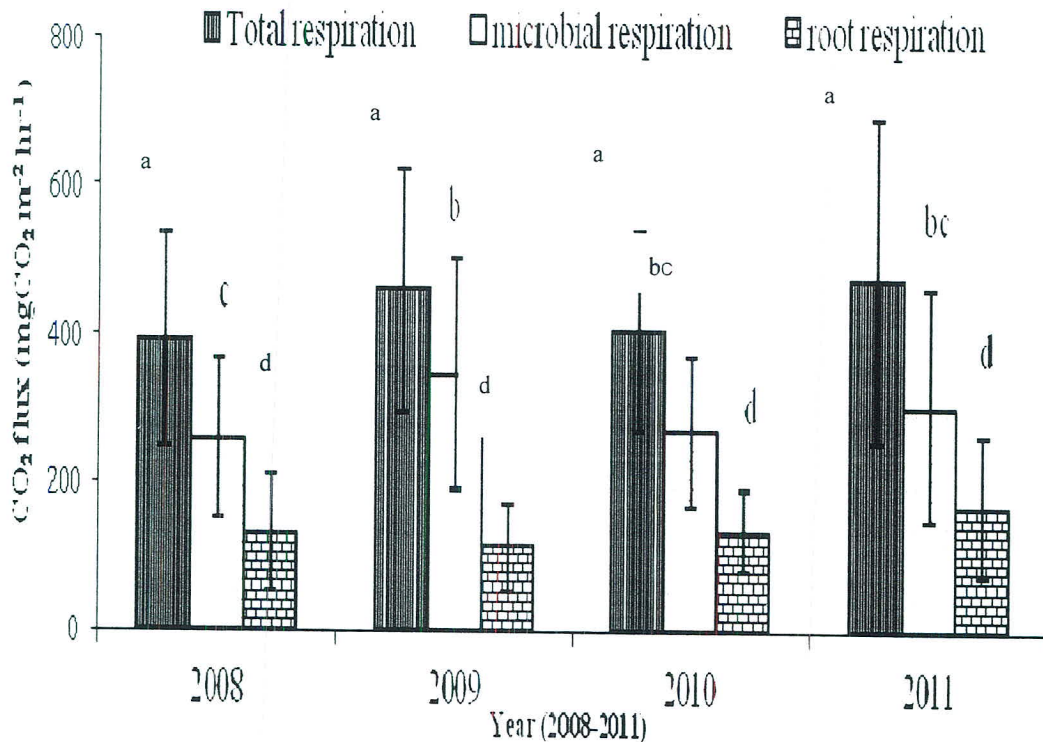


Figure 4.24 Yearly variations of soil respiration, microbial respiration and root respiration during 2008-2011

4.3.5 Partitioning of soil respiration

The average ratios of R_b/R_s and R_m/R_s were 34% and 66%, respectively. Seasonally, the contribution pattern from microbial respiration increased from 50% in January to 75% in July, and the contribution from roots decreased accordingly (Figure 4.25). The contribution of R_m increased significantly from dry to wet season, and remained high until the end of the wet period. However, the ratio of R_m/R_s as decreased during the middle wet season because of the rainfall pattern. Normally, the rainfall pattern in the site study was heavy rain in beginning and/or ending wet season while lacked rainfall in the middle wet season. This indicates that moisture is the important factor limiting microbial respiration in this ecosystem.

