MICROBIAL CONTRIBUTION TO THE CARBON MINERALIZATION AND DECOMPOSITION RATE OF LITTER ON THE FOREST FLOOR IN DRY EVERGREEN FOREST AT SAKAERAT ENVIRONMENTAL RESEARCH STATION

Warin Boonriam

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Biology

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อิทธิพลของจุลินทรีย์ในการปลดปล่อยคาร์บอนและอัตราการย่อยสลายของเศษซากพืชในป่าดิบแล้งที่สถานีวิจัยสิ่งแวดล้อมสะแกราช

นายวารินทร์ บุญเรียม

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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THESIS ADVISOR : ASST. PROF. NATHAWUT THANEE, Ph.D. 65 PP.

LITTER DECOMPOSITION RATE/ LITTER AND SOIL RESPIRATION/ LITTER CAGE/ C MINERALIZATION/ MICROBIAL RESPIRATION/ SAKAERAT ENVIRONMENTAL RESEARCH STATION

The field experiment was designed to compare decomposition processes among the treatments and the microbial contribution on litter decomposition rate and carbon mineralization of naturally accumulated litter in dry evergreen forest at Sakaerat Environmental Research Station. The litter cage decomposition method, was used, where microbial respiration (CO_2 measurement) of litter in fine and coarse cages with 0.2 and 2 mm mesh sizes were compared with the respiration of natural litters Soil respiration was also measured in 0-5, 5-10 and 10-20 cm depths under litter coarse cages, no litter coarse cages and natural litter, respectively. The litter decomposition constant rates (k) of coarse and fine cages were 1.62 and 0.74. The rate of litter weight loss was twice higher in coarse cages than in fine cages due to the intensity of litter removed by termites. The litter respiration rates by microbial decomposition on natural litter and litter samples were affected by litter quality in the rainy season. In dry season, litter quality did not affect microbial activity due to low availability of water. Soil respirations were not significantly different among three

different treatments. It may suggest that microbial decomposition under the litter treatments were affected from other carbon resources.

School of Biology

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วารินทร์ บุญเรียม : อิทธิพลของจุลินทรีย์ในการปลดปล่อยคาร์บอนและอัตราการย่อยสลายของเศษซากพืชในป่าดิบแล้งที่สถานีวิจัยสิ่งแวดล้อมสะแกราช (MICROBIAL CONTRIBUTION TO THE CARBON MINERALIZATION AND DECOMPOSITION RATE OF LITTER ON THE FOREST FLOOR IN DRY EVERGREEN FOREST AT SAKAERAT ENVIRONMENTAL RESEARCH STATION) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.ณัฐวุฒิ ธานี, 65 หน้า

การทดลองนี้มีวัตถุประสงค์เพื่อศึกษาเปรียบเทียบกระบวนการย่อยสลายในแต่ละการทดลองและอิทธิพลของจุลินทรีย์ต่ออัตราการย่อยสลายและการปลดปล่อยคาร์บอนของเศษซากพืชในพื้นที่ป่าดิบแล้งของสถานีวิจัยสิ่งแวดล้อมสะแกราช ด้วยวิธีการวัดอัตราการย่อยสลายของเศษซากพืช โดยใช้กล่องตาข่ายลวดสำหรับใส่เศษซากพืชสองขนาดคือ รูเล็กขนาด 0.2 มิลลิเมตร และรูใหญ่ขนาด 2.0 มิลลิเมตร และการวัดอัตราการหายใจของจุลินทรีย์ (การปลดปล่อยคาร์บอนไดออกไซด์) ของตัวอย่างเศษซากพืช ในกล่องตาข่ายลวดทั้งขนาดรูเล็ก และขนาดรูใหญ่ เปรียบเทียบกับเศษซากพืชตามธรรมชาติ ทั้งนี้รวมถึงการวัดอัตราการหายใจของชั้นดินใต้กล่องตาข่ายลวดขนาดรูใหญ่ที่ใส่เศษซากพืช ไม่ใส่เศษซากพืช และ ใต้เศษซากพืชธรรมชาติ ที่ความลึก 0-5 5-10 และ 10-20 เซนติเมตร ตามลำดับ ผลการศึกษาพบว่า อัตราการย่อยสลายของเศษซากพืชในกล่องขนาดรูใหญ่มีอัตราการย่อยสลายหรือการหายไปของตัวอย่างเศษซากพืชเร็วกว่ากล่องตาข่ายขนาดรูเล็กซึ่งเร็วกว่าเป็นสองเท่าในแต่ละช่วงเวลา โดยมีค่าอัตราการย่อยสลาย (k) ของกล่องตาข่ายรูเล็กและรูใหญ่เท่ากับ 0.74 และ 1.62 ตามลำดับ พบว่ากิจกรรมของปลวกที่เป็นกลุ่มใหญ่ที่เข้าไปกินเศษซากพืชในกล่องตาข่ายรูขนาดใหญ่ ส่วนอัตราการหายใจจากกิจกรรมของจุลินทรีย์ ในเศษซากพืชธรรมชาติและในตัวอย่างทดลอง พบว่าคุณภาพของเศษซากพืชที่ร่วงหล่นตามธรรมชาติ มีผลต่อการปลดปล่อยคาร์บอนและการย่อยสลายของจุลินทรีย์ในช่วงฤดูฝนเมื่อเปรียบเทียบกับคุณภาพเศษซากพืชในตัวอย่าง ส่วนในฤดูแล้งคุณภาพของเศษซากพืชไม่มีอิทธิพลต่อการย่อยสลายและกิจกรรมการปลดปล่อยคาร์บอนในเศษซากพืช เนื่องจากมีปริมาณความชื้นต่ำ ในขณะที่อัตราการหายใจของดินไม่มีความแตกต่างกันอย่างมีนัยสำคัญ (P>0.05) ของแต่ละการทดลอง ซึ่งการศึกษานี้สนับสนุนว่าอัตราการหายใจของดินจากแหล่งคาร์บอนอินทรีย์ใต้ชั้นดินของกล่องตาข่ายมีการเจือ

ปนมาจากแหล่งอื่นๆ ซึ่งมีผลต่อกิจกรรมการย่อยสลายของจุลินทรีย์ทำให้ไม่มีความแตกต่างกันเมื่อเปรียบเทียบกับตัวอย่างดินธรรมชาติ

สาขาวิชาชีววิทยา
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ลายมือชื่อนักศึกษา ภาวินทร์ บุญเรียม
ลายมือชื่ออาจารย์ที่ปรึกษา
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม

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Warin Boonriam

CONTENTS

CONTENTS (Continued)

Page

CONTENTS (Continued)

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

Figure **Page**

CHAPTER I

INTRODUCTION

1.1 General

Tropical forests are well-known as their harboring the prominently high bio-diversity, and simultaneously they are responsible for approximately 50% of the terrestrial primary production (photosynthesis by plants) on the earth (IPCC, 2001). In other words, tropical forests are the center of photosynthesis as well as biodiversity. Photosynthesis is the biosynthetic pathway where atmospheric carbon dioxide (CO_2) is fixed into organic matters (plant materials). According to the 2001 report by Intergovernmental Panel on Climate Change (IPCC), 3.1-3.7 $\times$ 10^{16} g of carbon (equivalent to 11.4-13.6 $\times$ 10^{16} g of CO_2) is absorbed and converted into plant materials in tropical forests. This means that tropical forests are an important CO_2 sink on the earth. As repeatedly emphasized, we are currently facing one of the climatic global warming problems, which is probably caused by elevated concentrations of CO_2 in the air. CO_2 is one of the principle greenhouse gases and keeps the heat from the sun in the stratosphere by capturing an infrared ray. IPCC (2002) report by Technical Paper V, Climate Change and Biodiversity pointed out that the mean concentration of CO_2 in the air from the period 1000-1750 was 280 ppm (i.e. 0.028%), whereas that in year 2000 had been increased into 368 ppm. As for the temperature, the global mean surface temperature has increased by 0.6°C (0.4-0.8°C)

over the last 100 years. Such an increasing temperature may affect the magnitude and/or frequency of large-scale climatic events such as El Niño and will change the current distribution and life cycles of animals and plants. These mean an impact on the biodiversity that is an essential basis of human life (Smith and Lazo, 2001). On the other hand, the recent increment in atmospheric CO_2 is most likely due to human activity, especially the combustion of fossil fuel. Instead of our industrial development, we have changed the underground stock of carbon (fossil fuel) into the atmospheric CO_2. Therefore, the IPCC report strongly encouraged the mitigation of climate change by reducing CO_2 emission. As mentioned above, we may expect that tropical forests absorb CO_2 and subsequently decrease its concentration in the air. However, the story is not so simple. This is because carbon or CO_2 is not a static element. It is continuously cycling through all ecosystems on the earth. The carbon (or CO_2) taken into plant bodies will be fallen onto/into the soil layers, such as carbon in dead leaves and branches. The carbon is to be utilized as energy source by decomposers, comprising microbes (e.g. bacteria and fungi) and soil animals (e.g. termites and earthworms); then, the carbon will be emitted as CO_2 and return into the air again. Meanwhile, not negligible part of carbon in dead plant body might be accumulated relatively deep in the soil without being decomposed into CO_2. Although the detailed processes of the decomposition of dead plant body are still remain unclear, the clarification of carbon cycling in tropical forests will allow us to better understand the function of the forests not only as a reservoir of biodiversity, but also as an important CO_2 sink.

1.2 The Research Purposes

1.2.1 Research Questions

1.2.1.1 How much of the litters which is determined by litter-cage methods, actually are “decomposed (mineralized)” by decomposers?

1.2.1.2 What is the contribution of microbes on CO_2 efflux from soils under fine cage, coarse cage and natural litter treatments?

1.2.2 Research Objectives

1.2.2.1 To determine the rate of decomposition between soil fauna and microbes by using litter cage.

1.2.2.2 To determine whether decomposition process (CO_2 mineralization) is affected by litter- layer and soil microbial activity.

1.2.2.3 To investigate the microbial respiration on above and below ground decomposition to drive CO_2 in tropical ecosystem (dry evergreen forest).

1.2.3 Scopes and Limitation of the Study

1.2.3.1 This study examined litter-weight loss by using two different mesh sizes (2 mm and 0.2 mm) of litter cage method in dry evergreen forest.

1.2.3.2 This study analyzed the rate of CO_2 emission from natural accumulated litter.

1.2.3.3 This study analyzed the rate of CO_2 soil- layers under the litter bag case (litter and no litter treatment).

CHAPTER II

LITERATURE REVIEW

2.1 Overview of Decomposition Processes in Tropical Forests

Decomposition of organic matter is one of the key biological processes critical to the functioning of tropical forest ecosystems. Decomposition is the processes which dead organic materials are transformed into simpler states with the concurrent release of energy and their contained biological nutrient and other element in organic forms (Lavelle and Spain, 2003). All the same decomposition is a process equivalent to photosynthesis in its importance for the biogeochemical cycling of energy and nutrients (Heal et al., 1997).

Plants generally produce organic matter from soil nutrient, water and CO_2, using the energy of light through photosynthesis mechanism. The main path ways of carbon into the decomposer system are the shedding of litter by trees. In particularly of carbon photosynthesized by plants are retuned to the atmosphere as CO_2 by above and below ground respiration of the plant parts. The remaining carbon is transformed into plant structure, and finally deposited as dead plant matter such as leave litter, branches, dead root and dead wood on soil surface. Some of carbon parts are mineralization as CO_2 to atmosphere by the decomposition processes. Another part of carbon is accumulated into the soil as shown in the Figure 2.1.

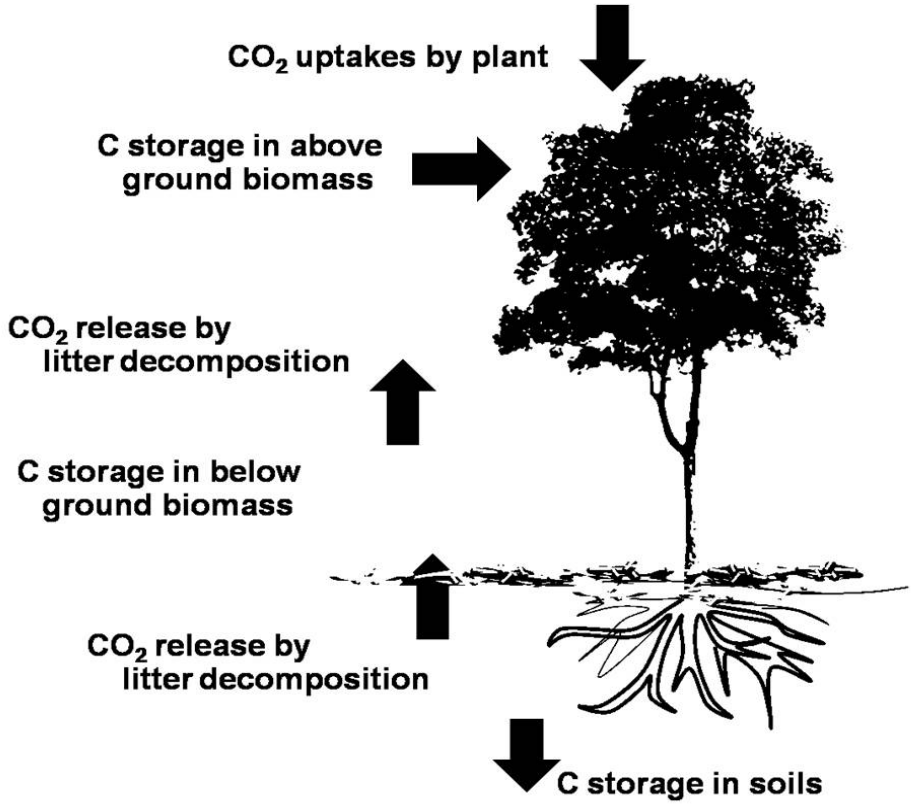

Figure 2.1 Carbon cycle in the forest ecosystem.

