THE INFLUENCE OF LITTER DIVERSITY ON DECOMPOSITION PROCESSES IN DRY DIPTEROCARP AND DRY EVERGREEN FORESTS AT SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA

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อิทธิพลของความหลากชนิดของเศษซากพืชต่อกระบวนการย่อยสลายในป่าเต็งรังและป่าดิบแล้งที่สถานีวิจัยสิ่งแวดล้อมสะแกราช จังหวัดนครราชสีมา

นายเสกสรร สรรสรพิสุทธิ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.ณัฐวุฒิ ธานี, 200 หน้า

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาอิทธิพลความหลากชนิดของเศษซากใบไม้ที่มีต่ออัตราการย่อยสลายเศษซากใบไม้ รวมทั้งการศึกษาความสัมพันธ์ระหว่างอัตราการย่อยสลายกับสภาพอากาศ คุณภาพของเศษซากใบไม้ สภาพทางกายภาพและเคมีของดิน ตลอดจนสัตว์ผู้ย่อยสลายที่ไม่มีกระดูกสันหลังที่เกิดขึ้นในป่าดิบแล้งและป่าเต็งรัง บริเวณสถานีวิจัยสิ่งแวดล้อมสะแกราช จังหวัดนครราชสีมา การทดลองใช้วิธี Mixed Litter Experiment โดยใช้ถุงตาข่ายไนล่อนสำหรับบรรจุเศษซากใบไม้ที่มีขนาดรูตาข่าย 5 มิลลิเมตร ในการศึกษาอัตราการย่อยสลายของเศษซากใบไม้ที่มีสัดส่วนจำนวนชนิดใบไม้แตกต่างกัน 5 สัดส่วน ได้แก่ เศษซากของใบไม้ชนิดเดียว เศษซากผสมของใบไม้ 1 2 3 และ 4 ชนิด รวมทั้งเศษซากใบไม้ที่ร่วงหล่นตามธรรมชาติโดยไม่ได้จำแนกชนิด การเก็บตัวอย่างทำทุก ๆ 2 เดือนระหว่างเดือนมิถุนายน พ.ศ. 2550 ถึงเดือนพฤษภาคม พ.ศ. 2551 ข้อมูลสภาพอากาศ ได้แก่ อุณหภูมิ ความชื้นสัมพัทธ์ และปริมาณน้ำฝนบริเวณแปลงทดลองตรวจวัดจากสถานีตรวจวัดสภาพอากาศของสถานีวิจัยสิ่งแวดล้อมสะแกราช ทำการศึกษาเกี่ยวกับคุณภาพเศษซากใบไม้จากการตรวจวัดการเปลี่ยนแปลงปริมาณคาร์บอน ไนโตรเจน ลิกนิน เซลลูโลส และอัตราส่วนระหว่างคาร์บอนกับไนโตรเจน ทำการศึกษาความหลากหลายของสัตว์ผู้ย่อยสลายไม่มีกระดูกสันหลังโดยจัดจำแนกถึงระดับอันดับ และตรวจติดตามการเปลี่ยนแปลงของสภาพดินใต้ถุงเศษซากใบไม้ที่ความลึก 5 - 10 เซนติเมตร ทำการวิเคราะห์หาค่าคงที่ของการย่อยสลายของเศษซากใบไม้แต่ละชนิดและหาความสัมพันธ์ระหว่างปัจจัยต่างๆ โดยใช้สถิติ ANOVA และ Pearson's correlation ผลการศึกษาพบว่าอัตราการย่อยสลายเศษซากใบไม้ ในป่าดิบแล้งสูงกว่าอัตราการย่อยสลายในป่าเต็งรัง โดยมีค่าคงที่ของการย่อยสลาย เท่ากับ 1.455 ± 0.846 และ 0.860 ± 0.578 ตามลำดับ จากการทดลองครั้งนี้พบแนวโน้มของอัตราการย่อยสลายที่แตกต่างกันระหว่างป่าทั้งสองประเภท โดยอัตราการย่อยสลายของเศษซากใบไม้ในป่าดิบแล้งในช่วงแรกจะสูงกว่า

ในช่วงท้ายของการทดลอง ในขณะที่อัตราการย่อยสลายของเศษซากใบไม้ในป่าเต็งรังจะมีค่าต่ำในช่วงแรกแล้วค่อย ๆ เพิ่มขึ้นในช่วงท้ายการทดลอง ความแตกต่างของจำนวนชนิดผสมของเศษซากใบไม้ ไม่ส่งผลกระทบต่ออัตราการย่อยสลายอย่างมีนัยสำคัญทั้งในป่าดิบแล้งและในป่าเต็งรัง จากการวิเคราะห์ความสัมพันธ์ระหว่างอัตราการย่อยสลายกับปัจจัยอื่น ๆ พบว่า อัตราการย่อยสลายมีความสัมพันธ์ในเชิงบวกกับปริมาณน้ำฝน และพบความสัมพันธ์ในเชิงลบกับอุณหภูมิและความชื้นสัมพัทธ์ในป่าเต็งรัง ส่วนในป่าดิบแล้งพบเฉพาะความสัมพันธ์ในเชิงบวกระหว่างอัตราการย่อยสลายกับปริมาณน้ำฝนเท่านั้น สำหรับความสัมพันธ์กับปัจจัยอื่นๆ พบว่า อัตราการย่อยสลายในป่าเต็งรังไม่มีความสัมพันธ์อย่างมีนัยสำคัญกับปริมาณเริ่มต้นของคุณภาพเศษซากใบไม้ ส่วนสภาพการสลายของเศษซากใบไม้พบว่ามีความสัมพันธ์กับความชื้นในดิน ค่าความเป็นกรด-เบส ปริมาณสารอินทรีย์ ปริมาณคาร์บอน ฟอสฟอรัส โปแตสเซียมและอัตราส่วนระหว่างคาร์บอนกับไนโตรเจนของดิน สำหรับในป่าดิบแล้ง ผลการศึกษาพบความสัมพันธ์ระหว่างอัตราการย่อยสลายกับปริมาณเริ่มต้นของคาร์บอน ไนโตรเจน ลิกนินและอัตราส่วนระหว่างคาร์บอนกับไนโตรเจนในเศษซากใบไม้ ตลอดจนมีความสัมพันธ์กับการเปลี่ยนแปลงปริมาณไนโตรเจน ปริมาณอินทรีย์สาร ปริมาณคาร์บอน ฟอสฟอรัส โปแตสเซียมและอัตราส่วนระหว่างคาร์บอนกับไนโตรเจนในดินอีกด้วย การสำรวจสัตว์ผู้ย่อยสลายจากการทดลองครั้งนี้ในป่าเต็งรัง มีสัตว์ไม่มีกระดูกสันหลังที่พบในถุงเศษซากใบไม้รวมจากจำนวนตัวเฉลี่ยต่อถุงทั้งหมด 557 ตัว จำแนกได้เป็น 15 อันดับ ส่วนในป่าดิบแล้งพบว่ามีความหลากหลายของสัตว์ผู้ย่อยสลายสูงกว่าป่าเต็งรัง โดยพบสัตว์ไม่มีกระดูกสันหลังในถุงเศษซากใบไม้รวมจากจำนวนตัวเฉลี่ยต่อถุงทั้งหมด 884 ตัว จำแนกได้เป็น 16 อันดับ ค่าดัชนีความหลากหลายแบบ Shannon-Weiner เฉลี่ยในป่าเต็งรังเท่ากับ 2.147 และในป่าดิบแล้งเท่ากับ 2.292 โดยพบว่าอัตราการย่อยสลายในป่าทั้งสองมีความสัมพันธ์อย่างมีนัยสำคัญในทางบวกกับค่าดัชนีความหลากหลายของสัตว์ผู้ย่อยสลาย

สาขาวิชาชีววิทยา ลายมือชื่อนักศึกษา_____

ปีการศึกษา 2553 ลายมือชื่ออาจารย์ที่ปรึกษา_____

SEKSAN SANSORRAPISUT : THE INFLUENCE OF LITTER DIVERSITY ON DECOMPOSITION PROCESSES IN DRY DIPTEROCARP AND DRY EVERGREEN FORESTS AT SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA. THESIS ADVISOR : ASST. PROF. NATHAWUT THANEE, Ph.D. 200 PP.

LITTER DECOMPOSITION RATE / INVERTEBRATE DECOMPOSER / DRY DIPTEROCARP FOREST / DRY EVERGREEN FOREST / SAKAERAT ENVIRONMENTAL RESEARCH STATION

The aims of this research were to study the influence of litter diversity on the decomposition rate and to investigate the relationship between decay rate and climate, litter quality, soil property and invertebrate decomposers. The Mixed Litter Experiment was used for this study in dry dipterocarp (DDF) and dry evergreen (DEF) forests at Sakaerat Environmental Research Station (SERS). Five different treatments were used in each ecosystem with 1, 2, 3, or 4 litter species or natural fallen litter, contained in 5mm mesh litter bags. The investigations were carried out at 2 month-intervals from June, 2007 to May, 2008. The meteorological data was recorded according to the SERS data. The invertebrate decomposers were investigated and classified to order. The properties of soil under the litter bags were measured at 5-10 cm depths. The decomposition rate constant among the different treatments of litter and the correlation of all parameters were analyzed by ANOVA and Pearson's correlation, respectively. The results showed that the mean annual decay rates (k) of DDF and DEF were 0.860 ± 0.578 and 1.455 ± 0.846, respectively. There was a

significantly different rate of annual litter mass loss between DDF and DEF forests at the significance level of 0.01. The patterns of decomposition rate were different between ecosystems. The effect of litter diversity on the annual k-constant was not found in either DDF or DEF. The decomposition rate had a positive relationship with rainfall and negative relationship with temperature and relative humidity in DDF forest, but it had only a positive correlation with precipitation in DEF. The results showed correlation of the k-constant with carbon concentration, lignin content, nitrogen content and C-N ratio in DEF. The relationships of litter decay rate were found with soil moisture, pH, soil organic matter (SOM), carbon concentration, available P, available K and C-N ratio in DDF forest, and found with nitrogen content, SOM, soil carbon content, available P, available K, and C-N ratio in DEF ($P \leq 0.05$). Invertebrate decomposers of 15 orders with an average of 557 individuals were found in DDF and 16 orders with on average of 884 individuals were found in DEF. The most abundant orders of decomposers in both DDF and DEF were Isoptera and Hymenoptera. The decomposition rate had positive correlation with the Shannon-Weiner diversity index in both DDF and DEF forests. The mean of Shannon-Weiner diversity index in dry DDF was 2.147 and it was 2.292 in DEF.

School of Biology Student's Signature_____

Academic Year 2013 Advisor's Signature_____

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CHAPTER I

INTRODUCTION

1.1 The Origin and Importance of the Problem

Decomposition is the physical and chemical breakdown of detritus (i.e., dead plant, animal, and microbial material). Decomposition causes a decrease in detrital mass, as materials are converted from dead organic matter into inorganic nutrients and CO_2 through the action of leaching, fragmentation, and chemical alteration (Chapin, 2002). The biological nutrients and other elements can be used for plant and microbial production. Decomposition is a consequence of interacting physical and chemical processes, so the remaining soil organic matter may be stabilized through these processes, or further decomposition. The important features of decomposition processes are the decay rates and the transfer of organic materials to different sites.

Decomposition has a role as an important process in a balanced ecosystem. The reasons are this process is a result of the physical breakdown of litter, the end figure of living things, the transfer of organic matter and nutrients to the soil and the release of carbon dioxide to the atmosphere (Gonzalez, 2002). So, decomposition is closely tied to nutrient cycling and is essential for the regeneration of organically bound nutrients in the ecosystem.

There are three important components of decomposition processes, litters, decomposers, and products. Litters are the detritus or the dead remnant of living

things, such as plant detritus or a carcass. Decomposers are the biota that exist by decomposing others, for example, microorganisms such as bacteria and fungi, and soil fauna namely millipedes, woodlice, mites, springtails, earthworms, etc. The products are substances, nutrients and gases which are the results of decomposition activities. The balanced interrelationship of decomposition components strongly affects the ecosystems.

Furthermore, efficient processes of decomposition are influenced by many factors. The most important factors are resource quality, decomposing organisms and environmental conditions (Swift et al., 1979 reviewed by Tian et al., 1997). Decomposition rates are highly dependent on the chemical quality of the decomposing resources, as assessed by various ratios, such as carbon, nitrogen, lignin and polyphenols (Heal, 1997). Traditionally, soil organisms, encompassing both fungi and bacteria, and soil fauna such as collembolan, mites and earthworms, among others, have been considered to be important factors for litter decomposition and such groups have been described as having different roles in decomposition (Berg and McClaugherty, 2003). Environmental conditions, both physical and chemical components, very much affect the decomposition. The most important factor of physico-chemical environment is climate. Climate has a dominant effect on litter decomposition rates on a regional scale, whereas litter quality dominates at a local level (Meentemeyer, 1984 quoted in Berg and McClaugherty, 2003). Thus, for a given site and climate, one should expect differences in mass-loss rates of litter to be primarily due to their chemical and physical properties (Berg and McClaugherty, 2003). The climate conditions that influence decomposition are microclimate, such as

moisture, temperature, pH, and aeration. The relationship of resource quality, decomposer organisms and environmental conditions affect decomposition rate.

However, many decomposition studies have shown the decay rate of litter to be very different in various places. In natural ecosystems, there are many factors that influence decomposition because of different site conditions. In general process, decomposition is controlled by the physical environment, the quantity and quality of substrate available to decomposers, and the characteristics of the microbial community (Swift et al. 1979, reviewed by Chapin, 2002). Although the main factors of decomposition over a regional scale are litter chemical composition and climate, there are numerous factors that are important in regulating decomposition at the local or even micro scale. These are related to soil characteristics, nutrient availability and cycling, soil fauna, topography, and plant community composition and structure (Berg and McClaugherty, 2003). These factors are different in various sites and exert their influence by modifying the microclimate and yield several litter types which have different decay rates.

A prominent factor in each place is plant species composition. The nature of the plant community present influences the relationship between plant litter quality and decomposition rate, because plant species differ tremendously in the quality of litter that they produce (Wardle et al., 2006). Seastedt (1984, reviewed by Smith and Bradford, 2003) suggested that, due to differences in resource quality between species, litter-mixtures might decompose at a different rate to that which would be predicted from single species litterbags. Numerous investigators have explored the effect of litter diversity on decomposition rate (Schadler and Brandl, 2005). Leaf litter chemistry also can influence overall decomposition rates and decay rates of

component litters within mixtures, through the transfer of nutrients and secondary chemicals among litter types or by influencing decomposer activity (Gartner and Cardon, 2004). As mentioned above, species diversity consequently affects decomposition processes in an ecosystem.

Much decomposition research has focused on how litters of individual species decompose (Gartner and Cardon, 2004). Most studies of decomposition have followed the decay of a single species of litter. A few studies have deliberately mixed litters to investigate the possibility that a mixture, reflecting the natural heterogeneity of litter fall, would behave differently than a single species (Berg and McClaugherty, 2003). Much research only studied the decomposition rate or the change of other factors in decomposition processes of total leaf litters, out of the interest in the effect of the litter species diversity factor. For this reason, knowledge of the effect of the litter diversity factor on decomposition processes is poorly understood. Much remains unknown about how litter mixing and diversity affects the abundance and diversity of decomposer organisms (Wardle et al., 2006). Thus, there has been considerable interest in the influence of litter species diversity on decomposition processes.

1.2 Research Objectives

The objectives of this research were:

1.2.1 To study the decomposition rate of eight dominant monocultures and different mixed litter species in dry dipterocarp forest and dry evergreen forest;

1.2.2 To study species diversity of invertebrate decomposers in litter in dry dipterocarp forest and dry evergreen forest;

1.2.3 To examine the changing in litter quality in decomposing mono-species and different mixed litters after the incubation;

1.2.4 To study the changing physical and chemical properties of soil after litter decomposition in dry dipterocarp forest and dry evergreen forest;

1.2.5 To analyze the linkages between soil fertility, decomposer diversity, litter quality and decomposition rate of mono-species and different multiple species in dry dipterocarp forest and dry evergreen forest.

1.3 Research Hypotheses

1.3.1 The tree species composition influences the decomposition processes in each ecosystem.

1.3.2 The soil properties are affected by decomposition processes.

1.3.3 There are interrelationships between decomposer diversity, litter quality and decomposition rate of different litter diversities in dry dipterocarp forest and dry evergreen forest.

1.4 Scope and Limitation of the Study

1.4.1 This study examined litter quality in terms of C content, N content, C/N ratio, lignin, and cellulose concentration.

1.4.2 The studied decomposers were meso- and macro-invertebrate decomposers and they were classified to order/class level.

1.4.3 The litter diversity referred to the number of component litter species.

1.4.4 The experimental time scale was 12 months from June, 2007 to May, 2008.

1.5 Expected Results

1.5.1 This study was expected to provide understanding of the decomposition of dominant species leaf litters and their relationship with nutrient dynamics in the forest.

1.5.2 Understanding of the influence of species diversity and related factors on decomposition processes in dry dipterocarp forest and dry evergreen forest, the dominant ecosystems in Sakaerat Environmental Research Station (SERS).

1.5.3 Useful results to apply for ecosystem management and planning, as well as in agricultural practices.

1.5.4 Identification of invertebrate decomposer species as a basis for conservation management in forest ecosystems.

1.6 Key Words

The key words of this research are Sakaerat Environmental Research Station, decomposition rate, litter bag experiment, litter quality, decomposers, dry dipterocarp forest and dry evergreen forest.

Sakaerat Environmental Research Station (SERS) is the station where many fields of research are conducted as a focal point for scientific research, conservation training and teaching, local community involvement, and eco-tourism. It is a biosphere reserve area in the Man and Biosphere Program (MAB) of UNESCO and administered by the Thailand Institute of Scientific and Technological Research (TISTR) as a facility for ecological and environmental research. SERS lies in Nakhon Ratchasima Province, Thailand.

Decomposition rate is the rate for mass loss of leaf litter by the interacting physical and chemical processes occurring inside and outside of living organisms. Decomposition results from three types of processes, (1) leaching, (2) fragmentation, and (3) chemical alteration.

Litter bag experiment is the experiment to study the decomposition. Leaf litter decomposition is most commonly measured using the litterbag technique. A known quantity of leaf litter is placed into a mesh bag, and the bag is then inserted into the litter layer of a forest floor. Bags are harvested at periodic intervals, dried and reweighed to determine the amount of mass lost.

Litter quality refers to the type of chemical compounds present in litter. In this experiment, the litter quality is defined in terms of C and N content, C/N ratio, lignin content and cellulose content.

Decomposers are the organisms which interact with plant residues and affect decomposition processes, such as microbial and invertebrate fauna. The decomposers in this research were meso- and macro-invertebrates.

Dry dipterocarp forest is one type of deciduous forest. Generally, this forest has an open canopy and is compose of xeric species, such as *Shorea obtusa* Wall., *Shorea siamensis* Miq., and *Dipterocarpus tuberculatus* Roxb. The forest floor is covered by grasses and herbs. Most of the trees in this area shed their leaves during the dry season and the new leaves begin to grow before the rainy season. Dry dipterocarp forest is the important forest type in SERS area, it covers about 18.57%.

Dry evergreen forest is the forest type associated with moist continental climate. This forest is composed of a high biodiversity of species; the dominant species are *Hopea ferrea* Pierre, *Hopea odorata* Roxb., *Shorea sericeifolia* Fisch, &

Hutch *Memecylon ovatum* Smith, *Walsura trichostemon* Miq., *Hydnocarpus ilicifolius* King, and *Aglaia pirifera* Hance (Charoenpol, 2003). The trees are mostly evergreen species because dry evergreen forest is defined as the tropical semi-evergreen rain forest, and it covers the most, 59.97% in SERS area (TISTR 2002).

CHAPTER II

LITERATURE REVIEW

2.1 Decomposition

As defined in the Oxford English Dictionary, decomposition is "the action or process of decomposing, separation or resolution (of anything) into its constituent elements; disintegration; putrescence" (Dickinson and Pugh, 1974). All of these meanings apply to ecology, i.e., decomposition is the physical and chemical breakdown of detritrus, such as dead plants, animals, and microbial materials. Decomposition causes a decrease in detrital mass, as materials are converted from dead organic matter into inorganic nutrients and CO_2 (Chapin et al., 2002). It may signify the mechanical disintegration of dead plant structures from the stage where they are still attached to the living plants, to the humus stage where the gross cell structure is no longer recognizable. The alternative meaning is the breaking down of complex organic molecules to CO_2, water, and mineral components (Dickinson and Pugh, 1974). Berg and McClaugherty (2003) defined decomposition as the physical, chemical and biological mechanisms that transform organic matter into increasingly stable forms. Decomposition occurs mainly on or below ground and is largely out of sight. It is also responsible for the formation of humic substances that contribute to soil fertility as well as to the long term storage of carbon. Decomposition is closely tied to nutrient cycling and is essential for the regeneration of organically bound nutrients. Two important features of decomposition processes are their overall rates

and the transfer of organic materials to different macro- or microsites within the ecosystem.

2.1.1 The important processes of decomposition

Leaching, fragmentation, and chemical alteration of dead organic matter by decomposition produce CO_2 and mineral nutrients and a remnant pool of complex organic compounds. Decomposition is a consequence of interacting physical and chemical processes occurring inside and outside of living organisms. It results from three types of processes with different controls and consequences (Chapin et al., 2002).

1. Leaching by water transfers which soluble materials away from decomposing organic matter into the soil matrix. These soluble materials either are absorbed by organisms, react with the mineral phase of soil, or are lost from the system in solution.

2. Fragmentation by soil animals that breaks large pieces of organic matter into smaller ones, which provide a food source for soil animals and create fresh surfaces for microbial colonization. Soil animals also mix the decomposing organic matter into the soil.

3. Chemical alteration of dead organic matter which is primarily a consequence of the activity of bacteria and fungi, although some chemical reactions also occur spontaneously in the soil without microbial mediation.

2.1.2 The decomposition components

Decomposition processes will be successful for a healthy ecosystem because of three components. These are the substrates, decomposers, and products. The sources of substrate for decomposition food webs are litter from above- and

belowground sources, other organisms in the soil, and the excreted and secreted material from all these trophic interactions (Adl, 2003). Most of substrate in general ecosystems is litter, such as leaf litter, wood litter, and root detritus. Decomposers are organisms that require organic substrates to obtain their carbon for growth and development. They obtain their energy from deceased organisms. Decomposers themselves are organisms that break down organic materials to gain nutrients and energy. Decomposers accelerate the natural process of decomposition. They supply the required nutrients for other trophic levels. The important natural decomposers are bacterial, fungi, and invertebrate organisms such as earthworms, millipedes, woodlice, etc. Products of decomposition are very important for ecosystems. There are inorganic components, namely carbon dioxide, water, and mineral nutrients such as nitrogen, phosphorus, and potassium (Chapin et al., 2002). The relationship of these three components always drives the nutrient cycle in a good and sustainable ecosystem.

2.1.3 Influencing decomposition factors

Decomposition begins with complex plant detritus and produces carbon gases and humus. The process can be characterized by the rate of mass loss and the rates of nutrient immobilization and release. In addition, the chemical composition of decaying litter changes during decay. These changes are not, in all cases, linearly associated with mass loss. Neither are the changes in composition the same for similar litter substrates decomposing under different environmental conditions. Thus, there is a complex and interacting set of factors that regulate mass loss, humus formation, nutrient dynamics and patterns of change in chemical composition of decomposing plant litter (Berg and McClaugherty, 2003).

Decomposition processes are therefore determined by interactions among three factors, namely;

(1) Organisms.

Many living things act as decomposers in ecosystems. They are the main agents of litter fragmentation. There are fungi, the main initial decomposers of terrestrial dead plant material, bacteria are also important in lysing and breaking down live and dead bacterial and fungal cells. Soil animals influence decomposition by fragmenting and transforming litter, grazing populations of bacteria and fungi, and altering soil structure.

(2) Environmental conditions.

Physico-chemical environmental factors may be regarded as "external factors" to the decomposition process. The main factors are temperature, moisture, atmospheric CO_2, and some soil conditions. The effect of these varying factors is to influence decomposition rate.

(3) The quality of decomposing resources.

Decomposing resources are made up of a wide rage of chemical substances. They differ in the relative proportions of their major constituents i.e., C and N content, lipids and waxes, water-soluble carbohydrates, hemicellulose, cellulose, lignin, proteins, phenols, and other secondary plant compounds. Each of these compounds is considered to have its own specific decomposition rate, and decomposition of any resource will depend on its relative abundance.

These factors are not equally important because they operate at different spatial and temporal scales and may have opposing influences on decomposition processes.

2.2 The Litter System

Litter is the main decomposition sources. In ecology it is used with two meanings: the layer of dead plant material, which may be present on the soil surface; and dead plant materials which are not attached to a living plant (Dickinson and Pugh, 1974). The litter on the soil, or forest floor, acts as a sink and source of nutrient, and the rate at which forest litter falls and decays, regulates the energy flow, primary production, and nutrient cycling in forest ecosystems (Sundarapandian and Swamy, 1999, reviewed by Tchimbakala and Reversat, 2006).

2.2.1 Composition

A litter system is that part of the ecosystem within which above-ground litter accumulates and decomposes. It includes the above-ground litter which serves as the energy source, a rich microflora dominated by fungi and the epigeic invertebrates and surface roots that act as regulatory macro-organisms. In ecosystems, above-ground litter is a heterogeneous resource and comprises a mixture of relatively high quality resources, such as fresh leaf-litter, flowers, fruits, seeds, dead micro-organisms and animals, and structures of lower quality, mainly woody materials. Litter composition are also highly variable in time, climate, different age of trees, and different species.

2.2.2 Classification

Dickinson and Pugh (1974) reported that the structure of litter-systems differed substantially among plant communities and depended on:

1. The quality of input

2. The nature of the communities present

3. The composition and abundance of the macro-invertebrate communities present

The litter system has been divided into three types. This classification is based on the increasing thickness of the holorganic layers and the properties and morphology of the upper mineral horizon;

(1) Muld or mull

In the mull litter system, decomposing leaves and other litter material do not accumulate at the soil surface, either because they are completely decomposed in less than one year, or because they are exported to different systems of decomposition, such as the drilospheres or the termitosphere.

(2) Muldagtig mor or moder

Decomposition in moder systems is slow due to climatic, edaphic or trophic (resource quality) conditions that limit or preclude the activities of anecic decomposers and active white-rot fungi. There are the largely of decomposition rate, nutrient release and phenol-protein decomposed by decomposers.

(3) Mor

Mor litter systems occur at sites with unfavourable climatic conditions (low temperatures and impeded drainage), often with nutrient-deficient soils and low-quality litter. This system has many extremely limited conditions for decomposers, and these result in low decomposition with the result that the phenol-protein complexes and matted layers of decomposing litter accumulate on the surface of the mineral soil.

2.2.3 Structure of litter systems

Litter systems have two structural patterns, vertical structure and horizontal or lateral structure. Vertical structure is caused by the burial of old litter by that fallen more recently. Lateral variation in litter systems may result from the distributions of structures such as bark and fruits that fall close to the plants that produce them. A number of important litter-system properties are directly derived from the vertical and horizontal heterogeneity present.

2.3 Invertebrate Decomposers

Decomposer organisms are an important factor, which influence the decomposition of plant residues. Decomposition is mainly the result of microbial activities; soil fauna are important in conditioning the litter and in stimulating microbial actions. There are two courses by which soil fauna can affect plant litter decomposition and the rates of mineralization and humification of soil organic matter: directly, by physically modifying the substrate and soil environment, and indirectly, through interactions with the microbial community (Gonzalez, 2002). Of the many decomposer organisms in the ecosystem, one of the major groups is the invertebrate organisms. The role of these species in the soil interstitial space is inseparable from decomposition processes (Adl, 2003).

2.3.1 The role of invertebrates in decomposition

Soil fauna enhance the biodegradation and humification of organic residues in several ways: (i) by comminuting organic residues and increasing the surface area for microbial activity; (ii) by producing enzymes which break down complex bio-molecules into simple compounds, and polymerize compounds to form

humus; and (iii) by improving the environment for microbial growth and interactions (Tian et al., 1997). Invertebrates have important roles in decomposition processes and with the microflora interactions. These interactions broadly occur at three levels of resolution: (i) 'microfood-webs', involving soil nematodes, protozoa, and their predators; (ii) 'litter-transforming systems' involving soil mesofauna and some macrofauna, in which interactions take place in purely organic structures, such as fragmented material and faecal pellets and (iii) 'ecosystem engineers' involving larger organisms, which interact with microorganisms in both the "internal" and "external" rumen, and which build organo-mineral physical structures that significantly alter the habitat for smaller organisms (Wardle and Lavelle, 1997).

These invertebrates are "litter transformers" and are generally unable to degrade phenol-protein complexes. Although certain groups may ingest some mineral components from the soil and mix them with organic matter, most litter transformers produce purely organic faecal structures and do not participate in the transfer of decomposing litter into the sub-soil or to other systems of decomposition, such as the drilosphere or termitosphere. Consequently, their direct contribution to decomposition through respiration is limited to a small percentage of overall mineralization. Soil fauna modify the soil environment by mixing organic and mineral particles, and changing the water infiltration and aeration regimens. Tillering by soil fauna directly alters soil physical, chemical, and biological properties. The effects of the substrate modification by soil fauna on the decomposition process are diverse (Gonzalez, 2002).

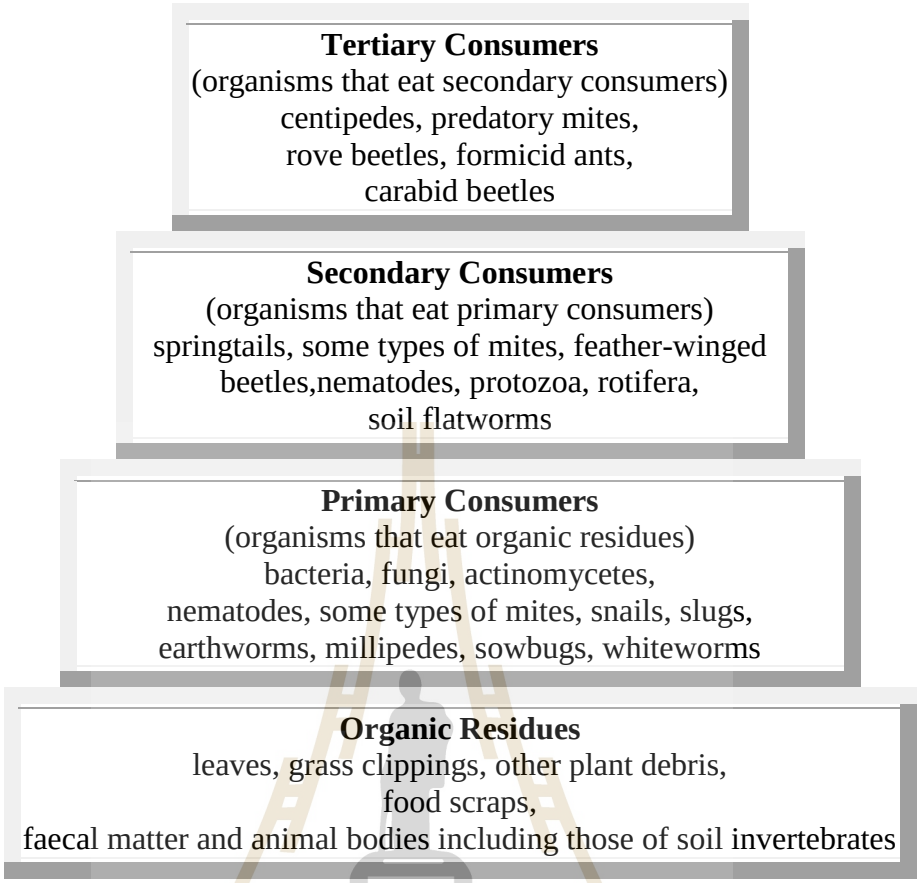


Figure 2.1 The pyramid of invertebrate decomposer cascade, in which organic residues are eaten by some types of invertebrates (Trautmann, 2007).

2.3.2 Classification of invertebrates

Invertebrates are classified in different ways. The function of decomposers may be considered under groupings based on body size, or on various physiological aspects of trophic function (Swift et al., 1979; Chapin, 2002); body length as micro- (less than 0.1 mm), meso- (0.1 to 10 mm) and macro- (greater than 10 mm). Protozoa are the only important members of the microfauna. Earthworms, members of the family Lumbricidae, are macrofauna and often present in large numbers in soil. The mesofauna are represented by many members, the composition

of the population depending on the environmental conditions of temperature, soil water content, aeration, and pH, and the composition of the leaf litter, Collembola (springtails) and Acari (mites) are often the most abundant.

Trophic function is the invertebrate grouping which classified by trophic relationships within decomposer communities. Decomposer communities have been subdivided frequently into the carnivores (feeding on animals), microbivores (feeding on micro-organisms), and the saprovores (feeding on dead plant and animal remains). This classification refers to food ingestion by animals, while other classifications that use the suffix "-troph" define the trophic role of decomposers in terms of the dynamic relationship between the organism and its food resource. They are necrotrophs, biotrophs, and saprotrophs. The necrotrophs have a short-term exploitation of living organisms which results in the rapid death of the food resource. This trophic group includes some herbivores and many plant parasitic microbes (which feed on and kill plant tissues), predators (animals and micro-organisms which kill animals), and the microtrophs (animals and microorganisms feeding on living fungi and bacteria). The biotrophs have a long-term exploitation of their living food source which is dependent upon the continued existence of the host. Saprotrophs are organisms utilising food already dead and the majority of decomposers therefore fall into this category (Swift et al., 1979) (Figure 2.1).

2.3.3 Important invertebrate decomposers in the ecosystem

(1) Nematodes (phylum Nemathelminthes: class Nematoda); there are more than 20,000 morphotypes of free-living interstitial nematodes that are found in terrestrial habitats and along a continuous gradient, into the deep-sea sediments. Functionally, and for ecological purposes, nematodes can be separated into groups

based on the structure of the stoma and pharynx. The free-living nematodes are divided into four basic groups based on what they can ingest, as follows:

(i) Those with a simple and narrow stoma which feed by suction alone and remove small particles from their habitats. Some taxa are the Oxystomatidae, Halaphanolaimidae, Draconematina, and Desmoscolecidae.

(ii) Those species that can feed on larger particles that include diatoms, cysts, spores, invertebrate eggs, and non-filamentous protests in general. The more common taxa include the Rhabditidae, Axonolaimidae, Desmodorina, and Paracanthonchinae.

(iii) Those species with a denticle can succeed in penetrating the cellulosic walls of fine roots, plant tissues, and algal filaments, or the chitinous wall of fungal hyphae and small invertebrates. Some common taxa are found in the Paracanthonchinae, Camacolaimidae, Tylenchidae, and Dorylaimidae.

(iv) Species with an 'armoured' stoma and more powerful denticles that also depend on oesophageal peristalsis for suction. Some taxa include the Enoplidae, Oncholaimida, Choanolaimidae, and Eurystominidae.

(2) Rotifers (phylum Aconthognatha: class Rotifera); commonly found in forest litter and surface soil of riparian areas; only a few families are important in terrestrial soil. Four families of the order Monogomontes are worth mentioning. These are the Dicranophoridae, Asplanchnidae, Notommatidae, and Atrchidae. The order Bdelloides contains many families, with terrestrial species that are active, in the surface soil water films, with the litter.

(3) Gastrotrichs (phylum Acanthognatha: classes Monokonta, Gastrotricha); being the same phylum as rotifers, the body plan is very similar. Unlike

the nematodes, which have secondarily lost cilia, both rotifers and gastrotrichs make use of their ciliature in motility, food acquisition, and fertilization. The order Chetonoides occurs in fresh water and terrestrial litter. The length of adult terrestrial species ranges from 75 to 500 micrometers.

(4) Tardigrades (phylum Lobopoda: classes Onychophora, Tardigrada); the class Tardigrada inhabit terrestrial surface soil and tree bark, marine sands and sediments, and they have been reported in deep sea sediments at 5,000 m. They can be abundant in riparian areas, especially if the sediment is rich in primary producer protests, such as diatoms and chlorophyte algae.

(5) Earthworms (phylum Annelida: classes Clitellata, Oligochaeta); there are more than 7,000 species known from aquatic and terrestrial habitats, and a small number of species are known to inhabit marine sediments. Lumbricina or true earthworms are the most important group of terrestrial earthworms involved in litter breakdown and turnover, particularly in temperate soils, as it is within the temperate zones that they are most widely distributed. Enchytraeidae are very small, pale-coloured worms, commonly known as potworms.

(6) Microarthopods (phylum Arthropoda: classes Chelicerata, Myriapoda, Insecta); many of microarthopods are very important in decomposition processes. They are Chelicerata, Acari or mites, Collembola or springtails, and Insecta. Representatives of Chelicerata in the soil include diverse orders such as the spiders (Araneae), Pseudoscorpiones, Opiliones and the acarids (mites). Mites are the most abundant and present in all soils. Seven families of the order Collembola occur in soil: Entomobryidae, Hypogastruridae, Isotomidae, Neelidae, Onychiuridae, Poduridae,

and Sminthuridae. They have important roles in feeding on pollen, hyphae, decomposing litter, and even nematodes.

(7) Macroarthropods (phylum Arthropoda: classes Crustacea, Symphyla, Diplopoda, Insecta); the main groups of macroarthropods that contribute to the breakdown of plant litter are the orders Isopoda (woodlice), Symphyla (symphylids), Diplopoda or millipedes, Isoptera (termites), Diptera larvae (flies), and Coleoptera or beetles (Table 2.1) (Swift et al., 1979; Adl, 2003; David et al., 2004).

Table 2.1 Taxonomic diversity of decomposer animals. Invertebrate members of terrestrial decomposer food webs are listed in approximate rank order from those groups which maintain an essentially aquatic mode of life in the soil to wholly terrestrial arthropods (Swift et al., 1979).

Phylum	Class	Sub-class or order	Common name
Protozoa	Flagellata		protozoa: flagellates
	Sarcodina		amoebae(naked and testate)
	Ciliate		ciliates
Rotifera			rotifers
Lobopoda			tardigrades (‘water bears’)
Nematoda			nematodes
Gastrotricha			gastrotrichs
Platyhelminthes	Turbellaria	Tricladida	planaria or flatworms
Nemertinea		Metanemertini	nemerteans or ribbon worms
Annelida	Oligochaeta		earthwormsand white worms (enchytraeids)
	Hirudinea		leeches
Mollusca	Gastropoda	Pulmonata	slugs and snails
Arthropoda	Crustacea	Ostracoda	
		Copepoda	
		Amphipoda	sand hoppers
		Decapoda	crabs
		Isopoda	woodlice
	Diplopoda		millipedes
	Chilopoda		centipedes
	Pauropoda		
	Symphyla		
	Insecta	Collembola	spring tails

Table 2.1 Taxonomic diversity of decomposer animals. Invertebrate members of terrestrial decomposer food webs are listed in approximate rank order from those groups which maintain an essentially aquatic mode of life in the soil to wholly terrestrial arthropods (Swift et al., 1979). (Continued)

Phylum	Class	Sub-class or order	Common name
		Diplura	
		Protura	
		Thysanura	bristle tails
		Isoptera	termites
		Coleoptera	beetles
		Diptera	flies
		Lepidoptera	moths (and butterflies)
		Hymenoptera	ants (etc.)
		Orthoptera	grasshoppers and crickets
		Dermaptera	earwigs
		Dictyoptera	cockroaches
	Arachnida	Scorpionida	scorpions
		Pseudoscorpionida	pseudoscorpions
		Solpugida	sun spiders
		Uropygi	
		Amblipygi	whip scorpions
		Ricinulei	
		Opiliones	harvestmen
		Acari	mites
		Araneae	spiders

2.4 Terrestrial Nutrient Cycling

Nutrient cycling is the important process for plant growth in terrestrial ecosystems. A general process of nutrient cycling of minerals through forest ecosystems is referred to as nutrient uptake, nutrient use, and loss by plants in the forest, these are the key steps in the mineral cycling of ecosystems (Chapin et al., 2002). These cycles can explain by how the ways are required, stored, and internally recycled within vegetation before being returned through detritus production and leachate to the forest floor. In the other way, minerals are driven by atmospheric inputs, biological fixation, and geologic weathering for supplying various nutrients to forest ecosystems (Richard and Steven, 2007).

Nutrient cycling in ecosystems involves highly localized exchanges between plants, soil, and soil microbes. The quantity of nutrients that cycle through vegetation depends on the dynamic balance between nutrient supply from the soil and nutrient demand by vegetation. So, to assess the nutrient balance of plants, four processes must be considered; uptake, storage, internal recycling, and return to litter (Richard and Steven, 2007).

2.4.1 Essential elements

Nutrient availability is a major constraint on the productivity of the terrestrial biosphere. The essential elements are defined in two groups, macronutrients and micronutrients. In addition to carbon (C), hydrogen (H), and oxygen (O), all plants require certain macronutrients. Nitrogen (N) is a major constituent of protein, nucleic acids, and chlorophyll. Phosphorus (P) is the most important as a component of the energy currency in biochemical reactions. Sulfur (S) is found in many amino acids. Specific roles are known for potassium (K) in controlling stomatal function and

the charge balance across plant membranes, for calcium (Ca) as a constituent of cell walls, and for magnesium (Mg) in chlorophyll. These nutrients also stimulate the rate of various enzymatic reactions. The micronutrients iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) are widely involved as coenzymes, whereas the essential role of boron (B) and chlorine (Cl) are still poorly known. Grasses and some other plants accumulate silicon (Si) in cell walls, which provide strength and reduce tissue palatability to herbivores. Molybdenum (Mo) is essential for N metabolism in plant tissues, as well as for N fixation by symbiotic bacteria. Cobalt (Co) is essential for the microorganisms involved in N fixation. All of the essential nutrients must be available in appropriate forms and in sufficient amounts to meet growth requirements (Richard and Steven, 2007).

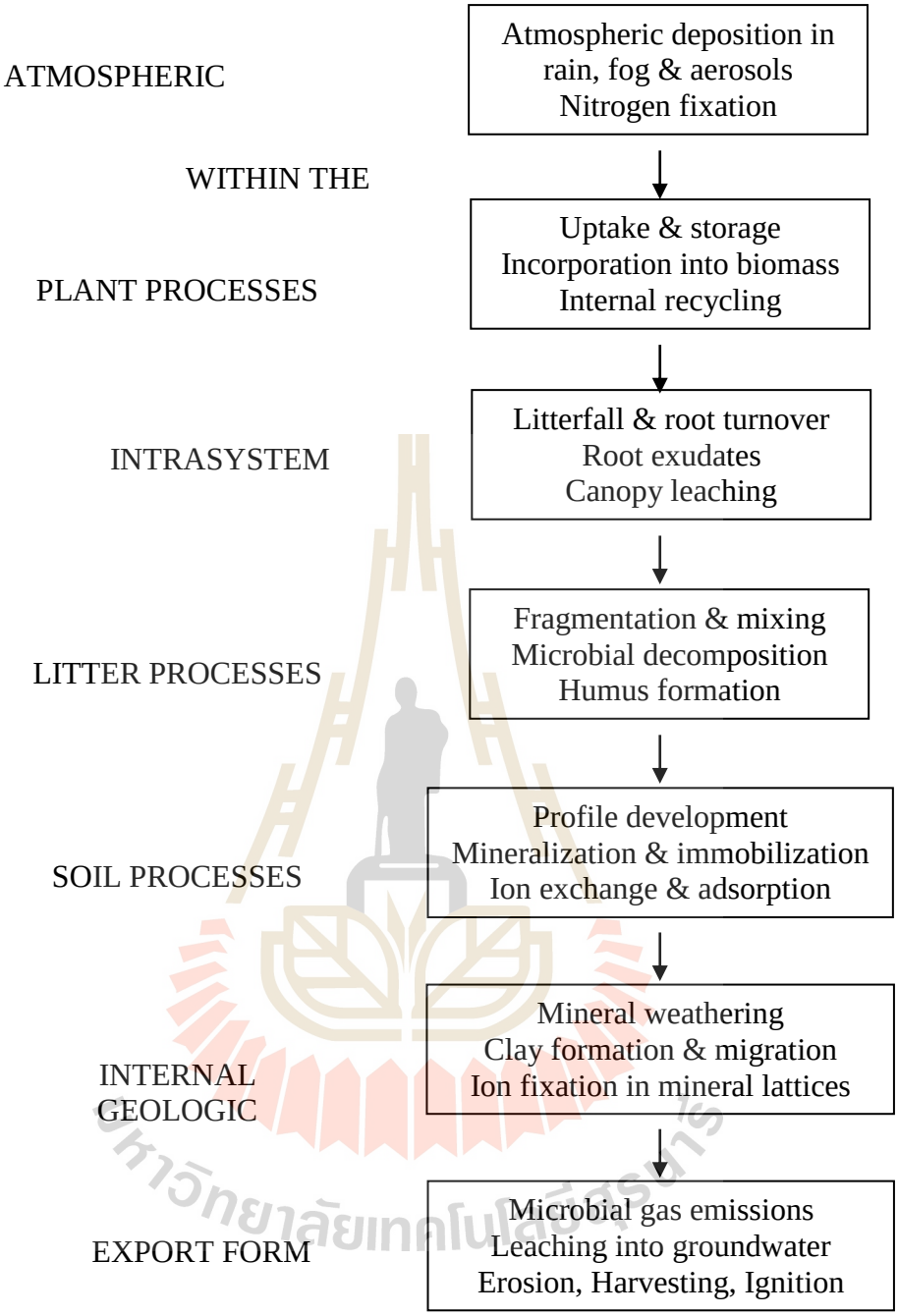


Figure 2 . 2 The mineral dynamics in a terrestrial ecosystem (Richard and Steven, 2007).

