# CHAPTER 5

# Discussion

## 5.1 Litterfall

Litterfall in restored forest in different ages depended on the age of restored forest except for the 2-year-site. Although, the 11-year-site was quite young, litterfall over two years was high (5.13 and 5.09 t/ha) compared with natural forest (7.01 and 7.26 t/ha/yr). The mean of annual litter in natural forest was 6.43 t/ha/yr which is around 25-year-old (personal communication). The relationship between annual litter and age was represented by the equation was y = 2.3402ln(x) – 0.5052, ($R^2$ =0.9189). Extrapolation of which estimates that 19.30 years would be required for restored forest to achieve litterfall rates similar to natural. So, it meant that the period of time that the amount of litter in restored forest site will be equal to the natural forest but spending less time (Fig. 5.1).

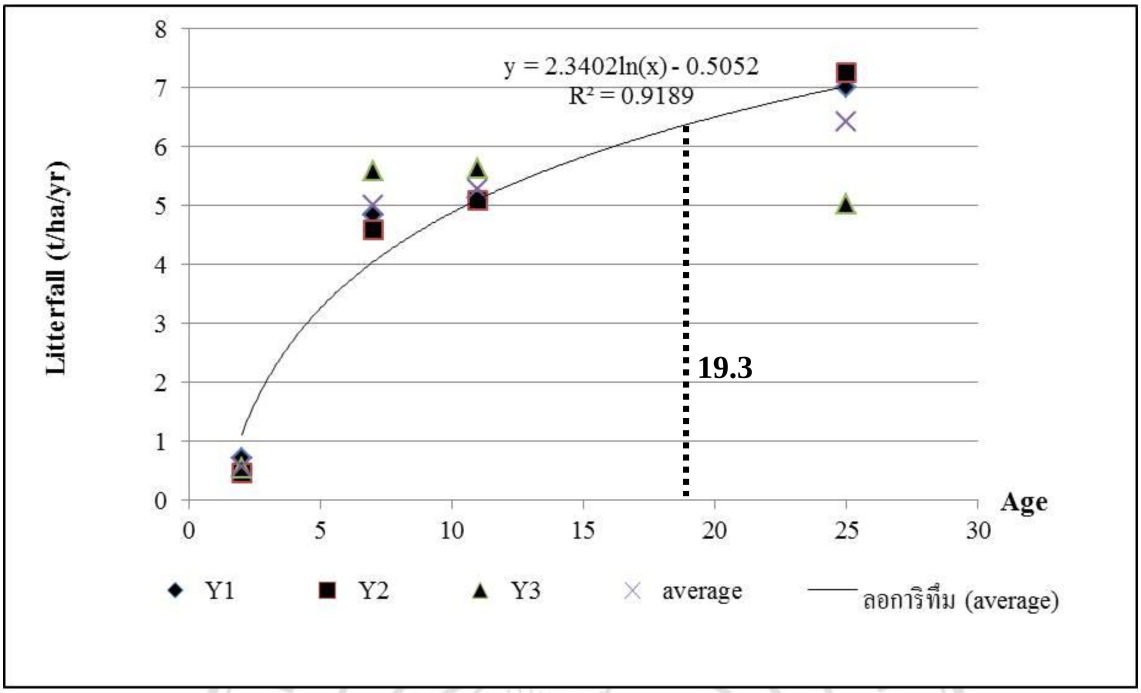


Figure 5.1 Relationship between total litterfall (t/ha/yr) and age since planted

Litter production in the present study is compared with that in other plantations in Table 5.1. Litterfall in my restored plots was similar to that of old un-thinned teak plantations in western Thailand (Sumantakul and Viriyabuncha, 2007). Nevertheless, the results of this study were lower than the results of Tanavat *et al*. (2011) who studied fast-growing tree species: *Eucalyptus camaldulensis, Acacia* hybrid (*mangium xauriculaemis*), *Leucaena leucecephala* and the study of Sumantakul and Viriyabuncha (2007) studies in *E. camaldulensis and A. mangium* of different ages.



And lower than that of fast-growing species e.g. *Acacia mangium* and *A. auriculiformis* which were similar ages to my sites. The results of this study were lower than the study of Lee and Woo (2012), Sale and Agbidye, (2011), Yang *et al*. (2004) and Celentano *et al.* (2011) due to many factors, such as old age of plantations, fast-growing plant species and also high annual precipitation. Those factors or combination of them can produced high amount of litter production (Table 5.2).

In natural forest was included in this study were hill evergreen forest dominated by Fagacece. The result of natural forest site of this study the amount of litter in adjacent natural forest ranged from 7.01 in the first year, 7.26 t/ha/yr in the second year and estimated litterfall in the third year was 5.02 t/ha/yr. Litterfall in my natural site was lower than the result of Glumphabutr and Kaitpraneet (2007) who studied in hill evergreen forest at Khao Khitchakut National Park, Chanthaburi province (Table 5.3).

Annual pattern of litterfall was similar to that reported by others. High amounts of litter were recorded during the dry season (December – April). Whereas, the study of Visaratana and Chernkhuntod (2005) in dry evergreen forest at Sakaerat environmental Research Station, Nakhon Ratchasima Province, North Eastern Thailand was 7.66 t/ha/yr. The amount of litter was very similar to my natural forest site but the highest peak was found in June.

Table 5.1 Comparison of the present study and other plantation studies in Thailand

| Location | Plantation | Litter production (t/ha/yr) | Mean Annual rainfall (mm) | References |
|---|---|---|---|---|
| Western Thailand (Prachinburi province) | Plantation (3-year-old) | | | |
| | -*Eucalyptus camaldulensis* | 11.43 | | Tanavat *et al*., 2011 |
| | -*Acacia* hybrid (mangium x auriculaemis) | 13.67 | 1,540 | |
| | -*Leucaena leucecephala* | 10.56 | | |
| Western Thailand (Kanchanaburi province) | Unthinned teak plantation | | | |
| | -6-year-old | 4.45 | | |
| | -14-year-old | 5.65 | | Sumantakul and Viriyabuncha, 2007 |
| Eastern Thailand (Cha Choeng Sao province) | -27-year-old | 6.69 | 1,655 | |
| | *Acacia mangium* | | | |
| | -6-year-old | 10.37 | | |
| | *Eucalyptus camadulensis* | | | |
| | -6-year-old | 8.29 | | |
| | -14-year-old | 8.97 | | |
| **FORRU, Doi Suthep–Pui National park, northern Thailand** | **Forest restoration plot** | | | |
| | **-11-year-old)** | **5.09 – 5.13** | **1,154** | **Present study** |
| | **-7-year-old)** | **4.60 – 4.85** | | |
| | **-2-year-old)** | **0.46 – 0.71** | | |
| | **-Control plot** | **2.27 – 2.46** | | |
| Huey Bong Silvicutural Research Station, Chiang Mai Province | *Pinus caribaea* plantation - 29-year-old | 4.68 | 1,100 | Sangsathien *et al*., 2012 |
| Mae Klong Watershed Research Station),Lintin, Thong Pha Phum, Kanchanaburi Province, western Thailand | Teak-gmelina stand planted in 1977 | 2.22 | 1,650 | Takahashi *et al*., 2012 |
| Huai Lam Kradon subwatershed in the Wang Thong watershed, lower northern Thailand | Para rubber tree plantation | 1.37 | 1,300 -1,700 | Podong and Poolsiri, 2012 |

