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Influence of Climate, Litter Quality and Soil Macrofauna Decomposers on Litter Decomposition in Dry Dipterocarp and Dry Evergreen Forests in Northeastern Thailand

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Litter decomposition is a complex ecological process that is controlled by various environmental factors. The aim of this study was to investigate the influence of climate, litter quality and soil macrofauna decomposers on litter decomposition rate in dry dipterocarp (DD) and dry evergreen forests (DE) in Sakaerat Biosphere Reserve (SBR), northeastern Thailand. The field experiment was carried out at 2 months interval from June 2007 to May 2008. Natural litter was incubated in 5 mm mesh bags for 12 months at their source sites. Meteorological data was recorded according to the SBR data. Soil macrofauna decomposers were collected and classified to class/order level. The results showed that the mean annual decomposition rates (k-constant) of leaf litter in DD and DE were 0.11±0.02 and 0.21±0.27, respectively. The litter mass loss was highly significantly different between DD and DE. The litter decomposition rate had a positive correlation with rainfall and negative correlations with temperature and relative humidity in DD, but it had only a positive correlation with precipitation in DE. The initial litter quality did not differ between both ecosystems. There were positive correlations between nitrogen content and lignin and decomposition rate, and a negative correlation between carbon content and C/N ration in DE. The influence of initial litter quality on decomposition rate was not found in DD. The soil macrofauna of 12 classes/orders with 176.34±6.13 individuals per bag were found in DD and 15 classes/orders with 260.68±7.98 individuals per bag were found in DE. The two most abundant orders of macrofauna in both DD and DE were Isoptera and Hymenoptera. The Shannon-Weiner diversity index in DD was 2.01 and was 2.22 in DE. The decomposition rates had positive correlations with abundance and diversity of soil macrofauna in both DD and DE.

Keywords: climate, litter quality, macrofauna, leaf, decomposition, Thailand

Introduction

Decomposition is an essential process in terrestrial ecosystems whereby dead organic materials are transformed into simpler states. This process results

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in the physical breakdown of litters and transfers organic matters, nutrients and carbon to the soil (Prescott, 2010). Subsequently, final substances from decomposition provide the primary source for plants and microorganisms (Moore *et al*., 2004), regulate the soil organic matter (Swift *et al*., 1979) and release carbon dioxide to the atmosphere (Gonzalez, 2002).

There are numerous important factors that regulate decomposition processes such as soil characteristics, nutrient availability and cycling, topography and plant community composition and structure (Berg and McClaugherty, 2008). However, only three factors highly influence on decomposition rate i.e. litter quality, decomposer communities and environmental factors (Tian *et al*., 1997; Coleman *et al*., 2004). These factors are different in various sites which result in difference of decomposition rates. Decomposition rates are highly dependent on the quality of decomposing resources. They are assessed by various ratios such as carbon, nitrogen, lignin and polyphenol (Heal, 1997; Mungai and Motavalli, 2006). Environmental conditions also much affect on the decomposition, particularly climate. Climate has a dominant effect on litter decomposition rates on a regional scale, whereas litter quality dominates at a local level (Meentemeyer, 1978; Dyer *et al*., 1990). Another important factor of decomposition is soil fauna. These soil animals play an important role in decomposition processes through breakdown and digestion of litter (Brussaard, 1998; Bradford *et al*., 2002) and stimulate microbial activity (Kampichler and Bruckner, 2009). Naturally, soil fauna is a species-rich group in most terrestrial ecosystems. Soil microfauna is high abundant in temperate terrestrial ecosystems, while soil macrofauna is common in tropical terrestrial ecosystems (Swift *et al*., 1979).

In Thailand, the amount of forest area is estimated at 15 million hectares. Of these, 31% are considered as tropical evergreen forest and 11% are classified as dry dipterocarp forest (Royal Forest Department, 2012). Information on litter decomposition processes in tropical rainforests is relatively poor when compared to temperate forests (Hirobe *et al*., 2004). Moreover, the influence of factors on litter decomposition is still not fully understood (Aerts, 1997). The objective of this study was to investigate the influences of climate, litter quality and soil macrofauna on decomposition rates of leaf litter in dry dipterocarp and dry evergreen forests in Sakaerat Biosphere Reserve, northeastern Thailand. Analyses of the linkages between environmental factors and decomposition rates may contribute to our understanding of the composition process in tropical forest ecosystems.