2.4.2 Mineral dynamics

The mineral cycling in terrestrial ecosystems is driven through four processes, which are the nutrient uptake, storage, internal recycling, and chemical return in litter (Figure 2.2) (Richard and Steven, 2007). The bulk of terrestrial net primary production (NPP), along with the bodies and excretions of animals, is returned to the soil as dead organic matter. Some 90% of NPP eventually enters the soil system through dead plants in grasslands; through organic residue in agricultural fields. Indeed, ecosystems may be viewed as consisting of four functional subsystems; (1) the production subsystem, (2) the consumption subsystem, (3) the decomposition subsystem, and (4) the abiotic subsystem (David et al., 2004).

Under field conditions, the concentration of nutrients in the soil solution is reduced during the period of exponential plant growth. Nutrients are supplied to plant root surfaces through three mechanisms; (1) the growth of roots and mycorrhizae into the soil; (2) the mass flow of ions with the movement of soil water as a result of transpiration; and (3) the diffusion of ions toward the root surface when uptake rates exceed supply (Eissenstat and Van Rees, 1994 reviewed by Richard and Steven, 2007). There are three factors governing nutrient uptake by vegetation: nutrient supply rate from the soil, root length, and root activity. The nutrient supply rate is the major factor accounting for differences among ecosystems in nutrient uptake at steady state. In other words, nutrient supply by the soil rather than plant traits determines biome differences in nutrient uptake by vegetation in ecosystems in which biomass is increasing rapidly after disturbance. Root length is the major factor governing which plants in an ecosystem are most successful in competing for a limited supply of nutrients (Chapin et al., 2002).

Nutrients absorbed by plants are used primarily to support the production of new tissues (NPP). Plants store nutrients only when nutrient uptake exceeds the requirements for production (Chapin et al., 1990). Total nutrient demands are highly variable from species to species. Within a species, nutrient concentrations also vary depending on growth rates and the availability of nutrients. When nutrients are added to deficient soils the growth rate of trees usually increases, often without inducing a change in foliar nutrient concentrations. When one nutrient or other factors limit growth, nutrients may be taken up in excess of immediate metabolic requirements (Richard and Steven, 2007). Nutrients absorbed by roots move upward through xylem and phloem to sites where production or storage occurs. Each mineral is incorporated into a different part of the tree and driven on many functions. Of the main nutrients, nitrogen is reserved in the form of proteins. Phosphorus is incorporated preferentially into sugar phosphates involved in energy transformations, nucleic acids, and phospholipids. Potassium is important in osmotic regulation, it is highly soluble and concentrated in stomatal guard cells. The highest concentrations of nitrogen, phosphorus, and potassium typically occur in leaves because of the importance of these elements in metabolism (Chapin et al., 2002.; Richard and Steven, 2007). The quantity of elements allocated to each tissue depends on tissue concentrations and on biomass allocation.

Large differences among species exist in the extent to which nutrients are concentrated in foliage, bark, and wood. The nutrient budget of plants is determined just as much by nutrient loss as by nutrient uptake. The chemical composition in each part of plants is referred to as “the litter quality” of species. Differences in litter quality affect decomposition rates, the availability of nutrients to other plants, and,

potentially, the development of soils under different types of vegetation (Turner and Lambert, 1988; Gower and Son, 1992; Richard and Steven, 2007). The potential ways of nutrient loss from plants include tissue senescence and death, leaching of dissolved nutrients from plants, consumption of tissues by herbivores, loss of nutrients to parasites, exudation of nutrients into soils, and catastrophic loss of nutrients from vegetation by fire, wind-throw, and other disturbances (Chapin et al., 2002). Small amounts of most nutrients are leached from living plant tissues. Potassium is particularly easily removed through leaching. Fine roots also lose nitrogen and potassium through exudation and leaching (Richard and Steven, 2007). Nutrient loss from plants is an internal transfer within ecosystems from plants to soil. Return of nutrients in litter fall is the major route of recycling from vegetation to soil. Nutrient return in litter fall can vary seasonally and from year to year depending on forest composition and the leaf abscission process.

In plant systems, nitrogen, phosphorus, and potassium are particularly mobile whereas calcium, which is bound within cell walls, is the least mobile nutrient (Richard and Steven, 2007). After the nutrient transfers to soil, nutrients are potentially available for uptake by microbes or plants or may be lost from the ecosystem. Nutrient loss from plants to soil therefore has very different consequences from nutrient loss from the ecosystem to the atmosphere or ground water (Chapin et al., 2002).

2.4.3 Nutrient movement during decomposition

A superficial examination of soil suggests that it comprises a heterogeneous collection of mineral and organic materials (Dickinson, 1975). Soil contains many of the same elements as found in the underlying substrate of rock, but

the proportions differ greatly. During the decomposition process, elements are converted from organic to inorganic forms (mineralized) and may enter exchangeable pools, from which they are available for plant uptake or microbial use. As plant litter decomposes, the elemental mix changes because of differential mobility and biological fixation. Carbon is lost through microbial respiration, as cellulose and other labile organic compounds are hydrolyzed and utilized in growth and maintenance. Potassium is highly mobile until it encounters exchange sites, where it can become fixed. Potassium is not a structural element, and is lost via solubilization more rapidly than mass is lost from decomposing leaf litter. The nitrogen content of decomposing litter increases during the initial stages of decomposition and then declines. Nitrogen is mineralized during decomposition and is simultaneously immobilized by microbes, resulting in an increase in the concentration of nitrogen in the litter and in the absolute amount of nitrogen if it is transported into the litter from soil or by atmospheric nitrogen fixation. Phosphorus and sulfur also show increase in absolute amounts during decomposition of some species of tree leaf litter, even though mass is being lost, sodium ions, which are more mobile in soil, are not accumulated in plants but are essential for animals. Sodium does accumulate in food chains, often increasing by a factor of 2-3 between trophic transfers. Calcium and magnesium concentrations in decomposing litter change only slightly through time. These may show an initial decrease in concentration followed by a slight increase. Thus the absolute amounts of these two elements during decomposition approximately track the loss of mass. In decomposition of woody litter, in contrast, accumulations calcium and phosphorus occur, evidently as a result of fungal invasion and translocation from soil. Nutrients and organic matter also move through soils in soluble form, for example, as dissolved

organic matter (DOM). In general, sorptive interactions between DOM and mineral phases contribute to the preservation of soluble, or soil, organic matter (David et al., 2004).

Nutrient cycling involves the entry of nutrients to ecosystems, their internal transfers between plants and soils, and their loss from ecosystems. Nutrients enter ecosystems through the chemical weathering of rocks, the biological fixation of atmospheric nitrogen, and the deposition of nutrients from the atmosphere in rain, wind-blow particles, or gasses. Fertilization is an additional nutrient input in managed ecosystems. Internal cycling processes include the conversion of nutrients from organic to inorganic forms, chemical reactions that change elements from one ionic form to another, biological uptake by plants and microorganisms, and exchange of nutrients on surfaces within the soil matrix. Nutrients are lost from ecosystems by leaching, trace – gas emission, wind and water erosion, fire, and the removal of materials in harvest. Most of the nitrogen and phosphorus required for plant growth in unmanaged ecosystems is supplied by the decomposition of plant litter and soil organic matter. Inputs and outputs in these ecosystems are a small fraction of the quantity of nutrients that cycle internally, producing relatively closed systems with conservation nutrient cycles. Human activities tend to increase inputs and outputs relative to transfers and make the element internal transfers and the element cycles more open (Chapin et al., 2002).

2.5 Soil in the Relation to Decomposition

The soil in terrestrial ecosystems, especially in forest ecosystems, usually consists of a number of layers, or horizons, that collectively comprise the complete

soil profile. Recognition of the processes that occur in these horizons is an essential part of understanding nutrient cycling in forest ecosystems. A characteristic property of forest soils is a nearly permanent cover of leaf litter and woody debris. Beneath this surface organic layer, distinct soil horizons usually develop with different chemical, physical, and biological properties. Humans have altered the development of soil horizons by changing the natural sequence of disturbance, the kinds of plants, animals, and microbes present, and the nutrient capital in forest soils. The basic processes, however, remain the same in which nutrients are made available in the soil, taken up by plants, and eventually returned in organic residues (Richard and Steven, 2007).

The soil is responsible for decomposition of dead organisms and material derived from living tissues, that releases nutrients for roots and growth of soil organisms. Roots constitute the bulk of living plant biomass and provide plants with water, oxygen and other essential nutrients from the soil. Roots also need soil to anchor the aerial portion of plants. Soil interstitial species responsible for decomposition are adapted to this particular habitat. Their trophic interactions release complex organic matter into simpler more soluble molecules, which are accessible to plant roots and their symbionts. One by-product of decomposition accumulates as chemically resistant humus. Another by-product of their respiration accumulates in the atmosphere as carbon dioxide, which is required for photosynthesis. The production of biologically useful inorganic molecules from organic compounds, as a result of biological activity, is termed biomineralization. The soil is responsible for irreplaceable ecosystem services, such as matter filtration, food production, recycling of nutrients through decomposition, and detoxification of chemicals. However, soils

can be variously abused by agricultural overexploitation, chemical pollution or poor management. As our global human population density increases, our demands from the soil and the impact on soil ecosystems are exacerbated. The complexity of the soil, and decomposition, is illustrated by the hundreds of species of bacteria, protozoa, fungi and invertebrates which can be found in just a few grams of most soils. Soil processes in nutrient cycling, carbon storage and the return of C as CO_2 to the atmosphere sustain primary production upon which organisms, including humans, depend (Adl, 2003).

2.5.1 Elemental constitution of soil

Many elements are found within the earth's crust, and most of them are in soil as well. However, a few elements predominate. These are hydrogen, carbon, oxygen, nitrogen, phosphorus, sulfur, aluminum, silicon, and alkali and alkaline earth metals. Various trace elements or micronutrients are also biologically important as enzyme co-factors, and include iron, cobalt, nickel, copper, magnesium, manganese, molybdenum, and zinc. A more functional and esthetically pleasing approach is to define soil as predominantly a sand - silt - clay matrix, containing living (biomass) and dead (necromass) organic matter, with varying amounts of gases and liquids within the matrix. In fact, the interaction of geological, hydrological, and atmospheric factors overlap with those of the biosphere, leading to the union of all, overlapping in part in the pedosphere. Soils, in addition to the three geometric dimensions, are also greatly influenced by the fourth dimension of time, over which the physicochemical and biological processes occur (David et al., 2004).

Soil is the solid inorganic matrix, which consists of clay (crystalline mineral particle < 2 μm in size), silt (soil mineral particles of 2-50 μm), sand (soil

mineral particles of 50 µm to 2 mm) and gravel (soil mineral particles > 2 mm). Depending on the proportions of each mineral fraction, soil is classified into textural types. This changes both the physical and chemical properties in the soil and consequently affects its biological properties. The physical and chemical properties of the mineral components are closely linked to soil texture and structure, two key factors in decomposition, nutrient release and fertility for plant growth. Texture refers to the percentage of clay - silt - sand proportion in the soil. The structure of the soil refers to how the soil mineral components aggregate into larger units. The properties of clays are different from those of larger mineral components. Rocks, stones, gravel, sand and silt are just incrementally smaller size fractions of primary minerals. They are the result of mechanical erosion (breaking and fragmenting) of the parent primary minerals. When primary minerals (such as quartz, feldspars, micas and ferromagnesians) are chemically weathered, they produce secondary minerals. This erosion of primary minerals is referred to as weathering. Secondary minerals mostly result from chemical reactions of the primary minerals with water and dissolved ions (hydrolysis, oxidation, hydration and dissolution). The secondary minerals which form are clays, and consist of crystalline aluminosilicates, other crystalline minerals and various free oxides, such as precipitates of the soluble crystals of monosilicic acid (H_4SiO_4). These minerals have crystalline or amorphous forms with chemical and physical properties different from those of the parent primary minerals (Adl, 2003).

2.5.2 Soil profile development

Soil is the resultant of the interactions of several factors - climate, organisms, parent material, and topography (relief) - all acting through time. These factors affect major ecosystem processes (e.g., primary production, decomposition,

and nutrient cycling), which lead to the development of ecosystem properties, unique to that soil type, given its previous history. These such characteristics as cation - exchange capacity, texture, structure, organic matter status, etc., are the outcomes of the aforementioned processes operating as constrained by the controlling factors. Different arrays of processes may predominate in various ecosystems (David et al., 2004).

The forest floor is often easy to separate from the underlying layers of mineral soil, but these two major categories may be further subdivided (Richard et al., 2007). The abiotic and biotic factors noted above lead to certain chemical changes down through the top few decimeters of soil. In many soils, particularly in more mesic or moist regions of the world, there is leaching and redeposition of minerals and nutrients, often accompanied by a distinct color change (profile development). As one descends through the profile from the air- litter surface, one passes through the litter (L), fermentation (F), and humification (H) zones, then reaching the mineral soil surface, which contains the preponderant amount of organic matter (A horizon). The upper portion of the A horizon is termed the topsoil, and under conditions of cultivation, the upper 12-25 centimeter is called the plow layer or furrow slice. This is followed by the horizon of maximum leaching, or eluviations, of silicate clays, Fe, and Al oxides, known as the E horizon. The B horizon is next, with deeper - dwelling organisms and somewhat weathered material. This is followed by the C horizon, the unconsolidated mineral material above bedrock. The solum includes the A, E, and B horizons plus some of the cemented layers of the C horizon. All these horizons are part of the regolith, the material that overlies bedrock (David et al., 2004).

The L layer consists of fresh, undecomposed litter. The F layer lies immediately below the L layer and consists of fragmented organic materials in a stage of partial decomposition. This layer is dominated by organic materials in cellular form, and fungi and bacteria are common. Beneath the F layer lies the H or humus layer, primarily consisting of amorphous, resistant products of decomposition and with lower proportions of organic matter in cellular form. The lower portion of the H layer often shows an increasing proportion of inorganic mineral soil constituents, but organic components still dominate. The upper mineral soil is designated as the A horizon. It may vary in thickness from several centimeters to 1 m. The A horizon is recognized as a zone of removal or *eluvial* processes. Soil water percolating through the forest floor contains organic acids derived from the humic materials. These waters remove iron, aluminum, and other cations by weathering of the mineral components of the A horizon. Iron and aluminum are complexed with the water - soluble fluvic acids in the soil solution and percolate to the lower horizons. Clay minerals are also removed from the A horizon. Substances leached from the A horizon are deposited in the underlying B horizon. This is defined as the zone of deposition or *illuvial* horizon. Soluble humic materials are complexed with the clay from the A horizon, and their deposition in the B horizon is known as *podzolization*. Below the B horizon, the C horizon consists of coarsely fragmented soil material with little organic content. When the soil has developed from local materials, the C horizon shows mineralogical similarity to the underlying parent rock (Richard and Steven, 2007).

2.5.3 Soil properties

Soil characteristics, nutrient availability and cycling are the important factors in regulating decomposition at the local or even micro scale. These factors

exert their influence by modifying the microclimate, operate primarily through biochemical or nutritional influences on microbial metabolism and also alter the composition of the microbial community. Soil factors include both physical and chemical properties. For examples, texture is perhaps the most important physical property of soil because it influences nutrient and water dynamics, porosity and permeability, and surface area. Chemical properties include pH, cation exchange capacity, and organic matter content, all of which can influence the mobility of nutrients and the composition of the microbial community (Berg and McClaugherty, 2003). Soil properties can be defined in two groups as follows;

2.5.3.1 Physical soil properties

The physical properties of soil includes the characteristic of **soil color**; this property is related to organic matter content, climate, soil drainage, and soil mineralogy. **Soil texture** is the relative properties of soil separates in a particular soil, there are sand, silts, and clays, which are ranged on a spectrum of light, intermediate, and heavy particles. The soil textural classes are classified by percentages of sand, silt, and clay, there are the types as sandy, loamy, or clayey soils. **Soil structure** refers to the ways in which soil particles are arranged or grouped spatially. The groupings may occur at any size level on a continuum from either extreme of what are nonstructural states: single grained (such as loose sand grains) or massive aggregates of aggregates (large, irregular solid) (David et al., 2004). Aggregates are secondary units or granules composed of many soil particles bound or cemented together by organic substances, iron oxides, carbonate, clays and/or silica. The implications of soil structure refer not only to the particles but also extend to the pore space within the structure. It is the nature of the porosity that exists in a well -

structured soil that leads to the most viable communities within it. Soil structure influences many important properties of the soil such as the rate of infiltration of water. **Soil porosity**, refers to the pore spaces of soil, it is the portion of the soil volume occupied by air and water. The total porosity is calculated from the dry bulk density and particle density. The density is the weight (or, more correctly, the mass) of an object per unit volume. Soil moisture is the quantity of water in the soil. The percentage of water in the soil relates to the size and arrangement of soil pores. The fine textures contain more water than a coarse soil because there is higher porosity than in coarse soils. Soil moisture might be changed in several ways, such as run off at the soil surface, evaporation, transpiration by plants, and deep percolation of water. There are many factors that influence soil moisture, such as, precipitation, plant use, water in ground level, and characteristics of soil (Chapin et al., 2002).

2.5.3.2 Chemical soil properties

The chemical soil properties are defined as the composition of chemical proportion in the soil. These characteristics are classified as follow: **Soil pH** is the property of the acidity or alkalinity of the soil. This factor is determined in pH units, the pH scale ranging from 0-14 with pH 7 as the neutral point. Soils ranging under 7 are acid soils, and those ranging from 7-14 are alkaline (basic) soils. **Soil organic matter** (SOM) content is a critical component of soils, affecting rates of weathering and soil development, soil water-holding capacity, soil structure, and nutrient retention. Soil organic matter originates from dead plant, animal, and microbial tissues, but includes a rage of materials from new, undecomposed plant tissues to resynthesized humic substances that are thousands of years old, whose origins are chemically and physically unrecognizable (Chappin et al., 2002). **Total**

nitrogen (N), refers to the composition of soil nitrogen in several forms as organic compounds, nitrate and nitrate anions, and ammonium ions. This composition results from the breakdown and humification of organic matter. The main forms of most nitrogen in soil are nitrate and ammonium. This supply might be changed by microbial activity and environmental conditions such as rain, temperature, and moisture. **Available phosphorus** (P) is one of the major plant nutrients. Phosphorus is contributed to the soil in the form of both organic and inorganic compounds. The main available form of phosphorus in soil is the phosphate form. The major source of new phosphorus to ecosystems is the weathering of primary minerals. Chemical reactions with soil minerals play a key role in controlling phosphorus availability in soils. Because potassium (K) occurs primarily in cell cytoplasm and is released through the leaching action of water moving through live and dead organic material, potassium in the form of Available potassium limits plant production in some ecosystems. Thus it is the third most likely nutrient element to limit plant growth and is therefore a very common constituent of fertilizers. This content in soils is found in cation form (K^+)(Chapin et al., 2002).

2.6 Related Literature in Thailand

Decomposition is one of the important topics for ecological researchers. A large number of paper have been published on decomposition issues. Most of them have concentrated on the relationship between decomposition rate and environmental and other factors or, the decomposition of important species in several ecosystems. The influence of litter mixing on decomposition processes and on decomposer communities is not well understood (Gartner and Cardon, 2004.; Wardle et al., 2006).

However, in recent years, little is also known about how litter mixing affects decomposer diversity and decomposition processes. Only a small number of studies have investigated the effects of litter mixing on microbial biomass, microfauna, microarthropods, litter quality, and decay rate. In Thailand, there are a few research projects that have studied decomposition and it related factors, especially in terms of the effect of litter diversity issues.

Chunkao and Boonyawat (1978) studied the accumulation of litterfall and some nutrients in a dry-evergreen forest at Sakaerat. An analysis of litterfall and decomposition rates of dry-evergreen forest was investigated at Sakaerat Experimental Station between March 1968 through February 1969. Ten sites of thirteen 1 x 1 meter plots were established in order to take samples all over the experimental area. Litter, as falling into the sample plots, was collected and dried in an oven at 70^0C. The results showed that annual accumulation of litter was 7.71 tons/ha, the maximum falling in April, the minimum in November. The decomposition rate was 3.76 tons/ha/yr. which was a little low because of the disturbance of microbial decomposer activity in the first year of the experiment. The maximum decomposition rate was found in October, approximately 0.42 ton/ha, December 0.36 ton/ha the second, and March 0.05 ton/ha the least. Some nutrients produced by litterfall were as follows: N 95.19, P 7.38, K 27.94, Ca 106.63, Mg 22.56, Fe 2.56 and Mn 8.75 kg/ha, respectively.

Yimratanabovorn (1993) studied the seasonal fluctuation of soil fauna and its influence on the decomposition of organic matter in a teak plantation in Changwat Phitsanulok province. It was found that the number and biomass of macro-soil fauna were at a maximum in the rainy season but at a minimum in summer and (where)

dominant species became mites and springtails. The highest rate of leaf litter decomposition was found in the rainy season and the rate became lowest in summer. These findings were positively correlated with soil fauna population density. However, there was no significant correlation between soil fauna population and plant nutrients.

Pimthongngam (2004) carried out studies on a comparison of diversity of soil arthropods and the decomposition rate of organic matter between forested and cultivated land in Khoa Suan Kwang district, Khon Kaen Province. The results showed that the diversity of soil arthropods was statistically different between forested and cultivated land, while the decomposition rate in the forest and the cassava plot were not significantly difference, but differed significantly from the sugarcane plot. The decomposition rate followed by rainy, winter and summer seasons in the forest, cassava and sugar plots. The changes of soil arthropods and the decomposition rate in forest were statistically different in different seasons, while in the cultivated land they were not significantly different. In a comparison of soil properties between forested and cultivated land, the results showed that organic mater and pH were statistically different, with forested soil having a higher organic matter than the cultivated land. The phosphorus and potassium contents were not significantly different, but nitrogen content in the cassava plot was lower than in the forest and sugarcane plot.

Jampanin (2004) researched the comparison of litter production and litter decomposition for carbon sequestration assessment in forest ecosystems at Kaeng Krachan National Park, Thailand. The results in mixed deciduous forest, dry evergreen forest, and hill evergreen forest, respectively, revealed that the highest

above ground carbon sequestration was obtained in primary hill evergreen forest. Litter decomposition was 4.49 and 3.83 tonne/ha in hill evergreen forest plots in which carbon sequestration in the aboveground NPP was 7.23 and 6.65 tonne C/ha/y. In mixed deciduous forest plots, while litter decomposition was 2.76 and 2.35 tonne/ha/y, carbon sequestration in the aboveground NPP was 7.67 and 5.02 tonne C/ha/y, respectively. Litter decomposition was 7.90 and 3.55 tonne/ha in the dry evergreen forest plots in which carbon sequestration in the aboveground NPP was 5.44 and 7.31 tonne C/ha/y. The positive relationships between total litter production and leaf litter production indicates that leaf litter is the major components of litter production. While total plant organic litter and woody organic litter are positively related, the relationships between plant organic litter and the exponential decomposition constant are negative. As the woody organic litter is increased, litter decomposition is decreased. Carbon sequestration potential in aboveground NPP of primary forest is lower than in secondary (disturbed) forest. However, appropriate management practices are necessary to restore and improve effective carbon sequestration on these disturbed forests.

Kongamol (2001) carried out his Ph.D. thesis on decomposition rates and associated degrading fungi in mangrove leaf litters of *Rhizophora apiculata* and *Avicennia alba* at Thachin Estuary, Samut Sakhon Province. The results showed that the average litter falls in natural mangrove forest and mangrove plantation were approximately 1,660 and 1,940 kg/rai/year with total nutrients gained from litter production of about 118.5 g/rai/year and 139.2 g/rai/year respectively. *Rhizophoro apiculata* and *A. alba* leaves, both in natural mangrove forest and mangrove plantation, were completely decomposed within 5-6 months, except the *A. alba* leaves

in mangrove plantations, which were decomposed completely within only 3-5 months. There were total of 49 species in 19 genera of fungi found on both leaves species. It was also found that the number of species of fungi colonizing leaves of both species in natural mangrove forest was larger than in the mangrove plantation. A study of enzyme activities of leaf component decomposition on cellulose, xylan, and lignin by 12 species of fungi indicated that *Trochoderma* was the best in degrading the leaf material into glucose. It was also found that *A. alba* leaves were decomposed faster than those of *R. apiculata*. Leaf component decomposition was largely dependent on the age of fungi, species, and salinity. The results of this investigation suggest a new finding on decomposition, by degrading fungi of litter falls, and enzyme activities of degrading fungi on *R. apiculata* and *A. alba* leaves in mangrove ecosystem for Thailand.

Dankittipakul (2003) studied the impacts of forest fire on litter dynamic in deciduous dipterocarp-oak forest in Doi Suthep-Pui National Park. Litter production, standing crops of litter on the forest floor, and leaf-litter decomposition were studied in four different forest sites, designated as unburnt and burnt areas in deciduous dipterocarp-oak forests at Doi Suthep-Pui National Park, Chiang Mai Province from March to December, 2002. There was no significant effect of burning on the litterfall. Mean annual litterfall in the study sites ranged from 4.2 to 7.2 t/ha/y. Contribution of leaf litter to the total litter was significantly greater compared to other components. Monthly variation in litterfall pattern showed 2 peaks, one in the dry season (March-April) and other in the rainy season (September-October). Fire considerably affects litter mass accumulation in the H horizon. Dry weight of organic matter on the forest floor ranged from 4.13 t/ha under the unburnt site to 1.04 t/ha under the burnt sites.

Decay rate coefficients (k) for the species varied between 1.62 and 4.12 for *Tectona grandis*, and from 2.01 to 9.21 for *Dipterocarpus tuberculatus*. The number of macroinvertebrate taxa was reported to be highest at the unburnt site while the highest number of individuals was found at the burnt site.

CHAPTER III

MATERIALS AND METHODS

3.1 Site Information

The study area of this research is located at the Sakaerat Environmental Research Station (SERS), the biosphere reserve area in the Man and Biosphere Program of UNESCO. This station has been dedicated as an ecological reserve for scientific purposes. It is administered by the Thailand Institute of Scientific and Technological Research (TISTR) as a facility for ecological and environmental research. SERS lies in Nakhon Ratchasima province. It spans Phu Luang subdistrict, Wang Nam Khieo district, and Udomsap subdistrict in the Pakthongchai district (Figure 3.1). It is located at approximately 14^0 30' N and 101^0 55' E, about 300 kilometers from Bangkok and 60 kilometers from Nakhon Ratchasima (Korat) on highway 304. The station grounds cover an area of 78 square kilometers (approximately 48,750 rai).

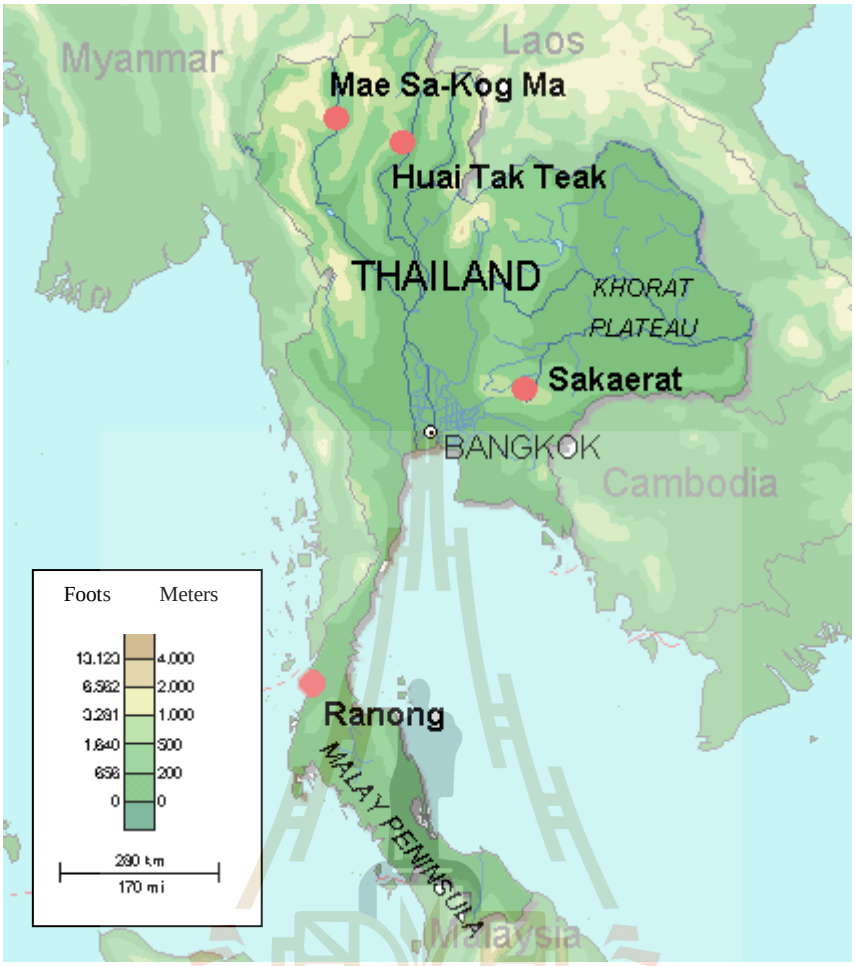


Figure 3.1 The location of Sakaerat Environmental Research Station. (From: http://www.unesco.org/mabdb/br/brdir/asia/Thailandmap.htm).

3.1.1 Topography and geography

SERS is situated in mountainous terrain at an altitude of 280-762 meters above sea level. Important mountains on the station grounds are Khao Phiat (762 meters), Khao Khieo (790 meters), and Khao Sung (682 meters). The station office is at 390 meters.

The entire area of SERS appears to be underlain by sandstone of the Phra Wihan Formation of the Korat group to a maximum thickness of 1,025 meters. It lies

comformably on the purplish siltstone, micaceous sandstone, and conglomerate on the Phu Kradung formation of the same group.

3.1.2 Climate

In 2008, the average annual temperature at Sakaerat was 25.7 degrees Celsius and annual rainfall was 1,131.90 millimeters. There are three seasons, namely rainy season from May to October, winter from November to February, and summer from March to mid-May. In general, the lowest relative humidity is about 84% and the highest is about 96%. The relative humidity increases after April until October, and decreases after February. The climate is monsoonic and classified as a "Tropical savanna type" according to Koppen (Lamotte et al., 1998).

3.1.3 Soil characteristics

The dominant great soil group of the SERS, occurring in the whole area, is underlain by sandstone of the Phra Wiharn Formation of the Korat group. The upper soil texture is characterized as clay loam, sandy loam, and sandy clay loam. Lower soil is clayey. The depth of soil varies from 40-120 centimeters. The soil series of SERS are Korat (Kt), Lat Ya (Ly), Tha Yang (Ty), Warin (Wn), Kamphaeng Saen (Ks), Sai Ngam (Sg), Muak Lek (Ml), and Khao Yai (Suriyapong, 2003; Charoenpol, 2003).

3.1.4 Vegetation and forest types

Vegetation types of the area are dry evergreen forest (46.84 km^2 or 59.97%), dry dipterocarp forest (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 dry evergreen forest occupies the south-western portion, while the dry dipterocarp forest occupies the north-eastern portion of the reserve area. The dry dipterocarp forest is a deciduous broad-leaved forest community type occurring on relatively dry sites,

and is mainly composed of trees belonging to the Dipterocarpaceae family. The dry evergreen forest is usually referred to as the tropical semi-evergreen rain forest. Tree species in this forest are mainly evergreen (Lamotte et al., 1998).

3.1.5 Study site

The study area is located at the Sakaerat Environmental Research Station (SERS), Wang Nam Khieo district, Nakhon Ratchasima province. The area is situated between 14^0 30' N and 101^0 55' E. The SERS covers an area of approximately 78 km^2 or 48,750 rai and is about 60 km from Nakhon Ratchasima.

Permanent plots were established in two main ecosystems of SERS, the dry dipterocarp forest and dry evergreen forest. There were three replicated plots of 20m x 20m experiment plots in each ecosystem and each plot was divided into fourteen quadrats for incubation and litter treatments (Figure 3.2).

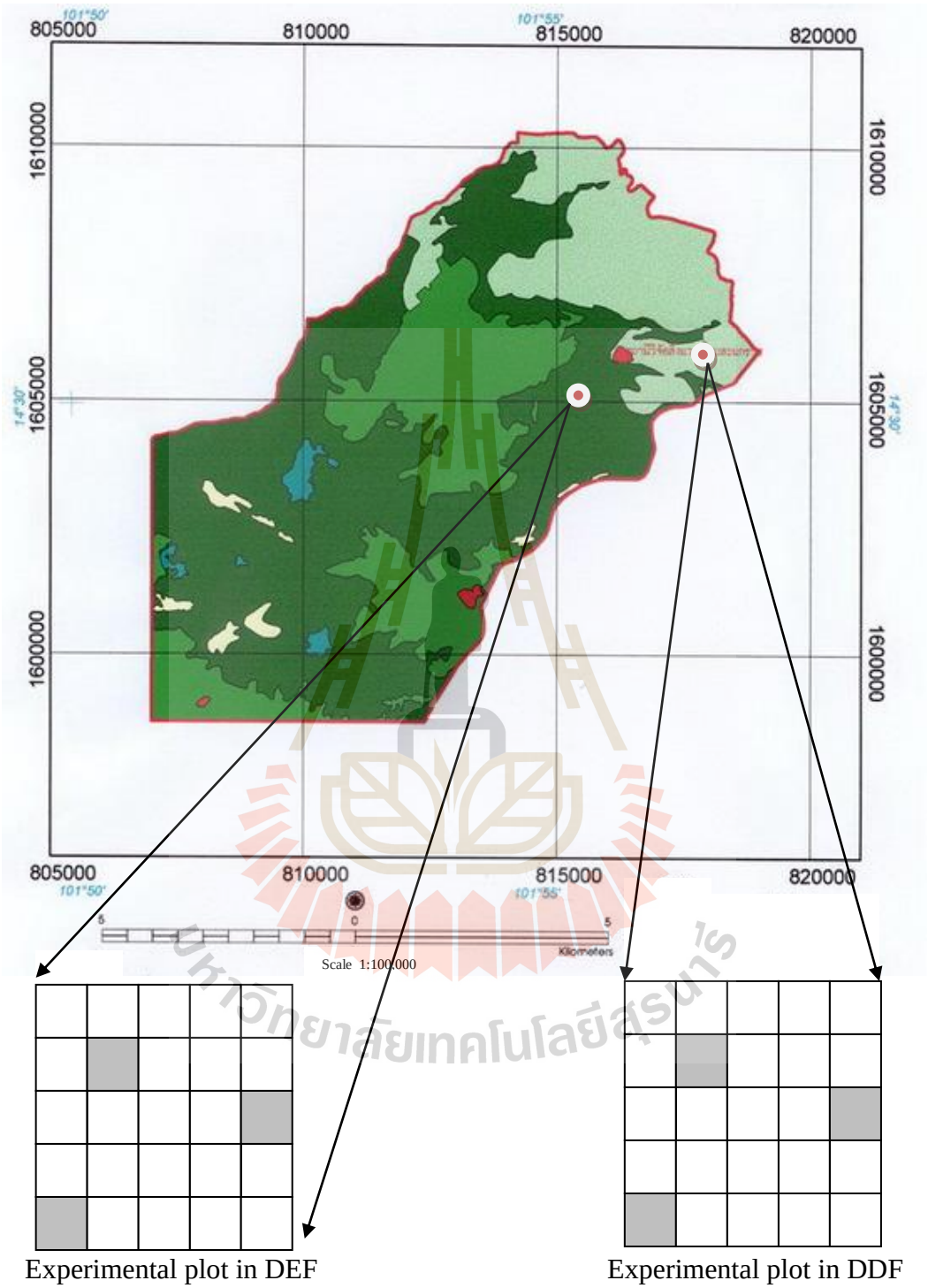
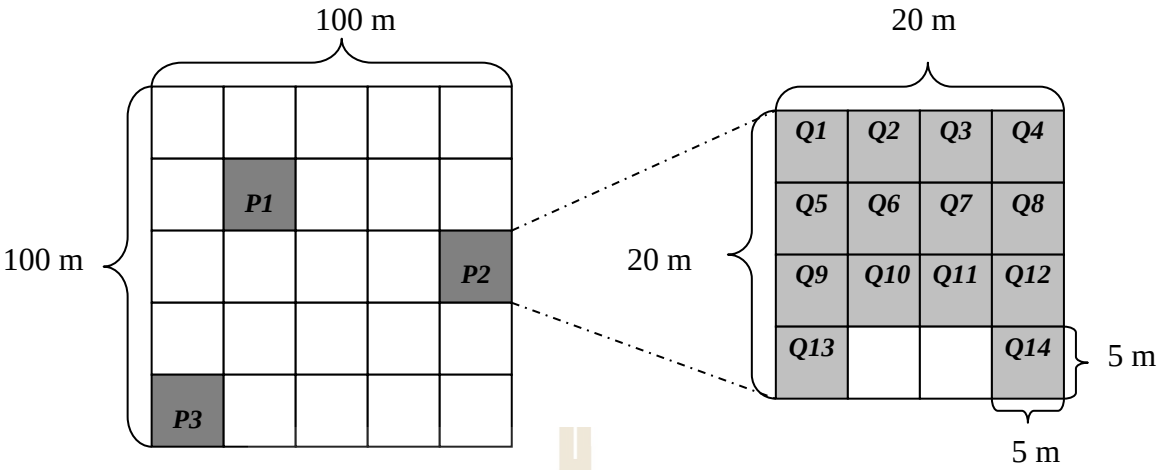


Figure 3.2 Map of experimental plot in DDF and DEF.



Permanent plot (100m x 100m) and P = Experiment plot (20m x 20m)

Q = Incubation quadrat (5m x 5m)

Figure 3.3 Experimental plot design used for incubating litter bags within each ecosystem.

3.2 Litter Preparation

Four deciduous leaf litters of dominant species were collected in each study site during December 2006 to April 2007; they were *Shorea obtusa* Wall. (in Thai called "teng"), *Shorea siamensis* Miq. (in Thai called "rang"), *Shorea roxburghii* G. Don (in Thai called "pa-yom") and *Dipterocarpus tuberculatus* Roxb. (in Thai called "pluang") in dry dipterocarp forest, and four dominant leaf litters, *Hopea ferrea* Laness (in Thai called "ta-kian-hin"), *Afzelia xylocarpa* (Kurz) Craib (in Thai called "ma-ka-mong"), *Memecylon ovatum* J. E. Smith (in Thai called "plong-kin-look") and *Memecylon caeruleum* Jack (in Thai called "plong-kee-kwai") in dry evergreen forest. Freshly-fallen leaf litter, the litter on the top layer of fallen leaves was collected from the forest floor and immediately transported to the laboratory at Suranaree University

of Technology, and separated according to species. At least 3 kg of pure litter was carried out for each species, cleaned, and then oven-dried at 60^0C for 48 h to a constant weight and stored in plastic bags at 5^0C until required for chemical analysis and incubation in the fields (Sariyildiz et al., 2003).

Three 1 x 1 m^2 litter traps were spreaded under the canopy to collect natural fallen litter in each experiment plot (18 litter traps for the study) during December, 2006 to April, 2007. The natural fallen litter collected was about 1500 g by the end of April and then prepared in the same way as for individual litter.

3.3 Experimental Design

A mixed litter experiment was used for the study, using 30 cm x 30 cm nylon net litterbags with 5 mm mesh size; this hole size allows entry and exit of macro fauna organisms (Wardle et al., 2006). Fourteen litterbags were set up for each of the 14 treatments used per ecosystem. These treatments were four monocultures, four for two species-mixtures, four for three spicies-mixtures, one of all multiple species and one of natural fallen litter. The multiple litterbags had equal weights of all component species. This experimental design followed the same techniques as used by Wardle et al. (1997), Duffy et al. (2003), and Wardle et al. (2006); it allowed the response variables for the multiple species mixtures to be compared directly with those for the component species in monoculture (Wardle et al., 2006).

Each litterbag treatment contained thirty grams (30 g) of dried weight litter (Dankittipakul, 2003), as 30 g of each monoculture and natural mixed litter. In addition to all monocultures, the litterbags were set up with 15 g per species of two species-mixtures, with 10 g per species of three species -mixtures and with 7.5 g per

species of all four species mixtures (Tables 3.1 and 3.2). All treatment samples of leaf litter were placed in litterbags, then the filled litterbags were sealled and labeled with an ID number with a plastic tag. The litterbag treatments were incubated for 12 months incubation period and there were 3 replicate plots within the study site.

A total of 504 litterbags were randomly placed in the field on 1 June, 2007 in three replicate plots of each of the two forests; each plot comprised 12 bags of each of the 14 treatments for 2 month intervals examination. All litterbags were placed directly on the soil surface and movements 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 natural litter fall from 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 60^0C for 48 h (Sariyildiz et al., 2002 and Alhamd et al., 2004) and then weighed.

Table 3.1 Litter treatments used in the study for dry dipterocarp forest (DDF).

Treatment code	**Species of litter**	**Weight (g/bag)**
D1	(a) *Shorea obtusa* Wall. (เต็ง)	30
D2	(b) *Shorea siamensis* Miq. (รัง)	30
D3	(c) *Shorea roxburghii* G. Don (พะยอม)	30
D4	(d) *Dipterocarpus tuberculatus* Roxb. (พลวง)	30
D5	Ab	15 + 15
D6	Ad	15 + 15
D7	Bc	15 + 15
D8	Cd	15 + 15
D9	Abc	10 + 10 + 10
D10	Acd	10 + 10 + 10
D11	Abd	10 + 10 + 10
D12	Bcd	10 + 10 + 10
D13	Abcd	7.5 + 7.5 + 7.5 + 7.5
D14	Natural mixed litter	30

Table 3.2 Litter treatments used in the study for dry evergreen forest (DEF).

Treatment code	Species of litter	Weight (g/bag)
E1	(e) *Hopea ferrea* Laness (ตะเคียนหิน)	30
E2	(f) *Afzelia xylocarpa* (Kurz) Craib (มะค่าโมง)	30
E3	(g) *Memecylon ovatum* J. E. Smith (พลองกินลูก)	30
E4	(h) *Memecylon caeruleum* Jack (พลองขี้ควาย)	30
E5	Ef	15 + 15
E6	Eh	15 + 15
E7	Fg	15 + 15
E8	Gh	15 + 15
E9	Efg	10 + 10 + 10
E10	Egh	10 + 10 + 10
E11	Efh	10 + 10 + 10
E12	Fgh	10 + 10 + 10
E13	Efgh	7.5 + 7.5 + 7.5 + 7.5
E14	Natural mixed litter	30

The comparisons of decomposition rate and other factors between mono species, 2-mixed, 3-mixed, 4-mixed species were analyzed for detecting the differences in data among the different levels of litter diversity in both DDF and DEF. For mono species (DD1, DE1) data was analyzed from the average data of D1 to D4 and E1 to E4, two mixed species (DD2, DE2) data was analyzed from the average data of D5 to D8 and E5 to E8, three mixed species (DD3, DE3) data was analyzed from the average data of

D9 to D12 and E9 to E12, and four mixed species (DD4, DE4) data was analyzed from D13 and E13. The data of natural mixed litter (DD5, DE5) was analyzed from D14 and E14.

3.4 Litter Analysis

3.4.1 Litter decomposition

Decomposition rates were determined by mass loss, the difference between initial litter weight and the dry mass of remaining litter after incubation. The decomposition rates of litter were fitted to a single exponential decay model of Olson (1963. reviewed by Liu et al., 2006), as the following exponential function;

$$\frac{L_t}{L_o} = e^{-kt}$$

Where

L_o is the initial mass of dry matter

L_t is the mass of dry matter after a given month of incubation t

k is the decomposition rate constant

3.4.2 Litter quality

The sub-samples of each litter treatment were used for determination of the change of litter quality from the concentration of C content, N content, C/N ratio, and lignin and cellulose concentrations. The initial C, N, lignin, and cellulose contents were determined in each litter treatment before placing in the field. After a given month of incubation, litter residues of each treatment were analyzed for C concentration by the dry digestion method, N concentration by the Kjeldahl method and then the C/N ratio was calculated. Lignin and cellulose were determined using the

acid detergent fibre method (ADF) procedure of Rowland and Roberts (1994, in Sariyildiz et al., 2003, Wardle et al., 2002 and Wardle et al., 2003).

The C and N remaining after a given month of incubation were calculated by the following formula;

$$Remaining\ (\%) = \frac{L_t C_t}{L_o C_o} x100$$

where

L_t is the mass of dry matter after a given month

L_o is the initial mass of dry matter

C_t is the concentration of C or N after a given month of incubation

C_o is the initial concentration of C or N in litter (Alhamd et al., 2004)

3.4.3 Invertebrate decomposers

The invertebrates in each litterbag were hand-picked by using paintbrushes and forceps and finally preserved in 90% ethanol. Counting and identification to order/class level of the invertebrates were done afterwards. The diversity index of invertebrates was calculated by the Shannon–Weiner Diversity Index, as follows;

$$H = -\sum_{i=1}^{s} (Pi)(\ln Pi)$$

where

H is the index of species diversity

S is the number of species

Pi is the proportion of total sample belonging to species i

3.4.4 Litter bag temperature

The temperature in each litter bag was investigated using a thermometer before harvesting.

3.5 Soil Analysis

3.5.1 Soil chemical analysis

Thirty grams of surface soil at 10 cm depth were collected from 13 places in each experimental plot (Figure 3.4) for studying the influence of litter decomposition on soil nutrient status before incubation. After that all of the soil samples were mixed. Each of them (3 samples from each ecosystem) were stored in plastic bags and transferred to the laboratory, air-dried, ground through a 2 mm sieve, and then stored in plastic bags before analysis.

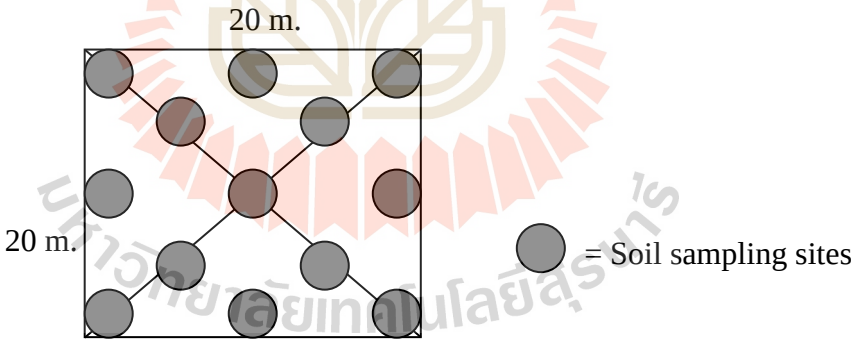


Figure 3.4 Soil sampling design used to collect soil samples within each experiment at plot before incubation times.