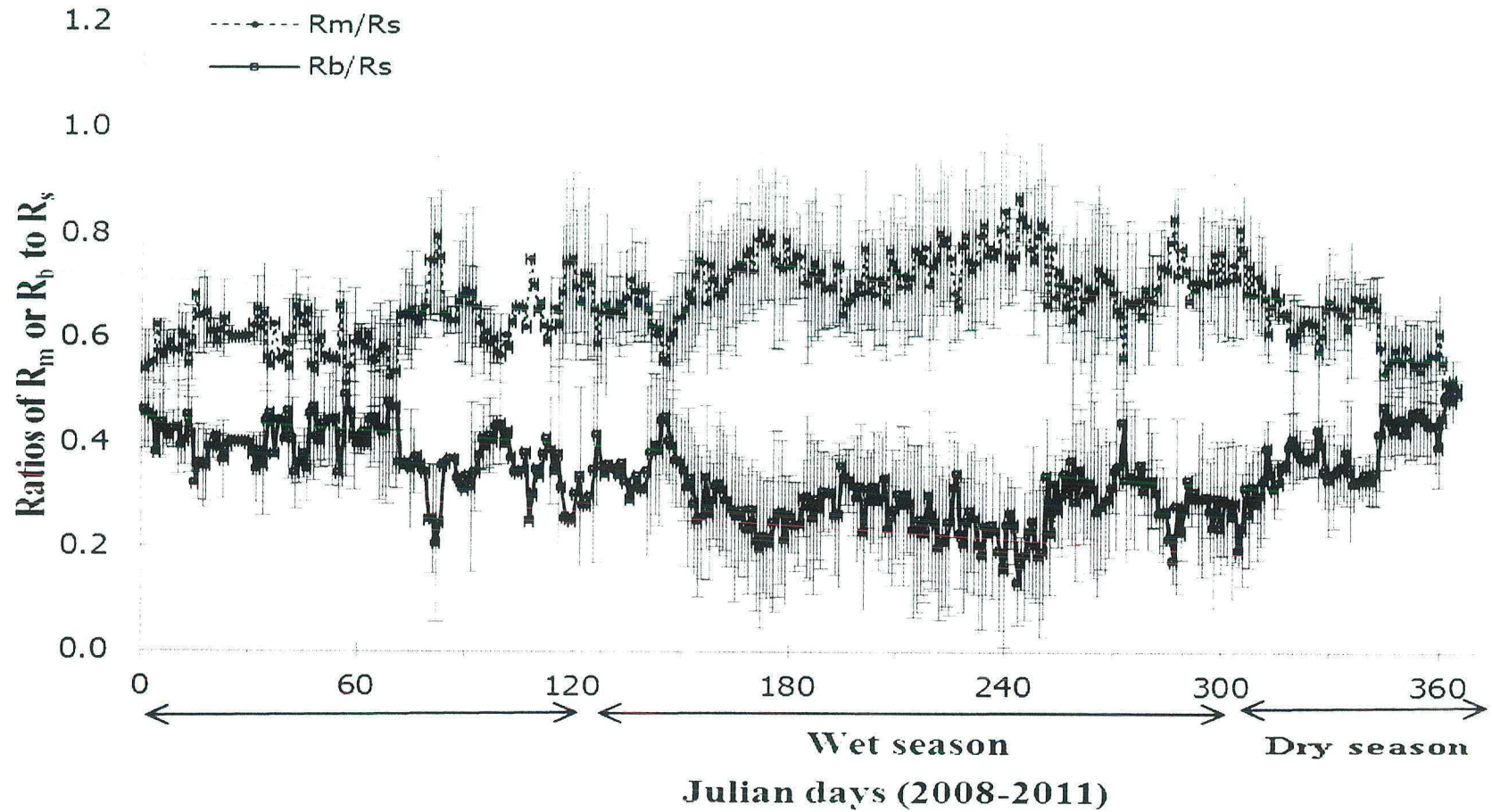


Figure 4.25 Temporal variations of R_m/R_s and R_b/R_s during 2008-2011. Error bars indicate S.D. of daily values averaged over 2008-2011.