Tropical forests are the center of the plant photosynthesis because the biomass as well as diversity of places is much higher then the other forest types such as temperate or board forest. Therefore, tropical forests are attractive to study the decomposition of litter decomposition and carbon cycle. A change in carbon mineralization with the decomposition rate of organic matter should equal to the primary production. Moreover, terrestrial biosphere–atmosphere CO_2 exchange is dominated by tropical forests (Cleveland et al., 2006). Therefore, the understanding of how nutrient availability affects carbon (C) decomposition in these ecosystems is central to predicting the global carbon cycle's response to environmental changes.

2.2 Production by Plant and Litterfall

Plant productivity is production of organic compound from atmospheric CO_2 through photosynthesis by plant. Absorb CO_2 by plants are dominant in tropical forests with research indicating an annual global uptake of around 1.3 Gt of carbon. Of this forest in Central and South America are estimated to take up around 0.6 Gt of carbon, African forest are estimated over 0.4 Gt of carbon and Asian forest around 0.25 Gt of carbon (Lewis et al., 2009). Malhi and Grace (2000) according the carbon dynamics of tropical forests are absorbed carbon for 30.4 t C ha^{-1} $year^{-1}$ and fixed into plant structural biomass for 15.6 t C ha^{-1} $year^{-1}$ in termed the net primary production that remained from respired through leaves, wood and roots approximately 14.8 t C ha^{-1} $year^{-1}$ before finally deposited into the soil in the form of litter, dead tree or animal faeces, from where it is finally released by decomposer decay, which of 9.7 C ha^{-1} $year^{-1}$ of heterotrophic respiration. The mean residence time of the carbon in biomass and soil can be estimated by dividing of directly measured as shown in Table 2.1.

Table 2.1 The carbon dynamic of the tropical forest are dominated by carbon cycle.

Tropical forest carbon cycle	C mineralization* and stocks (t C ha^{-1} $year^{-1}$ for fluxes, t C ha^{-1} for stocks)
Total C absorption (by photosynthesis)	30.4*
C stored in above ground biomass	180
C stored in below ground biomass	64
C stored in below ground (soil and animal biomass)	162
Total C emission from plant and soil (by respiration)	24.5*

Source: Malhi and Grace (2000).

Litterfall is the main pathway of nutrient cycles and accumulated become to soil organic matter by through the decomposition processes. The important production by forests in the tropical zone is the litterfall on forest floor because a tropical forest is high abundance of forest types. Sahunalu (2004) and Bunyavejchewin (1997) were found the total annual litterfall of 8.17 t ha^{-1} $year^{-1}$and 6.8 t ha^{-1} $year^{-1}$, respectively in dry evergreen forest at Sakaerat Environmental Research Station northeast, Thailand. Litter production provides the resources used by various decomposers. There is directly consumption on litter and divide the organic compound to be the inorganic compound. Most the organic carbon can be found in the vegetation, with biomass estimated of 170-250 t C ha^{-1} $year^{-1}$ (Malhi et al., 1999, Chave et al., 2008, Lewis et al., 2009) and Yamada et al. (2005) according carbon production of annual aboveground litterfall (Table 2.2).

Table 2.2 Carbon production of annual aboveground litterfall in tropical forests.

Natural ecosystem site	Annual rainfall (mm)	production (g C m^{-2} $year^{-1}$)
Tropical forest		
Sakaerat, Thailand	1,144	520
Mbalmayo, Cameroon	1,520	837
Pasoh, Malaysia	2,000	706
Manaus, Brazil	2,500	578
Sabah, Malaysia	2,700	765
Sarawak, Malaysia	5,000	544
Savanna		
Mokwa, Nigeria	1,175	270
Lamto, Cote d'Ivoire	1,297	240
Fete Ole, Senergal	435	80

Source: Yamada et al. (2005).

Comparison to the carbon stocks at each site are given by Malhi et al. (1999) in Table 2.3. At the tropical site no soil carbon inventory was undertaken, and the mean tropical forest value of 162 t C ha^{-1} estimated by Post et al. (1982). The total of carbon at the boreal and tropical sites is similar in amount (Table 2.3), but the balance amongst the component in very different. Approximately 60% of total carbon is stored on or below ground at the tropical and temperate sites, whereas 90% of carbon is below ground at the boreal site, predominantly the form of organic detritus. The value for foliage biomass at the boreal site includes shrub and moss biomass, estimated at 1.1 t C ha^{-1}. The below ground woody detritus pool includes both branch and leaf litter, but also tree stumps.

Table 2.3 Estimated stocks of carbon (Mg ha^{-1}) at the three forest ecosystems.

	Tropical	Temperate	Boreal
Aboveground			
tree foliage	4.6	1.6	6.2
tree branches	58	15.1	6.7
stems	117	57.1	36.3
Total above ground	217	79	49.2
Belowground			
Leaf and wood detritus	41.4	11.7	6.2
Fine root	38	N/K	2.8
Coarse root	26	19.1	8.0
Root detritus	N/K	8.7	1.2
Soil organic matter	162	55.7	390.4
Total below ground	230	62	409
Ecosystem total	447	169	458

N/K= not known, Source: Malhi et al. (1999).

2.3 Decomposers

The decomposers in tropical forest play an important role in degradation dead plant material because their diversity and very high abundance in each species. There are various decomposer groups such are the microflora (bacteria, fungi, actinomycetes and yeasts), mircofauna (Protozoa, Nematoda, Rotatoria and Tardigrada), mesofauna (Enchytraeidae, Acari, Collembola) and macrofauna (e.g. earthworms, Diptera larvae, millipedes, woodlice, insects, slugs and snails) as shows in Figure 2.2. They are contribution to weight loss and carbon mineralization on litter decomposition.

Bacteria and fungi are the most abundant of the microbial decomposers, numbering in the billions in only one handful of soil. They break down dead organisms into nutrient, and they play an integral role in the decomposition processes. In early stages of decomposition, well before leaf fall, colonies of bacteria, yeasts and other fungi invade leaf surfaces. Amycelium develops and after some weeks penetrates the leaf tissues (Lavelle and Spain, 2003). Bacteria and fungi are the major organisms decomposing dead organic matter as well as major contributors to carbon mineralization in high percentages are responsible for 80 to 95% of the total CO_2 respired and consequently of the organic carbon mineralization (Lavelle and Spain, 2003).

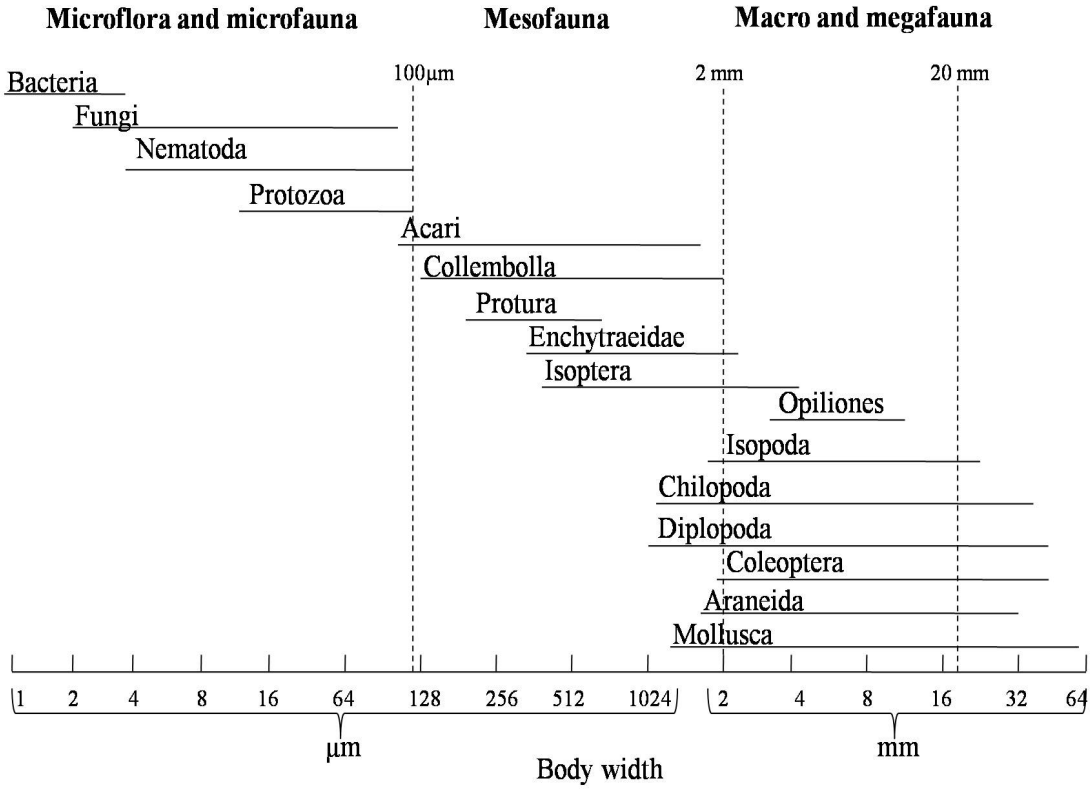

Figure 2.2 A generalized classification of soil fauna by body width (Wallwork, 1970).

The groups of soil fauna play an important role in decomposition processes of plant litter decomposition. They are abundance in tropical rainforest, Sarawak (Table 2.4). Instance the termites and their mounts are abundant, accounting for nearly 30% of all animal biomass and 80% of the entire biomass of insects (Ohashi et al., 2007). Termite population was 16.7 gm^{-1} of biomass in dry evergreen forest, Thailand. Termites mineralized 11.2% of annual litter aboveground litterfall from their populations and fungus comb (Yamada et al., 2005) (Table 2.5).

Table 2.4 Abundance of soil macro invertebrates in tropical forest.

	Abundance (N/m^2)
Saprophage	
Gastropoda	0
Oligochaeta	5±
Isopoda	31±34
Diplopoda	6±7
Blattodea	31±20
Isoptera	824±871
Orthoptera	14±15
Lepidoptera	0
Diptera	8±11
Elateridae	5±6
Other Coleoptera	3±5
Zoophage	
Araneida	83±43
Chilopoda	34±29
Staphylinidae	23±25
Formicidae	727±628

Source: Tsukamoto and Sabang (2004).

Termites possess symbiotic bacteria in their absence for assimilated wood. It's widely recognized that the physical break down of the litter by soil insects involves mechanical disintegration while the biological breakdown includes degradation by microbes. In many ecosystems of soil insects have special importance in leaf

consumption, sometime are abundance, concentrated in relatively small areas, and active during great part of the year.

Table 2.5 The carbon mineralization of termite populations and fungus combs in tropical forest.

Natural ecosystem site	Annual rainfall (mm)	Biomass ($g\ m^{-2}$)		Total C mineralization/litter annual aboveground
		Termite population	Fungus comb	
Tropical forest				
Sakaerat, Thailand	1,144	16.7	40.1	11.2%
Mbalmayo, Cameroon	1,520	75.5	14.3	8.3%
Pasoh, Malaysia	2,000	9.4	42.3	7.5%
Manaus, Brazil	2,500	6.8	0.0	1.3%
Sabah, Malaysia	2,700	3.5	6.1	1.1%
Sarawak, Malaysia	5,000	2.4	0.4	0.6%
Savanna				
Mokwa, Nigeria	1,175	10.6	98.5	38.7%
Lamto, Cote d'Ivoire	1,297	1.7	24.1	10.2%
Fete Ole, Senergal	435	1.0	3.4	5.3%

Source: Yamada et al. (2005).

2.4 How Do Researchers Carry Out Studies on the Decomposition?

There are many methods developed so far by the researchers on how to study the decomposition processes of dead plant material some of which are as follows.

2.4.1 Litter Bag Method

One of the most employed methods is the using of litter-bags. Litter-bag methods measure weight loss of the litter decomposition within bags, which are put on the surface soils by soil decomposer communities, and suppose the lost weight to be decomposed during the experimental period. Decomposer relative contributions are roughly distinguished by removing a known weight of litter in bag of difference size mesh, with restricts the size of organisms that can enter the litter bag.

The rate of decomposition is affected by soil fauna, microflora and environmental factors. Previous studies have shown that decomposition rate in tropical forest, China, for instant, the k values were 1.16-3.51 in middle subtropical zone at Xiging, Fujian (Lin et al., 2001), and 0.422-1.108 in Heshan (Zhou et al., 1995). A comparison of decomposition rate between tropical and temperate broad leaved litter were k = 1.85 and 0.929 for tropical and temperate forests, respectively (Takeda, 1995). Decomposition rate of leaf litter in tropical forests are approximately twice as high rate than those of temperate forests.

