THE EFFECT OF SOIL WATER CONTENT AND TEMPERATURE ON TROPICAL SOIL RESPIRATION

Karma Dorji

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ผลกระทบของความชื้นในดินและอุณหภูมิต่อการหายใจของดินในเขตร้อน

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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THE EFFECT OF SOIL WATER CONTENT AND TEMPERATURE ON TROPICAL SOIL RESPIRATION

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

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การศึกษาการหายใจของดินในระบบนิเวศที่แตกต่างกันอันประกอบด้วย พื้นที่การเกษตร สวนป่า และพื้นที่ป่าธรรมชาติ โดยทำการศึกษาทั้งในภาคสนามและห้องปฏิบัติการ โดยทดลองบ่มดินในห้องปฏิบัติการ เพื่อดูผลกระทบของสภาวะโลกร้อนต่ออัตราการหายใจของดิน ในการศึกษาในภาคสนามกระทำโดยการวางแนวเส้นสำรวจในระบบนิเวศต่างๆ ของมหาวิทยาลัยเทคโนโลยีสุรนารี สถานีวิจัยสิ่งแวดล้อมสะแกราช และสถานีวัฒนวิจัยสะแกราช จังหวัดนครราชสีมา โดยนำกล่องพลาสติกที่มีฝาปิดสนิทวางในแนวเส้นสำรวจทุกๆ ระยะ 20 เมตร แล้ววัดอัตราการหายใจของดินในระยะเวลา 24 ชั่วโมงโดยวิธี Soda-lime พบว่า ค่าเฉลี่ยของอัตราการหายใจของดินในมหาวิทยาลัยเทคโนโลยีสุรนารีมีค่าสูงสุดในแปลงปลูกข้าวโพด รองลงมา คือ แปลงปลูกทานตะวัน และมีค่าต่ำสุดในสวนป่ายูคาลิปตัส ซึ่งมีค่าเท่ากับ 4.2 3.7 และ 1.9 μmol CO_2 $m^{-2}d^{-1}$ ตามลำดับ สำหรับค่าเฉลี่ยของอัตราการหายใจของดินในพื้นที่สถานีวิจัยสิ่งแวดล้อมสะแกราช และสถานีวัฒนวิจัยสะแกราช พบว่า มีค่าสูงสุดพื้นที่ป่าดิบแล้ง ตามด้วยสวนป่ากระถินณรงค์ แต่มีค่าต่ำสุดในพื้นที่ป่าดิบแล้ง ซึ่งมีค่าเท่ากับ 4.3 3.5 และ 2.8 μmol CO_2 $m^{-2}d^{-1}$ ตามลำดับ โดยความชื้นของดินมีความสัมพันธ์กับการหายใจของดินอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น $p<0.01$ ส่วนการวัดในห้องปฏิบัติการพบว่าการหายใจสูงสุดของดินพบในแปลงปลูกทานตะวัน รองลงมาคือแปลงปลูกข้าวโพด ซึ่งมีค่าเท่ากับ 0.823 และ 0.4013 μmol CO_2 $g^{-1}h^{-1}$ ในขณะที่การหายใจของดินในพื้นที่อื่นๆ มีค่าต่ำมาก อย่างไรก็ตามการหายใจของดินที่อยู่ในความลึก 0-5 และ 5-15 เซนติเมตรมีค่าไม่แตกต่างกัน หลังจากปรับความชื้นของดิน (50 และ 75% water holding capacity) และอุณหภูมิของดิน (25 30 และ 35°C) พบว่าดินในป่าเต็งรังมีอัตราการหายใจเท่าๆ กับดินในแปลงปลูกข้าวโพด แต่อย่างไรก็ตามอุณหภูมิที่เพิ่มขึ้นไม่ได้ส่งผลต่อค่าเฉลี่ยของอัตราการหายใจของดินมากนัก ในขณะที่ความชื้นของดินที่เพิ่มขึ้นมีผลต่อการเพิ่มการหายใจของดินจากบางพื้นที่ ในระหว่างการบ่มดิน อัตราการหายใจจะมีค่าสูงสุดในวันที่สอง แล้วมีค่าลดลงหลังจากนั้น นอกจากนี้ดินในป่าเต็งรังบริเวณที่มีการเฝ้าระวังไฟป่ามีอัตราการหายใจมากกว่าในพื้นที่ๆ พึ่งเกิดไฟป่า (2.3 และ 1.8 μmol CO_2 $m^{-2}s^{-1}$) แต่เมื่อนำดินมาบ่มในห้องปฏิบัติการ กลับพบว่า ดินบริเวณที่เกิดไฟป่ามี

อัตราการหายใจมากกว่าดินที่ไม่มีไฟป่าเกิดขึ้น ทั้งนี้อาจเนื่องมาจากความชื้นของดินมีผลต่อการหายใจมากกว่าคุณสมบัติด้านอื่นๆ ของดิน

สาขาวิชาชีววิทยา ลายมือชื่อนักศึกษา _____

ปีการศึกษา 2553 ลายมือชื่ออาจารย์ที่ปรึกษา _____

KARMA DORJI : THE EFFECT OF SOIL WATER CONTENT AND TEMPERATURE ON TROPICAL SOIL RESPIRATION.
THESIS ADVISOR : PONGTHEP SUWANWAREE, Ph.D. 101 PP.

CARBON DIOXIDE / ECOSYSTEM / GREENHOUSE GASES / SAKAERAT ENVIRONMENTAL RESEARCHSTATION / SOIL RESPIRATION

Soil respirations of different tropical ecosystems which consisted of agricultural fields, plantation areas and natural forests were investigated both in field and laboratory environments. For the field study, a line transect was laid in each ecosystems at Suranaree University of Technology (SUT), Sakaerat Environmental Research Station (SERS) and Sakaerat Silvicultural Research Station (SSRS), Nakhon Ratchasima. Then plastic chambers with airtight lids were fixed along the line at 20 m interval. The 24 h Soil respiration was measured by Soda-lime method. In SUT sites, mean soil respiration rate was highest in cornfield, followed by sunflower but lowest in eucalyptus plantation sites (Eu1) with the value of 4.2, 3.7 and 1.9 µmol CO_2 $m^{-2}d^{-1}$. The significant higher water content and neutral soil pH of cornfield and sunflower soils might be the cause of higher soil respiration rates than other ecosystems in SUT. In SERS and SSRS sites, the soil respiration was highest in dry evergreen forest (DEF) followed by *Acacia auriculiformis* and lowest in dry dipterocarp forest with the value of 4.3, 3.5 and 2.8 µmol CO_2 $m^{-2}d^{-1}$, respectively. The significant higher ($p<0.01$) soil organic carbon, total nitrogen and water content of DEF soil might contribute to its higher respiration rates. However, soil respiration of DEF and cornfield were not significantly different.

In order to further study differences in soil respiration among different ecosystems in SUT, SERS and SSRS, soils were incubated in laboratory under field water at 25°C. The highest soil respiration was found in sunflower followed by cornfield with 0.823 and 0.4013 µmol CO_2 g^{-1} h^{-1} while the rest were very low. The soil respiration was significantly different between 0-5 and 5-15cm soil depths.

Further, study the effect of soil temperature and moisture on soil respiration, soils from DEF, cornfield and *Eucalyptus camaldulensis* were adjusted with water content of 50 and 75% water holding capacity (WHC) and incubated under 25, 30 and 35°C. The treatments of water and temperature significantly affected ($p<0.01$) soil respiration. Increasing soil water content generally stimulated more soil respiration in *Eucalyptus camaldulensis* and DEF but not in cornfield. However, increasing soil temperature had mix effects on soil samples. The respiration rate of DEF soil was not different from cornfield. During incubation, soil respiration reached the highest point rapidly at incubation day one to four then declined afterward suggesting that CO_2 efflux would increase rapidly if there is warming of the soil layer. This study also shows that increase in soil temperature from 25 to 35°C increase soil respiration rates of some soils but decreases for some under higher temperature at given water contents. The soil water content, temperature, pH, carbon and nitrogen contents were driving forces for the soil respiration.

School of Biology Student's Signature_____

Academic Year 2010 Advisor's Signature_____

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CHAPTER I

INTRODUCTION

1.1 Background and problems

Since the industrial revolution during the last few decades, the emission of greenhouse gases (GHG) like carbon dioxide (CO_2), methane (CH_4), chloroflurocarbons (CFCs) and nitrous oxide (N_2O) have been increased exponentially (IPCC, 2007). These gases trap the outgoing infrared radiation from the earth's surface and increase the net energy input of the lower atmosphere, leading to regional and global changes in climatic parameters like temperature and rainfall. The atmospheric concentration of CO_2 increased from 280 ppm since the pre-industrial times to 379 ppm in 2005 and the concentrations of CH_4 and N_2O have also increased from 715 to 1,774 and 270 to 319 ppb respectively (IPCC, 2007) of all, CO_2 is the most important anthropogenic GHG. Its annual emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004 (IPCC, 2007). The atmospheric concentration of CO_2 in 2005 exceeds the natural range over the last 650,000 years as determined from ice cores and this increase is considered mainly from anthropogenic activities including fossil-fuel burning, deforestation, land use changes, emission from automobiles and forest fires (IPCC, 2007).

