DIVERSITY OF SOIL INSECTS, LITTER INSECTS AND THEIR RELATIONSHIP TO THE DECOMPOSITION OF LITTER IN SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA

Wanichaya Charoonphong

มหาวิทยาลัยเทคโนโลยีสุรนารี

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ความหลากหลายของแมลงในดิน แมลงในซากพืชและความสัมพันธ์กับการย่อยสลายของซากพืชในสถานีวิจัยสิ่งแวดล้อมสะแกราช นครราชสีมา

นางสาววณิชยา จรูญพงษ์

มหาวิทยาลัยเทคโนโลยีสุรนารี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาชีววิทยาสิ่งแวดล้อม
มหาวิทยาลัยเทคโนโลยีสุรนารี
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DIVERSITY OF SOIL INSECTS, LITTER INSECTS AND THEIR RELATIONSHIP TO THE DECOMPOSITION OF LITTER IN SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA

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

Thesis Examining Committee

_____
(Asst. Prof. Dr. Yupaporn Chaiseha)
Chairperson

_____
(Asst. Prof. Dr. Nathawut Thanee)
Member (Thesis Advisor)

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(Assoc. Prof. Dr. Prapun Manyum)
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วณิชยา จรูญพงษ์ : ความหลากหลายของแมลงในดินแมลงในซากพืชและความสัมพันธ์กับการย่อยสลายของซากพืชในสถานีวิจัยสิ่งแวดล้อมสะแกราช นครราชสีมา. (DIVERSITY OF SOIL INSECTS, LITTER INSECTS AND THEIR RELATIONSHIP TO THE DECOMPOSITION OF LITTER IN SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA)
อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.ณัฐวุฒิ ธานี, 131 หน้า.

กิจกรรมของแมลงในดินและแมลงในซากพืชมีบทบาทสำคัญในระบบนิเวศโดยเฉพาะอย่างยิ่งกระบวนการหมุนเวียนของธาตุอาหาร โดยช่วยย่อยสลายเศษซากพืชและใบไม้แห้งทำให้คุณสมบัติทางกายภาพ และทางเคมีของดินดีขึ้น วัตถุประสงค์ของการศึกษาเพื่อเปรียบเทียบความหลากหลายและบทบาทของแมลงในดินและแมลงในซากพืชบริเวณป่าเต็งรัง ป่าดิบแล้ง และป่ารอยต่อ และศึกษาคุณสมบัติทางกายภาพและเคมีของดินบริเวณดังกล่าวในช่วงฤดูฝน ฤดูร้อน และฤดูหนาว ตั้งแต่เดือนมกราคม พ.ศ. 2548 ถึงเดือนธันวาคม พ.ศ. 2548 และตั้งแต่เดือนมิถุนายน พ.ศ. 2550 จนถึงเดือนกรกฎาคม พ.ศ. 2551 ที่สถานีวิจัยสิ่งแวดล้อมสะแกราช จังหวัดนครราชสีมา การศึกษาความหลากหลายโดยใช้มือเก็บและใช้วิธีถุงซากพืช ผลการศึกษาพบว่ามีแมลงทั้งหมด 6 อันดับ จำนวน 10 วงศ์ มดมีจำนวนพบมากที่สุดในปี พ.ศ. 2548 ปลวกถูกพบมีจำนวนมากที่สุดบนผิวดินในป่าป่าดิบแล้ง และมดถูกพบมีจำนวนมากที่สุดในดินในป่ารอยต่อ มากไปกว่านั้นแมลงในดินอยู่บนผิวดินมากกว่าในดิน อัตราการย่อยสลายของดินที่ผิวดินและใต้ผิวดินของป่ารอยต่อในฤดูร้อนมีค่ามากสุดเท่ากับ 61.00±12.76 และ 44.39±17.57 ตามลำดับ ความสัมพันธ์ระหว่างความหลากหลายของแมลงในดินและปัจจัยทางสิ่งแวดล้อมช่วงระยะเวลาปี พ.ศ. 2548 ผลการศึกษาพบว่า โพแทสเซียมมีความสัมพันธ์ในทิศทางบวกกับดัชนีความหลากหลายของแมลงในดินที่ระดับนัยสำคัญ 0.01 นอกจากนี้ ความสัมพันธ์ระหว่างความหลากหลายของแมลงในซากพืชและปัจจัยทางสิ่งแวดล้อมช่วงระยะเวลาปี พ.ศ. 2550-2551 ผลการศึกษาพบว่า ความหนาแน่น ความเป็นกรดด่าง และฟอสฟอรัส มีความสัมพันธ์ในทิศทางบวกกับดัชนีความหลากหลายของแมลง ที่ระดับนัยสำคัญ 0.05 ในขณะที่ความพรุนมีความสัมพันธ์ในทิศทางลบ ที่ระดับนัยสำคัญ 0.05

สาขาวิชาชีววิทยา ลายมือชื่อนักศึกษา_____
ปีการศึกษา 2552 ลายมือชื่ออาจารย์ที่ปรึกษา_____
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม_____

WANICHAYA CHAROONPHONG : DIVERSITY OF SOIL INSECTS, LITTER INSECTS AND THEIR RELATIONSHIP TO THE DECOMPOSITION OF LITTER IN SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA. THESIS ADVISOR : ASST. PROF. NATHAWUT THANEE, Ph.D. 131 PP.

SOIL INSECT/LITTER INSECT/ DECOMPOSITION OF LITTER /SAKAERAT ENVIRONMENTAL RESEARCH STATION

The activities of soil insects and litter insects play an important role in ecosystem in particular, proceeding nutrient cycling. The objectives of this study were to investigate diversity and the role of soil insects and litter insects in three different forests: dry dipterocarp forest (DDF), dry evergreen forest (DEF) and ecotone (ECO) during rainy season, winter and summer. Furthermore, physical and chemical parameters of the soil in each forest were investigated. The experiment was conducted at Sakaerat Environmental Research Station, Nakhon Ratchasima province during the period of January 2005 to December 2005 and June 2007 to July 2008. Samples were collected using hand collection and litter bag method. The result showed that there were 6 orders and 10 families of soil insects. Hymenoptera was the most commonly found in the year 2005. Isoptera was the most discovered on the soil surface at DDF and Hymenoptera was the most found in the subsoil at ECO in the year 2007-2008. Moreover, soil insects on the soil surface were higher than the subsoil insects. The rate of decomposition of soil surface and subsoil of the ECO in the summer had the highest at 61.00±12.76 and 44.39±17.57, respectively. The correlation between soil insect diversity and environmental factors was studied during year 2005. The results

showed that soil potassium was significantly positive correlation with soil insect diversity ($p \leq 0.01$). In addition, the correlation between litter insect diversity and environmental factors was studied during June 2007 and July 2008 showed that bulk density, soil pH and phosphorus were significantly positive correlation with soil insect diversity, while, porosity showed negative correlation ($p \leq 0.05$).

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School of Biology

Academic Year 2009

Student's Signature_____

Advisor's Signature_____

Co-advisor's Signature_____

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LIST OF ABBREVIATIONS

α	=	alpha
cm^3	=	cubic centrimeter
$inch^3$	=	cubic meter
m^3	=	cubic meter
^oC	=	degree Celsius
DDF	=	dry dipterocarp forest
DEF	=	dry evergreen forest
DMRT	=	duncan multiple range test
ECO	=	ecotone
mg/L	=	microgram per litter
mL	=	mililiter
ppm	=	part per million
%	=	percent
SD	=	standard deviation
SERS	=	Sakaerat Environmental Research Station
µL	=	microliter
mm	=	millimater
g	=	gram
y	=	year

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CHAPTER I

INTRODUCTION

1.1 General

The conservation of biological diversity is very necessary for sustainable development. The loss of biological diversity in Thailand is of high level, including loss of living organisms by a threat from human beings and other living things, as well as improper natural resources management. Insect is a group of living organisms that consists of the highest number of species, both useful and harmful ones. Some forest insects are pests that consume leaves, flowers, fruits and roots of the plants, while others help fertilize flowers and produce nectar as well as products from the insect life cycle. Some insects are predators or parasites in the biological control of agricultural pests and medical vectors. Several kinds of forest insects have their life cycles both on trees and in the soil. For the reason that insects play various roles in forests, they become the important member of the ecosystems that cause changes in biological diversity and forest products.

It is very difficult to observe soil insects with the naked eyes. Soil in the forest is normally covered with litter, which is composed of leaves, branches, flowers and fruits of the trees. When being disturbed, insects will escape or hide themselves in the soil and therefore, the study of forest insects normally generates inexact result. Some types of insects live in soil throughout their lifes because there is sufficient circulation of food substances, oxygen, and moisture for living. Therefore, it is very

necessary for the study of forest insects to intensively cover surface insects, litter insects, soil insects as well as environmental factors such as physical factors, climatic factors, landscape factors, other biological factors, and importantly, the physical and chemical factors of soil.

The study on diversity in different types of soil and litter insects, as well as the relationship between insects and some environmental factors in three different ecosystems located in Sakaerat Environmental Research Station, Nakhon Ratchasima province was therefore concluded with desirable and reliable investigation. Results from such research could then be used for publication of soil insects and litter insects checklist for ecological database which could lead to better proposed management of insect conservation in the future.

1.2 Objectives

The objectives of this study were:

1) To investigate species composition and species diversity of soil insects and litter insects in a dry evergreen forest, a dry dipterocarp forest and an ecotone area at the Sakaerat Environmental Research Station.

2) To measure the rate of litter decomposition in a dry evergreen forest, a dry dipterocarp forest and an ecotone area after incubation for 1 year.

3) To investigate interactions between ecological factors that effects the change in the composition of soil insects and litter insects and the decomposition of litter.

1.3 Scope and Limitations of the Study

1) The study of decomposition of litter was investigated at three stations representing three different habitats; the dry evergreen forest, the dry dipterocarp forest and the ecotone area.

2) The ecological factors affecting the change in population of soil insects, litter insects and the decomposition of litter were classified in four groups:

(1) Climatic factors: air temperature, relative humidity, and rainfall

(2) Biological factors: soil insects and litter insects

(3) Soil properties: physical soil properties and chemical soil properties

(4) Litter properties: water content in litter and nitrogen and carbon content

3) Collection of soil insects once a month for 12 months from January 2005 to December 2005 and identified at family levels.

4) Quantitative sampling of litter bags, collected once a month for 12 months from June 2007 to July 2008.

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CHAPTER II

LITERATURE REVIEW

2.1 Sakaerat Environmental Research Station (SERS)

2.1.1 Study Area

The study area is situated at the Sakaerat Environmental Research Station (SERS), located in Wang Nam Kheo district, Nakhon Ratchasima province. It is situated approximately at 14^{o} 30′ N, 101^{o} 55′ E, about 60 kilometers south of Nakhon Ratchasima and 300 kilometers northeast of Bangkok. The approximate area of the SERS is 81 km^2, which the Thailand Institute of Scientific and Technological Research (TISTR) had dedicated as a forest reserve for scientific purposes (UNESCO-MAB, online, 2006), and the location of SERS is shown in Figure 2.1.

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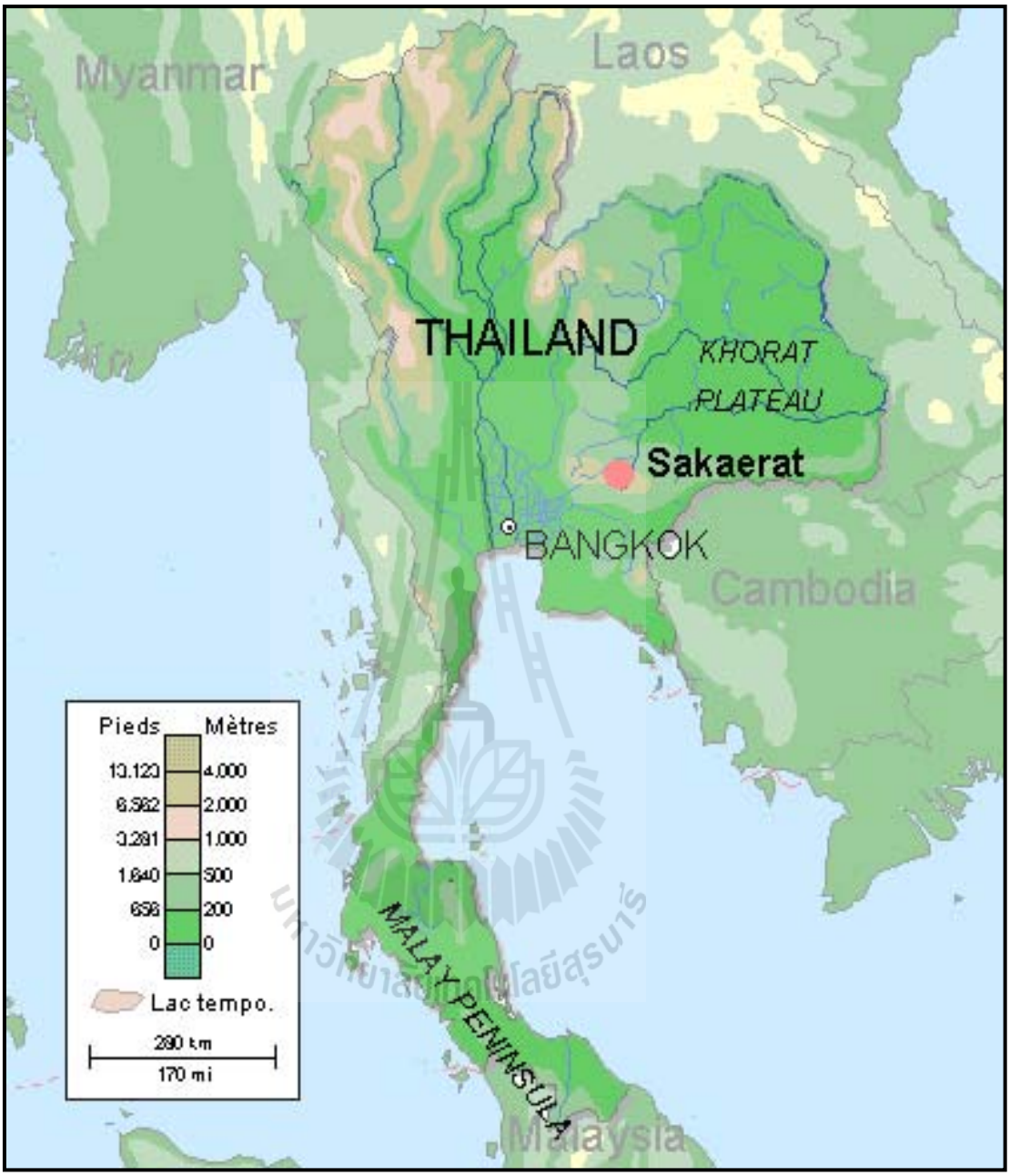

Figure 2.1 Location of Sakaerat Environmental Research Station (SERS) (UNESCO-MAB, Online, 2006).

There are two main types of forests in the SERS: dry evergreen forest and dry dipterocarp forest. The dry evergreen forest covers an area of about 36.67 km^2 (45.25%) while the dry dipterocarp forest covers an area of about 15.21 km^2 (18.78%). There is also an abundant grassland area which covers about 9.12 km^2 (11.26%) plus a plantation area of about 19.41 km^2 (23.95%).

Suriyapong (2003) reviewed literature that showed the dry evergreen forest is dominanted by species such as *Hopea ferrea* Pierre. (in Thai called ta-khian-nu), *Hopea odorata* Roxb. (in Thai called ta-khian-tong), *Shorea sericeiflora* Fisch.&Hutch.(in Thai called khiem-ka-nong), *Afzelia xylocarpa* (in Thai called ma-ka-mong). The undergrowth consists of sapling and shrubs. The dry dipterocarp forest is occupied by the domimant species; *Shorea obtusa* Wall. (in Thai called teng), *Shorea siamensis* Miq.(in Thai called rung), *Dipterocarpus intricatus* Dyer (in Thail called krad), *Shorea floribunda* (in Thai called pa-yom) and *Pterocarpus macrocarpus* (in Thai call pra-doo-pa). The ground is usually covered with tree seedlings and grasses. Dense mats of *Arundinaria pusilla* Cheval. & A. Camus (in Thai called yaa-ped) and *Imperata cylindrica* Beauv. (in Thai called yaa-ka) are also generally found. Ground fires occur annually during the dry season.

2.1.2 Geography

The elevation of the area ranges from 200 to 800 meters above mean sea level. The major hills consist of Khao Phiat (elevation 762 meters), Khao Khieo (elevation 729 meters), Khao Sung (elevation 682 meters), Khao Noi (elevation 569 meters) and Khao Phoeng (elevation 438 meters) (Charoenpol, 2003).

2.1.3 Geology and Soil

The whole area is underlain by sandstone of the Phra Wiharn formation of the Korat group. Soil texture is mainly coarse sandy clay loam to sandy loam and clay loam. The scarps mostly consist of rock outcrops and some stony scree materials (Charoenpol, 2003 and Suriyapong, 2003).

2.1.4 Climate

The SERS has been affected by some types of monsoons in three seasons viz the rainy season (May to October), the winter season (November to February) and the dry summer season and summer (March to mid-May). The climatological data recorded by SERS from 1982 to 2001 indicated that the air temperature in this region was normal viz. In the dry season, diurnal temperatures showed the largest variations during the day (nights were cool and days were warm). The smallest range between day and night temperatures occurred during the rainy season. In general, the lowest temperature was in December (21.7^{o}C), and the highest in April (29.5^{o}C). The temperature decreased from October to January and increased from February to September.

The lowest relative humidity was recorded from during 1982 to 2001 (about 81.55%), from March to April, and the highest (about 94.9%) from September to November. The relative humidity increased after April until October, and decreased after February. The monthly rainfall fluctuation from 1982 to 2001 was described as quite low, from December to February (about 7.08-13.5 mm) and high from August to October. The maximum amount of rainfall was 240.6 mm in September, and the minimum, of 7.08 mm, in January. There is little rain because the SERS is located in the rain shadow of Khoa Yai National Park.

The two main sources of precipitation in the study area are the South-West monsoon rainstorms and the occasional typhoons from the China Sea (Suriyapong, 2003).

2.2 Soil and Litter Faunas

There are two courses by which soil fauna can affect plant litter decomposition and the rates of mineralization and humidification of soil organic matter: Directly, by physically modifying the substrate and soil environments, and indirectly, through interactions with the microbial community. The most important groups of the soil fauna in most sites are the protozoan, nematodes, annelids, molluscans and arthropods.

Three groups of soil faunas are generally recognized as follows:

1) The micro-fauna, especially protozoan and nematodes, that are active particularly in water-filled soil spaces or in gels that surround growing plant roots.

2) The meso-fauna, especially mites, collembolans and enchytraeids, that are active in litter in the air-filled spaces between soil aggregates, in cracks, and in the spaces made in the soil by plant roots and by the larger burrowing soil animals.

3) The macro-fauna, mainly earthworms and the larger arthropods, especially termites, ants and millipedes, some of which are able to move and reshape soil particles and aggregates to make burrows and/or nests, which consequenly effects on pedological processes, soil structure and porosity.

Forest soil fauna contains many groups of invertebrates which vary greatly in nature and in numbers. Figure 2.2 demonstrates the range of body sizes that exist

among the main groups of soil arthropods in Europe. Species over 2 millimeters long are traditionally classed as “macro-arthropods” and those under 2 millimeters as “micro-arthropods” (De Rougemont, 2000).

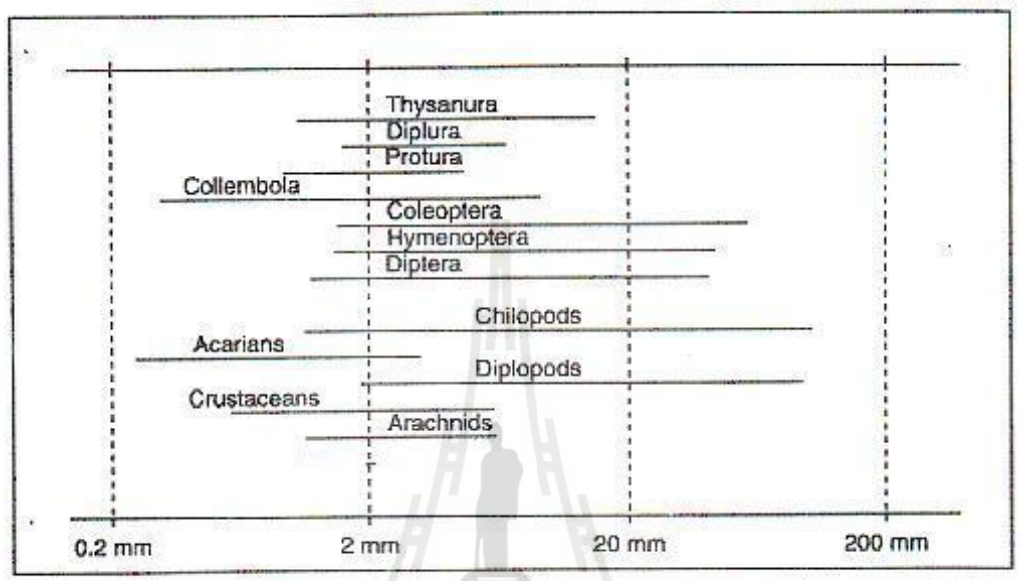

Figure 2.2 Variations in size in the main groups of arthropods of soil fauna in Europe (De Rougemont, 2000).

Members of phylum Arthopoda occur in virtually every soil type throughout the world. The phylum is ubiquitous in its distribution and the diversity of its soil-dwelling component is immense. Especially, insects play a major role in the functioning of the forest ecosystem, because of their abundance and diversity. All four classes of apterygote insects, namely the Thysanura, Diplura, Protura and Collembola, are associated with the soil. Pterygote insects such as orders Diptera, Lepidoptera and Coleoptera, are also associated with the soil but only for a part of their life cycles. Some soil insects are illustrated in Figure 2.3.

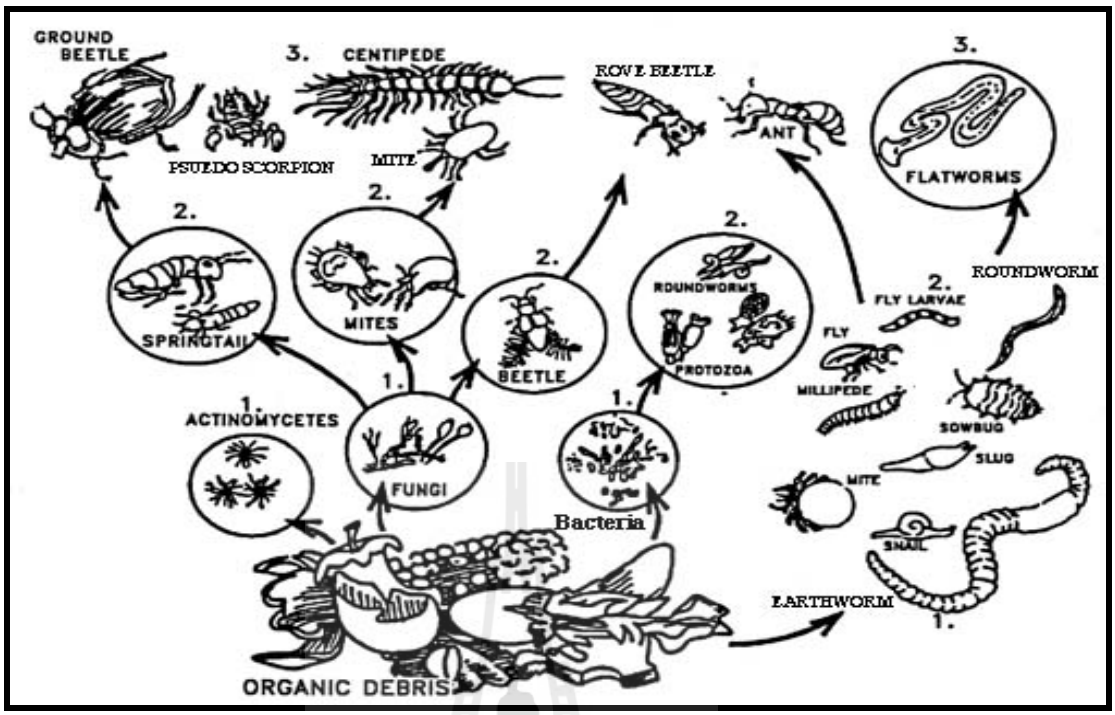

Figure 2.3 Organisms in decomposition (Texas A&M University System, Online, 2006).