Table 5.2 Comparison of the present study and other plantation studies

| Location | Forest type | Litter production (t/ha/yr) | Mean annual rainfall (mm) | References |
|---|---|---|---|---|
| Mount Makiling Forest Reserve is located in South Central Luzon,Philippines | *Acacia mangium* and *A. auriculiformis* were planted between 1993 and<br>1997 | 11.44<br>8.72 | 2,397 | Lee and Woo, 2012 |
| Shasha Forest Reserve, Nigeria | Teak plantations planted since 1965,<br>1970<br>1975<br>1980<br>1985 | 6.7<br>7.4<br>10<br>8.3<br>6.8 | | Sale and Agbidye, 2011 |
| Xinkou Experimental Forestry Centre of Fujian Agricultural and Forestry University, Sanming, Fujian, China | 33-year-old plantations of two coniferous trees, Chinese fir (*Cunninghamia*<br>*lanceolata,* CF)<br>*Fokienia hodginsii* (FH<br>*Ormosia xylocarpa* (OX)<br>*Castanopsis kawakamii* (CK) | <br>5.47<br>7.29<br>5.69<br>9.54 | 1,749 | Yang *et al*., 2004 |
| Las Cruces Biological Station Coto Brus county, southern Costa Rica | Planted species included two native timber-producing hardwoods (*Terminalia amazonia* and *Vochysia guatemalensis* ) interplanted with two N-fixing species (*Inga edulis* and *Erythrina poeppigiana*) | 6.3 | 3,500 | Celentano *et al*., 2011 |
| **FORRU, Doi Suthep –Pui National park, northern Thailand** | **Forest restoration plot**<br>**-11-year-old**<br>**-7-year-old**<br>**-2-year-old**<br>**-Control plot** | <br>**5.09 – 5.13**<br>**4.60 – 4.85**<br>**0.46 – 0.71**<br>**2.27 – 2.46** | **1,154** | **Present study** |
| Huitong Experim ental Station of Forest Eco logy, Hunan Province, China | Plantation of *C. lanceolata* and *Alnus cremastogyne* (MCA),<br>mixed plantation of *C. lanceolata* and *Kalopana* x *septemlobus* (MCK) 1990 | 4.97<br>3.98 | 1,200 | Wang *et al*., 2009 |
| Manipur, north eastern India | Plantation site with *Quercus serrata* | 4.20 | 1,384 | Pandey *et al*., 2007 |

Table 5.3 Litter production in different forest type in Thailand

| Location | Forest type | Litter production (t/ha/yr) | Mean Annual rainfall (mm) | References |
|---|---|---|---|---|
| Sakaerat environmental Research station, Nakhon Ratchasima | Dry evergreen forest (DEF) | 7.67 | 1,000 – 1,500 | Visaratana and Chernkhuntod, 2005 |
| Khao Khitchakut National Park and Khao Soi Dao Wildlife Sanctuary, Chanthaburi province | Moist evergreen forest (MEF)<br>Hill evergreen forest (HEF)<br>Dry evergreen forest (DEF) | 7.85<br>8.83<br>4.88 | - | Glumphabutr and Kaitpraneet, 2007 |
| **Doi Suthep–Pui National park, northern Thailand** | **Hill evergreen forest** | **5.02 - 7.26** | **1,154** | **Present study** |
| Mae Nam Phachi Wildlife Sanctuary, Ratchaburi province | Dry Dipterocarpus Forest (DDF)<br>Mixed Deciduous Forest (MDF) | 7.89<br>3.29<br>4.96 | 959 – 1,285 | Chaiyo *et al*., 2011 |
| The Huai Lam Kradon subwatershed in the Wang Thong watershed, in lower northern Thailand | Secondary mixed deciduous forest | 4.16 | 1,300 -1,700 | Podong and Poolsiri, 2012 |
| The Mae Klong Watershed Research Station), Lintin, Thong Pha Phum, Kanchanaburi Province, western Thailand | Mixed DeciduousForest (MDF) | 2.38 | 1,650 | Takahashi *et al*., 2012 |

## 5.2 The effect of species composition and density

The 2007 or 2-year-old site was accidentally on fire in March, 2010. The burnt site was vegetation for surveyed using circular plots in May, 2011. The survey revealed an average of 267 saplings/rai (FORRU, 2012). Some framework species could survive after the fire such as *Erythrina subumbrans*, *Melia toosendan*, *Prunus cerasoides* and *Spondias axillaris* (FORRU, 2012).

Jinto (2009) found that tree density in 2002, 1998 and natural site were 224, 288 and 192 tree/rai, respectively. Tree density in restored sites were similar to the result of Anusarnsunthorn and Elliott (2004). Since the planting density used for the framework species method is quite high (500 trees per rai), even with slightly higher than 50% mortality, average tree density was maintained at 224.7 trees per rai, which is equivalent to an average spacing of 2.7 m between trees. From a summary of the performance of the trees planted in 1998 that studied by the end of 2002 ($4^{th}$ years after planting), sixteen species (55%) maintained a survival rate of higher than 50%.

Sinhaseni (2008) reported that recruited species in 1998 and 2002 were 33 and 27 species, respectively. Most seedlings grew from seeds that dispersed into the planted plots by animals (rather than by wind). Half of the species of the surveyed seedlings were pioneers and one fourth of the species were climax tree species. However, once the forest canopy is closed, no more seedlings of pioneer species can grow to maturity. While, climax tree species grow for many years in shaded conditions. Therefore, climax tree species can regenerate beneath their own shade.



The proportion of climax and pioneer species in restored forests changed naturally. The proportion of climax species increased with age of planted plots. When the plots were older, the proportion of climax species increased (Sinhaseni, 2008). In the 1998 plots, the number of the climax was more than the pioneer species. Whist in the 2002 site, climax: pioneer species was 50: 50.

Litterfall can vary depending on various factors e.g. soil type, weather and age of plant community (Martius *et al*., 2004). In case of plantations or restored forest sites, planting density (Dickens *et al*., 2004) combined with other factors, such as growth rate (fast-growing species), survival rate after planted, proportion of pioneer and climax species, site preparation, management and precipitation also affects to litter production. In our restored plot, planting density was 3000 trees/ha, whilst Tanavat *et al.* (2011) used 10,000 trees/ha in fast-growing tree plantations, eastern Thailand. Moreover, high primary productivity related to high precipitation (Grosso *et al*., 2008). Therefore, high annual rainfall in eastern and western Thailand can promote the production of litterfall comparing with northern Thailand. Lawrence (2005) reported that annual litter production increased significantly with forest age. Moreover, Kohler (2008) stated that most studies on litterfall in tropical forests refer to old-growth forests and the few available data for young successional forests indicate that litterfall in early- to mid-successional stages may be higher than in mature forests (Ong *et al*., 1981).

**5.3 Carbon return through litterfall**

Most researchers normally use a conversion factor of 0.50 to provide estimate carbon pools (Lewis, 2009). But carbon concentration of litter in our study was ranged from 32.97 – 38.72% (Table 4.3) which was lower than typical values. And some studies for example in southern China, carbon concentration in litter averaged 45 % in natural *Castanopsis kawakamii* forest and monoculture plantations of *C. kawakamii* and Chinese fir (Guo *et al*., 2004) and ranged from 39.4 to 45.8 % in *Cunninghamia lanceolata* and *Michelia macclurei* plantations (Niu *et al*., 2009).