Materials and methods

Study area

The study area was located at Sakaerat Biosphere Reserve (SBR), Nakhon Ratchasima province, northeastern Thailand (14˚ 30' N and 101˚ 55' E) (Fig 1). The SBR covers an area of 78 km^2 and is situated in mountainous terrain at an altitude of 280 - 762 m above sea level. In 2008, the average annual temperature at SBR was 25.7 ˚C and annual rainfall was 1,131.9 mm. There are three seasons, namely the rainy season from May to October, the winter from November to February and the summer from March to mid-May. The lowest relative humidity is about 84% and the highest is about 96% (Sakaerat Biosphere Reserve, 2014).

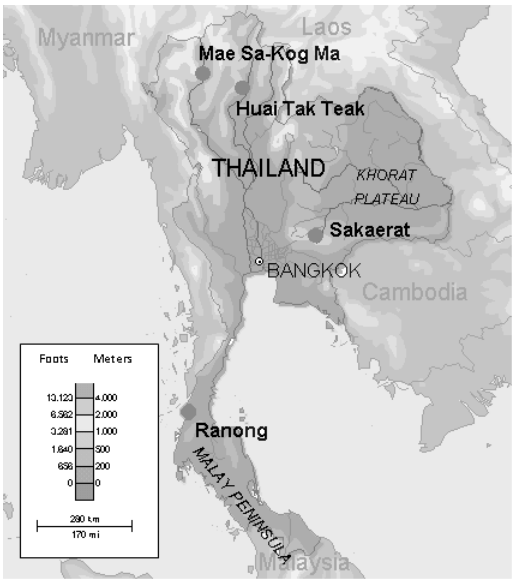

Fig. 1. The location of Sakaerat Biosphere Reserve (SBR), northeastern Thailand.

Vegetation types of the area are dry evergreen forest (DE) (46.84 km^2 or 59.97%), dry dipterocarp forest (DD) (15.51 km^2 or 18.57%), bamboo forest (1.12 km^2 or 1.43%), forest plantation (14.46 km^2 or 18.52%) and grassland (0.93 km^2 or 1.19%). The DD occupies the north-eastern portion, while the DE occupies the south-western portion of the area. The DD is a deciduous broad-leaved forest community type occurring on relatively dry sites and is mainly composed of trees belonging to the Dipterocarpaceae family such as *Shorea obtusa*, *S. siamensis*, *S. floribunda*, *Dipterocapus intricatus* and *Gardenia sootepensis*. The DE is usually referred to the tropical semi-evergreen rain

forest. The main vegetation in DE includes indigenous tree species such as *Hopea ferrea*, *H. odorata* and *Hydnocarpus ilicifolius* (Lamotte *et al*., 1998).

Litter preparation and experimental design

Six experiment plots (20 x 20 m) were established in two main ecosystems of SBR; 3 in DD and 3 in DE. During December 2006 to April 2007, three 1 x 1 m^2 of litter traps were spread under the canopy to collect natural fallen litter in each experiment plot. The litter was collected at the end of April 2007 and immediately transported to the laboratory at Suranaree University of Technology (SUT). Then, it was cleaned, oven-dried at 60 ˚C for 48 h to a constant weight and stored in plastic bags at 5 ˚C until incubation in the fields (Sariyildiz and Anderson, 2003).

A mixed litter experiment was used for the study, using 30 x 30 cm nylon net litterbags with 5 mm mesh size to allow the entry and exit of macrofauna (Wardle *et al*., 2006). Each litterbag treatment contained 30 g of dried weight litter, sealed and labeled with a plastic tag. A total of 36 litterbags were placed in DD and 36 bags were placed in DE on June 2007 and incubated for 12 months. Each plot comprised 12 litterbags for bimonthly interval examination. All litterbags were placed directly on the soil surface and movement from the sites were prevented by short pieces of wire attached to each of the four corners. There was a nylon net with 2 mm mesh size covering each plot to prevent the litter in disturbing the experiment.