For measured using the litterbag technique its advantages, litter bag is most commonly used. A known quantity of leaf litter is placed into a mesh bag, and the bag is then inserted into the litter layer of a forest floor. Bags are harvested at periodic intervals, dried and reweighed to determine the amount of mass lost. By incubating the leaves in situ, they are exposed to the normal fluctuations in temperature and moisture. The mesh bags allow smaller insects as well as microorganism access to the

leaves. In this experiment, the litter cage technique was used to compare the decomposition rates of interval seasons. It is non-destructive methodology with minimal or no disturbance to habitat. Litter bag technique can analyzed the contribution of difference organism, group in terms of their body sizes, to decomposition (Swift et al., 1979).

The disadvantages of this technique are that entire fragment may be broken off and lost from litter bags by fauna or itself, this string method may be overestimated the decomposition rates (Coleman et al., 1983). Litter bag also can keep humidity within the litter bag parallel on the ground.

In this case, the word "decomposition" includes the part of litter that has been completely decomposed (e.g. mineralized into CO_2) and that has been broken down into small particles and entered into the soil layers. In contrast, CO_2 measurements will reveal CO_2 afflux from the surface of ground, including from dead leaves and branches (litter layer), and soil layers. However, these methods have advantages and disadvantages at the same time.

2.4.2 Direct Method of Determining Microbial Activity

The measurement of soil respiration (CO_2 afflux from the soil) has been used to evaluate soil fertility and biological activities on litter layers and in soil (Luo and Zhou, 2006). Direct measurements of the activity of soil microorganism have been a study goal for soil biologists (Coleman et al., 2004), Measurement from the basic thermodynamic fact as organism's metabolic activity; they emit heat from enthalpy of reactions occurring in net catabolism. In Asian tropical rainforest, the natural distribution of soil respiration rate was distributed lognormally with mean rate ± standard deviation and coefficients of variation were 5.32±2.85 μmol m^{-2} s^{-1} (17.6 t

C ha^{-1} yr^{-1}). The CO_2 hot spot were found with extremely high values (15-25 μmol m^{-2} s^{-1}) (Ohashi et al., 2007), while the excess soil emission of CO_2 were 14.1 and 15.0 μmol m^{-2} s^{-1} in Thailand (Hashimoto et al., 2004) and the Brazilian Amazon (Davidson et al., 2000), respectively. Mean rates of the soil respiration vary widely within and among major vegetation biomes (Table 2.6). The lowest rates of soil respiration occur in the coldest (tundra and northern bogs) and driest (deserts) biomes, and the highest rates occur in tropical moist forest where both temperature and moisture availability are high year-round.

Table 2.6 Mean rates of soil respiration in different types of vegetation.

Vegetation	Soil respiration rate(g C/m^2/year) (mean±S.E.)	n	
Tundra	60±6	11	e
Boreal forests and wood land	322±31	16	cde
Temperate grassland	442±78	9	bcd
Temperate coniferous forests	681±95	23	b
Mediterranean woodlands	713±88	13	b
Croplands, fields	544±80	26	bc
Desert scrub	224±38	3	de
Tropical savannas and grasslands	629±53	9	bc
Tropical dry forests	673±134	4	b
Tropical moist forests	1260±57	10	a

Source: Raich (1992).

However, the advantages and disadvantages of the litter bag method and CO_2 measurement are described as the decomposition rate be calculated by litter mass

loss from litter bag during experiment period but we don't know where litter samples escaped from litter bag "mineralized to CO_2 or leaching". The CO_2 measurement can be used to measure how much rate of CO_2 flux from litter layer decomposition and decomposition in the soil, but can not measure how much decomposition rate of litter mass loss that loss by completely decomposition (mineralized to CO_2).

CHAPTER III

METHODOLOGY

3.1 Study Site Description

3.1.1 Study Area

This research had been conducted at Sakaerat Environmental Research Station (SERS) during January 2008- May 2010. Samples analysis had been investigated at SERS laboratory and Centre for Scientific Equipment and Technology, Suranaree University of Technology.

3.1.2 SERS History

Sakaerat is one of the four UNESCO designated biosphere reserves in Thailand. The Sakaerat Biosphere Reserve was established in September 1967 by the Applied Scientific Research Corporation of Thailand to use as a national forest reserve for scientific research by the Royal Forest Department, Ministry of Agriculture and Cooperative. The study area of this research is located in the Sakaerat Environmental Research Station (SERS) (Figure 3.1), the biosphere reserve areas in Man and Biosphere Program of UNESCO. This station has been being dedicated as an ecological reserve for scientific purposes. It is administered by the Thailand Institute of Scientific and Technological Research (TISTR) as a facility for ecological and environmental research. SERS is located in Nakhon Ratchasima Province. It spans Phu Luang Subdistrict, and Udomsap Subdistrict in the Pakthongchai District and Wang Nam Khieo District. It is located at approximately 14^0 30' N and 101^0 55' E, about

300 km northeast from Bangkok and 60 km from Nakhon Ratchasima (Korat) on highway 304. The station ground cover an area of 78 km^2 (approximately 48,750 rai).

The station consists of 29.5 km^2 of dry evergreen forest (DEF) and 12.2 km^2 of dry deciduous forest (DDF) (Wacharakitti et al., 1980). The dominant tree species is *Hopea ferrea* and canopy trees attain 30 to 40 m (Kanzaki et al., 1995). The sedimentary rock is sandstone; upper soil texture is characterized as clay loam, sandy loam, and sandy clay loam (Bunyavejchewin, 1997). The study site is in tropical seasonal forest with a mean annual temperature of 26.2°C and annual rainfall of 1240 mm. Monthly rainfall is typically less than 40 mm during the dry season, from December to February (Sakurai et al., 1998).

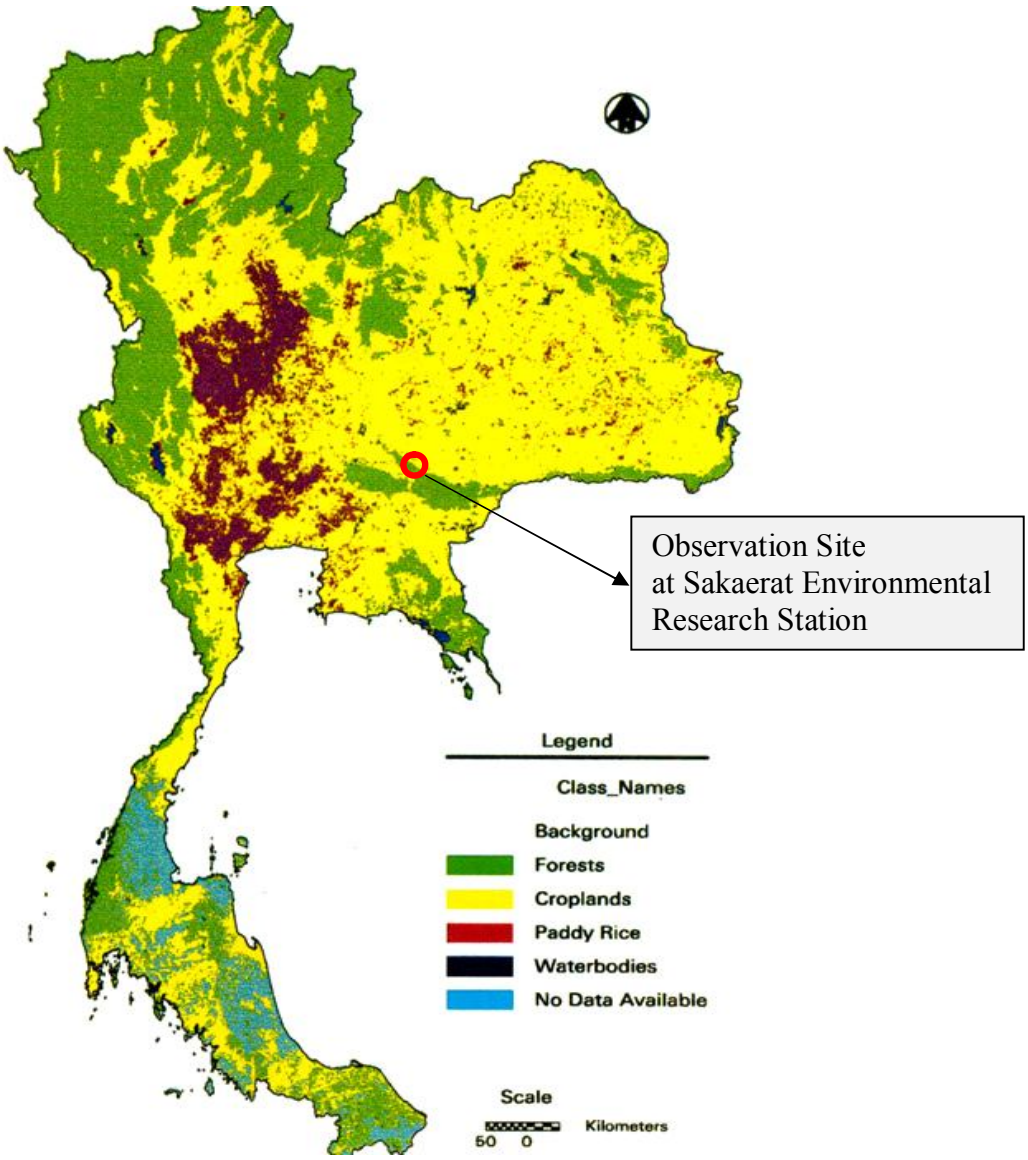

Figure 3.1 The location of Sakaerat Environmental Research Station.

(Source: http://compete.center.ku.ac.th/site3.htm).

3.1.3 Topography and Geography

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

The entire area of SERS appears to be underlain by sandstone of the Phra Wihan formation of the Khorat group to a maximum thickness of 1.025 m. It lies comformably on the purplish siltstone, micaceous sandstone, and conglomerate on the Phu Kradung formation on the same group.

3.1.4 Climate

Average annual temperature at Sakaerat is 26°C and average annual rainfall is 1,260 mm. There are three seasons, namely the rainy season from May to October, winter from November to February, and summer from March to mid May. In general, the lowest relative humidity is about 82% and the highest is about 95%. The relative humidity increases after April until October, and decreases after February. The climate is monsoonic and classified as a "tropical savanna type" (Lamotte et al., 1998).

3.1.5 Vegetation and Forest Types.

Vegetation types of the area are dry evergreen forest and dry dipterocarp forest is the dominant forest types, representing 70%. The dry evergreen forest occupies the south-western portion. The dry evergreen forest is usually referred to as the tropical semi-evergreen rain forest. Tree species in this forest are mainly evergreen (Lamotte et al., 1998).

Table 3.1 Defined forest types in Sakaerat Environmental Research Station in the year 2000.

Forest types	Km^2	Rai	Percentage
1. Dry evergreen forest	46.84	29,260	59.97
2. Dry dipterocarp forest	15.51	9,060	18.57
3. Forest plantation	14.46	9,038	18.52
4. Bamboo forest	1.12	697	1.43
5. Grassland	0.93	582	1.19
6. Building and official areas	0.25	157	0.32
Total	78.06	48,800	100.00

Source: TISTR (2002).

3.1.6 Soil Characteristics

The dominant great soil group of the SERS, occurring in all topographic positions is Red-Yellow Podzolic soils on materials derived from both sandstone and shale. Series are Khao Yai for the deep members, Tha Yang for the shallow stony members, and Muak Lek for the deeper soils on shale-derived material. The depth of soil is about 40-120 cm. Soil texture is mainly coarse sandy clay loam to sandy loam and clay loam. The scarps mostly consist of rock outcrop and some stony screen materials (Suriyapong, 2003).

3.1.7 Study Site

The study area was located in dry evergreen forest at the Sakaerat Environmental Research Station (SERS).

3.1.7.1 Dry Evergreen Forest (DEF)

At SERS, two distinct seasonal dry evergreen forest associations occur, characterized by their dominant species. One is dominated by *Hopea ferrea,* the other by *Shorea henryana.* Previous research (Bunyavejchewin, 1997) has shown that the *Hopea ferrea* type prefers level sites, has lower species richness and a greater tendency towards monodominance. The *Shorea henryana* type prefers slopes and has higher species richness. The upper canopy of the *Hopea ferrea* type is generally more continuous than that of the *Shorea henryana* type

3.2 Setup Litter Cage Plots

Thirteen plots (10 experiment plots and 3 extra plots) were set up in the dry evergreen forest as a map shown in Figure 3.2.