The soil samples under the litter bags were collected at about 30 grams each at 3 replicate places in each area after the incubation times (Figure 3.5). They were mixed, stored in plastic bags, and transferred to the laboratory. The total numbers

of soil samples in each permanent plot (14 samples following the litter treatment) were sieved through a 2 mm mesh sieve and stored in plastic bags again before analysis.

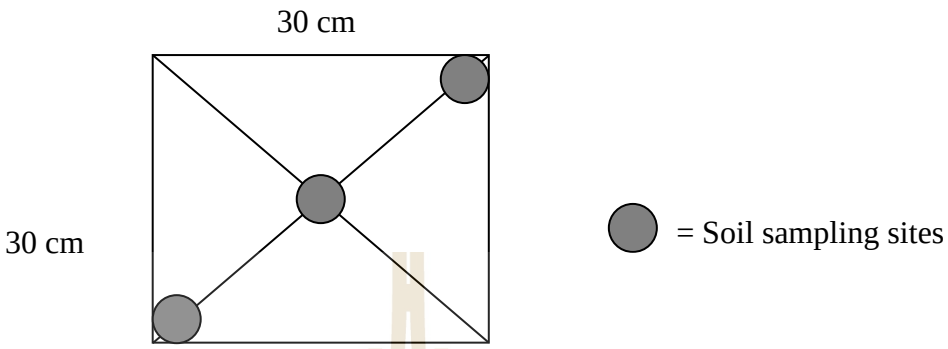


Figure 3.5 Soil sampling design used to collect soil samples within each litter bag area after the incubation times.

The soil samples were analyzed chemically for organic matters by the Walkley and Black rapid titration method, total N was measured by using the Kjeldahl method, available P by using the Bray I method, available K using a flame photometer, and pH of soil by making a suspension of 1/10 weight per volume dilution, then measuring the pH by using a pH meter (Chhatwal, 1997).

3.5.2 Soil physical analysis

The soil samples from the same area as collected for chemical analysis were analyzed for physical properties;

- Soil temperature was measured by using a soil thermometer.

- To obtain soil moisture content, a homogenized sample of soil was collected, the weighed, and dried in an oven at 105^{o}C for 24 h, then weighed and recorded as to the weight. The moisture content was calculated by using the following formula:

$$Moisture\ content\ (\%) = \frac{X_1 - X_2}{X_1} x100$$

where

X_1 is initial weight of sample (g)

X_2 is final weight of dried sample

3.6 Ecological Characteristics

The ecological characteristics at the study site were measured monthly, including temperature, relative humidity, and precipitation. These were according to the SERS data.

3.7 Data Analysis

The ANOVA and t-test were used for analysis of all parametric data and for detecting significant differences in the decomposition rate constant among the different treatments of litters. The Pearson Correlation was used for analysis of the interaction between decomposition rate and all factors.

CHAPTER IV

RESULTS AND DISCUSSION

The decomposition processes in dry dipterocarp and dry evergreen forests were studied as to their effect on leaf litter decomposition rate and what factors correlate with the processes. The results of this research were analyzed then presented and discussed in six parts of interaction. They are the interrelations of the meteorological data, decomposition rates, the litter quality, soil property, the decomposers, and the correlation between litter diversity and the interactive factors as follows:

4.1 Meteorological Data

The meteorological data were recorded according to the measurement by Sakaerat Environmental Research Station (SERS), and included the data of temperature, relative humidity, and precipitation. The litter bag temperatures were investigated using thermometer at the harvesting time.

From June 2007 to May 2008, mean monthly temperature in the dry dipterocarp forest (DDF) was higher than in the dry evergreen forest (DEF). The maximum mean temperature of 2nd months interval after incubation at the dry dipterocarp forest and dry evergreen forest were in June - July 2007 at 29.00^{0}C and 28.87^{0}C, respectively. The minimum mean temperature of dry dipterocarp

and dry evergreen forests were 24.55^{0}C and 22.27^{0}C, respectively, recorded in December 2007 - January 2008 (Figure 4.1).

The maximum humidity of dry dipterocarp and dry evergreen forests were 93.00% and 93.67%, respectively. The highest relative humidity was in August - September 2007 in both ecosystems, while the lowest was in December 2007 - January 2008, about 82.50% at DDF, and about 84.37% at DEF in the same incubation time of DDF (Figure 4.1).

The annual rainfall was 1,002.90 mm in DDF and was 889.07 mm in DEF. This precipitation was measured mostly from June to November 2007, and from April to May 2008 (Figure 4.1) at both sites. The highest rainfall was in August - September 2007 with 288.40 mm for DDF and in April - May 2008 with 281.93 mm for DEF, respectively (Figure 4.1).

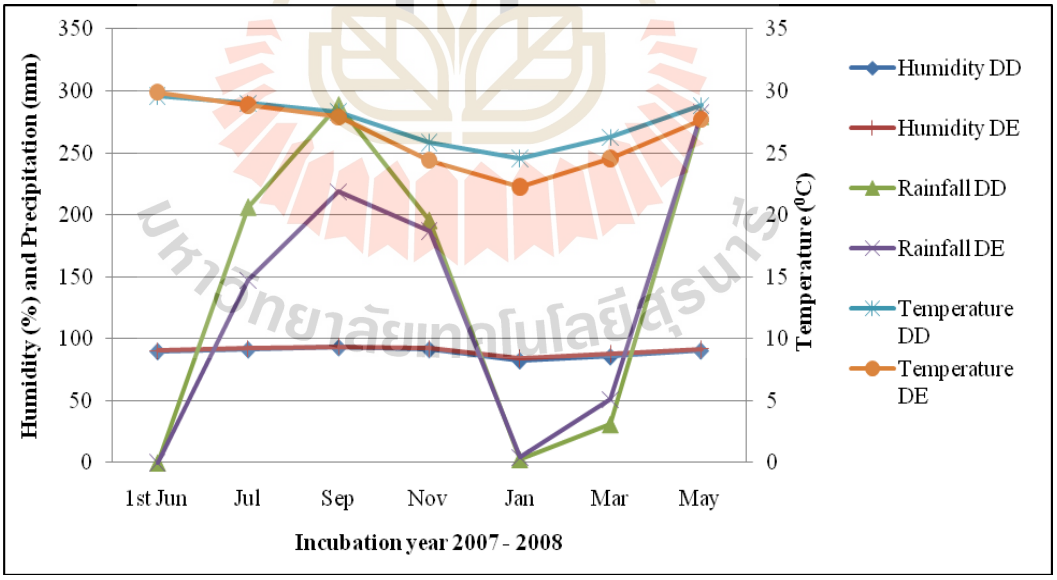


Figure 4.1 The mean temperature (^{0}C), relative humidity (%), and precipitation (mm) in dry dipterocarp forest (DDF) and dry evergreen forest (DEF) from June, 2007 to May, 2008.

The mean temperature of litter bag was determined, the highest temperature at DDF was in the 10th month (February - March, 2008) of incubation with 37.53^{0}C and the lowest temperature was in August - September 2007 with 26.59^{0}C (Figure 4.2). At DEF, the highest temperature was in 10th month (February - March 2008) with 27.91^{0}C and the lowest in the 6th month (October - November, 2007) with 22.67^{0}C (Figure 4.3). Mean temperature of litter bag differed according to forest (t= 10.298, $P < 0.001$).

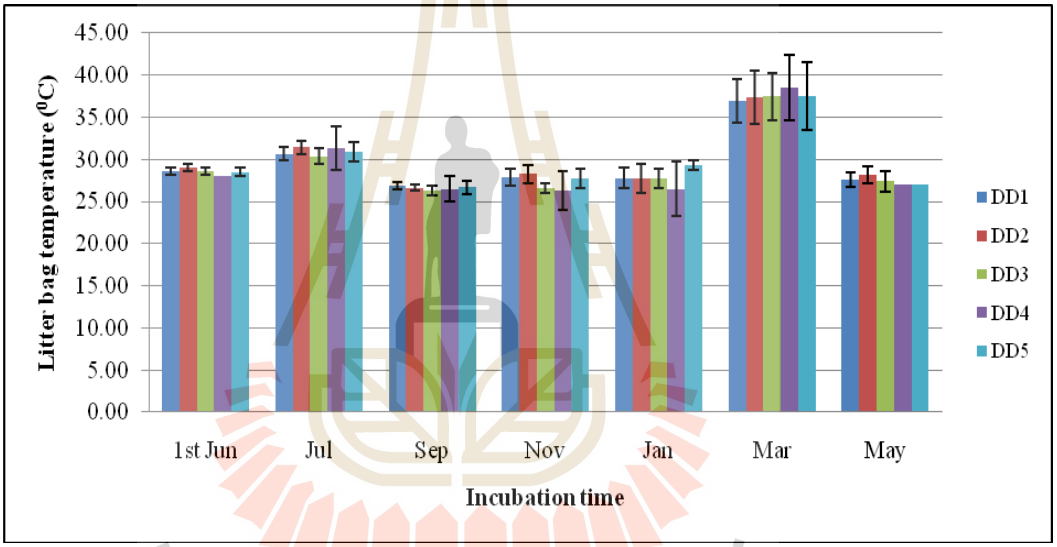


Figure 4.2 Litter bag temperatures (^{0}C) in dry dipterocarp forest (DDF) from June, 2007 to May, 2008.

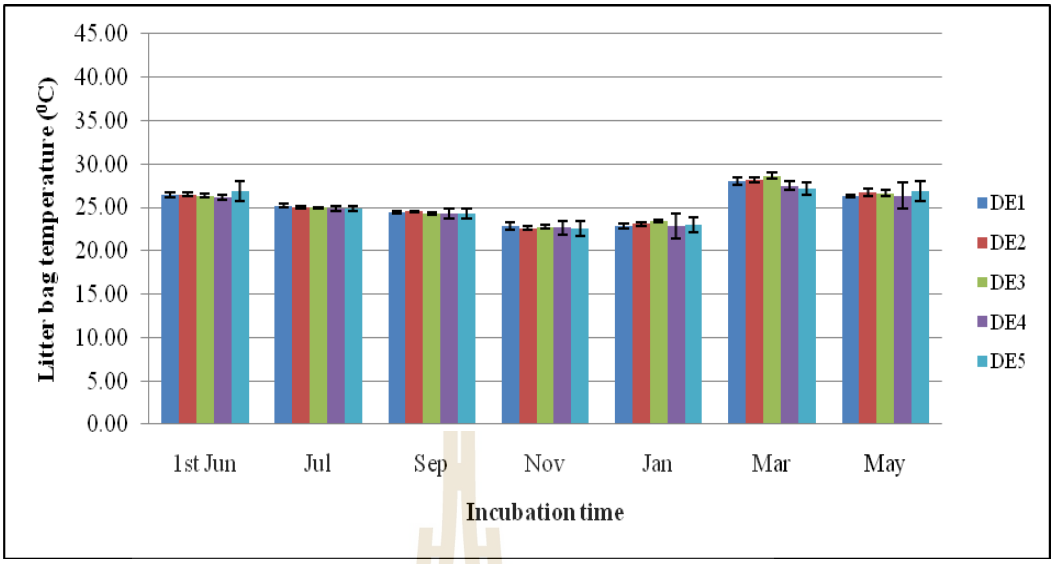


Figure 4.3 Litter bag temperature (^{0}C) in dry evergreen forest (DE) from June, 2007 to May, 2008.

There was a significant relationship of rainfall, temperature (r = 0.380**), and relative humidity (r = 0.765**) in the dry dipterocarp forest. In the dry evergreen forest, there was a significant correlation of rainfall, temperature (r = 0.255*), and relative humidity (r = 0.744**). The litter bag temperature was correlated to relative humidity and precipitation in DDF (r = -0.359** and r = -0.401, respectively), and there was a significant relationship to weather temperature (r = 0.380**) in dry evergreen forest.

4.2 Litter Decomposition Rate

4.2.1 Litter mass remaining

The decomposition rates of dominant mono species and different mixed litter species were determined along one year of incubation in both dry dipterocarp and dry evergreen forests. The results showed *D. tuberculatus* Roxb.

had the lowest remaining weight (17.73%) and the highest remaining weight was with *S. siamensis* Miq. species (32.80%) in dry dipterocarp forest. The remaining weight of *S. obtusa* Wall. and *S. roxburghii* Don were 20.87% and 24.33%, respectively (Figure 4.4). The remaining weight of mono species litter in dry evergreen forest showed the lower weight than that in dry dipterocarp forest. In the dry evergreen forest, the lowest of remaining weight was 12.68% with *H. ferrea* Laness, the highest was 33.67% with *M. caeruleum* Jack. The remaining weight of *A. xylocarpa* (Kurz) Craib and *M. ovatum* Smith was 13.34% and 31.11%, respectively (Figure 4.5).

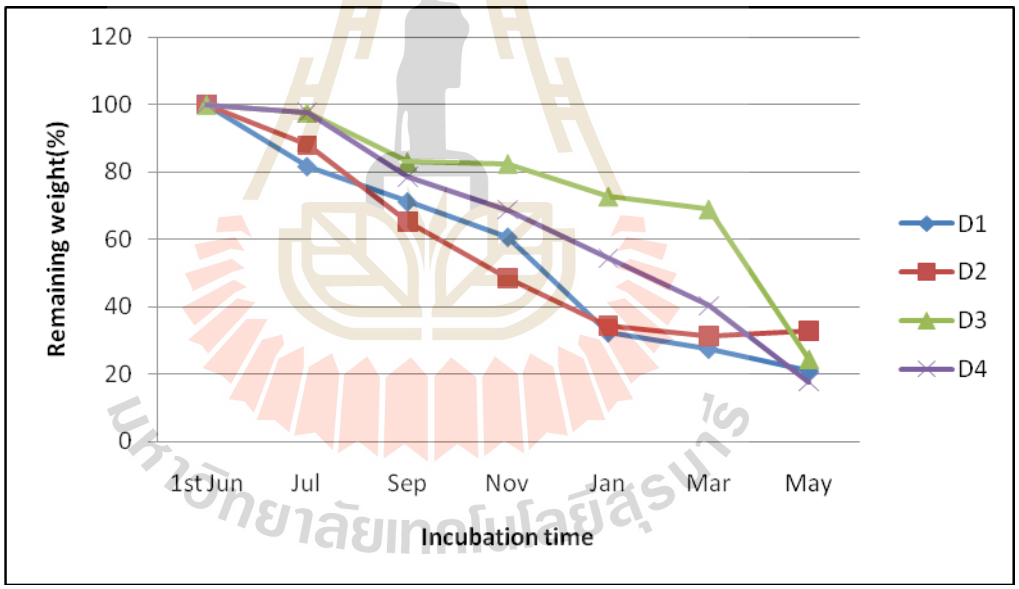


Figure 4 .4 The mean of mass remaining (%) of mono species leaf litter in dry dipterocarp forest during June 2007 to May 2008.

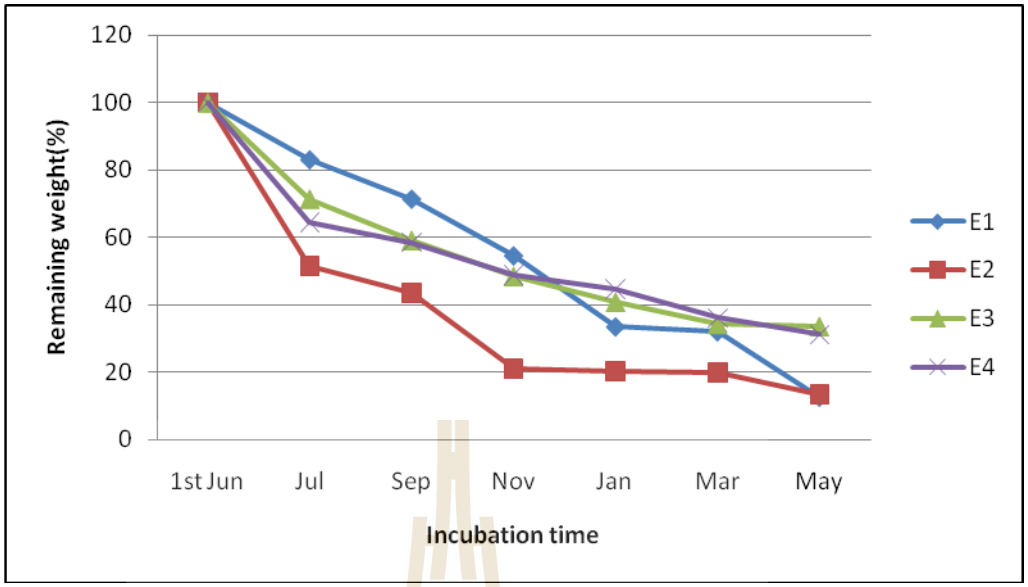


Figure 4 .5 The mean of mass remaining (%) of mono species leaf litter in dry evergreen forest during June 2007 to May 2008.

For two mixed species litter, the highest remaining weight was with D6 (32.07%), and then followed with D7 (22.83%). The lowest remaining weight was with D8 (19.83%) in dry dipterocarp forest. There was the highest remaining weight with treatment which contained *M. caeruleum* Jack. and *M. ovatum* Smith in dry evergreen litter (E8), at 43.82%. The lowest was 17.66% with E7 (Figures 4.6 and 4.7).

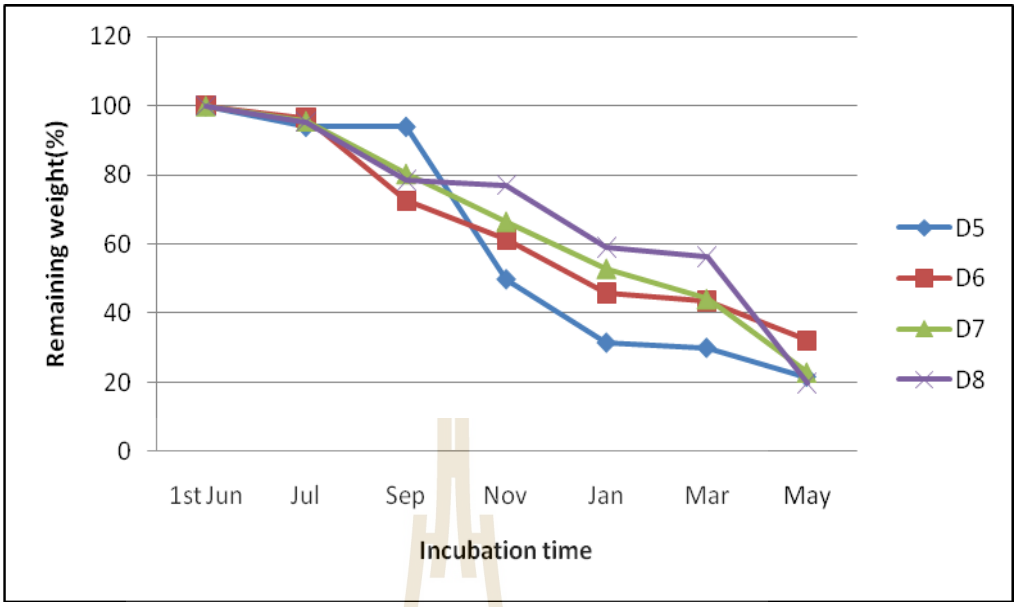


Figure 4.6 The mean of mass remaining (%) of 2-mixed species leaf litter in dry dipterocarp forest during June 2007 to May 2008.

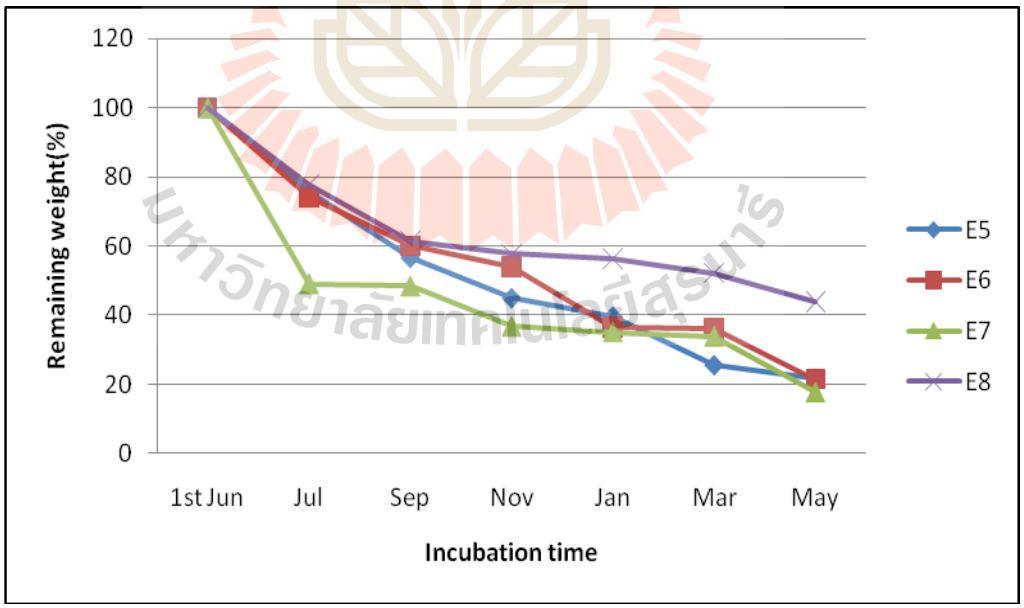


Figure 4.7 The mean of mass remaining (%) of 2-mixed species leaf litter in dry evergreen forest during June 2007 to May 2008.

The remaining weight of three mixed species was highest with D12 (19.20%) and E10 (33.36%) in dry dipterocarp and dry evergreen forest, respectively. The lowest remaining weight was 11.30% with D10 in dry dipterocarp forest and it was 20.39% with E9 in dry evergreen forest (Figures 4.8 and 4.9).

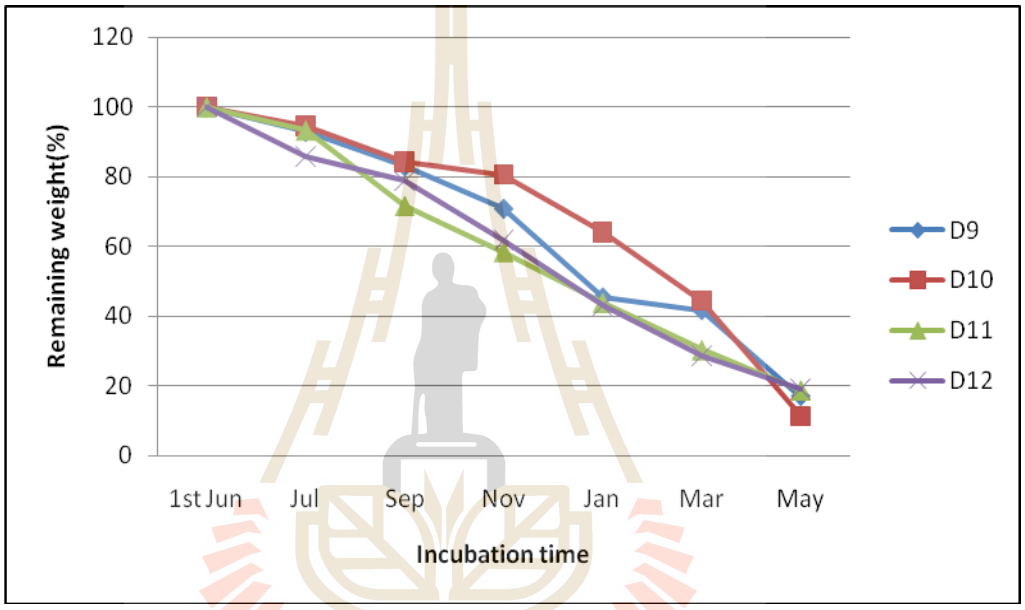


Figure 4.8 The mean of mass remaining (%) of 3-mixed species leaf litter in dry dipterocarp forest during June 2007 to May 2008.

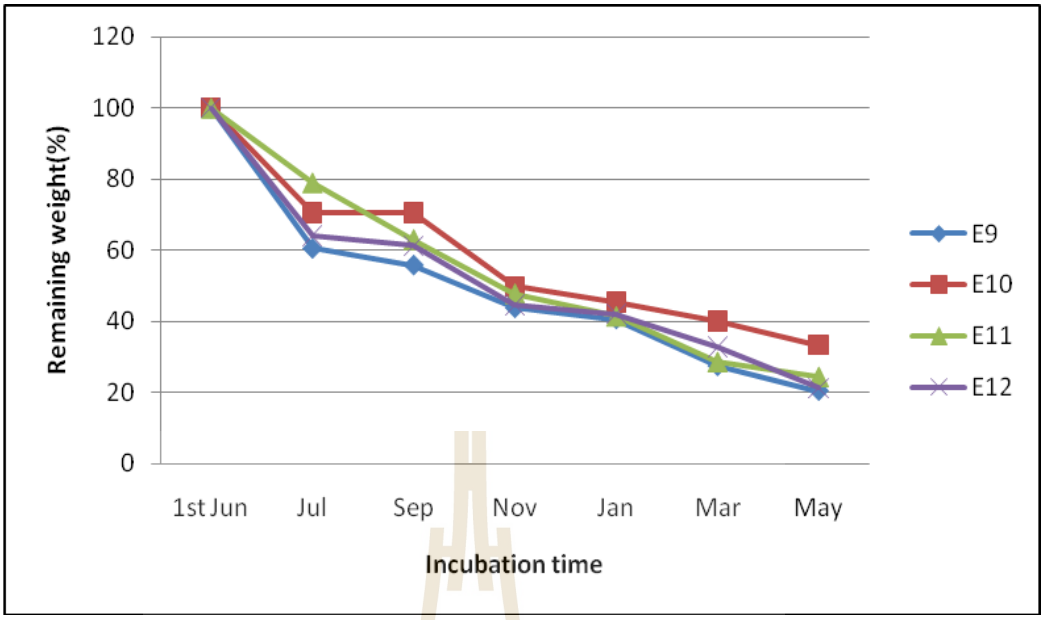


Figure 4.9 The mean of mass remaining (%) of 3-mixed species leaf litter in dry evergreen forest during June 2007 and May 2008.

The results showed a low rate of remaining weight with a high number of litter species, 4-mixed species and natural fallen leaf litter. There was 27.80% with D13 and 6.57% with D14 in dry dipterocarp forest. The remaining weight of E13 was 22.88%, and it was 14.83% with E14 in dry evergreen forest (Figures 4.10 and 4.11).

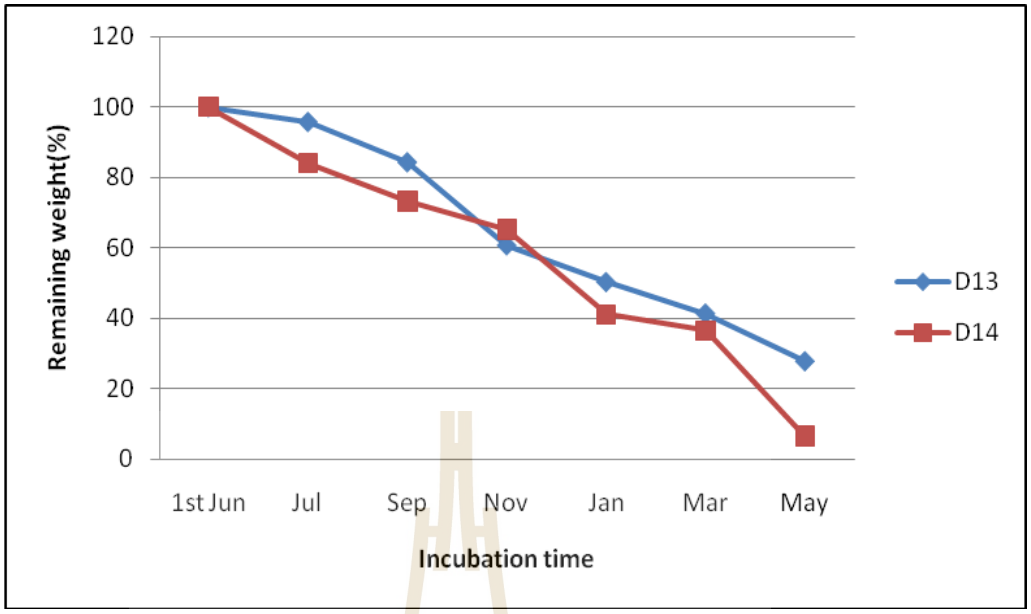


Figure 4 .10 The mean of mass remaining (%) of 4-mixed species and natural fallen leaf litter in dry dipterocarp forest during June 2007 to May 2008.

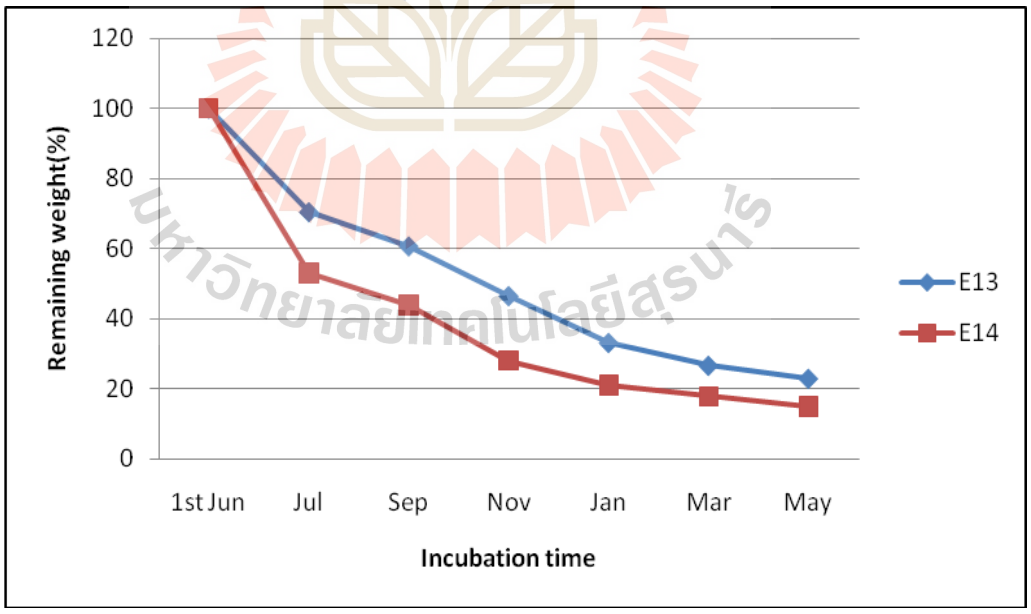


Figure 4 .11 The mean of mass remaining (%) of 4-mixed species and natural fallen leaf litter in dry evergreen forest during June 2007 to May 2008.

In general, the litter mass remaining decreased throughout the time of decomposing, but the rate of remaining weight may be different in the pattern case by case. In this case, the decomposition rates in the early period of incubation times were higher in dry evergreen forest (DEF) than those in dry dipterocarp forest (DDF). There were 91.59% (SD = 4.73) and 65.75% (SD = 7.16) of mean remaining weight at the first time of samples collection in DDF and DEF, respectively. In the contrast direction, the mean annual remaining weights of litters were 19.79% (SD = 8.44) and 22.28% (SD = 4.40) at the last period of incubation times; decay rates were higher in DDF and lower in DEF, respectively (Figures 4.12 and 4.13).

The different number of leaf litter species was studied for comparing the decomposition rate in each ecosystem. The results showed that natural fallen litter (DD5 and DE5) in both forests had a lower rate of remaining weight than in other treatments. There was 84.02% in the beginning time of determination, then after one year of incubation there was 6.57% of remaining weight for DD5 (Figure 4.12). There was the same state in DEF; the mean litter remaining was 53.07% at the 2nd month of incubation and 14.83% for DE5 in the last time of sample collection. Despite the incubation along the year, considerable litter mass remained for the mono- and 2 to 4-mixed species, the data were different between ecosystems. There was the highest rate of mass remaining with 4-species mixed (27.80%); the lowest rate was 3-species mixed with 16.56% in dry dipterocarp forest. But in dry evergreen forest, there was the highest rate of mean mass remaining for 2-mixed species with 26.14% and the lowest rate was 22.70% for monoculture species (Figures 4.12 and 4.13).

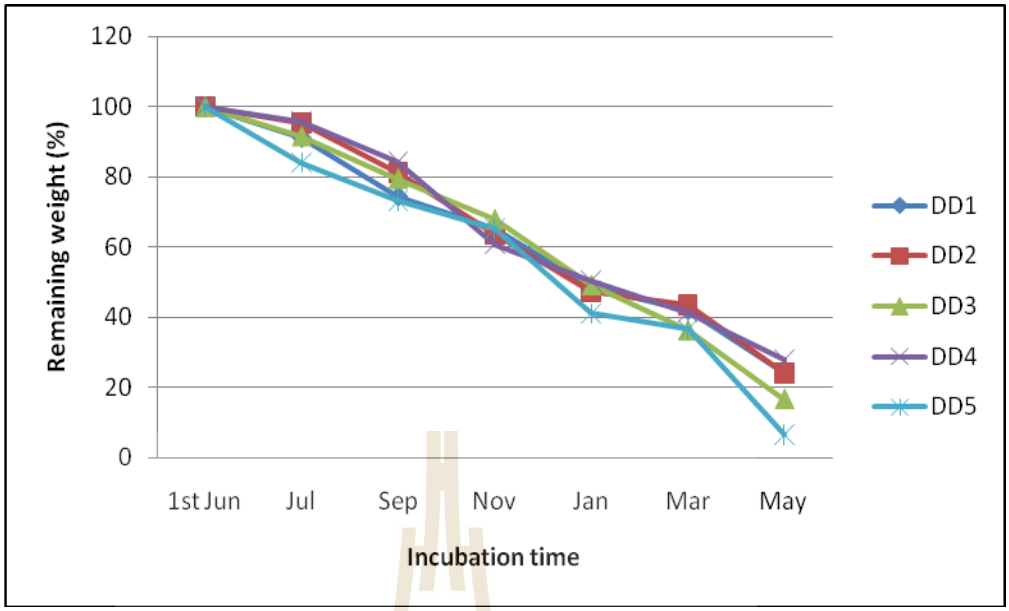


Figure 4.12 The mean of total mass remaining (%) of different leaf litter diversity in dry dipterocarp forest during June 2007 to May 2008.

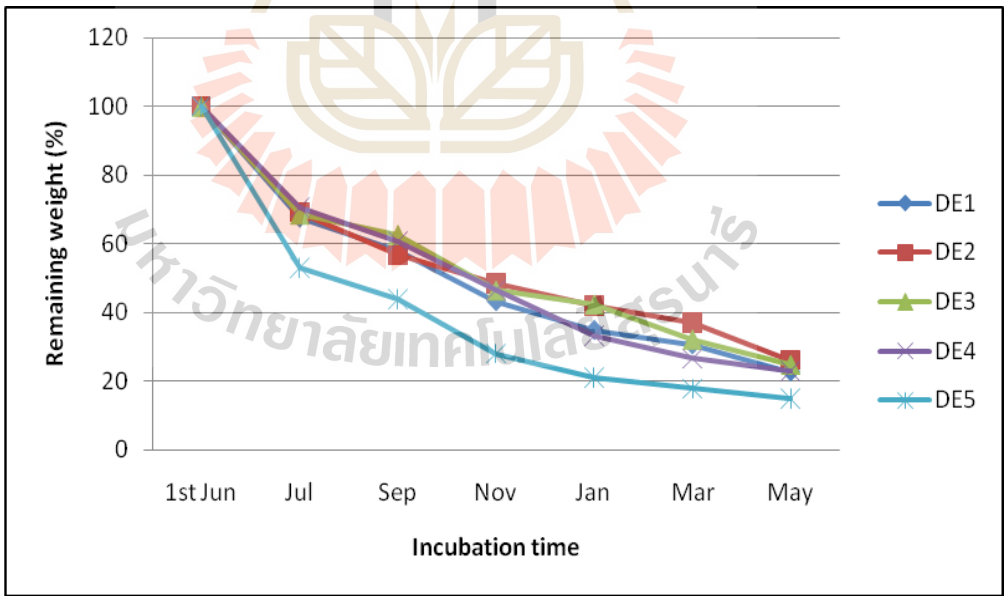


Figure 4.13 The mean of total mass remaining (%) of different leaf litter diversity in dry evergreen forest during June 2007 to May 2008.

4.2.2 Litter k-constant

The decomposition rates of litter were fitted to a single exponential decay model of Olson (1963, reviewed by Liu et al., 2006). The k - constant rate of dominant mono-species and different mixed litter species was calculated for annual decay rate in both dry dipterocarp and dry evergreen forest. The results showed that the decomposition rate of mono-species litter in dry evergreen forest was higher than that in dry dipterocarp forest. The highest rate of annual k - constant was 2.07 with *H. ferrea* Laness in dry evergreen forest, while it was 1.73 with *D. tuberculatus* Roxb species in dry dipterocarp forest. The decay rate was the lowest with D2, *S. siamensis* Miq. (1.12), and was with E3, *Memecylon ovatum* Smith (1.09) (Figures 4.14 and 4.15).

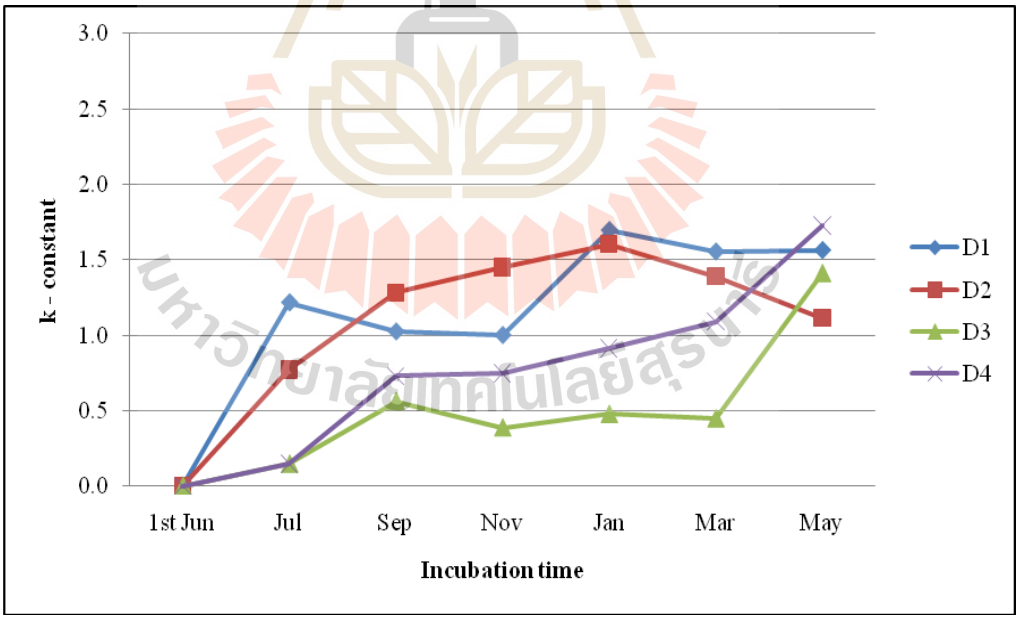


Figure 4.14 The decomposition constant (k) of mono-species leaf litter in dry dipterocarp forest during June 2007 to May 2008.

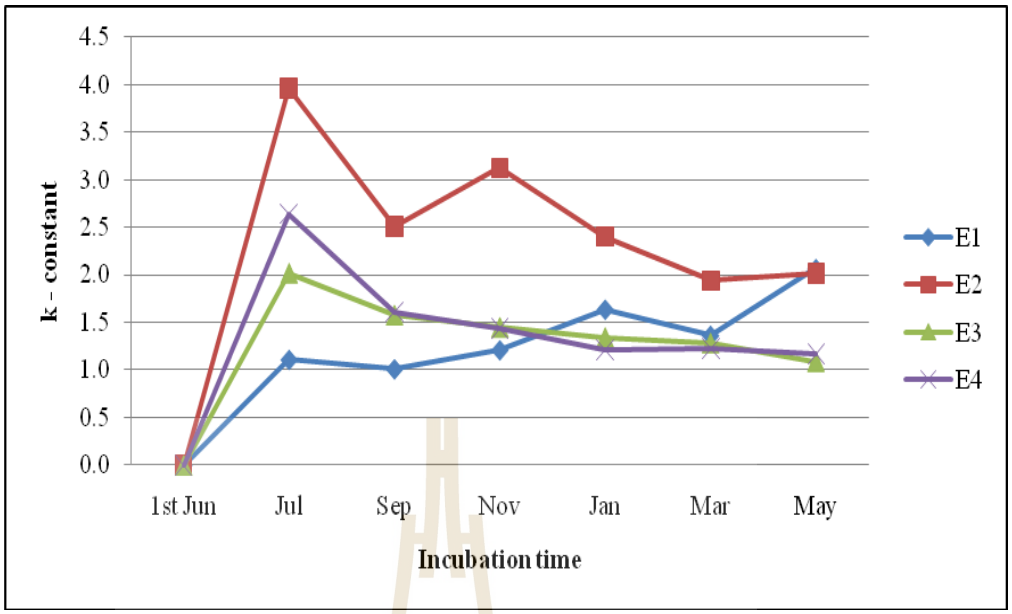


Figure 4.15 The decomposition constant (k) of mono-species leaf litter in dry evergreen forest during June 2007 to May 2008.

The annual decomposition rate of two mixed species was the highest with E7 (1.73), and the lowest was with E8 (0.83) in dry evergreen forest. There was the highest with D8 (1.62) and the lowest with D6 (1.14) in dry dipterocarp forest. The annual k - constant of D5 and D7 was 1.54 and 1.48, respectively, and there was the close rate with E5 and E6 (1.53 and 1.54, respectively) (Figures 4.16 and 4.17).

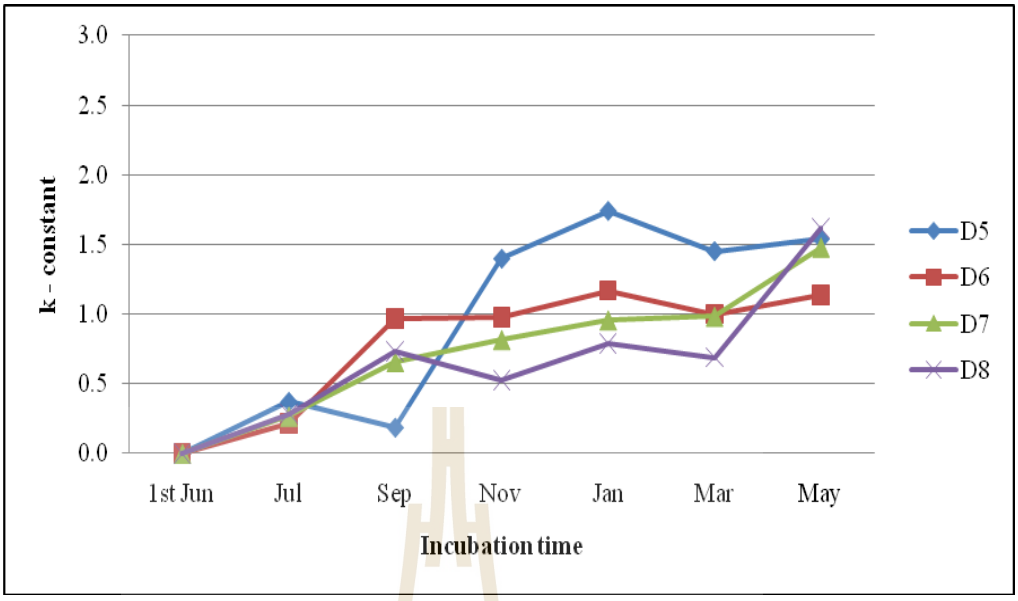


Figure 4.16 The decomposition constant (k) of 2-mixed species leaf litter in dry dipterocarp forest during June 2007 to May 2008.

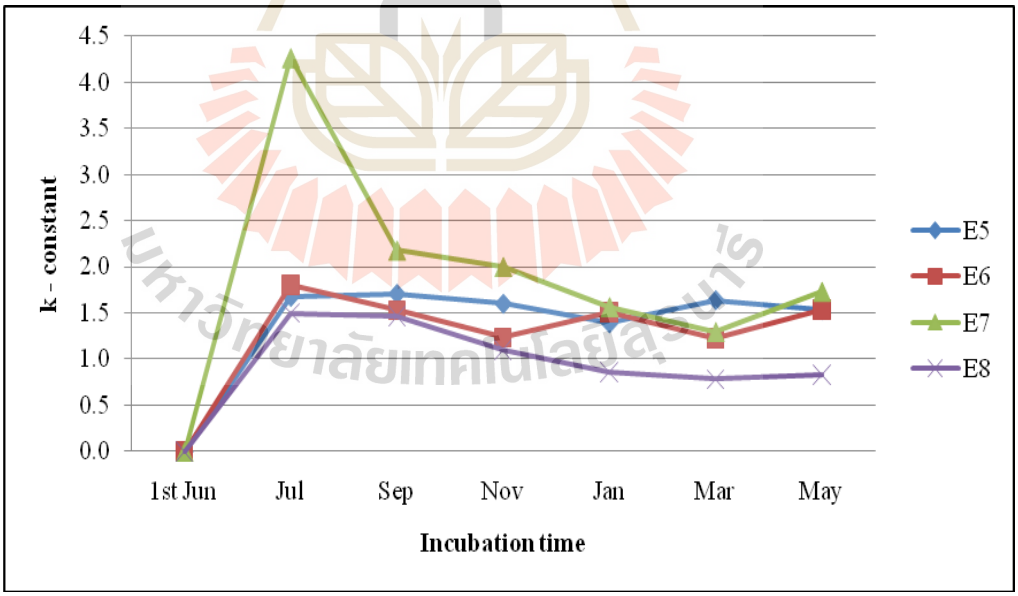


Figure 4.17 The decomposition constant (k) of 2-mixed species leaf litter in dry evergreen forest during June 2007 to May 2008.