Gajaseni (1976) carried out an ecological study on population, biomass and species composition of soil fauna in the dry evergreen forest at Sakaerat Environmental Research Station, Nakhon Ratchasima. There were two peaks in the number of meso-fauna (2588.8 individual/m^2) in June and (4275.2 individual/m^2) in December. The minimum number was in August and September (918.4 individual/ m^2) resulting mainly from the water content of soil and litter. It can be concluded that the water content of soil and litter are very important to soil faunas, and soil faunas have some correlation with the amount of nitrogen, phosphorus, potassium and organic matter in soil. Furthermore, there are relationships between predators (centipedes and spiders) and prey (collembola).

Ratanaphumma (1976) carried out an ecological study on population, biomass and species composition of soil fauna in the dry dipterocarp forest at Sakaerat Environmental Research Station, Nakhon Ratchasima. The results from this study showed that the biomass of soil fauna was highest in June (3.1015 gm/m^2) during the wet season and lowest in March during the day (0.1355 gm/m^2). These result reflected the importance and effect of water content on soil and litter. The biomass changes were mostly caused by the appearance of chafer lavae and millipedes. The total number of soil fauna was at a maximum in September (2168.4 individual/m^2) and at a minimum in April (39.6 individual/m^2). The population changes were mostly dependent on Acarina, and the other factors affecting soil fauna were the moisture content of the soil and litter. It was concluded that population, biomass and species composition of soil fauna fluctuated according to soil water content. Soil fauna also play an important role in organic matter decomposition but, there was no correlation between soil fauna and the amount of nitrogen, phosphorus and potassium in the soil.

Suriyapong (2003) carried out a study of ground dwelling ant populations and their relationship to some ecological factors in Sakaerat Environmental Research Station, Nakhon Ratchasima. The results demonstrated that a total sample of 50,673 ants which were composed of 113 species of 52 genera within 7 subfamilies. In term of the relationship between ecological factors, relative humidity, water content of litter, porosity and soil moisture was negatively correlated, while light intensity and temperature showed maximum positively correlation. Bulk density, silt particle, sand particle and phosphorus was not significantly correlated with ant composition.

Wiwatwitaya (1996) studied diversity of soil insects in the hilly evergreen forest of Doi Angkhang, Chaing Mai province. He found that soil insects in this area consisted of 13 orders, 46 families, and 91 genera. The diversity of soil insects during the dry and rainy seasons were slightly different. The role of soil insects in the forest can be divided into two groups. The first group was consumer which can be separated to primary consumers and secondary consumers with the density of 1.5 genera per m^2 and 3.06 genera per m^2. The second group, called decomposers, had a the density of 0.50 genera per m^2.

2.3 Some Ecological Factors Influence on Insects

2.3.1 Forest Climate and Its Influence on Insects

The most important climatic factors are light, temperature, rainfall and relative humidity. The vertical distribution of small soil faunas show a difference between the 2 areas because the important environment factors are quantity of litter in soil, atmosphere weather, water in soil and litter. Litter quantity in soil in dry evergreen forest is piled up more than in grassland. And litter is an important food source for soil faunas. Therefore, as the litter quantity increases so the soil insect population increases and releases nutrients to the soil. It can be concluded that dry evergreen forest have a larger insect community than grassland areas and the soil has more nutrient through digested animal litter. As a result the spread in the vertical distribution soil fauna occurs mainly in the top soil which is fulled of litter. At deeper soil levels the spread of soil faunas decreases due to decrease in the nutrient quantity in the soil (Ananthakrishnan, 1996).

The climatic factor, temperature, has influenced the distribution of soil faunas in every seasons. In generally, the dry season has higher temperature than in the rainy season. Grassland also has a larger surface area to receive the infrared rays from the sun. On the other hand, in the dry evergreen forest, many kinds of trees grow to cover the ground from the infrared rays. Therefore, in grassland the temperature level is higher than in the dry evergreen forest. The fluctuation of atmospheric weather should also affect vertical distribution of soil fauna. However, Thailand is located in the tropical and monsoon area and hence the fluctuation of temperature depends on the depth of soil in each season. But temperature is clearly not the causal factor in vertical distribution of soil faunas.

The water in soil and litter is the last factor that depends on rainfall. The water in soil in the rainy season is highest and gradually decreases in the summer season. The dry evergreen forest has many kinds of tree cover in all layers and will perform to absorb the water in soil. Therefore, the water quantity in soil is higher at every depth in the dry evergreen forest than in grassland throughout the year. In the rainy season, the quantity of water in litter is appropriate for soil faunas that aggregate on the surface of soil but decrease in deeper soil layers. On the other hand, in the dry season soil fauna are distributed in the soil at the deeper layers and have distributed from grassland to dry evergreen forest. It is concluded that in the rainy season, the distribution of soil faunas depends on the water in soil and litter as well as the quantity of litter. The water content in soil is one of the important factors for the distribution of soil faunas in the dry season (Yimratanabovorn, 1993).

2.3.2 Properties of Forest Soil and Its Influence on Insects.

2.3.2.1 Soil Texture

A more quantifiable approach is to characterize soils in terms of the sand, silt and clay present, which are ranged on a spectrum of light-intermediate-heavy or sandy-silt and clay. The array of textural classes shows the percentages of sand, silt and clay, and the resulting soil types such as sandy loamy or clayey soils. Texture is an important soil characteristic because it will, in part, determine water intake rates, water storage in the soil, the ease of tilling the soil, the amount of aeration, and will influence soil fertility.

2.3.2.2 Bulk Density

Soil bulk density measures how dense and tightly packed the soil is. It is determined by measuring the mass of dry soil in a unit of volume (g/mL or g/cm^3). Bulk density is the density for a volume of soil as it exists naturally, and includes any air space and organic materials in soil volume. Bulk densities should be below about 1.4 g/cm^3 for clays and 1.6 g/gm^3 for sands (Charoenpol, 2003).

2.3.2.3 Soil Moisture

Soil moisture refers to the quantity of water in the soil and is influenced by precipitation, land use, water at ground level and characterization of soil. The retention of water by soil is related to the size and arrangement of soil pores. In the soil pore system water moves and is retained for plant use. A fine soil usually contains more water than a coarse soil. Soil can also lose moisture in many ways, particularly in relation to soil texture and season (Charoenpol, 2003).

2.3.2.4 Soil Temperature

The temperature of the soil affects climate, plant growth, the timing of budburst or leaf fall, the rate of decomposition of organic wastes and other chemical, physical and biological processes that take place in the soil. Soil temperatures can range from approximately -40 to 60^{o}C. The greatest extremes in temperature occur at the surface and decrease rapidly with increasing depth. The absolute temperature and its variation with time and depth are greatly influenced by surface cover and by the thermal properties and water content of the soil. Soil temperature is a factor of paramount importance in terms of the distribution and activity of soil animals. In general, soil animals are very sensitive to overheating and tend to migrate down to deepest level to avoid high temperatures (Suriyapong, 2003).

2.3.2.5 Soil pH

The concentration of hydrogen ions is an important consideration when studying soil. As in the study of hydrology, the pH scale is used as an indication of the concentration of hydrogen ions in the soil. When the soil contains a high concentration of hydrogen ions, it is considered to be acidic and when it has a low number of hydrogen ions, it is considered to be alkaline. At a pH of 7 the soil is considered to be “neutral”. The pH of soil controls many of the chemical and biological activities that take place in the soil and also indicates something about climate, vegetation, and hydrologic conditions under which the soil is formed (Coleman, Crossley and Hendrix, 2004).

2.3.2.6 Soil Organic Matter

Soil organic matter consists of decomposing plant and animal residues. The freshly fallen leaves and dying roots begin rapid decomposition, and

the residues become a part of soil humus. Organic matter is responsible for most desirable surface soil structure, by promoting a greater proportion of larger pore sizes, improving water and air relations, and reducing erosion by wind and water. Chemical organic matter is the soil source of nearly all the nitrogen, 5-60 percent of phosphorus, perhaps up to 80 percent of sulfur, and large parts of the boron and molybdenum used by plants in a given season when the crop is not fertilized (Charoenpol, 2003).

2.4 Litter Decomposition

Light, temperature and water content largely determine the rate of decomposition of organic matter in soil. Soil holds the moisture and heat required for microorganisms to thrive and perform the decomposition process, changing organic materials into soil material call humus.

The term “decomposition” is often used to refer to the breakdown or disappearance of organic litter (Coleman and Crossley, 1996). Most mass loss data is from short-term studies, and using such data in these models assumes that long-term patterns of decay can be predicted from rates of early decay. Rates of litter decomposition have also been measured in many studies because decay rate is thought to play a role in determining how certain factors influence nutrient availability. The rate of litter decomposition has been associated, in particular, with its carbon and nitrogen content. Greater N availability in forest floors under some tree species has been reported in many studies and differences in litter quality and rates of decay were considered to be partly responsible. The higher quality and faster decay of broadleaf litter were thought to promote higher nutrient

availability in soils under broadleaved trees. Faster decomposition of N-enriched litter in N-fertilized forests might lead to a prolonged enhancement of N availability.

The decomposition of organic residue involves activities of a variety of soil biota, including both microbes and fauna. In the litter bag experiments, litter missing from the bag has not necessarily been consumed by fauna, and much of that which is consumed by fauna is passed through the gut rather than completely decomposed. Fecal material in soil fauna can be quite recalcitrant and fauna may also show slow decay rates through the production of casts or soil aggregates, or by mixing the organic materials with clay minerals.

The rate of litter decomposition has been measured in over 1000 studies since ecosystem studies became common in the 1960s, and since the litter bag technique was first employed by Bocock and Gilbert (1957) Those studies emphasised the importance of decomposition in the recycling of nutrients within ecosystems. The decomposition of plant litter influences the build up of soil organic matter, release of nutrients for plant growth, and flux of CO_2 from the soil (Prescott, 2005). It is a primary mechanism and has received considerable attention for sustainable soil fertility.

Litter breakdown rates vary between and among ecosystems on localized and broad geographic scales as functions of soil biota, substrate quality, microclimate, and ecosystem conditions. Studies of these relationships have generated conclusions such as “decomposition rates were regulated by climate in initial stages and by organic-chemical composition in later stages” (Prescott, 2005).

The effect of latitude on litter breakdown rates is not strictly a direct effect of climate. The abundance of the various soil biota also changes with latitude. Litter breakdown in tropical systems may be strongly influenced by the seasonality of litterfall as well as the fauna abundance.

Rates of litter breakdown are measured more easily using bagged leaf litter. Mesh bags (litter bags) containing a known mass of leaf litter are placed on the forest floor at the time of leaf drop. Litter bags are subsequently collected on a time schedule, and the remaining mass is measured. Litter bags have been a valuable tool for comparative studies of rates of litter breakdown. Such studies include mass loss rates by four tree species and have shown the importance of elemental contents, C/N ratios, and micro-fauna abundance in this process (Alhamd, Arakaki and Hagihara, 2004). Decomposition rates also vary between forest types, and litter bags have proved to be useful in delineating and analyzing these differences.

Paowongsa (1976) carried out the studies of litterfall and mineral nutrient content of litter in the dry dipterocarp forest at Sakaerat Environmental Research Station. He estimated the decomposition rate of leaf litter; by using the mature leaves of known weight of *Pentacme suavis* and *Shorea taluta* Roxb. which were tagged and laid down randomly on the forest floor. At the end of each month, the tagged leaves were randomly selected for measurement of their weight. The loss of leaf weight was assumed to be the decomposition rate. The mean concentrations of the various nutrients in litter were determined by chemical analysis. It was found that the various nutrient elements returned annually to the soil were 64.20 kg/ha. of nitrogen, 3.98 kg/ha. of phosphorus, 36.98 kg/ha. of

potassium, 48.80 kg/ha. of calcium and 12.74 kg/ha. of magnesium. The decomposition rates of *Shorea talura* Roxb. leaves were slower than those of *Pentacme suavis* A.DC.

Bunjavejchewin (2001) carried out the ecological studies of tropical semi-evergreen rain forest at Sakaerat Environmental Research Station. Litterfall experiments were conducted from May 1985 to April 1989 for *Shorea henryana* type and from March 1987 to February 1990 for *Hopea ferrea* type of semi-evergreen rain forest. The mean annual litterfall over a period of 48 months of *Shorea henryana* type was 6.8 t/ha/y, consisting of 70.3% leaves, 15.2% woody material, 5.0% reproductive structures and 9.5% unclassified. In the *Hopea ferrea* type, mean annual litterfall was 6.4 t/ha/y, comprising 73.5% leaves, 17.3% woody material 3.0% reproductive structures and 6.2% unclassified. The year-to-year variation in total litterfall was significant for both types. The seasonality of litterfall was more marked in the *Shorea henryana* type than in the *Hopea ferrea* type. Nutrient element concentrations in the litterfall were similar between the types. The concentrations of all elements were within the ranges reported for other tropical forests.

In addition, there have been many studies about soil fauna, soil properties, litterfall and nutrient content in litter at the Sakaerat Environmental Research Station (SERS), but those studies have not investigated correlations among litter fauna, rate of litter decomposition and ecological factors. Therefore, the study of diversity in types of soil and litter insects, and their relationship with physical and climate environmental factors, as well as soil richness in some condition of

ground-level ecosystem, is very necessary for the purposes of gathering information and creation guideline for sustainable natural resource management.

2.5 Other Related Literatures in Thailand

There have been few researchers that studied the soil fauna and decomposition rates in Thailand. Yimratanabovorn (1993) carried out studies of seasonal fluctuations of soil fauna and its influence on the decomposition of organic matter in a teak plantation in 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 when termites and ants were dominant species. The maximum number of soil meso-fauna was found in winter but declined to a minimum in summer when the dominant species became mites and springtails. The highest rate of leaf litter decomposition was found in the rainy season and the rate was 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.

Chidburee (1993) carried out studies on the seasonal fluctuations of soil fauna and its influence on the decomposition of organic matter in *Eucalyptus camadulensis* plantation in Phitsanulok province. Results showed highest peak of numbers, biomass and species composition of soil macro-fauna in the rainy season but lowest in summer, and the dominant groups were beetles, both adult and larval stages, termites, ants and spiders. The highest numbers of soil meso-fauna were found during the late rainy season in winter and the lowest were in summer in the early part of the rainy season. The dominant species of soil meso-fauna were

termites and springtails whose fluctuations brought significant changes in the total number of soil fauna. The highest rate of leaf litter decomposition was in the rainy season but the lowest in winter and summer. It showed positive correlations between the number of soil meso-fauna and leaf litter loss in the litter bag method.

Kaewkrom (1996) studied the effects of litter decomposition on nutrients in deciduous forest ecosystems of the Huai Kha Khaeng Wildlife Sanctuary. The results of this study demonstrated that the higher litter production and diversity in mixed deciduous forest resulted in higher diversity and abundance of soil meso-fauna in mixed deciduous forest ecosystem than in the dry dipterocarp forest ecosystem. This results in thehigher efficiency of the decomposition processes, which in turn is more efficient in nutrient cyclings in mixed deciduous forest ecosystem. This is one of the significant reasons making mixed deciduous forest better able to accommodate higher diversity and biomass of structure than dry dipterocarp forest ecosystem.

Somrithipol (1997) carried out the study on decomposition of bamboo and rang (*Shorea siamensis* Miq.) leaf litter in mixed deciduous forest and their decomposing fungi was carried out by the litter bag method at Mae Klong Watershed Research Station, Amphur Thong Pha Phoom, Kanchanaburi province. He found that the results of this study revealed that rang leaf litter was decomposed faster than bamboo leaf litter. Decomposition rate of the former equaled 95.14% per year and the latter equaled 85.03% per year. The decomposition constants (k) of rang and bamboo leaf litters were 3.03 and 1.90, respectively. Dry-weight loss per month of both litters had a positive correlation with temperature, relative humidity and precipitation of the area. The

concentrations of N and Ca in the 2 leaf litters were quite stable at the early stage of decomposition and increased at the later stage while the concentrations of P, K and Mg tended to decrease with the longer decomposition time. There were 42 species of decomposing fungi isolated from the two litters with *Aspergillus* being the highest in number of species and isolates and followed by *Penicillium*. The highest fungal species diversity was at 6 months after decomposition. Most of the fungal species at the early stage of decomposition disappeared at the later stages. It showed that a fungal succession occurred throughout the period of decomposition period.

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CHAPTER III

MATERIALS AND METHODOLOGY

3.1 Instrumentation and Reagents

3.1.1 Materials for Collecting Soil in Fieldwork

1. Litter bag (size 25cm x 25cm)
2. Litterfall trap (size 1m x 1m x 1m)
3. Thermometer
4. Light meter
5. Ethanol 70%
6. Vial
7. Plastic bag
8. Forceps
9. Soil core

3.1.2 Materials in Biology Laboratory

1. Stereo microscope
2. Berlese funnel
3. Sieve
4. Forcep
5. Petridish
6. Digital camera
7. Hot air oven

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3.1.3 Materials for Analyzing Soil Properties

1. Analytical balance
2. Hot plate
3. Digestion tools
4. Nitrogen distillation apparatus (Kjeltec auto sampler system 1035 analyzer)
5. pH meter
6. Hydrometer
7. Centrifuge
8. Atomic absorption spectrophotometer (Spectro AA-250 plus, Varian)
9. Spectro-photometer (Spectronic genesys 5, Becthai)
10. Whatman filter paper no, 1
11. Cylinder
12. Volumetric flask
13. Erlenmeyer flask
14. Beaker
15. Funnel
16. Cuvet
17. Pipette
18. Aluminum tray
19. Test tube

3.1.4 Reagents

1. Sulfuric acid (concentrated)	Carlo erba reagenti
2. Potassium dicromate	Carlo erba reagenti

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3. Hydrochloric acid	Carlo erba reagenti
4. Boric acid	Carlo erba reagenti
5. Sodium acetate	Carlo erba reagenti
6. Ammonium fluoride	Carlo erba reagenti
7. Potassium antimony tartrate	Carlo erba reagenti
8. Ascorbic acid	Carlo erba reagenti

3.2 Research Methodology

3.2.1 Study Sites

Three study sites at SERS were selected (Figure 3.1):

3.2.1.1 The Dry Evergreen Forest (DEF)

The study plot is situated at approximately 14° 30′ 08″ N, 101° 55′ 48.7″ E, and is about 3 kilometers from the headquarters. This plot was chosen as a representative of the major forest areas near the main micro-meteorogical tower and is in the least disturbed area. The area includes good samples of DEF and consists of dominant plant species such as *Hopea ferrea* Pierre., *Hopea odorata* Roxb. and canopy trees of 30 to 40 meters in height.

3.2.1.2 The Dry Dipterocarp Forest (DDF)

The study plot is situated at approximately 14° 30′ 29.50″ N, 101° 56′ 17.6″ E, and lies on the main road to the headquarters. The area includes good samples of DDF and is dominated by *Shorea obtusa* Wall., *Shorea siamensis* Mig., and *Arundinaria pusilla* Chevel *A. camus*. and regularly burned.

3.2.1.3 The Ecotone Area (ECO)

The study plot is situated at approximately 14° 30′ 08.2″ N, 101° 55′ 48.5″ E. This plot is represents a link between the dry evergreen forest and dry dipterocarp forest. It consists of large trees (*Dipterocarpus*) sparingly distributed amongst small shrubs and short grasses.

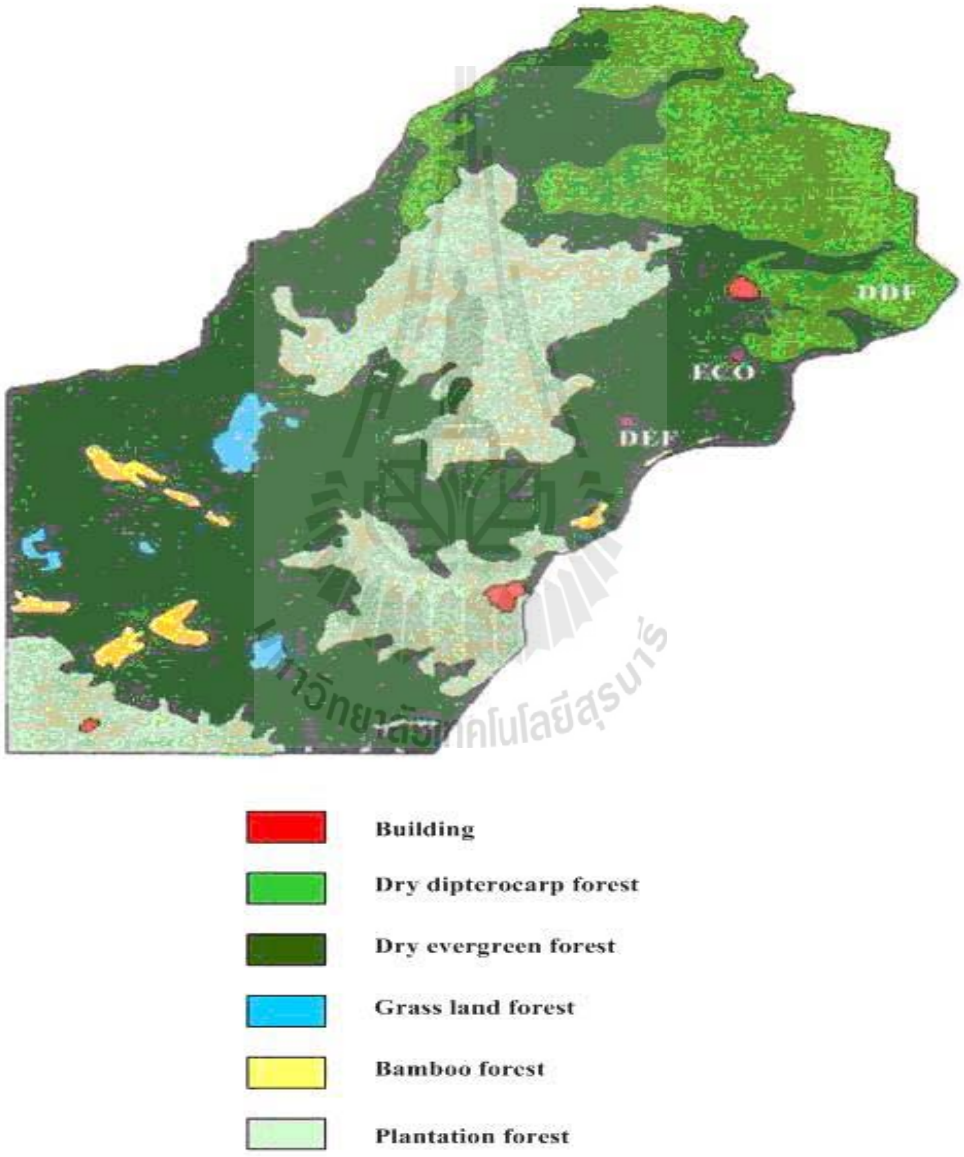


Figure 3.1 Land use and study plot of SERS. Source: Adapted from map of Sakaerat Environmental Research Station, 2001.

3.2.2 Soil Insects Sampling Methods

The following research methods were adapted from Suriyapong (2003).

1) The permanent plot was selected which best represented each of the three forest types viz. dry evergreen forest in perfect condition, dry dipterocarp forest in perfect condition, and an area between the edge of dry evergreen forest or the ecotone area- to form permanent plot sized 100 x 100 square meters. The selected area was based on the information obtained from maps of Sakaerat Environmental Research Station (2001) and ground survey.

2) Each permanent plot in no.1 was divided into 25 sample plots sized 20 x 20 square meters. One sample plot was used in each month by using simple random sampling method.

3) Each sample plot in no. 2 was further divided into 100 sub-plots of 2 x 2 square meters for collecting samples. Ten sub-plots, each of 2 x 2 square meters, were chosen after a random sampling process.

4) Samples were collected from 5 quadrats, each measuring 20 x 20 square centimetres, representing each 4 corners and the center of the sub-plot. (as shown in Figure 3.2). At monthly intervals from January 2005 to December 2005, five replications of soil samples were retrieved from each type of forest. Each soil sample was placed into a separate polyethylene bag and directly transferred to the laboratory. The soil samples were processed to determine the soil moisture, physical properties, chemical composition and soil insects.