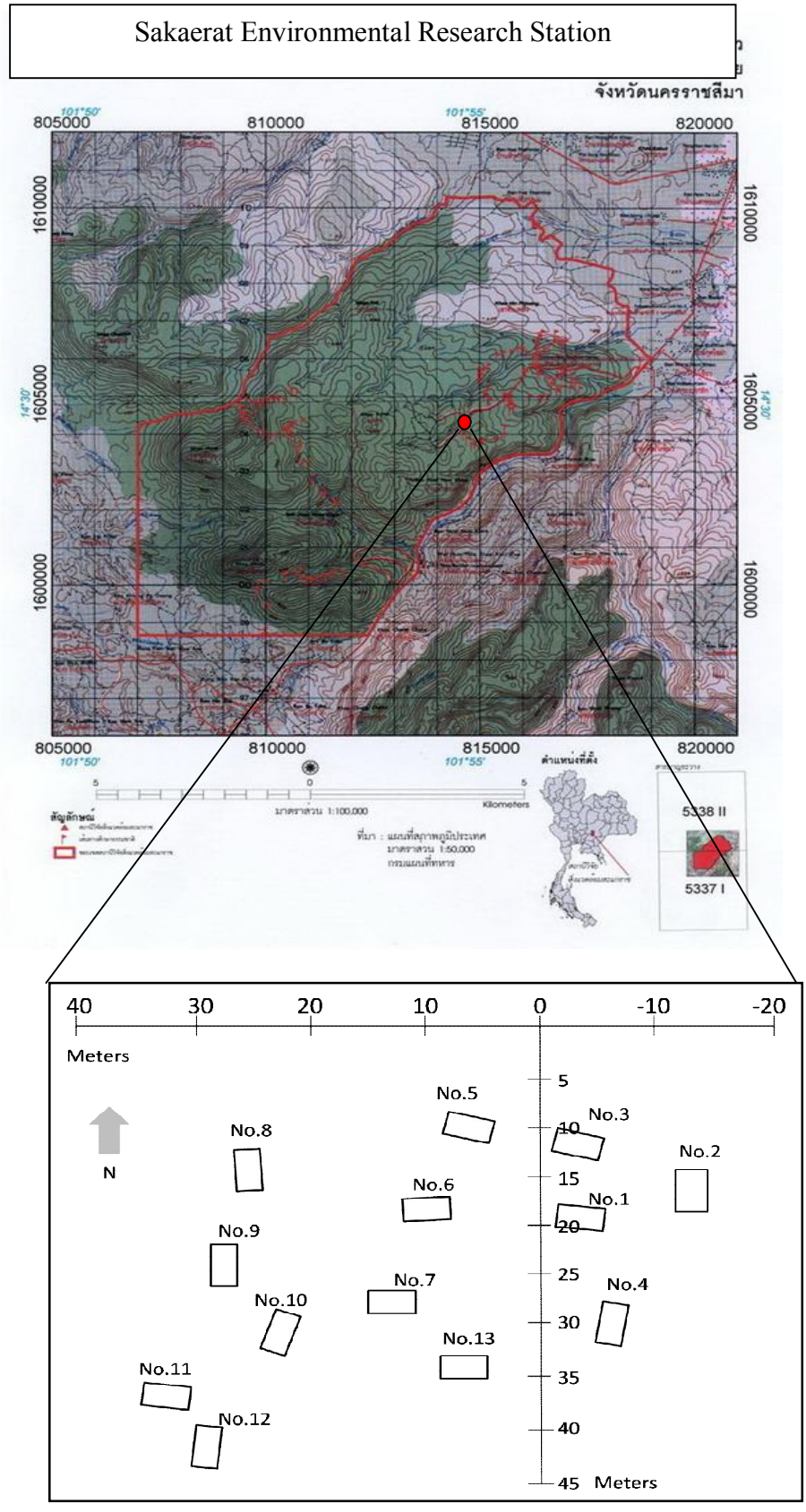

Figure 3.2 Map of total 13 plots in DEF.

Each plot (100 × 200 cm) consisted of forty quadrates which were divided into four treatments (Q) as Q1, Q2, Q3, and Q4, respectively, and each treatment had 10 quadrates. Two different sizes (2 mm and 0.2 mm) of netting (mosquito netting) were used for litter cages. Closed cages were set up in Q1 by using 0.2 mm mesh sizes with approximately 10 cm × 10 cm × 10 cm. Open bottom cages were set up in Q3 and Q4 by using 2 mm mesh sizes with approximately 10 cm × 10 cm × 10 cm, and no litter cage in Q2 (natural) as illustrated in Figure 3.3.

3.3 Litter Preparation

Litter samples were collected from within an area of 1 m^2 drawn randomly around each plot for all 13 plots. The litter samples were then washes with water to removed soil and dried at 80°C for 48 h and measured its total dry weight. The total dry weight was then divided by the area of a litter cage to find out the dry weight of litters and fixed in each litter cage. After recording the dry weight of each sample, they were stored in the plastic bags.

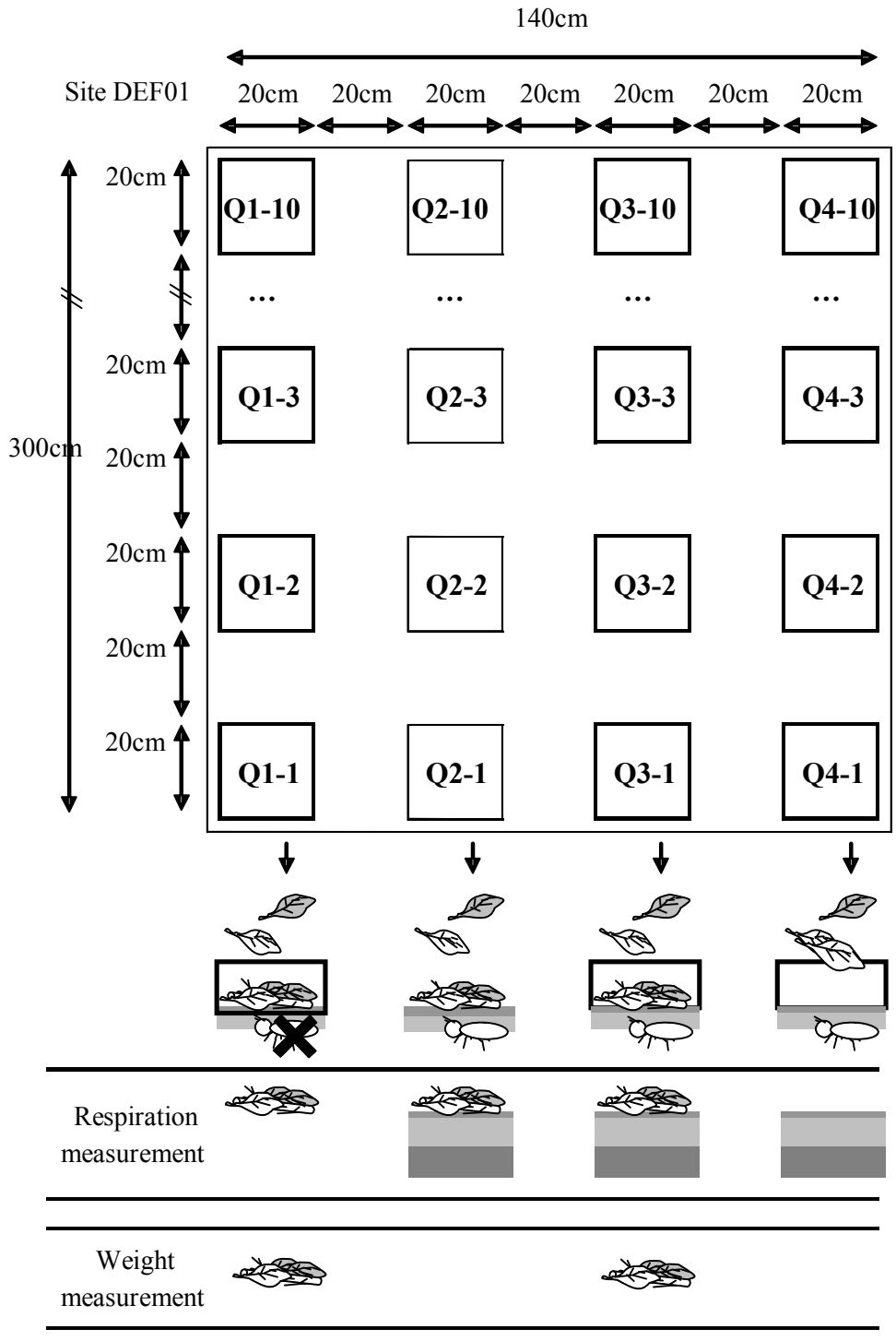

Figure 3.3 Experimental plot design for incubate litter cage within DEF.

3.4 Experimental Plot Design

A total of 260 litter samples were prepared. Twenty litter samples were used for each plot, of which 10 litter samples used in Q1 cage (closed cage) that were put on soil surface layer around 0-2 cm, and 10 litter samples for Q3 (open bottom cage).

For treatment Q2, no litter cage (natural) was used. At treatment Q4, all the litters were removed and used only the empty cage which was litter removal cage (Figure 3.4). All natural litters and small litter particles were removed from the soil surface within Q1 and Q3 cages were removed before the litter samples were put into a cage in all treatments.

At 2-month interval from January, 2009 to January, 2010, two litter cages and one natural litter per plot were harvested from all of 13 plots as well as soil samples at layer depth of 0-5, 5-10, and 10-20 cm from Q2, Q3, and Q4, respectively in each plot was sampled. The retrieved litter samples and soil samples were placed in separated plastic bags and were directly transferred for the measurement of CO_2 flux using CO_2 Gas Analyzer. For litter samples in only Q1 and Q3 were collected from January, 2009 to May, 2010 for measurement of litter remaining (Table 3.2).

Table 3.2 Time course of the litter and soil samples measurement.

Measurement of samples	Period								
	2009						2010		
	Jan	Mar	May	Jul	Sep	Nov	Jan	Mar	May
litter weight remaining	◄								►
CO_2 measurement of litter and soil samples	◄						►		

The wet weights of litter samples were measured after litters were washed with water to remove soils. Litters were oven-dried at 80°C for 48 h and measured the weight. For the soil samples, after measurements CO_2 afflux, wet weight was measured and removes stones and roots were removed. The soil samples were oven-dried at 105°C for 48 h, to determine the dry weight (Figure 3.5).

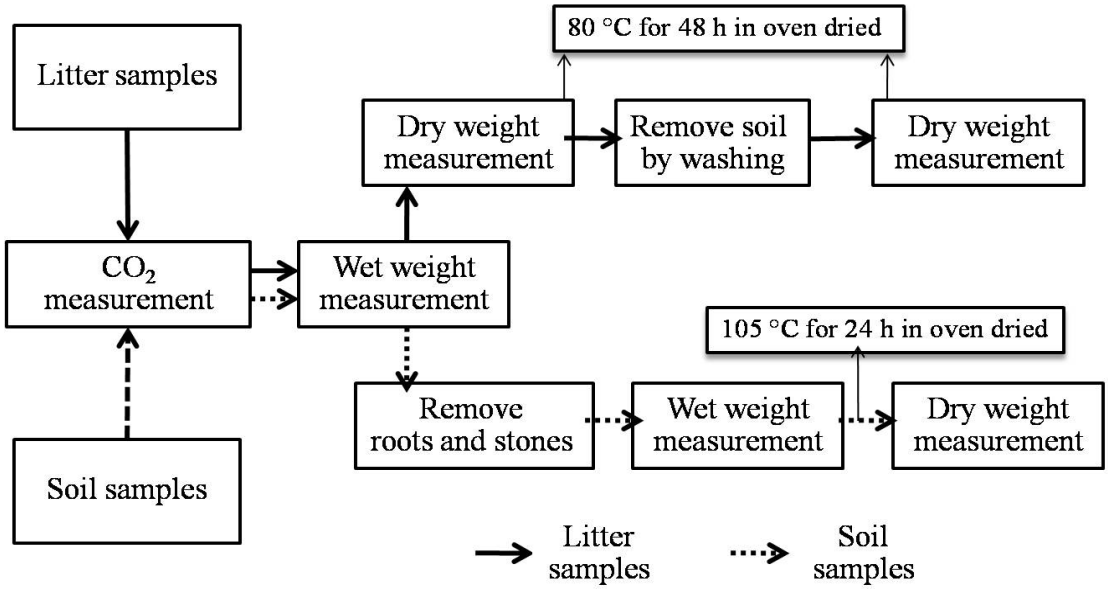

Figure 3.4 Flowchart of litter and soil samples measurements.

3.5 Analysis of Microbial Activity (CO_2 efflux measurement)

The LI-820 CO_2 Gas Analyzer (Environmental Measurement Japan Co. Ltd.) (Figure 3.6) had been used for analysis of microbial activity. It was an absolute, non-dispersive infrared (NDIR) for measuring CO_2 afflux of the samples. The CO_2 analyzer calibrated with CO_2 free gas generated by connecting it to a tube filled with soda lime. It was measured the value of the real CO_2 concentration (approximately

420 ppm) in the air by using Gas Detector Model GV-100 (Gastec Co. Ltd., Japan). The details of this analysis are shown in Appendix B.

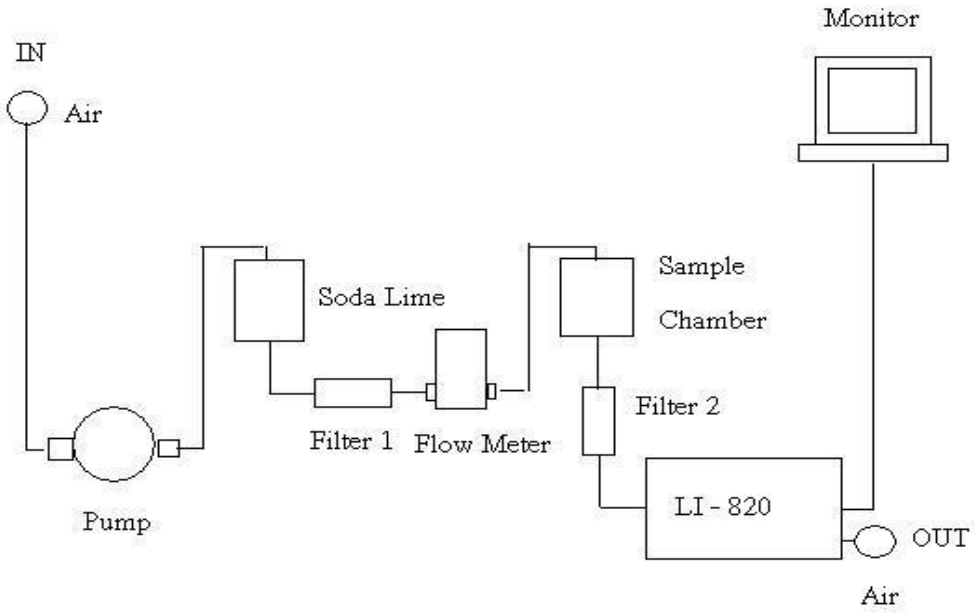

Figure 3.5 System of CO_2 Gas Analyzer for measuring CO_2 emission.