At 2-month intervals from June 2007 to May 2008, one litterbag per treatment was randomly harvested from each replicate plot. The retrieved litterbags were placed in separate plastic bags and directly transferred to the laboratory. Leaf residues were oven-dried at 60 ˚C for 48 h and then weighed (Sariyildiz and Anderson, 2003; Alhamd *et al*., 2004).

Litter quality

The initial C, N, lignin and cellulose contents were determined in each litter treatment before placing in the field. Each litter treatment was analyzed for C concentration by the dry digestion method, N concentration by the Kjeldahl method and then the C/N ratio was calculated (Alhamd *et al*., 2004). Lignin and cellulose were determined using the acid detergent fibre method (ADF) (Rowland and Roberts, 1994).

Climate data and macrofauna decomposer

The climate data at the study sites were measured bimonthly, including temperature, relative humidity and precipitation. These data were recorded according to meteorological stations in SBR. The invertebrates in each litterbag were hand-picked by using a paintbrush or forceps and preserved in 90% ethanol. Counting and identification to non-insect class and insect order level of the invertebrates were done afterwards.

Data analysis

Decomposition rates were determined by mass loss, the difference between initial litter weight and the dry mass of remaining litter after incubation was calculated. The decomposition rates of litter were fitted to a single exponential decay model of Olson (1963), as the following exponential function; $X_t/X_0 = e^{-kt}$, where X_0 is the initial mass of dry matter, X_t is the mass of dry matter after a given month of incubation t, t is the time and k is the decomposition rate constant.

The diversity index of invertebrates was calculated by the Shannon-Weiner diversity index (Krebs 1998). *T*-test was used for detecting significant differences in climate data, litter quality, macrofauna community and decomposition rates between the forest treatments. Pearson correlation was used for analysis the interaction between decomposition rates and all parametric data.

Log-transformation was employed when the data did not distribute normally. The level of significance was set at 0.05. All statistical analyses were performed using PASW Statistics 18 software (IBM, USA).

Results

Climate data

From June 2007 to May 2008, the mean monthly temperature in DD was higher than in DE. The maximum temperature after incubation in DD and DE were in June - July 2007 at 29 ˚C and 28.87 ˚C, respectively. The minimum temperature in DD and DE were 24.55 ˚C and 22.27 ˚C, respectively, recorded in December 2007 - January 2008 (Fig 2).

The maximum relative humidity in DD and DE were 93% and 93.67%, respectively. The highest relative humidity was found in August - September 2007 in both ecosystems, while the lowest was found in December 2007 - January 2008, about 82.50% in DD, and about 84.37% in DE (Fig 2).

The annual rainfall was 1,002.9 mm in DD and was 889.07 mm in DE. This precipitation was measured mostly from June to November 2007, and from April to May 2008 at both sites (Fig 2). The highest rainfall was in August - September 2007 with 288.40 mm in DD and in April - May 2008 with 281.93 mm for DE, respectively (Fig 2). There was no difference in all climate parameters between DD and DE ($p > 0.05$).