The k - constant of 3-mixed species showed a different range of the highest and the lowest rate in dry dipterocarp forest but it was quite close to those in dry evergreen forest. The highest k - constant was 2.18 with D10 and the lowest was 1.65 with D12 in dry dipterocarp, while the highest decay rate in dry evergreen forest was with E9 (1.59) and the lowest was with E10 (1.10) (Figures 4.18 and 4.19).

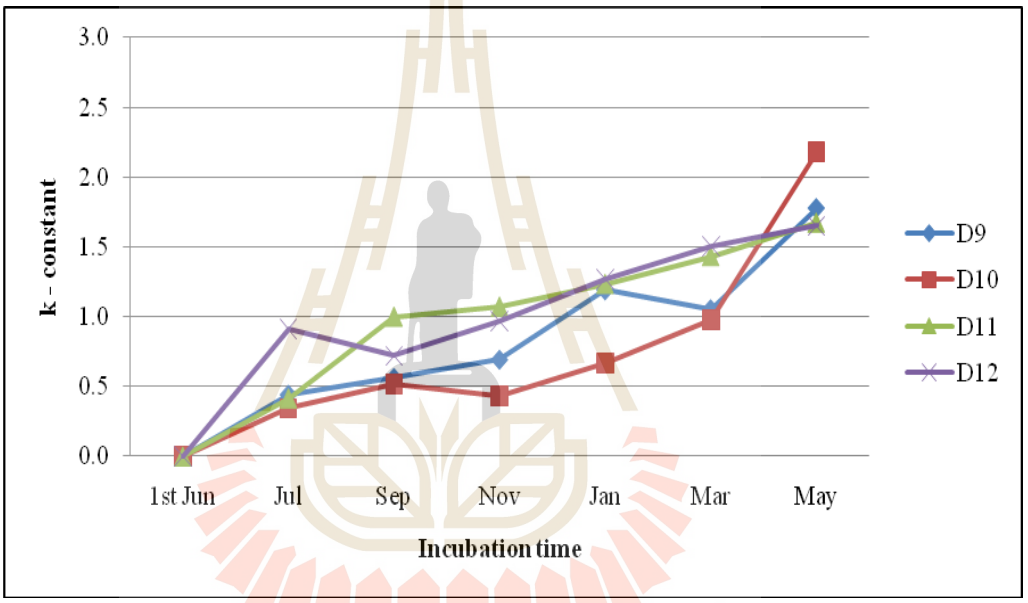


Figure 4.18 The decomposition constant (k) of 3-mixed species leaf litter in dry dipterocarp forest during June 2007 to May 2008.

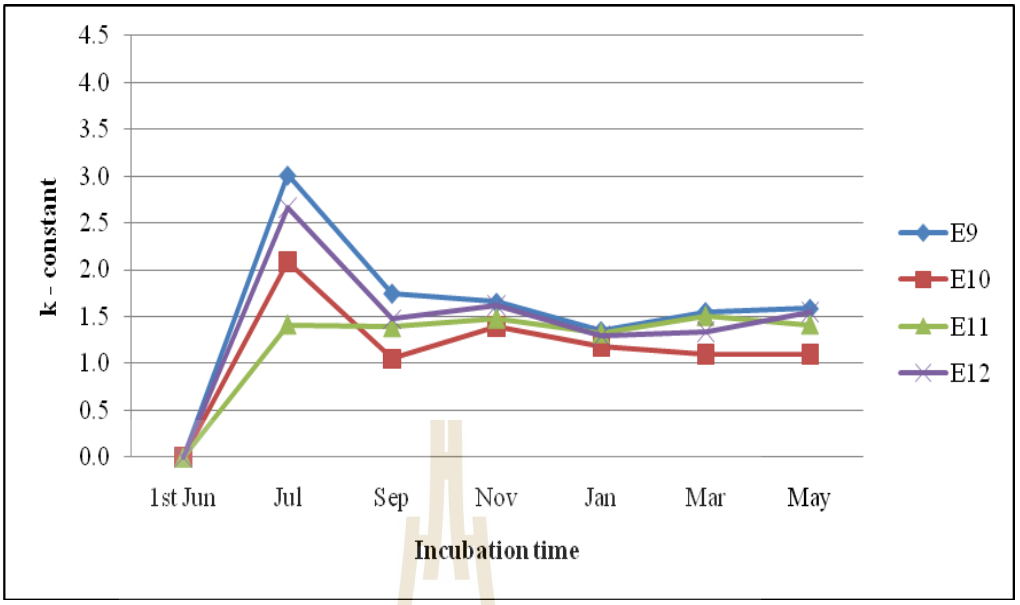


Figure 4.19 The decomposition constant (k) of 3-mixed species leaf litter in dry evergreen forest during June 2007 to May 2008.

The annual decomposition constant of 4-mixed species was 1.28 with D13 in dry dipterocarp forest, and it was 1.48 with E13 in dry evergreen forest. The natural fallen leaf litter decomposed with a high rate in both dry dipterocarp and dry evergreen forests. The annual k - constant of D14 was higher (2.72) than the k - constant of E14 (1.91) (Figures 4.20 and 4.21).

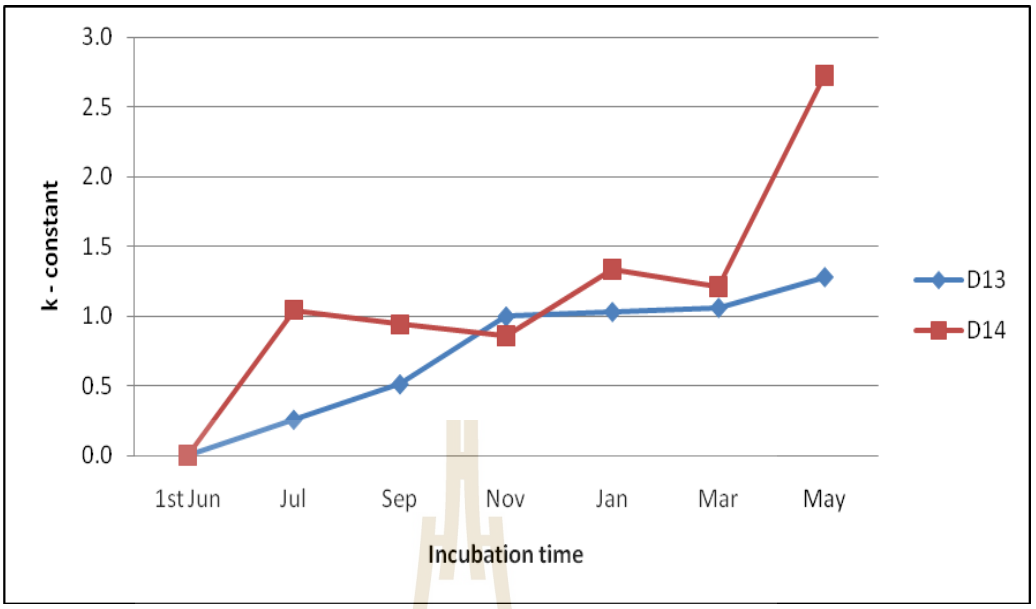


Figure 4.20 The decomposition constant (k) of 4-mixed species and natural fallen leaf litter in dry dipterocarp forest during June 2007 to May 2008.

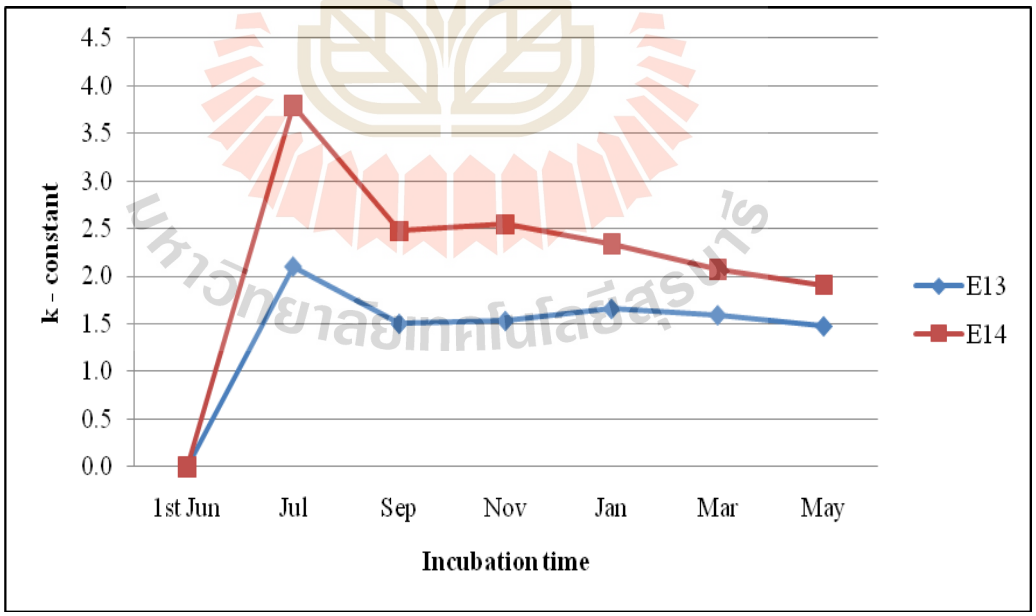


Figure 4.21 The decomposition constant (k) of 4-mixed species and natural fallen leaf litter in dry evergreen forest during June 2007 to May 2008.

After one year of incubation, the average k - constant of the different litter diversity treatments was analyzed. The results showed that decay rate constants (k) had different patterns of decomposition rates in DDF and DEF. There were higher rates in the early period (k = 2.43, SD = 1.001) and lower rates in the last period (k = 1.46, SD = 0.846) at DEF. On the other hand, there were lower rates in the early period (k = 0.49, SD = 0.350) but higher rates in the last period (k = 1.63, SD = 0.416) at DDF (Figures 4.22 and 4.23). The mean annual decay rates (k) of DDF and DEF were 0.86 (SD = 0.578) and 1.46 (SD = 0.846), respectively. The k - constants of natural fallen litters (DD5 and DE5) were higher than with single and multiple species in both forests. The minimum (1.24) and maximum (3.79) k - constant were found for DE2 at the10th month and for DE5 at the beginning of collecting in dry evergreen forest, respectively (Figure 4.23). There were the minimum (0.26) and maximum (2.72) k - constants for DD4 and DD5 in dry dipterocarp forest at the beginning and the last time of sample collection, respectively (Figure 4.22). The results showed a significantly different rate of annual litter mass loss (t = 5.751, $P < 0.001$) between dry dipterocarp and dry evergreen forests (Table 4.1).

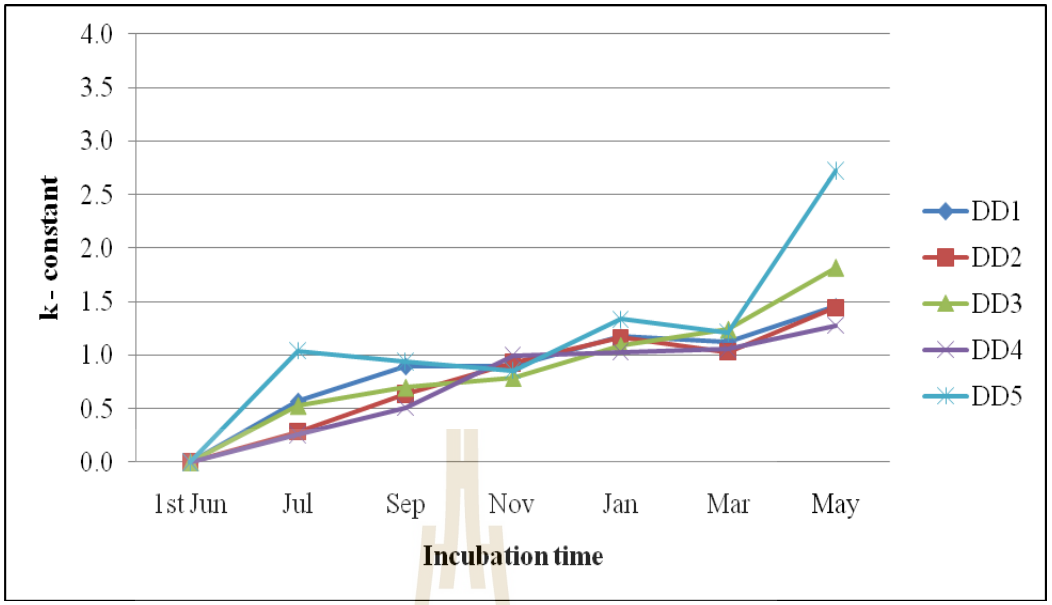


Figure 4.22 The decomposition constant (k) of different leaf litter diversity in dry dipterocarp forest during June 2007 to May 2008.

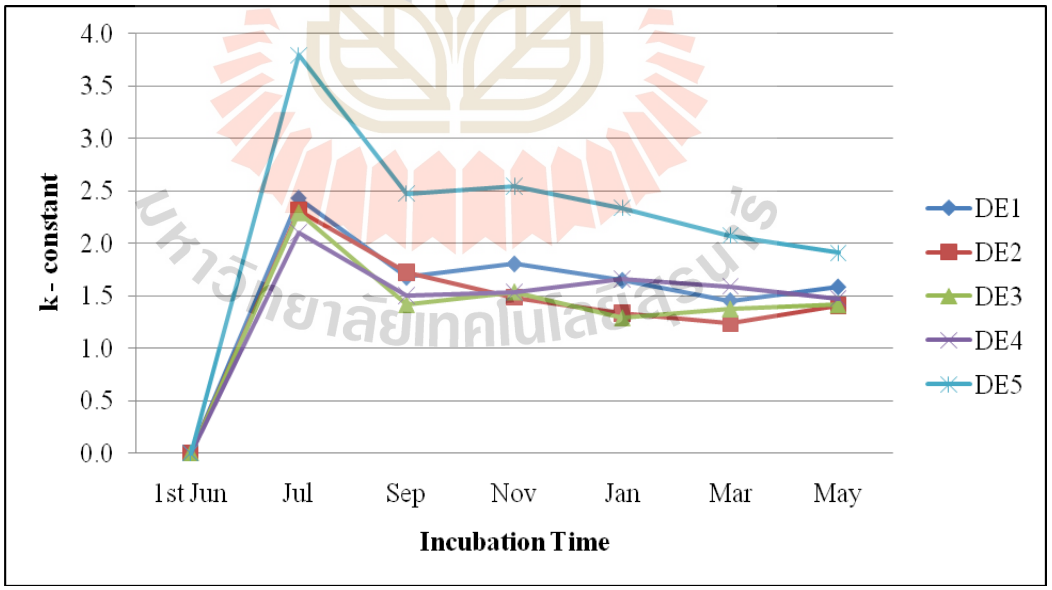


Figure 4.23 The decomposition constant (k) of different leaf litter diversities in dry evergreen forest during June 2007 to May 2008.

4.2.3 The linkage of decomposition rate to litter diversity and time intervals

The effect of litter diversity and period of incubation on annual k - constant was analyzed. The ANOVA showed no significant effects of mixed species number on k - constant in both dry evergreen forest (F = 0.606, *P* = 0.613) and dry dipterocarp forest (F = 0.791, *P* = 0.504). The results showed the interaction between time intervals and k - constant. There were the different decay rates of treatments by time of incubation in both ecosystems. The analysis of variance shows F-value at 21.944 (*P* < 0.001) in dry dipterocarp forest and F-value at14.237 (*P* < 0.001) in dry evergreen forest as shown in Table 4.1.

Table 4.1 Summary t-test and analysis of variance (F- and *P*- values) for factors affecting litter decomposition rate (k-constant).

Factors / **Response variable**	**forest**		**Species diversity (3d.f.)**		**Time intervals (6d.f.)**	
	t	*P*	F	*P*	F	*P*
k - constant	5.751	< 0.001				
k - constant in DDF			0.791	0.504	21.944	<0.001
k - constant in DEF			0.606	0.613	14.237	<0.001

Different data represent significant difference at *P* < 0.05.

4.3 The Litter Quality

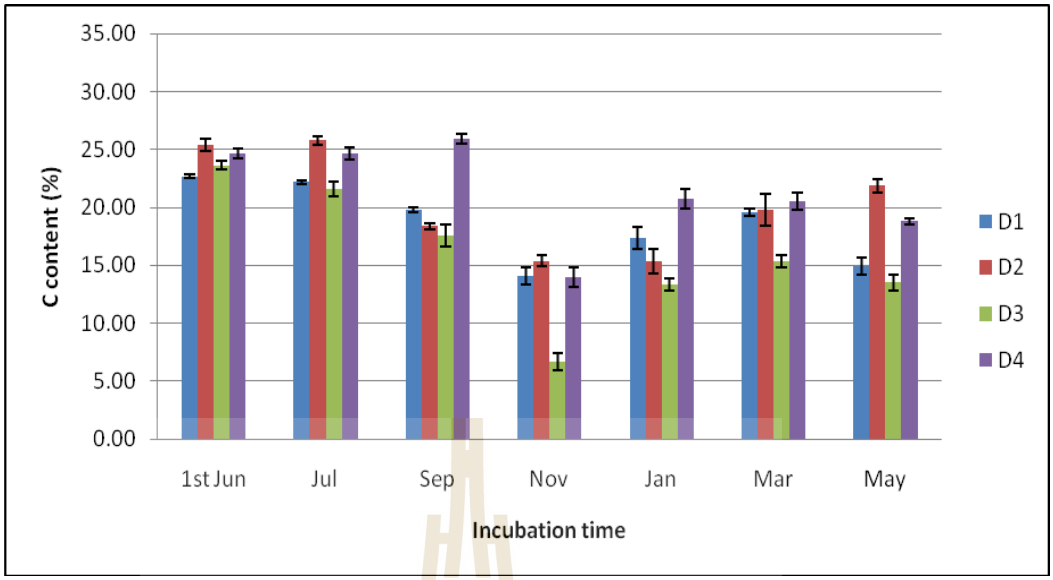
The chemical contents were the main factors influencing the decomposition rate. The initial leaf litter chemistry was investigated for studying its effect on the different mixed litter treatment and then the changing of leaf litter quality was studied during the course of the experiment. The results are as follows:

4.3.1 The quality of mono-species

4.3.1.1 Carbon concentration

In dry dipterocarp forest, *S. siamensis* Miq. contained the highest initial carbon content (25.41%), while the lowest content was in *S. obtusa* Wall. (22.69%). There was the highest initial carbon content in *M. caeruleum* Jack (31.18%), and the lowest content was in *H. ferrea* Laness (18.37%) in dry evergreen forest.

The changing of carbon content after the experiment varied among litter species, carbon content of all species decreased during the incubation time exception *H. ferrea* Laness. The remaining amount of carbon was the close rate for the highest concentration of *S. siamensis* Miq. with 21.88% and *M. caeruleum* Jack with 21.23% in DDF and DEF, respectively. The lowest remaining C content was in *S. roxburghii* Don with 13.52% in DDF, and it was with *A. xylocarpa* (Kurz) Craib with 17.33% in DEF (Figures 4.24a and 4.24b).



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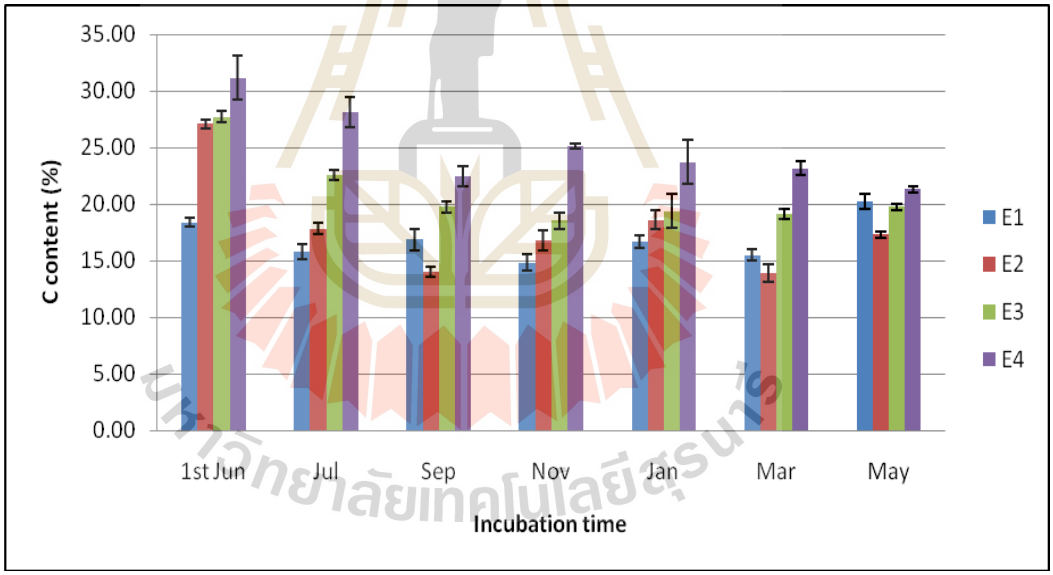


(b)

Figure 4.24 The carbon content of mono species leaf litter in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

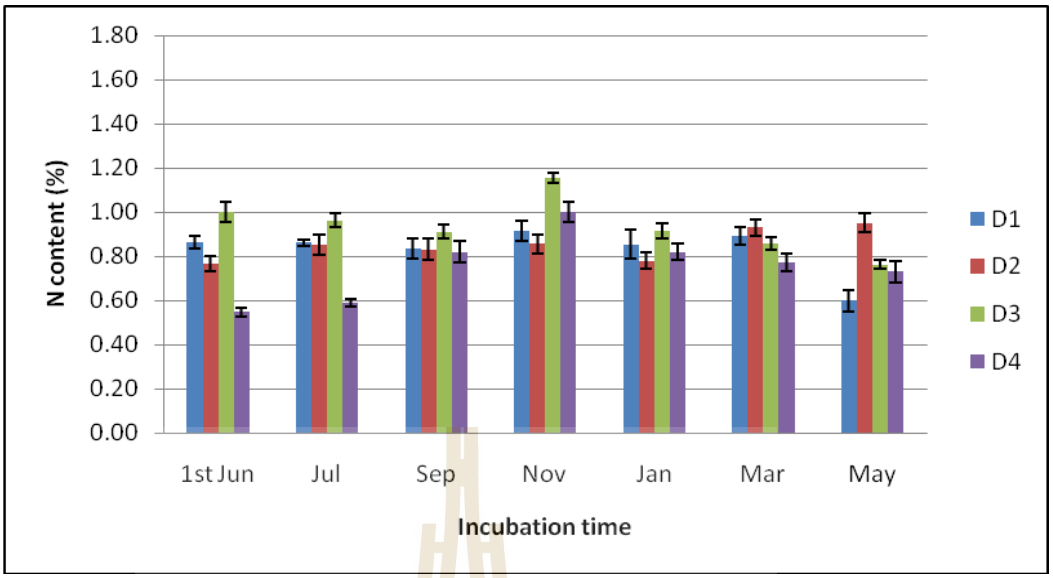
4.3.1.2 Nitrogen concentration

The nitrogen concentration of dry evergreen litter species was higher than that of dry dipterocarp litter species (Figures 4.25a and 4.25b). The highest initial N content was in *H. ferrea* Laness with 1.54% in DEF and it was in *S. siamensis* Miq. with 0.95% in DDF. The lowest initial N content in DEF was with *M. caeruleum* Jack (0.48%), and it was with *D. tuberculatus* Roxb. (0.55%).

The N concentration in the residual leaf litter was highest in *S. siamensis* Miq. with 0.95%, and it was lowest in *S. obtusa* Wall. with 0.60% in DDF. The highest rate of N content was in *H. ferrea* Laness with 1.54% and the lowest content was in *M. caeruleum* Jack with 0.84% in DEF. The percentage of N content in most species of residual litter was higher than the initial content, except *S. obtusa* Wall. and *D. tuberculatus* Roxb. in DDF (Figures 4.25a and 4.25b).

4.3.1.3 Lignin concentration

The lignin concentration of leaf litter varied among the species, the percentages of lignin in some species were different from that of other species, i.e., the *A. xylocarpa* (Kurz) Craib species in DEF contained higher lignin content than that in other species, while *S. siamensis* Miq. in DDF contained lower lignin content than that in other species.



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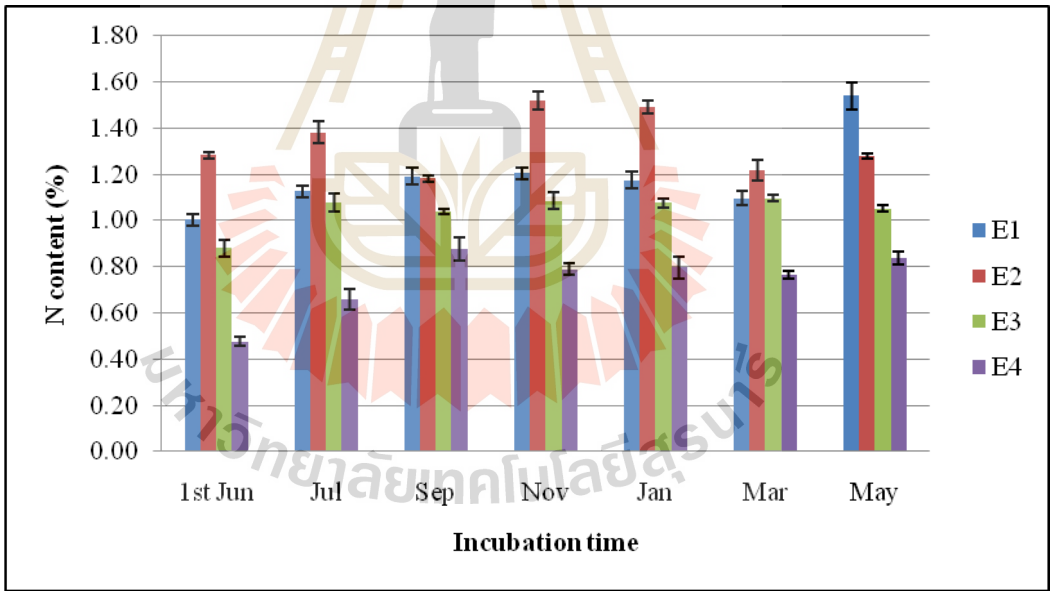


(b)

Figure 4.25 The nitrogen content of mono-species leaf litter in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

In dry dipterocarp forest, the highest initial lignin content was in *D. tuberculatus* Roxb. with 25.47%, and the lowest concentration was in *S. siamensis* Miq. with 12.73%. There was the highest initial lignin in *A. xylocarpa* (Kurz) Craib with 19.78%, and the lowest was in *M. ovatum* Smith with 7.44% in dry evergreen forest. After incubation, the lignin content of *D. tuberculatus* Roxb. increased and then it was the highest remaining percentage in DDF (26.71%). In the other hand, lignin concentration in *S. roxburghii* Don decreased and it was the lowest remaining percentage in DDF (8.97%). The remaining lignin content litter in DEF was quite higher than the initial content of most species. The highest rate was in *A. xylocarpa* (Kurz) Craib with 26.03% and the lowest rate was in *M. caeruleum* Jack with 11.22% (Figures 4.26a and 4.26b).

4.3.1.4 Cellulose concentration

D. tuberculatus Roxb. species had the highest rate of initial cellulose with 29.00%, and *S. siamensis* Miq. had the lowest cellulose concentration with 22.23% in dry dipterocarp forest. The litter species which contained the highest initial cellulose in DEF was *M. ovatum* Smith with 24.93%, and the lowest initial cellulose was in *A. xylocarpa* (Kurz) Craib with 17.49%.

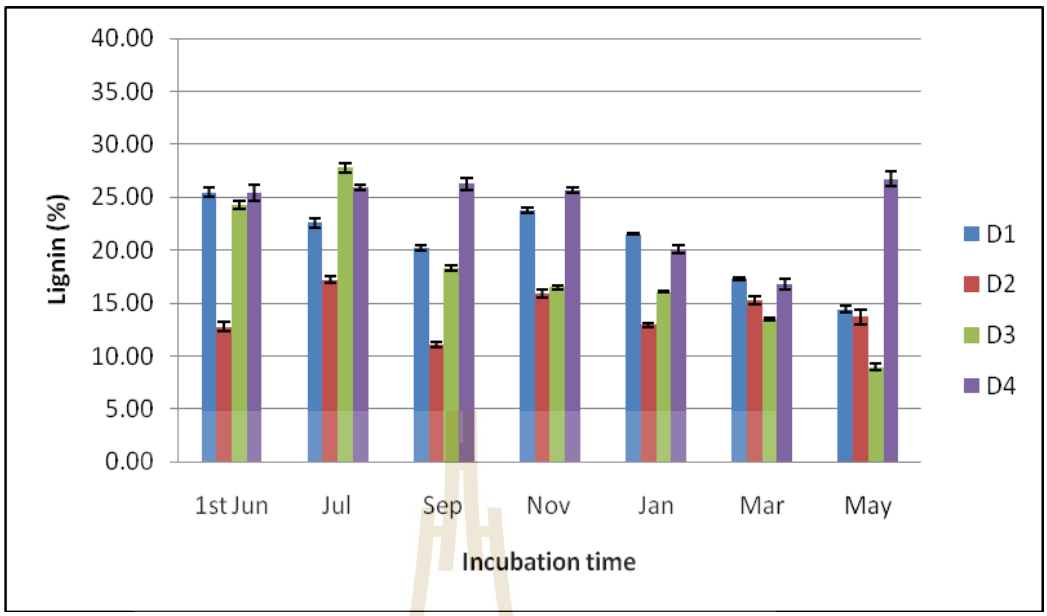
The tendency of cellulose was to decreased rate in both DDF and DEF, excepted for *S. siamensis* Miq. species in DDF, which had the lowest initial cellulose content and the highest remaining concentration with 23.01%. The lowest remaining cellulose was in *S. obtusa* Wall. with 4.10%, which was different from the initial percentage this in species (28.11%). The highest remaining cellulose content in DEF was in *H. ferrea* Laness with 14.51% and the lowest content was in *M. ovatum* Smith with 9.11%. This was the same as in

DDF, in which the lowest percentage was very different from the initial content (Figures 4.27a and 4.27b).

4.3.1.5 C/N ratio

There were much different levels between the highest C/N ratio and the lowest ratio in DDF and especially in DEF. There was the highest initial C/N ratio in *D. tuberculatus* Roxb. with 45.07 and the lowest initial ratio was in *S. roxburghii* Don with 23.58 in DDF. The results showed different levels between the highest C/N ratio in *M. caeruleum* Jack (65.39) and the lowest proportion in *H. ferrea* Laness (18.31) in DEF.

The C/N ratio in litter slightly decreased during the incubation time. The highest remaining C/N ratio was in *D. tuberculatus* Roxb. with 25.81 and the lowest remaining ratio was in *S. roxburghii* Don with 17.75 in DDF. The highest and the lowest remaining C/N ratio in DEF was with the same species which contained the highest and lowest initial proportion; there was the highest in *M. caeruleum* Jack with 25.45 and the lowest proportion in *H. ferrea* Laness with 13.11 (Figures 4.28a and 4.28b).



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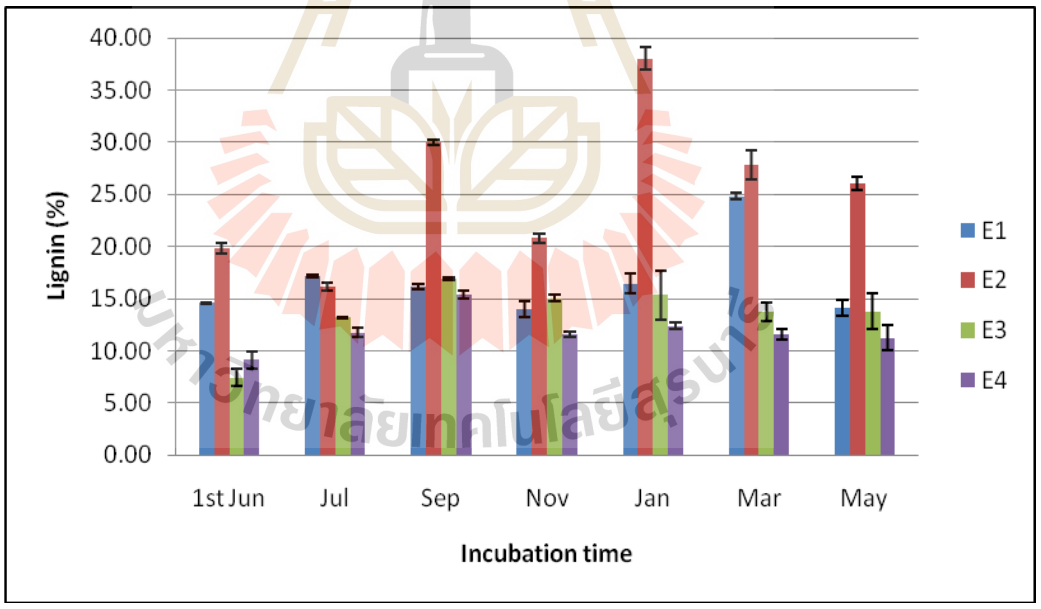

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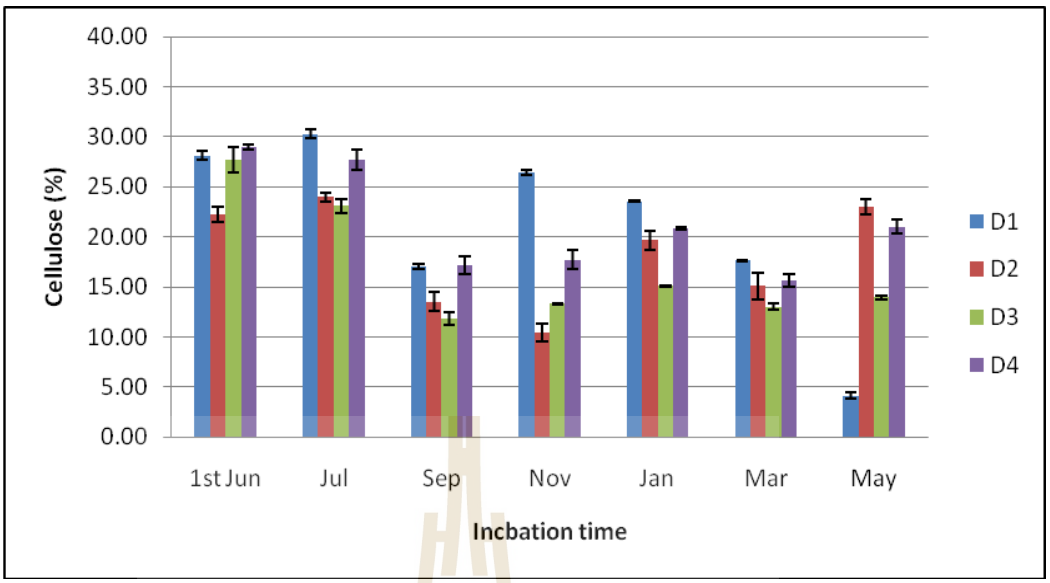
Figure 4.26 The lignin content of mono-species leaf litter in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.



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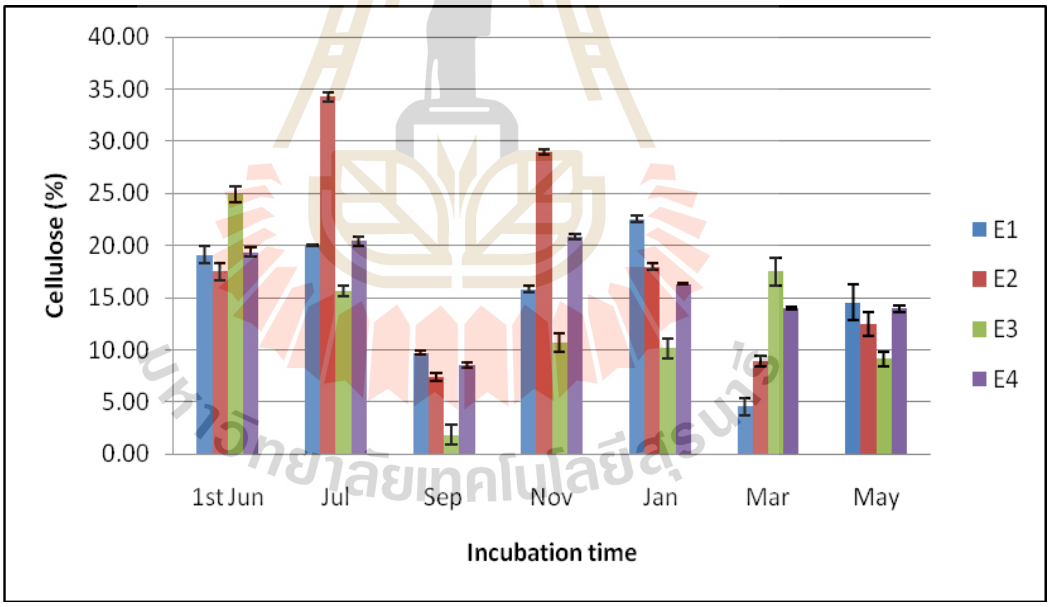
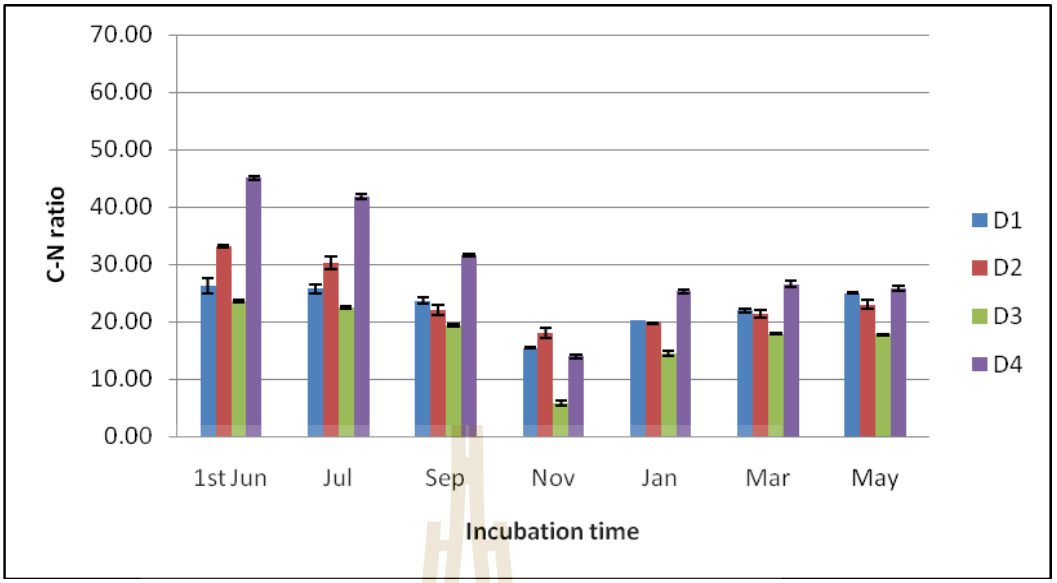


(b)

Figure 4.27 The cellulose content of mono-species leaf litter in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.



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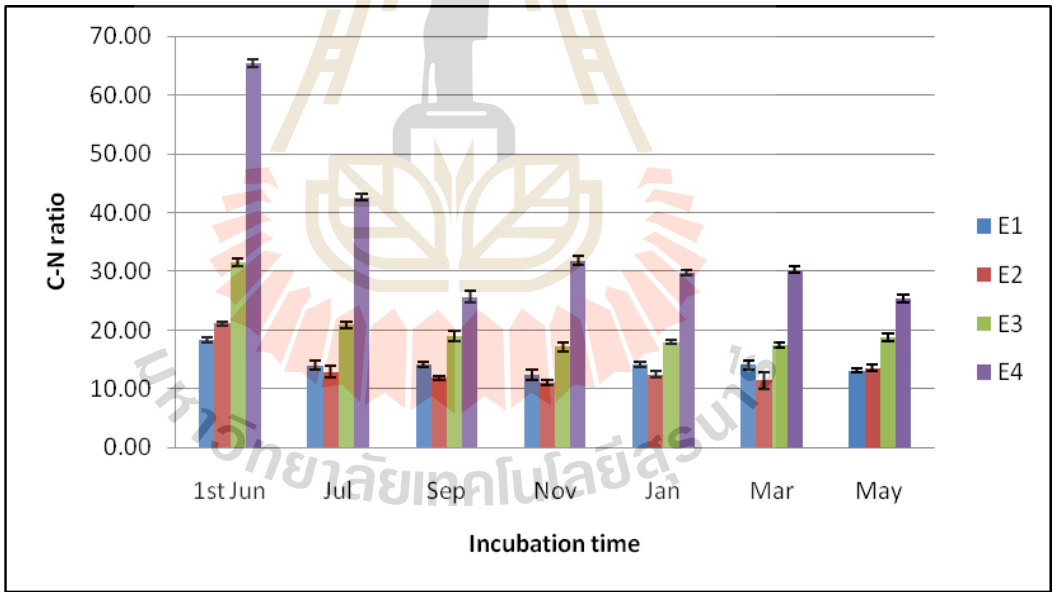


(b)

Figure 4.28 The C-N ratio of mono-species leaf litter in dry dipterocarp and dry evergreen forests during June 2007 to May 2008.

4.3.2 Quality of the different species mixed litter

4.3.2.1 Litter carbon content

The initial carbon concentration in leaf litter varied between the treatments. In dry dipterocarp forest, the highest percent of C content in natural leaf litter was 24.73% and the lowest percent in DD4 was 23.24% (Figure 4.29a). The highest initial percentage C content in dry evergreen forest was in DE4 and lowest in DE5 with 27.04% and 22.70%, respectively (Figure 4.29b). The results showed that the initial C content were not significantly different among the treatments in both sites (Table 4.2).

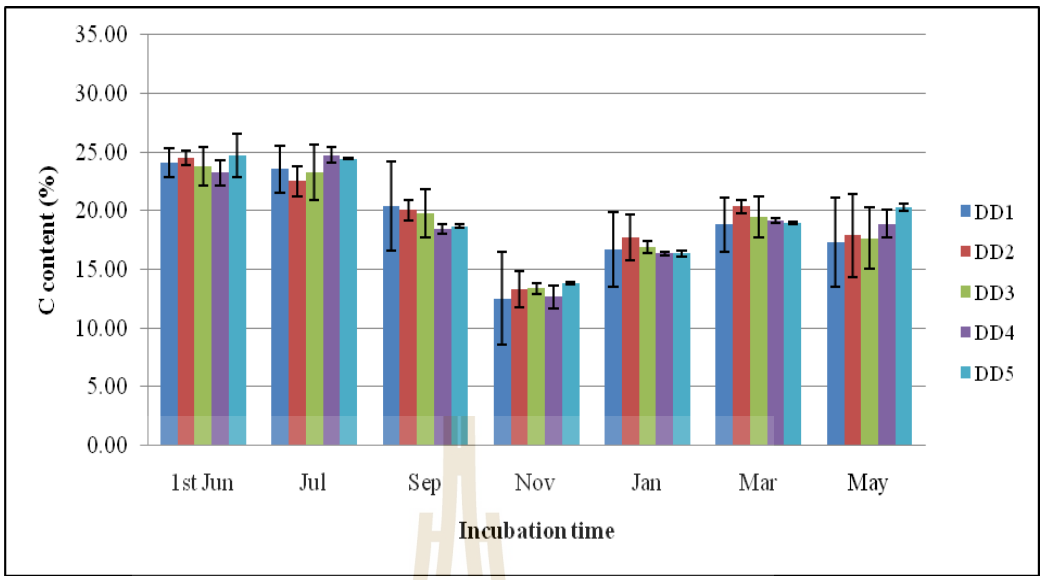
The C contents in leaf litter were investigated for the one - year property changing experiment, the result showed varied data among the treatments. The percentage of carbon content ranged from the initial of 24.73% with DD5 to 12.53% with DD1 on the 6th month of incubation at dry dipterocarp forest. For dry evergreen forest, the range of C content was 27.04% for DE4 at the initial property to 12.46% of DE4 when the 8th month of experiment. The patterns of carbon changing were in the same direction in both forests, the percentage of C content decreased from the first month (mean = 24.11 ± 1.10) until the 6th month intervals (mean = 13.11 ± 2.10) and then increased again from the 8th month (mean = 17.00 ± 1.88) until the last month of incubation (mean = 17.91 ± 2.89) at dry dipterocarp forest (Figure 4.29a). There was the same pattern for dry evergreen forest, the percentage of C content in leaf litter ranged from the highest in the initial property (mean = 25.93 ± 3.11) to the lowest in the 6th month of experiment (mean = 18.56 ± 2.83) and then the percentage increased from the 8th

month (mean = 18.71 ± 3.30) to the remaining C in the last time of sample harvest (19.55 ± 1.61) (Figure 4.29b).

The remaining C concentrations of dried leaf litter in dry dipterocarp forest were 20.32%, 18.88%, 17.91%, 17.67%, and 17.29% for DD5, DD4, DD2, DD3, and DD1, respectively (Fig.4.29a). In dry evergreen forest, the remaining C content in litter were 20.14%, 19.74%, 19.65%, 19.20%, and 18.04% for DE2, DE4, DE1, DE3, and DE5, respectively (Figure 4.29b). There was a different mean of remaining C content between ecosystems ($t = 40.511$, $P < 0.01$).

4.3.2.2 Litter nitrogen concentration

The concentrations of litter N content fluctuated with time of incubation and varied among treatments. The initial N concentration of litter at dry dipterocarp forest was the highest in DD1 with 0.79% and then 0.77%, 0.76%, 0.75%, and 0.69% in DD2, DD3, DD5, and DD4, respectively (Figure 4.30a). The highest N content of litter in dry evergreen forest was found in DE5 with 1.07% and the lower levels were 0.91%, 0.89%, 0.88%, and 0.81% in DE1, DE3, DE2, and DE4, respectively (Figure 4.30b). The result showed that initial N content was not significantly different among treatments in both sites (Table 4.2).