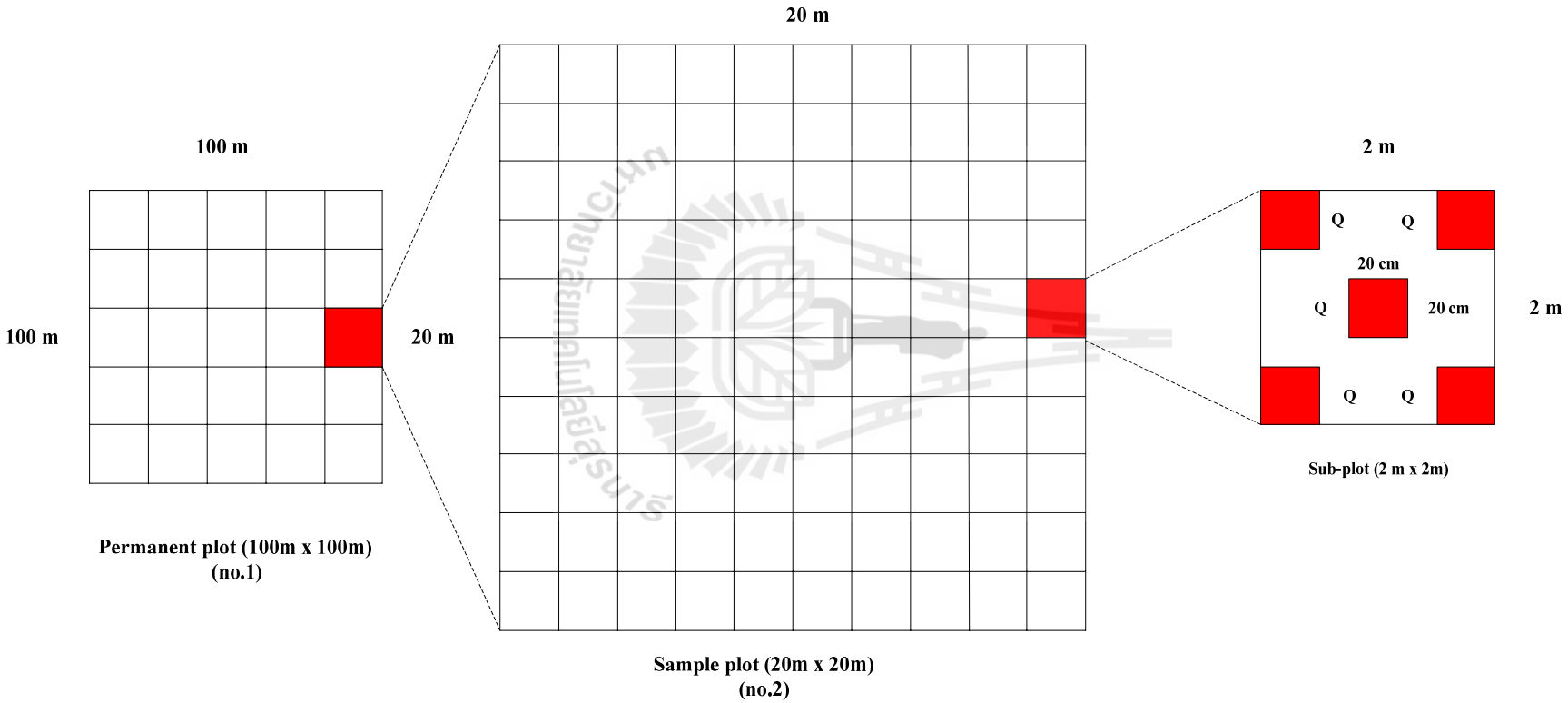


Figure 3.2 Sampling grid design used to sample soil insects community within each plot Q = quadrat

3.2.3 Litter Insects Sampling Methods

Three permanent plots of 100 x 100 square meters were established, each located in the dry evergreen forest, dry dipterocarp forest and in the ecotone. Twenty-five (1m x 1m x 1m) litter traps were placed at the centres of twenty-five 20 x 20 square meter sample plots within the 100 x 100 square meters permanent plot.

The area was divided into 25 small sample plots of 20 x 20 square meters. Three blocks of sample plot were chosen in a random position as illustrated in Figure 3.3. In each sample plot, one set of litter bags was randomly placed and at 10-15 centimeters depth in July 2006 and the contents were allowed to decompose under natural conditions. One set of litter bags consisted of 72 litter bags per each forest type.

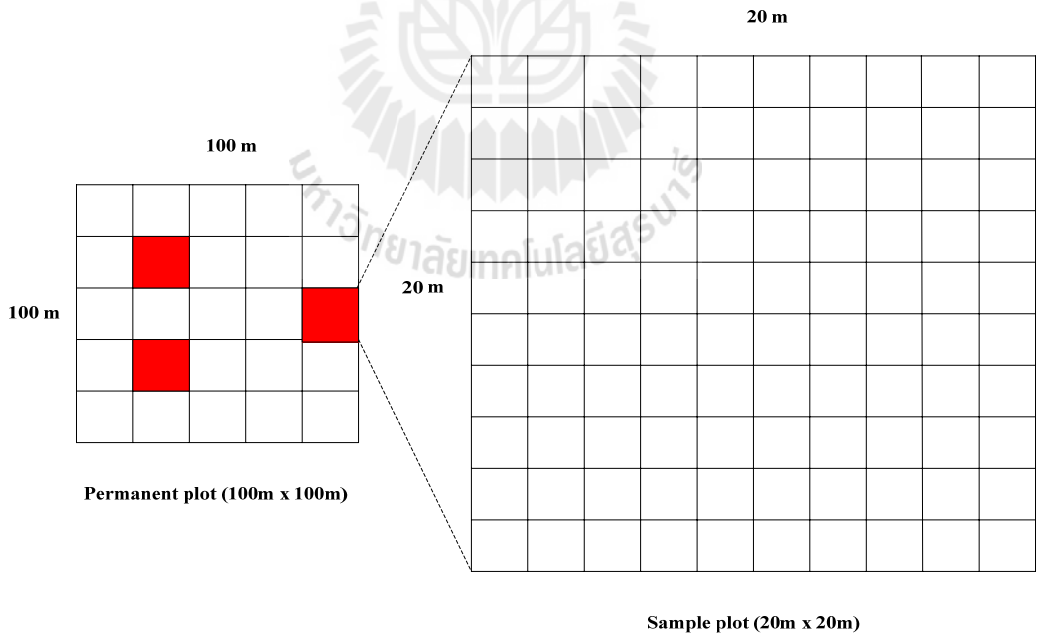


Figure 3.3 Sampling grid design used to sample litterfall trap and the litter bags within each sample plot.

The litter decomposition experiment was carried out for a 12-month period from July 2007 to June 2008. The decomposition rates were evaluated using 25 cm x 25 cm litter bags. Litter bags were constructed from nylon mesh with size 0.5 centimeters.

In July 2007, the litters were collected in the study site by applying litterfall traps in each type of the forest. The collected litter samples were immediately transported to the Suranaree University of Technology, Scientific Equipment and Technology Laboratory and then air-dried to a constant weight at room temperature. During the study, 25 litter traps from the dry evergreen forest, the dry dipterocarp forest and the ecotone were not disturbed by humans (Bunyavejchewin, 2001).

Twenty grams (3 replicates) of each litter type was weighed and checked for C/N ratios and moisture before transfering into in litter bags. All samples of litter were placed in litter bags. The top of the filled litter bags was sealed and a plastic tag with an ID number was wired to each litter bag. A total of 216 litter bags were randomly placed on the flat surface area and the other 216 litter bags in the soil in July 2006 by utilizing metal pins to prevent movement and to ensure a suitable contact between litter bags and organic soil layers.

At monthly intervals from July 2007 to June 2008, three replications of litter bags were retrieved from each type of forest. Each bag was placed into a separate polyethylene bag and directly transferred to the laboratory. The litter samples were processed to determine the initial weight, chemical composition and litter insects.

3.2.4 Data Collection

3.2.4.1 Climate

The following climate characteristics were considered; air temperature relative humidity and rainfall. They were measured at their sites in the field and obtained from the meteorological station of SERS.

3.2.4.2 Soil Insects

Soil samples were collected and transferred to the laboratory, at Suranaree University of Technology. Macroinsects in the soil were hand-picked**.** Most of soil insects were separated by sieve sized 3 millimeters. And then, preserved in 70% concentration of alcohol. In the laboratory, soil insects were taken and separated to determined families or subfamilies by stereo microscope.

3.2.4.3 Litter Insects

Litterbags were collected and transferred to the laboratory, at Suranaree University of Technology. Macroinsects in litter bags were hand-picked and the litter bags were then left at ambient temperature for one hour in a modified Berlese funnel and placed into 70% ethanol. The identification and counting of these insects were performed under a stereo microscope (Alhamd, Arakaki and Hagihara, 2004).

3.2.4.4 Soil Properties

After extracting soil insects from all soil samples, the soil samples were carried out to the Suranaree University of Technology Laboratory, where various analyses were conducted. After returing to the laboratory then the soil samples were dried at laboratory temperature for 48 hours. The soil samples were crushed by using a pestle and mortar and were separated roots and stones by using 2

mm. seive sizes. Physical and chemical soil properties were summarized in Tables 3.1 and 3.2.

Table 3.1 The method for soil properties analysis (Charoenpol, 2003).

Physical soil properties	Analytical method
Bulk density	By weighing the known volume sample after oven drying at 105^{o}C for 24 hours
Soil moisture (%)	By weighing the known volume sample after oven drying at 105-110^{o}C for 24 hours

Table 3.2 The method for chemical soil properties analysis (Charoenpol, 2003).

Chemical soil properties	Analytical method
Soil pH	1: 1 Soil: Water suspensions with pH meter
Soil organic matter (%OM)	Walkley and Black Rapid Titration method
Total nitrogen (%N)	Kjeldahl method
Available phosphorus (P)	Bray II method
Available potassium (K)	Flame photometer

3.2.4.5 Litter Properties

After extracting soil insects from all litter bags, the litter bags were analysed as follows:

1) Water content of litter

The litter was dried at 80^{o}C for 48 hours to a constant weight

(Bunyavejchewin, 2001). Water content of litter by weight was calculated as follows:

$$\%H_2O = \frac{\text{(wet weight litter – oven dry weight litter)}}{\text{oven dry weight litter}} \times 100$$

3.3 Data Analysis

3.3.1 Soil and Litter Insects Analysis

1) The total numbers of soil and litter insect species collected from each habitat types were classified to morphospecies.

2) Diversity index and evenness index were calculated by using the Shannon-Wiener index as follow**:**

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

H = index of species diversity

S = number of species

Pi = proportion of total sample belonging to i th species

Evenness

$$E = \frac{H}{H \max}$$

E = Equitability or evenness index

H = Shannon diversity index

Hmax = ln S

Remark: In this experiment, families were used as species data.

3.3.2 Litter Decomposition Rate

Collected leaf litters were air dried to a constant weight at a room temperature. They were placed in litter bags of 25 cm. x 25 cm. with 0.5 cm. mesh

size and placed on flat surface area and under ground in the forest using metal pins to prevent movement. Collected leaf litters were oven-dried at 80^{o}C for 24 hours and weighed.

Remaining weight (%) after a given months incubation were calculated by the following formula:

$$\text{Remaining weight (\%)} = \frac{Lt}{Lo} \text{ x } 100$$

Where *Lt* is the mass of dry matter after a given month, *Lo* is the initial mass of dry matter.

3.3.3 Statistical Analysis

Analysis of variance (ANOVA) was used for detecting a significant difference in the decomposition rate constant among the different forest types. Correlations were determined using the simple Pearson correlation coefficient by SPSS program.

3.4 Location of Research

The field research was conducted at Sakaerat Environmental Research Station. The insect identification, litter properties and soil properties were investigated at the Center for Scientific and Technological Equipment Building 2 and 3, Suranaree University of Technology, Nakhon Ratchasima province.

3.5 Study Period

The research has been conducted for 4 years since 2005 until 2008.

CHAPTER IV

RESULTS AND DISCUSSION

The result of this study can be divided into four parts. The first part is the climatic factors. The second part is the diversity of soil insects in each habitat type. The third part is to measurement of the rate of litter decomposition among the three forest types. The last part is to comparison of the correlation between environmental factors and species diversity of soil insects and litter insects.

4.1 Climatic Variations of SERS

The average monthly climatic data of the year 2005 were collected from the monthly meteorological observation at SERS. The average monthly temperature was observed highest in May and lowest in December with the value of 30.1^{o}C and 21^{o}C, respectively. The average relative humidity was highest during October (97%) and lowest in April (81%). The relative humidity was also low during January and February due to the lack of rainfall but was increased by the amount of rainfall. The average rainfall was highest in September (417 mm) and very little rain during December but no rainfall was observed during January and February (Figure 4.1).

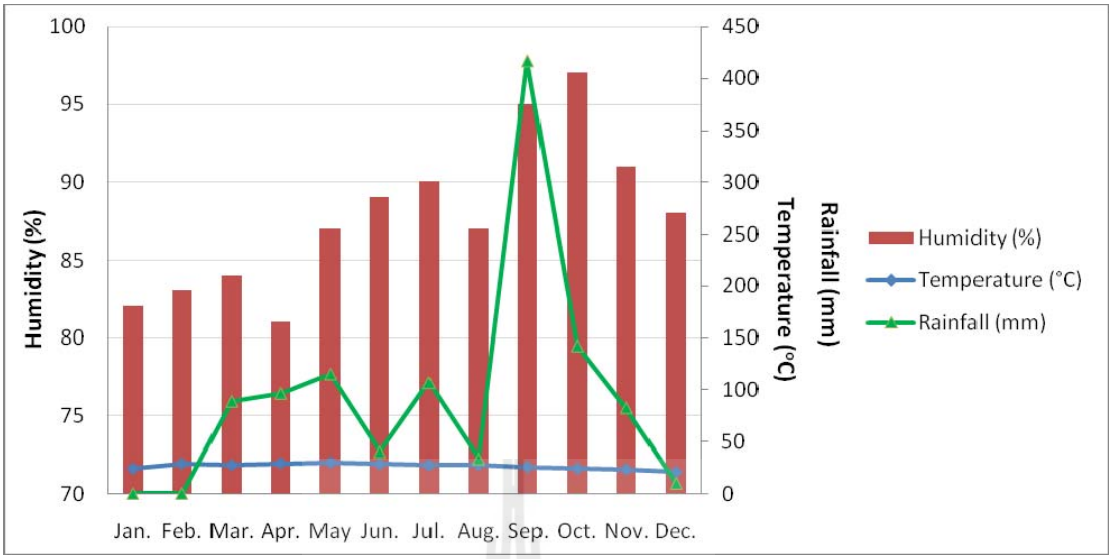


Figure 4.1 Changes of relative humidity, temperature and rainfall in the year 2005 at the SERS.

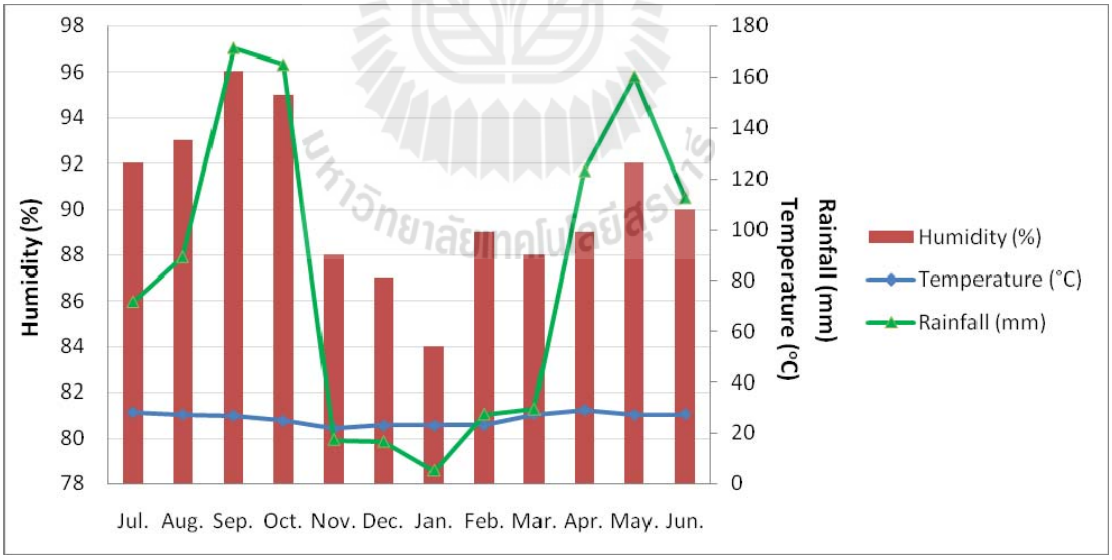


Figure 4.2 Changes of relative humidity, temperature and rainfall during 2007-2008 at the SERS.

The meteorological data at SERS from the month of July, 2007 to June, 2008, were collected. During 2007, the average monthly temperature was highest in July and lowest in November with 28.25^{o}C and 21.7^{o}C, respectively and the average humidity was highest in September (96%) and lowest in December (87%). There was highest rainfall during October (164.9 mm) but quite low during November and no rainfall was observed during December. During 2008 from January to June, the average temperature was highest in April and lowest in January with 29.9^{o}C and 22.9^{o}C, respectively but both average humidity and rainfall were the highest in May and the lowest in January with 92%, 160.3 mm and 84%, 5.1 mm, respectively (Figure 4.2).

4.2 Soil Insect Diversity

4.2.1 Comparison soil properties among habitat types in the year 2005

Mean and standard deviation values of soil physical properties and chemical properties of all three habitat types were shown in Table 4.1. It can be presented separately for each habitat types as following;

4.2.1.1 Soil moisture (%)

The investigation of the soil moisture in different types of forests in different seasons, it was found that in the rainy season every type of forests have shows value of soil moisture. The DEF had the highest value followed by ECO which was to 7.40±0.29, 6.71±0.29%, respectively and DDF in summer had least soil moisture which was to 4.17±0.2429% as shown in Figure 4.3 (a).

The average soil moisture of DEF was highest and DDF had the lowest with the value of 6.308 and 4.741 respectively. There were significantly

different in soil moisture content among the different ecosystem types and also the difference were significant at $p \leq 0.05$ during different seasons as shown in Tables 4.1 and 4.2.

4.2.1.2 Soil pH

The pH value of soil in different types of forests in different seasons was presented in Figure 4.3 (b). The least pH values were from DEF, DDF and ECO respectively which DEF in rainy season had the least pH value which was 3.53±0.27 and DDF in summer had the highest pH value which was 5.29±0.49.

The average pH of ECO was highest (4.849) and DEF has the lowest (3.651). The pH of DEF was significantly different from DDF and ECO as shown in Table 4.1.

4.2.1.3 Soil Organic Matter (% OM)

The amount of organic matter in soil of different types of forests in different seasons found that ECO forest in rainy season had the most organic matter in soil (3.03±0.15) DEF in summer followed by at 2.80±0.79% and DDF in rainy season had the least amount of organic matter at 1.19±0.24% as shown in Figure 4.3 (d).

ECO had the highest average organic matter content whereas DDF had the lowest with 2.673 and 1.522 respectively. The soil organic matter content in DDF was significantly different from DEF and ECO at $p \leq 0.05$ as shown in Table 4.1.

4.2.1.4 Total Nitrogen (%N)

Total nitrogen is an essential element for plant growing. Nitrogen accumulation in soil depends on organic matter that transforms to available element, or amount of total nitrogen which is directly related to the amount of organic matter.

The result of total nitrogen in soil of different types of forests in different season found that ECO forest in rainy season had the highest amount of total nitrogen followed by the DEF in summer at 0.17±0.05 and 0.15±0.02%, respectively and DDF in rainy season had the least total nitrogen in soil which is 0.06±0.02% as shown in Figure 4.3 (c).

The average nitrogen content of ECO was highest, followed by DEF and lowest in the DDF in the year. There was a significantly different in nitrogen content in DDF from DEF and ECO. Also, there was no significant difference in nitrogen content within the ecosystem during different seasons as shown in Table 4.1.

4.2.1.5 Available Phosphorus (P)

Phosphorus is a mineral that plants needed in high amount, and all of available phosphorus comes from soil. Therefore, it also determines the fertility of soil.

For the available phosphorus in soil of different types of forests in different seasons, the highest value found in ECO forest in rainy season at 1.16±0.51 and 1.08±0.58 ppm and DEF in winter had the least amount of available phosphorus in soil at 0.55±0.19 ppm as shown in Figure 4.3 (e).

Soil phosphorus content was found highest in ECO (0.9992) and lowest in DEF (0.6992). There were no significant differences observed in soil phosphorus contents among the ecosystem types and within the seasons as shown in Tables 4.1 and 4.2.

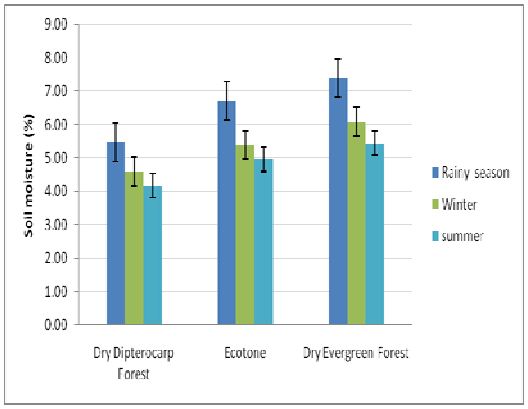
4.2.1.6 Available Potassium (K)

Potassium is another essential element that strengthens plant growth. Available potassium in the form of potassium cation (K^+) is derived and transformed from parent material, particularly mica and feldspar.

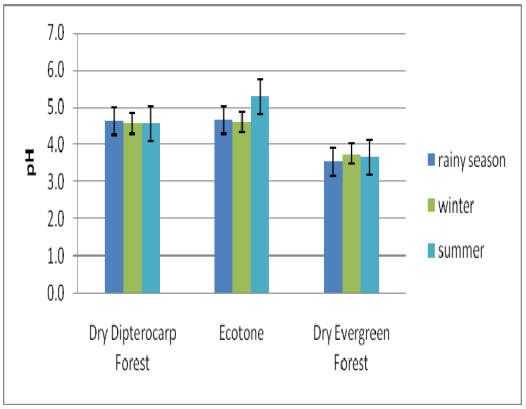
It was found that the amount of potassium in soil of different types of forests in different seasons was highest in DDF in rainy season followed by ECO in summer were 49.77±13.48 and 47.23±24.88 ppm. It was found that DEF in winter and rainy season had the least available potassium in soil as equally at 14.90±5.72 ppm as shown in Figure 4.3 (f).

Soil potassium content was found highest in ECO (42.249) and lowest in DEF (19.882). There was no significant difference between DDF and DEF but ECO was different significantly from them at $p \leq 0.05$. There was no significant variation in soil potassium contents with varying seasons in every ecosystem as shown in Table 4.1.

The study regraded to the soil insect from the collection of soil sample in 2005, the result was found that the soil moisture value between 4.80-5.91% which was nearly to the value that Suriyapong (2003) had studied between 4.20-5.38%. pH value was between 3.65-4.85 or had acidity. Organic matter value was between 1.52-2.67% which quite neutral to high and found had nearly value to the study by Charoenpol (2003) at the value of 1.71-3.06%. The soil had available nitrogen value between 0.07-0.14% or neutral. The available phosphorus value of soil found between 0.51-1.0 ppm or the very low amount of phosphorus. Potassium value was found between 19.87-42.25 ppm which was the very low value of potassium.