4.4 Variations of soil concentrations along soil profiles

Normally, soil CO₂ concentration had distinct vertical profiles, high in deep soil layers and low in the surface soil layer. The means CO₂ concentrations at 0, 25, 75, 150, 250 cm soil depth during January – December, 2011 were 512.19±148.21, 1,102.53±336.86, 2,384.34±2,485.90, 6,637.79±6405.80, and 19,360.89±10,529.89 ppmv, respectively. Seasonally, the CO₂ concentration in soil profiles was different between wet and dry season. The average CO₂ concentration profiles were increasing from 425.6 in the top layer to 16,869.10 ppm in the lower layer in the dry season and 668.58 to 26,252.03 ppm in the wet season (Figure 4.26). The monthly changes of CO₂ concentration between the dry season (November-April) and wet season (May - October) were quite pronounced (Figure 4.27). The mean differences of CO₂ concentration profiles from the dry season shift to the wet season were increasing of 264.73(40%), 492.46(27%), 1,491.77(30%), 2388.05(28%), 9,992.21(36%) ppm from top soil to 2.5 m soil depth (Figure 4.28). The monthly highest peaks of CO₂ concentration was occurred on June and October and lowest peaks in March and August in during a year (Figure 4.28). It was highly correlation with total soil respiration on ground floor in this forest (Figure 4.20 a).

In addition, monthly increasing rates of CO₂ concentrations ($\Delta C/\Delta T$) were calculated by the differences between CO₂ concentrations in each soil layer. The $\Delta C/\Delta T$ in the wet season was higher than in the dry season. The $\Delta C/\Delta T$ value of layer 25, 75, 150, and 250 cm in the dry season were 577.26, 439.19, 1,956.65, and 8,243.58 ppm, and in the wet season were 1,584.84, 4,743.03, 6,908.20, and 18,163.69 ppm, respectively. Normally, the seasonal variation of soil CO₂ concentrations as well as CO₂ efflux were well correlated with variations in soil temperature and soil water content (Figure 4.2 and 4.5). In addition, the biotic factors as root biomass and microbial biomass were highly effect to produce CO₂ emission in soil profiles.