The main carbon reservoirs are the ocean, atmosphere, soil, and land plant containing 38,000, 750, 1,500 and 560 Pg C, respectively (IPCC, 2001). Soil is the

major carbon pool in terrestrial ecosystems and soil respiration and decomposition contributes 63-77 Pg C y^{-1} (Raich and Schlesinger, 1992).

Recently, scientists have focused attention on soil as a major source and sink for atmospheric CO_2. Soil is the largest carbon pool on the Earth's surface with the highest (480 Gt) in tropical soils followed by the boreal forests and lowest in temperate forests (IPCC, 2001). Soil organic carbon pool is double that of in the atmosphere and is about two to three times larger than that in living matter in all terrestrial ecosystems (Post et al., 1990). Because of the large amount of carbon stored in soils, small deviations in its proportion may have a significant effect on the global carbon balance and therefore on climate change.

Soil respiration includes three biological processes, namely microbial respiration, root respiration and faunal respiration. Soil micro flora contributes to maximum CO_2 evolution as a result of decomposition of organic matter while the contribution of soil fauna is much less. Many factors such as soil texture, temperature, moisture, pH, available C, and N content of the soil affect the production and emission of CO_2. Soil respiration releases CO_2 into the atmosphere 11 times of current fossil fuel combustion (Peng et al., 2009).

Tropical soil has highest respiration rates with about twenty fold more than tundra and contributes to the highest CO_2 efflux into the atmosphere (Luo and Zhou, 2006). Understanding the interactions of soil moisture, nutrient availability and climate warming is critical for interpreting and predicting the partitioning of gross primary production to total below-ground C flux and therefore soil C sequestration, but these interactions are not yet sufficiently understood to incorporate them into global-scale C cycling models (Chapin et al., 2009). Many researchers are still

working on the proper understanding of the effects of soil temperature and moisture changes on the soil respiration rates which are found diverse in the different ecosystems. Therefore, it is necessary to have separate data of soil respiration for each different ecosystem so as to contribute to the recent global concern on soil carbon flux and global warming.

There are very few laboratory soil incubation experiments carried out to study the effect of soil temperature and moisture on the soil respiration in Thailand. Therefore, this incubation research was carried out using soil samples from different forest and agricultural ecosystems, to yield more insight into the change of soil respiration influenced by soil environments.

1.2 Research objectives

1.2.1 To investigate the rate of CO_2 emission (soil respiration) from different tropical ecosystem soils.

1.2.2 To investigate the effects of temperature and moisture on tropical soil microbial respiration.

1.3 Research hypotheses

1.3.1 Soil respiration rates differ in tropical ecosystem soils.

1.3.2 Soil temperature and water content affect soil microbial respiration rates.

1.4 Scope and limitations of the study

1.4.1 The study sites are agricultural lands and plantation areas in Suranaree University of Technology (SUT), the natural forests (Dry Evergreen and Dry

Dipterocarp forests) at Sakaerat Environmental Research Station (SERS) and different tree plantation sites at Sakaerat Silvicultural Research Station (SSRS).

1.4.2 The field respiration measurement and soil sampling were carried out once a month from January 2010 to May 2010.

1.4.3 Incubation experiments were conducted during January to April, 2010 using three different temperatures (25, 30 and 35°C) and two water contents (50 and 75% water holding capacity) treatments.

1.4.4 The soils total nitrogen, organic carbon, texture, pH, moisture and water holding capacity were analyzed.

CHAPTER II

LITERATURE REVIEW

2.1 Greenhouse gases and climate change

The major greenhouse gases are CO_2, CH_4, N_2O and O_3, causing 36-70, 9-26, 4-9 and 3-7% of greenhouse effects, respectively (IPCC, 2001). The global atmospheric concentrations of important greenhouse gases have increased markedly as a result of human activities since 1750 and that increase in CO_2 concentration are primarily due to fossil fuel use and land-use change, while those of CH_4 and N_2O are primarily due to agriculture (IPCC, 2007). From pre-industrial till 2005, the global atmospheric concentration of CO_2 has increased from 280 to 379 ppm and the concentration of CH_3 and N_2O have increased from 715 to 1,774 and 270 to 319 ppb respectively (Figure 2.1) and these values exceeds by far the natural range over the last 650,000 years as determined from ice cores (IPCC, 2007).

Over the twentieth century, there has been a consistent, large-scale warming of both the land and ocean surface, and it is likely that most of the observed warming over the last fifty years has been due to the increase greenhouse gas concentrations (IPCC, 2007). Global surface temperature increased 0.74°C during the last century. The climate model projections of IPCC indicate that global surface temperature will probably rise a further 1.1 to 6.4°C during the twenty-first century. Most studies focus on the period up to 2100. However, the warming is expected to continue beyond 2100 even if emissions stop, because of the large heat capacity of the oceans and

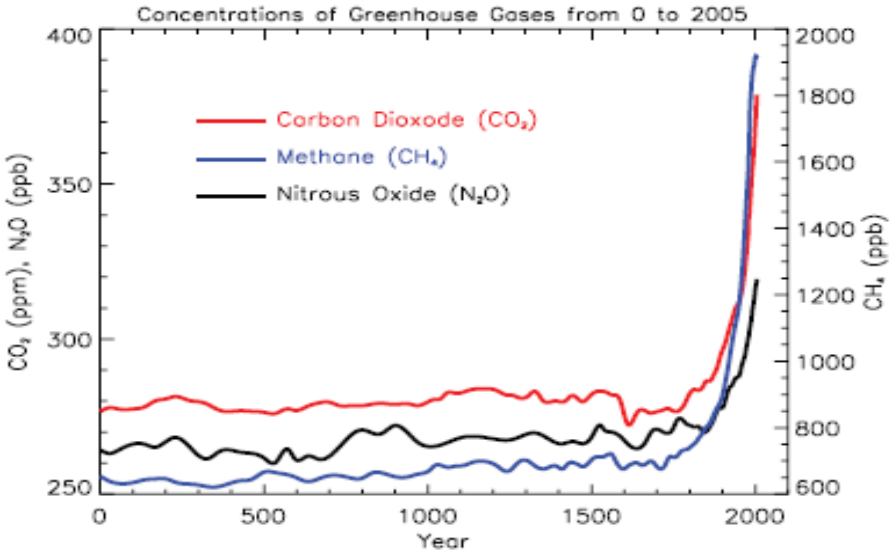

Figure 2.1 Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years (IPCC, 2007).

the long lifetime of CO_2 in the atmosphere. Observational evidence demonstrates that the composition of atmosphere is changing (e.g., increasing atmospheric concentrations of greenhouse gases such as CO_2 and CH_4) as is the Earth's climate (e.g., temperature, precipitation, sea level, sea ice, and in some regions extreme climatic events like heat waves, heavy precipitation and droughts).

Based on atmospheric measurements, a global temperature is increasing. Scientists believe that the rise in global temperature within the era of industrial revolution is mainly due to the increase in CO_2 gas concentration as a result of anthropogenic factors (Figure 2.2).

2.2 Carbon cycle

Carbon is present in the Earth's atmosphere, soil, ocean, and crust. When viewing the Earth as a system, these components can be referred to as carbon pools or

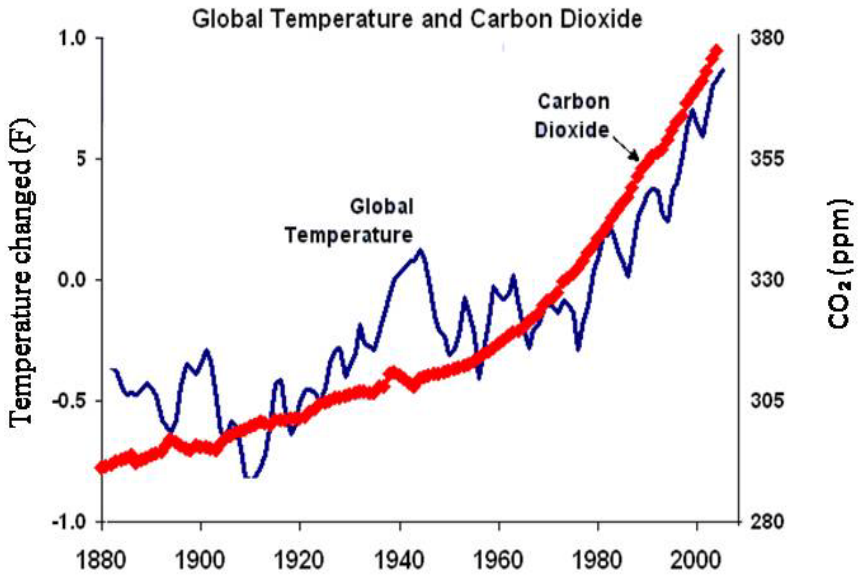

Figure 2.2 Carbon dioxide and global temperature since 1880 (Manchester Knowledge Capital, 2009).

stocks or reservoirs, because they act as storage houses for large amounts of carbon. These carbons move at various natural rates of transfer between these reservoirs. The main pathways to and from the atmosphere are diffusion into and out of the ocean, photosynthesis, respiration and the burning of fossil fuels and biomass. The greatest proportion of carbon stock is in the ocean containing 38,000 Pg C, followed by fossil fuel with 3,700 Pg C, then the carbon stock in all the vegetation and soils 2,300 and 750 Pg C, respectively (Figure 2.3). The carbon flux between terrestrial ecosystems (vegetation and soil) and atmosphere is more than between the ocean and atmosphere. Emissions of CO_2 from fossil fuel combustion and from cement manufacture are responsible for more than 75% of the increase in atmospheric CO_2 concentration since pre-industrial times (IPCC, 2007).