3.5.1 Litter and Soil Measurement

Litter and soil respiration rate was estimated by measuring microbial respiration of litter and soil samples during incubation period. After CO_2 analyzer calibrated to zero, each litter and soil samples were putted into sample chamber, then turn on an instrument again and shown that the main window displays value of CO_2 emission are showed a graph with data curve of CO_2 emission are highly and after that curve will be slowly down till stable and then control the flow rate is 100 ml/minute, originally from flow rate is higher after that curve of CO_2 emission are increate again till curve of CO_2 emission are straight line. It will shown CO_2 emission rate, there are

CO_2 emission of all microorganisms in litter and soil samples, and then record the data.

Each sample, wet weight (W.W.) was recorded and the samples were oven-dried at 80°C for 48 h for litter samples and at 105°C for 24 h for soil samples, to determine the dry weight (D.W.). The mean moisture ratio of litter samples and the aridity between seasons in the dry evergreen forest were compared. The formula for the percentage of water ratio is as follow:

$$\text{Water ratio} = (\text{W.W.} - \text{D.W.})/\text{D.W.}$$

where:

W.W. is the wet weight of the sample

D.W. is the dry weight of the sample

For the measurement, CO_2 emission as the amount of CO_2 gas of each litter and sample with equation of state, the ideal gas law, as follow;

$$PV = nRT$$

where:

P is the pressure in the cell (atm)

V is the volume of the gas flow per minute (L/MIN)

R is the gas constant ($R = 0.0820574587$ L atm $K^{-1}mol^{-1}$)

n is the amount of CO_2 (the number of gas molecules, usually in mole)

T is the temperature in the cell (K)

For example, these values are as follows: P = 96.7 kPa, gas flow rate = 100ML/MIN, temperature = 51.4°C, P (CO_2) = 400 ppm.

3.6 Analysis of Litter Decomposition Rate

Decomposition rates were determined by mass loss, the difference between initial litter weight and the dry mass of remaining litter after incubation. The decomposition rates of litter fitted to a single exponential decay model of Olson (1963) was analyzed following this formula;

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

where:

L_o is the initial mass of dry matter,

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

t is the incubation time

k is the decomposition rate constant.

3.7 Data analysis

A single exponential decay model (Olsen, 1963) was used to analyzed litter breakdown rate constant (k), and using tested by paired T-test to compare the difference between the cages in each sampling time. The significance of difference of litter respiration and soil respiration between the cages in each sampling time was tested by paired ANOVA with Tukey's post hoc test.

CHAPTER IV

RESULTS AND DISCUSSIONS

The results of this study were analyzed with statistical tests assessing the extent to which the contribution and control/comparison groups participated in the decomposition processes were different. The results of this study are divided into four parts as follows;

4.1 Determinants of the Climatic Variation of SERS

The average monthly climatic data of November 2008 to May 2010 was collected from the monthly values of meteorological observation by SERS (more details in the Appendix A).

During incubation period, the total rainfall was 1164.4 mm and there was less than 40 mm monthly rainfall from November 2008 to February 2009, June 2009, November 2009, December 2009, and February 2010, respectively as shown in Figure 4.1. The average monthly temperature was highest in May 2010 with the value of 30.2°C, and lowest in December 2008 with the value of 20.2°C. The average relative humidity was highest in November 2008 with the value of 92% and lowest in March 2010 with the value of 76%.

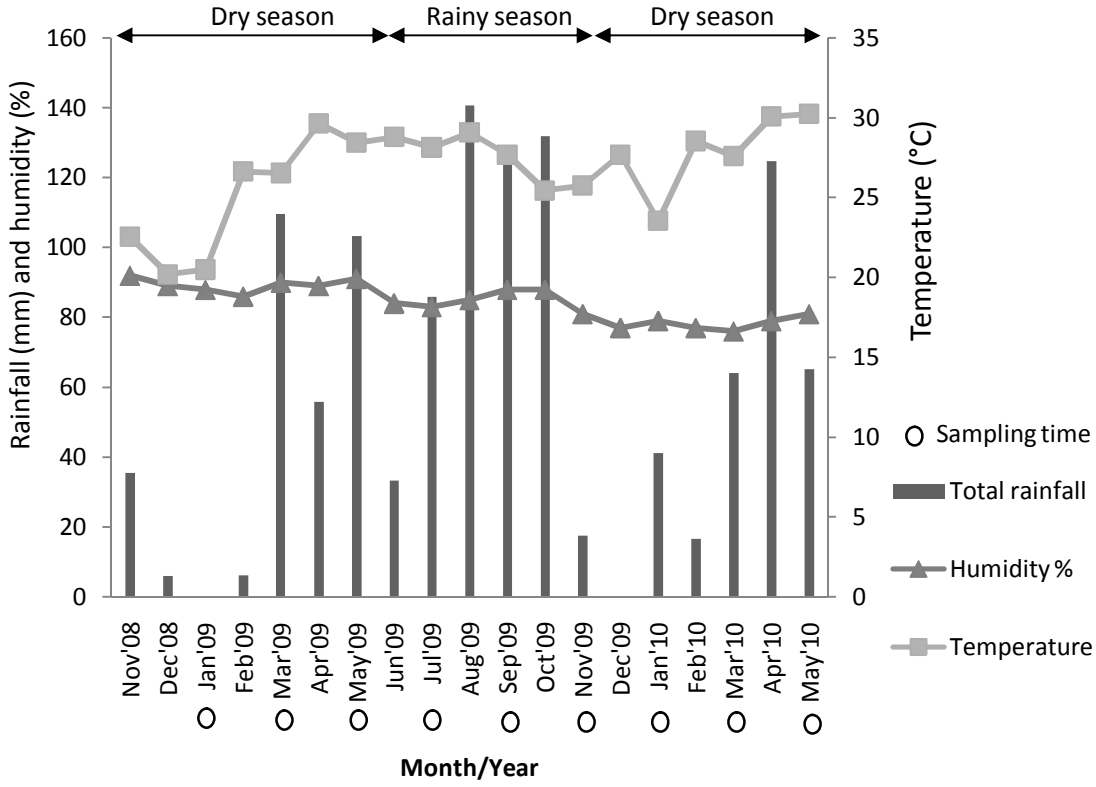

Figure 4.1 The monthly rainfalls, temperature and humidity from November 2008 to May 2010 in the SERS.

4.2 The Rate of Litter Decomposition

Time courses of litter weight loss in the cages are shown in Figure 4.2. There were significant differences between coarse and fine cages during November 2008 to May 2010. Decomposition rate constants (k year^{-1}, see Olsen, 1963) were 1.62 and 0.74 in the coarse and fine cages, respectively which were determined based on decomposition of naturally accumulated litter (i.e. a mixture of fresh and rotten litter).

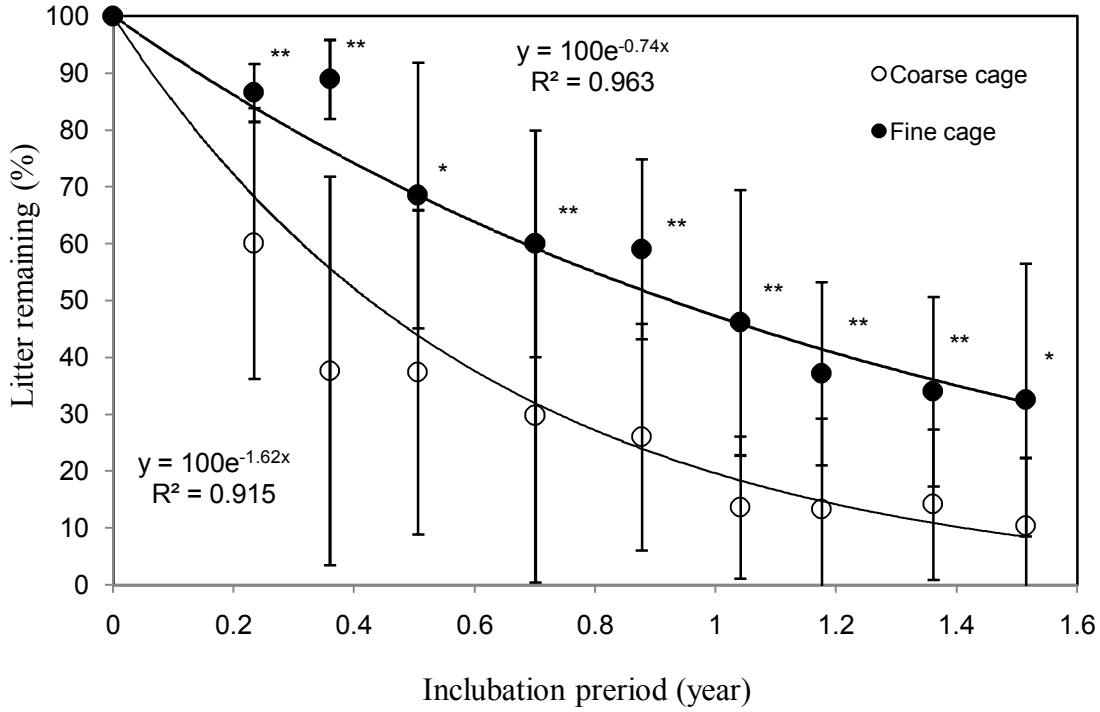

Figure 4.2 Decomposition rates of litter samples in coarse and fine cages; significance of difference between the cages in each sampling time was tested by paired T-test (* P <0.05, ** P <0.01).

A Comparison of the k values in Figure 4.2, suggests that the decomposition rates of the coarse cages are twice time as higher than the fine cages. As is evident from the single exponential decay model (Olsen, 1963), this faster weight loss was also observed by Yamashita and Takeda (1998) and Takeda (1996) due to a very similar decomposition rate constant which were investigated using litter bags with two mesh sizes (0.5 mm and 2.0 mm), of k = 2.15 and 1.85 for fresh leaf litter in coarse mesh litter bags higher than in the fine mesh bag (k = 0.76 and 0.80), respectively. The differences between the rates of decomposition of two different mesh sizes of litter cages were found. It may be suggested that termites attacked the litter samples in the

cages more intensively than those observed in the previous studies, in the field Yamada et al. (2005) showed the prominently importance of termites in litter decomposition.

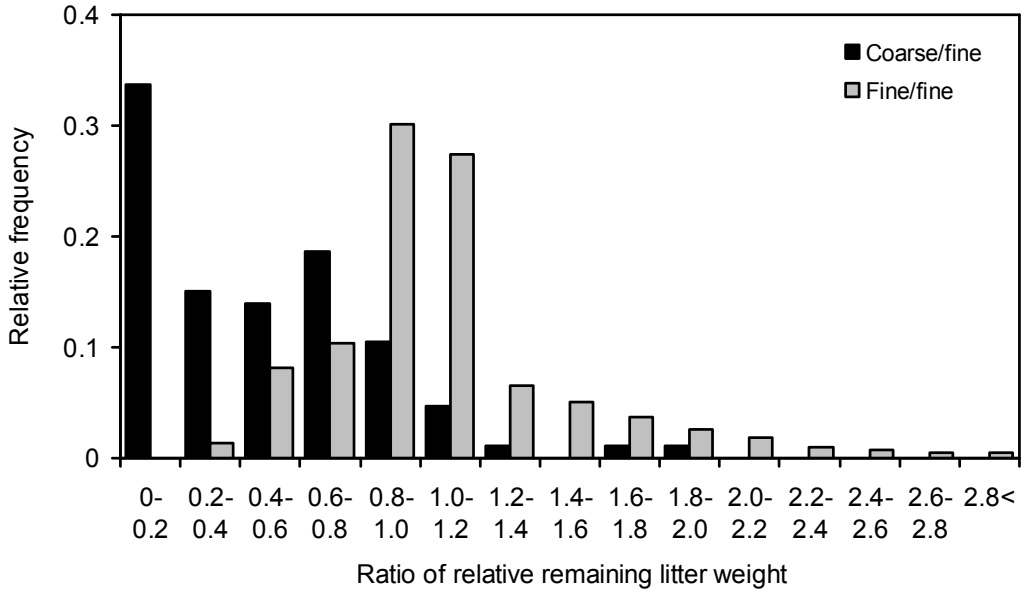

Figure 4.3 Distributions of the ratio of litter weight remaining between pairs of coarse and fine cages and between fine cages. The former is an index to represent the intensity of litter removal by termites.