Jain *et al*. (2010) stated that carbon concentration varies, depending on tree species, substrate, and location and the variability in carbon content as a function of forest type. So, high carbon content found in natural forest site higher than restored and control site. High carbon content was found in natural forest site followed restored forest (11, 7 and 2-year-old) and control plot were 38.72, 34.40 and 33.29%, respectively (Table 4.3). It showed that high carbon content was found in natural forest. It indicated that litter quality in terms of carbon content varied with tree species (Chandrashekar, 2011).

When calculated in terms of carbon content through litterfall, it ranged from carbon of 0.25 – 2.71 tC/ha in year1 and 0.75 – 2.81 tC/ha in year2. High input of carbon content was found in natural forest site next to 11 and 7-year-old site. However, restored forest site especially in 1998 and 2002 were young regenerated plot but can contribute the high amount of carbon input via litterfall.

### 5.4 Forest fire and the effect of forest fire

In this study forest fire occurred accidentally in March, 2010 and destroyed litter, ground flora and small planted tree in young study site (planted since 2007). After that some weeds and also ground flora recovered in the following rainy season. Some of the survival planted tree re-sprouted. Therefore, litterfall in 2-year-old site was not high, but in the other restored forest tended to increase with age. However, in May, 2011 burnt site was surveyed using circular sample and the survey revealed that average of 267 saplings/rai still survived in that site (FORRU, 2012). It showed that tree density decreased around 50%.



Fire has different effects on soil organic carbon in forest ecosystems. Wang *et al.* (2012) reported that fire decreased soil organic C by 20.3%, consistent with some other studies (Antunes *et al*., 2009). And also some studies demonstrated that fire significantly decreased soil organic C (Zhang *et al*., 2005), but some studies noted an increase (Boerner *et al*., 2004), and some other studies indicated the no effect or little effect of fire (Knoepp *et al*., 2004).

Fire resulted in disturbance of many forest lands depending on its severity and forest composition (Lecomte *et al*., 2005). The impact of fire on forest soil depends on various factors such as intensity of fire, fuel load and soil moisture (Verma and Jayakumar, 2012). Variations in fire intensity are related to many factors, including forest floor biomass/depth, slope position, aspect, and angle, and fire weather (Boerner *et al*., 2000b). Fire leads to burning of organic matter and this affects the nutrient status of soil for sometime (Lecomte *et al*., 2005). Moreover, the effect of fire on SOM is highly variable from total destruction of SOM to partially scorching depending on fire severity, dryness of the surface OM and fire type (Gonzalez-Perez *et al*., 2004). So in this study, forest floor was full of plenty of leaf litter that dropped during dry season and soil moisture content was quite low so it was quite severe when fire occurred. After fire occurred, it was spending long period for forest recovery process.

**5.5 Litter decomposition of mixed three species**
**(***Ficus subincisa*, *Erythrina subumbrans* and *Castanopsis diversifolia*)

Percentage of dry mass loss rapidly in first weeks varied from 10 to 60% among species. Percentage of *Ficus subincisa* decreased from 100% to 40 – 60 % compared to *Erythrina subumbrans* decreased around 25-45% but in *Castanopsis diversifolia* was decreased only 10-15 % among study sites. Decay rate varied among species but not among sites ($P$<0.05). Decay rates of *E. subumbrans* ranged from 1.05 - 2.12, while decay rate of *C. diversifolia* ranged from 0.41 - 0.87 and in *F. subincisa* ranged from 1.21 - 4.15.



Rapid initial rates of decomposition may reflect leaching of soluble compounds and the decay of easily degradable compounds and tissues (Loranger *et al*., 2002). After the initial rapid phase, *F. subincisa* and *E. subumbrans* decomposed slowly but dry mass of *C. diversifolia* was contant until the late phase dry mass was lost again. *C. diversifolia* was presented low *k* value and dry mass loss may be due to physical features of leaves (Cornelissen and Thompson, 1997) such as its hardness and thickness. A rapid mass loss observed during late rainy season in October could be due to the favorable conditions for fast decomposing litter and soil moisture contents, high relative humidity and congenial atmospheric temperature, all indirectly favoring the soil biological activity (Isaac and Nair, 2005). The higher decay rate in the wet months according to the results of Isaac and Nair (2005) and is attributed to rapid microbial activity and accentuated leaching due to rainfall. And the subsequent decline in the decomposition rate during the dry period may be due to the associated lowering of soil moisture and temperature which can decrease the activity of decomposing organisms (Seneviratne *et al*., 2006).

*K* value of *C. diversifolia* was less than 1 but the other two species were more than one. From the study of Melvin *et al.* (2011) suggested that if the litter decomposition constant or *k* values of the study sites were less than one, indicating that the turnover time for leaf litter is more than one year. Variations were observed in the decay rate within the different species. Substrate quality, climate and quantity and quality of decomposer organisms are the primary determinants of litter decay rates (Swift *et al*., 1979). In the present study, since the environmental conditions remained the same for all the three species, the variations in the decay rates may be attributed to the litter quality. Initial litter quality such as C/N ratio considered in the present study was found to be negatively correlated to litter decomposition rate whereas initial N and C was found to be the best predictors of the decomposition rate. According to Lavelle *et al*. (1993) model, it can be expected that under constant climate and a similar community of soil organisms, litter quality is the most important factor regulating decomposition. Therefore, they expected that high litter quality (low C/N) in secondary forest and broad-leaf forest would lead to accelerated decomposition. Compared to the present study, high N and low C/N was found in *Erythrina subumbrans* and *Ficus subincisa* but not in *Castanopsis diversifolia*. So in this study decomposition rates of *Erythrina subumbrans* and *Ficus subincisa* were, higher than *Castanopsis diversifolia*, probably because of litter quality.

Ostertag *et al*. (2008) suggested that site effects may be more important than litter quality in determining decomposition rates. Similarly, litter mass loss was faster in young secondary forest (25 years) than in bush fallow (4 years) or 12-year-old secondary forest in Cameroon (Hauser *et al*., 2005), also suggesting the importance of site effects. In contrast, in a comparison between a mid-successional forest (ca. 50 years) and an adjacent mature tabonuco forest in Puerto Rico, decomposition rate was slightly higher in the secondary forest, and this difference was related to litter quality, but not site quality (Zou *et al*., 1995). Similar to the present study which decompositions rates were not significantly different among study sites, but differed among species indicating that litter decomposition is related to litter quality more than site. Different species have different decomposition rates and nutrient release patterns, which are related to litter quality and environmental factors (Sundarapandian and Swamy, 1999). Nitrogen, the most common factor limiting litter decomposition, determines the growth and turnover of microbial biomass mineralizing organic carbon (Heal *et al*., 1997). In the present study, nitrogen in different species were not significantly different ranging from 1.15-2.09 in the initial phase. High N in *E. subumbrans*, overall, compared to other species may have been due to the fact that it is a nitrogen-fixing species.