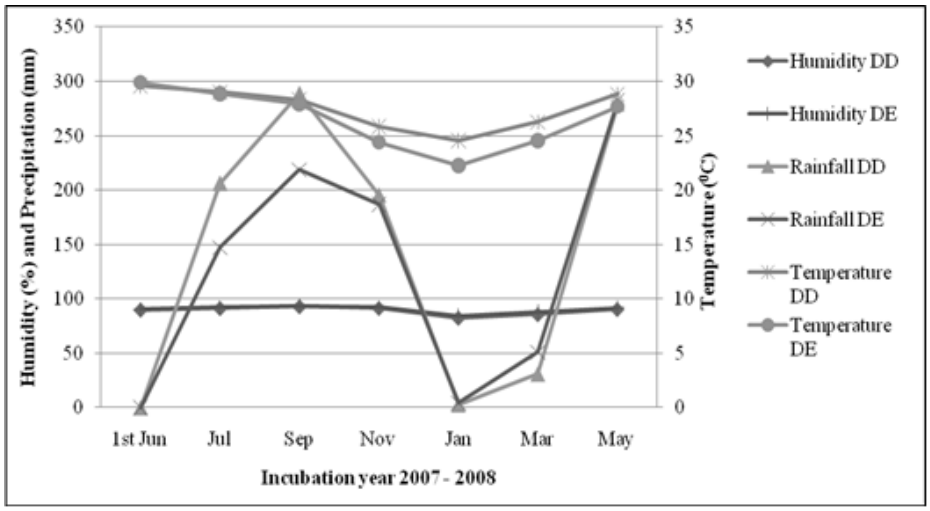

Fig. 2. The mean temperature (˚C), relative humidity (%), and precipitation (mm) in dry dipterocarp (DD) and dry evergreen forests (DE) in SBR from June 2007 to May 2008.

Litter quality, mass remaining and decomposition rate

The leaf litter in both forests had a low rate of remaining weight. In DD, there was 84.02% at the beginning period of determination and was 6.57% after one year of incubation. The litter remaining was 53.07% at the beginning time of incubation and was 14.83% at the last period of incubation in DE (Fig 3). The results showed a highly significant difference of annual litter mass loss between DD and DE ($p < 0.01$).

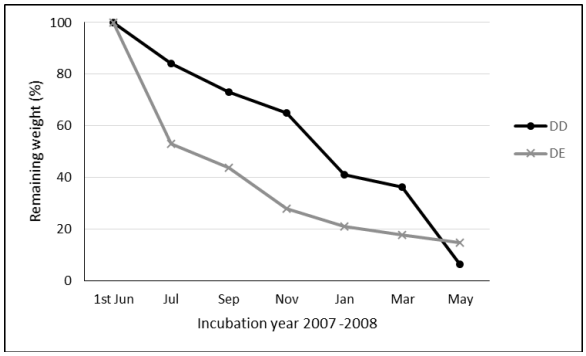

Fig. 3. The mean of total mass remaining (%) of leaf litter in dry dipterocarp (DD) and dry evergreen forests (DE) in SBR from June 2007 to May 2008.

The decomposition rates of leaf litter had different patterns between DD and DE. There were the lower rates in the early period (k = 0.09±0.07) but higher rates in the last period (k = 0.23±0.02) in DD. On the other hand, there were higher rates in the early period (k = 0.32±0.17) and lower rates in the last period (k = 0.16±0.01) in DE. Additionally, there was a highly significant difference in decomposition rates between ecosystems ($p < 0.01$). The mean annual decomposition rates of DD and DE were 0.11±0.02 and 0.21±0.27, respectively (Fig 4). The initial litter quality did not differ between ecosystems ($p > 0.05$) (Table 1).

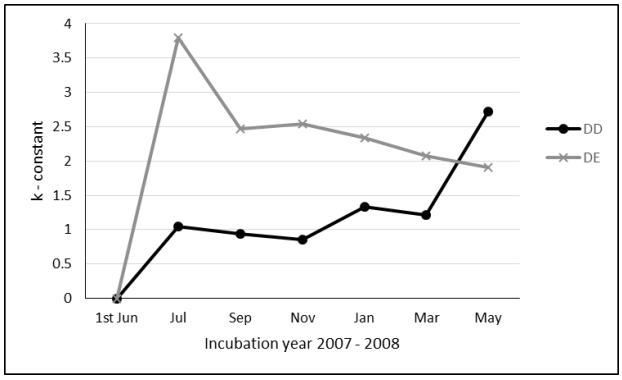

Fig. 4. The decomposition rate (k-constant) of leaf litter in dry dipterocarp (DD) and dry evergreen forests (DE) in SBR from June 2007 to May 2008.