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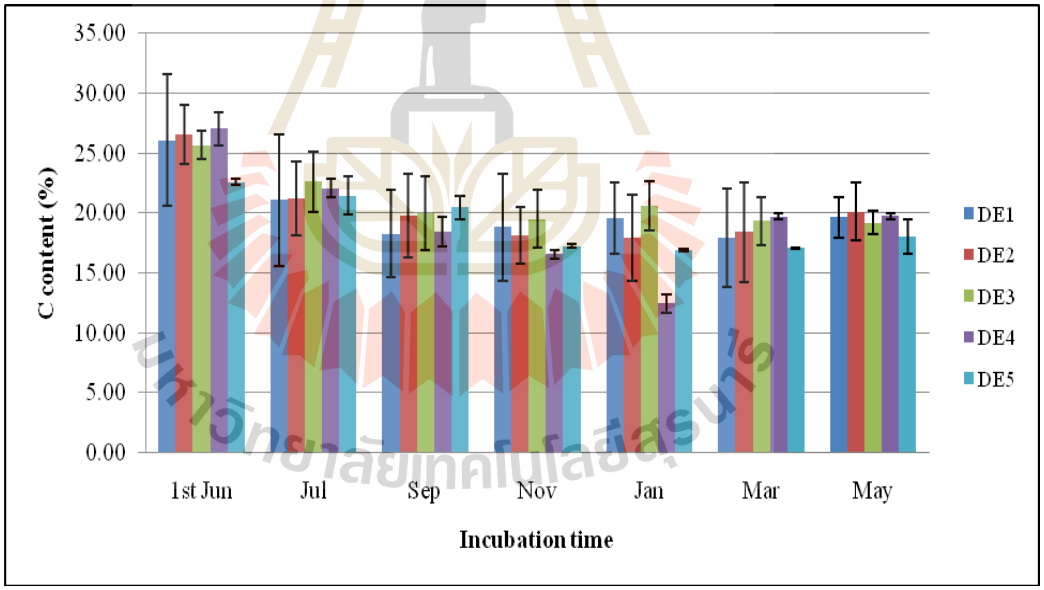
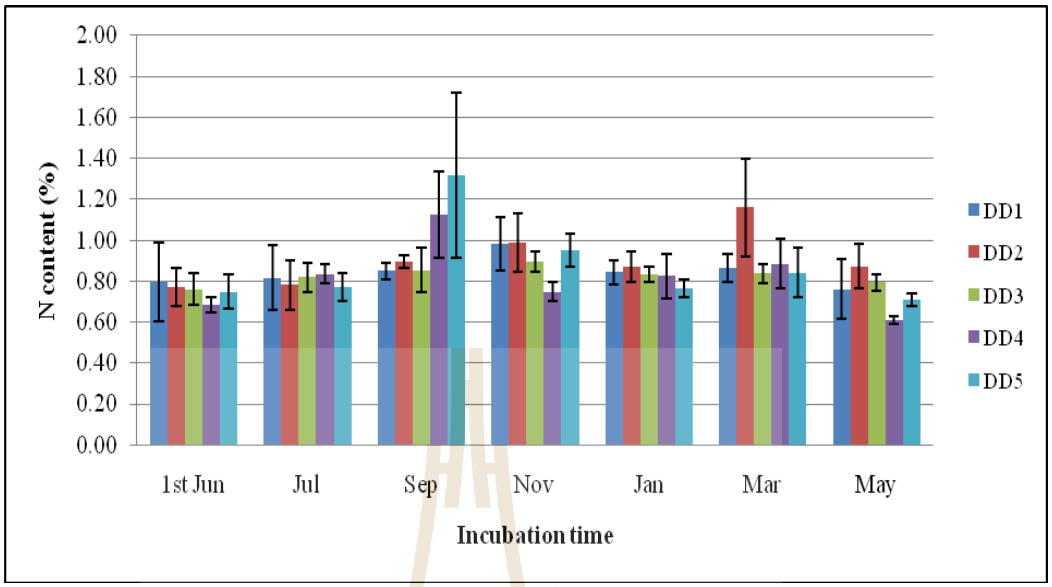


(b)

Figure 4.29 The carbon content of leaf litter in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

During one year of incubation, the N concentration of leaf litter in dry dipterocarp forest was increased in the early period of incubation. The mean of percentage of litter N concentration ranged from the initial with 0.77 ± 0.11 % and then increased to 0.81 ± 0.10 %, 0.92 ± 0.15%, 0.94 ± 0.12%, 0.84 ± 0.06%, 0.94 ± 0.19% along the sample collection time, until it was 0.79 ± 0.12% at the last time of incubation. There was the similar tendency of N content changing of litter in dry evergreen forest, the data showed that the percentage of mean N content in litter increased from the initial with 0.90 ± 0.21%, then there were 1.09 ±0.19%, 1.14 ± 0.12%, 1.13 ± 0.18%, 1.14 ± 0.17%, 1.08 ± 0.12%; and 1.14 ± 0.18% along the sample collection times (Figure 4.30a and 4.30b). It was found that the times of incubation related to the concentration changing of nitrogen in litter only in dry dipterocarp forest ($F = 6.850$, $P < 0.001$) but was not significantly related in dry evergreen forest ($F = 1.747$, $P = 0.125$).

The different number of litter species was studied to compare the changing of nitrogen concentration between treatments. The change of N content varied among the treatments in both ecosystems (Figure 4.30a and 4.30b). The result showed that the mean of N concentration changing along the experiment were significantly different between forests ($P < 0.001$). However, the different number of litter species did not affect the N content in both dry dipterocarp forest ($F = 2.173$, $P = 0.082$) and dry evergreen forest ($F = 0.652$, $P = 0.627$).



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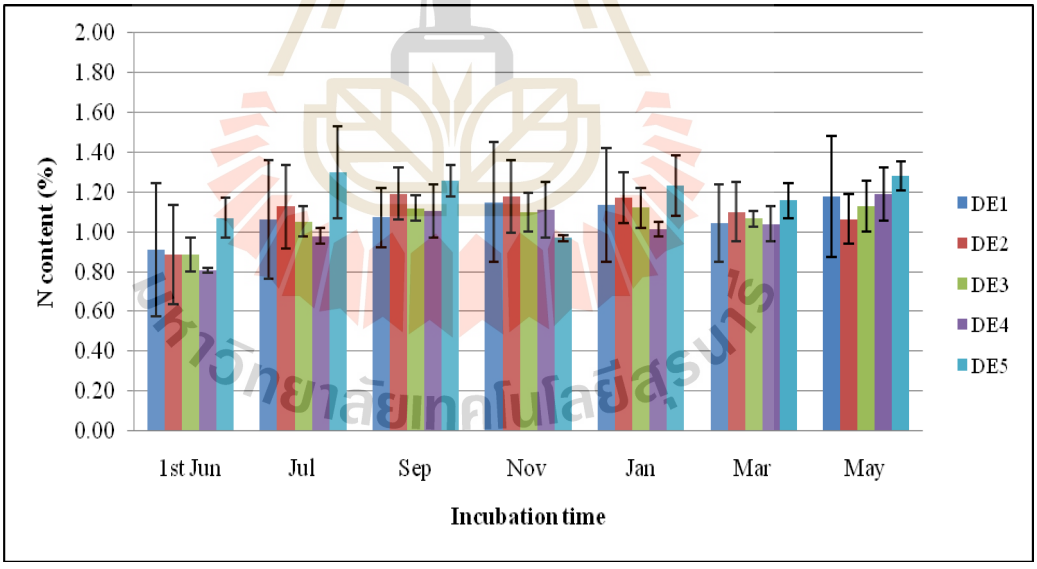


(b)

Figure 4.30 The nitrogen content of leaf litter in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

4.3.2.3 Lignin concentration in litter

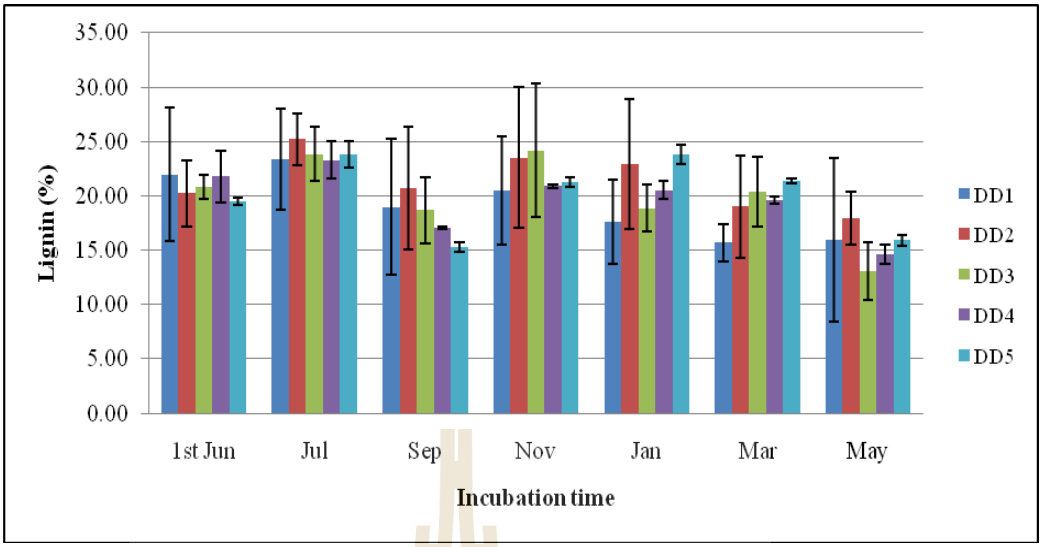
Lignin is one of the main components in leaf litter because it is the composition of leaf structure. So, lignin is defined as one chemical contribution to litter quality. For this research, the lignin content in litter varied among the treatments. The average initial of litter lignin concentration in dry dipterocarp forest (20.95 ± 3.47%) was higher than that in dry evergreen forest (13.59 ± 3.75%). The highest rate was found in DD1 (21.98%) and the lowest was in DD5 (19.47%) of dry dipterocarp forest and there was the highest in DE5 (17.61%), where the lowest was in DE2 (12.62%) in dry evergreen forest. The result showed initial lignin content was not significantly different between treatments in both sites (Table 4.2) but there was the significant differently content of mean initial lignin between forests ($P < 0.001$).

The changing of lignin content during the time of incubation was slightly curved. From the initial state, the lignin content increased in the 2nd month of investigation, and slightly decreased until the last month of experiment (Figures 4.31a and 4.31b), while the treatment that changed in the highest level of lignin after one year of incubation was DD3 (7.72%) and then were lower with DD4, DD1, DD5, and DD2, respectively, in dry dipterocarp forest. The highest changing level of lignin content was found in DE2 (3.59%) and then followed by DE1, DE5, DE3, and DE4, respectively, in dry evergreen forest. The interesting thing about the lignin content changing is the direction; the remaining lignin contents in dry dipterocarp forest were lower than the initial in all treatments, but in dry evergreen forest, in contrast, most of litter treatments were the higher remaining lignin than those in the initial incubation but except for DE4.

The time of incubation affecting lignin concentration was only found in dry dipterocarp forest (F = 3.343, *P* = 0.006), but did not significantly affect the concentration in dry evergreen forest (F = 1.415, *P* = 0.223). In contrast, for the effect of treatment, there was a significantly difference of lignin content between treatment in dry evergreen forest (F = 2.711, *P* = 0.038), but not a significantly difference in dry dipterocarp forest (F = 0.869, *P* = 0.487).

4.3.2.4 Cellulose concentration in litter

The fraction of leaf structural polysaccharides, cellulose, was studied as the one factor of litter quality. The results showed the average initial content in dry dipterocarp forest (25.85 ± 2.51%) was higher than that in dry evergreen forest (19.18 ± 2.62%). Therefore, the t-test analysis showed mean of initial cellulose content was significantly different between forest (*P* < 0.001). The treatment DD5 contained the highest cellulose (28.25%) and DD4 contained the lowest cellulose (24.88%) in dry dipterocarp forest. Considerable data showed the similar state in dry evergreen forest, there were the highest with DE5 (23.45%) and lowest with DE4 (16.33%). The ANOVA showed the initial cellulose concentrations were not significantly different between treatments in both forests (Table 4.2).



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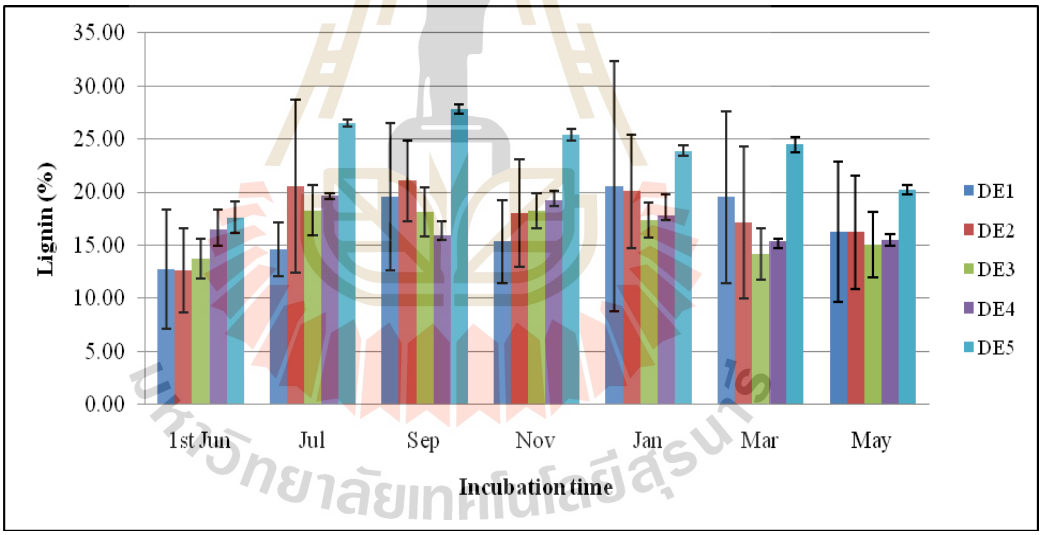
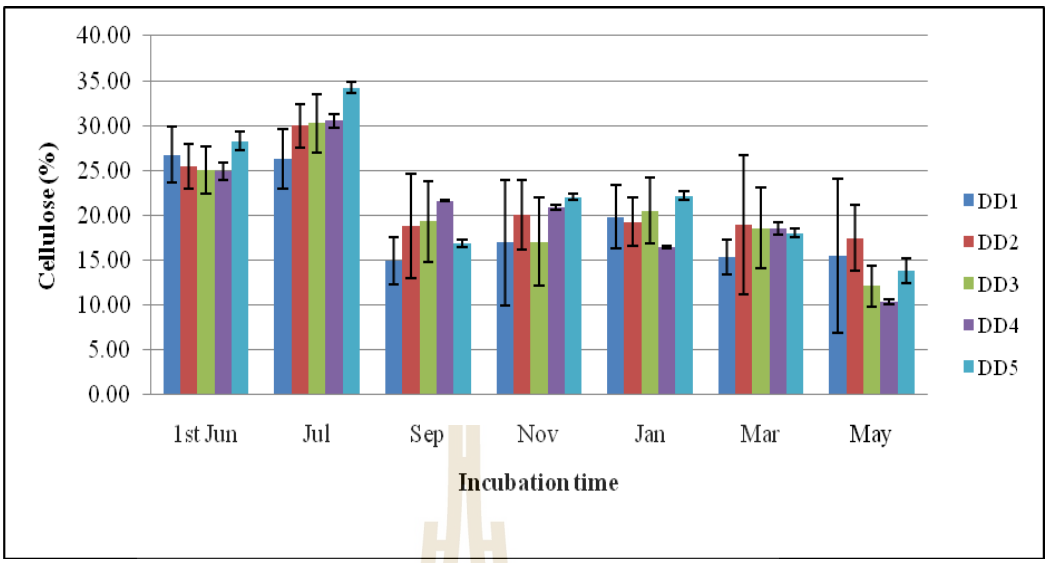


(b)

Figure 4.31 The lignin content of leaf litter in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

The treatment which changed in the highest level of cellulose after one year of incubation was in DD4 (14.51%) and then were lower with DD5, DD3, DD1, and DD2, respectively, in dry dipterocarp forest. The highest changing rate was found in DE5 (13.00%) and then followed by DE2, DE3, DE1, and DE4, respectively, in dry evergreen forest. The direction of cellulose degraded was decreased in all treatments of the both forests. The average cellulose concentration in dry dipterocarp forest was the lowest in April - May (14.61 ± 5.22%), but in dry evergreen forest was the lowest in August - September (7.96 ± 2.71%). The ANOVA showed the time of incubation affected cellulose content in both dry dipterocarp forest ($F = 14.271$, $P < 0.001$) and dry evergreen forest ($F = 10.252$, $P = < 0.001$). It was found the different treatments had significantly affected the average cellulose content in dry evergreen forest ($F = 3.196$, $P = 0.019$) but no significant effect in dry dipterocarp forest ($F = 1.029$, $P = 0.399$).

At the end of one year study, the cellulose concentration tended to decrease in all treatments of both sites. The highest remaining content were with DD2 (17.46%) in dry dipterocarp forest and with DE1 (12.51%) in dry evergreen forest (Figures 4.32a and 4.32b). The lowest contents were found in DD4 (10.37%) and in DE2 (10.15%) of dry dipterocarp and dry evergreen forests, respectively. The ANOVA showed that the residual amounts of litter cellulose concentrations were not significantly affected by different treatments ($P < 0.001$).



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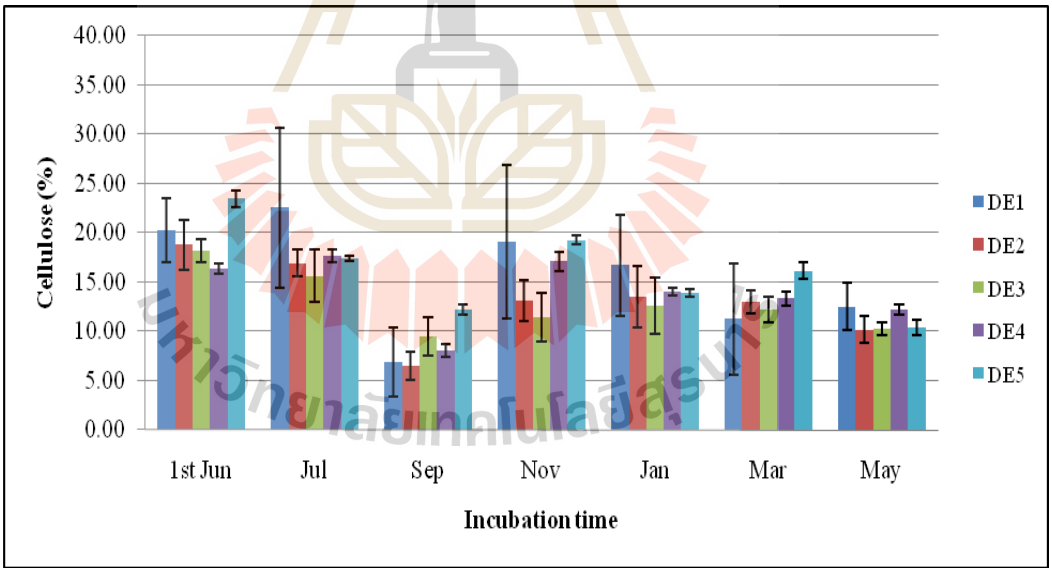


(b)

Figure 4.32 The cellulose content of leaf litter in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

4.3.2.5 C-N ratio in litter

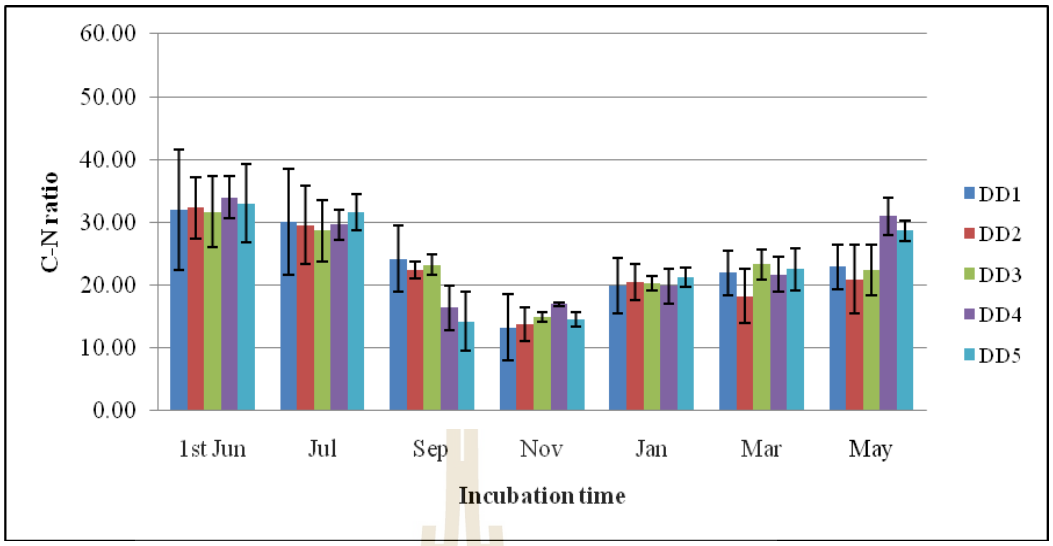
Carbon - to - nitrogen ratio is the proportion of carbon content and nitrogen content in leaf litter. This proportion is the one factor of litter quality with regulating processes of litter decomposition. In this experiment, the initial C-N ratios were investigated; there were the nearby proportion of C-N in average initial fraction at all of treatments. The mean of initial C-N ratio in dry dipterocarp forest (32.20 ± 5.88) was higher than that in dry evergreen forest (31.15 ± 12.07). Therefore, the t-test analysis showed that the average of initial C-N ratio was not significantly different between forests (t = 0.293, *P* = 0.771). However, the highest proportion was found in DD4 (33.94) of dry dipterocarp forest and in DE1 (34.07) of dry evergreen forest, where the lowest were found in DD3 (31.63) in dry dipterocarp forest and with DE5 (21.12) in dry evergreen forest. The different treatments did not significantly affect the initial C-N ratio in both dry dipterocarp (F = 0.026, *P* = 0.998) and dry evergreen forests (F = 0.205, *P* = 0.929).

The proportion of C-N in leaf litter was analyzed throughout the incubation year. The data showed a curve tendency in both sites (Figures 4.33a and 4.33b), in dry dipterocarp forest the C-N ratio decreased from the beginning until 6th month of incubation and then the data increased again throughout the end of experiment. There was a similar tending in dry evergreen forest but the decreasing was until 8th month before it increased again. The residual proportion of C-N in the end was lower than initial properties in both of dry dipterocarp forest (23.16 ± 4.74) and dry evergreen forest (17.67 ± 3.86). The highest remaining ratio was found in DD4 (30.97) and in DE2 (19.26), and the lowest were found in DD2 (20.90) and in DE4 (16.60).

The ANOVA showed the significant interaction between incubation times and C-N ratio in both of dry dipterocarp forest (F = 15.340, $P < 0.001$) and dry evergreen forest (F = 3.718, $P = 0.003$). In this experiment, the different proportion of litter species was not affected to C-N ratio in both of dry dipterocarp forest (F = 0.283, $P = 0.888$) and dry evergreen forest (F = 0.543, $P = 0.705$).

Table 4.2 Mean and summary analysis of variance (*F*- and *P*- values) for the different of initial leaf litter chemistry between treatment in dry dipterocarp (DDF) and dry evergreen (DEF) forests.

Initial chemical content of litter	**forest**	**mean**	**SD**	***F***	***P***
C content (%)	DDF	24.109	1.103	0.388	0.812
	DEF	25.930	3.113	0.290	0.877
N content (%)	DDF	0.767	0.112	0.150	0.958
	DEF	0.900	0.212	0.164	0.951
Cellulose (%)	DDF	25.848	2.513	0.448	0.771
	DEF	19.179	2.621	1.461	0.292
Lignin (%)	DDF	20.947	3.466	0.144	0.961
	DEF	13.589	3.748	0.462	0.763
C-N ratio	DDF	32.210	5.881	0.026	0.998
	DEF	31.148	12.071	0.205	0.929



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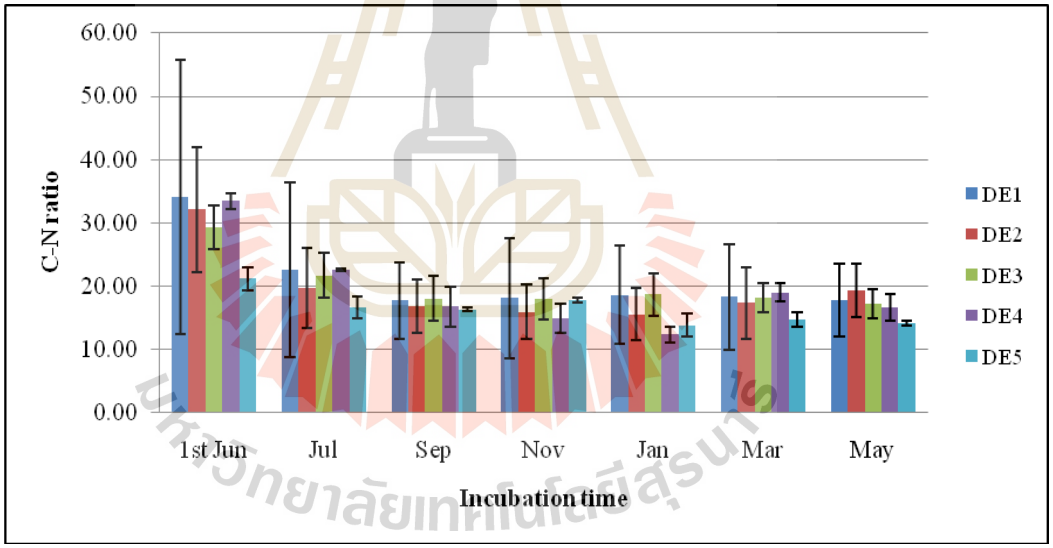


(b)

Figure 4.33 The C-N ratio of leaf litter in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

4.3.3 The correlation between litter quality, weather and decomposition rate

The chemical compositions of litter, especially the initial chemical concentration, and the chemical changes during decomposition have a prominent influence on decomposition. It is possible to predict how mass loss rates will change even in late decomposition stages. In this research, the correlations between litter quality, environmental condition factors, and litter decay rates were analyzed.

In dry dipterocarp forest, there was the significant correlation between weather temperature and litter qualities except lignin content. Carbon content, cellulose, and C-N ratio positively correlated with weather temperature, while the nitrogen concentration negatively correlated with the temperature. The data showed the correlation of precipitation to litter quality, there was the significantly negative correlation only with cellulose content, but had no significant correlation to other properties. There was not significant correlation between relative humidity and the litter quality (Table 4.3).

The correlation of litter quality and weather in dry evergreen forest was found greater than that in dry dipterocarp forest. The temperature was positively correlated with carbon content and C-N ratio in the litter, and negatively correlation with nitrogen content. There was not the correlation of relative humidity with litter quality factors. The precipitation was correlated to all factors, except the lignin content. It had positive correlation with nitrogen content and negative correlation with carbon content, cellulose content and C-N ratio (Table 4.3).

The significant influence of initial litter quality on decomposition rate was not found in dry dipterocarp forest but it was found only in dry evergreen forest. There were the influences of initial litter quality on k-constant in dry evergreen forest, the carbon concentration had negative correlation with k-constant ($r = -0.631$, $P < 0.05$). Both of the litter nitrogen content and lignin content had positive correlation with k-constant ($r = 0.602$, $P < 0.05$ and $r = 0.699$, $P < 0.01$, respectively). While the ratio of carbon and nitrogen in litter had negative correlation with k-constant ($r = -0.604$, $P < 0.01$).

Table 4.3 Pearson's correlation between the k-constant and the initial litter quality characteristics in dry dipterocarp (DDF) and dry evergreen forests (DEF).

Litter quality characteristics		**Litter decay rate** (k - constant)
Temperature	DDF	-0.372**
	DEF	-0.191
Humidity	DDF	-0.271**
	DEF	0.153
Precipitation	DDF	0.246*
	DEF	0.397**
C	DDF	0.012
	DEF	-0.631*
N	DDF	-0.153
	DEF	0.602*
Lignin	DDF	0.203
	DEF	0.699**
Cellulose	DDF	0.176
	DEF	-0.515
C-N ratio	DDF	0.153
	DEF	-0.604*

** Correlation is significant at the 0.01 level,

* Correlation is significant at the 0.05 level.

4.4 The Soil Properties

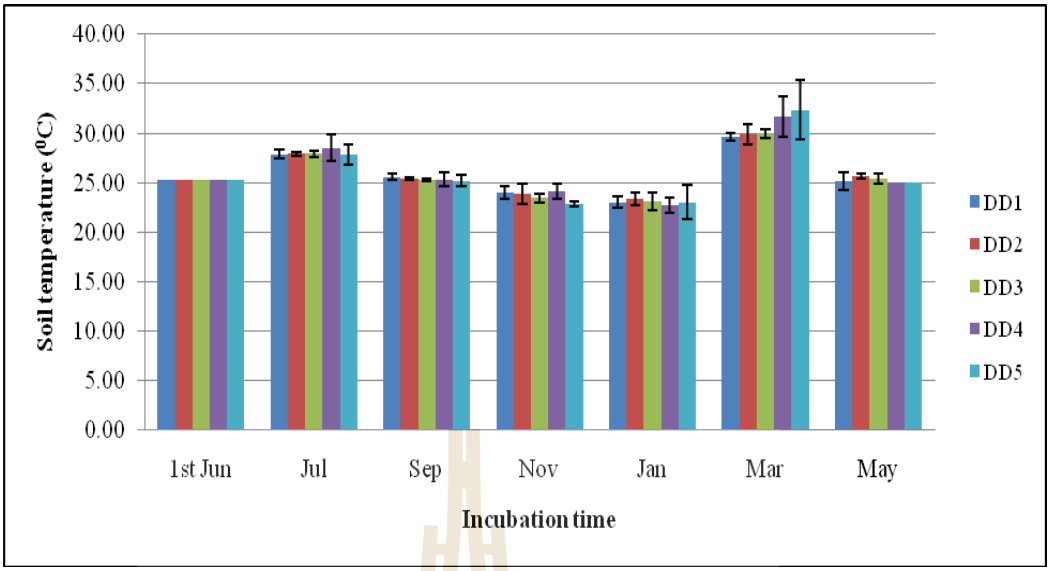
The surface soil (10 cm depth) was collected from each experimental plot before litter bag incubation time, and then after the experiment on 2-month intervals, the soil samples under the litter bags were collected. All of soil samples

were analyzed for the chemical content in the initial and the properties changing through the experiment year. The results are described as follows;

4.4.1 Soil temperature

The measurement showed that soil temperature ranged from 22.67^{0}C to 32.33^{0}C in dry dipterocarp forest, and from 18.83^{0}C to 24.92^{0}C in dry evergreen forest. The average of soil temperature in dry dipterocarp forest was significantly higher than that in dry evergreen forest ($t = 11.149$, $P < 0.01$).

The temperature of the surface soil under the litter bags which contained the different litter treatment was investigated. The data showed the similar tends into both of DDF and DEF for the high temperature, there were the high average temperature in February - March both in DDF and DEF (30.12^{0}C, 24.55^{0}C, respectively). But the low temperatures were different period between site, there was in December - January (23.11^{0}C) in dry dipterocarp forest but was in April - May (19.04^{0}C) in dry evergreen forest (Figures 4.34a and 4.34b). The comparison data between mean temperature of soil among the litter treatment found that DD4 had the highest soil temperature (26.10^{0}C), the lowest was found with DD3 (25.77^{0}C) in dry dipterocarp forest. In dry evergreen forest, there were quite similar degree for all treatments, the highest soil temperature was with DE3 (22.55^{0}C) and the lowest temperature was with DE5 (22.25^{0}C). However, the different degree of soil temperature were not significant between treatment in both of dry dipterocarp forest ($F = 0.039$, $P = 0.997$) and dry evergreen forest ($F = 0.046$, $P = 0.996$) (Table 4.5).



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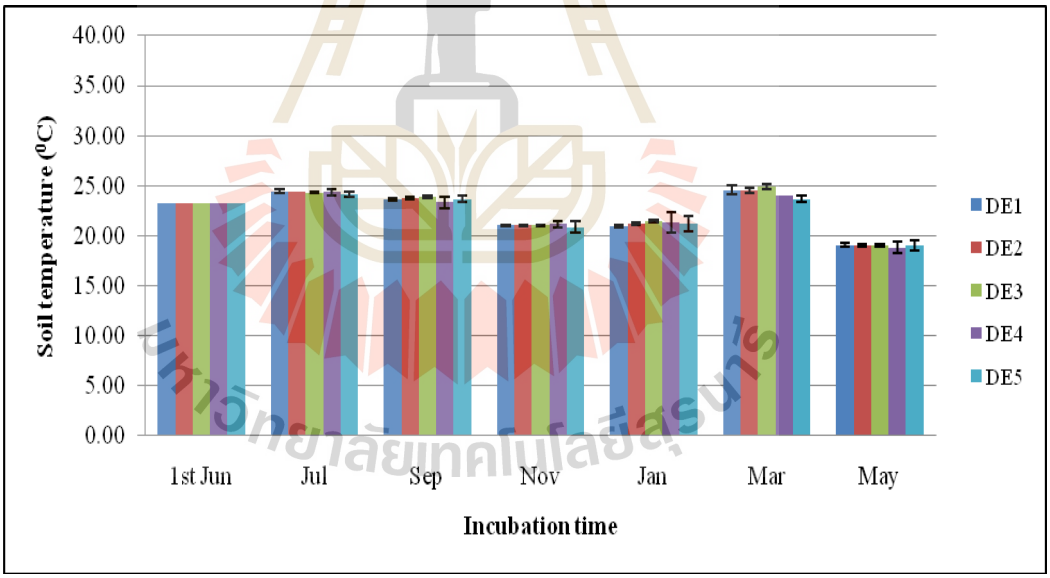


(b)

Figure 4.34 The soil temperature (^{0}C) in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

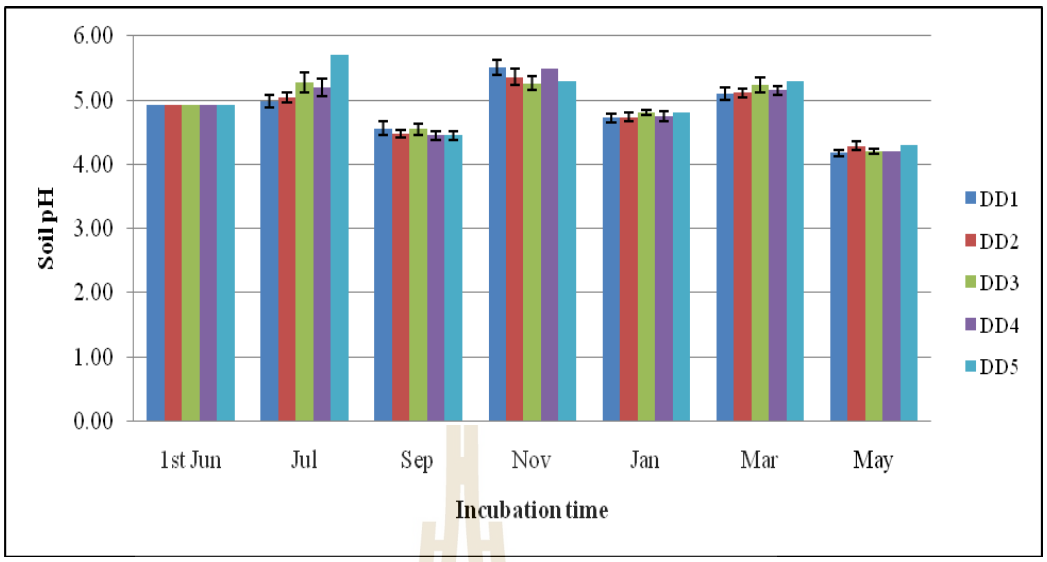
4.4.2 Soil pH

The surface soil in both experiment sites was quite strongly acidic. The investigation found that pH properties of surface soil were between pH 4.18 - 5.70 in dry dipterocarp forest. The pH of surface soil in dry evergreen forest were found between pH 3.70 - 4.71. These results showed that the pH of soil in dry evergreen forest (mean = 4.43 ± 0.30) were more acidic than that in dry dipterocarp forest (mean = 4.88 ± 0.39). The soil pH property was significantly different between ecosystems ($P < 0.01$).

The pH of surface soil under the different treatment bags were not driven the different pH rate in both of dry dipterocarp forest (F = 0.157, P = 0.960) and dry evergreen forest (F = 0.434, P = 0.784). There was the highest pH level of soil under DD5 (pH = 4.97 ± 0.50) and the lowest with DD2 (pH = 4.85 ± 0.36) in dry dipterocarp forest (Figure 4.35a). The data showed the highest pH level of soil under DE1 (pH = 4.49 ± 0.30) and the lowest with DE4 (pH = 4.33 ± 0.32) in dry evergreen forest (Figure 4.35b).

4.4.3 Soil moisture

The highest average of soil moisture content in dry dipterocarp forest was in the rainy season (August - September), and the lowest average was in the dry season (February - March), i.e. 17.17% (SD = 0.94) and 5.85% (SD = 0.75), respectively (Figure 4.36a). In dry evergreen forest, both of the highest and the lowest of soil moisture were found in the same period of dry dipterocarp forest (August - September, and February - March, respectively). The result was 17.62% (SD = 1.05) in rainy season and 8.15% (SD = 0.50) in summer. The results



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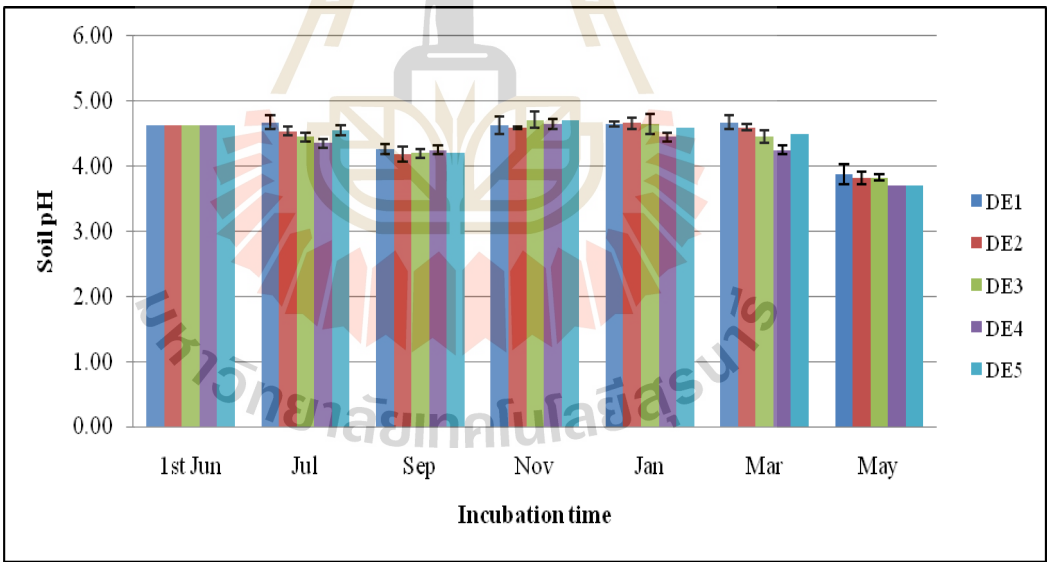


(b)

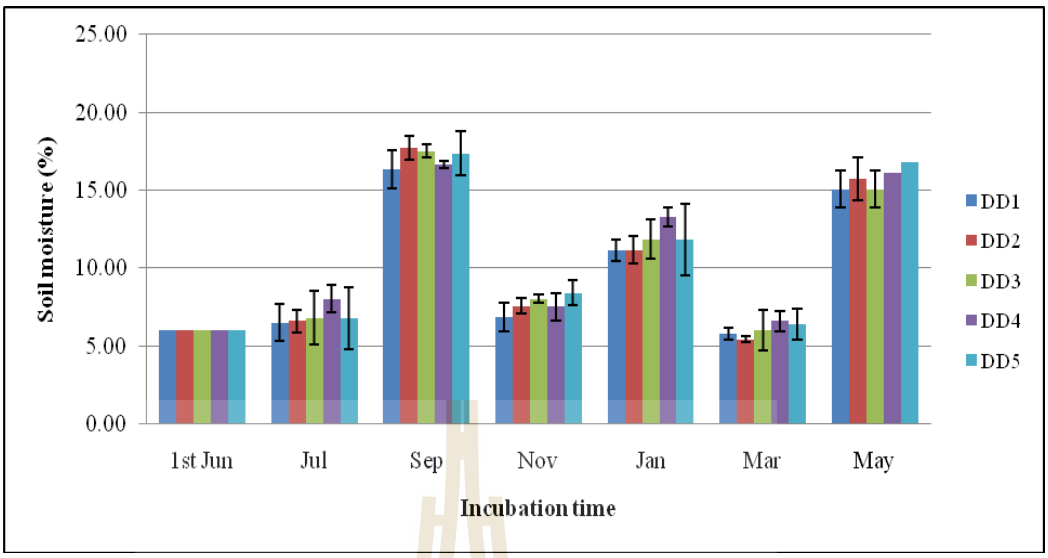
Figure 4.35 The soil pH in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

showed that the dry evergreen forest had the higher average of soil moisture than in dry dipterocarp forest, and there was the highest average content of moisture in both the dry season and the rainy season. These properties showed that the soil moisture in dry dipterocarp forest and dry evergreen forest were significantly different ($t = 11.146$, $P < 0.01$).

The comparison of soil moisture content under the litter bag with the different treatments, the result showed that DD4 driven the highest of moisture (10.60%, SD = 4.60) and DD1 driven the lowest of moisture (9.68%, SD = 4.33) contain in the soil under the litter bag at dry dipterocarp forest. There was the highest of soil moisture content in DE3 (11.88%, SD = 3.48) and the lowest in DE4 (10.86% SD = 3.20) at dry evergreen forest (Figure 4.36b). However, the ANOVA showed that the different numbers of litter species in bag had not driven the soil moisture under the litter bag in both the dry dipterocarp and dry evergreen forests (i.e. $F = 0.096$, $P = 0.983$ and $F = 0.201$, $P = 0.937$, respectively).

4.4.4 Soil organic matter

The dry evergreen forest had the higher average level of soil organic matter (SOM) than that in dry dipterocarp forest. The clear difference was found at the beginning of the investigation. The initial average rate of SOM in dry evergreen forest was 3.75% and in dry dipterocarp forest was 1.82%. After incubation, the data showed the percentages of soil organic matter under the litter bags were lower than that initially rates in both forests. The highest average rate



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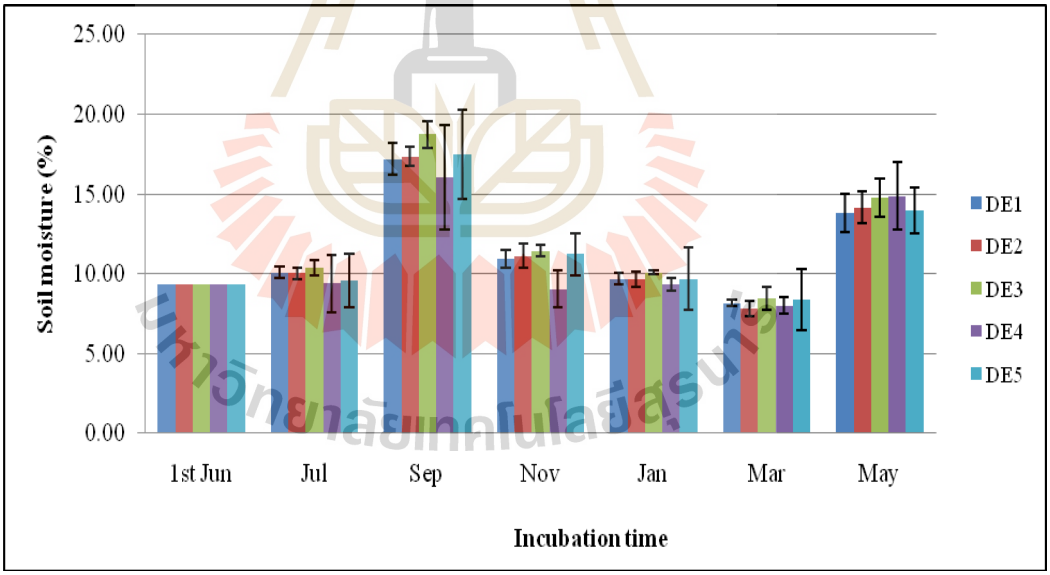

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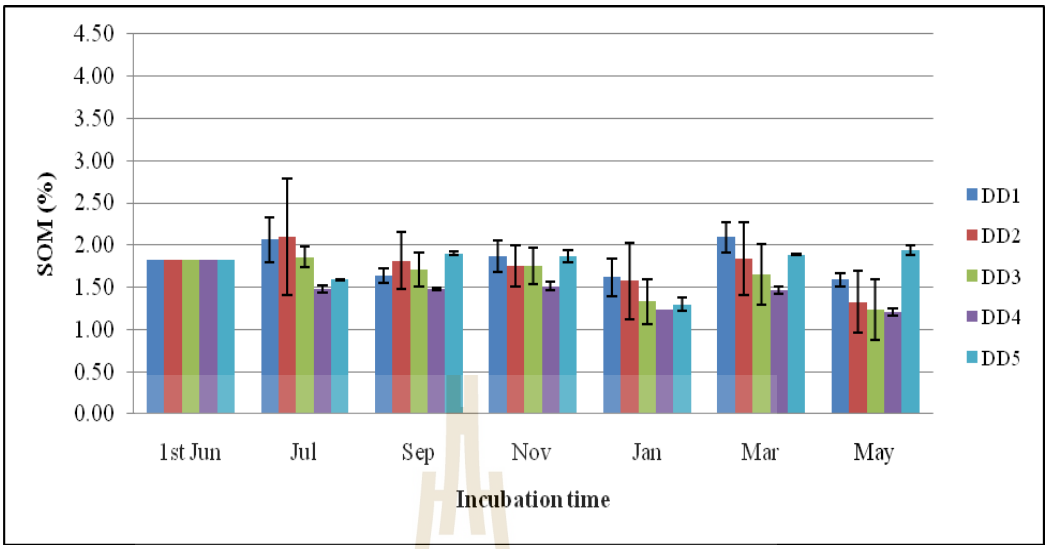
Figure 4.36 The soil moisture (%) in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

of soil organic matter was found in June - July in dry dipterocarp (1.94 ± 0.42%), while dry evergreen forest was found in August - September (3.36 ± 0.37%). The period when driven the lowest rate of SOM was in the late of incubation, April - May, in both of dry dipterocarp (1.41 ± 0.33%) and dry evergreen forests (2.93 ± 0.30%).