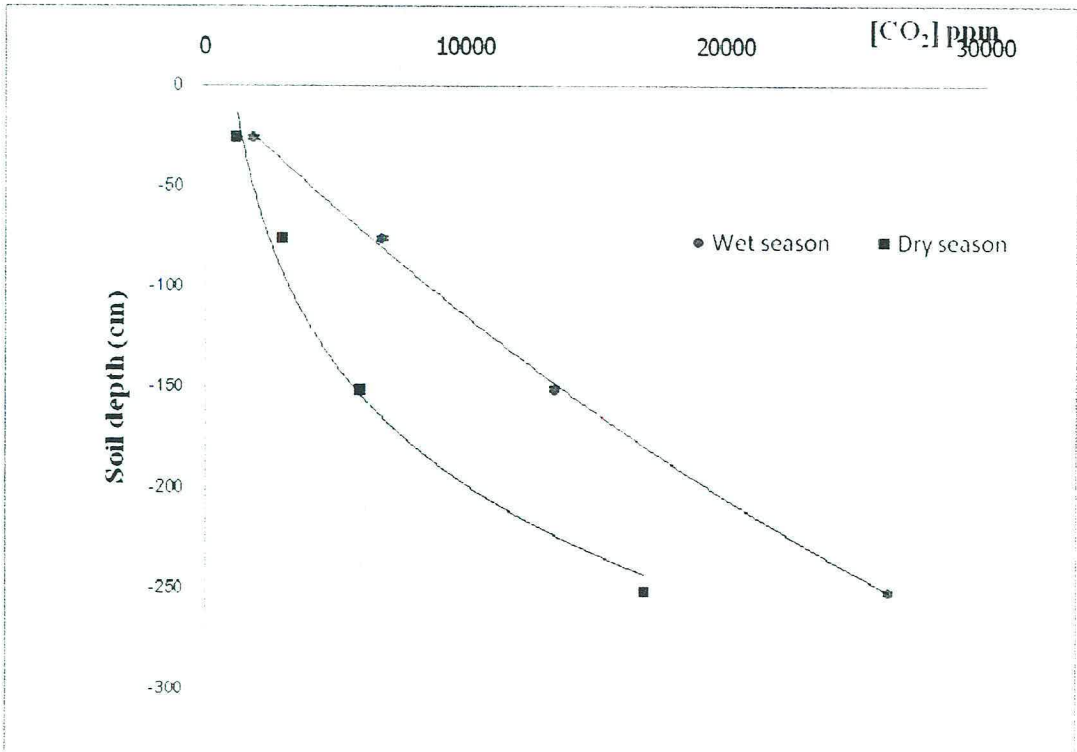


Figure 4.26 Gradients of mean soil CO₂ concentrations during the wet and dry seasons during January to December 2011

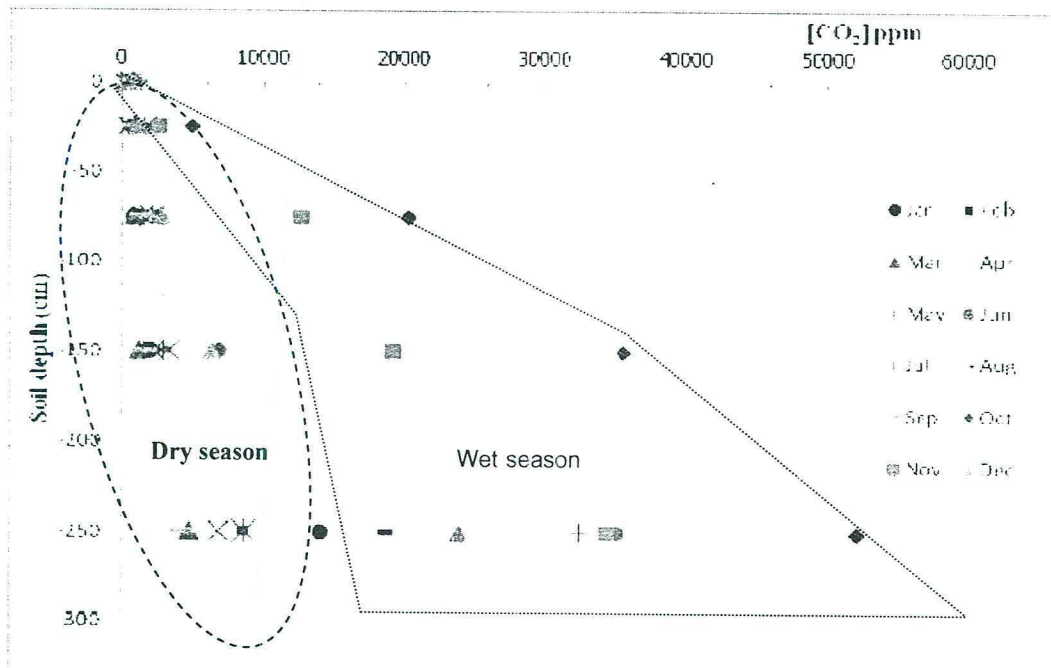


Figure 4.27 Soil CO₂ concentrations versus depth and month to show seasonal shifts between wet and dry seasons in dry dipterocarp forests