Table 1 Initial leaf litter quality in dry dipterocarp (DD) and dry evergreen forests (DE) in SBR from June 2007 to May 2008.

Treatment	C (%)	N (%)	Lignin (%)	Cellulose (%)	C/N ratio
DD	24.73	0.75	19.47	28.25	33.02
DE	22.61	1.07	17.61	23.45	21.12

Soil macrofauna diversity

The results showed that 12 classes/orders of macrofauna decomposers were found in DD and 15 classes/orders were found in DD. These macrofauna decomposers comprised of 2 non-insect classes and 10 insect orders in DE, and 5 non-insect classes and 10 insect orders in DE. An average number of macrofauna per bag in DD was 176.34±6.13 individuals. It was the lower number than in DE which was 260.68±7.98 individuals per bag. Isoptera was the highest abundance of decomposers both in DD (34.59% of total macrofaunas) and DE (32.86% of total macrofaunas). The second highest abundance was Hymenoptera, which was approximately 24.01% of total macrofaunas in DD and was 18.40% of total macrofaunas in DE (Table 2).

The macrofauna in DE had a higher diversity than in DD ($p < 0.05$). The Shannon-Weiner diversity index of total macrofauna in the whole year was 2.01 in DD, and it was 2.22 in DE. However, the *t*-test showed that the diversity of total macrofauna in both forests were not significantly different ($p > 0.05$).

Table 2 Relative abundance (individuals per bag) and proportion (%) of macrofauna (class/order) in dry dipterocarp (DD) and dry evergreen forests (DE) in SBR from June 2007 to May 2008.

TAXA	DD		DE	
	Relative abundance	%	Relative abundance	%
O.Thelyphonida	-	-	15.33	5.88
C.Chilopoda	1.33	0.75	1.67	0.64
C.Diplopoda	-	-	6	2.3
C.Oligochaeta	4.33	2.46	3.33	1.28
C.Gastropoda	-	-	7.67	2.94
O.Orthoptera	16.67	9.46	22.67	8.7
O.Homoptera	7.67	4.35	6.67	2.56
O.Hemiptera	2	1.13	7.67	2.94
O.Blattaria	14.33	8.12	19.67	7.54
O.Diptera	4	2.27	1	0.38
O.Collembola	14.67	8.32	25.67	9.85
O.Coleoptera	11	6.24	16.33	6.26
O.Isoptera	61	34.59	85.67	32.86
O.Hymenoptera	33	18.72	31.67	12.15
O.Thysanura	6.33	3.59	9.66	3.71
Total	176.34	100	260.68	100

Influence of climate, litter quality and macrofauna on leaf litter decomposition

In DD, litter decomposition was influenced by temperature (r = - 0.32, $p < 0.01$), precipitation (r = 0.23, $p < 0.05$) and relative humidity (r = - 0.27, $p < 0.01$), while relation between precipitation and decomposition rate was found in DE (r = 0.4, $p < 0.01$) (Table 3).

Table 3 The correlation between climate, litter quality and macrofauna and decomposition rate in dry dipterocarp (DD) and dry evergreen forests (DE) in SBR from June 2007 and May 2008.

Factor of decomposition	**DD**	**DE**
Climate		
Temperature (˚C)	- 0.32**	0.2
Relative humidity (%)	- 0.27**	0.24
Precipitation (mm)	0.23*	0.4**
Litter quality		
C content (%)	0.23	- 0.91*
N content (%)	- 0.52	0.2*
Lignin (%)	- 0.44	0.84**
Cellulose (%)	- 0.5	0.52
C-N ratio	0.52	- 0.54*
Macrofauna		
Abundance	0.21*	0.38*
Diversity	0.56**	0.67**

** Significant at the 0.01 level; * Significant at the 0.05 level.

The significant influence of initial litter quality on decomposition rate was not found in DD but it was found only in DE. There were positive correlation between the N content and lignin content and decomposition rate (r = 0.2, $p < 0.05$ and r = 0.84, $p < 0.05$, respectively) and negative correlation between the carbon content and the ratio of carbon and nitrogen in litter in DE (r = - 0.91, $p < 0.05$ and r = - 0.54, $p < 0.05$, respectively) (Table 3).