(a)



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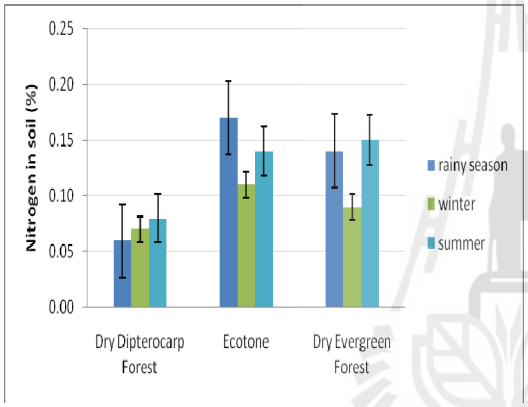

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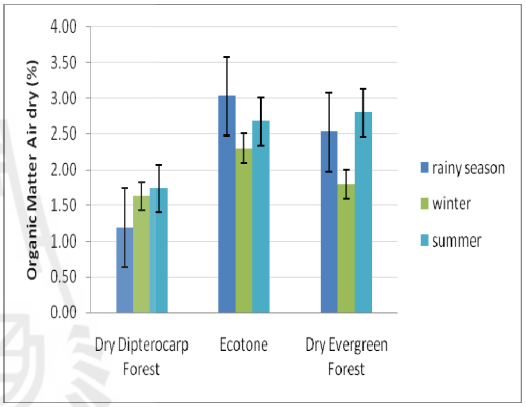

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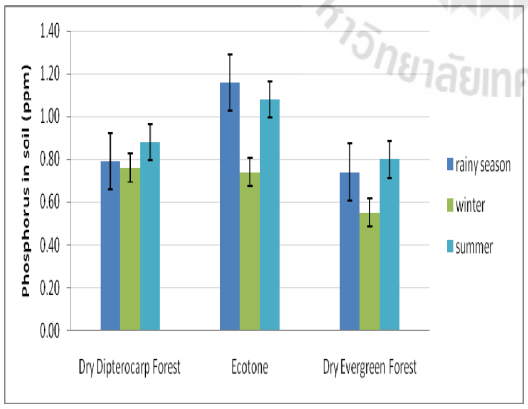

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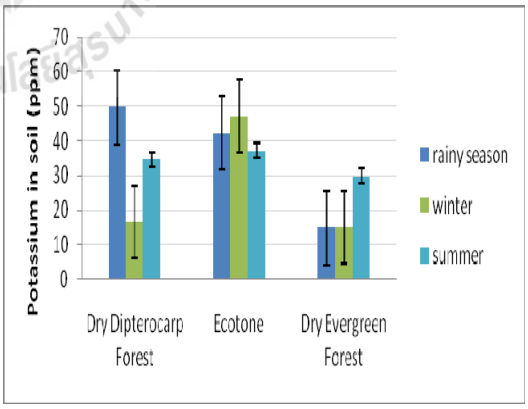

(f)

Figure 4.3 The mean of soil physical properties and chemical properties from January to December 2005.

Table 4.1 Mean of soil physical properties and chemical properties of three habitat types from January to December 2005.

Soil Properties	DDF	ECO	DEF	*F-values*	*P-values*
Soil moisture (%)	4.741 [a]	5.693 [b]	6.308 [c]	36.195	0.000*
Soil pH	4.598 [b]	4.849 [b]	3.651 [a]	16.614	0.000*
Organic matter (%OM)	1.522 [a]	2.673 [b]	2.375 [b]	17.09	0.000*
Total nitrogen (%)	0.073 [a]	0.1375 [b]	0.130 [b]	9.804	0.001*
Available phosphorus (ppm)	0.810 [a]	0.999 [a]	0.699 [a]	2.129	>0.05
Available potassium (ppm)	22.356 [a]	42.249 [b]	19.881 [a]	4.292	0.024*

Means in the same row with same letter were not statistically different *p≤ 0.05 (DMRT)

Table 4.2 Mean of soil physical properties and chemical properties of season in three habitat types from January to December 2005.

Soil Properties	Rainy season	Winter	Summer	*F-values*	*P-values*
Soil moisture (%)	6.523 [a]	5.361 [b]	4.857 [c]	42.341	0.000*
Soil pH	4.280 [a]	4.304 [a]	4.513 [a]	0.685	>0.05
Organic matter (%OM)	2.252 [a]	1.913 [a]	2.405 [a]	3.062	>0.05
Total nitrogen (%N)	0.125 [a]	0.092 [a]	0.1242 [a]	2.878	>0.05
Available phosphorus (ppm)	0.898 [a]	0.688 [a]	0.923 [a]	1.548	>0.05
Available potassium (ppm)	31.514 [a]	24.843 [a]	28.129 [a]	0.318	>0.05

Means in the same row with same letter were not statistically different *p≤ 0.05 (DMRT)

4.2.2 Soil Insect Diversity

The investigation of insects in 2005 of summer dipterocarp forest, summer evergreen forest and ecotone, five orders of insects was found in seven families. For instances, the order of Blattodea (Blaberidae family), the order of Coleoptera (Carabidae, Scarabaeidae and Staphylinidae family), the order of Hemiptera (Cydnidae family), the order of Hymenoptera (Cydnidae family) and the order of

Isoptera (Termitidae family). The collecting of sample in the soil area 20 cm. and at 20 cm. depth that brought the soil to put in Berlese funnel.

The Collecting of Sample in the Soil Area

It was the sample collection from soil at 0-15 cm. depth and it was found that in DEF had total of 159 insects by calculating as the ratio of insects which found in the study area. And the most found are Isoptera, Hymenoptera, Coleoptera and Blattodea were 50.32, 35.22, 6.29 and 8.17% of insects in DEF and the insects were mostly found in summer season and hardly found in winter which this was 47.80 and 8.18% of insect in DEF as shown in Table 4.3.

Table 4.3 Soil insects in dry evergreen forest of each season from January to December 2005.

Orders	Families	Seasons (individual)		
		Winter	**Rainy season**	**Summer**
Blattodea	Blaberidae	2(1.26%)	1(0.63%)	1(0.63%)
Coleoptera	Carabidae	0	0	1(0.63%)
	Scarabaeidae	2(1.26%)	1(0.63%)	5(3.14%)
	Staphylinidae	0	0	1(0.63%)
Hemiptera	Cydnidae	0	0	0
Hymenoptera	Formicidae	9(5.66%)	42(26.42%)	14(8.81%)
Isoptera	Termitidae	0	26(16.35%)	54(33.96%)

In ECO, the total of insects were 153 individuals by calculating in the ratio of insects found in the studied area, the mostly found were Hymenoptera, Isoptera, Blattodea and Coleoptera which are 47.06, 20.28, 18.96 and 13.07%, respectively and only forest found Hemiptera was 0.65% of insects in ECO and the insects are mostly found in rainy season while found least in winter which was 47.06 and 17.00% of insects in ECO.

Table 4.4 Soil insects in ecotone of each season from January to December 2005.

Orders	Families	Seasons (individual)		
		Winter	**Rainy season**	**Summer**
Blattodea	Blaberidae	7(4.55%)	4(2.60%)	19(12.34%)
Coleoptera	Carabidae	0	1(0.65%)	1(0.65%)
	Scarabaeidae	4(2.60%)	4(2.60%)	5(3.25%)
	Staphylinidae	0	4(2.60%)	1(0.65%)
Hemiptera	Cydnidae	0	0	1(0.65%)
Hymenoptera	Formicidae	13(8.44%)	37(24.03%)	22(14.29%)
Isoptera	Termitidae	3(1.95%)	22(14.29%)	6(3.90%)

In DDF, the total of insects were 81 individuals by calculating the ratio of insects found in the studied area which mostly found were the orderes Isoptera, Blattodea, Coleoptera and Hymenoptera which were 57, 25.93, 19.75 and 19.75%, respectively of insects in DDF and the insects were mostly found in rainy season and least found in summer season which was 50.62 and 13.58% of insects in DDF.

Table 4.5 Soil insects in dry dipterocarp of each season from January to December 2005.

Orders	Families	Seasons (individual)		
		Winter	**Rainy season**	**Summer**
Blattodea	Blaberidae	14(17.07%)	7(8.54%)	0
Coleoptera	Carabidae	1(1.22%)	3(3.66%)	1(1.22%)
	Scarabaeidae	1(1.22%)	4(4.88%)	2(2.44%)
	Staphylinidae	3(3.66%)	1(1.22%)	0
Hemiptera	Cydnidae	0	0	0
Hymenoptera	Formicidae	0	8(9.76%)	9(10.98%)
Isoptera	Termitidae	10(12.20%)	18(21.95%)	0

Blattodea order found in DEF for four could be calculated as 2.52%, ECO for 30 calcutlated as 19.48% and in DDF found 21 could be calculated as 20.24% only one family found which was Blaberidae.

For the Coleoptera order, there was three families were found; Carabidae, Scarabaeidae family and Staphylinida. In DEF, 10 Coleopterans were found and

counted to be 21.74%, the most frequent family found was Scarabaeidae. In ECO, 20 coleopterans were found and counted to be 43.48%, the most frequent family found was Scarabaeidae and in DDF 16 coleopterans were found and counted to be 34.78%, the most family found was Scarabaeidae. In all three types of forest, it was found that the among the Coleoptera order-Scarabaeidae family was the most insect family found.

Hymenoptera order found in total of three forests were 154 individuals and mostly found in ECO at 72 or 46.75%, secondly was in the DEF at 65 or 42.21% and the least amount found in DDF for 17 or 11.04%, and only family found was Cydnidae.

Isoptera order was found only in one family which was Termitidae, the total number found in three types of forests was 139 and mostly found in DEF for 80 or about 57.55% while secondly was in ECO for 31 or 22.30% and the least was found in DDF at 28 insects or 20.15%.

In the ECO, DEF and DDF forests, the Formicidae family of Hymenoptera order and Termitidae family of Isoptera order were found at the most and it was also mostly found in the rainy season followed by summer and winter respectively as shown in Table 4.6.

It was also found that in 7 families consisted of 395 insects and Formicidae family had the highest amount at 154 or calculated as 38.99%, followed by the Termitidae, Blaberidae, Scarabaeidae, Staphylinidae, Carabidae and Cydnidae families at the amount of 139, 55, 28, 10, 8 and 1 calcutated to be 5.19, 13.95, 7.09, 2.53, 2.03 and 0.25%, respectively.

Table 4.6 Total of soil insects in three habitat types from January to December 2005.

Orders	Families	Number (individual)
Blattodea	Blaberidae	55 (13.92%)
Coleoptera	Carabidae	8 (2.03%)
	Scarabaeidae	28 (7.09%)
	Staphylinidae	10 (2.53%)
Hemiptera	Cydnidae	1 (0.25%)
Hymenoptera	Formicidae	154 (38.99%)
Isoptera	Termitidae	139 (35.19%)

Table 4.7 Species diversity index and evenness index of soil insects in the SERS.

Habitat type	DEF	ECO	DDF
Shannon's index	1.468	2.028	2.134
Evenness	0.565	0.722	0.919

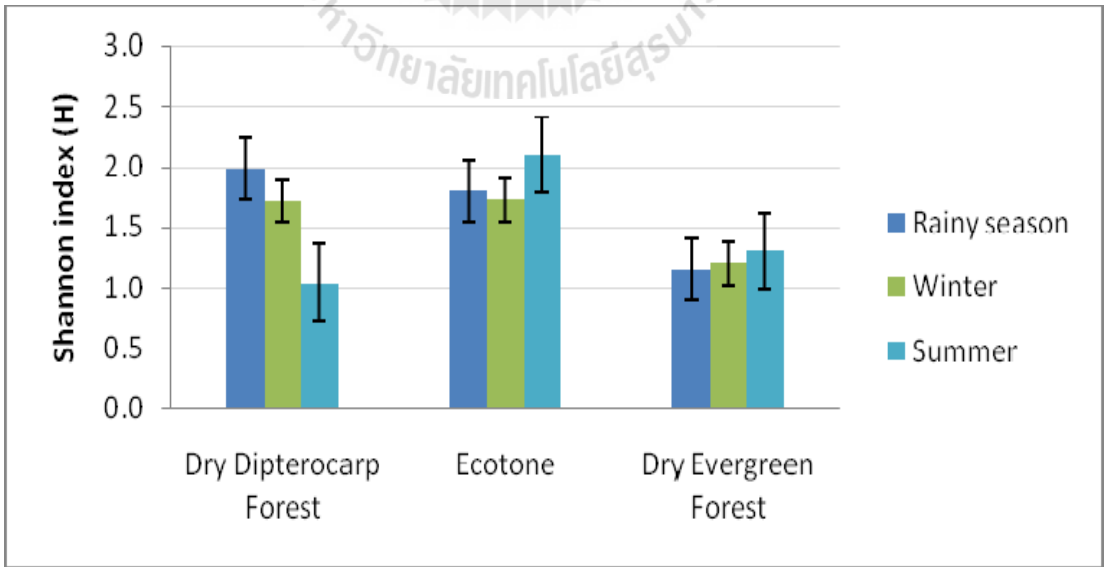

Figure 4.4 The Shannon's index in soil different in January to December 2005.

Seasonal species diversity for every ecosystem was calculated using Shanon's index (H′) which was found varying with the ecosystem types. For DEF, the species diversity index was observed highest during summer (1.304) and lowest during rainy season (1.148) but the species evenness was found the lowest during summer and the highest during winter. The average diversity index and species equitability of all seasons in DEF were 1.468 and 0.565, respectively.

In DDF, both the species diversity index and evenness were found the lowest during summer with the value of 0.811 and 0.81, respectively. The highest diversity index was during the rainy season but the species evenness was highest in winter. The average species diversity index and species equitability of all seasons were 2.134 and 0.919, respectively.

The species diversity index of ECO forest was calculaed and the highest was during summer (2.037) and the lowest was during the winter (1.722). The species equitability was found highest in winter (0.885) and the lowest in rainy season (0.695). The average diversity index and species equitability of all seasons were 2.028 and 0.722, respectively.

The species diversity index and eveness of soil insects in the SERS were shown in Table 4.7 and Figure 4.4.

4.2.3 Comparison of Correlation of Environmental Factors and Soil Insects

The correlation of environmental factors and Shannon diversity index under the surface of ground at 0-15 cm. depth investigated in 2005 of DDF, ECO and DEF, and the amount of phosphorus had consistent related in the same direction with Shannon diversity. If the amount of phosphorus increases, it may result in the increasing amount of Shannon diversity index as shown in Table 4.8.

Table 4.8 Correlation (r) of environmental factors and soil insects.

Soil properties	Shanon's index					
	DDF		ECO		DEF	
	r	*P-value*	*r*	*P-value*	*r*	*P-value*
Soil moisture (%)	-0.068	0.834	0.02	0.951	0.006	0.986
Soil pH	-0.443	0.149	0.304	0.336	-0.471	0.123
Organic matter (%OM)	-0.223	0.496	0.336	0.295	0.066	0.838
Total nitrogen (%N)	0.600	0.466	-0.285	0.369	0.085	0.792
Available phosphorus (ppm)	0.350	0.265	0.237	0.458	0.272	0.392
Available potassium (ppm)	0.786**	0.002	0.141	0.369	-0.313	0.322

Data analysis by Peason's correlation matrix at the different level of confidence (*p≤0.05, **p≤0.01)

In DDF, it was found that the amount of nitrogen, potassium, organic matter, pH and soil moisture had inconsistent related with Shannon diversity index. Morover, the amount of organic matter, pH and soil moisture had changed in opposite direction to the Shannon diversity which the amount of these parameters were increased and result in the reduction of the amount of Shannon diversity index. And potassium had relationship in the same direction with Shannon diversity index. If the

amount of nitrogen and potassium increase, it may result in the increasing amount of Shannon diversity index as well.

In ECO, the amount of nitrogen had changed in the contrastive direction with the Shannon diversity index which the increasing amount of nitrogen may result to the reduction of the amount of Shannon diversity index and the amount of potassium, organic matter, pH and soil moisture had the same direction of relationship with the Shannon diversity index. If the amount of these parameter increased, it may result in the increasing amount of Shannon diversity index.

In DEF, the amount of potassium and pH had changed in the contrastive direction with Shannon diversity index. The increasing amount of potassium and pH may result in the reduction of the amount of Shannon diversity index and the amount of nitrogen organic matter. And soil moisture has relationship in the same direction with Shannon diversity index. If the amount of those increases, it may result in the increasing amount of Shannon diversity index as well.

4.3 The Study of Rate Decomposition

Decomposition of leaf litter, by which organic matter and nutrients are returned to the forest soils, is a primary mechanism and has received considerable attention for sustainable soil fertility. The rate of litter decomposition has been associated with the carbon and nitrogen content.

4.3.1 Physical Properties of Soil and some Chemical Properties of Soil

4.3.1.1 Soil Moisture (%)

For soil moisture in different season and in different types of forests, it was found that the rainy season had the highest amount of soil moisture followed by

winter which was found in the area of DEF on the surface of soil at 13.85±4.28%. ECO forest in rainy season had the highest moisture value at the subsoil at 13.53±4.65% but DDF in summer had the least value of soil moisture in either surface or subsoil at 5.01±1.54 and 5.30±1.13% respectively as shown in Figure 4.5 (a).

The surface soil moisture was the highest in DEF (9.73) and the lowest in DDF (9.07). There were no significant differences in soil moisture among the ecosystems but their variations among the seasons were statistically significant at $p \leq 0.05$ as shown above in Tables 4.9 and 4.10.

The soil moisture of the lower soil layer found the highest in DEF (10.28) and the lowest in DDF (9.19). There were no statistically significant differences in soil moisture content between the ecosystems but observed significant differences with the seasons as shown above in Tables 4.11 and 4.12.

4.3.1.2 Soil pH

For pH value of soil in different seasons of different types of forests, it was found that in summer, the forests had the highest pH value of soil. The ECO had the highest pH value on surface at 5.29±0.36. DDF had the highest pH value of subsoil at 5.53±0.53 and DEF in rainy season had the least pH value of either surface or subsoil at 3.80±0.71 and 3.73±0.51 as shown in Figure 4.5 (c).

During 2007, the average surface soil pH of DDF, DEF and ECO were 4.9614, 3.9283 and 4. 9117, respectively. The pH of DDF was significantly different from ECO and DDF but there was no significant difference between the later at $p \leq 0.05$. The variations of soil pH during the summer were significantly different from rainy and winter seasons at the same p-value shown above in Tables 4.9 and 4.10 ($p \leq 0.05$).

The average soil pH of lower layer of DDF, DEF and ECO were 5.0628, 3.9122 and 4.8944, respectively. The pH of DEF was significantly different from DDF and ECO but there was no significant difference between the later two at $p \leq 0.05$. The variation of soil pH during rainy season was statistically different from the summer and the winter season as shown in Tables 4.11 and 4.12.

4.3.1.3 Soil Porosity (%)

The result of porosity of soil according to the seasons in different type of forests, found that DEF and followed by DDF had the highest value of soil porosity in rainy season at 58.34±3.15, 56.63±4.15%. The least porosity of soil value was found in area of ECO in summer which was 47.47±10.37% as illustrated in Figure 4.5 (b).

DEF had average highest porosity and ECO has the lowest. DDF was not significantly different from ECO and DEF, but there were significantly different observed between ECO and DEF at $p \leq 0.05$ as shown in Tables 4.9 and 4.10 ($p \leq 0.05$).

4.3.1.4 Bulk Density (g/cm^3)

Bulk density of soil in different seasons of forests from all studies, the forest in summer had the highest value of soil bulk density which ECO had the highest bulk density of soil while the second was ECO forest in winter at 1.39±0.27, 1.38±0.42 g/cm^3, respectively. The least value of bulk density of soil was resulted from DEF in rainy season at the value of 1.10±0.08 g/cm^3 as shown in Figure 4.5 (d).

The average bulk density of ECO forest was the highest and DEF has the lowest of the year. There was significantly different in bulk density among the three ecosystem types at $p \leq 0.05$ as shown in Tables 4.9 and 4.10.

4.3.1.5 Soil Temperature (^{o}C)

For soil temperature in different seasons in different types of forests, it was found that in summer, ECO area had the highest temperature on soil surface at 32.42±3.09^{o}C. While in rainy season, DDF subsoil had the highest temperature at 30.00±1.50^{o}C and DEF area in winter had the least temperature of soil either in surface and subsoil which was at 21.50±2.32 and 20.50±1.98^{o}C, respectively as shown in Figure 4.5 (e).

The average lower soil temperature was found the highest in DDF and the lowest in DEF with 27.29^{o}C and 22.59^{o}C, respectively. The soil temperature of DEF was significantly different from that of DDF and ECO at $p \leq 0.05$. The soil temperature during winter season was significantly different from summer and rainy season at $p \leq 0.05$ as shown in Tables 4.9 and 4.10.

The average surface temperature was the highest in DDF and the lowest in DEF with 29.79 and 23.63^{o}C, respectively. There was significantly different in soil temperature of DEF from ECO and DDF at $p \leq 0.05$. The soil temperature of winter season was statistically different from rainy season and summer at $p \leq 0.05$ as shown above in Tables 4.11 and 4.12.

4.3.1.6 Total Nitrogen (%N)

For total nitrogen in soil in different seasons in different types of forests, it was found that DEF in rainy season had the highest value of total nitrogen on surface at 0.23±0.03% while DEF in summer had the highest value of total nitrogen in subsoil at 0.18±0.03 and DDF in rainy season had least total nitrogen in soil either in surface and subsoil at 0.12±0.05 and 0.09±0.05 as shown in Figure 4.5 (f).

During 2007, the mean surface soil nitrogen content was the highest in DEF and the lowest in DDF. The soil nitrogen content of DEF was significantly different from DDF and ECO but there was no significant difference between DDF and ECO. There were no statistical significant differences in soil nitrogen changes with seasons in all ecosystems as shown above in Tables 4.9 and 4.10.

The average lower soil nitrogen content of DEF was the highest and DDF has the lowest with 0.170 and 0.089, respectively. The variation of soil nitrogen contents among the ecosystems was significantly different at $p \leq 0.05$, but there was no significant difference observed among the seasons in every ecosystem as shown in Tables 4.11 and 4.12.

4.3.1.7 Available Phosphorus (P)

For the available phosphorus in soil in different seasons in different forests, it was found that DDF in rainy season had the highest available phosphorus on the surface at 6.28±5.99 ppm. ECO in rainy forest found the most available of phosphorus in subsoil at 5.84±5.64ppm and least available phosphorus in soil found in rainy season of DEF either on surface or subsoil at 3.80±1.23 and 2.84±0.95 ppm as shown in Figure 4.5 (g).

The surface soil phosphorus content during the year 2007 was the highest in ECO and the lowest in DEF with 4.898 and 4.799, respectively. There was no significant difference in soil phosphorus contents among the ecosystems but its variation among seasons were significantly different during rainy season, summer and winter seasons at $p \leq 0.05$ as shown in Tables 4.9 and 4.10.

The average lower soil phosphorus was found the highest in ECO and the lowest in DEF with 4.493 and 3.543, respectively. There was no significant

difference in soil phosphorus contents among the ecosystems but its variation in rainy season was found significantly different from summer and rainy season at $p \leq 0.05$ as above as shown in Tables 4.11 and 4.12.

4.3.1.8 Available Potassium (K)

For the available potassium in soil in different seasons and different types of forests, it was found that in rainy season of DEF the available of potassium found in surface at 48.16±11.13 ppm while DDF in winter had the highest available of potassium in subsoil at 63.11±31.02 ppm and DEF in summer had least available potassium in soil both on surface and subsoil at 18.05±8.63 and 19.95±8.63 ppm as shown in Figure 4.5 (h).

The surface soil potassium content was the highest in DDF (37.781) and the lowest in DEF (34.120) in the year 2007. There was no statically differences observed in potassium content among the ecosystems but its variation during hot season was significantly different during summer than during rainy season and winter at $p \leq 0.05$ as shown in Tables 4.9 and 4.10.

In the lower soil layer, the average potassium content was found thehighest in DDF and the lowest in ECO with the value of 35.665 and 30.683, respectively. There were no statistically significant differences in soil potassium contents among the ecosystems but its variation with seasons was significantly different in all ecosystems at $p \leq 0.05$ as shown in Tables 4.11 and 4.12.

4.3.1.9 Soil Organic Matter (%OM)

For the amount of organic matter in soil in different seasons in different type of forests, it was found that DEF in winter had the highest amount of organic matter on the soil surface at 4.12±0.44% while, DEF in rainy season had the

least amount of organic matter in subsoil at 3.54±0.63% and ECO in winter season had the least amount of organic matter in either surface or subsoil which was 2.41± 0.33% and 2.44±0.44% as shown in Figure 4.5 (i).