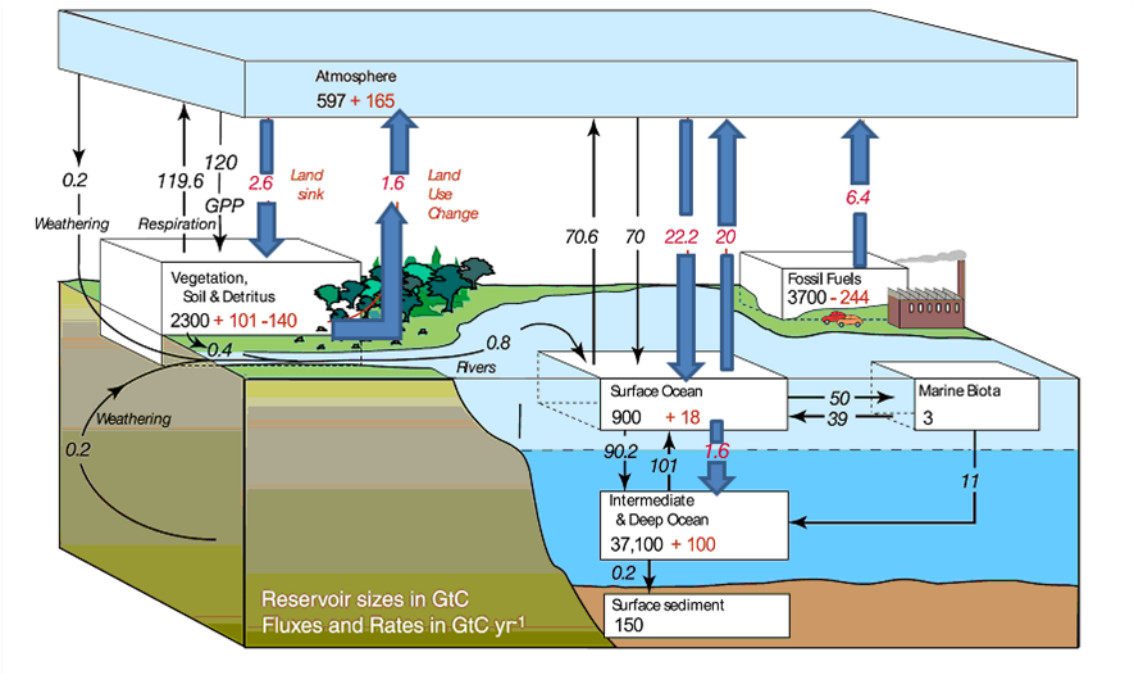

Figure 2.3 The global carbon cycle where thick lines indicate the annual flows of carbon in pre-industrial times and thin lines indicate recent human-caused annual flows. The flows and stores are in billions of tonnes or Gigatonnes of carbon (Gt C) (IPCC, 2007).

On a global scale, soil respiration was estimated to produce 80.4 Pg C y^{-1} with a range of 79.3-81.8 Pg C y^{-1} (Raich and Schlesinger, 1992), accounting for 60-90 % of total respiration of global terrestrial ecosystems (Peng et al., 2009). Annual fossil CO_2 emissions increased from an average of 6.4 Gt C y^{-1} in the 1990s, to 7.2 Gt C y^{-1} in 2000-2005 and the CO_2 emissions associated with land-use change are estimated to be 1.6 Gt C y^{-1} over the 1990s (IPCC, 2007). A mean residual land sink of 1.7 and 2.6 Gt C y^{-1} were obtained in 1980s and 1990s respectively. Almost 45% of combined anthropogenic CO_2 emissions have remained in the atmosphere and the oceans are estimated to have taken up approximately 30% (about 118 Gt C). The estimate of

mean ocean CO_2 sink is 2.2 Gt C y^{-1}. A considerable amount of anthropogenic CO_2 can be buffered or neutralized by dissolution of $CaCO_3$ from surface sediments in the deep sea, but this process requires many thousands of years.

2.3 Soil carbon content in different ecosystems

The storage of carbon in soil and in the vegetations is affected by the forest type and the current carbon stocks are much larger in soils than in vegetation, particularly in non-forested ecosystems in middle and high latitudes like temperate grasslands, wetlands and in high altitude tree less tundra regions. The tropical soils (tropical savanna and tropical forests) contain the highest carbon stock (480Gt C) followed by the boreal forests and lowest in temperate forests (Table 2.1).

Table 2.1 Global carbon stocks in vegetation and soil carbon pools down to a depth of 1 m (IPCC, 2001).

Biome	Area (10^9 ha)	Global Carbon Stocks (Gt C)		
		Vegetation	Soil	Total
Tropical forests	1.76	212	216	428
Temperate forests	1.04	59	100	159
Boreal forests	1.37	88	471	559
Tropical savannas	2.25	66	264	330
Temperate grasslands	1.25	9	295	304
Deserts and semi-deserts	4.55	8	191	199
Tundra	0.95	6	121	127
Wetlands	0.35	15	225	240
Croplands	1.6	3	128	131
Total	15.12	466	2,011	2,477

2.4 Soil respiration

Soil respiration is the process of CO_2 efflux originating from litter, soil organic matter and roots, controlled by soil faunal activity and environmental drivers such as soil temperature, air temperature, soil water content and photosynthetically active radiation (Luo and Zhou, 2006). Soil respiration provides the main carbon efflux from terrestrial ecosystems to the atmosphere; therefore, it is an important component of the global carbon balance. The detailed understanding of controlling factors of soil respiration is critical for constraining the ecosystem carbon budget and for understanding the response of soils to changing land use and global climate change (Buchmann, 2000). Even a little change in soil respiration rate may have profound impact on the atmospheric CO_2 budget. Soil respiration produce about 79.3-81.8 Pg C y^{-1} on a global scale, accounted for 60-90 percent of total respiration of global terrestrial ecosystems (Peng et al., 2009)

The mean annual soil respiration rates differ twenty folds among major vegetation biomes, ranging from 60 to 1,260 gC $m^{-2}y^{-1}$ (Table 2.2). It is lowest in the cold tundra and northern bogs but highest in the tropical moist forests where both temperature and moisture availability are high throughout the year. In general, the tropical soils have the highest annual respiration rates compared to other vegetation types which show that tropical soil contributes the highest CO_2 flux into the atmosphere.

Table 2.2 The mean yearly soil respiration rates of different major vegetation biomes of the world (Modified from Luo and Zhou, 2006).

Vegetation type	Mean soil respiration rate ($g\ C\ m^{-2}y^{-1}$)
Tundra	60
Boreal forests and woodlands	322
Temperate grasslands	442
Temperate coniferous forests	681
Temperate deciduous forests	647
Mediterranean woodlands and heath	713
Croplands and field	544
Desert scrub	224
Tropical savannas and grasslands	629
Tropical dry forests	673
Tropical moist forests	1,260
Northern bogs and mires	94
Marshes	413

2.5 Factors controlling soil respiration

Factors affecting soil respiration rates are: soil temperature, soil moisture, substrate supply and ecosystem productivity, oxygen, nitrogen, C:N ratio, soil texture, and soil pH value, among which soil temperature and moisture are dominated (Liu et al., 2006).

2.5.1 Soil temperature

Numerous enzymes, in the respiration processes, depend on the temperature. The respiration rates increase exponentially with temperature, reaching maximum at 45 to 50°C and decline above it (Luo and Zhou, 2006). Most of the enzymes are not activated in low temperature but temperature higher than the optimum denatures them by limiting the diffusion process which transports substrates and products of metabolites (sugar, oxygen, CO_2). Diffusivity of soil increases with the temperature at a given soil water but, increasing temperature over the time may cause reduction in soil water and thickness of soil water films. The temperatures

above 35°C may breakdown protoplasm system. Young roots are more sensitive to temperature for their respiration than the older roots. Higher temperature helps the root growth and has indirect influence on the root respiration (Luo and Zhou, 2006).