In this study, I focused on litter decomposition in restored forest, using framework species which established variety of plant species and also plant litter. Altered decomposition rate and litter quality were determined in different litter materials. From the present study, litter quality of each species was important in affecting to decomposition rates and also need more information for further studies in any other framework species. Rapid decomposition rate and high litter quality (low C/N, high initial N) were also found in plant litter of framework species that we selected (*F. subincisa* and *E. subumbrans*). Moreover, decay rates (*k* values) of those two species were more than one and can be indicated that turnover rate of leaf litter less than one year. Therefore, not only do *F. subincisa* and *E. subumbrans* posses all the essential characteristics of framework species, but they also supply high-quality litter, in terms of transferring from litter to organic matter and returned to soil during decomposition process.

### 5.6 Litter decomposition of mixed species using big bag

Carbon content of litter in natural forest was significant higher than that of other sites, whilst nitrogen content in 7-year-old site was higher than at the other sites. After 286 days carbon and nitrogen content (%) in natural were still higher than at other sites. Martinez-Yrizar *et al.* (2007) proposed that decomposition rates vary among litter types differing in structural or nutritional quality. The litter types used in their experiment significantly differed in initial quality and annual decomposition rates. Faster decomposition rates were found for high quality litter (i.e., low lignin content and lignin:nutrient ratios in *Encelia farinosa*) and lower for poor quality litter (i.e., high lignin content and lignin:nutrient ratios in *Olneya tesota*). Many studies have reported a direct influence of litter chemistry and physical properties of the leaves on litter decomposition rates. So in this study, the effect of site and litter quality were combined and dominated decomposition rates. However, initial mixed litter in older restored sites were not different in terms of plant species. So decomposition rate was dominated by other factors and may be microclimate which is the primary influence on understory composition many biogeochemical processes e.g. humid and warm weather (Heal *et al.*, 1997) due to different aspect was the main reason for high decomposition in 7-year-old site.

Such differences in nitrogen release pattern from the leaf litter might be associated to the litter quality and the dependent decomposer communities. Net release or net immobilization can be predicted from the organic material's C/N ratio or N concentration. Carbon and nitrogen during period of times gradually decreased. But the relationship between C/N and duration times ($R^2$ = 0.43) was very week. The line was quite stable (C/N = 23 – 25). Carbon content (%) in litter in different periods were determined and found that after 286 days carbon content among study sites were raged 25 – 30 % which was significant highly in natural site. While nitrogen content were ranged 1.01 - 1.33% which was not different among study sites. Available studies suggest that plant materials with N >1.7%, C/N ratio < 25 generally mineralize, whilst those with N<1.7%, C/N ratio>25 lead initially to immobilization of mineral N (Seneviratne, 2000) likely because of greater N demand by microbes decomposing litter with relatively lower N content (Hobbie *et al*., 2006), until respiration and decomposition lower the C/N ratio (Heal *et al*.

1997). It is clear that nitrogen concentration and C/N ratio are major determinants of the ability of plant residues to supply N (Seneviratne, 2000).

After 286 days, *k* values ranged from 1.08 – 2.85. *K* value in 7-year-old was significantly higher than other sites (*k* = 2.85). *K* values from previous studies in different types of forest in Thailand were quite varied (Table 5.4). Moreover, decay rate of this study was compared with other studies especially in tropical forest (Table 5.5). In lowland tropical forest in Sarawak *k* values were ranged from 0.38 – 2.36 and mean rate of decomposition was 1.10 (Hirobe *et al*., 2004). Whereas, Melvin *et al*. (2011) studied in standing forest plot in different ages compared with secondary forest in Sarawak, Malaysia found that *k* values in 1991, 1993, 1999 plot and secondary forest were 0.224, 0.216, 0.216 and 0.208, respectively. In upper montane rainforest of Sri Lanka, *k* value was 0.76 (Weerakkody and Parinson, 2006). But the study of Barbbuiya *et al*. (2008) in wet evergreen forest of northeast India ranged from 1.042 – 5.374. Moreover, Yang *et al*. (2004) studied in four plantation of coniferous and broad leaved trees compared with natural forest in subtropical China and *k* values ranged from 1.157 – 4.619. While the study of Yang and Chen (2009) in southwestern China, Xishuangbanna, using mixed species of litter in each forest type. *K* values in secondary forest, broad-leaved forest and rainforest were 1.075, 1.989 and 2.123, respectively. Compared with the previous studies, *k* values in the present study were quite moderate.  If the litter decomposition constant or *k* values of the study sites were less than one, it indicates that the turnover time for leaf litter is longer than one year (Melvin *et al.*, 2011) and it also indicates that litter turnover in all study sites is shorter than 1 year.

Table 5.4 Decay rates of variety plant species in different forest type of Thailand

| Location | Forest type | Dominated species | *k* | Annual rainfall (mm) | References |
|---|---|---|---|---|---|
| Doi Suthep pui National park, Chiang Mai province | Forest restoration site | | | | Gavinjan, 2005 |
| | Planted 1997 | | 2.07 | | |
| | 1999 | Mixed of two species | 2.40 | | |
| | 2001 | *Prunus cerasoides* and *Ficus altissima* | 3.14 | 1, 500 | |
| | control | | 2.69 | | |
| Kabin buri, Prachinburi province | Plantation | *Eucalyptus camaldulensis* | 1.36 | 1,000 | Tanavat *et al*., 2012 |
| | | *Acacia* hybrid (*mangium x auriculaeformis*) | 0.53 | | |
| | | *Leucaena leucocephala* | 2.5 | | |
| Meaklong Watershed Research station, Kanchanaburi Province | Mixed deciduous forest | *Pterocarpus macrocarpus* | 1.83 | 800 | Ladpala and Phanuthai, 2006 |
| | | *Xylia xylocarpa* | 1.83 | | |
| | | *Schleichena oleosa* | 1.28 | | |
| | | *Holarrhena pubescens* | 2.09 | | |
| | | *Berrya cordifolia* | 1.99 | | |
| | | *Bambusa tulda* | 1.83 | | |
| | | *Gigantachloa albociliata* | 1.34 | | |
| Sakaerat Environmental Research Station, Nakornratchasrima province | Dry evergreen forest | *Hopea ferrea* | 1.62 | 1,240 | Boonriam, 2010 |
| **Doi Suthep pui National park, Chiang Mai province** | **Forest restoration site** | ***Erythrina subumbrans*** | **1.05 - 2.12** | **1,154** | **Present study** |
| | | ***Castanopsis diversifolia*** | **0.41 - 0.87** | | |
| | | ***Ficus subincisa*** | **1.21 – 4.15** | | |
| | | **Mixed of three species** | **1.46 – 1.87** | | |
| | **Control site** | **Grass** | **1.20** | | |
| | **2-year-old site** | **Grass + mixed framework species** | **1.08** | | |
| | **7- year-old site** | **Mixed framework species** | **2.85** | | |
| | **11-year-old site** | **Mixed framework species** | **1.27** | | |
| | **Natural** | **Mixed species dominated by *Castanopsis diversifolia*** | **1.12** | | |
| Kog-ma watershed reseaech area, Doi Suthep –pui National park | Hill evergreen forest | *Castanopsis accumunatissima* | 0.99 – 1.05 | 2,784 | Torreta and Takeda, 1999 |
| | | *Schima wallichii* | 0.55 – 0.61 | | |
| Huai Lam Kradon subwatershed in the Wang Thong watershed in lower northern Thailand | Secondary mixed deciduous forest | | 0.06 – 0.51 | 1,300 - 1,700 | Podong and Poolsiri, 2012 |
| | Para rubber plantation | | 0.02 – 0.59 | | |
| Kaeng krachan National park, Petchaburi and Prachuab Kiri Khan provinces | Mixed deciduous forest | *Alchornea tiliifolia* | 0.07 – 0.11 | 967.9 | Jampanin, 2004 |
| | Dry evergreen forest | *Blachia siamensis* | 0.03 – 0.07 | | |
| | | *Bhesa robusta* | | | |
| | Hill evergreen forest | *Castanopsis diversifolia* | 0.04 | | |
| | | *Quercus lamellosa* | | | |