Distribution of termites is usually aggregated (Bignell and Eggleton, 2000 and Inoue et al., 2001), and their foraging is generally done in a large group within a relatively small area basically because of their sociality. On this basis, this study expects the pattern of litter removal by termites to be much more intensive than that by microorganisms such as bacteria and fungi (A typical case of litter removal by termites in Appendix C). To evaluate the intensity, the result were calculated an index (intensity index) as the ratio of the litter weight remaining in a coarse cage to that in

the paired fine cage (Figure 4.3). The intensity index become more close to 0 when termites remove more litter from the coarse cage, while around 1 when termites scarcely remove litter from the coarse cage. In order to know the dispersion of the index in the case of only microbial decomposition, the ratio of the litter weight remaining were calculated in the fine cages between all pairings separately in each sampling time (a total of 976 pairs). There was a significant difference between the two distributions by Kolmogorov-Smirnov test ($D = 0.634$, $P < 0.01$). Judging from the distribution of the ratios between fine cages, the distribution of intensity index seems to be a mix of two distributions: one is the similar distribution to that between fine cages, but slightly shifted to left, and the other is the distribution highly skewed to low levels (i.e. 0 to 0.4). The former distribution probably means the absence of intensive foraging by termites. The latter distribution clearly indicates the evidence of intensive litter-removal by termites.

4.3 The Litter Respiration

The respiration rate of litter samples and natural litter were significantly different between the cages in each samples as show in Figure 4.4. Litter respiration rates were significant difference between litter cages and natural litter ($P < 0.01$) as well as a high rate with high rate of water ratios caused by peak rain and rainy season in May and September 2009, respectively (Figure 4.5). In dry season, litter quality do not affected with the microbial decomposition due to low ability of the water in both natural litter and litter cage but litter quality have effected in microbial decomposition in rainy season because available of water as a high litter respiration rate in natural litter while low litter respiration rate in litter sample with high ability of water.

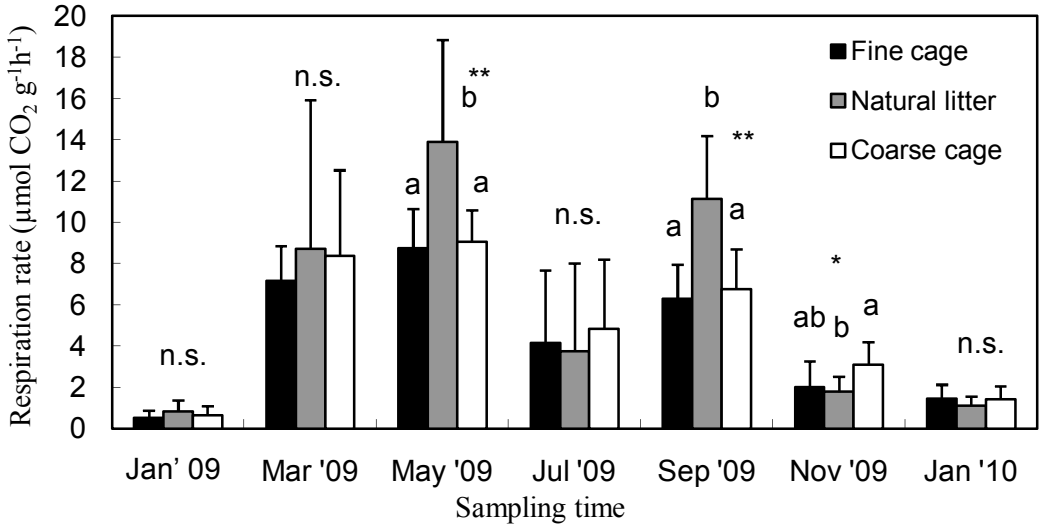

Figure 4.4 Respiration rates of litter samples and natural litter; significance of difference between the cages in each sampling time was tested by paired ANOVA with Tukey's post hoc test (*P <0.05, **P <0.01). Means not sharing a letter are significantly different.

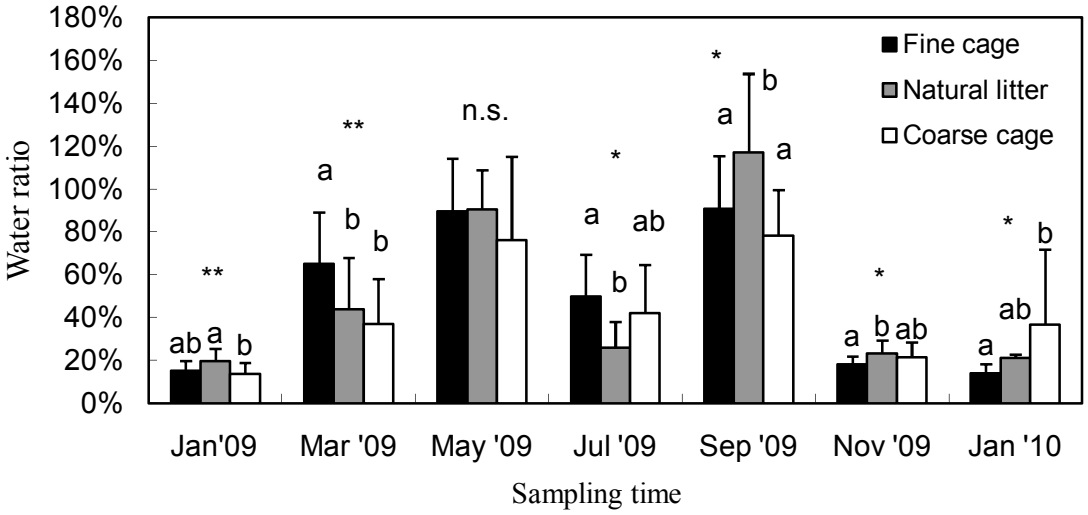

Figure 4.5 Water ratio of litter samples and natural litter; significance of difference between the cages in each sampling time was tested by paired ANOVA with Tukey's post hoc test (*P <0.05, **P <0.01). Means not sharing a letter are significantly different.

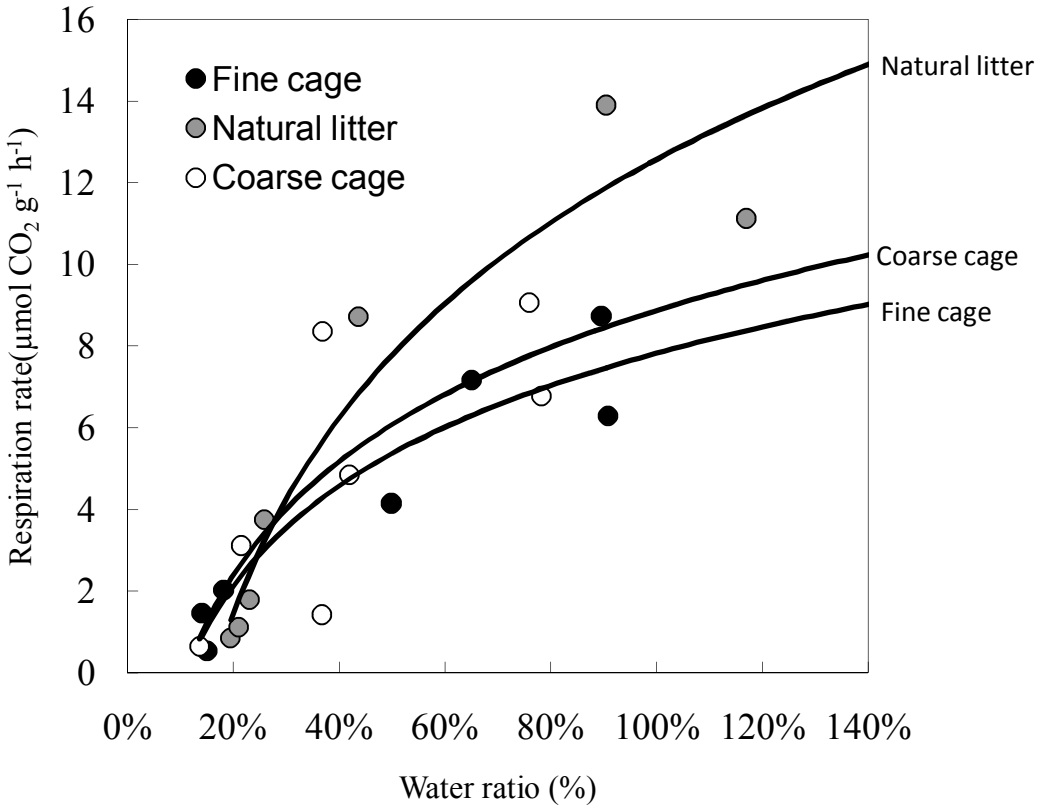

Figure 4.6 Plot of litter-respiration rate against water ratio.

The pattern of the relationship of litter respiration rate with the water ratio (Figure 4.6), the regression equations are: y = 3.5488Ln(x) + 7.8246, R^2 = 0.8972 for fine cage; y = 6.9107Ln(x) + 12.58, R^2 = 0.9092 for natural litter; y = 4.0421Ln(x) + 8.8757, R^2 = 0.5866 for coarse cage. Litter respiration rates tended to increase with the water ratio. The rate of litter respiration is quite similar in between 0.20 and 0.40 of water ratio, while respiration rate of natural litter tended to higher than litter samples with increase water ratio indicating ability of microbial decomposition control by litter quality.

4.4 The Soil Respiration Rate

The soil respiration rate of surface soil (0-5), middle soil (5-10) and deep soil (10-20) were not significant difference among three different treatments. Water availability is the dominant factor in influencing decomposition by microbes, which are in shown below.

Respiration rates of surface soil (0-5) are not significant difference among the cages in each sampling time (Figure 4.7). Water ratio of surface soil (0-5 cm) is also not significant difference among the cages in each sampling time (Figure 4.8).

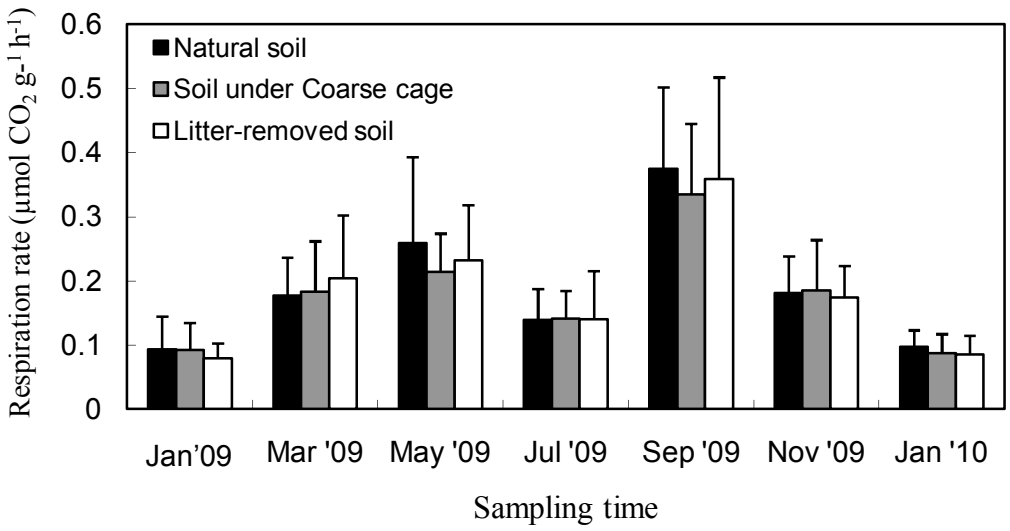

Figure 4.7 Respiration rates of surface soil (0-5 cm).

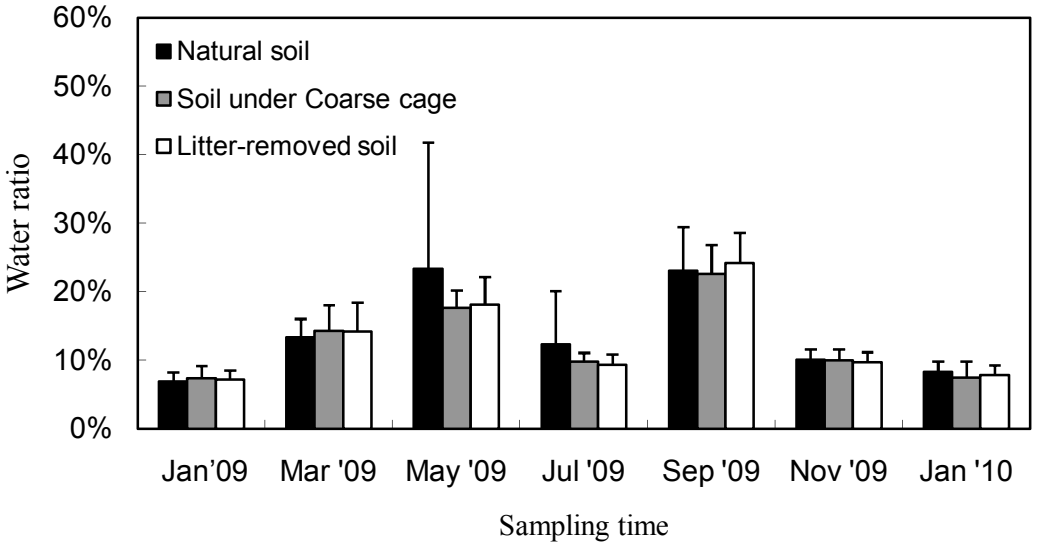

Figure 4.8 Water ratio of surface soil (0-5 cm).