For example, Jian-fen et al. (2009) incubated surface soil samples (0-10 cm depth) from 88-year-old Chinese fir (*Cunninghamia lanceolata*) forest in Nanping, Fujian, China, for 90 days in the laboratory and measured soil respiration using alkali absorption method. The mean CO_2 evolution rate and cumulative amount of CO_2 evolution from soil were highest at 35°C, followed by those at 25 and 15°C (Figure 2.4).

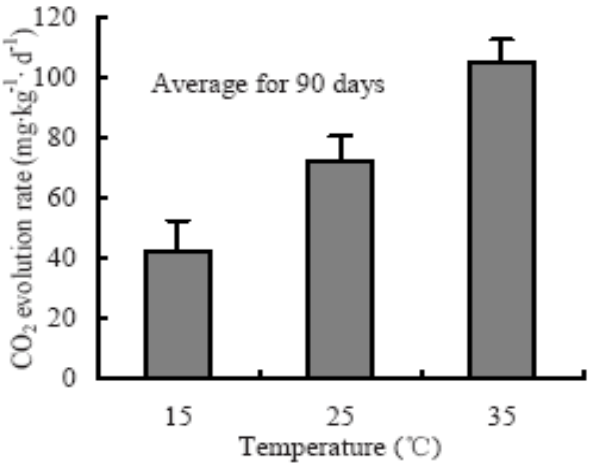

Figure 2.4 Mean CO_2 evolution rate for surface soil (0-10 cm) at 15, 25 and 35°C during the 90 days incubation period from 88-year-old Chinese fir forest in China (Jian-fen et al., 2009).

2.5.2 Soil moisture

Soil CO_2 efflux is usually low under dry conditions due to low root and microbial activities, and is increasing with soil moisture till some limit. The maximal CO_2 efflux rates for humid acrisols and boreal mor layer occurs at 50% of the water holding capacity (WHC) (Luo and Zhou, 2006). In very high soil moisture condition, soil CO_2 efflux is reduced due to limitation of diffusion of O_2 and suppression of CO_2 emissions. Although laboratory studies suggests that maximal soil respiration occurs at optimal soil water content, many of the field observations suggests that soil moisture limits soil CO_2 efflux only at the lowest and highest levels (Luo and Zhou, 2006).

Soil organisms, as a community, have a capacity to adapt to a wide range of soil moisture environments. Although some microorganisms lack the physiological mechanisms to adjust internal osmotic potential in response to water stress, many possess the osmoregulatory strategies for growth and survival under water stress. For example, microorganism’s activities get activated after several hours to few days following rainfall after dry days (Luo and Zhou, 2006).

Miao et al. (2004) measured CO_2 release from Erman's birch forest, dark coniferous forest, and broad-leaved/Korean pine forest soils and found that soil respiration rate increased with increase of soil water content within the limits of 21 to 37%, while it decreased with soil water content more than the given range (Figure 2.5).

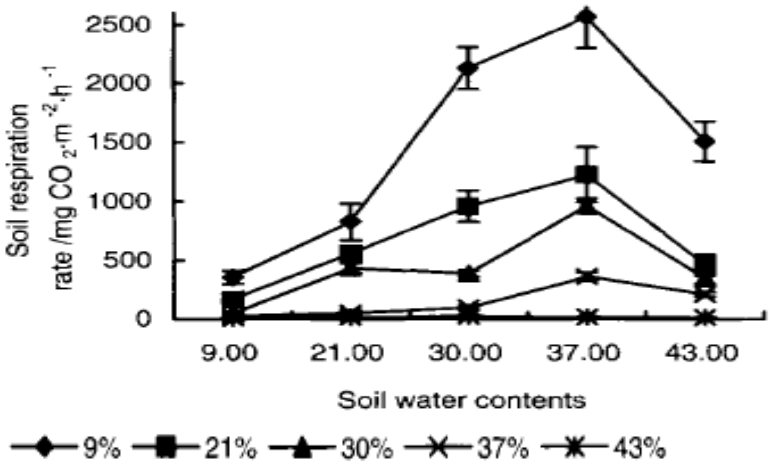

Figure 2.5 Effect of soil water content on soil respiration rate in Broad-leaved/Korean pine forest (Miao et al., 2004).

Nsabimana et al. (2009) measured soil CO_2 flux in six monospecific stands (*Cedrela serrata, Entandrophragma excelsum, Eucalyptus maculata, Eucalyptus maidenii, Eucalyptus microcorys,* and *Eucalyptus saligna)* forest plantations in Southern Rwanda. Their results indicated that soil water content explained 36-77% of the temporal variation in soil CO_2 flux and that soil CO_2 flux declined with soil water content above 0.25 $m^3 m^{-3}$ of soil.

2.5.3 Substrate supply and ecosystem productivity

The CO_2 in soil respiration comes from the breaking down of carbon-based organic substrates. Soil microorganisms consume all kinds of substrates, like simple sugar, contained in the fresh residues and root exudates, to the complex humic acids in soil organic matter (SOM). Simple sugars can be decomposed easily by microbes and get converted into CO_2 with short residence time but the residence time varies for humic acids from hundreds to thousands of years. The root respiration uses intercellular and intracellular sugars, proteins, lipids and other substrates (Luo and Zhou, 2006).

Schaefer et al. (2009) carried out a study on the chemical and biological effects of aboveground litterfall denial, root trenching and tree-stem girdling in subtropical forest of southwestern China. Soil respiration was measured for three years in plots where those treatments were applied singly and in combination. They found that after carbon storage below the stem girdles is depleted, the girdled trees die. Root trenching immediately terminates root exudates as well as water and nutrient uptake. Removing aboveground litterfall and the humus layer reduced soil respiration by more than the C input from litter, a respiration priming effect. Stem girdling significantly reduced soil respiration as a single factor, but root trenching did not. These results suggest that aboveground carbon inputs exert strong controls on forest soil respiration.

2.5.4 Soil oxygen

Oxygen becomes a limiting factor for soil respiration when the soil water content exceeds its optimal conditions. Therefore, oxygen is the main limiting factor for soil respiration in wet lands, flooding areas and rainforests. The soil O_2 concentration greatly affects root and microbial respiration. The microorganisms are divided into three types of their O_2 need; obligatory aerobes, facultative aerobes, and obligatory anaerobes. At O_2 concentration below 0.01 to 0.02 m^3 m^{-3}, the CO_2 release from obligatory aerobes decreases sharply but the facultative anaerobes can carry out respiration even at low or zero O_2 concentration by using either oxygen or organic acids as electron receptors. The respiration of obligatory anaerobes takes place only at oxygen close to zero (Luo and Zhou, 2006).

2.5.5 Nitrogen

High nitrogen content is generally associated with the high growth rates, leading to high growth respiration. The litter decomposition is enhanced by the nitrogen availability, either through higher concentration in the litter or elevated mineral nitrogen concentration. The degradation of cellulose is a nitrogen-limited process and it increases with nitrogen. Xua and Wan (2008) conducted their field experiment in semiarid grassland in northern China to examine the effects of nitrogen fertilization on soil respiration. Soil respiration in the fertilized plots with nitrogen was 11.4% greater than that in the unfertilized plots and the positive responses of soil respiration to nitrogen fertilization were attributable to stimulated plant growth, root activity and respiration. But some researchers found that addition of nitrogen fertilizers reduced the soil respiration rates. For example, Bowden et al. (2004) found decreased in soil respiration by adding nitrogen fertilizer to hardwood and pine forest in their Harvard Forest Long-term Ecological Research Site (Figure 2.6).

2.5.6 Soil texture

Soil texture influences soil respiration mainly through its effects on soil porosity, moisture and fertility. It also affects soil respiration through its influences on the rooting systems. Generally, root growth is slower in courser texture (more sandy) than in the finer texture (less sandy) due to lower fertility, low unsaturated hydraulic conductivity and lower water storage capacity (Luo and Zhou, 2006).

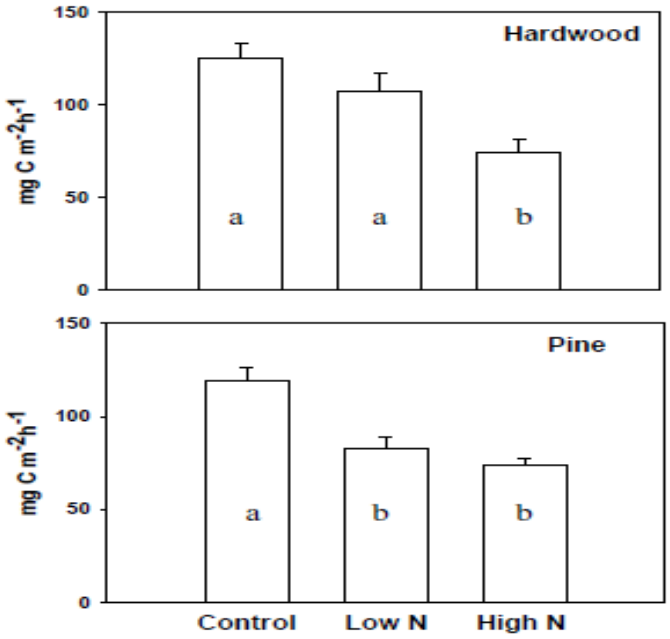

Figure 2.6 Mean rates of soil respiration in control and fertilized hardwood and red pine forest stands at the Harvard Forest Long-term Ecological Research Site Chronic Nitrogen Amendment Study over the growing season, 2001. Rates (within each stand) with the same letter are not significantly different (Bowden et al., 2004).