In the year 2007, the highest average surface soil organic matter content was observed in DEF (3.910) and the lowest in ECO (2.884). The soil organic matter content in DEF was significantly different from ECO and DDF and also its variation during the summer was significant from winter and rainy season, at $p \leq 0.05$ shown in Tables 4.9 and 4.10.

The soil orgainc matter of lower layer was found the highest in DEF and the lowest in ECO with 3.320 and 2.616, respectively. The soil organic matter content of DEF was significantly different from ECO and DDF. Also, the variation of soil orgainic matter during the summer was significantly different from winter and rainy seasons at same p value as shown in Tables 4.11 and 4.12.

The study regrads to the decomposition rate from the soil sample collection in July 2007- June 2008, can be concluded that the study of the decomposition rate in three types of forest which were DDF, ECO and DEF found had soil moisture value in surface at between 9.24-9.73% and in the subsoil; soil moisture value was between 9.57-10%. This value found less than the study conducted by Charoenpol (2003) who had soil moisture value on surface at 12.77-23.69% and in the subsoil between 15.04-18.26%. The studied on bulk density found the value between 1.15-1.35 g/cm^3 and porosity was between 50.71-56.73%, respectively. Fortunately the value is to the study of Suriyapong (2003) and Charoenpol (2003) that conducted before which showed the bulk density value between 1.22-1.38 g/cm^3 and 1.24-1.31 g/cm^3, respectively. The values of porosity

were between 47.73-53.72% and 46.31-51.11%, respectively. Thus, this can be noticed that bulk density and porosity had opposite relationship. If the bulk density value was high, the porosity value would low.

The study found that pH value in three types of forest which were DDF, ECO and DEF on the surface was between 3.84-4.96 or had strong acidity and for the subsoil pH was between 4-5.06 or had acidity also. The study of organic matter, in DDF, ECO and DEF found that organic matter value in soil surface was been 2.88- 3.91% which was quite high and in the subsoil organic matter value was between 2.62-3.32% which was also high. The study found that available nitrogen in three types of forest which were DDF, ECO and DEF had available nitrogent value on the surface between 0.14-0.31% or high to highest. For the subsoil, available nitrogent value was between 0.12-0.21% or high. Available phosphorus value found on the surface was between 4.45-4.90 ppm which was low available phosphorus and in the subsoil, available phosphorus was between 3.60-4.10 ppm which also low. And the last, DDF, ECO and DEF had potassium value in the surface between 34.12-37.78 ppm which was low and the subsoil had potassium value between 33.29-35.67 ppm which also low.

4.3.2 Physical Properties of Litter and some Chemical Properties of Litter

4.3.2.1 Water Content of Litter (%)

The study on amount of water content of litter in different seasons and different types of forests found that in the rainy season had the highest value of water content of litter with DEF had the highest amount of water content of litter at 18.96±7.07% and the least water content of litter found in the area of DDF in summer at 7.20±1.97% as shown in Figure 4.5 (k).

The water content of litters was found the highest in ECO (13.064) and the lowest in DDF (10.546). There was significantly different in litter water content among the ecosystems but the variation of litter water content during suumer and winter was significantly different from rainy season at $p \leq 0.05$ as shown in Tables 4.9 and 4.10.

4.3.2.2 Litter Organic Carbon (%)

For the organic carbon in litter in different season and different type of forest, it was found that DEF in rainy season had the highest organic carbon in litter either in surface or subsoil at 17.76±7.53 and 23.84±14.95%, respectively and the least organic carbon in litter found in winter of ECO both in surface and subsoil at 8.38±3.70 and 10.08±3.94% as shown in Figure 4.5 (j).

An average surface organic carbon in leaves in the year 2007 was found the highest in DEF and the lowest in DDF with 14.209 and 8.633, respectively. There was no significant difference in leaf organic carbon content among the ecosystems but its variation among three seasons was significantly different at $p \leq 0.05$ as shown in Tables 4.9 and 4.10.

The lower layer soil organic carbon in 2007 year was found the highest in DEF and the lowest in ECO with 14.076 and 13.0159, respectively. There was no significant difference in leaf letter nitrogen content among the ecosystems but its variation during rainy season was significantly different from winter and summmer, both calculated at $p \leq 0.05$ as shown above in Tables 4.11 and 4.12.

4.3.2.3 Litter Total Nitrogen (%)

Nitrogen in litter in different seasons and different types of forests, it was found that DEF in rainy season had the highest value of nitrogen in litter either in

surface or subsoil at 1.49±0.60 and 2.05±0.97%, respectively and the least of nitrogen in litter found in winter of ECO both in surface and subsoil at 0.29±0.20 and 0.38± 0.28% as shown in Figure 4.5 (l).

The average nitrogen content in surface leaf letters of 2007 was found the highest in DEF and lowest in DDF with 0.927, and 0.404, respectively. There was no statistically significant difference in leaf letter nitrogen contents among the ecosystems but its variation during the rainy season was significantly different from winter and summer at $p \leq 0.05$ as shown in Tables 4.9 and 4.10.

The average nitrogen content of lower soil leaf litters was found the highest in DEF and the lowest in DDF with 0.905 and 0.397, respectively. There was no significant difference in nitrogen among the ecosystems but significant difference in its change during rainy season than summer and winter at $p \leq 0.05$ as shown in Tables 4.11 and 4.12.

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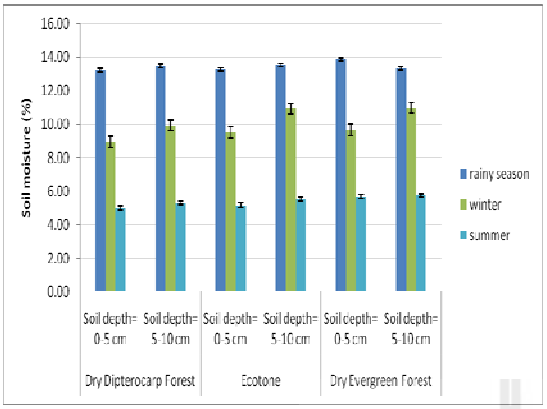
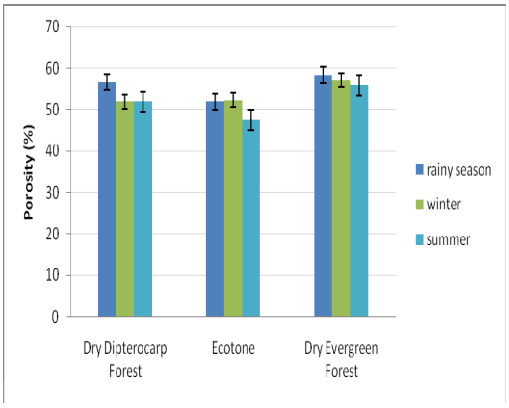


(a)



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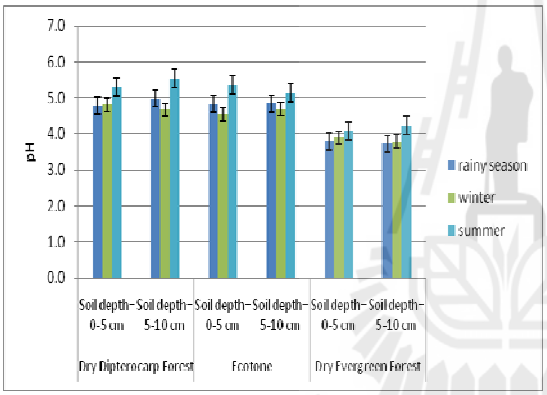

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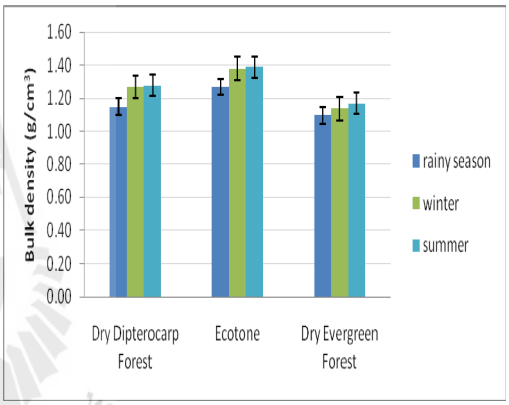

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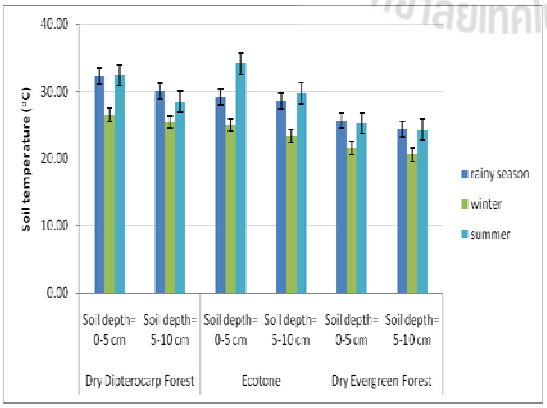

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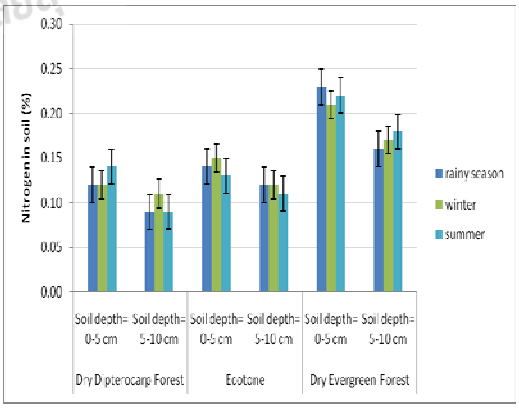
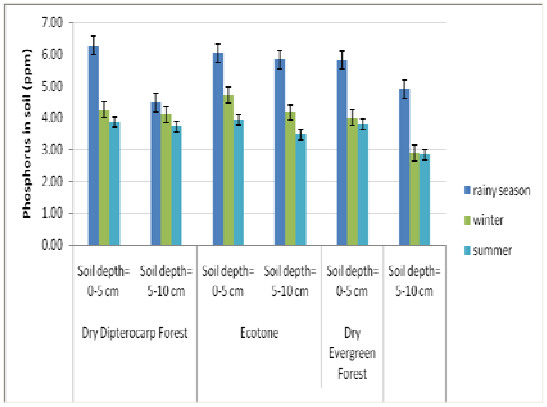


(f)

Figure 4.5 The mean of soil physical properties and chemical properties during July 2007 to June 2008.



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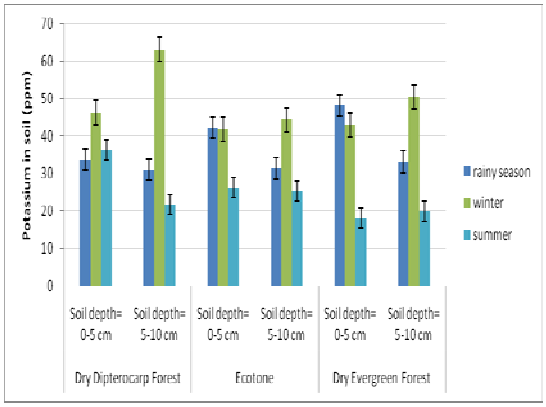

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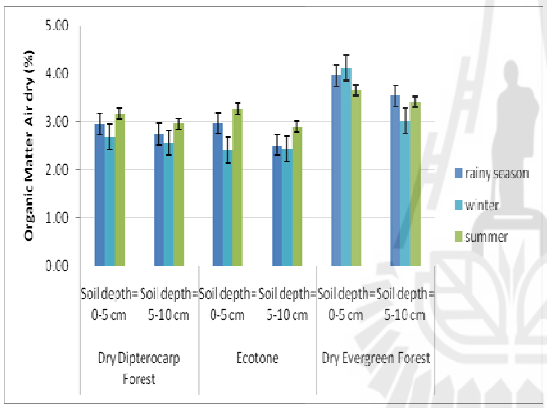
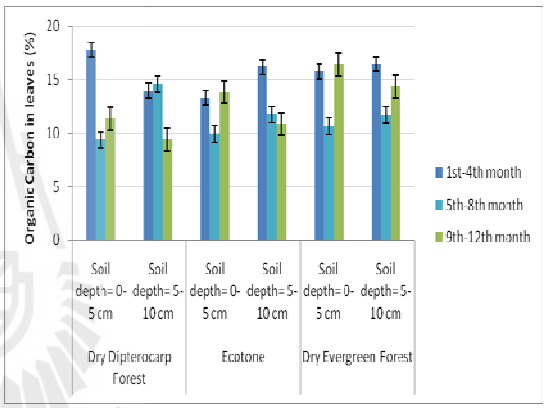
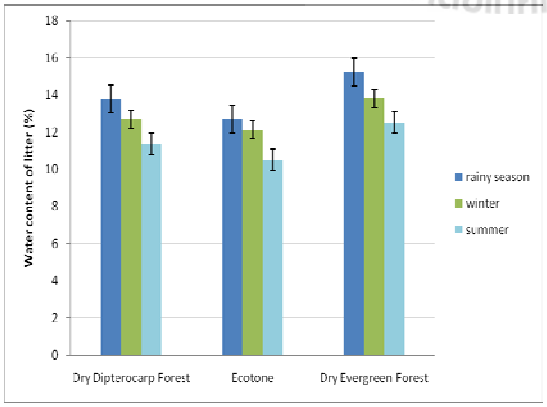


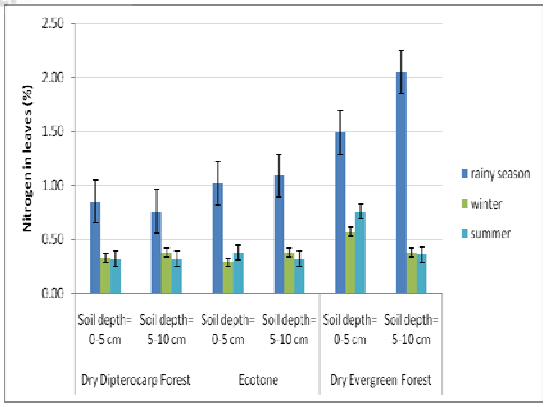
(i)



(j)



(k)



(l)

Figure 4.5 (Continued).

Table 4.9 Mean of surface soil physical properties and chemical properties of three habitat types from July 2007 to June 2008.

Soil Properties	DEF	ECO	DDF	*F-values*	*P-values*
Bulk density (g/cm^3)	1.105 ^{a}	1.348 ^{b}	1.233 ^{c}	10.282	0.000*
Porosity (%)	55.519 ^{b}	49.136 ^{a}	53.474 ^{ab}	3.679	0.029*
Soil moisture (%)	9.727 ^{a}	9.326 ^{a}	9.070 ^{a}	0.516	>0.05
Soil pH	3.928 ^{a}	4.912 ^{b}	4.961 ^{b}	40.207	0.000*
Soil temperature (^{o}C)	23.630 ^{a}	29.500 ^{b}	29.796 ^{b}	42.130	0.000*
Total nitrogen (%)	0.223 ^{b}	0.138 ^{a}	0.132 ^{a}	24.688	0.000*
Available phosphorus (ppm)	4.540 ^{a}	4.799 ^{a}	4.898 ^{a}	0.189	>0.05
Available potassium (ppm)	34.120 ^{a}	36.049 ^{a}	37.781 ^{a}	0.189	>0.05
Organic matter (%)	3.910 ^{b}	2.884 ^{a}	2.934 ^{a}	36.702	0.000*
Organic carbon in litter (%)	14.209 ^{a}	12.379 ^{a}	11.596 ^{a}	1.575	>0.05
Total nitrogen in litter (%)	0.927 ^{a}	0.548 ^{a}	0.404 ^{a}	1.745	>0.05
Water content in litter (%)	12.981 ^{a}	13.064 ^{a}	12.982 ^{a}	0.855	>0.05
Decomposition (%)	48.805 ^{a}	40.449 ^{a}	34.103 ^{a}	1.365	>0.05

Means in the same row with same letter were not statistically different *p≤0.05 (DMRT)

Table 4.10 Mean of surface soil physical properties and chemical properties of each season in three habitat types from July 2007 to June 2008.

Soil Properties	Rainy season	Winter	Summer	*F-values*	*P-values*
Bulk density (g/cm^3)	1.258 ^{a}	1.269 ^{a}	1.157 ^{a}	2.462	>0.05
Porosity (%)	48.829 ^{a}	52.130 ^{ab}	56.345 ^{b}	4.836	0.010*
Soil moisture (%)	13.462 ^{a}	9.387 ^{b}	5.275 ^{c}	79.082	0.000*
Soil pH	4.470 ^{a}	4.421 ^{b}	4.911 ^{b}	8.629	0.000*
Soil temperature (^{o}C)	29.056 ^{b}	24.319 ^{a}	30.611 ^{b}	47.262	0.000*
Total nitrogen (%)	0.162 ^{a}	0.163 ^{a}	0.167 ^{a}	0.061	>0.05
Available phosphorus (ppm)	6.048 ^{b}	4.323 ^{a}	3.868 ^{a}	7.306	0.001*
Available potassium (ppm)	39.585 ^{b}	43.724 ^{b}	24.641 ^{a}	5.678	0.005*
Organic matter (%)	3.292 ^{a}	3.069 ^{a}	3.367 ^{a}	2.624	>0.05
Organic carbon in litter (%)	16.953 ^{a}	9.178 ^{b}	12.403 ^{c}	13.167	0.000*
Total nitrogen in litter (%)	1.051 ^{b}	0.336 ^{a}	0.480 ^{a}	3.502	0.034*
Water content in litter (%)	15.918 ^{b}	10.141 ^{a}	9.602 ^{a}	5.474	0.009*
Decomposition (%)	48.636 ^{a}	43.816 ^{a}	30.904 ^{a}	2.110	>0.05

Means in the same row with same letter were not statistically different *p≤0.05 (DMRT)

Table 4.11 Mean of subsoil soil physical properties and chemical properties of three habitat types from July 2007 to June 2008.

Soil Properties	DEF	ECO	DDF	*F-values*	*P-values*
Soil moisture (%)	10.274 [a]	10.255 [a]	9.196 [a]	2.103	0.127
Soil pH	3.912 [a]	4.984 [b]	5.062 [b]	70.827	0.000*
Soil temperature (^{o}C)	22.593 [a]	26.796 [b]	27.296 [b]	38.789	0.000*
Total nitrogen (%)	0.170 [a]	0.116 [b]	0.089 [c]	26.919	0.000*
Available phosphorus (ppm)	3.543 [a]	4.493 [a]	4.102 [a]	1.011	>0.05
Available potassium (ppm)	32.872 [a]	30.683 [a]	35.665 [a]	0.394	>0.05
Organic matter (%)	3.320 [b]	2.616 [a]	2.685 [a]	11.292	0.000*
Organic carbon in litter (%)	14.076 [a]	13.159 [a]	13.303 [a]	0.272	>0.05
Total nitrogen in litter (%)	0.905 [a]	0.554 [a]	0.397 [a]	1.639	>0.05
Water content in litter (%)	12.982 [a]	13.064 [a]	10.546 [a]	0.855	>0.05
Decomposition (%)	28.917 [b]	35.076 [b]	13.56 [a]	4.571	0.020*

Means in the same row with same letter were not statistically different *p≤0.05 (DMRT)

Table 4.12 Mean of subsoil physical properties and chemical properties of each season in three habitat types from July 2007 to June 2008.

Soil Properties	Rainy season	Winter	Summer	*F-values*	*P-values*
Soil moisture (%)	13.434 [c]	10.602 [b]	5.511 [a]	60.40	0.000*
Soil pH	5.074 [b]	3.722 [a]	3.342 [a]	3.680	0.029*
Soil temperature (^{o}C)	27.667 [b]	23.083 [a]	27.514 [b]	42.856	0.000*
Total nitrogen (%)	0.122 [a]	0.127 [a]	0.127 [c]	0.105	>0.05
Available phosphorus (ppm)	30.983 [a]	50.878 [b]	17.358 [c]	17.948	0.000*
Available potassium (ppm)	16.693 [b]	11.397 [a]	12.087 [a]	4.703	0.012*
Organic matter (%)	2.860 [ab]	2.672 [a]	3.089 [b]	3.257	0.043*
Organic carbon in litter (%)	15.918 [b]	10.141 [a]	9.602 [a]	5.474	0.009*
Total nitrogen in litter (%)	1.271 [b]	0.297 [a]	0.284 [a]	7.797	0.001*
Water content in litter (%)	15.918 [b]	10.141 [a]	9.602 [a]	5.474	0.000*
Decomposition (%)	47.508 [b]	22.291 [b]	12.223 [a]	11.963	0.000*

Means in the same row with same letter were not statistically different *p≤0.05 (DMRT)

4.3.3 Rate of Decomposition

The comparison of decomposition rate of organic matter in the area of three forests from July 2007 to June 2008 was conducted using litter bag method which can divide into two patterns. First, laying the litter bag on the ground and second, burying

the litter bag under the ground then followed up the result of decomposition through the year. The rate of decomposition in both patterns which first laying the litter bag on the ground, in each area of forests had no statistical difference but statistical significant difference was found at $p \leq 0.05$ in each season collected between the period of rainy season. The rate of decomposition found the highest and significant differences in the rainy season in every type of forest. For the second pattern, burying the litter bag underground found that in each area of forest had no statistical difference.There was the statistical significant difference at $p \leq 0.05$ in each season within one year. The statistical significant difference between the period of rainy season in every type of forest could be detected in decomposition in every forest. The method of laying litter bag on the ground had less decomposition rate than the method of burying the litter bag underground as shown in Figure 4.6.

The average decomposition rate on the surface soil was highest in DEF (48.805) and lowest in DDF (34.103). The decomposition rate among the ecosystems found no significant difference as shown in Table 4.13.

The average decomposition rate was highest in subsoil at DDF (48.636) and lowest in DEF (30.904). The decomposition rate among the ecosystems was not significantly different as shown in Table 4.13.

Table 4.13 The mean of decomposition rate of three habitat types.

Properties	Rainy season	Winter	Summer	*F-values*	*P-value*
Decomposition on surface soil	48.805 [a]	40.449 [a]	34.103 [a]	1.365	>0.05
Decomposition in subsoil	48.636 [a]	43.816 [a]	30.904 [a]	2.110	>0.05

Means in the same row with same letter were not statistically different *p≤0.05 (DMRT)

Table 4.14 The mean of decomposition rate of different seasons in three habitats types.

Properties	Rainy season	Winter	Summer	*F-values*	*P-value*
Decomposition on surface soil	28.917 [b]	35.076 [b]	13.56 [a]	4.571	0.020*
Decomposition in subsoil	47.508 [b]	22.291 [a]	12.223 [a]	11.963	0.000*

Means in the same row with same letter were not statistically different *p≤0.05 (DMRT)

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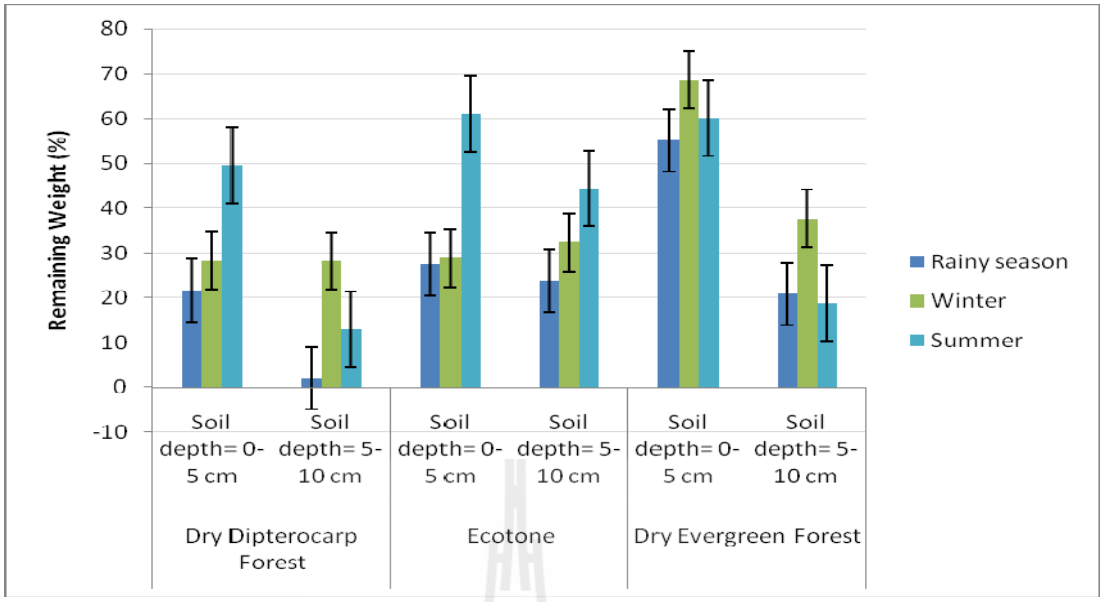

Figure 4.6 The mean of decomposition rate during July 2007 to June 2008.