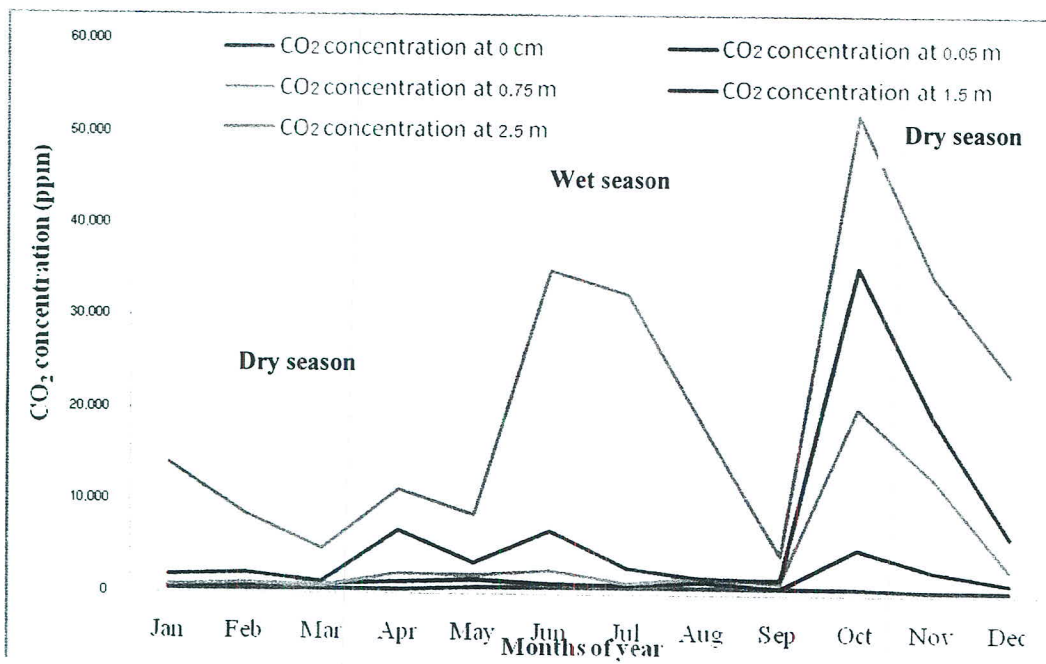


Figure 4.28 Monthly variation of means soil CO₂ concentrations versus soil depth during January to December 2011

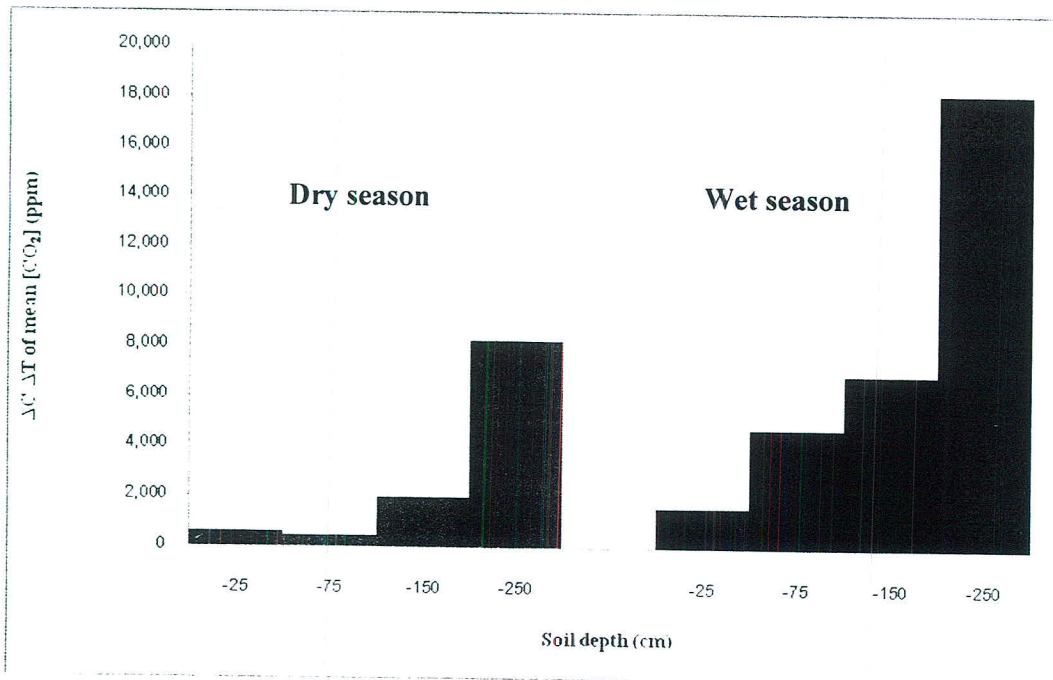


Figure 4.29 Monthly variations of increasing CO₂ concentrations in each profile ($\Delta C/\Delta T$) between dry and wet seasons in 2011