The changing levels of percentage SOM after incubation varied among the treatments (Figures 4.37a and 4.37b), the highest percentage SOM in DD2 of the 2nd month and the lowest in DD4 of the last month of incubation in dry dipterocarp forest. In dry evergreen forest, there was the highest level with DE5 in the 6th month and the lowest with DE2 in the end of experiment. The results showed the significant interaction between time of incubation and the changing level of percentage SOM in both of dry dipterocarp forest ($F = 3.111$, $P = 0.10$) and dry evergreen forest ($F = 8.573$, $P < 0.001$). The interaction of treatments and soil organic matter were found in both forests too ($F = 2.948$, $P = 0.027$ and $F = 4.425$, $P = 0.003$), in DDF and DEF, respectively. At the end of the experiment, the t-test at the significance level 0.01 showed that average percentage of SOM in dry dipterocarp forest and dry evergreen forest had significant difference.



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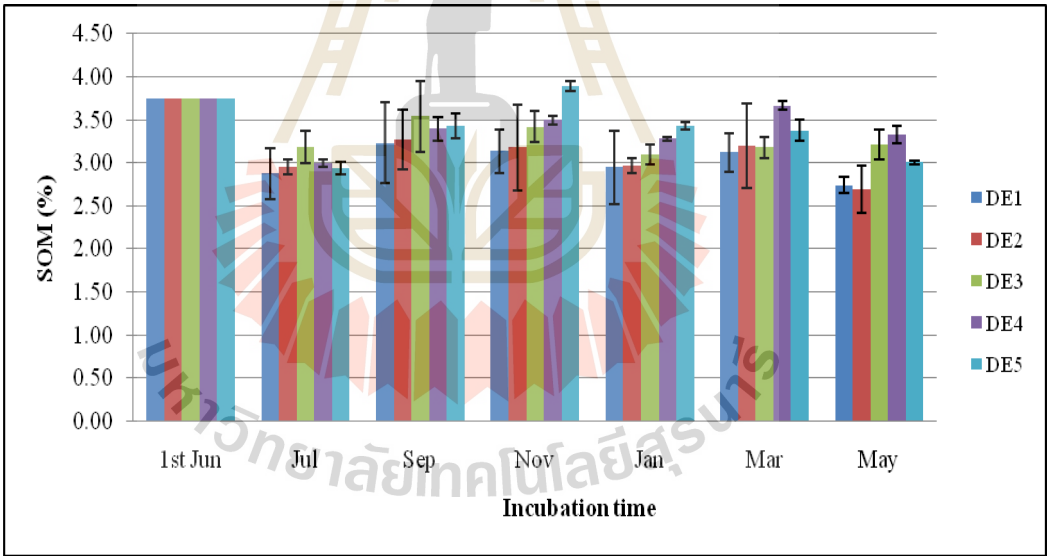

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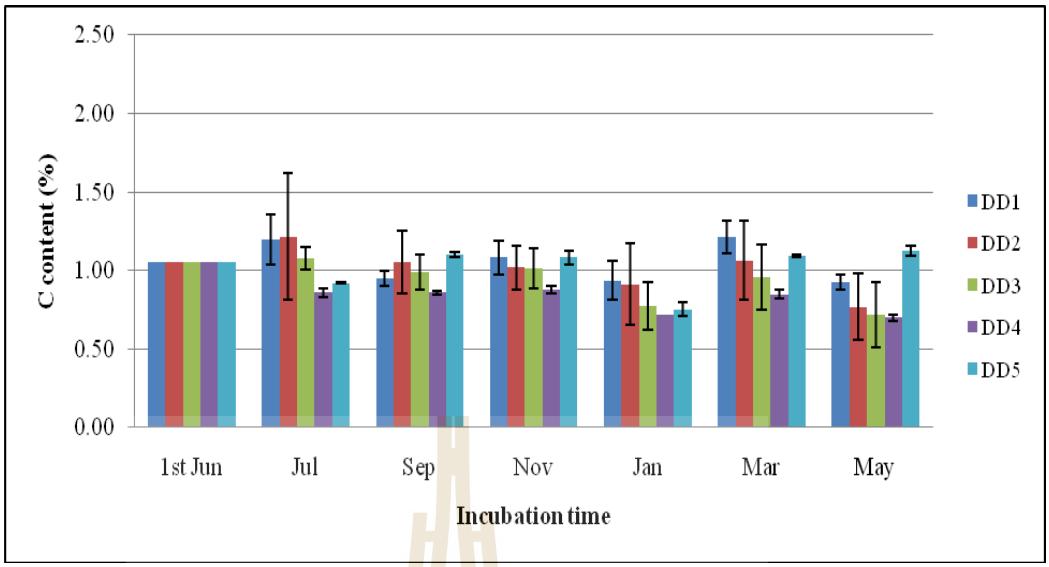
Figure 4.37 The soil organic matter (%) in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

4.4.5 Soil carbon content

The soil organic content is the fraction in the soil which related to the soil organic matter. So, there were the higher percentages of average carbon content in dry evergreen forest (1.06%) than that in dry evergreen forest (2.17%). The carbon content in all of soil decreased after initial incubation, excepted DD5 in dry dipterocarp forest, the level of changing were varies among the treatments. Most of released soil carbon content from the initial content was found with DD4 in dry dipterocarp forest and with DE2 in dry evergreen forest (0.36% and 0.62%, respectively). There were the lowest changing level in DD5 (0.07%) of dry dipterocarp forest and in DE4 (0.24%) of dry evergreen forest.

The highest concentrations of average soil carbon after incubation were found in June - July, 2007 in dry dipterocarp forest (1.12 ± 0.24%), and in August - September, 2007 in dry evergreen forest (1.95 ± 0.21%). The lowest level of average soil carbon appeared in the end of experiment, there were 0.82 ± 0.19% in dry dipterocarp forest and 1.69 ± 0.18% in dry evergreen forest (Figures 4.38a and 4.38b). The t-test at the significance level 0.01 showed that average percentage of carbon in dry dipterocarp forest and dry evergreen forest had significant difference.

The ANOVA showed that the different treatment of litter bags influenced the changing of soil carbon content in both dry dipterocarp forest ($F = 2.948$, $P = 0.027$) and dry evergreen forest ($F = 4.425$, $P = 0.003$). The interaction of incubation time had also affected the changing of soil carbon content in both of dry dipterocarp forest ($F = 3.111$, $P = 0.010$) and dry evergreen forest ($F = 8.573$, $P < 0.001$), too.



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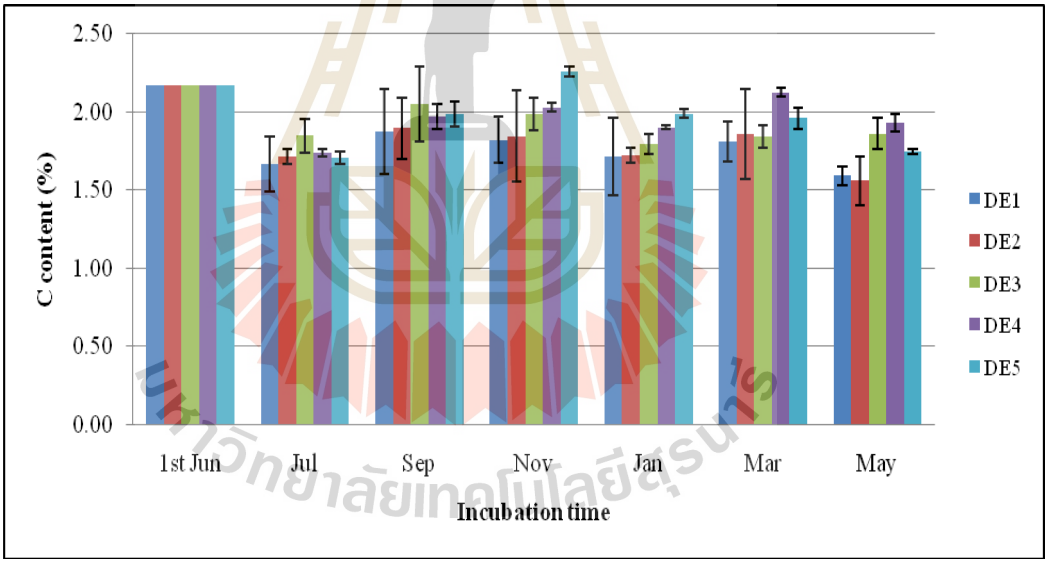

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Figure 4.38 The soil carbon content (%) in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

4.4.6 Total nitrogen content

Nitrogen is one the essential minerals for plants in all ecosystems. It is one of the commonest factors relating litter decomposition. The amount of total nitrogen in the soil directly depended on the content of organic matter in the soil. Therefore, as the SOM property in the soil, there was the higher total nitrogen in dry evergreen forest than that amount in dry dipterocarp forest.

The t-test at the significance level 0.01 showed that the average amount of initial total nitrogen in dry dipterocarp forest and dry evergreen forest was significantly different. The initial of soil total nitrogen in dry evergreen forest was average with 1.21 g/kg, while it was average with 0.79 g/kg in dry dipterocarp forest.

The tendency of total nitrogen increased along the incubation, especially in dry evergreen forest (Figures 4.39a and 4.39b). The highest total amount of soil nitrogen was in the 2nd month (1.64 ± 0.27 g/kg), and the lowest total was in the last month (0.88 ± 0.24 g/kg) of the experiment in dry dipterocarp forest. There was the highest total nitrogen in the 10th month of incubation (2.05 ± 0.32 g/kg), and there was the lowest in the 2nd month of incubation (1.81 ± 0.27 g/kg) in dry evergreen forest. The changing level of total nitrogen varied among the different treatments. The result showed the highest amount of total N (1.70 g/kg) in the 2nd month and the lowest (0.71 g/kg) in the 12th month of incubation were with in the soil under DD3 in the dry dipterocarp forest. While in dry evergreen forest, there were the lowest amount of total soil nitrogen (1.64 g/kg) in the 2nd month but the highest rate (2.25 g/kg) in the late of incubation, in the 10th month. However, the differences of litter diversity in the litter bags were not

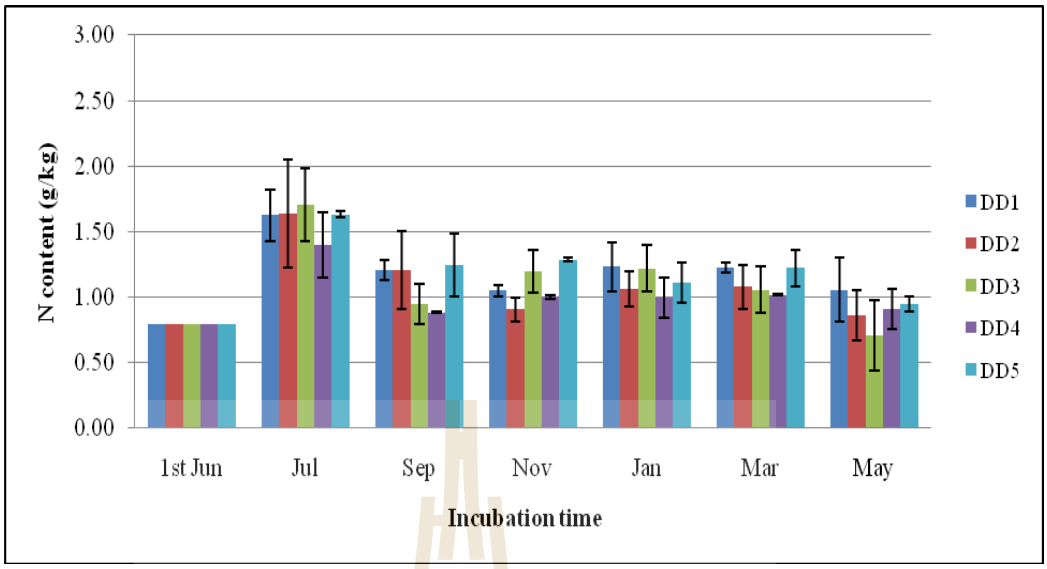
affected to the changing of soil N content under the bags in both of dry dipterocarp forest (F = 1.829, P = 0.134) and dry evergreen forest (F = 2.000, P = 0.105) forests.

After the end of experiment, the data showed that the average of residues N content in soil was significantly different between forests at the significance level of 0.01.

4.4.7 Available phosphorus in soil

Even though the inputs of phosphorus in terrestrial ecosystems come primarily from rocks, and then it can be taken up directly by plants or microorganisms, but some how of it relating to the decomposition processes. Phosphorus turnover is somewhat tightly linked to litter decomposition. The investigation of available P in the soil before the study and in the soil under the litter bag found a varied properties among the sites of experiment and among the litter bag treatments. The average initial properties of available P in dry evergreen forest (5.13 g/kg) were higher than in dry dipterocarp forest (3.79 g/kg).

The treatment which induced the highest rate of available P in the soil under the litter bags were in DD2 at the end of experiment (7.10 g/kg) of dry dipterocarp forest, and DE2 at the 10^{th} month of incubation (7.06 g/kg) of dry evergreen forest. When the lowest rate of available P in soil was with DD4 (0.77 g/kg) at 8^{th} month in dry diptrocarp forest and was with DE5 (3.55 g/kg) at 2^{nd} month of incubation in dry evergreen forest. The results showed the different treatment of litter was affected to the soil available P content just in dry dipterocarp forest (F = 2.823, P = 0.032) but was not affected in dry evergreen forest (F = 0.481, P = 0.749) (Figures 4.40a and 4.40b).



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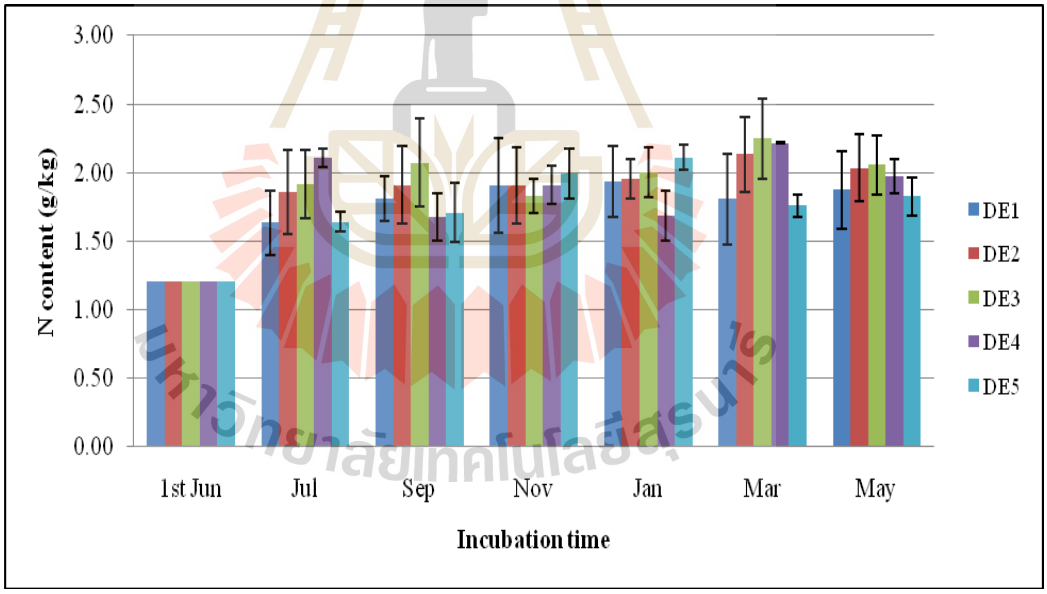

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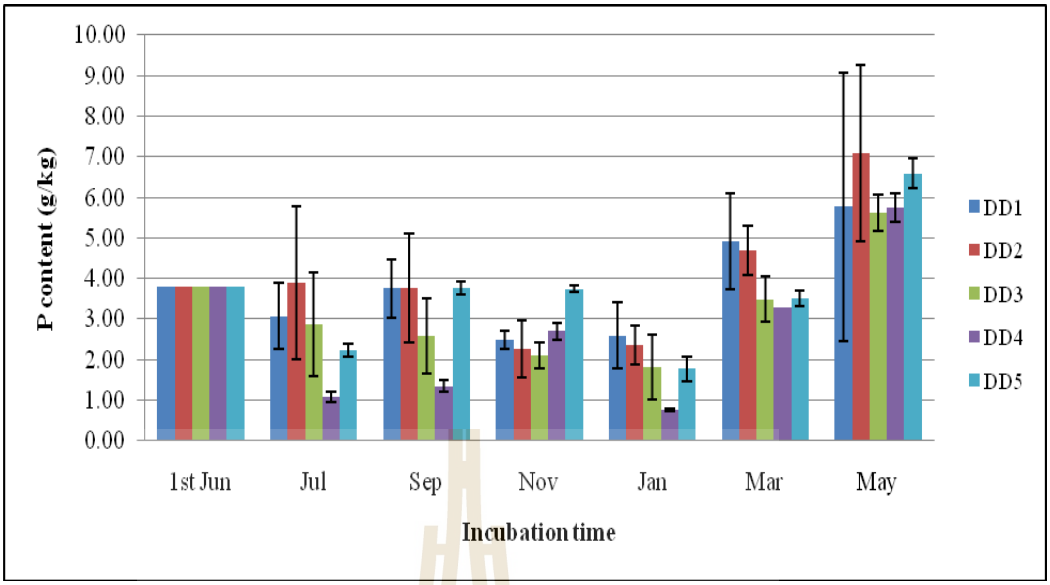
Figure 4.39 The soil nitrogen content (g/kg) in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

The lowest average of soil phosphorus content was in December 2007 - January 2008 in both of dry dipterocarp forest (2.11 ± 0.79 g/kg) and dry evergreen forest (3.92 ± 0.69 g/kg), while the highest average was found at the late of incubation, i.e. during February - March 2008 in dry evergreen forest (6.75 ± 1.09 g/kg), and in the last month of experiment in dry dipterocarp forest (6.16 ± 2.02 g/kg). The interaction of time had significant affected to amount of soil P in both of dry dipterocarp ($F = 12.831$, $P < 0.001$) and dry evergreen forest ($F = 8.222$, $P < 0.001$).

4.4.8 Available potassium in soil

Potassium is an essential nutrient for plant growth. Potassium is involved in many functions of plants, i.e. metabolism reaction, formation of cellular structure and photosynthesis. Rock weathering is the primary avenue for potassium input in ecosystem. Potassium occurs primarily in cell cytoplasm and is released through the leaching action of water moving through live and dead organic material.

This study found the amounts of soil available K were slightly traces in the experiment sites. The initial average of available K in dry evergreen forest (0.38 g/kg) was higher than in dry dipterocarp forest (0.28 g/kg). The amounts of available K content in soil after incubation were lower than initial properties in both forests. There was the lowest rate at 4th month with average rate 0.17 ± 0.04 g/kg in dry evergreen forest and there was lowest at the last month of incubation



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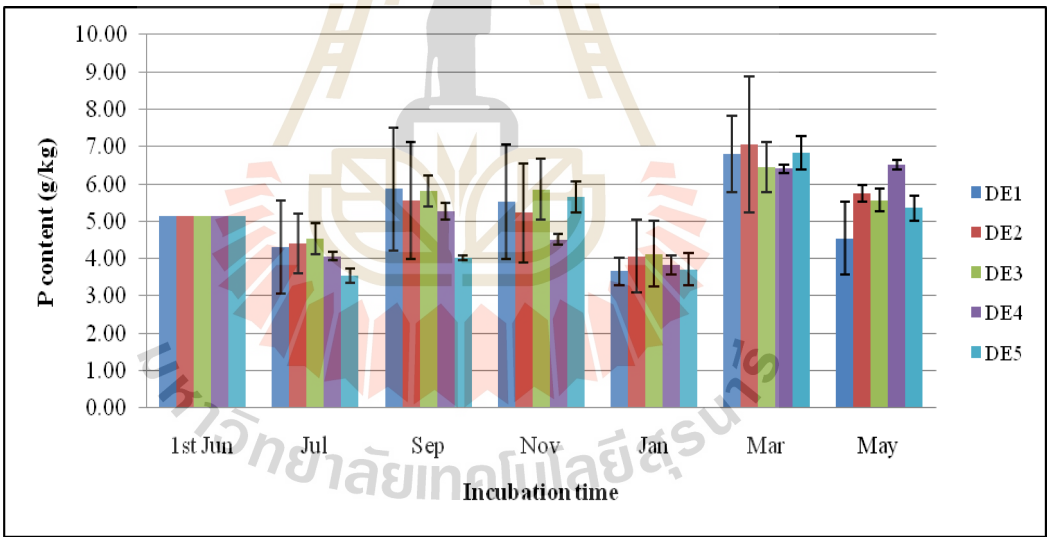

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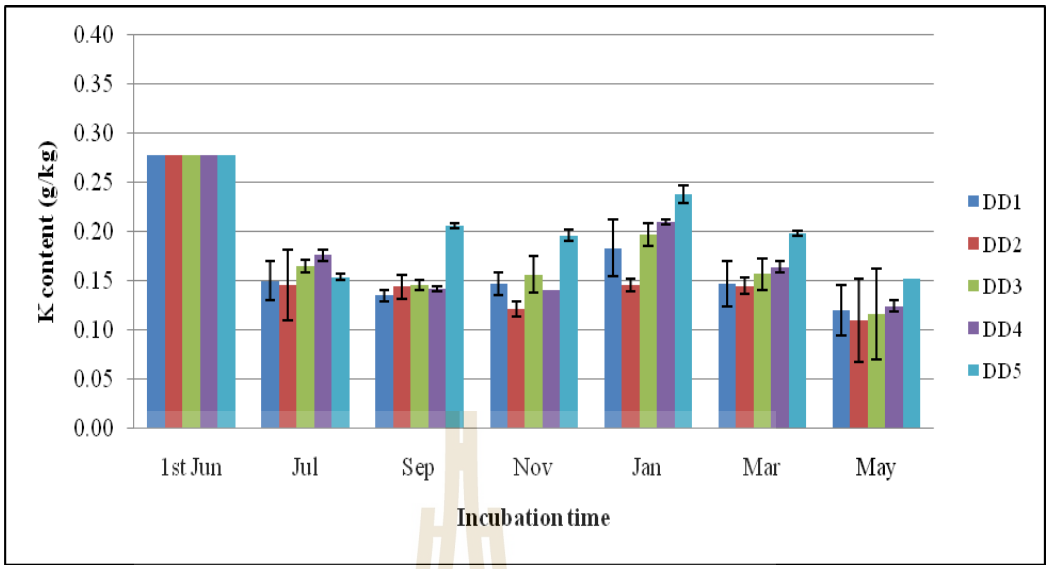
Figure 4.40 The soil available phosphorus (g/kg) in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

with average rate 0.12 ± 0.03 g/kg in dry dipterocarp forest. The highest of average K contents of soil were found in 8th month in both dry dipterocarp forest with 0.18 ± 0.03 g/kg and dry evergreen forest with 0.22 ± 0.03 g/kg (Figures 4.41a and 4.41b). The data showed that the time of incubation affected to soil available K in dry dipterocarp forest ($F = 52.984$, $P < 0.001$) and in dry evergreen forest ($F = 19.445$, $P < 0.001$).

The ANOVA presented the interaction of treatments and available soil K changing was only in dry dipterocarp forest ($F = 8.448$, $P < 0.001$) but there was not the significant interaction in dry evergreen forest ($F = 1.591$, $P = 0.188$). The residual available K in the soil was signifcantly different between dry dipterocarp forest and dry evergreen forest at the significance level of 0.01.

4.4.9 C - N ratio in soil

The carbon to nitrogen ratio is directly relate to the content of organic matter and nitrogen content in soil. In this experiment, the result showed a high initial proportion of carbon and nitrogen, there were the average with 13.36 in dry dipterocarp forest and 17.97 in dry evergreen forest. The data presented that C-N ratio in soil decreased after incubation. There were a various changing among the treatments and time of incubation (Figures 4.42a and 4.42b).



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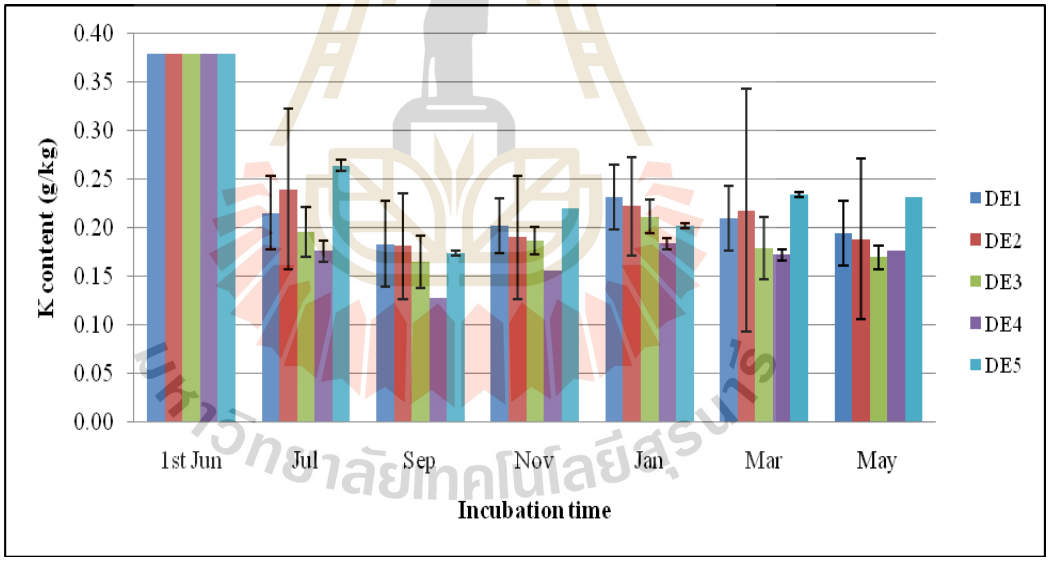

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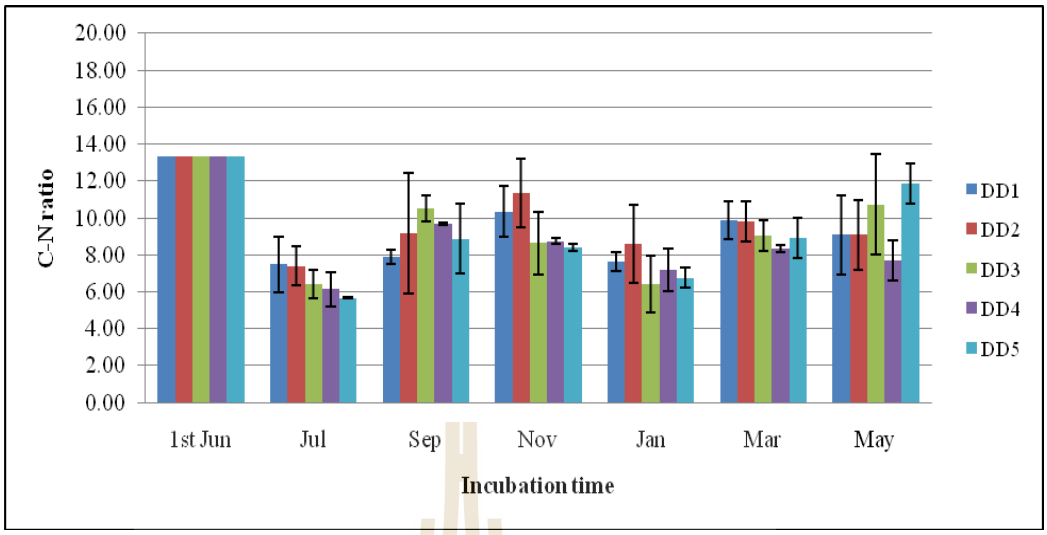
Figure 4.41 The soil available potassium (g/kg) in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

There were the highest level of C-N ratio at the late of experiment and the lowest level at the early period with DD5 (i.e. 11.86 in the 12th month and 5.65 in the 2nd month, respectivly) in dry dipterocarp forest. While the opposite ways occurred in dry evergreen forest, there were the highest level in the early period with DE4 (11.74 in the 4th month) and the lowest level in the last time of data collection with DE2 (7.70 in the 12th month).

The lowest average level of C-N ratio was in June - July in dry dipterocarp forest (6.92 ± 1.17) and in April - May in dry evergreen forest (8.67 ± 1.24), the highest proportion were found in October - November in dry dipterocarp forest (9.89 ± 1.83) and in August - September in dry evergreen forest (10.33 ± 0.91). The interaction between the different treatment had not affected to soil C-N properties in both of dry dipterocarp ($F = 0.966$, $P = 0.433$) and in dry evergreen forests. ($F = 2.123$, $P = 0.088$) However, time of incubation induced the changing of C-N ratio in both ecosystem (i.e. $F = 18.066$, $P < 0.001$ in DDF and $F = 61.725$, $P < 0.001$).

4.4.10 The correlation of soil properties and decomposition rates.

The linkage of decomposition and soil properties occur when the decomposition subsystem serves to reduce dead residues to carbon dioxide and soil organic matter, and to release nutrient elements for entry into soil food webs, and ultimately for accumulation by plants. Thereby, the properties of soil are closely depending on leaf litter decomposition.



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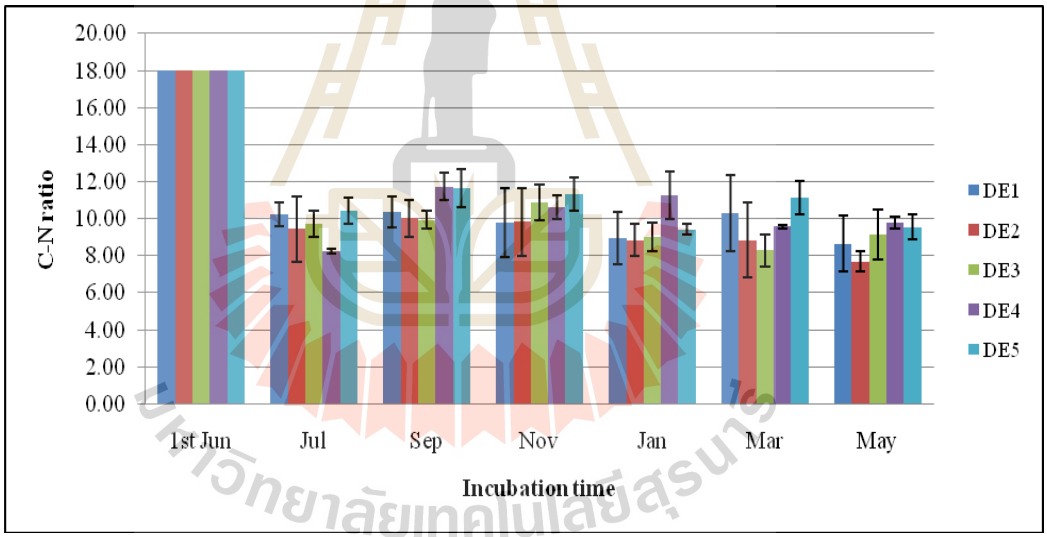


(b)

Figure 4.42 The C-N ratio of soil in dry dipterocarp (a) and dry evergreen (b) forests during June 2007 to May 2008.

In dry dipterocarp forest, the weather temperature had positively correlated with soil temperature, available phosphorus, available potassium and C-N ratio, and it had negatively correlated with soil pH. There were the significant positively correlated between precipitation and soil moisture, and available phosphorus, and negatively correlated between precipitation and soil pH, available K, and C-N ratio. There was significant correlation between humidity and soil moisture (Table 4.4).

The correlation of soil properties and weather in dry evergreen forest were found higher than that in dry dipterocarp forest. The temperature had positively correlated with soil temperature, soil moisture, soil organic matter, carbon content, available K, and C-N ratio, and it had negatively correlated with soil pH and soil nitrogen content. The rainfall had positively correlated with soil moisture and nitrogen content, and it had negatively correlated with soil pH, soil temperature, soil organic matter, carbon content, available K, and C-N ratio. There was significant correlation between humidity and soil pH, moisture, and bulk density (Table 4.4).

The influence of litter decay level in dry dipterocarp forest were found with soil moisture, pH, SOM, carbon concentration, available P, available K and C-N ratio (Table 4.5). There were the positive correlation between k-constant with soil moisture ($r = 0.418$, $P < 0.01$) and available phosphorus ($r = 0.270$, $P < 0.01$). The k-constant had a negative correlated with soil pH ($r = -0.355$, $P < 0.01$), soil organic matter ($r = -0.239$, $P < 0.01$), carbon content ($r = -0.239$, $P < 0.01$), available K ($r = -0.594$, $P < 0.01$) and C-N ratio ($r = -0.252$, $P < 0.05$).

The results showed significant correlation between k-constant and soil properties in dry evergreen forest (Table 4.5). There was the positive correlation between k-constant and soil nitrogen content (r = 0.466, $P < 0.01$). While the negative correlation occurred between k-constant and soil organic matter (r = -0.411, $P < 0.01$), soil carbon content (r = -0.411, $P < 0.01$), available P (r = -0.235, $P < 0.01$), available K (r = -0.515, $P < 0.01$) and C-N ratio (r = -0.631, $P < 0.05$) (Table. 4.5).

Table 4.4 Pearson's correlation between the climatic factors and soil properties in dry dipterocarp (DDF) and dry evergreen forests (DEF).

Litter quality characteristics		Climatic factors		
		Temperature	Humidity	Precipitation
SOM	DDF	0.151	0.191	-0.065
	DEF	0.238*	0.107	-0.294**
Soil C	DDF	0.151	0.191	-0.065
	DEF	0.238*	0.107	-0.294**
Soil N	DDF	-0.065	0.022	0.150
	DEF	-0.476**	-0.105	0.318**
Soil P	DDF	0.395**	0.149	0.225*
	DEF	0.015	0.186	0.125
Soil K	DDF	0.212*	-0.145	-0.634**
	DEF	0.379**	-0.129	-0.536**
C-N ratio	DDF	0.318**	0.192	-0.210*
	DEF	0.512**	0.091	-0.444**
Soil temp	DDF	0.251*	0.005	-0.071
	DEF	0.259**	0.078	-0.413**
Soil pH	DDF	-0.303**	-0.063	-0.368**
	DEF	-0.301**	-0.391**	-0.731**
Soil mois	DDF	0.082	0.209*	0.612**
	DEF	0.280**	0.597**	0.742**

** Correlation is significant at the 0.01 level,

* Correlation is significant at the 0.05 level.

Table 4.5 Pearson's correlation between the k-constant and soil properties in dry dipterocarp (DDF) and dry evergreen forests (DEF).

Soil properties		Litter decay rate (k-constant)
SOM	DDF	-0.239**
	DEF	-0.411**
Soil C	DDF	-0.239**
	DEF	-0.411**
Soil N	DDF	-0.022
	DEF	0.466**
Soil P	DDF	0.270**
	DEF	-0.235*
Soil K	DDF	-0.594**
	DEF	-0.515**
C-N ratio	DDF	-0.252*
	DEF	-0.631**
Soil temp	DDF	-0.030
	DEF	0.025
Soil pH	DDF	-0.355**
	DEF	-0.120
Soil mois	DDF	0.418**
	DEF	0.153

**Correlation is significant at the 0.01 level,

* Correlation is significant at the 0.05 level.

4.5 The Litter Decomposers

Traditionally, soil animals have been considered as important decomposers for litter decomposition. Such groups have been ascribed for different roles in decomposition. The ecology of decomposer communities can influence the pattern of decay. In this research, the soil invertebrate was studied as the litter decomposer. The soil faunas were collected 6 times from the all of litter bags in dry dipterocarp forest and dry evergreen forest. The results are follow as:

4.5.1 Invertebrate decomposer

The results showed that 15 orders/classes of invertebrate decomposers were found in dry dipterocarp forest and 16 orders/classes were found in dry evergreen forest. The total of average number per bag in dry dipterocarp forest was 557.05 individuals. It was the lower number than in dry evergreen forest which the total of average number per bag was 844.01 individuals (Tables 4.6 and 4.7). The most two abundant invertebrates in both of dry dipterocarp and dry evergreen forests were the order Isoptera, and then followed by Hymenoptera. Isoptera was the highest number with 135.08 individuals approximately 24.25% of the total invertebrates in dry dipterocarp forest. The highest number of this order was also found in dry evergreen forest, it was about 24.50% with 206.75 individuals. This was followed by the second abundance, Hymenoptera, which was approximately 24.01% (133.76 individuals) in DDF and about 18.40% (155.34 individuals) in DEF. The third most abundant order was Collembola, collected with 57.81 individuals (10.38%) in DDF and it was order Blattaria with 72.42 individuals (9.17%) in DEF. The lowest individual of order in both of dry dipterocarp and dry evergreen forests was Mantodea. It was found

approximately 0.22% (1.25 individuals) and 0.19% (1.58 individuals) in DDF and DEF, respectively.

The association of fauna decomposers in dry dipterocarp leaf litter was found with the highest in DD5 at the 8th month, with 52.67 individuals of 6 orders, and the two mostly abundant orders were Isoptera and Hymenoptera. The lowest number of associated fauna was found in DD2 at the 6th month with 10 orders and 7.25 individuals. In dry evergreen forest, the result showed the most abundant of invertebrate individuals in DE5 in the 8th month were found. The numbers were 9 orders with 70.67 individuals, and the two mostly abundant orders were Isoptera and Hymenoptera. The 15 orders of fauna with 14.00 individuals were found as the lowest abundance of invertebrate in DE3 in the 6th month. The amount of invertebrates varied throughout the incubation times. High abundance of invertebrate decomposers appeared in December - January with 14 orders, 150.92 individuals in dry dipterocarp forest. Most numbers were Hymenoptera (32.91%), followed by Isoptera (29.98%) and Collembola (9.22%), but the earthworm was not found in this period. At the same period, the highest invertebrate abundance was found in the 8th month in dry evergreen forest. The collected invertebrates included 13 orders, 170.00 individuals which consisted of Isoptera (27.79%), Hymenoptera (22.79%), and Orthoptera (10.64%). The Chilopoda, Oligochaeta and Mantodea were not found in this period. (Figures 4.43 and 4.44).

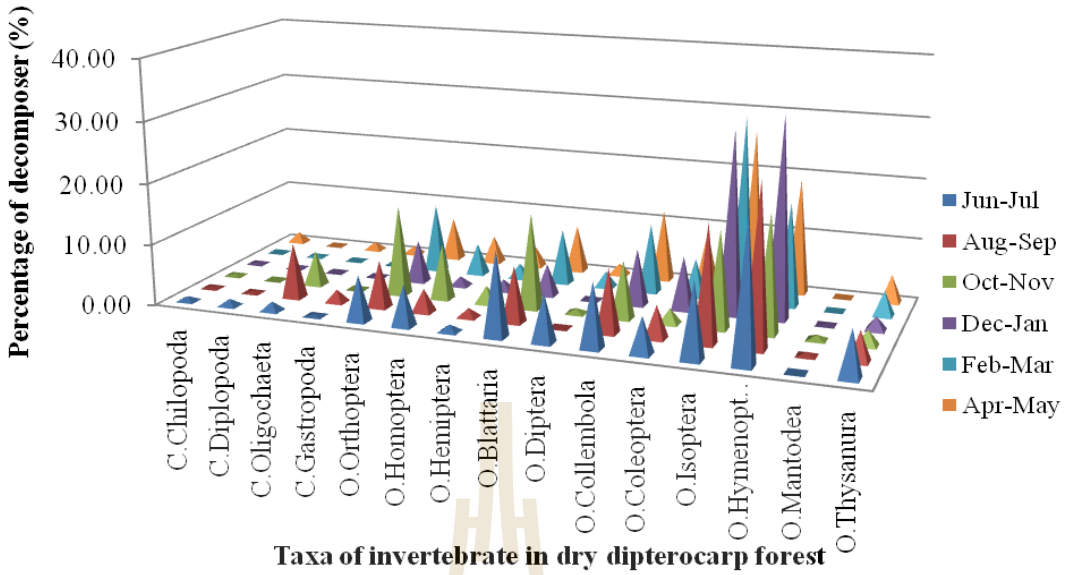


Figure 4.43 The percentage of invertebrate decomposers in dry dipterocarp forest during June 2007 to May 2008.

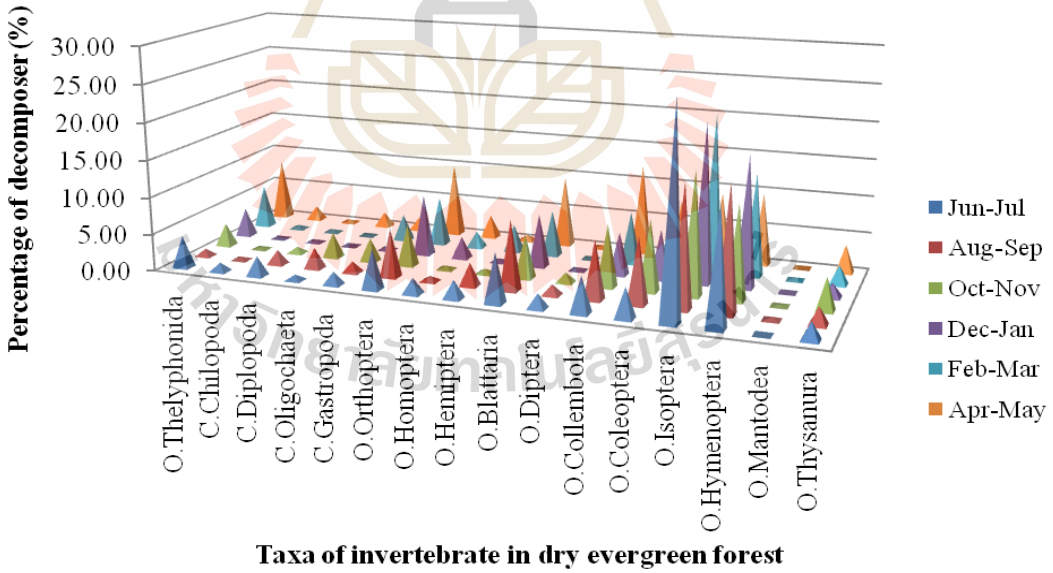


Figure 4.44 The percentage of invertebrate decomposers in dry evergreen forest during June 2007 to May 2008.

Table 4.6 Number of invertebrate decomposers in dry dipterocarp forest (individual per litter bag; N = 3).

TAXA	Jun-Jul	Aug-Sep	Oct-Nov	Dec-Jan	Feb-Mar	Apr-May	Total
C.Chilopoda	0.50	0.25	0.25	0.50	0.00	1.58	3.08
C.Diplopoda	0.75	0.25	0.00	0.75	0.50	0.00	2.25
C.Oligochaeta	1.00	7.58	3.41	0.00	0.00	1.25	13.24
C.Gastropoda	0.25	1.75	0.00	0.25	0.00	1.25	3.50
O.Orthoptera	4.92	6.42	8.83	10.50	11.58	6.50	48.75
O.Homoptera	4.42	3.25	5.42	2.33	5.33	4.17	24.92
O.Hemiptera	0.75	1.25	1.75	2.75	2.50	3.25	12.25
O.Blattaria	9.08	7.67	9.33	7.83	9.33	7.17	50.41
O.Diptera	5.17	0.00	0.50	0.25	2.67	1.75	10.34
O.Collembola	6.83	8.72	5.67	13.92	11.75	10.92	57.81
O.Coleoptera	3.92	4.50	1.50	13.25	6.50	8.25	37.92
O.Isoptera	8.08	16.00	9.50	45.25	31.50	24.75	135.08
O.Hymenoptera	15.17	22.00	11.50	49.67	17.67	17.75	133.76
O.Mantodea	0.00	0.50	0.50	0.25	0.00	0.00	1.25
O.Thysanura	5.00	4.08	1.54	3.42	4.25	4.25	22.50
Total	65.83	84.22	59.66	150.92	103.58	92.84	557.05

Table 4.7 Number of invertebrate decomposers in dry evergreen forest (individual per litter bag; N = 3).

TAXA	Jun-Jul	Aug-Sep	Oct-Nov	Dec-Jan	Feb-Mar	Apr-May	Total
O.Thelyphonida	8.58	1.75	3.67	8.33	11.75	10.50	44.58
C.Chilopoda	2.42	0.75	0.25	0.00	1.00	2.42	6.84
C.Diplopoda	5.33	3.42	1.00	0.75	0.75	0.50	11.75
C.Ologochaeta	1.50	5.00	4.08	0.00	0.25	2.50	13.33
C.Gastropoda	3.50	2.67	3.75	1.25	7.25	2.25	20.67
O.Orthoptera	10.92	11.50	6.67	18.08	13.25	12.58	73.00
O.Homoptera	4.33	1.25	0.58	6.42	4.42	3.92	20.93
O.Hemiptera	4.92	5.42	0.75	1.00	7.50	1.00	20.59
O.Blattaria	13.50	16.50	7.00	15.75	12.50	12.17	77.42
O.Diptera	3.92	2.50	1.58	0.75	0.25	0.50	9.50
O.Collembola	9.75	14.00	10.00	12.67	14.25	15.50	76.17
O.Coleoptera	8.17	15.66	11.42	14.75	16.92	9.83	76.75
O.Isoptera	55.92	28.75	19.75	47.25	43.25	11.83	206.75
O.Hymenoptera	31.25	29.50	15.17	38.75	28.25	12.42	155.34
O.Mantodea	0.00	0.75	0.25	0.00	0.58	0.00	1.58
O.Thysanura	4.75	4.33	5.25	4.25	5.42	4.83	28.83
Sum	168.75	143.75	91.17	170.00	167.59	102.75	844.01

4.5.2 Species diversity index

The invertebrate diversity was calculated by using the Shannon–Weiner Diversity Index. The results showed the dry evergreen forest had a higher of diversity rate than that in dry dipterocarp forest. The Shannon-Weiner Diversity Index of total invertebrates in whole year was 2.147 in dry dipterocarp forest, and it was 2.292 in dry evergreen forest. However, the t-test at the significance level 0.01 showed that the Shannon-Weiner Diversity Index of total invertebrates in whole year in dry dipterocarp forest and dry evergreen forest were not significantly different. The highest species diversity was observed during June - July (2.266) and it was lowest rate during December, 2007 - January, 2008 (1.800) in dry dipterocarp forest. For dry

evergreen forest, the highest index was found in the last period of incubation (2.385) and the lowest rate during December, 2007 - January, 2008 (2.035) (Table 4.8).