2.5.7 Soil pH

Microorganisms consist of many enzymes and the soil pH regulates the multiplicity of those enzymes. A bacteria cell consists of about 1,000 enzymes, many of which are pH dependent and associated with cell components such as membranes. Most of the known bacterial species grow between the pH of 4 to 9 and fungi are moderately acidophilic with the pH range of 4 to 6. Therefore, soil pH has great effect on the growth and proliferation of soil microbes and the soil respiration (Luo and Zhou, 2006).

Kemmitta et al. (2006) studied the effect of soil pH on regulating organic matter turnover and inorganic nitrogen production in agricultural soils in

Rothamsted grassland (Red Fescue), and Woburn grassland (Italian ryegrass), southern England. Measurements of respiration (alkali absorption method) following addition of urea and amino acids showed a significant decline in CO_2 evolution with increasing soil acidity.

2.6 Soil respiration research

A century ago soil respiration researches were emphasized on the understanding of the soil properties and the influence on crop productions. But recently the focus is on the global change and the prediction of future climatic change.

2.6.1 Field soil respiration research

2.6.1.1 Field soil respiration research in places other than Thailand

Many soil respiration researches were conducted around the world recently. Some of them are summarized in table 2.3.

Keith et al. (1997) measured rates of soil respiration for a year in a mature *Eucalyptus pauciflora* forest in phosphorous-unfertilized and phosphorus-fertilized plots using the soda lime absorption technique in Brindabella Range, Australia. Soil CO_2 efflux showed a distinct seasonal trend, and average daily rates ranged from 2.98 to 13.78 g CO_2 $m^{-2}d^{-1}$. Temperature and moisture were the main variables that cause variation in soil CO_2 efflux. The total annual efflux of carbon from soil was estimated to be 7.11 t C $ha^{-1}y^{-1}$.

Table 2.3 The of field soil respiration rates measurements from different ecosystems.

Location	Vegetation/ experimental site	Respiration rate ($g\ CO_2\ m^{-2}d^{-1}$)	Measurement method	Citation
Brindabella Range, Australia	Dry scherophyll eucalypt forest	2.98 to 13.78	Alkali-absorption method	Keith et al. (1997)
Ohio, USA	Additions of crop residue in a no till system	1.47 to 15.39	Alkali-absorption method	Duiker and Lal (2000)
Congo	*Eucalyptus* plantation	6.08-21.29	IRGA, Li 6250	Eprona et al. (2004)
Coastal Congo	3-year-old *Eucalyptus sp.*	6.08 to 21.29	Li-6250	
Mexico	Tropical cloud forest	1.98 to 8.1	Alkali-absorption method	Campos (2006)
	Corn–potato–corn rotation plot	1.58 to 11.25		
	Grassland	5.53 to 17.85		
Malaysian Peninsula	Tropical primary forest	19.94	LI-6400, LI-COR	Adachi et al. (2006)
	Tropical secondary forest	20.11		
	Oil palm plantation	23.18		

Table 2.3 (continued).

Location	Vegetation/ experimental site	Respiration rates ($g\ CO_2\ m^{-2}d^{-1}$)	Measurement method	Citation
Peninsular Malaysia	Tropical dipterocarp forest	9.51 to 24.72	IRGA	Kosugi et al. (2007)
Mid-subtropical China	Paddy	2.47	IRGA, ZEP-5	Iqbal et al. (2008)
	Peach trees	1.99		
	Sesame–peanut rotation	1.52		
	Woodland soils	1.46		
Southeast Spain	Mediterranean shrubland	7.83	IRGA, LI-6400-09	Almagro et al. (2009)
	25-years old abandoned agricultural field	6.50		
	Rainfed olive grove	4.26		
Southern Rwanda	*Eucalyptus saligna*	14.90	IRGA, LI 6400-09	Nsabimana et al. (2009)
	Eucalyptus maidenii	14.11		
	Entandrophragma excelsum	11.90		
China	*Zea mays*	16.36	IRGA	Ding et al. (2010)
Italy	Semiarid shrubland	4.9	IRGA	Dato et al. (2010)

Ohashi et al. (1999) measured soil respiration in Japanese cedar forests (*Cryptomeria japonica*), using a portable open-flow chamber systems, for three years, to establish the relationship between soil respiration and environmental factors. Soil respiration rates was ranged from 2,570 to 3,060 and 1,830 to 2,170 g CO_2 $m^{-2}y^{-1}$ in the thinned and intact sections, respectively increasing during the summer and decreasing in winter. The soil respiration rates were significantly correlated with soil surface temperature.

Melillo et al. (2002) carried out soil-warming studies, using heating cables in Harvard forest, New England, USA and found that CO_2 efflux from heated plots was about 40% higher than that of control plots in the first year but the effects of warming gradually disappear after six years of warming treatment (Figure 2.7).

Eprona et al. (2004) measured soil respiration in a 3-year-old *Eucalyptus* sp. plantation in coastal Congo using Li 6250 infrared gas analyzer. Soil respiration was minimum (6.08 g CO_2 $m^{-2}d^{-1}$) at the end of the dry season in September, 2001 and maximum (21.29 g CO_2 $m^{-2}d^{-1}$) after re-wetting in December, 2001. Plots exhibiting the highest soil respiration also contained the highest amounts of aboveground litter. Microbial respiration associated with litter decomposition is likely a major component of soil respiration and the spatial heterogeneity in litter fall probably accounts for most of its spatial variability in this *Eucalyptus* sp. plantation.

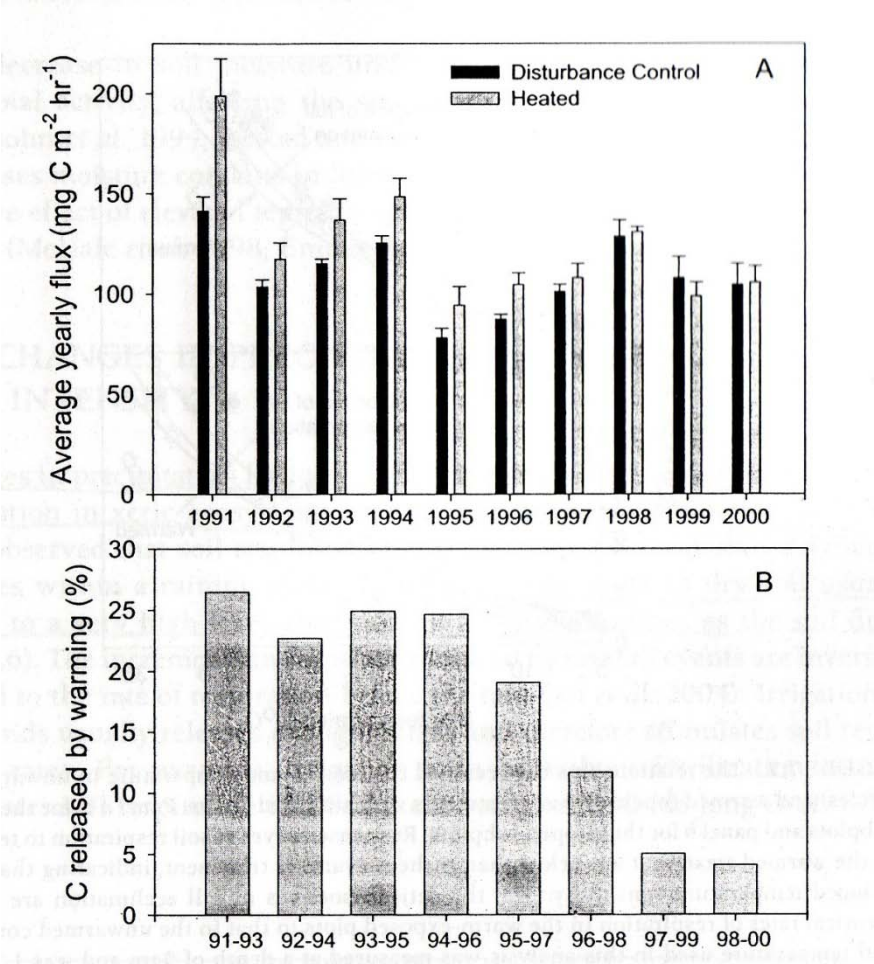

Figure 2.7 The CO_2 fluxes from warming-soil (using heating cables) and control plot in Harvard forest, USA. A: Average yearly fluxes of CO_2 from the heated and disturbance control plots. B: Percentage increase in the amount of carbon released from the heated plots relative to disturbance control plots (Melillo et al., 2002).