4.5 Seasonal variations of soil respiration (R_s) and ecosystem respiration (R_e)

The seasonal pattern for R_s and R_e in a dry dipterocarp forest (DDF) during 2009 - 2010 is shown in Figure 4.31. The mean soil respiration during 2009 – 2010 were 459.10 ± 162.67 and 404.28 ± 133.31 $\text{mgCO}_2\text{m}^{-2}\text{hr}^{-1}$, and average ecosystem respiration during the same year were 497.30 ± 336.12 and 686.32 ± 416.04 $\text{mgCO}_2\text{m}^{-2}\text{hr}^{-1}$ (Montri, 2012 , personal communication), respectively. Normally, both of R_s and R_e increase in beginning of wet season and remained high until beginning of dry season (April - November). The CO_2 released during this period was 80% of total CO_2 emission during the year. The result indicated that the seasonal variations in R_s and R_e were closely related to soil water content and soil temperature as well as during the dry period (November - April), when soil water content was low and high of temperature (Figure 4.1 and 4.4), CO_2 releases were also low. In contrast, CO_2 emission in DDF increased during the wet season (May - October). This well-known effect is a result of the stimulation of biological activity in the soil (Borken 2003; Lee 2003; Liu 2002). After rain coming during the beginning wet season, the soil activities were possibly enhanced.

Annual estimates of soil and ecosystem respiration indicate that the annual R_s/R_e ratio ranges from 0.24-1.20, with mean of 0.57. R_s/R_e ratio was relatively high in dry season dry [0.91, during November to April] when compared with during wet season [0.55, during May to October] (Figure 4.30). The ratios varied widely ranges during both seasons, which were according to the vegetation pattern in the seasons.