Table 5.5 Decay rates of variety plant species in different forest types

| Location | GPS | Forest type | Dominated species | *k* | Annual rainfall | References |
|---|---|---|---|---|---|---|
| Changlang district of Arunachal Pradesh, northeast India. | 27$^0$ 23’30’’ N to 27$^0$ 39’ 40’’ N to 96$^0$ 15’2’’ E to 96$^0$ 58’ 33’’ E | Tropical wet evergreen forest | *Ailanthus grandis* | 1.89 | 2,000 – 3,400 | Barbbuiya *et al.* , 2008 |
| | | | *Altingia excelsa* | 2.47 | | |
| | | | *Castanopsis indica* | 1.76 | | |
| | | | *Duabanga sonneratioides* | 3.89 | | |
| | | | *Dysoxylum binectariferum* | 5.37 | | |
| | | | *Mesua ferrea* | 1.04 | | |
| | | | *Shorea assamica* | 3.12 | | |
| | | | *Talauma hodgsonii* | 2.30 | | |
| | | | *Terminalia myriocarpa* | 2.78 | | |
| | | | *Vatica lancefolia* | 2.05 | | |
| **Doi Suthep pui National park, Chiang Mai province** | | **Forest restoration site** | ***Erythrina subumbrans*** | **1.05 -2.12** | **1,154** | **Present study** |
| | | | ***Castanopsis diversifolia*** | **0.41 - 0.87** | | |
| | | | ***Ficus subincisa*** | **1.21 – 4.15** | | |
| | | | **Mixed of three species** | **1.46 – 1.87** | | |
| | | **Control site** | **Grass** | **1.20** | | |
| | | **2-year-old site** | **Grass + mixed framework species** | **1.08** | | |
| | | **7- year-old site** | **Mixed framework species** | **2.85** | | |
| | | **11-year-old site** | **Mixed framework species** | **1.27** | | |
| | | **Natural** | **Mixed species dominated by *Castanopsis diversifolia*** | **1.12** | | |
| The main research sites of the Chinese Ecological Research Network (CERN) in Xishuangbanna tropical area , SW China | 101$^0$ 46’E, 21$^0$ 54’N | Secondary forest | *Litsea monopetala* *Millettia laptobotrya* | 1.08 | 1,500 – 1,600 | Yang and Chen, 2009 |
| | | Broad-leaf forest | *Lithocarpus truncates Castanopsis mekongensis Pometia tomentosa* | 1.11 | | |
| | | Rain forest | *Amoora tetrapetala* | 2.12 | | |
| Hakgala strict natural reserve, Sri Lanka | 6$^0$ 55’N, 80$^0$ 49’E | Montane rainforest | *Allophylus varians*, *Cinnamonum ovalifolium* etc. | 0.76 | 2,013 | Weerakkody and Parkinson, 2006 |
| Riau, Indonesia | 101$^0$47’32.1’’E 00$^0$ 20’ 48.2’’ | *Acacia mangium* industrial forest | *Acacia mangium* | 0.7 | 2,000 | Samingan and Sudirman, 2009 |
| Semengoh Forest Reserve, Sarawak Malaysia | 1$^0$23’N, 110$^0$19’E | Lowland tropical rain forest | 15 species e.g. *Shorea*, *Hopea*, *Cotylelobium* etc. | 0.38 – 2.36 | 3,850 | Hirobe *et al*., 2004 |
| Universit Putra Malaysia Bintulu Sarawak Campus, MalaysiaSarawak Malaysia | 03$^0$ 12 N , 113$^0$ 02 E | Rehabilitation of Tropical Rainforest Ecosystems | Standing forest plot in 1991 | 0.224 | 2, 933 | Melvin *et al*., 2011 |
| | | | 1993 | 0.216 | | |
| | | | 1999 | 0.216 | | |
| | | | Secondary forest | 0.208 | | |

## 5.7 Organic carbon

Litter on the forest floor was the major input of carbon into the soil and accumulated in the top soil. Highly significant amounts of carbon content were found in the top soil (0 – 5 cm) in the natural and 11-year-old sites, due to high loading of the litter accumulation. Organic carbon (%) (derived by multiplying organic matter content by 0.58) declined sharply with increasing soil depth, through the upper soil layers, and less steeply lower down, closely following a power law relationship:

$$OC\% = A \text{ x } Depth^{K}$$

… where depth is measured in cm and A and K are constants for each site. Constant A varied from 7.75 (2-year-old site) to 22.17 (11-year-old site), whereas constant K varied from -0.410 (7-year-old site) to -0.805 (11-year-old site). The coefficients of determination ($R^2$) for these relationships were very high (0.92 – 0.97) (Figs 4.14 a-e.), indicating that for future studies, once A and K have been determined from upper soil layers (0-1 m), OC% in lower soil layers (1-2 m) can be reliably predicted.

## 5.8 Comparing organic matter and organic carbon data after restoration

Soil data (1998 site or 11-year-old site) before planting (since 1997) at the same soil depth (0 -10 cm in depth) are compared with the present study and shown in Table 5.6. Organic matter had increased from 5.37 % to 6.93 %. Thus over 11 years following restoration work, by the framework species method, soil organic matter content increased from 73% to 94% of the level typically recorded in undisturbed evergreen forest soil at a similar elevation (Elliott *et al*., 2000). Moreover, the restored plot (R11) result was compared with adjacent natural hill evergreen forest (elevation 1,300 m), the result showed that it takes around 20 % (from 63% to 82%) to reach the value of OM in natural forest. Mean organic carbon increased in both control plots and those subjected planted with framework tree species. However the increase in carbon in the control plots was not significant, whilst in the 11-year restoration plot was increased significantly (*P*<0.05). Organic carbon increased significantly from 3.10 % to 4.02%.

Table 5.6 % OM and % OC before restoration and during this study in the C, 11-year-old site and natural forest site.

| Soil properties | Site | | | |
|---|---|---|---|---|
| | Pre-restoration study 1997 (N = 16) | C (this study) (N = 6) | 11-year-old site (this study) (N = 6) | Natural forest site (this study) (N = 6) |
| % OM | 5.35 ± 1.00 **c** | 6.69 ± 0.73 **bc** | 6.93 ± 1.45 **b** | 8.45 ± 0.21 **a** |
| % OC | 3.10 ± 0.58 **c** | 3.88 ± 0.42 **bc** | 4.02 ± 0.84 **b** | 4.90 ± 0.12 **a** |

Note: Means±SD and significant differences at *P*<0.05 among sites.