Harper et al. (2005) studied the changes of soil water content and their affects on soil respiration in Konza prairie for four years. Their results showed 8% decreased in soil respiration rates when the natural rainfall quantity decreased by 70%. A 50% increase in the length of dry intervals between rainfall reduced soil

respiration by 13% and when both rainfall amounts and rainfall intervals are altered, soil respiration decreased by 20% (Figure 2.8).

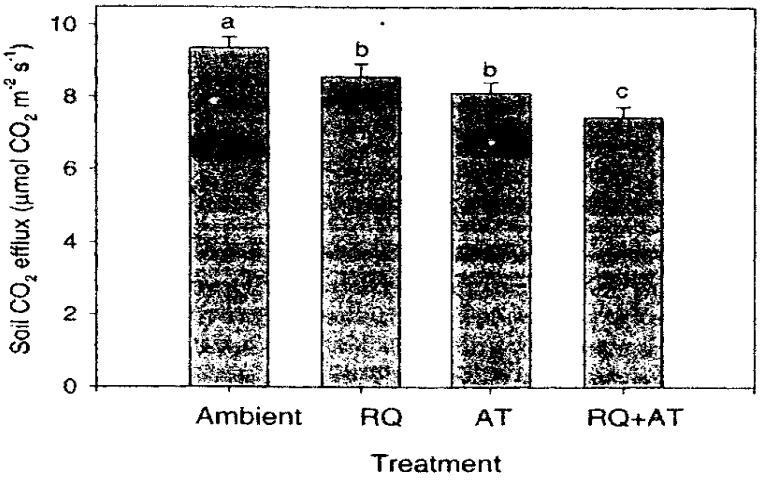

Figure 2.8 Mean soils CO_2 efflux during growing seasons for Ambient rainfall (ambient), reduced rainfall quantity (RQ), altered rainfall timing (AT), and reduced quantity + altered timing (RQ + AT) (Harper et al., 2005).

Adachi et al. (2006) found soil respiration rates of 23.18, 20.11 and 19.94 g CO_2 $m^{-2}d^{-1}$ in the oil palm plantation, secondary forest and tropical primary forest, respectively in Malaysian Peninsula. The main causes of spatial variation in soil respiration were fine root biomass, soil water content and soil carbon contents.

Campos (2006) investigated the response of soil surface CO_2 flux to land use change over a 1.2-year period in Mexico. Soil surface CO_2 flux was measured monthly in a tropical cloud forest, a corn–potato–corn rotation plot and a grazed mixed-grass prairie, which were converted from tropical cloud forest, using

the alkali absorption method. Average CO_2 flux varied from 1.98 to 8.1 g CO_2 $m^{-2}d^{-1}$ in the tropical cloud forest, 1.58 to 11.25 g CO_2 $m^{-2}d^{-1}$ in the corn–potato–corn rotation and 5.53 to 17.85 g CO_2 $m^{-2}d^{-1}$ in the grassland. Soil surface CO_2 flux increased significantly with the change from tropical cloud forest to managed ecosystems. The highest CO_2 flux occurred in summer.

Zhou et al. (2007) conducted warming experiment consists of long term with a 2°C increase and one short term with a 4.4°C increase to investigate main and interactive effects of warming and doubled precipitation on soil CO_2 efflux and its temperature sensitivity in a tall grass prairie in Oklahoma, USA. On average, the increase in soil CO_2 efflux by warming was 13.0 and 22.9%, respectively.

Kosugi et al. (2007) studied the influence of soil temperature and water content on soil respiration rate and its spatio-temporal variation in primary lowland mixed dipterocarp forest in Peninsular Malaysia. The average soil respiration rate was maximum during rainy months and minimum during the dry period with 24.72 and 9.51 g CO_2 $m^{-2}d^{-1}$, respectively.

Iqbal et al. (2008) measured soil respiration rates in four different land use types of subtropical red soil, using static closed chamber method in mid-subtropical China. Soil CO_2 fluxes revealed seasonal fluctuations, with the tendency that maximum values occurred in summer, minimum in winter and intermediate values in spring and autumn. Average soil CO_2 fluxes were 901, 727, 554 and 533 g CO_2 $m^{-2}y^{-1}$ in paddy, orchard, upland and woodland soils, respectively. Soil temperature was an important variable controlling 26-59% of soil CO_2 flux.

Mo et al. (2008) studied the response of soil respiration to simulated nitrogen deposition in a mature tropical forest in southern China from October 2005

to September 2006 using static chamber and gas chromatography techniques. Results showed that soil respiration exhibited a strong seasonal pattern, with the highest rates found in the warm and wet growing season (2.28 g CO_2 $m^{-2}d^{-1}$) and the lowest rates in the dry dormant season (1.03 g CO_2 $m^{-2}d^{-1}$). Soil respiration rates and soil temperature showed a significant positive exponential relationship but soil moisture only affects soil respiration at dry conditions in the dormant season. Annual mean soil respiration rate in the Control, Low-N and Medium-N treatments (1.66, 1.73 and 1.51 g CO_2 $m^{-2}d^{-1}$, respectively) did not differ significantly, whereas it was 14% lower in the High-N treatment (1.39 g CO_2 $m^{-2}d^{-1}$) compared with the Control treatment. The results suggest that response of soil respiration to atmospheric nitrogen deposition in tropical forests is decline, but it may vary depending on the rate of nitrogen deposition.

Ding et al. (2010) conducted experiments to understand the effects of nitrogen fertilization on soil respiration in an intensively cultivated fluvo-aquic loamy soil in Fengqiu State Key Agro-Ecological Experimental Station, Henan province, China. Soil CO_2 efflux during the maize growth season (16.36 gCO_2 $m^{-2}d^{-1}$) was significantly affected by soil temperature and soil moisture and there was a significant interdependence between them on the soil CO_2 efflux in the presence of maiz. The results showed that the effects of N fertilization on soil respiration mainly depended on the concentration of easily decomposed organic carbon in soil and N fertilization possibly reduced soil respiration.

Dato et al. (2010) carried out soil warming and precipitation manipulation experiments in arid and semiarid shrubland ecosystems of the Mediterranean basin, Capo Caccia peninsula, northeast Sardinia, Italy. Three

treatments were applied: Warming (covering the vegetation and soil with aluminium curtains during the night), Drought (covering the plots with waterproof transparent plastic curtains) and Control (did not have any curtains) and soil respiration was measured for 3 years from 2002 to 2004 by a portable IRGA. The mean soil CO_2 efflux rates were 3.2, 2.1 and 2.6 µmol CO_2 $m^{-2}s^{-1}$ for year 2002, 2003 and 2004, respectively. The variation of soil respiration with temperature and soil water content did not differ significantly among the treatments, but was affected by the season and it was higher during the wet vegetative season and lower during the dry non vegetative season.

2.6.1.1 Field research in Thailand

In Thailand, the interest of soil respiration and its effect on global warming and climate change has been increased. Many recent researches are summarized in Table 2.4.

Wiriyatangsakul (2004) measured soil CO_2 efflux using LCi-001 potable photosynthesis system fitted with a soil chamber, in the tropical uplands (maize field and dry evergreen forest) in Phanom Sarakarm District, Thailand. Her data showed an exponential increase in the respiration rates with the temperature of soil and the air. The respiration rates of agricultural land and forest sites were 1.354 and 1.47 g CO_2 $m^{-2}d^{-1}$ during May and 3.082 and 12.85 g CO_2 $m^{-2}d^{-1}$ during and February months, respectively.

Table 2.4 Field soil respiration research of different ecosystems in Thailand.

Location	Vegetation/ experimental site	Respiration rate ($g\ CO_2\ m^{-2}d^{-1}$)	Measurement method	Citation
Thong Pha Phum	Teak (*Tectona grandis*) plantation	10.66–11.58	IRGA	Takahashi et al. (2009)
Ratchaburi	Dry dipterocarp forest	10.05	closed-automatic chamber	Hanpattanakit et al. (2008)
Sakaerat	Dry evergreen forest	29.20	closed chamber method	Gamo et al. (2005)
Maeklong	Mixed deciduous forests	62.80		
Sakaerat	Dry evergreen forest	11.92	LI-800	Panuthai et al. (2005)
Maeklong	Mixed deciduous forest	14.08		
Phanom Sarakarm district	Cornfield	1.35	LCi-001	Wiriyatangsakul (2004)
	Dry evergreen forest	3.08		
Chiang-Mai	Tropical monsoon evergreen forests	8.12 to 53.57	IRGA	Hashimoto et al. (2004)

Hashimoto et al. (2004) measured soil respiration in tropical monsoon evergreen forests of Kog-Ma Experimental Watershed, northern Thailand using closed-chamber method (IRGA). Measurements were made at three sampling points of 30 m at 3-month intervals from 1998 to 2000. The results showed significant high soil respiration rates during the rainy season and low during the dry season with large interannual fluctuations. There was little fluctuation of soil temperatures but fluctuation of soil moisture was high between dry and wet seasons which predominantly determined the rates of soil respiration. Soil respiration rates ranged from 8.12 to 53.57 g CO_2 $m^{-2}d^{-1}$ and the rough estimated annual soil respiration rate was 2,560 g C $m^{-2}y^{-1}$.