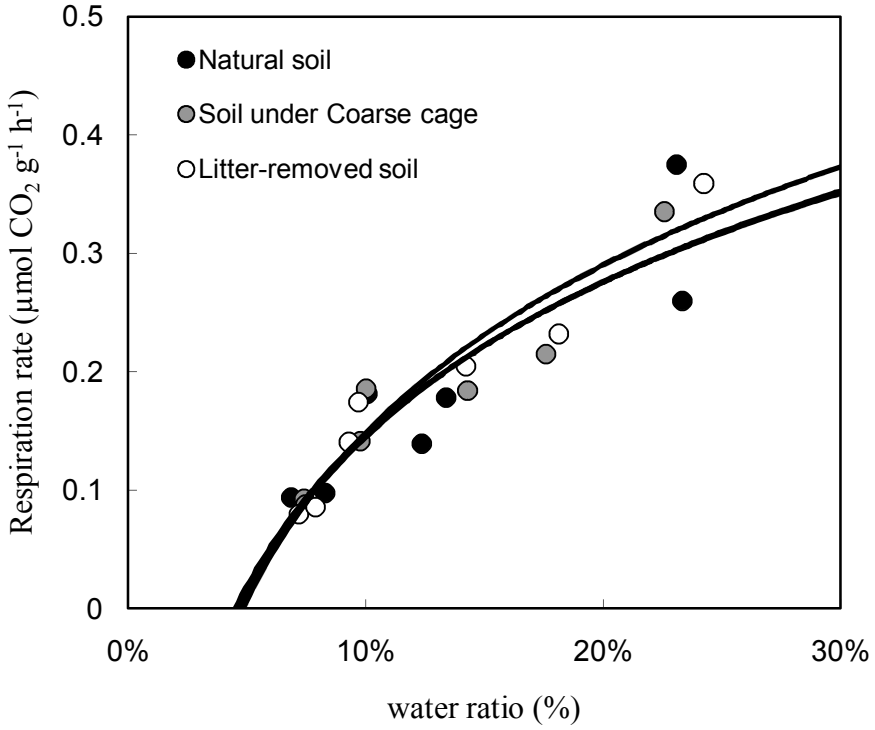

Figure 4.9 Plot of 0-5 cm-soil respiration rate against water ratio.

This result plotted show that the litter respiration rate of the litter samples and natural litter plotted lines linearly increase with water ratio. The regression equations are: $y = 0.1893\text{Ln}(x) + 0.5805$, $R^2 = 0.8062$ for natural soil; $y = 0.1853\text{Ln}(x) + 0.5738$, $R^2 = 0.8808$ for soil under coarse cage; $y = 0.2048\text{Ln}(x) + 0.6194$, $R^2 = 0.9309$ for litter-removed soil.

Respiration rates of middle soil (5-10 cm) are not significant difference among the cages in each sampling time (Figure 4.10). Water ratio of middle soil (5-10 cm) is also not significant difference among the cages in each sampling time (Figure 4.11).

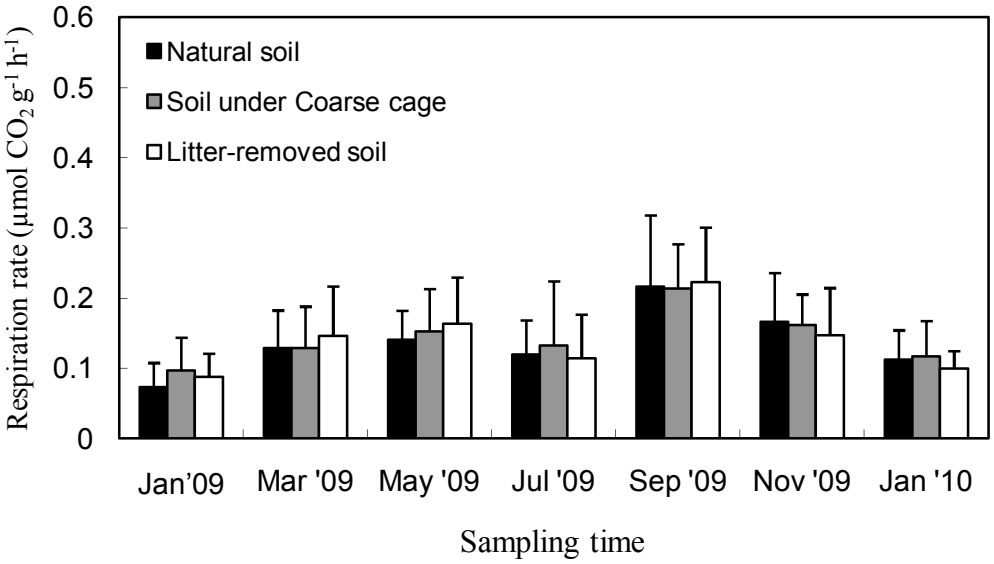

Figure 4.10 Respiration rates of middle soil (5-10 cm).

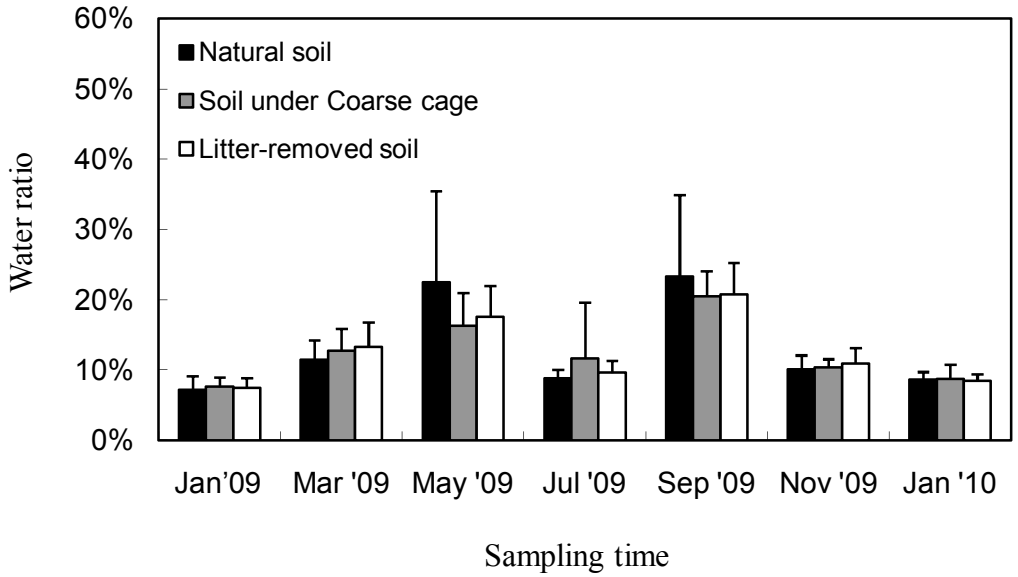

Figure 4.11 Water ratio of middle soil (5-10 cm).

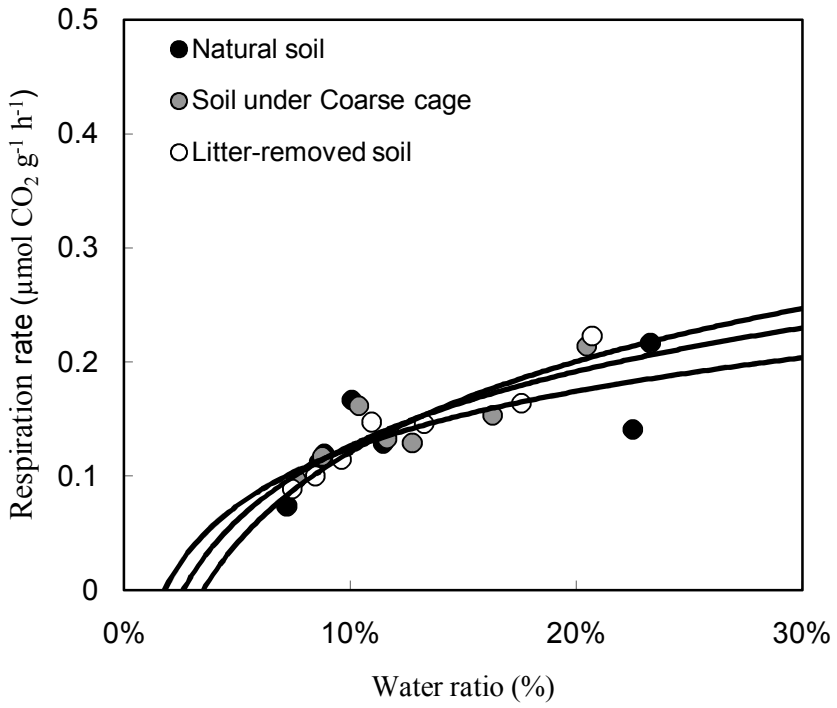

Figure 4.12 Plot of 5-10 cm-soil respiration rate against water ratio.

This result plotted show that the litter respiration rate of the litter samples and natural litter plotted lines linearly increase with water ratio. The regression equations are: $y = 0.0742\text{Ln}(x) + 0.2909$, $R^2 = 0.5705$ for natural soil; $y = 0.0942\text{Ln}(x) + 0.3433$, $R^2 = 0.736$ for soil under coarse cage; $y = 0.1149\text{Ln}(x) + 0.3853$, $R^2 = 0.909$ for litter-removed soil.

Respiration rates of deep soil (10-20 cm) are not significant difference among the cages in each sampling time (Figure 4.13). Water ratio of middle soil (10-20 cm) is also not significant difference among the cages in each sampling time (Figure 4.14).

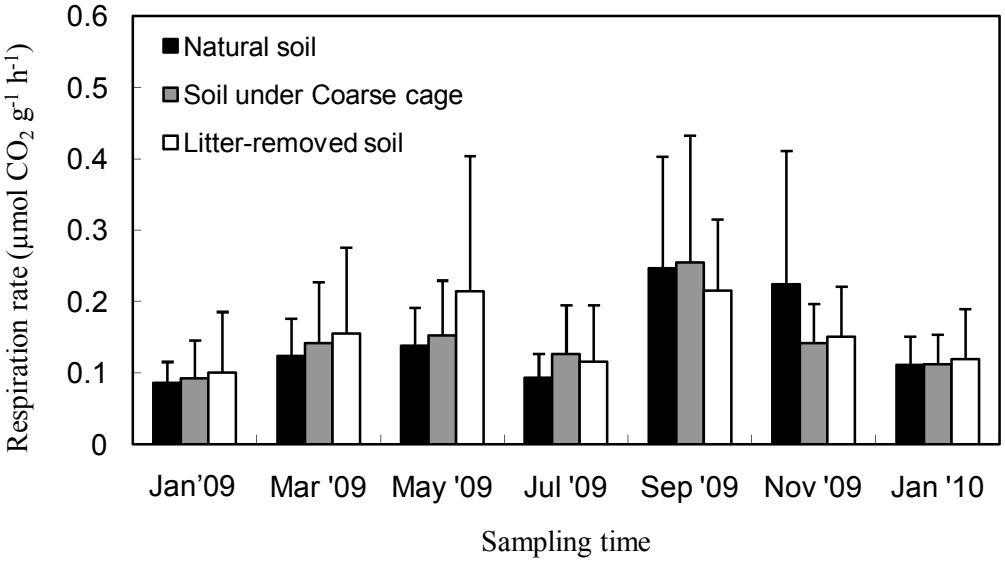

Figure 4.13 Respiration rates of deep soil (10-20 cm).

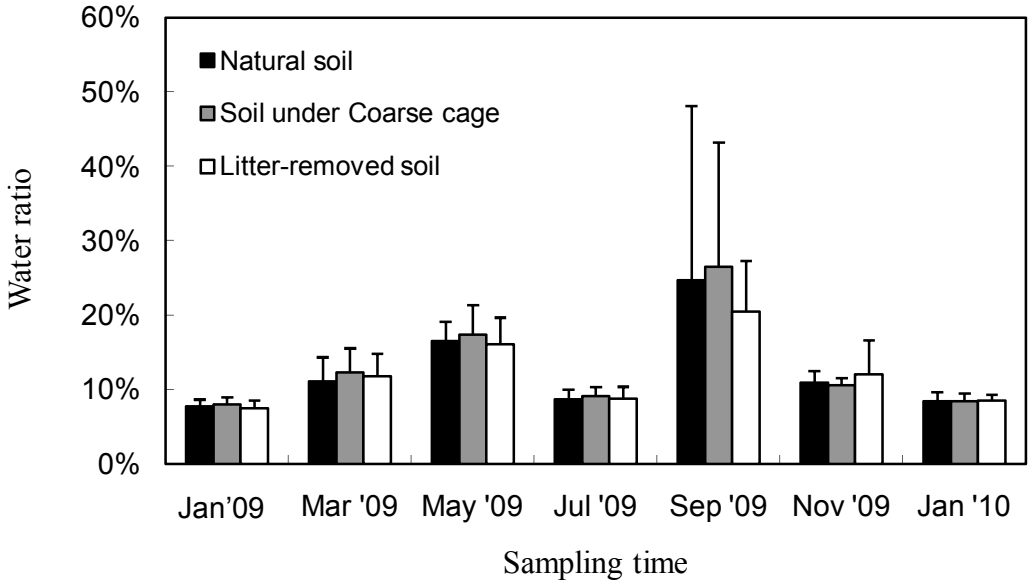

Figure 4.14 Water ratio of deep soil (10-20 cm).