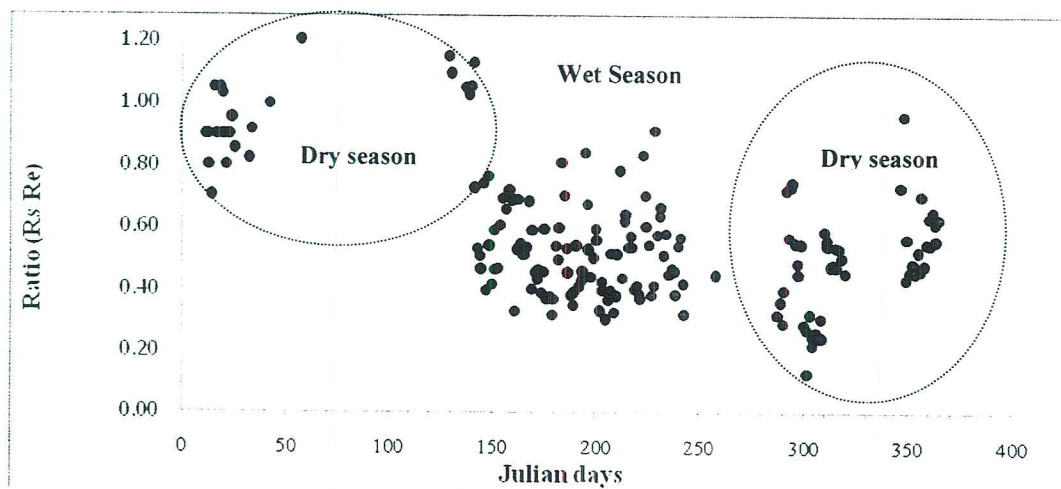


Figure 4.30 The ratios of R_s/R_e during wet and dry seasons in DDF

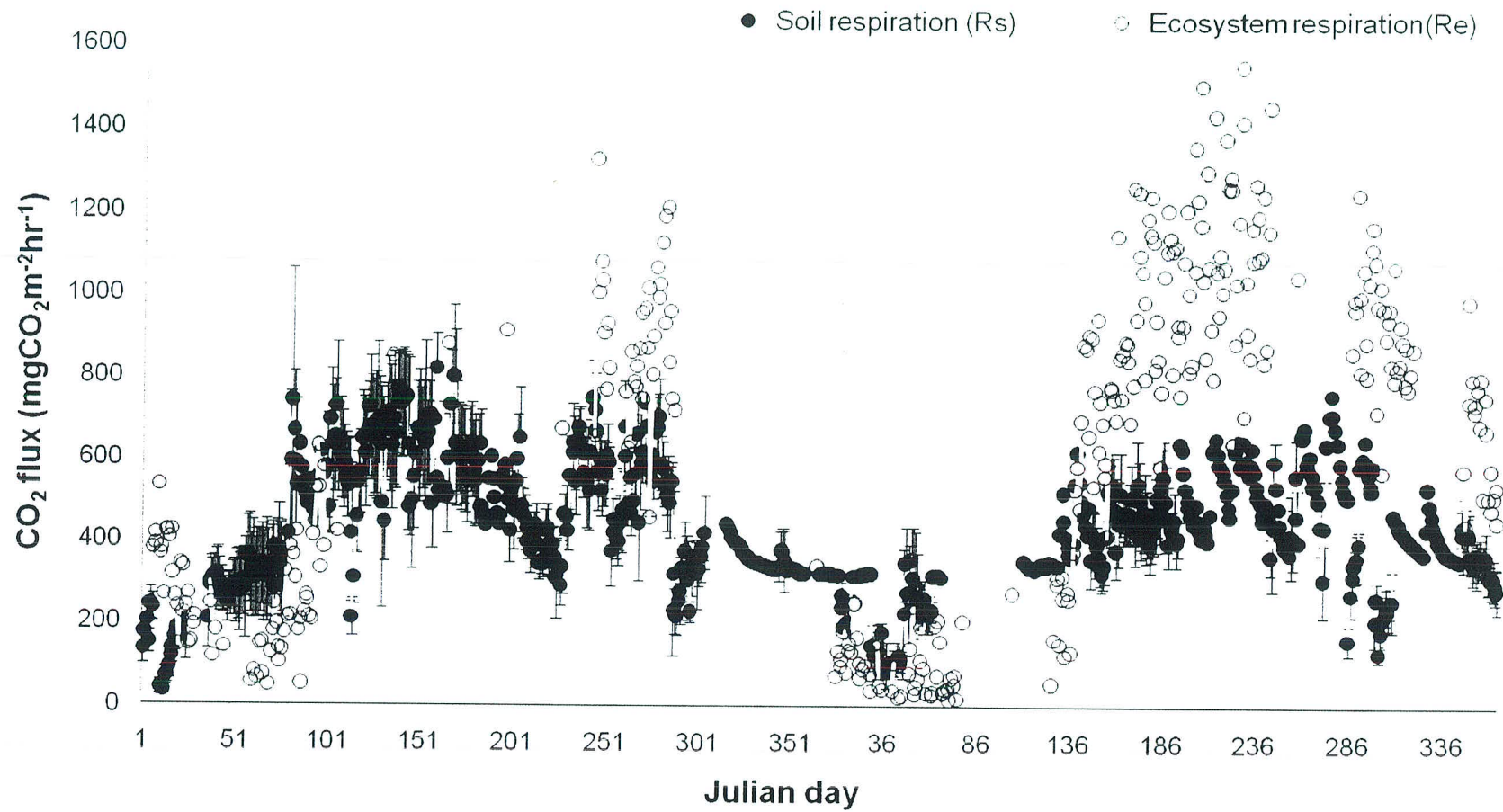


Figure 4.31 Seasonal variations of mean soil respiration and ecosystem respiration observed during 2009 – 2010