Gamo et al. (2005) carried out CO_2 flux observation in the tropical seasonal forests in Thailand at the Sakaerat (dry evergreen forest) and Maeklong sites (mixed deciduous forests) using closed chamber method. The results showed that CO_2 released in dry evergreen and mixed deciduous forests in 2003 were 29.2 and 62.8 t C $m^{-2}y^{-1}$, respectively.

Panuthai et al. (2005) studied CO_2 emissions from soils in dry evergreen forest at the Sakaerat Environmental Research Station, Nakhon Ratchasima, in comparison with those in mixed deciduous forest at the Maeklong Watershed Research Station, Kanchanburi, using CO_2 Gas Analyzer LI-800. CO_2 released by soil respiration in both forest types varied remarkably with climatic changes, particularly soil moisture content. The annual estimated CO_2 released by soil in dry evergreen and mixed deciduous forests were 11.92 and 14.08 g CO_2 $m^{-2}d^{-1}$. The variation in soil CO_2 released apparently reflects difference in litter fall, soil characteristics and vegetation types.

Hanpattanakit et al. (2008) studied diurnal and seasonal variations of soil respiration in dry dipterocarp forest located in Chombung District, Ratchaburi Province by using closed-automatic chamber method during February to July 2008. The results showed that soil respiration varied significantly both spatially and seasonally. On a seasonal scale, a negative relationship between soil respiration and temperature was observed. A strong positive relationship between soil respiration and soil moisture over the moisture range of 17-19% by volume was found but beyond it, soil respiration decreased. The total CO_2 emissions during the six-month period in dry dipterocarp forest were 4.9 t C/ha.

Takahashi et al. (2009) measured soil respiration by closed chamber method system using an IRGA at different stand ages (1, 6 and 21 year-old) of teak (*Tectona grandis*) plantations in Mae Klong Watershed Research Station, Thong Pha Phum, Kanchanaburi Province, Thailand. The soil respiration was found high during the rainy seasons (April to November) and low in dry seasons (December to March) but there were no significant differences in soil respiration among plots of different ages. The annual CO_2 efflux from the soil in 1997 was estimated to be 10.66-11.58 g CO_2 $m^{-2}d^{-1}$ and in 1998, annual CO_2 efflux declined to 80% in 6 years old plantation area (919 g CO_2 $m^{-2}y^{-1}$) and the reason given is probably due to low rainfall.

2.6.2 Laboratory soil incubation research works

In order to clearly understand the temperature and water treatment effects on soil respiration, only few laboratory incubation experiments have been carried out until now (Table 2.5).

Fang and Moncrieff (2001) collected intact soil cores (31 cm in diameter and 45 cm in depth) from a farmland and a sitka spruce site near Edinburgh, Scotland, and incubated them in a growth chamber with varying temperature (10- 40°C) and soil moisture (wet, medium and relatively dry soil). Both soils showed an exponential increase in respiration rate with temperature. The influence of soil moisture content, varying between 20 and 50%, on soil respiration and its response to temperature was not obvious.

Miao et al. (2004) measured CO_2 release of soils from Erman's birch, dark coniferous and broad leaved/Korean pine forest by using CI301 PS portable CO_2 analyzer in Changbai Mountain, China. The soil water contents were adjusted to five different levels (9, 21, 30, 37 and 43%) and the soil samples were incubated at 0, 5, 15, 25 and 35°C for 24 h. Soil respiration rate increased with increase of soil water content within the limits of 21 to 37%. There were significant differences in soil respiration among the various forest types. The soil respiration rate was highest in broad-leaved/Korean pine, middle in Erman's birch and the lowest in dark coniferous forest. The optimal soil temperature and soil water content for soil respiration was 35°C and 37% in broad-leaved/Korean pine, 25°C and 21% in dark coniferous, and 35°C and 37% in Erman's birch forest.

Wiriyatangsakul (2004) incubated tropical uplands (cornfield and dry evergreen forest) soils from Phanom Sarakarm District, Thailand, under different moisture (air dried, 25, 50, 75 and 100% of WHC) and temperature (10, 20, 30 and 45°C) treatments and then measured their respiration rates weekly for a month.

Table 2.5 Laboratory soil incubation experiments of different ecosystems.

Location	Vegetation	Incubation			Respiration rate ($mgCO_2\ m^{-2}\ h^{-1}$)	Measurement Method	Citation
		Duration	Water content (%)	Temp (°C)			
Scotland (Intact soil cores)	Farmland	120 days	Wet, medium and dry	10	126	LI-COR 6262	Fang and Moncrieff (2001)
	Sitka spruce			10	205.2		
Changbai Mountain, China	Broad-leaved forest	24 hours	37	35	2569	CI301 PS	Miao et al. (2004)
	Dark coniferous forest		21	25	450		
	Erman's birch forest		37	35	650		
	Dry evergreen forest				0.42-16.67		
North China	Typical steppe (Calciorthids soil)	5 weeks	75	30	3.1	Soda-lime method	Liu et al. (2006)
			35	30	2.7		
			75	10	5.8		
			35	10	4.0		
	Meadow steppe (Chernozem soil)		75	30	3.9		
			35	30	3.0		
			75	10	7.7		
			35	10	7.4		

Table 2.5 (continued).

Location	Vegetation	Incubation			Respiration rate (µmol CO_2 $g^{-1}d^{-1}$)	Measurement Method	Citation
		Duration	Water content (%WHC)	Temp. (ºC)			
Phanom Sarakarm district, Thailand	Cornfield	1 month	50	20	33	LCi-001	Wiriyatangsakul. (2004)
			75		95		
			50	30	138		
			75		135		
			50	45	44		
			75		96		
	Dry evergreen forest		50	20	207		
			75		112		
			50	30	256		
			75		312		
			50	45	151		
			75		56		

The results showed that the soil respiration rates was highest with soil moisture content of 25 to 75% WHC and lowest for air dry soil and saturated soils. The respiration rates of soil in average increased with the temperature from 10 to 30°C.

Liu et al. (2006) took two types of grassland soils differing in vegetation and moisture status in Duolun Restoration Ecology Research Station, China and incubated them under two temperatures (10 and 30°C) and two soil moisture regimes (35 and 75% WHC) for 5 weeks. Soil respiration was measured by using soda-lime method with changing temperature in water bath. Results showed that soils became less sensitive to temperature when incubated under higher temperature with higher moisture conditions, but more sensitive in lower temperature with higher moisture conditions.

CHAPTER III

MATERIALS AND METHODS

3.1 Study sites

Three study sites; Suranaree University of Technology (SUT), Sakaerat Environmental Research Station (SERS) and Sakaerat Silvicultural Research Station (SSRS) were chosen for this research (Figure 3.1).

3.1.1 Suranaree University of Technology

Suranaree University of Technology (SUT) was established as a public autonomous university, outside the civil service system, under the supervision of the Royal Thai Government. It is located in Muang District, Nakhon Ratchasima. The sites at SUT consist of cornfield (*Zea mays*), sunflower (*Helianthus annuus*), grassland, and about 20 years old E*ucalyptus* sp. and rubber trees (*Hevea brasiliensis*) (Figure 3.2). The study sites are located within the university campus (Figure 3.3).

3.1.2 Sakaerat Environmental Research Station

Sakaerat Environmental Research Station (SERS) is one of the five UNESCO-designated biosphere reserves in Thailand, established in September, 1967. This station has been dedicated as an ecological reserve for scientific purposes, administered by the Thailand Institute of Scientific and Technological Research (TISTR). SERS is located at approximately 14° 30’ N and 101° 55’ E about 300 km northeast of Bangkok and 60 km from Nakhon Ratchasima on highway 304 (Figure 3.1). The station covers an area of 81 km² (Somniyam, 2008).

Figure 3.1 The locations of Suranaree University of Technology (SUT), Sakaerat Environmental Research Station (SERS) and Sakaerat Silvicultural Research Station (SSRS).