**5.9 Soil organic carbon stock**

Routine soil surveys usually measure carbon stock data down to a depth of only 1 m Batjes (1996) estimates that if this was increased to 2 m depth, global estimates of soil organic carbon (SOC) storage would increase by 60%. In this study, soil organic carbon was investigated down deep to 2 m. High amounts of soil organic carbon stock in total 2 m in young study site (2 and 7-year-old) were 254.40 and 251.14 tC/ha, respectively. And assumed that high soil organic carbon in young study site due to less utilization by young tree. Young forests have initially high carbon sequestration rates, these decline in ageing forests. While, mature forests eventually reach equilibrium, in which no or little further sequestration takes place (SFC ad hoc WG climate change and forestry, 2010).



Nevertheless, soil organic carbon in control site in total 2 m (205.88 tC/ha) was which was higher than 11-year-old site (161.82 tC/ha). The control plots had been continually covered in grasses and other herbaceous weeds, restoration plot establishment. The control site was not planted area with trees and retained covered with grass e.g. *Imperata cylindrical*. Soil carbon in control site was also high especially on topsoil (0 – 10 cm), due to the high root density under grass (van der Kamp *et al*., 2009) and the fact that the Imperata roots penetrate into the subsoil, inputting organic matter directly into lower soil layers (Billings, 2006).

One explanation for this apparent contradiction is that the larger rooting system of these C4 species (in this control site of this study mostly C4 grass) may release greater quantities of labile material to the microbial community (e.g., fine root turnover and exudation), stimulating carbon mineralization in the rooting zone (Baer *et al.*, 2002).

Although routine soil surveys collect carbon stock data down to a depth of 1 m, Batjes (1996) estimates a 60% increase in the global soil organic carbon (SOC) storage with depth extended to 2.0 m. Therefore, soil profile and collection below 1 m. in this study site should be might interesting. Nevertheless, when we compared with other studies we might compared in the same level of soil sampling.

Generally in Thailand, soil carbon stock normally investigated to 100 cm depth. In present study, soil carbon stock in 100 cm of depth among study sites ranged from 127.41 – 172.99 tC/ha. The highest amount of soil carbon was found in natural forest site comparing to 2, 7, control and 11-year-old site which were quite higher than other plantations in Thailand. The result of Pibumrung *et al.* (2008) which conducted in reforestation plot with native and exotic species was 146.83 tC/ha. Their results were quite similar to my study plot, especially the 7 and 2-year-old sites, which ranged from 160.16 – 168.12 tC/ha (Table 5.7a).

It is interesting that soil carbon in teak plantations of Pumijumnong (2007) especially in old plots (61.72 -105.67 tC/ha) is lower than the result of this study (Table 5.6a). This might have been the soil texture, which strongly affects soil carbon dynamics (Parton *et* *al.*, 1994). In general terms, fine-textured soils have a higher soil carbon content than coarse-textured soils (Hassink, 1994). At the study site of Pumijumnong (2007), the soil was loamy sand and sandy loam texture, the coarse-textured with low aggregating, and low water absorption, nutrients and organic carbon. The accumulation of soil organic carbon was less than in clay-textured soil. In contrast, the soil in this study site contained a high clay percentage and also higher soil organic carbon than has been reported for reddish brown lateric soils (Tangsinmankong, 2007) (Table 5.7a).

Moreover, Saengruksawong *et al.* (2012) studied soil carbon stock in different ages of rubber plantation in northeastern Thailand which changed from dipterocarpus forest by farmers. The soil group was very shallow, red yellow podzolic with high soil erosion and low level of water absorption during the rainy season and low fertility. Consequently, soil carbon stocks in plantation plots were lower than at other sites (13.37–18.52 tC/ha) (Table 5.7b).

Soil carbon stock of natural forest in the present study was moderate rate which was higher than dry dipterocarp forest and mixed deciduous forest of many previous researches. But lower than upper montane of Doi Inthanon National park (Tables 5.8a-b).



A comparison between this study and a forest restoration experiment at University Putra Malaysia, Bintulu Sarawak Campus (Ch'ng *et al*., 2011) is shown in Table 5.9, since the forest restoration concept there (i.e. restoration of a near-natural forest ecosystem) matches the objective of the plots in the present study. The Bintulu study measured carbon down to 40 cm depth only, so the comparison is with 40 cm depth from the present study. SOC values in our restored plots were much higher than in the Bintulu plots, overall.

Soil organic matter and soil organic carbon in younger restored site considered higher than in the Bintulu rehabilitated forest. Moreover, Ch'ng *et al*. (2011) also found no significant difference in the quantity of stable carbon for the different ages of rehabilitated forest similar to this study that soil organic carbon that found in different restored site was not higher with forest stand ages (Table 5.9). This was similar to the result of Pumijumnong (2007), who estimated soil carbon in different ages of teak plantation in 10, 14, 18, 27 and 28 year-old in central region of Thailand were 157.03, 61.72, 78.78, 105.67 and 66.83 tC/ha, respectively. The quantity of soil carbon stock did not increase with age (Table 5.7a).

Even though their research conducted in tropical rain forest but different kind of method and plant species (planting indigenous timber species from the family Dipterocarpaceae and Non-Dipterocarpaceae) which established since 1991 after shifting cultivation in restored plot accompanied with other factors such as previous land use can build different level of carbon stock (Ch'ng *et al*., 2011). Moreover, as reported by other authors, the number of years under the previous land use, the stage of the succession, distance from seed sources and intervention or management, among others (Mesquita, 2000) may all be factors, that individually or in a combination, determine the amount of carbon found at the soil.

Table 5.7a Soil carbon studies in different plantation and other land use type in Thailand

| Study site | Land histories | Vegetation type | soil organic carbon (t C ha$^{-1}$) | Soil depth (cm) | Soil group | Parent material | References |
|---|---|---|---|---|---|---|---|
| Num Yao sub-watershed, Nan province | Protected from logging for over half a century<br>Planted since 1979<br>Cleared prior to 1957 | Reforestation planted since 1979 (exotic+ native species) :*Gmelina aborea,Eucalyptus camaldulensis, Tectona grandis,Pterocarpus macrocarpus ,Afzelia xylocarpa,Pterocarpus macrocarpus, Acacia catechu* | 146.83±7.22 | 0 - 100 | Red yellow podzolic soils, Red brown lateritic soils | Sandstone, shal stone and limestone | Pibumrung *et al*., 2008 |
| **FORRU,northern Thailand** | **Degraded hill evergreen forest and agriculture before restoration** | **Forest restoration plot**<br>**- 1998 (14-year-old)**<br>**- 2002(10-year-old)**<br>**- 2007(5 year-old)**<br>**Natural forest** | <br>**127.41**<br>**160.16**<br>**168.12**<br>**172.99** | **0 – 100** | **Red brown lateritic soils** | **Granite** | **Present study** |
| Huay Kha Khaeng Wildlife Sanctuary and teak plantation of Thai Plywood Co., Ltd. Lansak, Uthaithani Province | | Teak plantation<br>- 24-year-old<br>- 15-year-old<br>- 6-year-old | <br>105.67<br>78.78<br>157.03 | 0-100 | | | Tangsinmankong, *et al*., 2007 |
| Central Thailand | Mixed deciduous forest before Planted since 1989 | Teak plantation<br>- 28-year-old<br>- 27-year-old<br>- 18-year-old<br>- 14-year-old<br>- 10-year-old | <br>66.83<br>105.67<br>78.78<br>61.72<br>157.03 | 0 – 100 | Non calcic Brown soils | Limestone | Pumijumnong *et al*., 2007 |
| Sakaerat environmental research station, Nakornratchasrima Province | Forner land-use of agricultural land was changed from forest 40 years ago | Reforest *Acacia mangium* (16 –year-old)<br>Agriculture maize | 66<br>60 | 0-50 | | | Chidthaisong and Lichaikul, 2005 |