Table 4.8 Species diversity index in dry dipterocarp and dry evergreen forests.

Forest	***Shannon's index (H')***						
	Jun-Jul	Aug-Sep	Oct-Nov	Dec-Jan	Feb-Mar	Apr-May	Whole year
DDF	2.266	2.169	2.180	1.800	2.040	2.178	2.147
DEF	2.198	2.295	2.309	2.035	2.247	2.385	2.292

4.5.3 The linkages of soil fauna on litter decomposition

The interaction of soil fauna diversity with decomposition rate, weather, litter quality and soil property were analyzed by using Pearson's correlation. The results showed that the species diversity of invertebrate decomposers (the Shannon-Weiner Diversity Index) influenced the decomposition rate in both dry dipterocarp and dry evergreen forests. The diversity of invertebrates had positive correlation with some factors in dry dipterocarp forest, i.e. rainfall, soil moisture and total nitrogen in soil. While it had the significantly negative relationship with weather temperature, carbon concentration, and C-N ratio in litter, available potassium and C-N ratio in soil. The decomposer diversity index was correlated with many factors in dry evergreen forest, i.e. the positive correlation with precipitation, nitrogen concentration, lignin content in litter, soil moisture, and total nitrogen in soil. Whereas, the negative relations was found with weather temperature, carbon concentration, cellulose and C-N ratio in litter, soil pH, SOM, soil C, available K and C-N ratio in soil was found (Table 4.9).

Table 4.9 The correlation between invertebrate decomposer diversity (H') and decomposition rate and other factors in dry dipterocarp and dry evergreen forests during June 2007 and May 2008.

Decay rate and other factors	Shannon-Weiner Diversity Index	
	Dry dipterocarp	Dry evergreen
k-constant	0.569**	0.635**
Temperature (^{0}C)	-0.309**	-0.365**
Relative humidity (%)	-0.012	0.046
Precipitation (mm)	0.439**	0.433**
Litter bag temperature (^{0}C)	0.022	-0.171
Litter C - content (%)	-0.308**	-0.591**
Litter N - content (%)	0.116	0.480**
Lignin content (%)	0.096	0.392**
Cellulose content (%)	-0.190	-0.211**
C-N ratio in litter	-0.333**	-0.563**
Soil temperature (^{0}C)	0.060	-0.156
Soil pH	-0.064	-0.231*
Soil moisture (%)	0.332**	0.229*
Soil organic matter (%)	-0.127	-0.306**
Soil carbon content (%)	-0.127	-0.306**
Total nitrogen (g/kg)	0.333**	0.573**
Available phosphorus (g/kg)	-0.057	0.107
Available potassium (g/kg)	-0.575**	-0.518**
C-N ratio	-0.509**	-0.671**

** Correlation is significant at the 0.01 level.

* Correlation is significant at the 0.05 level.

4.6 Discussion

Decomposition is the process that accounts for a huge majority of the biological carbon processing on planet Earth. This process occurs mainly on or below ground, it is carried out primarily by bacteria and fungi which is sometimes associated with products that are unappealing. Decomposition of organic matter is responsible for huge amounts of the carbon dioxide returned to the atmosphere. It is also responsible for the formation of humic substances that contribute to soil fertility as well as the long-term storage of carbon. Decomposition is closely tied to nutrient cycling and is essential for the regeneration of organically bound nutrients (Berg and McClaugherty, 2003). Litter forms one of the facets of nutrient cycling in forest, representing a major process for the transfer of nutrients from aboveground vegetation to soils. Litter production depends primarily on the productivity of the plant community at the site, and exhibits seasonal patterns varying with vegetation type and latitude, besides altering the physical and chemical environment. Chemical and physical degradation, heterotrophic consumption and decomposition reduce litter accumulation on the surface. These are interrelated processes with decomposition being the most important. Litter is considered as a biological system in which organic matter, mineral component, mocroflora, soil fauna and vegetation interact (Ananthakrishnan, 1996). Decomposition is controlled by three types of factors, i.e. the physical environment, the quantity and quality of substrate available to decomposers, and the characteristics of the microbial community (Swift et al., 1979). In this research, the interrelation of leaf litter decomposition rates and their main factors were investigated; the prominences of all results were discussed as follows:

4.6.1 Climatic factors

Climate has a dominant effect on litter decomposition rate on a regional scale, whereas litter quality dominates on a local level (Meentemeyer, 1984. Reviewed by Berg and McClaugherty, 2003). In this experiment, the results of mean monthly temperature in dry dipterocarp forest (DDF) was higher than in dry evergreen forest (DEF). The highest temperature was found during June - July 2007, when it was the rainy season, and the lowest temperature was in December 2007 - January 2008 when it was the winter season in both of DDF and DEF. The different rate of mean temperature between DDF and DEF forests might be related to the plant composition in studied area. Krittayaporn (2003) found that the density of tree in DEF was higher than that in DDF. That means the plant cover over DEF area is closer than the cover in DDF, this state could protect the sunlight and reduce rate of temperature in DEF. These interrelation may concern to the moisture content in forest. Suriyapong (2003) and Pinmongkholkul (2008) described that the high density caused the closed plant cover and high moisture content, it reduced light and radiation from the sun. The modification of temperature by plant cover is both significant and complex. Shaded ground is cooler during the day than open area. Vegetation interrupts the laminar flow of air, impeding heat exchange by convection. Moreover, the relative humidity in DEF was also higher rate than that in DDF, it was also due to the tree density where vegetation was higher density in DEF than the density in DDF. Suriyapong (2003) summarized that because of relative humidity which was referred to water vapor content in the air. In the forest which contain high organic matter on the ground surface and cover with a high density of canopy may affect from moist surfaces and from transpiration by plants.

4.6.2 The decomposition rate of leaf litter

The decomposition rate of dominant species litter in dry evergreen forest was quite higher than the decay rate of dominant species in dry dipterocarp forest. In this research the high rate of annual k - constant in DEF was with *H. ferrea* Laness. and *A. xylocarpa* (Kurz) Craib species (2.07 and 2.01, respectively). These species contained the small size litter and had the thin leaves. Moreover, the result showed the low rate of C/N ratio, cellulose content, and the high concentration of nitrogen inside the leaf. These may be the important reason of the rapid decomposition rate in these species (Chapin et al., 2002; Adl, 2003; Berg and McClaugherty, 2003). The annual k - constant in DDF was high rate with *D. tuberculatus* Roxb species, then follow by *S. obtusa* Wall., *S. roxburghii* Don and the lowest rate with *S. siamensis* Miq. species. By these results in DDF, the size of leaves was not the direct factor which influenced the decay rate and the clear effect of the chemical contents in leaves on decomposition rate were not found. That is because *D. tuberculatus* Roxb is the bigger size than the leaf of other species, so these may be the indirect factor which induce the high decay rate in DDF through fauna decomposers who use those species to protect them from the high temperature of climatic factor.

4.6.3 Mixed species litter, decomposition rates, litter quality and soil property

The decomposition of leaf litter mixtures has recently become an active research area because it mimics the nature of leaf litter in most forests (Blair et al., 1990). A range of litter mixing effects on decomposition processes has been reported in the literature, ranging from negative to positive aspects, indeed both positive and negative effects of litter mixing have sometimes been detected in the same study

(Wardle et al., 2003). As the hypothesis of the research, we expected that the litter diversity would induce the different rate of litter decomposition was expected. The results showed that the mean annual decay rate in DEF was higher than that in DDF, while the effect of litter diversity on annual k - constant was not found either in DDF or DEF. These phenomenon may caused by the difference of species composition in DDF and DEF. The high density of tree species in the forest had direct and indirect affect on the decomposition rate. The study of Wardle et al. (2003) found that species differed significantly in their effects on decomposition. Li et al. (2009) concluded that the study about mixed litter decomposition in a managed Missouri Ozark forest ecosystem demonstrated significant effects of litter mixtures on decomposition rate. In 2005, Wardle et al. found litter mixing have little effect on net decomposition rates of the study about the influence of plant litter diversity on decomposer abundance and diversity. The tree species composition in dry evergreen forest is higher density than that in dry dipterocarp forest, then there was the high rate of decomposition. However, the influence of the litter diversity was not clearly significant in both DDF and DEF, thus it may be driven the decomposition rate in the large scale as between different ecosystem but had no effect on the decomposition rate in the small scale.

Litter chemistry is the main determinant of litter decomposition. The litter decay and nutrient release are controlled by the litter quality, including the nitrogen concentration of litter, the carbon to nitrogen (C/N) ratio, as well as other chemical properties (Yang and Chen, 2009). On a smaller spatial scale, litter quality is considered as the most important factor influencing decomposition rate (Liu et al., 2006). The correlation between initial litter quality and decomposition rate was prominent by carbon concentration, nitrogen concentration, lignin and C/N ratio in

only DEF. Carbon content and C/N ratio show the negative correlation to the k - constant, that mean when carbon concentration and C/N ratio decrease, the decay rate will increase, while nitrogen and lignin content had the positive correlation to k - constant. This results was supported from the study of Herman et al. (2008), they found the litter characteristics had significant effects on the proposed LCI threshold for lignin decay. Depending on the functional attributes of species added or lost from community, both positive and negative changes in decomposition rates may occur and average rates could be independent of plant diversity. The C/N ratio of the litter mixture explained a large proportion of the observed variation in decomposition rates. Litter species with high nitrogen concentration and low C/N ratio show high early decomposition rates and may stimulate decay of more recalcitrant litters (Scherer-Lorenzen, 2008).

4.6.4 The linkage of invertebrate diversity on leaf litter decomposition

The dominant primary decomposers in boreal and temperate forest soil systems are the microorganisms, encompassing both fungi and bacteria. The main groups of microorganisms can degrade cellulose, hemicelluloses, and the different lignins. By tradition, soil animals such as collembolans, mites and earthworms, among others, have been considered important for litter decomposition. Such group have been ascribed different roles in decomposition (Berg and McClaugherty, 2003). The importances of soil fauna are due to their functional role in the acceleration of organic matter decomposition and nutrient transformations. The positive influence of soil fauna on plant litter decomposition is widely known and well accepted for many ecosystems.

Although there has been much recent interest in the effect of litter mixing on decomposition processes, much remains unknown about how litter mixing and diversity affects the abundance and diversity of decomposer organisms (Wardle et al., 2005). In this research, it was found that higher abundance of individual invertebrates in DEF than that in DDF. At the same time, the results presented that the litter diversity induced the different rate of species diversity (the Shannon-Weiner Diversity Index) in both of DDF and DEF, and the decay rate had positive correlation with decomposer diversity index. These results were similar to the study of Wardle et al. (2005), they concluded that litter mixing affects the abundance and diversity of decomposer biota. Yang and Chen (2009) studied the contribution of soil fauna to litter decomposition in humid tropical forests, southwestern China; they found the relationship between the decomposition of mixed leaf litter and soil fauna roles. Hansen and Coleman (1998) and Kaneko and Salamanca (1999) found microarthopod diversity to be greater in two- and three-species litter mixtures than in litter monocultures. It might be expected that litter mixing stimulated decomposer diversity through promoting habitat diversity (Wardle et al., 2005). However, some converse cases which have found the linkage between plant species diversity and decomposer diversity to be weak and often unpredictable. Ilieva-Makulec and Szanser (2006) found that only the litter quality, but not litter diversity was the factor which affected the three animal groups under their study. So, more experiments are needed to elucidate the influence of litter mixing on the decomposer community (Gartner and Cardon, 2004).

CHAPTER V

CONCLUSION

This research was a study of the decomposition processes in dry dipterocarp and dry evergreen forests. The objectives of this thesis were; to study the decomposition rate of the different mixed litter species; to examine the changing of litter quality after the incubation; to study the changing of physical and chemical properties of soil along the incubation year; to study species diversity of invertebrate decomposers; and to analyze the linkages between the decomposition rate and litter quality, soil fertility, and decomposer diversity. The major results were concluded as the fallowing.

Leaf litter decomposition in dry diptercarp and dry evergreen forests was analyzed from the litter mass remaining and the k-constant of decay rate. The results showed *D. tuberculatus* Roxb. had a lowest of remaining weight (17.73%) and the highest remaining weight was with *S. siamensis* Miq. species (32.80%) in dry dipterocarp forest (DDF). The lowest of remaining weight was 12.68% with *H. ferrea* Laness, the highest was 33.67% with *M. caeruleum* Jack. species in dry evergreen forest (DEF). The k-constant data showed that the highest rate of annual decomposition rate was 2.07 with *H. ferrea* Laness in DEF, while it was 1.73 with *D. tuberculatus* Roxb species in DDF. The results can be concluded that the decomposition rate of leaf litter in DEF was faster than the decay rate in DDF.

The patterns of leaf litter decomposition were different between DDF and DEF, the accomposition rate of litter in DEF decreased rapidly in the early period (k = 2.431, sd = 1.001) and then it showed the slower rate in the late period (k = 1.455, sd = 0.846). On the other hand, the decreasing rate of leaf litter in DDF was slowly in early of incubation (k = 0.488, sd = 0.350) and then it was increased the rate in the late of incubation (k = 1.634, sd = 0.416). The natural fallen leaf litters had the higher decay rates than that of the single species and 2-mixed, 3-mixed and 4-mixed species in both of DDF and DEF. However, there were no significant effects of litter diversity k- constant in both dry evergreen forest and dry dipterocarp forest.

The changing of leaf litter chemistry was investigated along the experiment**.** The results showed significant influence of initial litter quality on decomposition rate was not found in dry dipterocarp forest but it was found only in dry evergreen forest. The important factors influence to decay rate in DEF were the initial of carbon concentration, nitrogen content, lignin content, and the carbon and nitrogen ratio. The litter diversity influenced the changing of some properties in litter quality, which was found the changing of leaf lignin content and cellulose content in dry evergreen forest but the litter diversity did not affect the quality of litter in dry dipterocarp forest

There were the linkage between litter decomposition and soil properties, the litter diversity had the linkage with SOM, soil C and soil N content in DEF, and SOM, soil C, available P and available K in DDF.

Invertebrates are one group of soil organisms which have been considered as the main factor for leaf litter decomposition. In this research, 15 orders/classes of invertebrate decomposers were observed in dry dipterocarp forest and 16 orders/classes were found in dry evergreen forest. The sum of average number per bag

of invertebrates in dry evergreen forest was higher than that in dry dipterocarp forest. The total average of 884.01 individuals in DEF and average of 557.05 individuals in DDF were observed. The most abundant invertebrates in both of dry dipterocarp and dry evergreen forests were Isoptera (termites) and Hymenoptera (ants). The period which induced the highest abundance of invertebrate decomposers was in December 2007 - January 2008 with 14 orders, average of 150.92 individuals in dry dipterocarp forest and in the same period, the highest invertebrate abundant was found in dry evergreen forest with 13 orders, average of 170 individuals.

It was summarized that the decomposer diversity in dry evergreen forest was higher than the diversity in dry dipterocarp forest. The Shannon-Weiner Diversity Index of total invertebrates in whole year was 2.147 in dry dipterocarp forest, and 2.292 in dry evergreen forest. The result of ANOVA showed the linkage between litter diversity and invertebrate diversity. The difference of litter treatments induced the different rates of the Shannon-Weiner Diversity Index in both of DDF and DEF.

Recommendations for Further Study

1. From this study, the litter decomposers were found with the big groups of prominent orders, so there should studies of all micro-, meso- and macro- invertebrates in the future for conclusion and make the clearly role of soil fauna on the composition rate in the forest.

2. The interaction of microorganisms with the leaf litter decomposition processes should be conducted to investigate the possible factors which are the most important environment to predict the decomposition rate.

3. This research was focused on the two types of forests; further study should include other ecosystems for investigation the leaf litter decomposition in the whole spatial scale of SERS.

REFERENCES

REFERENCES

Aber, J. D. and Melillo, J. (1991). **Terestrial ecosystems**. Saunders College: Toronto.

Adl, S. M. (2003). **The ecology of soil decomposition**. Wallingford, UK: Cab International.

Aert, R. and de Caluwe, H. (1997). Initial litter respiration as indicator for long - term litter decomposition of *Carex* species. **Oikos**. 80: 353-361.

Aert, R. (1997). Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: a triangular relationship. **Oikos**. 79: 439-449.

Alhamd, L., Arakaki, S. and Hagihara, A. (2004). Decomposition of leaf litter of four tree species in a subtropical evergreen broad-leaved forest, Okinawa Island, Japan. **Forest Ecology and Management**. 202(1-2): 1-11.

Ananthakrishnan, T. N. (1996). **Forest litter insect communities; biology and chemical ecology**. USA: Science Publishers.

Arunachalam, A., Maithani, K., Pendey, H. N. and Tripathi, R. S. (1998). Leaf litter decomposition and nutrient mineralization patterns in regrowing stands of a humid subtropical forest after tree cutting. **Forest Ecology and Management**. 109:151-161.

Baldock, J. A., Sewell, T. and Halcher, P. G. (1997). Decomposition induced changes in the chemical structure of fallen red pine, white spruce and tamarack logs. In: Cadisch, G. and Giller, K. E.: **Driven by nature**. Wallingford, UK: Cab International.

Barajas-Guzman, G. and Alvareez-Sanchez, J. (2003). The relationships between litter fauna and rates of litter decomposition in a tropical rain forest. **Applied Soil Ecology**. 24: 91-100.

Berg, B. and McClaugherty, C. (2003). **Plant litter decomposition, humus formation, carbon sequestration**. New York: Springer.

Berg, B., McClaugherty, C., De Santo, A. V. and Johnson, D. (2001). Humus buildup in boreal forest: effects of litter fall and its N concentration. **Canadian Journal of Forest Research**. 31: 988-998.

Blair, J. M., Parmelee, R. W. and Beare, M. H. (1990). Decay rates, nitrogen fluxes, and decomposer communities of single and mixed species foliar litter. **Ecology**. 71: 1976-1985.

Bockheim, J. G., Jepsen, E. A. and Heisey, D. M. (1991). Nutrient dynamics in decompositing leaf litter of four tree species on a sandy soil in north western Wisconsin. **Canadian Journal of Forest Research**. 21: 803-812.

Borror, D., Delong, D. and Triplechorn, C. (1976). **An introduction to the study of insects**. New York: Holt, Rinchart and Wiston.

Bosatta, E. and Agren, G. (1985). Theoretical analysis of decomposition of heterogenous substrates. **Soil Biology and Biochemistry**. 17: 301-310.

Brussaard, L. (1999). Soil fauna, guilds, functional groups and ecosystem processes. **Applied Soil Ecology**. 9: 123-135.

Carcamo, H. A., Abe, T. A., Prescott, C. E., Holl, F. B. and Chanway, C. P. (2000). Influence of millipedes on litter decomposition, N mineralization and microbial communities in a coastal forest in British Columbia Canada. **Canadian Journal of Forest Research**. 30: 817-826.

Cauteaux, M. M., Bottner, P. and Berg, B. (1995). Litter decomposition, climate and litter quality. **Trends in Ecology and Evolution**. 10: 63-66.

Chan, Z. S., Hsich, C. F., Jiang, F. Y., Hsich, T. H. and Sun, I. F. (1997). Reflection of soil properties to topography and vegetation in subtropical rain forest in southern Taiwan. **Plant Ecology**. 132: 229-241.

Chapin, F. S., Matson, P. A. and Mooney, H. A. (2002). **Principles of terrestrial ecosystem ecology**. New York: Springer.

Charoenpol, K. (2003). **A comparative study on physical and chemical soil properties in dry dipterocarp forest and dry evergreen forest in the Sakaerat Environmental Research Station, Changwat Nakorn Ratchasima.** M.Sc. Thesis, Mahidol University, Thailand.

Chhatiwal, G. R. (1997). **Encyclopedia of environmental soil and marine pollution** (Volume 2). India: Mehra Offset Press.

Chunkao, K. and Boonyawat, S. (1978). **An accumulation of litterfall and some nutrients in dry-evergreen forest Sakaerat**. Final Report, Kasetsart University, Thailand.

Coleman, D. C. and Crossley, D. A. (1996). **Fundamental of soil ecology**. New York: Academic Press.

Cornelissch, J. H. C. (1996). An experimental composition of leaf decomposition rate in a wide range of temperate plant species and types. **Journal of Ecology**. 54: 573-582.

Dankittipakul, M. (2003). **Impacts of forest fire on litter dynamic in deciduous dipterocarp-oak forests in Doi Suthep-Pui National Park**. M.Sc. Thesis, Chiang Mai University, Thailand.

De D8eyn, G. B., Raaijmakers, C. E., van Ruijven, J., Berendse, F. and van der Putten, W. H. (2004). Plant species identity and diversity effects on different trophic levels of nematodes in the soil food web. **Oikos**. 106(3): 576-584.

Dickinson, C. H. and Pugh, G. J. F. (1974a). **Biology of plant litter decomposition** (Volume 1). New York: Academic Press.

Dickinson, C. H. and Pugh, G. J. F. (1974b). **Biology of plant litter decomposition** (Volume 2). New York: Academic Press.

Didham, R. K. (1997). Altered leaf-litter decomposition rates in tropical forest fragments. **Oecologia**. 116: 397-406.

Duffy, J. E., Richardson, J. P. and Canuel, E. A. (2003). Grazer diversity effects on ecosystem functioning in seagrass beds. **Ecology Letters**. 6: 637-645.

Edwards, C. S. and Health, G. (1963). The role of soil animals in breakdown of leaf materials. In: Docksen, J. and van der Drift, J. (Eds.). **Soil Organism**. Amsterdam: North-Holland.

Finzi, A. C. and Schlesinger, W. H. (2002). Species control variation in litter decomposition in a pine forest exposed to elevated CO_2. **Global Change Biology**. 8: 1217-1229.

Fox, K. (1998). The effect of added nitrogen on the rate of decomposition of organic matter. **Biological Reviews**. 63: 433-463.

Gartner, T. B. and Cardon, Z. G. (2004). Decomposition dynamics in mixed-species leaf litter. **Oikos**.104: 230-246.

George, S. J. and Kumar, M. B. (1998). Litter dynamics and cumulative soil fertility changes in silvopastural systems of a humid tropical region in Central Kerala, India. **International Tree Crops Journal**. 9: 267-282.

Gonzalez, G. (2002). Soil organisms and litter decomposition. In: Ambasht, R. S. and Ambasht, N. K. **Modern Trends in Applied Terrestrial Ecology**. New York: Kluwer Academic.

Gonzalez, G. and Seastedt, T. R. (2000). Comparison of the abundance and composition of litter fauna in tropical and subalpine forests. **Pedobiologia**. 44: 545-555.

Gonzalez, G. and Seastedt, T. R. (2001). Soil fauna and plant litter decomposition in tropical and subalpine forests. **Ecology**. 82: 955-964.

Hansen, R. A. and Coleman, D. C. (1998). Litter complexity and composition are determinants of the diversity and species composition of oribatid mites (Acari: Oribatida) in litterbags. **Applied Soil Ecology**. 9: 17-23.

Hattenschwiler, S., Tiunov, A. V. and Scheu, S. (2005). Biodivrsity and litter decomposition in terrestrial ecosystems. **Annual Review of Ecology, Evolution, and Systematics**. 36: 191-218.

Heal, O. W., Anderson, J. M. and Swift, M. J. (1997). Plant litter quality and decomposition: an historical overview. In: Cadisch, G. and Giller, K. E.. **Driven by nature**. Wallingford, UK: Cab International.

Herman, J., Moorhead, D. and Berg, B. (2008). The relationship between rates of lignin and cellulose decay in aboveground forest litter. **Soil Biology and Biochemistry**. 40: 2620-2626.

Hirobe, M., Sabang, J., Bhatta, B. K. and Takeda, H. (2004). Leaf – litter decomposition of 15 tree species in a lowland tropical rain forest in Sarawak: decomposition rates and initial litter chemistry. **Journal of Forest Research**. 9: 341-346.

Hon, P. C. L., Xiaoming, Z., Huang, C. Y. and Chen, H. J. (2005). Plant litter decomposition influenced by soil animals and disturbance in a subtropical rainforest of Taiwan. **Pedobiologia**. 49: 539-547.

Honeghan, L., Coleman, D. C., Zon, X., Crossley., D. A. and Haines, B. L. (1999). Soil microarthropod contribution dynamics: tropical-temperate compositions of a single substrate. **Ecology**. 50: 1873-1882.

Hoover, C. M. and Crossley, jr., D. A. (1995). Leaf litter decomposition and microarthropod abundance along altitudinal gradient. In: Collins, H. P., Robertson, G. P. and Klug, M. J. (Eds.) **The significance and regulation of soil biodiversity**. Dordrecht: Kluwer Academic.

Hunter, M. D., Adl, S., Pringle, C. M. and Coleman, D. C. (2003). Relative effects of macroinvertebrates and habitat on the chemistry of litter during decomposition. **Pedobiologia**. 47(2): 101-115.

Ilieva-Makulec, K., Olejniczak, I. and Szanser, M. (2006). Response of soil micro- and mesofauna to diversity and quality of plant litter. **European Journal of Soil Biology**. 42: S244-S249.

Isaac, S. R. and Nair, M. A. (2005). Biodegradation of leaf litter in the warm humid tropic of Kerala, India. **Soil Biology and Biochemistry**. 37: 1656-1664.

Jackson, M. L. (1973). **Soil chemistry analysis**. New Dehli: Prentice Hall of India.

Jampanin, S. (2004). **Comparison of litter production and litter decomposition for carbon sequestration assessment in forest ecosystems at Kaeng Krachan National Park, Thailand**. M.Sc. Thesis, Chulalongkorn University, Thailand.

Kaneko, N. and Salamanca, E. (1999). Mixed leaf litter effects on decomposition rates and soil microarthropod communities in an oak-pine stand in Japan. **Ecological Research**. 14(2): 131-140.

Kongamol, S. (2001). **Decomposition rates and associated degradation fungi on mangrove leaf litters of *Rhizophora apiculata* and *Avicennia alba* at Thachine estuary, Samut Sakhon province**. Ph.D. Thesis, Kasetsart University, Thailand.

Krebs, C. J. (1978). **Ecology: The experimental analysis of distribution and abundance** (2nd edition). New York: Harper and Row.

Lamotte, S., Gajaseni, J. and Malaisse, F. (1998). Structure diversity in three forest types of north-eastern Thailand (Sakaerat Reserve, Pak Tong Chai). **Biotechnology, Agronomy, Society and Environment.** 2: 192-202.

Lavelle, P., Blanchart, E., Martin, S., Spain, A., Toutan, F., Barois, I. and Schacfer, R. (1993). A hierachical model for decomposition in terrestrial ecosystems: application to soils of the humid tropics. **Biotropica**. 25: 130-150.

Leroy, C. J. and Marks, J. C. (2006). Litter quality, stream characteristics and litter diversity influence decomposition rates and macroinvertebrates. **Freshwater Biology**. 51(4): 605-617.

Li, Q., Moorhead, D. L., DeForest, J. L., Henderson, R., Chen, J. and Jensen, R. (2009). Mixed litter decomposition in a managed Missouri Ozark forest ecosystem. **Forest Ecology and Management**. 257: 688-694.

Liu, P., Huang, J., Han, X., Sun, O. J., and Zhou, Z. (2006). Differential responses of litter decomposition to increased soil nutrients and water between two contrasting grassland plant species of Inner Mongolia, China. **Applied Soil Ecology**. 34: 266-275.

Maheswaran, J. and Gunatilleke, I. U. A. N. (1988). Litter decomposition in a lowland rainforest and a degraded area in Sri Lanka. **Biotropica**. 20: 90-99.

McClaugherty, C. A., Pastor, J., Aber, J. D. and Melillo, J. M. (1985). Forest litter decomposition in relation to soil nitrogen dynamics and litter quality. **Ecology**. 66: 266-275.

Milcu, A., Partsch, S., Langel, R. and Scheu, S. (2006). The response of decomposers (earthworms, springtails and microorganisms) to variations in species and functional group diversity of plants. **Oikos**. 112(3): 513-521.

Okeke, A. I. and Omaliko, C. P. E. (1992). Leaf litter decomposition and carbon dioxide evolution of some agroforestry fallow species in southern Nigeria. **Forest Ecology Management**. 50: 103-116.

Pimthongngam, S. (2004). **Comparison of diversity of soil arthropods and decomposition rate of organic matters between forested and cultivated land in Khoa Suan Kwang district, Khon Kaen province**. M.Sc. thesis, Khon Kaen University, Thailand.

Pinmongkholgul, S. (2008). **Population dynamics and health status of small mammals at Sakaerat Environmental Research Station, Nakhon Ratchasima**. Ph.D. thesis, Suranaree University of Technology, Thailand.

Prescott, C. E. (2005). Do rate of litter composition tell us anything we really need to know? **Forest Ecology and Management**. 220: 66-74.

Prescott, C. E., Hupe, G. D. and Blevins, L. L. (2003). Effect of gap size on litter composition and soil nitrate concentrations in a high elevation spruce-fir forest. **Canadian Journal of Forest Research**. 33: 2210-2220.

Prescott, C. E., Maynard, D. G. and Laiho, R. (2000). Humus in boreal forest: friend or foe? **Forest Ecology and Management**. 133: 23-36.

Quested, H. M., Callaghan, T. V., Cornelissen, J. H. C. and Press, M. C. (2005). The impact of hemiparasitic plant litter on decomposition: direct, seasonal and litter mixing effects. **Journal of Ecology**. 93: 87-98.

Richard, H. W. and Steven, W. R. (2007). **Forest ecosystems: analysis at multiple scales** (3rd edition). UK: Elsevier Academic Press.

Ritter, E. (2005). Litter decomposition and nitrogen mineralization in newly formed gaps in a Danish beech (*Fagus sylvatica*) forest. **Soil Biology and Biochemistry**. 37: 1237-1247.

Sariyildiz, T. and Anderson, J. M. (2003). Interactions between litter quality, decomposition and soil fertility: a laboratory study. **Soil Biology and Biochemistry**. 35: 391-399.

Schadler, M. and Brandl, R. (2005). Do invertebrate decomposers affect the disappearance rate of litter mixtures? **Soil Biology and Biochemistry**. 37(2): 329-337.

Scherer-Lorenzen, M. (2008). Functional diversity affects decomposition processes in experimental grasslands. **Functional Ecology**. 22: 547-555.

Smith, V. C. and Bradford, M. A. (2003a). Do non-additive effects on decomposition in litter-mix experiments result from differences in resource quality between litters? **Oikos**. 102: 235-242.

Smith, V. C. and Bradford, M. A. (2003b). Litter quality impacts on grassland litter decomposition are differently dependent on soil fauna across time. **Applied Soil Ecology**. 24: 197-203.

Suriyapong, Y. (2003). **Study of ground dwelling ant populations and their relationship to some ecological factors in Sakaerat Environmental Research Station, Nakhon Ratchasima**. Ph.D. thesis, Suranaree University of Technology, Thailand.

Swift, M. J., Heal, O. W. and Anderson, J. M. (1979). **Decomposition in terrestrial ecosystems**. Los Angeles: University of California.

Tchimbakala, J. G. and Reversat, F. B. (2006). Comparison of litter dynamics in three plantations of an indigenous timber-tree species (*Terminalia superba*) and a natural tropical forest in Mayombe, Congo. **Forest Ecology and Management**. 229: 304-313.

Thailand Institute of Scientific and Technological Research (TISTR). (2002). **Final report of Sakaerat database information development**. [CD-ROM]. Bangkok. (in Thai).

Thomas, K. D. and Prescott, C. E. (2000). Nitrogen availability in forest floors of three species on the same size: the role of litter quality. **Canadian Journal of Forest Research**. 30: 1698-1706.

Tian, G., Brussaard, L., Kang, B. T. and Swift, M. J. (1997). Soil fauna-mediated decomposition of plant residues under constrained environmental and residue quality conditions, In: Cadisch, G. and Giller, K. E.: **Driven by nature**. Wallingford, UK: Cab International.

Trautmann, N. (2007). **Invertebrates of the compost pile**, [online]. Available: http://www.css.cornell.edu/compost/invertebrates.html.

Triplehorn, C. A. and Johnson, N. F. (2005). **Borror and DeLong's introduction to the study of insects** (7th edition). USA: Thomson Brooks/Cole.

Vargas, D. N., Bertiller, M. B., Ares, J. O., Carrera, A. L. and Sain, C. L., (2006). Soil C and N dynamics induced by leaf – litter decomposition of shrubs and perennial grasses of the Patagonian Monte. **Soil Biology and Biochemistry**. 38: 2401-2410.

Vityakon, P. (2002). **Nitrogen and phosphorus availability as influenced by litter of various agroforestry trees of Northeast Thailand: relationship to litter quality**. Research Report. Khon Kaen University, Thailand.

Wachendorf, C., Irmler, U. and Blume, H. P. (1997). Relationships between litter fauna and chemical changes of litter during decomposition under different moisture conditions. In: Cadisch, G. and Giller, K. E., **Driven by nature**. Wallingford, UK: Cab International.

Wardle, D. A. (2006). The influence of biotic interactions on soil biodiversity. **Ecology Letters**. 9: 870-886.

Wardle, D. A., Bonner, K. I. and Barker, G.M. (2002). Linkages between plant litter decomposition, litter quality, and vegetation responses to herbivores. **Functional Ecology**. 16: 585-595.

Wardle, D. A. and Lavelle, P. (1997). Linkages between soil biota, plant litter quality and decomposition. In: Cadisch, G. and Giller, K. E., **Driven by nature**. Wallingford, UK: Cab International.

Wardle, D. A., Nilsson, M. C., Zackrisson, O. and Gallet, C. (2003). Determinants of litter mixing effects in a Swedish boreal forest. **Soil Biology and Biochemistry**. 35: 827-835.

Wardle, D. A., Yeates, G. W., Barker, G. M. and Bonner, K. I. (2006). The influence of plant litter diversity on decomposer abundance and diversity. **Soil Biology and Biochemistry**. 38: 1052-1062.

Warren, M. W. and Zou, X. (2002). Soil macrofauna and litter nutrients in three tropical plantations on a disturbed site in Puerto Rico. **Forest Ecology and Management**. 170: 161-171.

Webb, D. P. (1977). Regulation of deciduous forest litter decomposition by soil arthropod feces. In: Mattson, W. J. (Ed.) **The role of arthropods in forest ecosystems**. New York: Springer.

Xuluc-Tolosa, F.J., Vester, H. F. M., Ramirez-Marcial, N., Castellanos-Albores, J. amnd Lawrence, D. (2003). Leaf litter decomposition of tree species in three successional phases of tropical dry secondary forest in Campeche, Mexico. **Forest Ecology and Management**. 174: 401-412

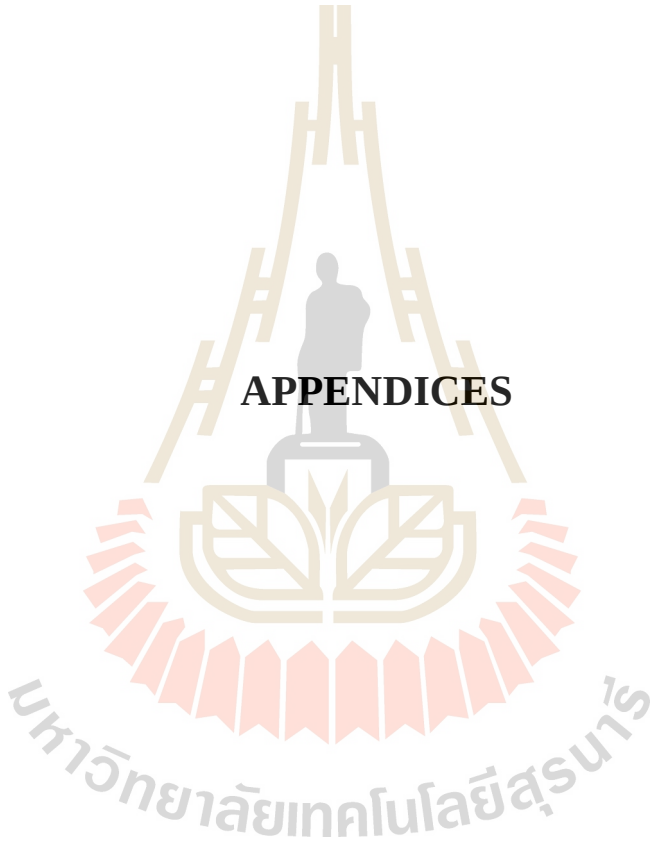
Yang, X. and Chen, J. (2009). Plant litter quality influences the contribution of soil fauna to litter decomposition in humid tropical forests, southwestern Chaina. **Soil Biology and Biochemistry**. 41: 910-918.

Yimruttanabaworn, J. (1993). **Seasonal fluctuations of soil fauna and its influence on the decomposition of organic matters in a teak plantation at Changwat Phitsanulok**. M.Sc. Thesis, Chulalongkorn University, Thailand.

Yanai, R. D., Currie, W. S. and Goodale, C. L. (2003). Soil carbon dynamics after forest harvest: an ecosystem paradigm reconsidered. **Ecosystem**. 6: 197-212.

Zimmer, M., Kautz, G. and Topp, W. (2005). Do woodlice and earthworms interact synergistically in leaf litter decomposition? **Functional Ecology**. 19: 7-16.

APPENDICES



APPENDIX A

MEAN AND STANDARDS DEVIATION OF LEAF LITTER REMAINING AND DECOMPOSITION RATE OF LITTER IN DRY DIPTEROCARP AND DRY EVERGREEN FORESTS FROM JUNE 2007 TO MAY 2008

Table A1 The mean mass remaining (%) of leaf litter in dry dipterocarp forest (DDF).

Treatment	1st June		July		September		November		January		March		May	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
D1	100.000	0.000	81.63	5.944	71.14	1.365	60.69	7.386	32.29	4.477	27.43	3.682	20.97	ns
D2	100.000	0.000	87.88	2.387	65.27	6.934	48.38	9.861	34.29	6.334	31.39	6.672	32.80	ns
D3	100.000	0.000	97.59	0.540	82.94	1.831	82.42	5.443	72.75	3.281	68.89	11.004	24.33	ns
D4	100.000	0.000	97.54	0.590	78.45	4.710	68.80	3.497	54.38	3.980	40.32	3.779	17.73	ns
D5	100.000	0.000	93.99	1.144	93.95	0.594	49.73	8.597	31.34	9.812	29.86	10.673	21.47	ns
D6	100.000	0.000	96.49	0.694	72.52	1.911	61.44	8.259	45.88	3.019	43.53	5.648	32.07	ns
D7	100.000	0.000	95.64	0.486	80.34	2.116	66.52	7.412	52.89	6.777	44.12	1.449	22.83	ns
D8	100.000	0.000	95.37	0.641	78.37	3.018	77.04	2.217	59.08	7.637	56.40	3.446	19.83	ns
D9	100.000	0.000	92.88	0.395	82.93	3.210	70.75	6.214	45.28	3.576	41.62	6.032	16.93	ns
D10	100.000	0.000	94.44	1.292	84.26	2.780	80.59	2.983	64.07	5.681	44.38	5.723	11.30	ns
D11	100.000	0.000	93.29	1.272	71.70	6.668	58.53	6.246	43.94	5.845	30.34	3.037	18.80	ns
D12	100.000	0.000	85.87	5.105	78.72	1.254	61.67	6.808	42.94	6.387	28.56	2.027	19.20	ns
D13	100.000	0.000	95.79	0.554	84.35	0.723	60.74	4.161	50.29	3.092	41.36	2.833	27.80	ns
D14	100.000	0.000	84.02	3.508	73.11	2.829	65.16	4.368	41.07	1.315	36.44	4.377	6.57	ns

Table A2 The mean mass remaining (%) of leaf litter in dry evergreen forest (DEF).

Treatment	1st June		July		September		November		January		March		May	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
E1	100.000	0.000	83.07	1.028	71.42	3.309	54.58	5.669	33.52	3.646	32.09	2.968	12.68	2.710
E2	100.000	0.000	51.59	2.547	43.41	5.640	20.96	1.624	20.14	1.940	19.90	2.285	13.34	0.602
E3	100.000	0.000	71.43	2.111	59.20	5.376	48.51	0.331	40.90	3.246	34.36	0.309	33.67	3.572
E4	100.000	0.000	64.34	4.862	58.48	6.565	48.82	4.637	44.72	4.107	36.08	4.602	31.11	7.958
E5	100.000	0.000	75.60	3.586	56.62	4.385	44.93	1.969	39.60	3.631	25.51	3.467	21.61	2.457
E6	100.000	0.000	74.03	3.526	60.08	4.664	53.97	5.505	36.54	3.438	36.16	1.145	21.49	2.302
E7	100.000	0.000	49.04	7.023	48.38	6.219	36.73	4.400	35.12	1.784	33.90	3.079	17.66	1.794
E8	100.000	0.000	77.86	0.830	61.43	2.950	57.75	3.641	56.34	3.704	52.21	3.635	43.82	5.820
E9	100.000	0.000	60.47	5.365	55.78	5.295	43.72	2.498	40.61	3.123	27.37	1.620	20.39	3.545
E10	100.000	0.000	70.60	4.201	70.54	2.448	49.81	3.309	45.39	2.291	40.08	2.375	33.36	3.779
E11	100.000	0.000	78.97	1.958	63.02	1.779	47.76	4.028	41.40	3.774	28.54	1.492	24.31	3.907
E12	100.000	0.000	64.08	3.655	61.27	1.599	44.54	0.989	42.08	0.745	32.91	2.178	21.28	2.518
E13	100.000	0.000	70.42	4.571	60.68	8.390	46.50	2.819	33.12	3.553	26.59	3.152	22.88	2.985
E14	100.000	0.000	53.07	5.281	43.87	10.203	28.02	7.353	21.02	3.704	17.78	4.106	14.83	0.717

Table A3 The mean of decomposition rate (k-constant) of leaf litter in dry dipterocarp forest (DDF).

Treatment	1st June		July		September		November		January		March		May	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
D1	0.000	0.000	1.215	0.130	1.023	0.016	0.999	0.066	1.695	0.068	1.553	0.047	1.562	ns
D2	0.000	0.000	0.774	0.045	1.281	0.097	1.452	0.104	1.605	0.072	1.391	0.071	1.115	ns
D3	0.000	0.000	0.146	0.009	0.562	0.018	0.387	0.040	0.477	0.019	0.447	0.069	1.413	ns
D4	0.000	0.000	0.149	0.010	0.729	0.048	0.748	0.029	0.913	0.031	1.090	0.035	1.730	ns
D5	0.000	0.000	0.371	0.021	0.188	0.005	1.397	0.102	1.739	0.146	1.451	0.124	1.539	ns
D6	0.000	0.000	0.214	0.012	0.965	0.022	0.974	0.092	1.168	0.026	0.998	0.040	1.137	ns
D7	0.000	0.000	0.267	0.008	0.657	0.022	0.815	0.061	0.955	0.060	0.982	0.011	1.477	ns
D8	0.000	0.000	0.284	0.011	0.732	0.033	0.522	0.016	0.789	0.065	0.688	0.020	1.618	ns
D9	0.000	0.000	0.442	0.007	0.562	0.033	0.692	0.046	1.188	0.032	1.052	0.044	1.776	ns
D10	0.000	0.000	0.342	0.023	0.514	0.028	0.432	0.020	0.668	0.035	0.975	0.040	2.180	ns
D11	0.000	0.000	0.416	0.023	0.999	0.080	1.071	0.057	1.233	0.051	1.432	0.034	1.671	ns
D12	0.000	0.000	0.912	0.106	0.718	0.013	0.967	0.068	1.267	0.061	1.505	0.025	1.650	ns
D13	0.000	0.000	0.258	0.010	0.511	0.007	0.997	0.040	1.031	0.025	1.060	0.022	1.280	ns
D14	0.000	0.000	1.042	0.070	0.941	0.034	0.857	0.037	1.334	0.014	1.212	0.038	2.723	ns

Table A4 The mean of decomposition rate (k-constant) of leaf litter in dry evergreen forest (DEF).