4.3.4 Litter Insect Diversity

The investigation of insects was conducted during July 2007 to June 2008 of summer dipterocarp forest, summer evergreen forest and ecotone from the burying of litter at the amount of 20 grams in litter bags at the soil surface and the level of 5-10 cm. depth. Five orders and a families of insect were found such as Blattodea in (Blaberidae family), Coleoptera order (Carabidae, Scarabaeidae, Staphylinidae and Tenebrionidae families), Hymenoptera order (Cydnidae family), Isoptera order (Termitidae family) and Orthoptera order (Acrididae and Gryllidae family).

4.3.4.1 The Insect Sample Collection on the Ground

The sample collecting on the surface found that DEF had 29 insects counted as the ratio of insects found in the studied area, mostly found were the Blattodea order**,** Hymenoptera order, Coleoptera order and Orthoptera order or counted as 44.83, 17.24, 34.48 and 3.45%, respectively of total insect numbers. The

highest amount of insects found in summer season while the least amount was found in rainy season and calculated to be 48.28 and 10.35% of all the insects found as shown in Table 4.15.

In ECO, the total numbers of insects were 46 by counted as the ratio of insects found in the studied area. Mostly found were the Isoptera order, Coleoptera order and Blattodea order, Hymenoptera order had the same amount which counted as 45.65, 19.57 and 17.39% of total insects which none of insects found in Orthoptera order and the highest amount of insects were found in summer season and least amount found on rainy season which counted as 71.74 and 8.70% of total insects found as shown in Table 4.16.

In DDF, there were 72 insects found by calculating in the ratio of insects found in the studied area, mostly found was the Blattodea order, Isoptera order, Coleoptera order, Hymenoptera order and Orthoptera order at the same amount which are 62.5, 18.06, 8.33 and 5.56% of total insects. The highest amount of insects found in winter while the least was found in summer season at 37.5 and 29.17% of total insects found as shown in Table 4.17.

Blattodea order found in DEF at the amount of 13 individuals was 19.70%, ECO found 8 individual was 12.12% and found in DDF for 45 individual was 61.18%. Only one family found was Blaberidae family. In all three types of forest, the Blattodea was the most found family.

Coleoptera order found in four families which were Carabidae, Scarabaeidae, Staphylinidae and Tenebrionidae, in DEF five were found and calculated to be 25%. The most family found was Carabidae. In ECO, nine individauls were found and calculated to be 45%, the most family found was

Scarabaeidae and in DDF six individuals were found or 30% and the most family found was the Scarabaeidae.

Hymenopter order was found in three types of forest at 22 individuals. They mostly found in DEF at the amount of 10 individuals that was 45.45% followed by the ECO had 8 individuals that was 45.45% and the least were found in DDF for 4 individuals that was 18.18% and only family found was the Cydnidae.

Isoptera order found only family Termitidae at the total amount in three forests at 35 individuals, mostly found in ECO for 21 individuals that was 60% followed by DDF that found at the amount of 13 individuals that was 37.14% and the least were found in DDF only one individual that was 2.6%.

Orthoptera order found two families which were Acrididaeand and Gryllidae that investigated only in DDF for 4 individuals and mostly found in summer season for 3 insects or 75%, rainy season for 1 insect or 25%.

From the study of litter insect found on the surface soil in three types of 3 forests, it was found that within the amount of 9 families had 146 insects, Blaberidae family had the highest amount at 67 individuals that was 45.89% followed by Termitidae, Formicidae, Carabidae, Scarabaeidae, Tenebrionidae, Staphylinidae and Acrididae family which equal to Gryllidae at the amount of 67, 35, 22, 11, 4,2 and 1, respectively that were 45.89, 23.97, 15.07, 7.53, 2.74, 1.37 and 0.68%, respectively as shown in Table 4.18.

In ECO forest, the amount of insect in Formicidae family found the most in summer while in DEF and DDF, found the insects of Blaberidae family which the most appeared in winter and rainy season, respectively.

In the ECO and DEF forest, the most insects from every family found in summer except in DDF forest that insect in every family mostly found in winter.

4.3.4.2 The Insect Sample Collection in Subsoil Area

Orthoptera order was not found in the subsoil areas of the three forest habitats. In DEF found 33 individuals which counted as the ratio of insects found in the studied area, mostly found were the Isoptera order, Hymenoptera order, Coleoptera order and Blattodea order which were 48.49, 33.33, 12.12 and 6.06%, respectivly. The most amount of insects were found in summer season and winter at 36.36% of total insects found as shown in Table 4.15.

In ECO, all 79 insects found by calculating in the ratio of insects found in the study area mostly found were the Hymenoptera order, Isoptera order, Coleoptera order equal to Blattodea order and Orthoptera order which were 41.77, 34.18, 11.39 and 12.66%, respectively. The mostly amount of insects were found in summer season and the least were found in winter at 49.38 and 22.79% of total insects found as shown in Table 4.16.

In DDF, 60 insects, mostly found were the Hymenoptera order, Isoptera order, Coleoptera order, Blattodea order and Orthoptera order which were 51.67, 25, 11.67, 10 and 1.67% of total insects. The highest amount of insects was found in summer season and the least was found equally in rainy season and winter at 55.66 and 21.67% of total insects found as shown in Table 4.17.

Blattodea order was found in DEF at 2 individuals or 11.11%, ECO at 9 individuals or 50% and found in DDF for 7 individuals or 38.89%. Only one family

found was the Blaberidae family. In three types of forest, it was found that Blattodea order was the most abundant.

Coleoptera order was found in four families which were Carabidae, Scarabaeidae and Staphylinidae and Tenebrionidaer at the same amount. Coleoptera order in ECO was found at 9 individuals or 50%, the most family found was Carabidae. In DDF, found at the amount of 5 individuals or 27.78%, the most family found was the Scarabaeidae and in DEF, 4 individuals were found or 22.22% and the most family found was Carabidae.

Hymenoptera order had the total amount from three types of forests at 75 individuals most were found in ECO at 33 individuals or 44% followed by DDF at the amount of 31 individuals or 41.33% and the least were found in DEF at the amount of 11 individuals or 14.67%, only one family was found which was Cydnidae.

Isoptera order was found in only one family which was Termitidae in total from three forests at 58 individuals. Mostly was found in ECO for 27 individuals or 46.55% followed by DEF for 16 individuals or 27.59% and the least were found in DDF for the amount of 15 individuals or 25.86%.

Orthoptera order was found in two families which were Acrididaeand family and Gryllidae and found in summer season of ECO and rainy season of DDF at the same amount of 2 individuals and none of Orthoptera order found in DEF.

From the study, insect in the litter that found in subsoil of three forests found that in 9 families had the total number of 172, mostly were Formicidae family at 67 or counted to be 45.89% secondly, were Termitidae, Blaberidae, Scarabaeidae, Carabidae, Gryllidae and Tenebrionidae were equal to Staphylinidae at the amount of

75, 58, 18, 11, 6, 2 and 1 counted as 43.60, 33.72, 10.47, 6.39, 3.49, 1.17 and 0.58%, respectively and did not find Acrididae family as shown in Table 4.18.

In the ECO and DDF forest, we found most of the insect found were in Formicidae family in summer while, in DEF most of the insect found in Termitidae family in rainy season. The soil insect in three forests which were ECO, DEF and DDF forest mostly found in all families in summer.

When bringing the amount of insect found on the surface and subsoil from three types of forests, the total number was 318 by the family that mostly found was Formicidae at the amount of 97 individuals that was 30.50% followed by Termitidae, Blaberidae, Scarabaeidae, Tenebrionidae, Staphylinidae Gryllidae and Acrididae families at the amount of 97, 93, 85, 17, 15, 4, 3 and 1, respectively which were 30.50, 29.25, 26.73, 5.35, 4.71, 1.26, 0.93 and 0.31%, respectively.

Table 4.15 Litter insects in dry evergreen forest of each season from July 2007 to June 2008.

Orders	**Families**	**Soil types (individual)**					
		Surface soil			**Subsoil**		
		Winter	**Rainy season**	**Summer**	**Winter**	**Rainy season**	**Summer**
Blattodea	Blaberidae	9 (14.29%)	1 (1.59%)	4 (6.35%)	0	0	2 (3.15%)
Coleoptera	Carabidae	3 (4.76%)	0	1 (1.59%)	2 (3.15%)	0	1 (1.59%)
	Scarabaeidae	0	0	0	0	0	1 (1.59%)
	Staphylinidae	0	0	0	0	0	0
	Tenebrionidae	0	0	1 (1.59%)	0	0	0
Hymenoptera	Formicidae	0	2 (3.15%)	8	6 (9.52%)	0	5 (7.94%)
Isoptera	Termitidae	1 (1.59%)	0	0	4 (6.35%)	9 (14.29%)	3 (4.76%)
Orthoptera	Acrididae	0	0	0	0	0	0
	Gryllidae	0	0	0	0	0	0

Table 4.16 Litter insects in ecotone of each season from July 2007 to June 2008.

Orders	Families	Soil types (individual)					
		Surface soil			Subsoil		
		Winter	Rainy season	Summer	Winter	Rainy season	Summer
Blattodea	Blaberidae	0	3 (2.4%)	5 (4%)	1 (0.8%)	4 (3.2%)	4 (3.2%)
Coleoptera	Carabidae	1 (0.8%)	1 (0.8%)	1 (0.8%)	0	0	2 (1.6%)
	Scarabaeidae	0	0	4 (3.2%)	1 (0.8%)	0	4 (3.2%)
	Staphylinidae	0	0	2 (1.6%)	0	1 (0.8%)	0
	Tenebrionidae	0	0	0	1 (0.8%)	0	0
Hymenoptera	Formicidae	8 (6.4%)	0	0	8 (6.4%)	8 (6.4%)	17 (13.6%)
Isoptera	Termitidae	0	0	21 (16.8%)	7 (5.6%)	9 (7.2%)	11 (8.8%)
Orthoptera	Acrididae	0	0	0	0	0	0
	Gryllidae	0	0	0	0	0	1 (0.8%)

Table 4.17 Litter insects in dry dipterocarp forest of each season from July 2007 to June 2008.

Orders	Families	Soil types (individual)					
		Surface soil			Subsoil		
		Winter	Rainy season	Summer	Winter	Rainy season	Summer
Blattodea	Blaberidae	10 (3.14%)	18 (5.66%)	17 (5.35%)	3 (0.94%)	3 (0.94%)	1 (0.31%)
Coleoptera	Carabidae	3 (0.94%)	1 (0.31%)	0	0	1 (0.31%)	0
	Scarabaeidae	0	0	0	0	2 (0.63%)	3 (0.94%)
	Staphylinidae	0	0	0	0	0	0
	Tenebrionidae	1 (0.31%)	0	1 (0.31%)	0	0	0
Hymenoptera	Formicidae	0	4 (1.26%)	0	5 (1.57%)	2 (0.63%)	24 (7.55%)
Isoptera	Termitidae	13 (4.09%)	0	0	5 (1.57%)	4 (1.26%)	6 (1.89%)
Orthoptera	Acrididae	0	0	1 (0.31%)	0	0	0
	Gryllidae	0	1 (0.31%)	0	0	1 (0.31%)	0

Table 4.18 Total of Litter insects in three habitat types from July 2007 to June 2008.

Orders	Families	Number (individual)
Blattodea	Blaberidae	85(26.73%)
Coleoptera	Carabidae	17(5.35%)
	Scarabaeidae	15(4.72%)
	Staphylinidae	3(0.94%)
	Tenebrionidae	4(1.26%)
Hymenoptera	Formicidae	97(30.50%)
Isoptera	Termitidae	93(29.25%)
Orthoptera	Acrididae	1(0.31%)
	Gryllidae	3(0.94%)

Table 4.19 Species diversity index and evenness index of surface soil insects in the SERS.

Habitat type	DEF	ECO	DDF
Shannon's index	1.743	2.001	1.915
Evenness	0.891	0.862	0.682

Seasonal species diversity for every ecosystem was calculated using Shannon's index (H′) which was found varying by the ecosystem types. For DEF, the species diversity index was observed highest during summer (2.30) and lowest during rainy season (0.92) but the species evenness was found the lowest during summer and the highest during winter. The average diversity index and species equitability of all seasons in DEF were 1.743 and 0.891, respectively. In DDF, both the species diversed in summer and even in winter were found the lowest during with the value of 0.99 and 0.49, respectively as shown in Figure 4.7.

The highest diversity index was during the winter but the species evenness was highest in rainy season. The average species diversity index and species equitability of all seasons were 1.915 and 0.682, respectively.

The species diversity index of ECO forest was observed the highest during summer (1.59) and the lowest during the winter (0.50). The species equitability was found highest in rainy season (0.81) and the lowest in winter (0.50). The average diversity index and species equitability of all seasons were 2.001 and 0.862 respectively as shown in Table 4.20.

Table 4.20 Species diversity index and evenness index of subsoil insects in the SERS.

Habitat type	DEF	ECO	DDF
Shannon's index	1.640	2.72	1.864
Evenness	0.739	0.738	0.721

Seasonal species diversity for every ecosystem was calculated using Shannon's index (H′) which was found varying by the ecosystem types. For DEF, the species diversity index was observed highest during summer (2.52) and lowest during rainy season (0.51) but the species evenness was found the lowest during rainy and the highest during summer. The average diversity index and species equitability of all seasons in DEF were 1.640 and 0.739, respectively.

In DDF, both the species diversity index and evenness were found the lowest during summer with the value of 1.25 and 0.63, respectively. The highest diversity index was shown during the rainy season but the species evenness was highest in

winter. The average species diversity index and species equitability of all seasons were 1.864 and 0.721, respectively.

The species diversity index of ecotone forest was highest during summer (2.07) and the lowest during the winter (0.75). The species equitability was found highest in rainy season (0.85) and lowest in winter (0.75). The average diversity index and species equitability of all seasons were 2.72 and 0.738 respectively as shown in Table 4.20.

The species diversity index and eveness of soil insects in the SERS were shown in Table 4.20 and Figure 4.7.

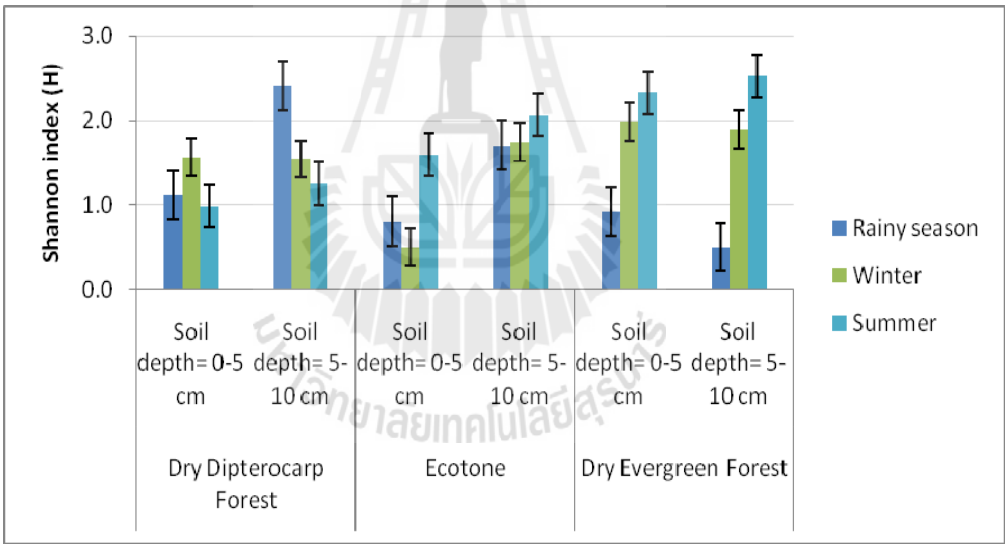

Figure 4.7 The Shannon's index in soil different from during July 2007 to June 2008.

4.3.5 The Comparison of Correlation between Environmental Factor and Abundance of Soil and Litter Insects

The investigation in 2007-2008, the correlation value of the environmental factors and Shannon diversity index of DDF, DEF and ECO as shown in Table 4.21,

the amount of phosphorus and C/N ratio were consistently related in the same direction with Shannon diversity index which if the amount of phosphorus and C/N ratio increase it may result to the increasing amount of Shannon diversity as well.

Table 4.21 Correlation (r) between environmental factor and abundance of soil and litter insects from June 2007 and July 2008.

Soil properties	Shanon's index					
	DDF		ECO		DEF	
	r	*P-value*	*r*	*P-value*	*r*	*P-value*
Bulk density (g/cm^3)	0.831*	0.040	-0.011	0.983	0.457	0.362
Porosity(%)	-0.831*	0.040	0.011	0.983	0.457	0.362
Soil moisture (%)	-0.721	0.106	0.398	0.434	0.432	0.392
Soil pH	0.905*	0.013	-0.504	0.308	0.021	0.968
Organic matter (%OM)	0.538	0.270	-0.788	0.063	0.284	0.585
C/N ratio	0.336	0.580	0.511	0.300	0.115	0.828
Water content of litter (%)	0.402	0.429	0.612	0.197	0.172	0.744
Total nitrogen (%N)	0.593	0.214	-0.362	0.480	-0.087	0.870
Available phosphorus (ppm)	0.707	0.117	-0.093	0.861	0.864*	0.026
Available potassium (ppm)	0.523	0.287	0.001	0.998	0.266	0.611

Data analysis by Peason's correlation matrix at the different level of confidence (*p≤0.05, **p≤0.01)

In DDF, it was found that the amount of nitrogen, potassium, organic matter, pH, soil moisture, bulk density and porosity had inconsistent related to Shannon diversity by the amount of soil moisture and porosity had changed in contrastive direction with the Shannon diversity index. If those amount of things increased, it may result on the reduction of the amount of Shannon diversity index. The amount of nitrogen, potassium, organic matter, pH and bulk density had relationship in the same direction with Shannon diversity index. If those amounts of things increased, it may result on the increasing amount of Shannon diversity index.

In ECO, the amount of phosphorus, nitrogen, organic matter, pH and bulk density had changed in converse direction with the Shannon diversity index. If those amount of things increased, it may result on the reduction of the amount of Shannon diversity index. And the amount of potassium, soil moisture and porosity had relationship in the same direction with Shannon diversity index. If those amounts of things increased, it may result on the increasing amount of Shannon diversity index as well.

In DEF, the amount of nitrogen and porosity had changed in converse direction with the Shannon diversity index. If the amount of nitrogen and porosity increase, it may result to the reduction amount of Shannon diversity index and the amount of potassium, organic matter, pH, soil moisture and bulk density also had the relationship in the same direction with Shannon diversity index as if those amount of things increased, it may result on the increasing in the amount of Shannon diversity index.

The results could be explained in the way of the vertical distribution of soil fauna in the difference forest type, dry evergreen forests, dry dipterocarp forest and

ecotone, differ due to the environmental factors including; climate, organic matter in the soil, soil moisture and water conternt of litter.

Organic matter: a greater deposit of organic matter is presented in the dry evergreen forest biomes compared to dry dipterocarp forest biomes and soil fauna feeds on them as their primary source of food. It appears that when there is an abundant deposit of organic matter it can cause the built up of soil fauna population resulting in plentiful excretion of various nutrients into the soil. Therefore, it can be concluded that the dry evergreen forest will shelter more soil fauna than dry dipterocarp forest. Moreover, the nutrient level in the soil, brought about by the decomposition process, is also higher. In term of vertical distribution, there will be a greater distribution of soil fauna in the top soil (surface soil) that is abundant in organic matter. As the depth in soil layer increases, the vertical distribution decreases as with the level of nutrients and soil fauna (Gajaseni, 1976).

Climate as a factor: Climate has a great influence on the vertical distribution of soil fauna in terms of temperature that vary from season to season. In the summer, the temperature in forests will be higher compared to the rainy season. However, because the dry dipterocarp forest is an open area it will receive direct contact with heat-rays from the sun which is a different case in dry evergreen forests that is inhabited by diverse trees that block out the sky. These trees act as shields blocking heat-rays. From this reason, the temperature during the summer will be higher around dry diptrocarp forest than the dry evergreen forests. With the changes in weather, this could possibly cause an effect on the vertical distribution of soil fauna.

Soil moisture and water content of litter: The level of moisture in the soil and in the organic matter will be large or small depending on the quantity of rainfall. It

can be observed that during the rainy season the soil moisture reaches its highest point and this gradually decrease as summer approaches. The dry evergreen forest is rich in diverse trees that aid the process of water absorption in the soil. The level of water content is higher in the dry evergreen forests than the dry dipterocarp forest throughout the year. Therefore, during the rainy season where adequate moisture is present in the organic matter there will be gathering of soil fauna. However, as the depth increases, the distribution decreases. In the summer, soil fauna will present in deeper areas of the soil. Conclusions that can be summerized from this research is the fact that in the rainy season the vertical distribution of soil fauna depends on the level of moisture in the soil and organic matter as well as the quantity of organic matter combined. On the other hand, during the summer the main determining factor is the soil moisture.

Most of the insects live in soil have been taken the role of decomposers which usually, the insects were only the factor that help speed the decomposition. Thus, there were several types of insect that help reduce the size of organic matter in the forest which resulted to the bacteria, fungus and other microbe. The weather, as well, can make rapidly decomposing of organic matter and to add better plentitude to the soil of the forest. The important insect that took the role as decomposer in the forest were such as underground termite, damp wood termite, beetle lavae that ate decaying wood and forest Blattodea that ate the decayed wood. Moreover, there were also many of collemborans and thysanulans that lived with the humus of organic matter or classes of soil however, it did not have much important to help improve the structure and the plentitude of soil.

The important of the insects lived in soil resulted from their soil digging to get food and place for living as well as the decomposing of things in the soil to be the food. The insect lived in soil ate the organic matter as their food but for the earth science aspect insect had rarely important. However, it still be benefit to soil and plants. Both insects and other arthropods related to soil quality in each area which may create changing in soil structure. Besides, these could be the predator such as Scarabidae, Staphylinidae that ranked in the class of Coleoptera and some were Scavenger like Hymenoptera and Isoptera (Wiwatwitaya, 1991)

Wiwatwitaya (1991) summarized that the burnt area will not find any insect live and in the area largely burnt together with the spraying of the pesticide had resulted on the less size of the insect population in the soil. But if the area had the plentitude level of organic matter, it could protect the impact from fire if stayed in the deeper surface. The fire caused those insect eat the plant humus as die food which those insect had made the plant organic matter into litter and decomposed the humus. The catch fire made the climate in that area change such as higher temperature and unstable moisture of soil surface. The change of weather conditions in that area made the hard wings Coleoptera could not live in that area. The result of research found that diversity and intensity of the insect in the soil area that was not burnt were more than the area that was burnt for 5 day and the area after 1-7 years burnt found the class of Hymenoptera especially, Formicidae in the big amount similar to this study. It was also found that though it took a long time to burn since, the soil insect had the place to hide and the source of food as well as it could adapt themselves to changing condition. Though, after the catch fire, the decomposer insect returned to live in the burnt area or the plant litter was not all burnt. Especially, Isoptera and Hymenoptera

came to live before other type of insect. Ahlgren (1974) found that Hymenoptera and Isoptera had the ability to adapt themselves to the hot and dry climate condition. If there was much amount of class of plant humus, many of these insect will be found live in the high amount as well. These enhanced the decomposition of litter and humus to the better structure of soil and added more plentitude to soil. Thus, insects trend to live more in the area.

CHAPTER V

CONCLUSION

This study, in regards to diversity of soil insects, litter insects and their relationship to the decomposition of litter, can be concluded that there were 6 orders and 10 families of soil insects. Hymenoptera was the most commonly found in the year 2005. Isoptera was the most discovered on the soil surface at DDF and Hymenoptera was the most found in the subsoil at ECO in the year 2007-2008. Moreover, soil insects on the soil surface were higher than the subsoil insects.