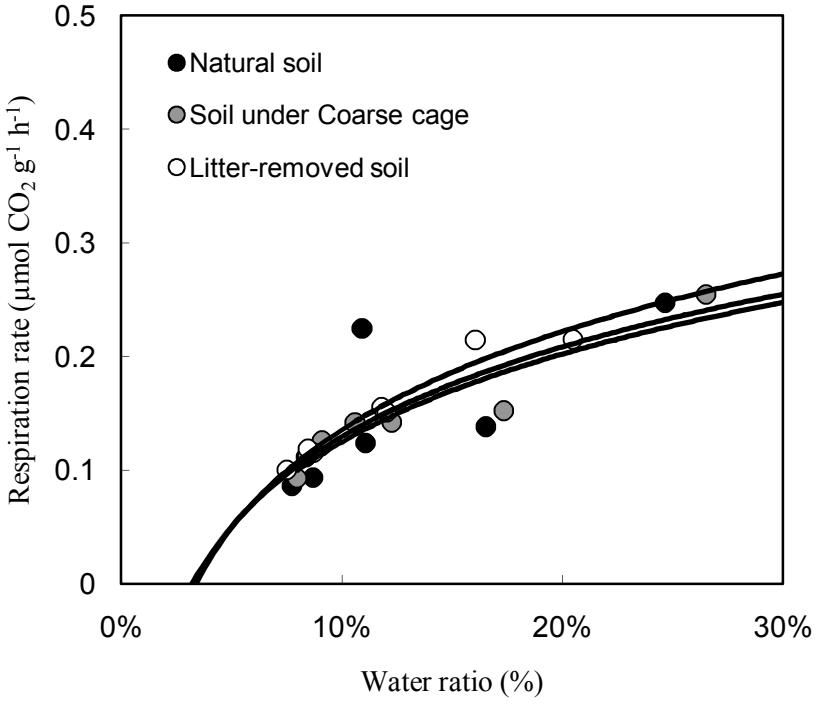

Figure 4.15 Plot of 10-20 cm-soil respiration rate against water ratio.

This result plotted show that the litter respiration rate of the litter samples and natural litter plotted lines linearly increase with water ratio. The regression equations are: $y = 0.1143\text{Ln}(x) + 0.3926$, $R^2 = 0.5616$ for natural soil; $y = 0.1117\text{Ln}(x) + 0.3822$, $R^2 = 0.879$ for soil under coarse cage; $y = 0.125\text{Ln}(x) + 0.4234$, $R^2 = 0.9559$ for litter-removed soil.

Nevertheless, the respiration rates of soil under litter sample cages in different treatments would become lower than soil under natural litter in each depth because new litter sources cannot input to the soil layers under litter samples and litter removed cages, but our result shown that respiration rates are not significantly different among the cages in each sampling time. Respiration rate in each depth of soil samples are high in 0-5 cm, 5-10 cm and 10-20 cm, respectively.

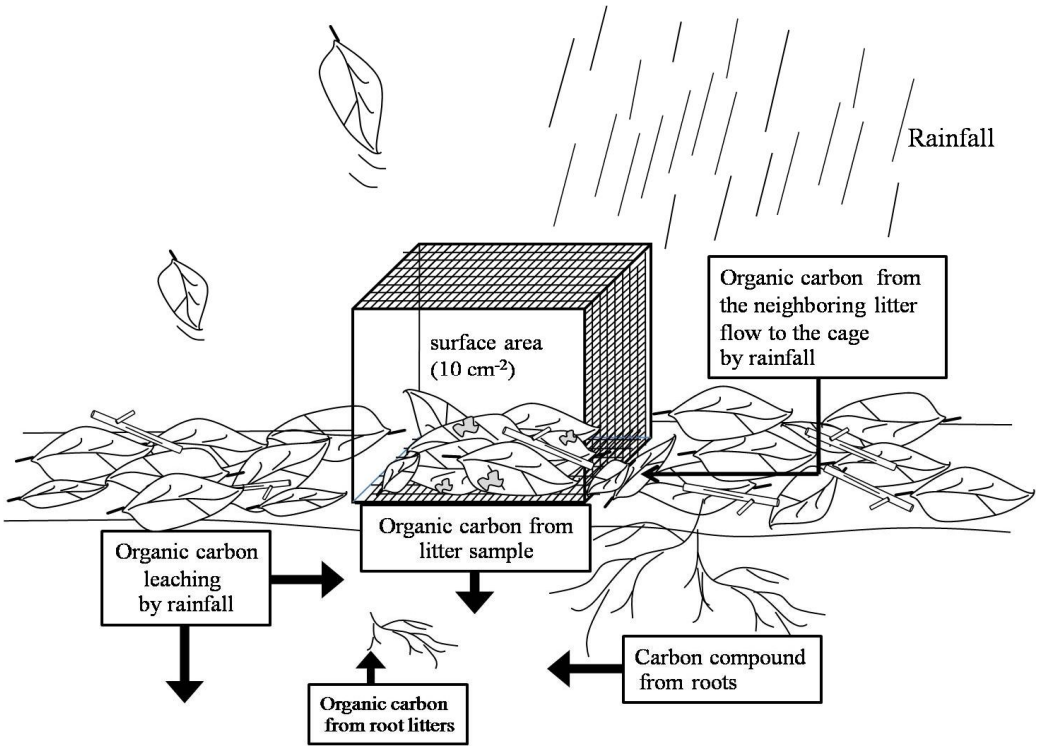

Figure 4.16 The pattern of organic carbon contaminated in litter cage and soil under the cage.

In this case, it may suggest that soil respiration was influenced by other carbon resources which are contaminated due to the major causes of spatial variation in soil respiration were exclusion from roots and organic carbon from root litters upon turnover soil organic carbon. Moreover, leaching of new carbon resources from neighboring litter flow to inside the litter cage by rainfall or contaminated due to rainfall itself. One more possible thing is that area of litter cages (10 cm × 10 cm) where covered on surface soil are too small that provide the area to protect new litterfall is not large enough (Figure 4.6).

For these reasons, to get more correct results of carbon mineralization from soil respiration, much attention need to be given in designing the better methods in order to refrain from contamination of soils from nearby areas.

CHAPTER V

CONCLUSIONS

The aim of this study was to investigate the litter decomposition rates and carbon mineralized by microbes in dry evergreen forest at Sakaerat Environmental Research Station. The rate of litter cages decomposition was two times higher in coarse cages than the fine cages due to the intensity of litter removed by termites. The litter respiration rates by microbial decomposition on natural litter and litter samples were affected by litter quality in the rainy season. In dry season, litter quality did not affect microbial activity due to low availability of water.

We expected that the soil respiration rates under the litter cages and no litter cages would become lower than natural litter due to no new litter input into the soil surface under the litter cages. But this study showed that soil respirations under the litter cages were not significantly different among three different treatments. Therefore, this study suggested that microbial decomposition under the litter treatments were affected from neighboring carbon resource such as root excretion, root litter, contamination by rain water flowing into litter cages.

However, this study provides data on litter decomposition factors and carbon mineralization in detail. The important data of carbon mineralization on organic carbon in the litter and this data can be used in the multitude of aggregation levels to represent detritus and variety of decomposition formulations and used in consistencies

of simulation results of the path ways of carbon flows influence in equilibrium of the tropical forest systems.

Further works on the sources of soil respiration are necessary in order to obtain an overall picture of soil carbon flow processes in tropical forests.

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APPENDICES

APPENDIX A

CLIMATIC DATA

Table A Monthly climatic data at the SERS from November 2008 to May 2010 (http://www.tistr.or.th/sakaerat/Meteorlogical.HTM).

Month	Temperature (°C)			Humidity (%)	Rainfall (mm)
	Mean Maximum	Mean minimum	Mean		
November,08	25.5	19.6	22.55	92	35.5
December,08	24.9	15.5	20.2	89	5.9
January,09	31.9	9.1	20.5	88	0
Febuary,09	37.4	15.9	26.65	86	6
March,09	37.1	16	26.55	90	109.8
April, 09	36.5	22.8	29.65	89	55.7
May,09	33.6	23.3	28.45	91	103.3
June,09	35.4	22.2	28.8	84	33.3
July,09	35.1	21.2	28.15	83	85.9
August,09	34.8	23.4	29.1	85	140.7
September,09	32.5	22.9	27.7	88	127.5
October,09	29.8	21.1	25.45	88	131.9
November,09	38.4	13.1	25.75	81	17.4
December,09	32.6	22.8	27.7	77	0
January,10	32.9	14.2	23.55	79	41.1
Febuary,10	37.6	19.5	28.55	77	16.5
March,10	38.4	16.8	27.6	76	64
April, 10	38.1	22.1	30.1	79	124.7
May,10	37.3	23.2	30.25	81	65.2
Mean	34.2	19.19	26.70	84	61.3

APPENDIX B

THE LI-820 CO_2 GAS ANALYZER

The LI-820 is an absolute, non-dispersive, infrared (NDIR) gas analyzer based upon a single path, dual wavelength, and infrared detection system (Figure 1). It has been used for analysis of microbial activity analysis in this study.

Figure 1 MIJ-08 systems with LI-820.

Initial Setup

Click on the LI-820 program icon to start the program. The LI-820 Main Window appears. Select "Connect" from the File menu. The Main window appears; select [Connect] from the File Menu Connect the RS232 serial cable, through a RS232-USB convert cable, to a free USB port of the computer. Each value will begin to appear in the window. Main window displays the CO_2 concentration (ppm) as well as the status of various LI-820 parameters (Figure 2).

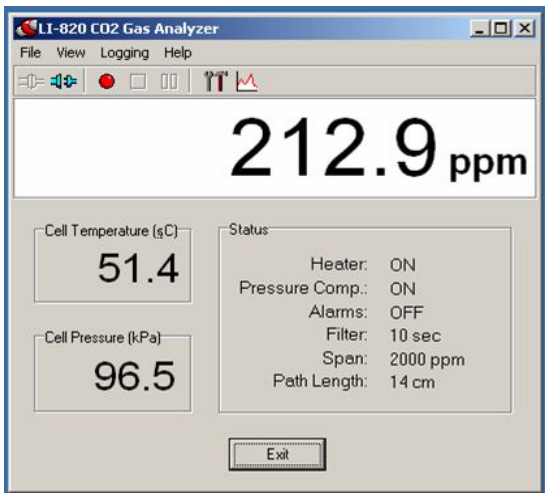

Figure 2 The main window displays of LI-820 Gas Analyzer and LI-820 Parameter.

Calibration

The CO_2 analyzers are calibrated with CO_2 free gas generated by connecting them to a tube filled with soda lime. Before verifying the calibrations turn on the instrument and left it on for a minimum of 20 minutes to stabilize the temperature of the detectors and then measure the value of the real CO_2 concentration (approximately 420 ppm) in the air by using Gas Detector Model GV-100 (Gastec Co. Ltd., Japan) (Figure 4). This value can be used to perform as a span gas in the span window in the LI-820 Gas analyzer (Figure 3), followed by the zero calibration. To zero, flow dry, CO_2-free gas through the LI-820, and make sure the optical cell is completely purged.

CO_2 afflux is measured by zero gas with empty chamber and change to soda lime respectively. Then wait for the value of CO_2 emission from high to low (approximately$\pm$2ppm). Selecting [View] [Calibration] and were access to the calibration screen. Click on [zero], after about minute, a message will appear that indicates the IRGA is zeroed. Calibration for first the zero and the span gas, enter the

value of the span gas. Click on span, after few minute, a massage will appear indicating the span calibration is completed.

Figure 3 The windows displays of calibration.

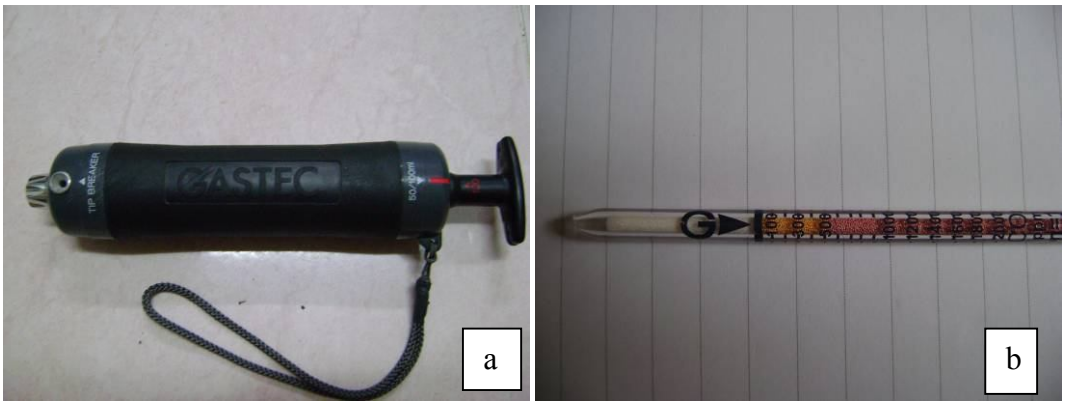

Figure 4 (a) The Gas Detector Model GV-100 (b) the detector tube color change clearly signals the present value of real CO_2 emission.

APPENDIX C

PHOTOGRAPHS OF FIELD DATA COLLECTION

Picture 1 Fine and enclose cage Termimesh® (0.2 mm) No allowance of termites.

Picture 2 Coarse and open-bottom cage General mesh (2.0 mm) Allowance of termites.

Picture 3 Setting of coarse cages.

Picture 4 Setting of fine cages.

Picture 5 A total of 13 subplots were set within the main plot placed in the dry evergreen forest of Sakaerat, Northeast Thailand.

Picture 6 Sample collections: A total of 7 times, bimonthly from November 2008 to January 2010.

Picture 7 Termite foraging is very intensive and sometimes completely removes the litter in a small area.

Picture 8 A typical case of litter removed by termites.

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Publications

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Awards -

Grants and Fellowships Suranaree University of Technology

Position and Place of Work -