Treatment	1st June		July		September		November		January		March		May	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
E1	0.000	0.000	1.111	0.021	1.011	0.037	1.211	0.065	1.639	0.049	1.365	0.029	2.065	0.058
E2	0.000	0.000	3.963	0.084	2.506	0.132	3.125	0.047	2.403	0.045	1.938	0.037	2.014	0.013
E3	0.000	0.000	2.014	0.050	1.574	0.071	1.447	0.004	1.340	0.031	1.283	0.003	1.089	0.031
E4	0.000	0.000	2.640	0.138	1.611	0.100	1.434	0.059	1.206	0.038	1.224	0.040	1.168	0.066
E5	0.000	0.000	1.675	0.083	1.708	0.062	1.600	0.024	1.389	0.037	1.640	0.044	1.532	0.034
E6	0.000	0.000	1.800	0.083	1.530	0.069	1.234	0.053	1.509	0.040	1.221	0.010	1.538	0.032
E7	0.000	0.000	4.266	0.234	2.181	0.105	2.003	0.064	1.569	0.021	1.299	0.034	1.734	0.030
E8	0.000	0.000	1.499	0.018	1.463	0.042	1.098	0.033	0.860	0.030	0.780	0.022	0.825	0.040
E9	0.000	0.000	3.012	0.165	1.753	0.074	1.655	0.033	1.351	0.035	1.556	0.019	1.590	0.066
E10	0.000	0.000	2.085	0.095	1.048	0.028	1.394	0.036	1.184	0.022	1.098	0.019	1.098	0.037
E11	0.000	0.000	1.414	0.041	1.387	0.024	1.478	0.052	1.322	0.037	1.505	0.017	1.414	0.043
E12	0.000	0.000	2.665	0.100	1.471	0.021	1.618	0.012	1.298	0.007	1.334	0.024	1.548	0.031
E13	0.000	0.000	2.100	0.112	1.500	0.141	1.531	0.035	1.657	0.048	1.590	0.047	1.475	0.034
E14	0.000	0.000	3.794	0.174	2.475	0.203	2.544	0.158	2.338	0.083	2.073	0.093	1.908	0.014

Table A5 The mean mass remaining (%) of different leaf litter diversity in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	100.000	0.000	91.161	7.824	74.448	7.816	65.073	14.293	48.426	19.037	42.008	18.714	23.958	6.481
	DD2	100.000	0.000	95.372	1.038	81.294	9.065	63.681	11.346	47.297	11.924	43.478	10.847	24.050	5.483
	DD3	100.000	0.000	91.619	3.892	79.403	5.654	67.886	9.930	49.058	10.051	36.225	7.937	16.558	3.642
	DD4	100.000	0.000	95.789	1.846	84.346	2.411	60.738	13.871	50.289	10.308	41.356	9.444	27.800	ns
	DD5	100.000	0.000	84.022	11.692	73.107	9.430	65.161	14.559	41.067	4.384	36.444	14.590	6.567	ns
DEF	DE1	100.000	0.000	67.608	13.177	58.126	11.465	43.220	15.097	34.821	10.836	30.606	7.322	22.700	11.240
	DE2	100.000	0.000	69.133	13.484	56.628	5.862	48.344	9.429	41.903	9.807	36.944	11.161	26.144	11.927
	DE3	100.000	0.000	68.528	8.125	62.654	6.097	46.457	2.837	42.370	2.100	32.225	5.753	24.833	5.924
	DE4	100.000	0.000	70.422	15.238	60.678	27.968	46.504	9.397	33.122	11.844	26.589	10.505	22.878	9.951
	DE5	100.000	0.000	53.067	17.603	43.866	34.010	28.021	24.511	21.022	12.348	17.778	13.687	14.833	2.390

Table A6 The mean of decomposition rate (k-constant) of different leaf litter diversity in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	0.000	0.000	0.571	0.521	0.899	0.318	0.896	0.448	1.172	0.580	1.120	0.488	1.455	0.261
	DD2	0.000	0.000	0.284	0.065	0.635	0.326	0.927	0.365	1.163	0.414	1.030	0.315	1.443	0.212
	DD3	0.000	0.000	0.528	0.260	0.698	0.219	0.790	0.288	1.089	0.283	1.241	0.266	1.819	0.247
	DD4	0.000	0.000	0.258	0.116	0.511	0.086	0.997	0.478	1.031	0.299	1.060	0.263	1.280	ns
	DD5	0.000	0.000	1.042	0.835	0.941	0.404	0.857	0.444	1.334	0.163	1.212	0.456	2.723	ns
DEF	DE1	0.000	0.000	2.432	1.198	1.676	0.618	1.804	0.887	1.647	0.535	1.452	0.329	1.584	0.528
	DE2	0.000	0.000	2.310	1.310	1.720	0.324	1.484	0.406	1.332	0.323	1.235	0.354	1.407	0.399
	DE3	0.000	0.000	2.294	0.700	1.415	0.290	1.536	0.122	1.289	0.073	1.373	0.207	1.412	0.223
	DE4	0.000	0.000	2.100	1.337	1.500	1.693	1.531	0.416	1.657	0.572	1.590	0.564	1.475	0.408
	DE5	0.000	0.000	3.794	2.087	2.475	2.433	2.544	1.899	2.338	0.996	2.073	1.122	1.908	0.170

APPENDIX B

MEAN AND STANDARDS DEVIATION OF LITER BAG TEMPERATURE AND LITTER QUALITY OF LITTER IN DRY DIPTEROCARP AND DRY EVERGREEN FORESTS FROM JUNE 2007 TO MAY 2008

Table B1 The mean of carbon concentration (%) in mono species leaf litter in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	D1	22.690	0.113	22.169	0.127	19.790	0.255	14.091	0.721	17.314	0.948	19.591	0.297	14.941	0.764
	D2	25.413	0.523	25.798	0.354	18.390	0.283	15.392	0.495	15.392	1.061	19.809	1.400	21.883	0.594
	D3	23.620	0.368	21.584	0.622	17.600	0.948	6.688	0.707	13.305	0.537	15.352	0.495	13.517	0.665
	D4	24.661	0.382	24.693	0.523	25.925	0.424	13.955	0.849	20.769	0.834	20.526	0.778	18.832	0.269
DEF	E1	18.370	0.368	15.791	0.622	16.896	0.948	14.840	0.707	16.646	0.537	15.474	0.495	20.194	0.665
	E2	27.116	0.382	17.824	0.523	14.018	0.424	16.802	0.849	18.605	0.834	13.924	0.778	17.328	0.269
	E3	27.729	0.509	22.559	0.410	19.740	0.523	18.567	0.721	19.373	1.513	19.129	0.453	19.758	0.283
	E4	31.177	1.895	28.128	1.349	22.482	0.878	25.111	0.184	23.709	1.922	23.168	0.617	21.299	0.283

Table B2 The mean of nitrogen concentration (%) in mono species leaf litter in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	D1	0.862	0.029	0.862	0.015	0.835	0.048	0.915	0.047	0.854	0.064	0.893	0.039	0.598	0.048
	D2	0.766	0.036	0.853	0.045	0.832	0.049	0.856	0.044	0.781	0.039	0.930	0.038	0.950	0.043
	D3	1.002	0.044	0.963	0.031	0.912	0.029	1.155	0.020	0.915	0.036	0.858	0.030	0.762	0.021
	D4	0.547	0.020	0.590	0.015	0.821	0.048	1.002	0.047	0.821	0.038	0.773	0.039	0.730	0.048
DEF	E1	1.003	0.027	1.126	0.024	1.192	0.037	1.205	0.023	1.176	0.036	1.098	0.030	1.541	0.058
	E2	1.285	0.014	1.382	0.049	1.182	0.012	1.518	0.040	1.491	0.028	1.219	0.045	1.280	0.013
	E3	0.882	0.037	1.078	0.042	1.038	0.013	1.085	0.037	1.077	0.019	1.098	0.015	1.053	0.016
	E4	0.477	0.019	0.661	0.044	0.877	0.050	0.789	0.024	0.797	0.049	0.765	0.019	0.837	0.027

Table B3 The mean of lignin concentration (%) in mono species leaf litter in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	D1	25.460	0.427	22.560	0.468	20.200	0.253	23.780	0.225	21.520	0.048	17.290	0.099	14.420	0.302
	D2	12.730	0.450	17.210	0.343	11.070	0.239	15.900	0.434	12.960	0.195	15.280	0.363	13.680	0.694
	D3	24.260	0.427	27.790	0.468	18.280	0.253	16.480	0.225	16.070	0.048	13.500	0.099	8.970	0.302
	D4	25.470	0.764	25.930	0.289	26.260	0.577	25.680	0.289	20.060	0.397	16.770	0.500	26.710	0.689
DEF	E1	14.560	0.113	17.180	0.127	16.100	0.255	13.990	0.721	16.430	0.948	24.830	0.297	14.120	0.764
	E2	19.780	0.523	16.130	0.354	29.970	0.283	20.790	0.495	38.030	1.061	27.870	1.400	26.030	0.594
	E3	7.440	0.830	13.170	0.079	16.910	0.177	15.060	0.339	15.340	2.343	13.740	0.868	13.750	1.717
	E4	9.100	0.877	11.740	0.455	15.400	0.396	11.570	0.221	12.380	0.338	11.590	0.508	11.220	1.195

Table B4 The mean of cellulose concentration (%) in mono species leaf litter in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	D1	28.110	0.427	30.290	0.468	17.030	0.253	26.450	0.225	23.560	0.048	17.630	0.099	4.100	0.302
	D2	22.230	0.760	23.960	0.482	13.490	0.960	10.420	0.889	19.660	0.927	15.120	1.325	23.010	0.716
	D3	27.720	1.280	23.080	0.737	11.850	0.626	13.310	0.098	15.110	0.064	13.010	0.334	13.930	0.148
	D4	29.000	0.282	27.750	1.014	17.200	0.905	17.730	0.909	20.860	0.147	15.620	0.666	20.980	0.707
DEF	E1	19.080	0.830	20.020	0.079	9.720	0.177	15.790	0.339	22.540	0.343	4.530	0.868	14.510	1.717
	E2	17.490	0.877	34.280	0.455	7.350	0.396	28.940	0.221	17.970	0.338	8.944	0.508	12.460	1.195
	E3	24.930	0.760	15.600	0.482	1.810	0.960	10.720	0.889	10.130	0.927	17.490	1.325	9.110	0.716
	E4	19.340	0.427	20.400	0.468	8.540	0.253	20.870	0.225	16.300	0.048	14.020	0.099	13.970	0.302

Table B5 The mean of carbon to nitrogen proportion (C/N ratio) in mono species leaf litter in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	D1	26.311	1.280	25.706	0.737	23.695	0.626	15.397	0.098	20.265	0.064	21.944	0.334	24.969	0.148
	D2	33.158	0.282	30.251	1.014	22.103	0.905	17.981	0.909	19.713	0.147	21.309	0.666	23.025	0.707
	D3	23.582	0.160	22.408	0.183	19.298	0.183	5.789	0.438	14.537	0.479	17.901	0.167	17.749	0.160
	D4	45.068	0.293	41.823	0.361	31.585	0.319	13.933	0.340	25.303	0.389	26.561	0.581	25.811	0.506
DEF	E1	18.312	0.523	14.019	0.834	14.174	0.424	12.318	0.849	14.155	0.382	14.098	0.778	13.106	0.269
	E2	21.105	0.354	12.893	1.061	11.855	0.283	11.066	0.495	12.476	0.523	11.421	1.400	13.537	0.594
	E3	31.453	0.622	20.919	0.537	19.010	0.948	17.115	0.707	17.992	0.368	17.428	0.495	18.768	0.665
	E4	65.388	0.622	42.566	0.537	25.641	0.948	31.835	0.707	29.755	0.368	30.293	0.495	25.453	0.665

Table B6 The mean of litter bag temperature (^{0}C) in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	28.583	0.441	30.625	0.786	26.875	0.394	27.875	1.049	27.750	1.221	36.875	2.598	27.625	0.854
	DD2	29.000	0.408	31.417	0.799	26.625	0.370	28.250	1.101	27.750	1.756	37.333	3.186	28.125	1.031
	DD3	28.583	0.441	30.375	0.985	26.292	0.551	26.583	0.645	27.750	1.175	37.458	2.787	27.375	1.250
	DD4	28.000	0.000	31.333	2.566	26.500	1.500	26.333	2.309	26.500	3.279	38.500	3.905	27.000	Ns
	DD5	28.500	0.500	30.833	1.155	26.667	0.764	27.667	1.155	29.333	0.577	37.500	3.969	27.000	Ns
DEF	DE1	26.417	0.319	25.208	0.160	24.375	0.160	22.833	0.491	22.875	0.315	28.000	0.408	26.250	0.167
	DE2	26.500	0.272	25.042	0.160	24.542	0.083	22.625	0.160	23.083	0.215	28.208	0.285	26.750	0.397
	DE3	26.334	0.192	24.958	0.083	24.333	0.136	22.708	0.210	23.458	0.160	28.667	0.360	26.625	0.344
	DE4	26.167	0.289	24.833	0.289	24.333	0.577	22.667	0.764	22.833	1.443	27.500	0.500	26.333	1.528
	DE5	26.833	1.155	24.833	0.289	24.333	0.577	22.500	0.866	23.000	0.866	27.167	0.764	26.833	1.155

Table B7 The mean of carbon concentration (%) in different leaf litter diversity in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	24.096	1.191	23.561	2.011	20.426	3.776	12.532	3.949	16.695	3.171	18.820	2.346	17.293	3.796
	DD2	24.531	0.622	22.540	1.302	20.059	0.887	13.354	1.539	17.753	1.948	20.360	0.553	17.909	3.518
	DD3	23.762	1.640	23.281	2.397	19.738	2.055	13.375	0.498	16.891	0.518	19.465	1.746	17.668	2.583
	DD4	23.244	1.049	24.727	0.673	18.457	0.438	12.690	0.980	16.349	0.191	19.174	0.243	18.879	1.188
	DD5	24.728	1.839	24.423	0.046	18.692	0.167	13.843	0.105	16.352	0.229	18.953	0.109	20.315	0.304
DEF	DE1	26.098	5.453	21.075	5.491	18.284	3.646	18.830	4.456	19.583	2.980	17.924	4.121	19.645	1.675
	DE2	26.581	2.471	21.262	3.087	19.789	3.524	18.151	2.358	17.927	3.618	18.423	4.161	20.142	2.459
	DE3	25.664	1.164	22.619	2.547	19.992	3.100	19.523	2.412	20.642	2.056	19.333	1.993	19.198	0.994
	DE4	27.038	1.365	22.086	0.786	18.494	1.241	16.572	0.369	12.459	0.768	19.709	0.233	19.739	0.302
	DE5	22.605	0.276	21.463	1.613	20.457	0.965	17.253	0.122	16.902	0.140	17.086	0.040	18.041	1.447

Table B8 The mean of nitrogen concentration (%) in different leaf litter diversity in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	0.794	0.191	0.817	0.159	0.850	0.042	0.982	0.130	0.843	0.057	0.863	0.067	0.760	0.145
	DD2	0.770	0.092	0.781	0.119	0.896	0.031	0.986	0.142	0.870	0.075	1.159	0.240	0.873	0.108
	DD3	0.762	0.079	0.819	0.073	0.853	0.109	0.896	0.049	0.832	0.036	0.836	0.044	0.793	0.038
	DD4	0.685	0.037	0.835	0.047	1.125	0.211	0.747	0.047	0.824	0.107	0.885	0.123	0.610	0.020
	DD5	0.749	0.086	0.771	0.071	1.317	0.403	0.950	0.079	0.766	0.044	0.842	0.120	0.709	0.030
DEF	DE1	0.912	0.335	1.062	0.299	1.072	0.148	1.149	0.302	1.135	0.287	1.045	0.195	1.178	0.302
	DE2	0.884	0.249	1.127	0.211	1.192	0.131	1.176	0.182	1.171	0.130	1.099	0.149	1.064	0.126
	DE3	0.886	0.087	1.052	0.077	1.118	0.064	1.100	0.098	1.122	0.099	1.068	0.040	1.129	0.126
	DE4	0.808	0.011	0.979	0.040	1.104	0.136	1.114	0.140	1.013	0.038	1.038	0.088	1.189	0.134
	DE5	1.070	0.102	1.298	0.231	1.258	0.081	0.968	0.013	1.230	0.153	1.158	0.088	1.282	0.072

Table B9 The mean of lignin concentration (%) in different leaf litter diversity in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	21.980	6.193	23.373	4.644	18.953	6.259	20.460	4.997	17.653	3.885	15.710	1.702	15.945	7.572
	DD2	20.215	3.070	25.215	2.367	20.743	5.665	23.530	6.500	22.880	5.985	19.000	4.705	17.928	2.461
	DD3	20.808	1.078	23.840	2.509	18.703	3.032	24.198	6.179	18.873	2.136	20.345	3.206	13.085	2.653
	DD4	21.780	2.343	23.260	1.717	17.060	0.079	20.890	0.177	20.530	0.830	19.560	0.339	14.600	0.868
	DD5	19.470	0.338	23.840	1.195	15.330	0.455	21.260	0.396	23.770	0.877	21.420	0.221	15.900	0.508
DEF	DE1	12.720	5.604	14.555	2.531	19.595	6.944	15.353	3.908	20.545	11.782	19.508	8.046	16.280	6.627
	DE2	12.618	3.966	20.578	8.161	21.090	3.804	18.020	5.043	20.088	5.367	17.160	7.150	16.210	5.367
	DE3	13.713	1.840	18.295	2.331	18.100	2.307	18.235	1.628	17.365	1.640	14.213	2.427	15.050	3.064
	DE4	16.430	1.922	19.650	0.283	15.940	1.349	19.220	0.878	17.840	1.895	15.380	0.184	15.430	0.617
	DE5	17.610	1.513	26.500	0.283	27.830	0.410	25.390	0.523	23.900	0.509	24.490	0.721	20.220	0.453

Table B10 The mean of cellulose concentration (%) in leaf litter in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	26.765	3.070	26.270	3.360	14.893	2.653	16.978	6.994	19.798	3.525	15.345	1.897	15.505	8.541
	DD2	25.408	2.501	29.995	2.396	18.785	5.820	20.075	3.906	19.258	2.705	18.943	7.779	17.455	3.682
	DD3	25.013	2.670	30.258	3.244	19.340	4.520	17.045	4.886	20.535	3.664	18.580	4.460	12.120	2.284
	DD4	24.880	0.948	30.520	0.764	21.640	0.127	20.860	0.255	16.440	0.113	18.540	0.721	10.370	0.297
	DD5	28.250	1.061	34.230	0.594	16.870	0.354	22.060	0.283	22.180	0.523	18.000	0.495	13.850	1.400
DEF	DE1	20.210	3.251	22.575	8.102	6.855	3.500	19.080	7.770	16.735	5.133	11.246	5.689	12.513	2.429
	DE2	18.780	2.490	16.920	1.389	6.465	1.447	13.083	2.045	13.503	3.142	12.935	1.163	10.148	1.344
	DE3	18.190	1.133	15.640	2.610	9.455	1.922	11.465	2.467	12.603	2.818	12.218	1.314	10.230	0.658
	DE4	16.330	0.537	17.610	0.665	8.020	0.622	17.080	0.948	14.060	0.368	13.330	0.707	12.190	0.495
	DE5	23.450	0.834	17.440	0.269	12.250	0.523	19.270	0.424	13.880	0.382	16.150	0.849	10.450	0.778

Table B11 The mean of carbon to nitrogen proportion (C/N ratio) in different leaf litter diversity in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	32.030	9.580	30.047	8.484	24.170	5.267	13.275	5.264	19.955	4.401	21.929	3.562	22.888	3.620
	DD2	32.300	4.918	29.554	6.209	22.424	1.409	13.763	2.638	20.540	2.832	18.211	4.307	20.902	5.472
	DD3	31.632	5.674	28.696	4.873	23.244	1.639	14.943	0.703	20.333	1.159	23.323	2.409	22.376	3.997
	DD4	33.943	3.358	29.606	2.465	16.409	3.524	16.983	0.251	19.842	2.844	21.671	2.764	30.970	2.954
	DD5	33.023	6.300	31.669	2.858	14.195	4.690	14.565	1.108	21.336	1.523	22.520	3.377	28.661	1.631
DEF	DE1	34.065	21.634	22.599	13.776	17.670	6.093	18.083	9.531	18.594	7.790	18.310	8.358	17.716	5.764
	DE2	32.083	9.933	19.699	6.295	16.843	4.213	15.929	4.386	15.539	4.200	17.273	5.714	19.264	4.181
	DE3	29.223	3.461	21.674	3.589	18.035	3.626	17.914	3.247	18.626	3.410	18.153	2.357	17.188	2.306
	DE4	33.463	1.221	22.555	0.110	16.752	3.208	14.882	2.218	12.302	1.223	18.980	1.384	16.604	2.144
	DE5	21.118	1.760	16.541	1.721	16.267	0.276	17.823	0.360	13.737	1.834	14.749	1.155	14.077	0.338

APPENDIX C

MEAN AND STANDARDS DEVIATION

OF PHYSICAL AND CHEMICAL PROPERTY OF SOIL

UNDER THE LITTER BAGS IN DRY DIPTEROCARP

AND DRY EVERGREEN FORESTS

FROM JUNE 2007 TO MAY 2008

Table C1 The mean of soil temperature (^{0}C) in soil under the litter bags in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	25.333	0.000	27.875	0.479	25.583	0.289	24.000	0.593	23.000	0.561	29.583	0.397	25.125	0.854
	DD2	25.333	0.000	27.917	0.215	25.417	0.096	23.875	0.975	23.333	0.609	29.875	1.022	25.625	0.250
	DD3	25.333	0.000	27.917	0.319	25.250	0.096	23.417	0.419	23.125	0.927	29.958	0.417	25.375	0.479
	DD4	25.333	0.000	28.500	1.323	25.333	0.764	24.167	0.764	22.667	0.764	31.667	2.082	25.000	ns
	DD5	25.333	0.000	27.833	1.041	25.167	0.577	22.833	0.289	23.000	1.732	32.333	3.014	25.000	ns
DEF	DE1	23.233	0.000	24.458	0.160	23.625	0.083	21.042	0.083	20.958	0.160	24.542	0.438	19.083	0.167
	DE2	23.233	0.000	24.333	0.000	23.750	0.167	21.042	0.083	21.208	0.160	24.542	0.250	19.042	0.083
	DE3	23.233	0.000	24.292	0.083	23.875	0.160	21.042	0.083	21.458	0.083	24.917	0.289	19.042	0.083
	DE4	23.233	0.000	24.333	0.289	23.333	0.577	21.167	0.289	21.333	1.041	24.000	0.000	18.833	0.577
	DE5	23.233	0.000	24.167	0.289	23.667	0.289	20.833	0.577	21.167	0.764	23.667	0.289	19.000	0.500

Table C2 The mean of soil moisture (%) in soil under the litter bags in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	6.019	0.000	6.498	1.199	16.347	1.217	6.867	0.895	11.142	0.718	5.817	0.380	15.075	1.193
	DD2	6.019	0.000	6.603	0.707	17.708	0.744	7.567	0.482	11.175	0.874	5.408	0.183	15.725	1.360
	DD3	6.019	0.000	6.803	1.699	17.523	0.450	8.033	0.248	11.867	1.270	5.983	1.305	15.075	1.187
	DD4	6.019	0.000	8.027	0.869	16.653	0.239	7.533	0.874	13.267	0.611	6.600	0.656	16.100	ns
	DD5	6.019	0.000	6.770	2.008	17.370	1.422	8.400	0.794	11.833	2.281	6.400	0.985	16.800	ns
DEF	DE1	9.327	0.000	10.089	0.383	17.201	0.974	10.950	0.540	9.683	0.336	8.175	0.177	13.817	1.220
	DE2	9.327	0.000	10.020	0.357	17.364	0.630	11.108	0.755	9.667	0.454	7.817	0.507	14.150	0.999
	DE3	9.327	0.000	10.374	0.495	18.723	0.838	11.425	0.348	10.083	0.123	8.442	0.721	14.767	1.234
	DE4	9.327	0.000	9.380	1.814	16.053	3.272	9.033	1.159	9.333	0.404	8.000	0.529	14.867	2.113
	DE5	9.327	0.000	9.563	1.655	17.477	2.773	11.233	1.332	9.667	1.950	8.400	1.929	13.967	1.422

Table C3 The mean of soil pH in soil under the litter bags in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	4.930	0.000	4.988	0.103	4.563	0.103	5.513	0.111	4.725	0.065	5.100	0.091	4.175	0.050
	DD2	4.930	0.000	5.038	0.075	4.475	0.065	5.363	0.131	4.738	0.075	5.113	0.075	4.288	0.063
	DD3	4.930	0.000	5.275	0.155	4.550	0.091	5.263	0.111	4.800	0.041	5.238	0.111	4.200	0.041
	DD4	4.930	0.000	5.200	0.141	4.450	0.071	5.500	0.000	4.750	0.071	5.150	0.071	4.200	0.000
	DD5	4.930	0.000	5.700	0.000	4.450	0.071	5.300	0.000	4.800	0.000	5.300	0.000	4.300	0.000
DEF	DE1	4.630	0.000	4.675	0.104	4.263	0.085	4.625	0.132	4.650	0.041	4.675	0.104	3.875	0.150
	DE2	4.630	0.000	4.538	0.063	4.188	0.111	4.588	0.025	4.663	0.085	4.600	0.041	3.825	0.096
	DE3	4.630	0.000	4.450	0.071	4.200	0.071	4.713	0.131	4.650	0.158	4.463	0.095	3.825	0.050
	DE4	4.630	0.000	4.350	0.071	4.250	0.071	4.650	0.071	4.450	0.071	4.250	0.071	3.700	0.000
	DE5	4.630	0.000	4.550	0.071	4.200	0.000	4.700	0.000	4.600	0.000	4.500	0.000	3.700	0.000

Table C4 The mean of soil organic matter (%) in soil under the litter bags in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	1.820	0.000	2.064	0.270	1.639	0.084	1.867	0.185	1.616	0.217	2.092	0.182	1.591	0.081
	DD2	1.820	0.000	2.097	0.694	1.816	0.343	1.754	0.239	1.574	0.450	1.835	0.434	1.327	0.363
	DD3	1.820	0.000	1.855	0.122	1.710	0.195	1.749	0.217	1.331	0.264	1.654	0.356	1.239	0.360
	DD4	1.820	0.000	1.479	0.048	1.480	0.015	1.513	0.048	1.232	0.000	1.465	0.047	1.204	0.039
	DD5	1.820	0.000	1.589	0.012	1.903	0.025	1.866	0.071	1.298	0.076	1.888	0.013	1.940	0.061
DEF	DE1	3.747	0.000	2.875	0.302	3.235	0.468	3.141	0.253	2.951	0.427	3.124	0.225	2.743	0.099
	DE2	3.747	0.000	2.953	0.084	3.270	0.341	3.184	0.499	2.965	0.084	3.203	0.493	2.688	0.274
	DE3	3.747	0.000	3.187	0.185	3.540	0.413	3.421	0.179	3.099	0.111	3.178	0.122	3.207	0.175
	DE4	3.747	0.000	2.994	0.045	3.395	0.136	3.496	0.048	3.278	0.023	3.664	0.048	3.328	0.095
	DE5	3.747	0.000	2.942	0.071	3.430	0.139	3.895	0.055	3.428	0.047	3.379	0.119	3.009	0.024

Table C5 The mean of carbon concentration (%) in soil under the litter bags in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	1.056	0.000	1.197	0.156	0.951	0.049	1.083	0.107	0.937	0.126	1.213	0.105	0.923	0.047
	DD2	1.056	0.000	1.216	0.403	1.053	0.199	1.018	0.139	0.913	0.261	1.064	0.252	0.770	0.211
	DD3	1.056	0.000	1.076	0.071	0.992	0.113	1.015	0.126	0.772	0.153	0.959	0.207	0.719	0.209
	DD4	1.056	0.000	0.858	0.028	0.858	0.009	0.878	0.028	0.714	0.000	0.850	0.027	0.698	0.023
	DD5	1.056	0.000	0.922	0.007	1.104	0.015	1.082	0.041	0.753	0.044	1.095	0.008	1.125	0.035
DEF	DE1	2.174	0.000	1.668	0.175	1.876	0.271	1.822	0.147	1.712	0.248	1.812	0.131	1.591	0.057
	DE2	2.174	0.000	1.713	0.049	1.897	0.198	1.847	0.289	1.720	0.049	1.858	0.286	1.559	0.159
	DE3	2.174	0.000	1.849	0.107	2.053	0.240	1.984	0.104	1.797	0.065	1.844	0.071	1.860	0.101
	DE4	2.174	0.000	1.737	0.026	1.969	0.079	2.028	0.028	1.902	0.013	2.126	0.028	1.931	0.055
	DE5	2.174	0.000	1.706	0.041	1.989	0.081	2.259	0.032	1.988	0.027	1.960	0.069	1.745	0.014

Table C6 The mean of nitrogen concentration (g/kg) in soil under the litter bags in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	0.790	0.000	1.627	0.197	1.207	0.079	1.050	0.045	1.233	0.187	1.228	0.038	1.057	0.242
	DD2	0.790	0.000	1.638	0.408	1.207	0.298	0.905	0.091	1.062	0.132	1.078	0.166	0.858	0.191
	DD3	0.790	0.000	1.703	0.280	0.948	0.157	1.194	0.161	1.221	0.175	1.057	0.174	0.711	0.268
	DD4	0.790	0.000	1.398	0.253	0.885	0.003	1.005	0.015	0.996	0.157	1.018	0.007	0.910	0.156
	DD5	0.790	0.000	1.631	0.022	1.245	0.242	1.286	0.017	1.114	0.153	1.225	0.140	0.949	0.059
DEF	DE1	1.209	0.000	1.635	0.235	1.809	0.161	1.906	0.343	1.935	0.263	1.806	0.332	1.873	0.281
	DE2	1.209	0.000	1.858	0.311	1.910	0.279	1.906	0.276	1.954	0.146	2.133	0.276	2.034	0.246
	DE3	1.209	0.000	1.919	0.250	2.074	0.318	1.832	0.124	2.004	0.181	2.248	0.293	2.058	0.215
	DE4	1.209	0.000	2.106	0.069	1.677	0.172	1.908	0.138	1.687	0.179	2.216	0.006	1.973	0.124
	DE5	1.209	0.000	1.639	0.071	1.706	0.217	1.992	0.186	2.111	0.092	1.760	0.082	1.825	0.141

Table C7 The mean of available phosphorus (g/kg) in soil under the litter bags in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	3.787	0.000	3.078	0.821	3.758	0.715	2.491	0.235	2.590	0.813	4.915	1.179	5.766	3.302
	DD2	3.787	0.000	3.894	1.884	3.770	1.335	2.262	0.709	2.356	0.487	4.695	0.616	7.096	2.164
	DD3	3.787	0.000	2.874	1.286	2.589	0.924	2.107	0.308	1.811	0.807	3.489	0.559	5.619	0.450
	DD4	3.787	0.000	1.075	0.127	1.347	0.146	2.707	0.212	0.767	0.027	3.297	0.004	5.750	0.359
	DD5	3.787	0.000	2.237	0.170	3.770	0.168	3.746	0.078	1.781	0.305	3.520	0.198	6.584	0.366
DEF	DE1	5.135	0.000	4.308	1.257	5.861	1.652	5.526	1.542	3.660	0.365	6.807	1.023	4.538	0.977
	DE2	5.135	0.000	4.407	0.795	5.552	1.554	5.223	1.318	4.056	0.974	7.056	1.836	5.746	0.229
	DE3	5.135	0.000	4.531	0.406	5.818	0.413	5.848	0.817	4.130	0.875	6.457	0.667	5.566	0.294
	DE4	5.135	0.000	4.067	0.119	5.267	0.216	4.512	0.139	3.833	0.253	6.413	0.116	6.512	0.122
	DE5	5.135	0.000	3.548	0.182	4.031	0.064	5.650	0.424	3.710	0.437	6.834	0.437	5.350	0.339

Table C8 The mean of available potassium (g/kg) in soil under the litter bags in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	0.278	0.000	0.150	0.020	0.135	0.006	0.147	0.012	0.184	0.029	0.147	0.023	0.120	0.025
	DD2	0.278	0.000	0.146	0.036	0.144	0.012	0.122	0.008	0.146	0.006	0.145	0.008	0.110	0.042
	DD3	0.278	0.000	0.165	0.007	0.146	0.005	0.157	0.019	0.197	0.011	0.157	0.016	0.116	0.046
	DD4	0.278	0.000	0.176	0.006	0.142	0.003	0.140	0.000	0.210	0.003	0.164	0.006	0.124	0.006
	DD5	0.278	0.000	0.154	0.003	0.206	0.003	0.196	0.006	0.238	0.008	0.198	0.003	0.152	0.000
DEF	DE1	0.379	0.000	0.216	0.038	0.184	0.044	0.202	0.028	0.232	0.034	0.210	0.033	0.195	0.033
	DE2	0.379	0.000	0.240	0.082	0.181	0.054	0.191	0.063	0.223	0.051	0.218	0.125	0.189	0.083
	DE3	0.379	0.000	0.196	0.026	0.165	0.027	0.187	0.014	0.212	0.017	0.179	0.032	0.170	0.012
	DE4	0.379	0.000	0.176	0.011	0.128	0.000	0.156	0.000	0.184	0.006	0.172	0.006	0.176	0.000
	DE5	0.379	0.000	0.264	0.006	0.174	0.003	0.220	0.000	0.202	0.003	0.234	0.003	0.232	0.000

Table C9 The mean of carbon to nitrogen proportion (C/N ratio) in soil under the litter bags in dry dipterocarp forest (DDF) and dry evergreen forest (DEF).

Forest	Treatment	1st June		July		September		November		January		March		May	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DDF	DD1	13.361	0.000	7.477	1.524	7.888	0.361	10.355	1.384	7.626	0.503	9.901	1.023	9.081	2.148
	DD2	13.361	0.000	7.399	1.061	9.191	3.258	11.331	1.845	8.615	2.122	9.813	1.084	9.082	1.867
	DD3	13.361	0.000	6.404	0.784	10.533	0.716	8.633	1.682	6.400	1.521	9.045	0.832	10.731	2.737
	DD4	13.361	0.000	6.137	0.927	9.695	0.064	8.735	0.147	7.171	1.146	8.349	0.208	7.674	1.084
	DD5	13.361	0.000	5.651	0.031	8.863	1.876	8.415	0.209	6.755	0.538	8.941	1.090	11.856	1.115
DEF	DE1	17.973	0.000	10.257	0.644	10.347	0.847	9.780	1.848	8.937	1.401	10.303	2.061	8.663	1.524
	DE2	17.973	0.000	9.436	1.760	10.013	1.012	9.820	1.832	8.847	0.854	8.851	2.019	7.698	0.570
	DE3	17.973	0.000	9.700	0.716	9.946	0.482	10.872	0.960	9.017	0.760	8.285	0.889	9.139	1.325
	DE4	17.973	0.000	8.245	0.148	11.742	0.737	10.629	0.626	11.273	1.280	9.591	0.098	9.785	0.334
	DE5	17.973	0.000	10.412	0.707	11.661	1.014	11.339	0.905	9.419	0.282	11.135	0.909	9.561	0.666

มหาวิทยาลัยเทคโนโลยีสุรนารี

APPENDIX D

THE INDIVIDUAL PER BAG OF INVERTEBRATE DECOMPOSER IN DRY DIPTEROCARP AND DRY EVERGREEN FORESTS FROM JUNE 2007 TO MAY 2008

Table D1 The mean of invertebrate decomposer (individual per litter bag) in dry dipterocarp forest (DDF) and dry evergreen forest (DEF) during June to July 2007.

Taxa	DD1	DD2	DD3	DD4	DD5	DE1	DE2	DE3	DE4	DE5
O.Thelyphonida	0.00	0.00	0.00	0.00	0.00	2.50	1.00	1.75	0.00	3.33
C.Chilopoda	0.25	0.25	0.00	0.00	0.00	0.25	0.50	0.00	1.67	0.00
C.Diplopoda	0.25	0.25	0.25	0.00	0.00	0.50	0.75	0.75	0.00	3.33
C.Ologochaeta	0.25	0.25	0.50	0.00	0.00	0.50	0.25	0.75	0.00	0.00
C.Gastropoda	0.25	0.00	0.00	0.00	0.00	0.50	0.25	0.75	0.00	2.00
O.Orthoptera	1.00	1.00	0.25	1.33	1.33	4.00	2.00	1.25	1.00	2.67
O.Homoptera	1.00	0.50	1.25	0.00	1.67	0.50	0.25	0.25	0.00	3.33
O.Hemiptera	0.25	0.25	0.25	0.00	0.00	1.00	0.50	0.75	0.00	2.67
O.Blattaria	1.50	1.50	0.75	3.67	1.67	3.50	4.50	1.50	1.33	2.67
O.Diptera	0.50	0.75	0.25	2.33	1.33	0.25	0.50	0.50	2.67	0.00
O.Collembola	1.00	1.50	2.00	1.00	1.33	2.75	2.00	1.00	0.00	4.00
O.Coleoptera	1.50	0.50	0.25	1.67	0.00	0.25	1.00	1.25	1.67	4.00
O.Isoptera	0.00	1.50	4.25	2.33	0.00	14.25	12.75	8.25	0.00	20.67
O.Hymenoptera	3.25	2.50	2.75	3.00	3.67	6.25	8.00	6.00	3.67	7.33
O.Mantodea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O.Thysanura	0.75	1.25	2.00	0.00	1.00	1.00	0.75	1.00	1.00	1.00

Table D2 The mean of invertebrate decomposer (individual per litter bag) in dry dipterocarp forest (DDF) and dry evergreen forest (DEF) during August to September 2007.

Taxa	DD1	DD2	DD3	DD4	DD5	DE1	DE2	DE3	DE4	DE5
O.Thelyphonida	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.25	0.00	0.00
C.Chilopoda	0.00	0.00	0.25	0.00	0.00	0.50	0.00	0.25	0.00	0.00
C.Diplopoda	0.00	0.25	0.00	0.00	0.00	0.00	0.25	0.50	0.00	2.67
C.Ologochaeta	0.75	1.00	0.50	2.33	3.00	1.00	1.50	1.50	0.00	1.00
C.Gastropoda	0.25	0.50	1.00	0.00	0.00	0.50	0.00	0.50	1.67	0.00
O.Orthoptera	0.75	1.00	1.00	1.00	2.67	2.75	1.75	2.00	3.00	2.00
O.Homoptera	0.25	0.75	0.25	1.00	1.00	0.25	0.50	0.50	0.00	0.00
O.Hemiptera	0.25	0.50	0.50	0.00	0.00	0.00	1.75	0.00	1.00	2.67
O.Blattaria	1.25	1.25	1.50	1.67	2.00	3.00	2.00	3.50	4.00	4.00
O.Diptera	0.00	0.00	0.00	0.00	0.00	0.50	0.25	0.75	0.00	1.00
O.Collembola	1.25	1.50	1.00	1.30	3.67	3.00	4.00	3.00	0.00	4.00
O.Coleoptera	1.25	1.50	0.75	1.00	0.00	2.00	1.25	3.75	6.33	2.33
O.Isoptera	4.75	0.75	1.50	0.00	9.00	2.25	15.25	3.25	8.00	0.00
O.Hymenoptera	3.50	6.75	3.75	8.00	0.00	9.25	7.50	5.75	7.00	0.00
O.Mantodea	0.00	0.50	0.00	0.00	0.00	0.00	0.50	0.25	0.00	0.00
O.Thysanura	1.25	0.25	1.25	0.00	1.33	0.75	1.00	1.25	0.00	1.33

Table D3 The mean of invertebrate decomposer (individual per litter bag) in dry dipterocarp forest (DDF) and dry evergreen forest (DEF) during October to November 2007.

Taxa	DD1	DD2	DD3	DD4	DD5	DE1	DE2	DE3	DE4	DE5
O.Thelyphonida	0.00	0.00	0.00	0.00	0.00	0.50	0.67	1.50	0.00	1.00
C.Chilopoda	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00
C.Diplopoda	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.50	0.00	0.00
C.Ologochaeta	0.50	0.25	0.00	1.33	1.33	0.25	1.00	0.50	0.00	2.33
C.Gastropoda	0.00	0.00	0.00	0.00	0.00	1.00	0.50	0.25	1.00	1.00
O.Orthoptera	1.00	1.25	1.25	2.33	3.00	1.25	1.25	0.50	1.67	2.00
O.Homoptera	0.50	0.50	0.75	2.00	1.67	0.00	0.33	0.25	0.00	0.00
O.Hemiptera	0.75	0.50	0.50	0.00	0.00	0.25	0.25	0.25	0.00	0.00
O.Blattaria	1.75	0.75	1.50	2.00	3.33	1.50	1.00	1.50	1.00	2.00
O.Diptera	0.25	0.00	0.25	0.00	0.00	0.33	0.75	0.50	0.00	0.00
O.Collembola	1.00	1.25	0.75	1.67	1.00	2.50	0.50	1.00	2.33	3.67
O.Coleoptera	0.50	0.50	0.50	0.00	0.00	1.75	3.00	2.00	3.67	1.00
O.Isoptera	1.25	1.00	0.25	2.00	5.00	4.50	5.25	1.00	0.00	9.00
O.Hymenoptera	1.50	1.00	2.00	3.00	4.00	3.25	2.00	3.25	4.00	2.67
O.Mantodea	0.25	0.00	0.25	0.00	0.00	0.00	0.25	0.00	0.00	0.00
O.Thysanura	0.75	0.25	0.50	0.00	0.00	1.75	0.75	0.75	0.00	2.00

Table D4 The mean of invertebrate decomposer (individual per litter bag) in dry dipterocarp forest (DDF) and dry evergreen forest (DEF) during December 2007 to January 2008.

Taxa	DD1	DD2	DD3	DD4	DD5	DE1	DE2	DE3	DE4	DE5
O.Thelyphonida	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	2.33	5.00
C.Chilopoda	0.25	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C.Diplopoda	0.00	0.25	0.50	0.00	0.00	0.50	0.00	0.25	0.00	0.00
C.Ologochaeta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C.Gastropoda	0.25	0.00	0.00	0.00	0.00	0.25	0.50	0.50	0.00	0.00
O.Orthoptera	2.00	0.75	0.75	3.33	3.67	2.25	3.25	3.25	2.33	7.00
O.Homoptera	0.50	0.50	0.00	1.33	0.00	0.50	1.75	0.50	2.00	1.67
O.Hemiptera	0.75	0.75	0.25	1.00	0.00	0.50	0.00	0.50	0.00	0.00
O.Blattaria	1.50	2.00	1.00	2.00	1.33	3.50	1.75	1.50	4.00	5.00
O.Diptera	0.00	0.00	0.25	0.00	0.00	0.00	0.50	0.25	0.00	0.00
O.Collembola	3.00	2.25	2.00	2.67	4.00	2.50	2.75	1.75	1.67	4.00
O.Coleoptera	2.00	2.75	2.50	1.00	5.00	2.00	2.75	3.00	2.00	5.00
O.Isoptera	3.50	8.00	5.75	7.00	21.00	4.25	7.00	9.00	0.00	27.00
O.Hymenoptera	3.75	15.25	6.00	7.00	17.67	8.00	10.50	3.25	3.00	14.00
O.Mantodea	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O.Thysanura	1.00	0.50	0.25	1.67	0.00	0.75	1.00	0.50	0.00	2.00

Table D5 The mean of invertebrate decomposer (individual per litter bag) in dry dipterocarp forest (DDF) and dry evergreen forest (DEF) during February to March 2008.

Taxa	DD1	DD2	DD3	DD4	DD5	DE1	DE2	DE3	DE4	DE5
O.Thelyphonida	0.00	0.00	0.00	0.00	0.00	1.00	0.75	1.00	5.00	4.00
C.Chilopoda	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.75	0.00	0.00
C.Diplopoda	0.25	0.00	0.25	0.00	0.00	0.25	0.25	0.25	0.00	0.00
C.Ologochaeta	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00
C.Gastropoda	0.00	0.00	0.00	0.00	0.00	0.25	0.75	0.25	2.33	3.67
O.Orthoptera	2.00	2.00	2.25	2.33	3.00	2.00	2.25	1.00	3.00	5.00
O.Homoptera	0.25	1.00	0.75	0.00	3.33	0.50	0.75	1.50	1.67	0.00
O.Hemiptera	0.50	1.00	1.00	0.00	0.00	1.00	1.25	1.25	1.67	2.33
O.Blattaria	1.75	0.75	1.50	2.33	3.00	2.50	2.00	2.00	3.00	3.00
O.Diptera	0.00	0.00	0.00	0.00	2.67	0.00	0.00	0.25	0.00	0.00
O.Collembola	2.00	1.50	2.25	3.00	3.00	3.00	1.25	3.00	2.00	5.00
O.Coleoptera	1.25	1.00	2.25	0.00	2.00	3.75	2.50	4.00	5.00	1.67
O.Isoptera	2.25	4.00	6.25	11.00	8.00	1.00	3.50	1.75	14.00	23.00
O.Hymenoptera	5.75	4.00	2.25	4.00	1.67	5.25	5.75	5.25	8.00	4.00
O.Mantodea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.33	0.00
O.Thysanura	1.00	0.75	0.50	0.00	2.00	0.50	1.75	0.50	1.67	1.00

Table D6 The mean of invertebrate decomposer (individual per litter bag) in dry dipterocarp forest (DDF) and dry evergreen forest (DEF) during April to May 2008.

Taxa	DD1	DD2	DD3	DD4	DD5	DE1	DE2	DE3	DE4	DE5
O.Thelyphonida	0.00	0.00	0.00	0.00	0.00	1.75	1.25	1.50	4.00	2.00
C.Chilopoda	0.25	0.00	0.00	0.00	1.33	0.50	0.00	0.25	0.00	1.67
C.Diplopoda	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00
C.Ologochaeta	0.50	0.00	0.75	0.00	0.00	0.50	0.50	1.50	0.00	0.00
C.Gastropoda	0.25	0.50	0.50	0.00	0.00	0.75	0.25	0.25	0.00	1.00
O.Orthoptera	1.00	1.25	1.25	0.00	3.00	2.75	1.25	1.25	3.33	4.00
O.Homoptera	0.75	0.75	1.00	1.67	0.00	0.50	1.00	0.75	0.00	1.67
O.Hemiptera	0.25	0.25	0.75	0.00	2.00	0.25	0.00	0.75	0.00	0.00
O.Blattaria	1.25	0.75	0.50	1.67	3.00	2.00	3.25	1.25	2.67	3.00
O.Diptera	0.25	1.00	0.50	0.00	0.00	0.00	0.00	0.50	0.00	0.00
O.Collembola	2.00	1.50	2.75	3.00	1.67	2.75	2.75	2.00	3.00	5.00
O.Coleoptera	1.00	1.75	1.50	0.00	4.00	2.75	2.25	1.50	1.00	2.33
O.Isoptera	0.00	3.25	3.50	0.00	18.00	1.00	1.75	0.75	2.33	6.00
O.Hymenoptera	2.25	2.00	3.50	4.00	6.00	2.00	1.25	3.50	2.00	3.67
O.Mantodea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O.Thysanura	0.50	1.00	0.75	0.00	2.00	0.75	1.25	0.50	0.00	2.33

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