Table 5.7b Soil carbon studies in different plantation and other land use type in Thailand

| Study site | Land histories | Vegetation type | Soil organic carbon ($tCha^{-1}$) | Soil depth (cm) | Soil group | Parent material | References |
|---|---|---|---|---|---|---|---|
| Prachuap Khiri Khan Silvicultural Research Station, Southern Thailand | | Native and exotic species plantation (14-15-year-old) | | | | | Meungpong *et al*., 2010 |
| | | - *Acacia* | 58.63 | | | | |
| | | *crassicarpa* | | 0-50 | | | |
| | | - *Azadirachta indica* | 44.49 | | | | |
| | | - *Pterocarpus* | 46.78 | | | | |
| | | *macrocarpus* | 62.64 | | | | |
| | | - *Shorea roxbyrghii* | 56.77 | | | | |
| | | - *Tectona grandis* | 49.00 | | | | |
| | | - *Xylia xylocarpa* | 49.90 | | | | |
| North – east (Nongkhai province) | Dipterocarpus forest | Rubber plantation | | | Red yellow podzolic soils | Siltstone and sandy stone | Saengruksawong *et al*., 2012 |
| | | - 1-year-old | 14.26 | | | | |
| | | - 5-year-old | 16.83 | 0-100 | | | |
| | | - 10-year-old | 18.52 | | | | |
| | | - 15-year-old | 16.05 | | | | |
| | | - 20-year-old | 13.37 | | | | |

Table 5.8a Soil carbon studies in different forest type in Thailand

| Study site | Vegetation type | Soil organic carbon (t C $ha^{-1}$) | Soil depth (cm) | References |
|---|---|---|---|---|
| Doi Inthanon National park (Keaw Mae Pan area) | Upper montane forest | 262.47 – 288.80 | 0 -100 | Timpan, 2008 |
| Num Yao sub-watershed, Nan province | Hill evergreen and Mixed deciduous forest | 196.24±22.81 | 0-100 | Pibumrung *et al*., 2008 |
| **FORRU, northern Thailand** | **Forest restoration plot**<br>**- 1998 (14-year-old)**<br>**- 2002(10-year-old)**<br>**- 2007(5 year-old)**<br>**Natural forest** | <br>**127.41**<br>**160.16**<br>**168.12**<br>**172.99** | **0 – 100** | **Present study** |
| Doi Suthep-Pui national park, Chiang Mai province | Dry dipterocarp forest (DDF)<br>Mixed deciduous forest (MDF)<br>Dry evergreen forest (DEF)<br>Pine forest (PF)<br>Montane forest (MF) | 67.99<br>136.57<br>139.01<br>123.20<br>133.03 | 0 -100<br>0-100<br>0-160<br>0-160<br>0-120 | Khamyong, 2009 |
| Boakaew watershed station, Chiang Mai province | Fragmented Montane forest<br>Dominated by<br>- *Pinus kesiya*<br>- *Castanopsis accuminattissima*<br>- *Castanopsis diversifolia*<br>- *Shima wallichii* | <br><br>84.33<br>93.07 – 150.78<br>107.99<br>263.87 | 0 -100 | Satienpirakul, 2013 |
| Sakaerat environmental research station, Nakornratchasrima Province | Dry evergreen forest (DEF) | 118 | 0-50 | Chidthaisong and Lichaikul, 2005 |
| Huay Kha Khaeng Wildlife Sanctuary and teak plantation of Thai Plywood Co., Ltd. Lansak, Uthaithani Province | Mixed deciduous forest | 70.96 | 0-100 | Tangsinmankong, *et al*., 2007 |
| Ban Sai Thong Community forest, Lamphun Province | DDF old conservation area<br>DDF new conservation area<br>MDF old conservation area<br>MDF new conservation area | 42.95<br>16.16<br>40.49<br>86.11 | 0- 80<br>0 – 20<br>0 – 110<br>0 - 100 | Phonchaluen, 2009 |

Table 5.8b Soil carbon studies in different forest type in Thailand

| Study site | Vegetation type | Soil organic carbon (t C $ha^{-1}$) | Soil depth (cm) | References |
|---|---|---|---|---|
| Huai Hong Khrai Royal Development Study Center (HHK), Chiang Mai Province, Northern Thailand | Dry dipterocarp forest (DDF) | 29.57 | 0 -100 | Chaiwong et al., 2013 |
| | Mixed deciduous forest (MDF) | 39.88 | 0 - 160 | |
| Petrified wood forest park, Tak province | Dry dipterocarp forest (DDF) | 31.22 | 0 -100 | Wongin, 2011 |

Table 5.9 Comparison SOM and SOC the UPM Mitsubishi Forest Restoration Project, Sarawak, Malaysia and the present study

| Location | Land histories | Forest type | SOM at 40 cm ($Mgha^{-1}$) | SOC at 40 cm (MgCha-1) | Reference |
|---|---|---|---|---|---|
| FORRU, Doi Suthep – Pui National park, northern Thailand | Degraded hill evergreen forest and agriculture before restoration | Restored forest plot | | | Present study |
| | | -2-year-old | 128.34 | 74.61 | |
| | | -7-year-old | 129.53 | 75.32 | |
| | | -11-year-old | 123.97 | 72.08 | |
| UPM-Mitsubishi rehabilitated forest at University Putra Malaysia, Bintulu Sarawak Campus | Previously abandoned after shifting cultivation and rehabilitated since 1991 by planting indigenous forest tree species at very high density. | Rehabilitated forest | | | Ch'ng *et al.*, 2011 |
| | | -1-year-old | 64.31 | 37.30 | |
| | | -2-year-old | 95.96 | 55.66 | |
| | | -3-year-old | 68.21 | 39.56 | |
| | | -4-year-old | 61.77 | 35.83 | |
| | | -5-year-old | 43.59 | 25.28 | |
| | | -6-year-old | 59.12 | 34.29 | |
| | | -7-year-old | 67.45 | 39.12 | |

### 5.10 Comparing some soil properties the study of Schuler (2008) and present study

Schuler studied soil characteristic and soil profile in Mae Sa Mai area in various vegetation types including evergreen forest, deciduous forest, pine forest, fruit tree orchards and also under cultivation of agronomy. Soil in the Mae Sa Mai area were mostly Acrisols, covering about 70% of the area according to World References Base for Soil Resources (WRB). In present study the soil type classed as a Ultisol. Soil color, structure, fraction and texture of both studies were similar, bulk density from my study was lower than that reported by Schuler (2008) (Table 5.10).