The rate of decomposition of soil surface and subsoil of the ECO in the summer had the highest at 61.00±12.76 and 44.39±17.57, respectively. In Addition, the method of laying litter bag on the ground had less decomposition rate than the method of burying the litter bag underground.

The correlation between soil insect diversity and environmental factors was studied during year 2005. The results showed that soil potassium was significantly positive correlation with soil insect diversity ($p \leq 0.01$). It can be concluded that the correlation of environmental factors and Shannon diversity index that was investigated in 2005, the amount of potassium had consistent relation in the same direction with Shannon diversity index. If the amount of potassium increases, it may result to the increasing amount of Shannon diversity index as well.

In addition, the correlation between litter insect diversity and environmental factors was studied during June 2007 and July 2008 showed that bulk density, soil pH and phosphorus were significantly positive correlation with soil insect diversity, while, porosity showed negative correlation ($p \leq 0.05$). Therefore, the correlation value of the environmental factors and Shannon diversity index, the amount of phosphorus, bulk density and soil pH were consistently related in the same direction with Shannon diversity index. If the amounts of phosphorus, bulk density and soil pH increase it may result to the increasing amount of Shannon diversity as well.

Suggestion

1. Sampling of soil insect by hand-sorting can be used for ants and termites, but not suitable for small and fast moving insects.

2. The disadvantages of using Berlese funnel could be that soil insects may die due to the heat.

3. This study composed of three types of forest, i.e. dry dipterocarp forest, dry evergreen forest, and the ecotone area. Further study should be carried out to study different types of forests.

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APPENDICES

APPENDIX A

DATA OF EXPERIMENTS

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Table A1 Surface soil properties in dry evergreen forest of SERS in 2005.

Month	Soil moisture (%)	Water content in litter (%)	pH	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)
Jan	6.35	13.11	3.94	1.17	.92	0.05	0.29	9.93
Feb	5.696	13.97	4.15	1.78	1.4	0.16	0.60	19.86
Mar	4.71	12.94	3.79	2.85	2.24	0.17	0.82	9.91
Apr	5.49	11.61	3.36	2.85	2.25	0.13	0.81	39.86
May	5.83	11.51	3.39	3.71	2.92	0.16	0.99	49.74
Jun	7.00	14.73	3.57	2.4	1.89	0.13	0.49	19.83
Jul	7.38	15.55	3.38	2.17	1.71	0.16	1.07	19.87
Aug	7.64	14.96	3.89	2.81	2.21	0.14	0.51	9.976
Sept	7.56	15.67	3.28	2.73	2.15	0.14	0.88	9.91
Oct	2	14.27	3.23	1.84	1.45	0.13	0.76	9.95
Nov	5.33	13.87	3.59	2.31	1.82	0.11	0.56	9.95
Dec	5.88	13.99	4.24	1.88	1.48	0.08	0.61	29.79
Mean	5.91	13.85	3.65	2.38	1.87	0.13	0.70	19.87
SD.	1.55	1.36	0.34	0.67	0.53	0.04	0.23	13.42

Table A2 Surface soil properties in ecotone forest of SERS in 2005.

Month	Soil moisture (%)	Water content in litter (%)	pH	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)
Jan	5.82	12.08	5.23	2.37	1.87	0.13	0.67	39.78
Feb	5.35	11.56	6	3.48	2.74	0.02	0.96	19.71
Mar	4.06	10.84	4.88	1.96	1.55	0.18	0.93	39.71
Apr	4.91	9.94	5.11	3.17	2.49	0.20	0.53	39.79
May	5.57	10.09	5.15	2.12	1.67	0.14	1.91	49.56
Jun	6.31	12.14	4.43	3.04	2.39	0.11	1.87	39.81
Jul	6.69	12.31	4.86	3.02	2.38	0.16	1.13	29.83
Aug	6.89	13.23	4.48	3.22	2.54	0.18	1.04	39.79
Sept	6.97	13.07	4.9	2.85	2.25	0.22	0.63	59.83
Oct	5.94	12.29	3.78	1.91	1.50	0.13	0.80	49.82
Nov	5.61	12.07	4.86	2.30	1.81	0.07	0.65	79.52
Dec	4.65	12.06	4.51	2.64	2.08	0.11	0.87	19.82
Mean	5.73	12.52	4.85	2.67	2.11	0.14	1.00	42.25
SD.	0.90	2.55	0.54	0.53	0.42	0.06	0.45	16.53

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Table A3 Surface soil properties in dry dipterocarp forest of SERS in 2005.

Month	Soil moisture (%)	Water content in litter (%)	pH	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)
Jan	4.23	12.23	4.98	1.72	1.35	0.08	0.62	19.74
Feb	4.37	12.44	5.24	1.09	0.86	0.06	0.59	0.00
Mar	3.83	11.81	4.6	1.32	1.04	0.03	0.70	39.60
Apr	4.18	9.69	4.28	2.13	1.68	0.11	1.66	29.80
May	4.31	11.54	4.21	2.40	1.89	0.13	0.58	0.00
Jun	5.91	13.43	5.75	1.38	1.09	0.05	0.87	0.00
Jul	5.91	13.64	4.38	0.87	0.68	0.05	0.65	19.83
Aug	5.11	13.90	4.47	1.38	1.08	0.08	0.57	29.84
Sept	5.63	14.21	3.97	1.15	0.91	0.08	1.06	99.64
Oct	5.06	13.03	3.8	1.56	1.23	0.07	1.16	9.94
Nov	4.55	12.86	3.95	1.11	0.87	0.06	0.75	0.00
Dec	4.54	12.63	5.54	2.15	1.69	0.08	0.51	19.88
Mean	4.80	12.62	4.60	1.52	1.20	0.07	0.81	22.36
SD.	0.71	1.23	0.64	0.48	0.38	0.03	0.34	27.89

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Table A4 Surface soil properties in dry evergreen forest of SERS in July 2007 - June 2008.

Month	Bulk density (g/cm^3)	Porosity (%)	Soil moisture (%)	Water content in litter (%)	pH	Soil temperature (^0C)	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)	Remaining Weight (%)
Jul	1.103	58.37	12.36	8.39	4.12	26	4.21	3.32	0.23	6.77	29.73	71.45
Aug	1.08	59.21	10.69	12.03	4.20	25	3.82	3.01	0.21	8.82	43.00	67.30
Sept	1.06	59.89	11.82	10.74	3.03	26	3.55	2.79	0.25	4.37	29.71	48.98
Oct	1.097	58.62	10.54	11.67	4.43	23.33	4.04	3.18	0.27	5.13	99.12	43.40
Nov	1.18	55.48	11.83	11.93	4.4	19.67	4.20	3.30	0.21	3.10	29.92	60.16
Dec	1.21	54.23	9.30	17.59	3.4	19	4.26	3.35	0.19	3.31	13.33	50.21
Jan	1.28	55.58	7.01	22.23	2.28	24	3.99	3.14	0.24	4.49	42.82	30.89
Feb	1.013	61.79	6.68	9.39	4.43	24.33	3.93	3.10	0.20	4.46	32.68	52.23
Mar	0.96	63.22	5.60	8.43	4.04	26.33	2.73	2.15	0.23	3.78	49.77	82.57
Apr	1.46	44.79	4.72	14.41	4.10	25.33	4.03	3.18	0.19	2.83	9.87	59.57
May	1.23	53.67	5.62	8.30	3.76	25	3.92	3.09	0.25	4.12	41.08	11.22
Jun	1.17	55.89	20.55	16.07	3.85	25.67	4.24	3.34	0.21	3.33	32.37	8.22
Mean	1.15	56.73	9.73	12.60	3.84	23.63	3.91	3.08	0.22	4.45	37.78	48.85
SD.	0.13	4.79	4.37	4.29	0.65	2.60	0.42	0.33	0.03	1.72	22.55	22.69

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Table A5 Subsoil properties in dry evergreen forest of SERS in July 2007 - June 2008.

Month	Soil moisture (%)	pH	Soil temperature (^{0}C)	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)	Remaining Weight (%)
Jul	7.67	3.85	24	2.95	2.33	0.11	5.6231	32.66	68.62
Aug	11.24	4.21	24	4.03	3.17	0.17	8.81	32.71	79.98
Sept	12.69	3.09	24	3.02	2.38	0.19	3.28	29.83	30.14
Oct	14.09	3.99	22	3.28	2.58	0.22	3.79	98.92	6.58
Nov	11.43	3.92	19	2.80	2.21	0.11	2.02	86.40	18.83
Dec	11.35	3.60	18.33	2.85	2.25	0.15	2.49	16.53	26.33
Jan	6.97	3.65	22.67	3.13	2.46	0.19	3.263	29.58	36.82
Feb	5.23	4.12	21.67	3.74	2.94	0.20	3.72	29.81	5.97
Mar	5.12	4.32	24.33	2.90	2.28	0.16	2.11	9.95	19.75
Apr	6.07	4.21	25.67	3.59	2.83	0.17	2.35	9.96	22.50
May	6.49	4.24	25.33	3.39	2.67	0.18	3.18	22.78	2.57
Jun	21.65	4.76	24.33	4.17	3.28	0.17	2.52	28.87	0.36
Mean	10	4.00	22.59	3.32	2.62	0.17	3.60	35.67	26.54
SD.	4.81	0.42	2.63	0.47	0.37	0.03	1.92	27.96	25.13

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Table A6 Surface soil properties in ecotone forest of SERS in July 2007 - June 2008.

Month	Bulk density (g/cm^3)	Porosity (%)	Soil moisture (%)	Water content in litter (%)	pH	Soil temperature (^0C)	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)	Remaining Weight (%)
Jul	1.28	51.57	11.03	5.77	4.77	29	2.80	2.21	0.15	6.69	56.05	63.97
Aug	1.28	51.67	10.90	10.71	4.69	28.5	2.90	2.28	0.10	8.56	29.72	69.75
Sept	1.178	55.55	12.02	6.61	4.34	30	2.44	1.92	0.19	5.72	42.90	64.96
Oct	1.175	55.68	10.21	8.75	3.78	25	2.21	1.74	0.20	5.91	59.25	67.21
Nov	1.25	52.28	10.94	13.96	5.16	23	2.86	2.26	0.10	3.33	43.14	42.10
Dec	1.65	55.93	10.57	27.60	4.42	26.67	2.18	1.71	0.10	4.27	19.92	43.35
Jan	1.42	46.41	6.44	19.29	4.83	25	2.38	1.87	0.18	5.35	49.64	36.13
Feb	1.104	58.32	5.38	10.37	5.19	34.33	2.36	1.85	0.11	4.02	26.28	19.55
Mar	1.37	48.40	5.65	7.25	6.10	39.33	3.20	2.52	0.12	3.94	9.96	26.89
Apr	1.76	33.54	4.86	11.53	4.47	32.67	3.93	3.09	0.13	3.89	9.95	27.31
May	1.34	49.61	4.76	7.62	5.69	30.33	3.60	2.84	0.14	3.92	19.97	5.10
Jun	1.35	49.56	19.17	12.78	5.52	29.17	3.74	2.95	0.13	3.2	42.66	19.07
Mean	1.35	50.71	9.33	11.85	4.91	29.50	2.88	2.27	0.14	4.90	34.12	40.45
SD.	0.19	6.46	4.19	6.22	0.65	5.26	0.61	0.48	0.04	1.59	17.15	21.86

Table A7 Subsoil properties in ecotone forest of SERS in July 2007 - June 2008.

Month	Soil moisture (%)	pH	Soil temperature (^{0}C)	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)	Remaining Weight (%)
Jul	11.42	4.88	27.5	2.07	1.63	0.11	3.92	39.42	73.61
Aug	10.83	4.75	29.5	2.35	1.85	0.08	5.84	34.22	58.80
Sept	11.98	4.62	29	2.24	1.77	0.16	10.76	26.44	56.80
Oct	12.70	4.61	24.33	2.62	2.06	0.12	4.47	82.56	20.75
Nov	13.12	4.85	22.33	2.39	1.88	0.13	3.63	36.56	41.34
Dec	10.86	4.61	24	2.43	1.91	0.13	3.54	16.51	42.81
Jan	7.01	4.71	22.67	2.33	1.83	0.10	5.05	66.22	41.10
Feb	6.34	5.15	28	1.99	1.56	0.13	3.45	26.57	7.00
Mar	5.13	5.70	33.33	3.08	2.43	0.11	3.36	9.97	23.02
Apr	5.09	4.17	30	3.11	2.45	0.09	4.1	10	43.29
May	5.47	5.59	27.83	3.40	2.68	0.12	2.96	19.97	1.98
Jun	19.87	5.1	28.67	3.39	2.67	0.12	2.85	32.69	9.69
Mean	9.99	4.9	26.8	2.62	2.06	0.12	4.50	33.43	35.02
SD.	4.4	0.43	3.71	0.50	0.40	0.02	2.15	21.74	22.57

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Table A8 Surface soil properties in dry dipterocarp forest of SERS in July 2007 - June 2008.

Month	Bulk density (g/cm^3)	Porosity (%)	Soil moisture (%)	Water content in litter (%)	pH	Soil temperature (^0C)	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)	Remaining Weight (%)
Jul	1.087	58.99	12.78	6.33	5.28	31	2.61	2.06	0.10	5.47	36.16	54.55
Aug	1.287	51.47	12.27	5.49	4.52	32	2.22	1.75	0.08	12.38	59.30	82.05
Sept	1.064	59.84	11.07	6.44	4.68	32	2.99	2.35	0.18	5.07	33.03	29.69
Oct	1.185	55.28	10.17	6.85	4.42	25	2.73	2.15	0.14	4.39	88.51	31.89
Nov	1.24	53.14	12.02	10.04	4.97	23	2.63	2.07	0.10	2.96	36.20	54.68
Dec	1.46	44.79	8.79	20.09	5.07	29.5	2.54	2.00	0.13	4.38	19.71	32.86
Jan	1.21	54.41	4.84	19.37	4.81	28.67	2.81	2.22	0.11	5.27	23.12	32.93
Feb	1.13	57.81	5.26	6.28	5.34	31	2.84	2.24	0.15	5.397	33.11	17.55
Mar	1.13	57.42	4.66	5.62	5.66	36.67	3.11	2.45	0.15	3.564	9.96	14.68
Apr	1.65	37.70	6.46	10.82	5.12	32	2.98	2.34	0.15	3.5	19.88	50.95
May	1.2	54.61	3.66	5.31	5.03	30	3.77	2.97	0.18	2.999	33.24	3.77
Jun	1.16	56.23	18.89	14.36	4.65	32.33	3.97	3.13	0.12	2.196	40.39	3.64
Mean	1.23	53.47	9.24	9.75	4.96	29.80	2.93	2.31	0.13	4.80	36.05	34.10
SD.	0.17	6.37	4.49	5.39	0.36	4.04	0.50	0.39	0.03	2.62	20.7	23.26

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Table A9 Subsoil properties in dry dipterocarp forest of SERS in July 2007 - June 2008.

Month	Soil moisture (%)	pH	Soil temperature (^{0}C)	OM (%)	OC (%)	N (%)	P (ppm)	K (ppm)	Remaining Weight (%)
Jul	12.53	5.09	30	1.45	1.14	0.05	4.98	27.73	54.39
Aug	11.71	5.09	28.5	1.88	1.48	0.06	4.895	32.83	40.77
Sept	12.35	4.78	31.5	3.06	2.41	0.60	6.28	23.12	2.40
Oct	11.62	4.26	24	3.37	2.66	0.07	6.25	71.72	1.03
Nov	12.20	4.85	21.67	2.05	1.61	0.13	2.02	35.87	7.82
Dec	10.86	5.00	29.33	2.29	1.80	0.11	3.51	13.29	21.01
Jan	5.03	4.58	26.67	2.55	2.00	0.04	4.64	56.37	3.07
Feb	5.15	5.67	27.67	2.26	1.78	0.12	7.63	29.49	0.92
Mar	4.95	5.93	28.33	3.02	2.38	0.08	2.434	14.90	2.13
Apr	4.36	5.16	29	2.86	2.25	0.08	2.15	16.52	2.06
May	6.75	5.37	29	3.72	2.93	0.07	2.648	29.95	2.80
Jun	17.27	4.97	30	3.71	2.92	0.08	1.76	29.31	0.6
Mean	9.57	5.06	24.3	2.69	2.11	0.12	4.10	33.29	12.38
SD.	4.15	0.45	2.77	0.73	0.57	0.15	1.96	16.95	18.61

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Table A10 Type of insect in ecotone forest of SERS in 2005.

Family	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blattodea												
Blaberidae	0	2	3	3	11	2	0	2	0	2	3	2
Coleoptera												
Carabidae	2	0	1	1	1	0	0	0	0	0	0	0
Scarabaeidae	0	3	0	1	0	1	0	0	3	0	2	0
Staphylinidae	0	0	0	1	0	4	0	0	0	0	0	0
Hemiptera									0			
Cydnidae	0	0	0	1	0	0	1	0	0	0	0	0
Hymenoptera												
Formicidae	8	5	0	0	17	5	20	0	12	0	5	0
Isoptera												
Termitidae	0	1	0	4	0	3	5	14	0	3	0	0
Total	10	11	4	8	29	15	26	16	15	5	10	2

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Table A11 Type of insect in dry dipterocarp forest of SERS in 2005.

Family	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blattodea												
Blaberidae	0	0	0	0	0	0	6	0	1	14	0	0
Coleoptera												
Carabidae	0	0	0	0	1	1	1	0	0	0	0	3
Scarabaeidae	1	1	0	0	1	0	1	0	3	0	0	0
Staphylinidae	0	0	0	0	0	0	1	0	0	13	0	0
Hemiptera												
Cydnidae	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera												
Formicidae	0	0	5	4	0	0	0	0	8	0	0	0
Isoptera												
Termitidae	0	0	0	0	0	0	0	13	5	0	10	0
Total	1	1	5	4	2	1	9	13	17	27	10	3

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Table A12 Type of insect in dry evergreen forest of SERS in 2005.

Family	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blattodea												
Blaberidae	2	0	0	0	1	0	0	0	1	0	0	0
Coleoptera												
Carabidae	0	0	0	0	1	0	0	0	0	0	0	0
Scarabaeidae	0	2	1	2	0	0	0	0	1	1	0	1
Staphylinidae	0	0	0	1	0	0	0	0	0	0	0	0
Hemiptera												
Cydnidae	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera												
Formicidae	0	0	0	10	4	0	0	30	12	0	9	0
Isoptera												
Termitidae	0	0	39	3	12	13	10	3	0	0	0	0
Total	2	2	40	6	18	13	10	33	14	1	9	1

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Table A13 Surface soil type of insect in ecotone forest of SERS in July 2007 - June 2008.

Family	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blattodea												
Blaberidae	0	1	0	0	4	0	1	2	0	0	0	0
Coleoptera												
Carabidae	0	1	0	0	0	0	0	0	1	0	0	1
Scarabaeidae	0	0	0	0	4	0	0	0	0	0	0	0
Staphylinidae	0	0	0	0	2	0	0	0	0	0	0	0
Tenebrionidae	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera												
Formicidae	8	0	0	0	0	0	0	0	0	0	0	0
Isoptera												
Termitidae	0	0	9	12	0	0	0	0	0	0	0	0
Orthoptera												
Acrididae	0	0	0	0	0	0	0	0	0	0	0	0
Gryllidae	0	0	0	0	0	0	0	0	0	0	0	0
Total	8	2	9	12	10	0	1	2	1	0	0	1

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Table A14 Subsoil type of insect in ecotone forest of SERS in July 2007 - June 2008.

Family	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blattodea												
Blaberidae	0	0	0	0	4	0	2	0	2	0	0	1
Coleoptera												
Carabidae	0	1	2	0	0	0	0	0	0	0	0	0
Scarabaeidae	0	0	1	0	2	0	0	0	0	1	0	0
Staphylinidae	0	0	0	0	0	0	0	0	1	0	0	0
Tenebrionidae	0	0	0	0	0	0	0	0	0	0	1	0
Hymenoptera												
Formicidae	8	9	5	2	1	5	1	1	1	0	0	0
Isoptera												
Termitidae	7	6	0	5	0	0	0	9	0	0	0	0
Orthoptera												
Acrididae	0	0	0	0	0	0	0	0	0	0	0	0
Gryllidae	0	1	0	0	0	0	0	0	0	0	0	0
Total	15	17	8	7	7	5	3	10	4	1	1	1

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Table A15 Surface soil type of insect in dry dipterocarp forest of SERS in July 2007 - June 2008.

Family	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blattodea												
Blaberidae	7	3	0	0	14	0	9	9	0	3	0	0
Coleoptera												
Carabidae	0	0	0	0	0	0	0	1	0	0	0	3
Scarabaeidae	0	0	0	0	0	0	0	0	0	0	0	0
Staphylinidae	0	0	0	0	0	0	0	0	0	0	0	0
Tenebrionidae	0	0	1	0	0	0	0	0	0	0	1	0
Hymenoptera												
Formicidae	0	0	0	0	0	2	0	0	2	0	0	0
Isoptera												
Termitidae	0	0	0	0	0	0	0	0	0	0	13	0
Orthoptera												
Acrididae	0	0	0	0	1	0	0	0	0	0	0	0
Gryllidae	0	1	0	0	2	0	0	2	0	0	0	0
Total	7	4	1	0	17	2	9	12	2	3	14	3

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Table A16 Subsoil type of insect in Dry dipterocarp forest of SERS in July 2007 - June 2008.

Family	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blattodea												
Blaberidae	0	0	1	0	0	0	0	1	1	1	0	2
Coleoptera												
Carabidae	0	0	0	0	0	0	1	0	0	0	0	0
Scarabaeidae	0	0	0	2	1	1	0	1	0	0	0	0
Staphylinidae	0	0	0	0	0	0	0	0	0	0	0	0
Tenebrionidae	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera												
Formicidae	0	4	13	7	0	0	1	0	1	5	0	0
Isoptera												
Termitidae	5	0	0	6	0	11	0	4	0	0	0	0
Orthoptera												
Acrididae	0	0	0	0	0	0	0	0	0	0	0	0
Gryllidae	0	0	0	0	0	1	0	0	0	0	0	0
Total	5	4	14	15	1	13	2	6	2	6	0	2

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Table A17 Surface soil type of insect in dry evergreen forest of SERS in July 2007 - June 2008.

Family	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blattodea												
Blaberidae	2	0	3	1	0	0	0	0	1	0	1	6
Coleoptera												
Carabidae	0	0	0	0	1	0	0	0	0	0	0	3
Scarabaeidae	0	0	0	0	0	0	0	0	0	0	0	0
Staphylinidae	0	0	0	0	0	0	0	0	0	0	0	0
Tenebrionidae	0	0	0	1	0	0	0	0	0	0	0	0
Hymenoptera												
Formicidae	0	0	4	4	0	0	0	0	2	0	0	0
Isoptera												
Termitidae	0	0	0	0	0	0	0	0	0	1	0	0
Orthoptera												
Acrididae	0	0	0	0	0	0	0	0	0	0	0	0
Gryllidae	0	0	0	0	0	0	0	0	0	0	0	0
Total	2	0	14	6	1	0	0	0	3	1	1	9

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Table A18 Subsoil type of insect in dry evergreen forest of SERS in July 2007 - June 2008.

Family	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Blattodea												
Blaberidae	0	1	0	1	0	0	0	0	0	0	0	0
Coleoptera												
Carabidae	0	0	1	0	0	0	0	0	0	1	0	1
Scarabaeidae	0	1	0	0	0	0	0	0	0	0	0	0
Staphylinidae	0	0	0	0	0	0	0	0	0	0	0	0
Tenebrionidae	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera												
Formicidae	0	0	4	1	0	0	0	0	0	6	0	0
Isoptera												
Termitidae	3	0	0	0	3	8	1	0	0	0	1	0
Orthoptera												
Acrididae	0	0	0	0	0	0	0	0	0	0	0	0
Gryllidae	0	0	0	0	0	0	0	0	0	0	0	0
Total	3	2	5	2	3	8	1	0	0	7	1	1

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APPENDIX B

REAGENT PREPARATION PROTOCOL

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APPENDIX B

REAGENT PREPARATION PROTOCOL

1. Measurement of Soil Moisture

Water in a soil may be measured in a number of ways, namely (1) Gravimetric and volumetric method (2) Neutron scattering (3) Gamma ray attenuation (4) Soil moisture tension and (5) Electrical conductivity.