The abundance of macrofauna decomposers influenced the decomposition rates in both DD and DE (r = 0.21, $p < 0.05$ and r = - 0.58, $p < 0.05$, respectively). In addition, the species diversity of macrofauna also correlated with decomposition rates in both DD and DE (r = 0.56, $p < 0.01$ and r = 0.67, $p < 0.01$, respectively) (Table 3).

Discussions

Influence of climate on leaf litter decomposition

The climate is known that it has a direct effect on decomposition rate. It also has various indirect effects on decomposition processes such as plant community composition and litter quality (Pérez-Harguindeguy *et al*., 2007). The major climate factors influenced on litter decomposition i.e. temperature, rainfall, moisture and evapotranspiration (Swift *et al*., 1979). Similarly, environmental conditions also affected the decomposition rate in this study. Precipitation had a positive correlation with the decomposition rate in both DD and DE, implied that increasing of rainfall caused higher the decomposition rate in both ecosystems. In contrast, temperature and relative humidity had a negative correlation to the decomposition in DD. It can be inferred that decreasing of temperature and relative humidity caused the higher decomposition rate in DD.

Influence of litter quality on leaf litter decomposition

Litter quality is considered as the most important factor influencing decomposition rate (Lavelle *et al*., 1993). The major litter quality controlled decomposition rates, including N concentration (Bosatta and Staaf, 1982), C concentration (Hoorens *et al*., 2003), P concentration (Liu *et al*., 2007), C/N ratio (Sundarapandian and Swamy, 1999; Tateno *et al*., 2007), cellulose (Herman *et al*., 2008), hemicellulose (Vaieretti *et al*., 2005) as well as lignin (Meentemeyer 1978). In this study, the correlation between initial litter quality and decomposition rate was prominent by C concentration, N concentration, lignin concentration and C/N ratio only in DE. Nitrogen content and lignin had the positive correlation to k-constant. It implied that when N concentration and lignin increase, decomposition rate will increase. In contrast, C concentration and C/N ratio show the negative correlation to the k-constant. It means that when C concentration and C/N ratio decrease, the decomposition rate will increase. These data support that leaf litter quality is an important factor influencing decomposition process.

Nevertheless, some studies demonstrated that no correlation between litter quality and decomposition rate. For instance, the study of Schaefer *et al*. (1985) revealed that initial N concentration and lignin did not relate to litter mass loss in Chihuahuan Desert, North America. Castro *et al*. (2010) showed that lignin and C/N ratio in litter did not correlate to decomposition rate in the National Ecological Research Park, Oak Ridge, Tennessee. Furthermore, Aerts (1997) suggested that no good litter quality parameter for predicting

decomposition rate. These data similar to the DD in this study that no correlation between litter quality and decomposition rate.

Influence of macrofauna decomposer on leaf litter decomposition

In this study, decomposition rates had positive correlations with abundance and diversity of macrofauna decomposers. However, it was found that higher abundance of macrofauna decomposers in DE than in DD but the diversity did not differ between forests. Similarly, many previous studies also showed that macrofauna decomposers had influences on litter decomposition (Brussaard, 1998; Bradford *et al*., 2002). Gonz áez and Seastedt (2001) revealed that fauna affected on leaf litter decomposition in tropical and subalpine forests between 1.6% and 66.2%. The influence of macrofauna decomposers on litter decomposition vary on many factors such as litter type, litter quality and climate conditions (Wardle *et al*., 2006).

Several studies reported that termites and ants were important decomposers of leaf litter (Silva *et al*., 1985; McGlynn and Poirson, 2012). According to this study, Isoptera (eg. termites) and Hymenoptera (eg. ants) were two most abundant orders of macrofauna in both DD and DE. Moreover, millipedes and earthworms also considered as important macrofauna for litter decomposition (Slade and Riutta, 2012). Nevertheless, millipedes and earthworms were low abundances in this study. They may have little role in the litter decomposition in this study.

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