Table 5.10 Comparison soil study of Schuler and present study

| Soil | Schuler (2008) | Present study |
|---|---|---|
| Type | Acrisol | Ultisol |
| Color | Reddish color | Reddish color |
| Structure | | |
| Topsoil (0 -20 cm) | Granular | Granular |
| Subsoil (below 20 cm) | Subangular blocky | Subangular blocky |
| Soil fraction | Sand dominated | Sand domainated |
| Texture | | |
| Topsoil | Clay loam | Sandy loam, Sandy clay loam, Clay loam |
| Subsoil | Clay | Clay loam, Clay |
| Bulk density ($g/cm^3$) | 1.1 - 1.3 | 0.6 – 1.14 |

### 5.11 Comparing some soil properties of the study of Laorpansakul (2000) and present study

The study of Laorpansakul (2000) determined soil characteristic in the Queen Sirikit Botanic Garden (QSBG) where closed to Ban Mae Sa Mai. He conducted soil in different type of forest. In this case, soil in hill evergreen forest was compared to this study and shown in Table 5.11a-b. Soil type, structure and soil texture in both studies were similar. Bulk density in QSBG was quite higher than present study. Soil pH in QSBG was quite higher than this study. Organic matter (%) of upper and middle slope in hill evergreen forest of QSBG were similar to organic matter (%) in natural forest of this study. Therefore, SOC of QSBG natural forest was similar to this study.

Table 5.11a Comparison soil study of QSBG and present study

| Soil | QSBG | | | Present study | | | | |
|---|---|---|---|---|---|---|---|---|
| | Upper | Middle | Lower | control | 2-year-old | 7-year-old | 11-year-old | Natural forest |
| Type | Ultisol | | | Ultisol | | | | |
| Structure<br>Topsoil (0–20 cm)<br>Subsoil (below 20 cm) | Granular<br>Subangular blocky | | | Granular<br>Subangular blocky | | | | |
| Texture<br>Topsoil (0–20 cm)<br>Subsoil (below 20 cm) | Sandy loam<br>Clay loam to clay | | | Sandy clay loam, Sandy clay, clay loam<br>Sandy clay loam, clay loam, clay | | | | |
| Bulk density ($g/cm^3$) | 0.79 – 1.31 | 0.72 - 1.23 | 1.13 – 1.46 | 0.78 – 1.12 | 0.68 – 1.07 | 0.75 – 1.14 | 0.78 - 1.12 | 0.62 – 1.06 |

Table 5.11b  Comparison soil study of QSBG and present study

| Soil | QSBG | | | Present study | | | | |
|---|---|---|---|---|---|---|---|---|
| | Upper | Middle | Lower | Control | 2-year-old | 7-year-old | 11-year-old | Natural forest |
| pH (0 – 5 cm) | 5.28 | 6.09 | 5.11 | 5.01 | 4.76 | 5.75 | 4.65 | 4.52 |
| OM (%) (0 -5 cm) | 10.31 | 12.50 | 5.49 | 10.08 | 6.86 | 7.71 | 8.97 | 11.59 |
| OC (%) (0 – 5 cm) | 5.98 | 7.25 | 3.19 | 5.85 | 3.98 | 4.47 | 5.20 | 6.72 |
| Base saturation (%) (0 – 5 cm) | 23.45 | 43.63 | 21.33 | 28.70 | 35.81 | 68.76 | 19.00 | 10.83 |
| CEC (0 – 5 cm) | 24.80 | 43.53 | 19.07 | 15.49 | 15.49 | 20.59 | 19.74 | 16.77 |
| SOM 0-1 m (t/ha) | 262.90 | 307.37 | 226.60 | 268.49 | 289.17 | 275.48 | 219.15 | 297.54 |
| SOC 0-1 m (tC/ha) | 152.48 | 178.27 | 131.43 | 156.10 | 168.12 | 160.16 | 127.41 | 172.99 |

According to the study of Fonseca *et al.* (2011) which investigated carbon accumulation in the biomass and soil of different aged secondary forests in the humid tropics of Costa Rica. They found a positive but low correlation between the amount of soil carbon and the age of the forest, in contrast high correlation was found between biomass and forest age. The low correlation between soil carbon and forest age can be attributed partly to the slow incorporation of carbon into the soil (Gamboa *et al*., 2008) together with the young age of the studied forests. However, as reported by other authors, previous land use, the number of years under the previous land use, the stage of the succession, distance from seed sources and intervention or management, among others (Mesquita, 2000) may all be factors, that individually or in a combination, determine the amount of carbon found at the soil. However, this assumption still needs to be proven.

Recent works suggested that increase of organic matter storage in subsoils may not be as straight forward, because subsoil carbon may become available to microbial decomposition, following carbon input (Fontaine *et al*., 2007 ) and/or mechanical disruption (Xiang *et al*., 2008 ). It also has been found that subsoil C may respond to land-use and/ or management change (Follett *et al*., 2009 ). Main C sources of subsoil OM are dissolved organic matter, root biomass and physically or biologically transported particulate organic matter. Organic matter input into subsoil horizons occurs as root litter and root exudates, dissolved organic matter and/or bioturbation. The relative importance of these sources is dependent on climatic parameters, soil inherent processes as well as land-use. For example, high input of dissolved organic matter can be expected under humid climate conditions (Michalzik *et al*., 2001).



Another important source of subsoil OM is plant roots. These affect the placement of carbon in soil. In a global review of root distribution, grasses had the shallowest root profiles, trees were intermediate and shrubs had the deepest profiles (Jackson *et al*., 1996). Specific allocation patterns through vegetation types were also found to govern vertical SOC distribution (Jobbagy and Jackson, 2000). The importance of roots for soil C sequestration was underlined by the fact that they have a high potential to be stabilized in soil (Rasse *et al*., 2006). So, below 40 cm in depth we still determined much more soil organic carbon especially in young restored site (2002 and 2007 site).

Several factors affect SOC stock change including previous land-use (Stevens and van Wesemael, 2008), precipitation (Jackson *et al*., 2002) and the type of forest established (Guo and Gifford, 2002). Given such variation in the direction of soil C stock change and the period required for recovery to initial soil C stock levels, elucidating the mechanisms related to SOC accumulation after afforestation and also in forest restoration program in more detail are still essential because the SOC dynamics vary among forests due in part to soil type (Hagedorn *et al*., 2003).

## 5.11 Model

The simulated soil carbon in 11, 7, control and natural site increased yearly and ranged from 1.93 – 4.49, 1.72 – 5.62, 0.05 – 0.46, and 3.13 – 9.57 tC/ha, respectively. From starting year (2010), soil carbon mass was highest in natural next to 11, 7, control and 2-year-old site. Since 2011, soil carbon mass in natural site was to higher than 7, 11, control site. Initial litter input per year and clay percentage were the important data that input for model simulation. So that, trend line of natural, 11, 7-year-old site were more increased rapidly than others due to litterC input. However, simulated soil carbon mass was quite different from current measured soil organic carbon in the study sites. And may be probably under-estimated than the real situation. Soil carbon mass in study sites may be more or less than present due to many relevant factors with unpredictable changes such as forest fire, termites and tree fall or harvesting problems. Moreover, several factors affecting SOC stock change including the previous land-use type (Stevens and van Wesemael, 2008) and the type of forest established (Guo and Gifford, 2002) were not included in this model. Nevertheless, data that input in model just two year (2010-2011) need more information in long-term for validation and comparing data between measurement and simulation.