Gravimetric Method

This is the simplest and most widely used method for measuring soil moisture.

Principle

Weighed soil sample is placed in an oven at 105 ^{o}C and it is dried to constant weight. The weight difference is considered to be water present in soil sample.

$$\text{Per cent moisture} = \frac{\text{Loss in weight}}{\text{Oven dry weight of soil}} \times 100$$

Equipments

1. Sample auger
2. Moisture cans (numbered)
3. Drying oven
4. Desiccator

Method

1. Weigh the empty moisture can.
2. Take soil sample of about 100 g from the required depth with the help of auger.
3. Put soil sample immediately in the moisture can and close it to prevent loss of moisture by evaporation
4. Bring the cans containing the moist soil to the laboratory and weigh immediately
5. Remove the lids and place moisture cans in oven to a constant weight at 105 ^{o}C. This takes approximately 46 hours.
6. Allow the sample to cool for some time in oven. Then close the cans and put them in a desiccators for further cooling. Now weigh the closed cans with the oven dry soil.

Observations

Wt. of empty moisture can = (x)

Wt. of moisture can + moist soil = (y)

Wt. of moisture can + oven dry soil = (z)

Calculations

Moisture content in soil = (y-z)

Weight of oven dry soil = (z-x)

Percentage moisture in soil = $\frac{(y-z)}{(z-x)}$ x 100

2. Electric pH Meter Method

The instrument commonly used in this method is a glass electrode pH meter with calomel reference electrode introducing salt bride. Most digital pH meter now a days have single (combined) electrode assembly. The instrument being a potentio-meter requires to be calibrated before use with buffer solutions of known pH values.

Principle

A glass surface in contact with hydrogen ions of the solution under test, acquires an electrical potential which depends on the concentration of H ions. A measure of the electrical potential is, therefore, give H ion concentration or pH of the solution.

Equipments and Reagents

1. Glass electrode pH meter.
2. Standard buffer solutions: These may be of pH 4.0, 7.0 or 9.2 in pure water. To prepare buffer solution, in case of buffer tablets (available in the market) a single piece is to be dissolved in freshly prepared double distilled water and make up volume to 100 ml. It is necessary to prepare a fresh buffer after every few days. In case a standard buffer is not available, a saturated solution of potassium hydrogen tartarate (AR) may be used which gives a pH of 3.56 at 25^{o}C.
3. Beaker, glass rod and distilled water.

pH in soil is determined in following ways:

(a) pH in Saturated Soil Paste

1. Take workable amount of soil.

2. Prepare a soil paste by adding small amounts of distilled water gradually into soil while working with a spatula.
3. At saturation, the soil paste glistens, flows slightly when the container is tilted, slides freely and cleanly off the spatula.
4. After mixing, allow it to stand with a cover above the container for about four hours.
5. Now see that there should be no free water on the soil surface and also paste should not stiffen markedly or lose its glistening appearance on standing. The saturation paste at this stage is ready to determine pH.
6. Remix with water if soil paste looses its shine.

(b) pH in 1:2 Soil Water Suspension

To prepare 1:2 soil water suspension, weigh 40 g of soil into a 250 mL Erlenmeyer flask and add 80 mL of distilled water in it. Stopper the flask and shake the mixture on the reciprocating shaker for one hour.

Method

1. Take either saturation paste or 1:2 soil water suspension in which pH is to be determined.
2. On the pH meter, set the temperature compensating knob and confirm that the electrode is completely filled with the saturated potassium chloride (KCl) solution.Allow the pH meter to warm up for 15 minutes to eliminate the asymmetric potential of the instrument.
3. Place known standard buffer solution in a beaker say having pH 7 and emerse both the electrodes or the one electrode (in case combined electrode is provided) into the buffer solution. Electrode should no be touched the wall of

the beaker. With the help of the knob adjust the instrument reading at the known pH of the buffer (in this case at pH 7). The buffer is then removed and the electrodes are carefully flushed with distilled water. Now take another buffer solution of hnown pH say 9.2. See reading after immersing electrodes in it. The pH meter must read 9.2 (it, reading is not approached 9.2, the instrument is to be readjusted by repeating above procedure). The second buffer is then removed and electrodes are again flushed with distilled water.

4. The electrodes are then immersed in the beaker containing soil paste or soil water suspension and read pH on the dial and record it on the observation.
5. Remove the electrodes from the soil paste/or soil suspension, clean them with distilled water and then dip into a beaker of distilled water. The electrodes are maintained in working condition by keeping them immersed in distilled water.

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3. Determination of Organic Carbon

One of the most widely used rapid soil test for the assessment of available nitrogen is based upon the estimation of readily oxidisable organic carbon which roughly represent 58% of the soil organic matter, the seat of nitrogen in soil. This technique has been found to work fairly well unless the bulk of the organic matter is non humic is non humic in nature and the organic carbon values are on the very high side.

Various methods are available for the determination of organic carbon through dry combustion and wet digestion. The dry combustion method gives absolute values and useful for very accurate estimation of organic and total carbon. For routine work and easily oxidizable carbon determination, most widely acceptable methods in India are modified Walkley-Black method and colorimetric method. The above methods operate on one basic principle i.e. Wet oxidation (digestion) of organic carbon in an acid dichromate solution followed by back titration of the remaining dichromate with ferrous ammonium sulphate or by photometric determination of Cr^{3+}.

Walkley and Black Rapid Titration Method

Principle

The organic matter in the soil gets oxidized by potassium dichromate and concentrated sulphuric acid utilizing the heat of dilution of H_2SO_4. The excess potassium dichromate, not reduced by the organic matter of the soil is determined by back titration with standard ferrous sulphate ($FeSO_4$ $7H_2O$) or ferrous ammonium sulphate [$FeSO_4$ $(NH_4)_2$ SO_4 $6H_2O$].

Reagents

1. **Standard 1N potassium dichromate:** 49.04 g of AR grade $K_2Cr_2O_7$ (oven dried at 90^oC) is dissolved in distilled water and make up the volume to one Liter.
2. **0.5 N ferrous ammonium sulphate:** 196 g of the hydrated crystalline salt dissolved in one liter of distilled water containing 20 mL of conc. H_2SO_4. This solution is relatively more stable and convenient to work than that of ferrous sulphate. However, it should be prepared fresh for each set of samples.
3. **Diphenylamine indicator:** 0.5 g diphenylaine dissolved in a mixture of 20 mL. of water and 100 mL of conc. H_2SO_4.
4. Concentrated sulphuric acid (sp. Gr. 1.84) containing 1.25 percent silver sulphate (In case of soils free from chlorides use of Ag_2SO_4 can be avoided).
5. Ortho-phosphoric acid (85%) and/or sodium fluoride (chemically pure).

Method

1. Take 1.00 g soil in a dry 500 mL conical flask (Corning^{TM}/Pyrex^{TM})
2. The quantity of soil maybe 0.5-2.0 g for mineral soil and 0.05-0.2 g for organic soil.
3. 10 mL of 1N $K_2Cr_2O_7$ is pipette in and swirled a little.
4. The flask is kept on asbestos sheet. Then 20 mL of H_2SO_4 (containing 1.25% Ag_2SO_4) is added and swirled again two or three times.
5. The flask is allowed to stand for 30 minutes and then add 200 mL of distilled water.
6. Add 10 mL of phosphoric acid or/and 0.5 g sodium fluoride and 1 mL of diphenylamine indicator.

7. Titrate the contents with 0.5 N ferrous ammonium sulphate solution till the colour changes from blue-violet to green.
8. Simultaneously, a blank is run without soil.
9. If burette reading $FeSO_4$ is 0-4 mL repeat with less soil, if it is 17 mL or higher repeat with more soil.
10. **O-phenanthroline indicator:** Dissolve 3.0 g of o-phenanthroline monohydrate and 1.4 g of ferrous sulphate hepta hydrate ($FeSO_4$ $7H_2O$) in water. Dilute the solution to a volume of 200 mL. This indicator commercially available under the name Ferroin. At the end point change in colour is from greenish blue to reddish brown.

$$\textbf{\% carbon in soil} = N \frac{(B-C)}{Weight\ of\ soil\ (g)} \times 0.003 \times 100$$

Where N = normality of ferrous ammonium sulphate.

There is in complete oxidation of the organic matter in this procedure. Therefore, the organic carbon obtained by above method is multiplied by a factor 1.3 based on assumption that there is 77 percent recovery.

Organic carbon= organic carbon estimated x 1.3

To determine organic matter content of soil, this organic carbon is multiplied by Van Bemmelen factor of 1.724 because organic matter contains 58% organic cabon.

Table B1 Rating organic matter translation in soil.

Rating	Organic Matter (%) in Soil
Very low	<0.5
Low	0.5-1.0
Rather low	1.1-1.5
Medium	1.6-2.5
Rather high	2.6-3.5
High	3.6-4.5
Very high	>4.5

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4. Total Nitrogen by Auto analyzer

Digestion

Principle

The sample is digested in H_2SO_4 to convert organic N to NH_4^+-N. Highly refractory organic N compounds containing N-N or N-O linkages are not completely recovered by the Kjeldahl digestion; however, very little of the N in most soils is in this form. If soils do contain high amounts of NO_3-N or NO_2-N, then pretreatment must be carried out to include these forms of N.

Apparatus

1. Digestion block: a 20 place block digester with tractor auto temperature controller.
2. 250 mL digestion tubes (295 x 40 mm diameter).

Reagents

1. Concentrated H_2SO_4 (18M), 96%.
2. Kjeltab: each tablet contains 3.5 g K_2SO_4 and 0.4g $CuSO_4$ $5H_2O$.

Method

1. Transfer 1 to 2 g mineral soil low in N (60 mesh) into a digestion tube, with accuracy in weighing to 0.01 g.
2. Add 10 mL concentrated H_2SO_4 and mix by swirling.
3. Heat at 200^{o}C in a digestion block until very black (about 30 minutes). To avoid acid irritation to the analyst, the digestion block must be loaded in a fume hood to ensure the removal of fumes and vapors release during digestion.
4. Add one Kjeltab.
5. Heat for 15-20 minutes until Kjeltab dissolves (200^{o}C).

6. Increase heat to 300^{o}C and heat for 30 minutes.
7. Raise the temperature to 375^{o}C and heat until sample turns turquoise (45 minutes).
8. Remove the digestion tubes from the block and allow cooling for 5 minutes. Do not allow cooling in the heating block: NH_3 from the $(NH_4)_2SO_4$ formed by digestion will be lost if heated.
9. Add about 50 mL water and mix well until sample is in solution.

Determination

Distillation (Kjeltec Auto 1030 Analyzer) Method

Principle

In the Kjetec Auto 1030 Analyzer method, NH_4-N (liberated by distillation of the digest with strong alkali) is absorbed in unstandardized H_3BO_3. Ammonium borate is formed. The borate is titrated back to H_3BO_3 by titration against standard strong acid (HCl).

Apparatus

Distillation and titration apparatus: Kjeltec Auto 1030 Analyzer.

Reagents

1. 40% NaOH solution: 10 kg NaOH+15 L H_2O.
2. Receiving solution: Disolve 100 g H_3BO_3 in 10 L water. Add 100 mL bromocresol green solution (100 mg in 100 mL methanol). Add 70 mL methyl red solution (100 mg in 100 mL methanol). Add 5 mL of 4% NaOH.
3. Standard acid (0.01 M HCL).

Method

1. Bring the digest up to about 100 mL.
2. Follow instructions for the operation of Kjeltec Auto 1030 Analyzer (Tecator 1985).
3. Set the alkali pump to deliver 30 mL of 40% NaOH.
4. Titrate with 0.01 M HCl.

Calculations

Report total N as percentage (accuracy 0.01%) on dry-weight basis.

$$\%N \text{ in soil} = \frac{(T-B)\times \text{molarity of standard HCl} \times 1.401}{\text{Weight of Oven dry sample digested (g)}}$$

Where, T = the volume (mL) of standard HCl for titration of the sample.

B = the (mL) of standard HCL for titration of the bank.

Table B2 Rating total nitrogen translation in soil.

Rating	Total Nitrogen (%) in Soil
Very low	<0.02
Low	0.02-0.08
Medium	0.08-0.12
High	0.12-0.18
Very high	>0.18

5. Determination of Available Phosphorus

Phosphorus in soils ranges from 0.01 to 0.3 percent occurs in several forms and combinations. The apatite group of primary minerals is the original source of about 95 percent or more of the soil phosphorus. The different phosphate compounds in soils can be generally classed as floro-carbonate and hydroxyl-phosphates of Fe, Al, Ti, Mn, Ca and Mg, of which the Fe, Al and Ca-phosphates are the most important ones quantitatively. The total amount of phosphorus present in soil is not available to the plants, only small fraction of it maybe available which is of direct relevance in assessing the phosphorus fertility levels.

Several chemical tests for available P has been proposed by various which extract variable quantities of phosphorus. Most commonly used methods for determination of plant available P in soil are:

1. The Olsen's method used for neutral-alkaline soils
2. The Bray and Kurtz method used for acid soils

Bray and Kurtz No 1 Method

This method is suitable for acid soils having pH around 5.5 or less.

Principle

The combination of HCl with ammonium fluoride NH_4F which is used as an extractant in the procedure extracts adsorbed and acid soluble phosphorus bound with Al, Fe and Ca.

Phosphate in the extract is determined colorimetrically as phosphomolybdenum blue with ascorbic acid as a reducing agent. The presence of antimony gives a stable Mo-P-Sb complex.

Reagents

1. **Bray and Kurtz extracting solution:** The extractant consist of 0.03 N NH_4F in 0.025 N HCl solution. Dissolve 11.1 g of AR grade NH_4F in 100 mL distilled water. Filter the solution. Now add 1 liter distilled/deionized water having 20 mL conc. HCl. Dilute the contents of 10 Liter. It can be stored for a long time (one year) in a polyethylene bottle.
2. **Ammonium molybdate solution**: Dissolve 40 g of ammonium molybdate [$(NH_4)_6Mo_7O_{24}4H_2O$] in 1000 mL of deionized or distilled water.
3. **Ascorbic acid solution:** Dissolve 26.4 g of L-ascorbic acid ($C_6H_8O_6$) in 500 mL of deionized or distilled water.
4. **Antimony potassium tartrate solution:** Dissolve 1.454 g of antimony potassium tartrate [$K(SbO)C_4H_4O_6$ ½ H_2O] in 500 mL of deionized or distilled water. This compound is also named as potassium antimonyl tartrate.
5. **Sulphuric acid 2.5 M:** Dilute 140 mL of concentrate H_2SO_4 to one Liter. The above solutions are stable for 2 to 3 months if well stoppered and stored under refrigeration.
6. Using the above reagents, prepare the Murphy-Riley colour developing solution as follows: Take 500 mL volumetric flask and add 250 mL of 2.5 M H_2SO_4, followed by 75 mL of ammonium molybdate solution, 50 mL of ascorbic acid solution, and 25 mL of antimony potassium tartrate solution. Then add 100 mL of deionized or distilled water and mix on a magnetic stirrer.
7. **Standard stock P solution:** Dissolve exactly 0.439 g A.R. grade potassium dihydrogen orthophosphate (KH_2PO_4) in 500 mL distilled water after drying in

oven at 60 °C for 1 hour and cooled in desicator. Add 25 mL of 7 N H_2SO_4 to the solution and make the volume to 1 liter with distilled water. This gives a 100 ppm stock solution of P (100 μgP mL^{-1}) from this take 5 mL solution in a 100 mL volumetric flask and make the volume. This gives 5 ppm P solution (5 μgP mL^{-1}).

Preparation of Standard Curve

To prepare standard curve of P, take 1, 2, 3, 4 and 5 mL of 5 ppm P solution in 50 mL volumetric flaks. To these 5 mL of extraction solution ($NaHCO_3$) is added. Now add 10 mL of deionized or distilled water and one drop of p-nitrophenol indicator. Then add 2.5 M H_2SO_4 dropwise until the solution becomes clear. At the point where indicator's yellow colour disappears, the correct pH (5.0) for the colour development has been attained. If the end-point is exceeded through addition of excessive acid, the pH may be brought back up again by adding NaOH.

To each flask add 8 mL of the Murhpy-Riley solution. Make the volume with deionized or distilled water 50 mL and mix. Now these standards have P concentration 0.1, 0.2, 0.3, 0.4 and 0.5 μgP/mL. Prepare a blak with $NaHCO_3$ solution, distilled or deionized water and Murphy-Riley reagent.

After waiting for 15 minutes, read the intensity of the blue colour on colorimeter or spectrophotometer at 730 nm. Absorbance values (Readings) for the standards having 0, 0.1, 0.2, 0.3, 0.4 and 0.5 μgP/mL are used to construct a standard curve between absorbance values and the concentration of P in standards.

Method

1. Take 5g air dry soil into a 150 mL Erlenmeyer flask.
2. Add 50 mL of Bray extraction solution (1:10 soil to solution ratio).

3. Stopper the flasks and shake the suspension for exactly 5 minutes on mechanical shaker.
4. Filter the mixture through Whatman No 42 filter paper. If the filtrate is turbid, quickly filter it again from the same filter paper.
5. Take 5 mL aliquot of the extract in a 25 mL volumetric flask. If necessary, add 7.5 mL of 0.8 M boric acid (50 g H_3BO_3 in 1 liter) to the aliquot to avoid interference of fluoride. Add distilled water to 20 mL and then add 4 mL of Murphy Riley solution.
6. Run blank without soil.
7. After 15 minutes, read the internsity of the blue colour using 730 nm on spectrophotometer or colorimeter. Prior to this, blank may be adjusted on zero of the colorimeter or spectrophotometer's scale.
8. With the help of standard curve calculated the quantity of available phosphorus in soil.

Calculations

$$\text{Bray's P (kg ha}^{-1}) = c \times \frac{\text{volume of the extractant}}{\text{volume of aliquot}} \times \frac{1}{\text{Wt. of soil taken}} \times 2.24$$

Where C = μg P in the aliquot (obtained from the standard curve)

= C x 50/5 x 1/5 x 2.24 = C x 4.48

(μgP mL^{-1} or ppm x 2.24 = kg ha^{-1})

Table B3 Rating available phosphorus translation in soil.

Rating	Available Phosphorus (ppm) in Soil
Very low	<3
Low	3-5
Rather low	6-10
Medium	11-15
Rather high	16-25
High	26-45
Very high	>45

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6. Determination of Available or Exchangeable Potassium

Potash (K_2O) in Indian soils ranges from 0.05-3.5 percent out of which 95% part is persent in complexed form, 1-10% part in relatively non-available form, and 2% part in available form. The term available potassium includes both exchangeable and water souluble forms of the potassium present in soil. The available K (readily exchangeable+water soluble K) is usually determine in neutral normal ammonium acetate (1N CH_3COONH_4) extract of soil. The degree of agitation during extraction and the extraction time can affect CH_3COONH_4 extractable K, and this effect may vary among soils. To estimate exchangeable K, first water soluble K is estimated in a saturation extract and the same is deducted from the ammonium acetate extractable K.

Principle

Potassium is extracted from the soil with the help of suitable extractant (CH_3COONH_4) by shaking, followed by filtration or centrifugation and is determined in the extract using flame photometer. The analysis photometer is based on the measurement of the intensity of characteristic line emission given by the element to be determined. When a solution of a salt is sprayed into a flame the salt gets separated into its component atoms because of the high temperature. The energy provided by flame excites the atoms to higher energy levels (the electrons of atom go to high energy level). When the electrons return back to the ground or unexcited state, they emit radiation of characteristic wave length (line emission spectrum). The intensity of these radiations is proportional to the concentration of particular element in solution which is measured through a photo cell in the flame photometer.

Equipments

1. Erlenmeyer flask (150 mL)
2. Flame photometer with K filter
3. Centrifuge with centrifuge tubes
4. Volumetric flask (100 mL)

Reagents

1. N ammonium acetate solution of pH7: Dissolve 154 g ammonium acetate in distilled water dilute it to 1.8 Liter. Mix thoroughly, adjust pH to 7.0 with dilute ammonium hydroxide or acetic acid as required and make to 2 Liter or take 700 mL of distilled water. Add 57 mL 99.5% glacial acetic acid and then 69 mL of concentrate ammonium hydroxide in it. Dilute to a volume of 900 mL and adjust pH to 7.0 by the addition of more of NH_4OH or CH_3CHOOH and make up 1 liter. Store in Pyrex^{TM} or polypropylene bottle.
2. Standard KCl solution: Dissolve 1.908 g AR grade KCl (dried at 60^{o}C for 1 hr) in distilled or deionized water and make volume to 1 liter. This will give stock solution of 1000 ppm K. Now take 100 mL of this stock solution and dilute it with neutral normal ammonium acetate (extracting solution) upto 1 Liter. This gives solution of 100 ppm K.

   From this solution, take 0, 5, 10, 15 and 20 mL in volumetric flasks of 100 mL capacity and make the volume by further adding normal neutral ammonium acetate solution. This will give a series of standard solutions having 0, 5, 10, 15 and 20 ppm K, respectively.

Method

The ammonium acetate extract of soil can be obtained by shaking followed by filtration or shaking followed by centrifugation.

Shaking and Filtration

1. Place 5 g air dried soil in a 150 mL Erlenmeyer flask and pour in 25 mL (1:5 soil to extractant) of neutral normal ammonium acetate.
2. Shake on a mechanical shaker for 5 minutes and immediately filter through Whatman filer paper No. 1. First few mL of the filtrate, may be discarded.

Shaking and Centrifugation

1. Place 5 g air dried soil in a 50 mL centrifuge tube.
2. Add 25 mL of neutral normal ammonium acetate solution, stopper and shake the tube for 10 minutes.
3. Centrifuge the tube at 2000 rpm for 10 minutes until the supernatant liquid is clear.
4. Decant the supernatant liquid into a 100 mL volumetric flask.
5. Make three additional extraction in the same manner. Dilute the combined extracts to 100 mL with ammonium acetate and mix.
6. Determine K in the extract prepared by either of the above methods with the help of flame photometer using K filter after necessary setting and calibration of the instrument as follows.
7. Read the operation manual of flame photometer. Set the K filter. Start compressor and light the burner of flame photometer. Keep air pressure at 5 lbs and adjust the gas feeder so as to have a blue sharp flame cones.

8. Adjust zero reading on the scale by feeding extract solution (CH_3COONH_4) in the flame photometer.
9. Feed standard KCl solution of the hightest value in the standard series (20 ppm K) and adjust the flame photometer to read full scale i.e. 100 reading. Now take reading of each standard solution. Plot a standard curve between concentration and readings of standard K solution.
10. Take extract of sample and feed in flame photometer. Note the reading for sample and determine K content in the sample with the help of standard curve.

Calculations

Standard Curve for Potassium

A curve is drawn by plotting flame photometer readings on the Y axis against concentrations of K on X axis. The concentration of K in the unknown sample is read from the curve. Suppose it is C μg mL^{-1} (ppm).

Available K (kg ha^{-1}) = $\frac{C \times \text{Volume of extractant}}{\text{Wt. of soil taken}}$ x 2.24 = $\frac{C \times 25}{5}$ x 2.24

Where C = ppm or μg mL^{-1} of K (obtained from standard curve).

If extraction was made with shaking and centrifugation the calculation will be:

Available K (kg ha-1) = $\frac{C \times 100}{5}$ x 2.24

Table B4 Rating available potassium translation in soil.

Rating	Available Potassium (ppm) in Soil
Very low	<30
Low	30-60
Medium	60-90
High	90-120
Very high	>120

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CURRICULUM VITAE

Name Miss Wanichaya Charoonphong

Date of Birth April 5, 1978

Place of Birth Udon Thani, Thailand

Education and Experience

1995-1998	B.Sc. (Environmental Science), Khon Kaen University, Khon Kaen, Thailand
2000-2003	M.Sc. (Environmental Biology), Suranaree University of Technology, Nakhon Ratchasima, Thailand
2004-2009	Ph.D. Candicate (Environmental Biology), Suranaree University of Technology, Nakhon Ratchasima, Thailand

Grants and Fellowships Udon Thani Rajabhat University Scholarship

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