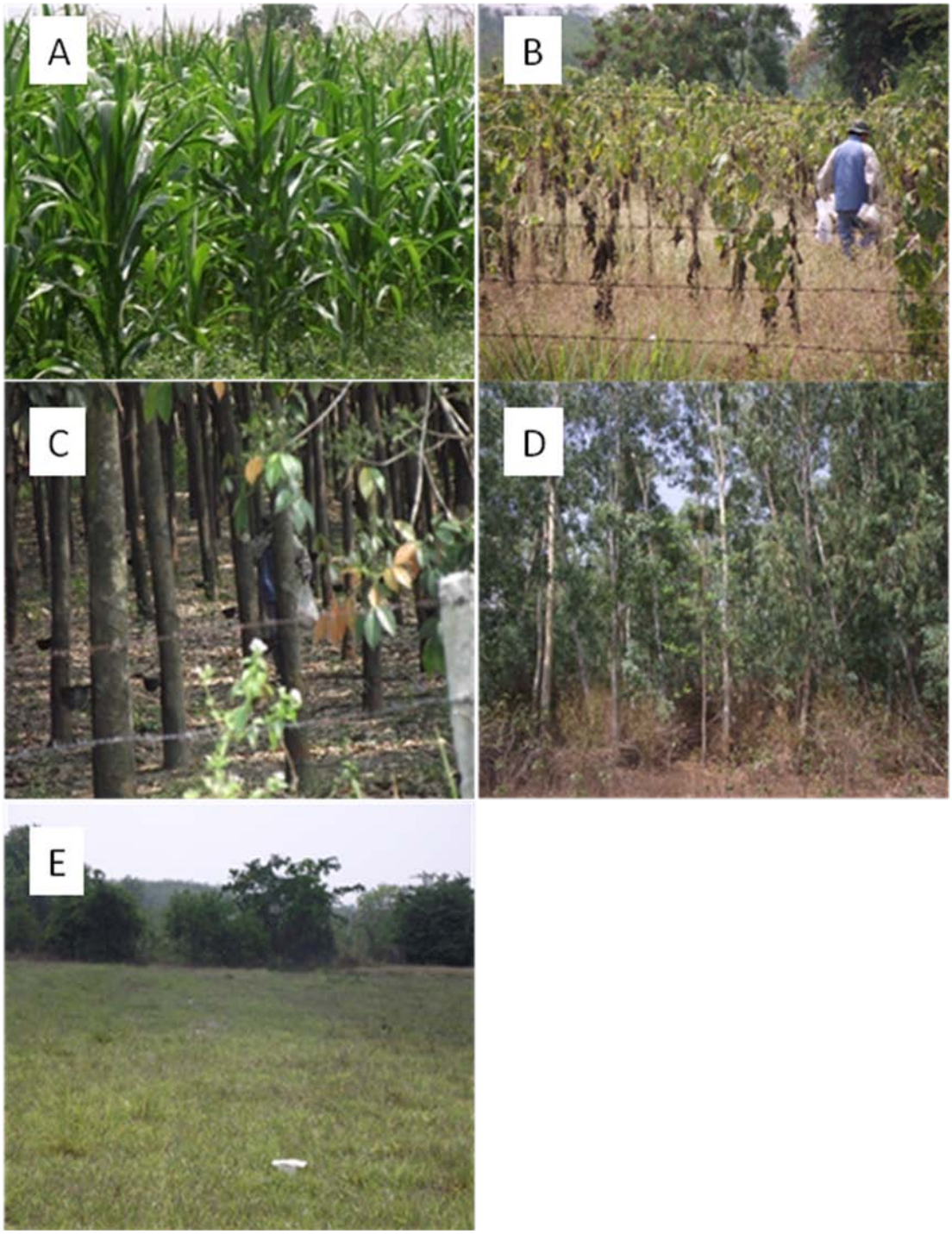

Figure 3.2 Photographs of different ecosystems sites at SUT. A: Cornfield, B: Sunflower, C: Rubber plantation, D: *Eucalyptus* sp. plantation and E: Grassland.

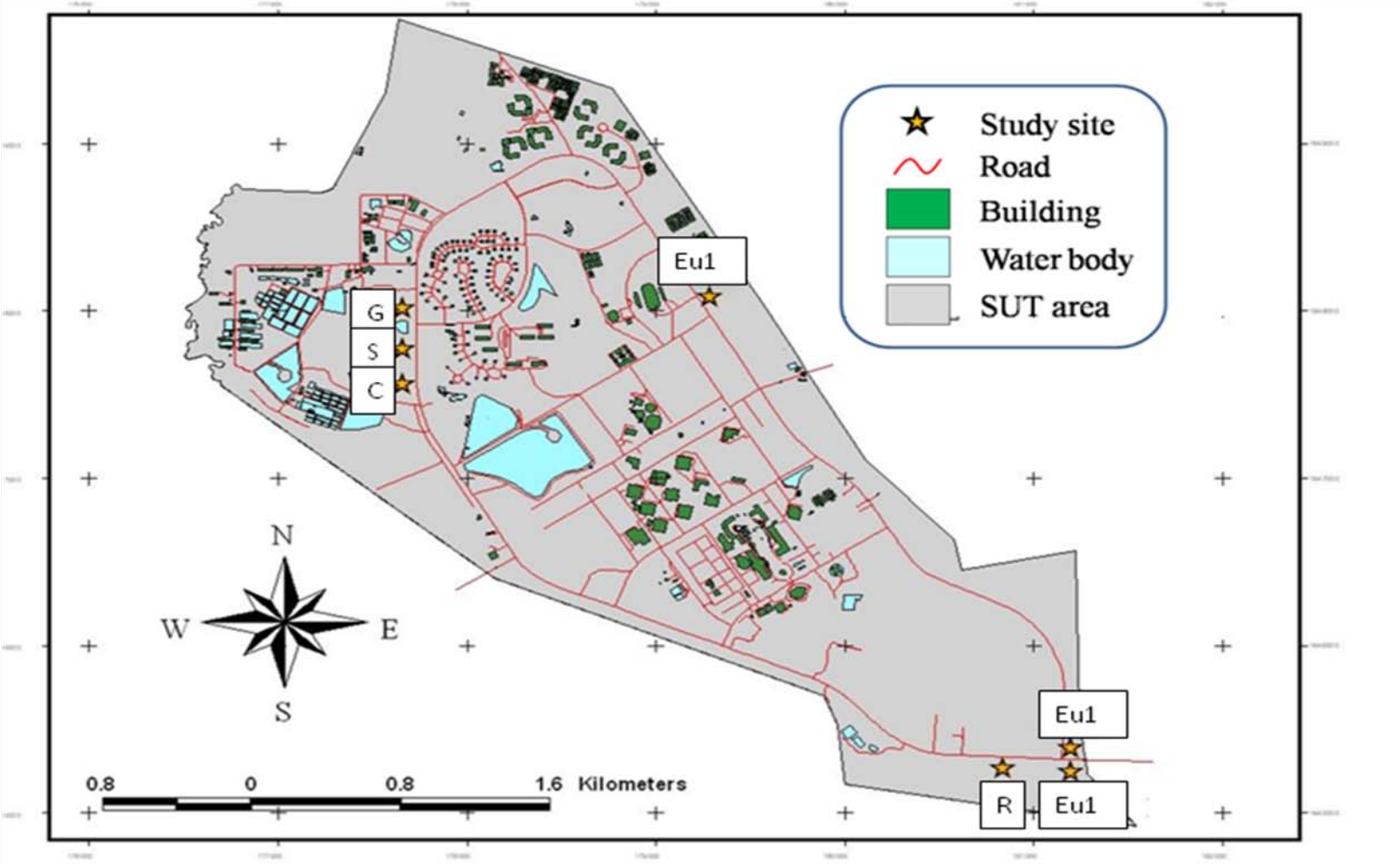

Figure 3.3 Location of different study sites in SUT. C: cornfield, S: sunflower, G: grassland, Eu1: *Eucalyptus* sp. and R: rubber.

3.1.1.1 Topography and soil

The altitudinal range of SERS is from 200 to 800 m above sea level and the major hills are Khao Phiat (762 m), Khao Khieo (790 m), Khao Sung (682 m), Khao Noi (569 m) and Khao Phoeng (438 m). Red-yellow Podzolic soil is a dominant soil group of SERS, occurring in all topographic positions where the materials of the soils are derived from both sandstone and shale. Soil texture is mainly coarse sandy clay loam to sandy loam and clay loam (Somniyam, 2008).

3.1.1.2 Climate

There are three seasons in SERS; the rainy (May to October), winter (November to February) and summer (March to mid-May). The average annual temperature at SERS is 26°C and the average annual rainfall is 1,260 ml. The relative humidity of the place ranges from 82 to 95% in Dry Evergreen Forest (Lamotte et al., 1998).

3.1.1.3 Vegetation

Vegetation types of the area are dry evergreen forest (46.82 km^2 or 59.96%), dry dipterocarp forest (14.51 km^2 or 15.1%), forest plantation (14.46 km^2 or 18.52%), bamboo forest (1.12 km^2 or 1.43%) and grassland (0.93 km^2 or 1.19%) (Figure 3.4). The dry evergreen forest occupies the south-western portion, usually referred to as the tropical semi-evergreen rain forest (SERS, 2009). The study site at SERS consists of dry evergreen and dry dipterocarp forests (Figures 3.4 and 3.5).

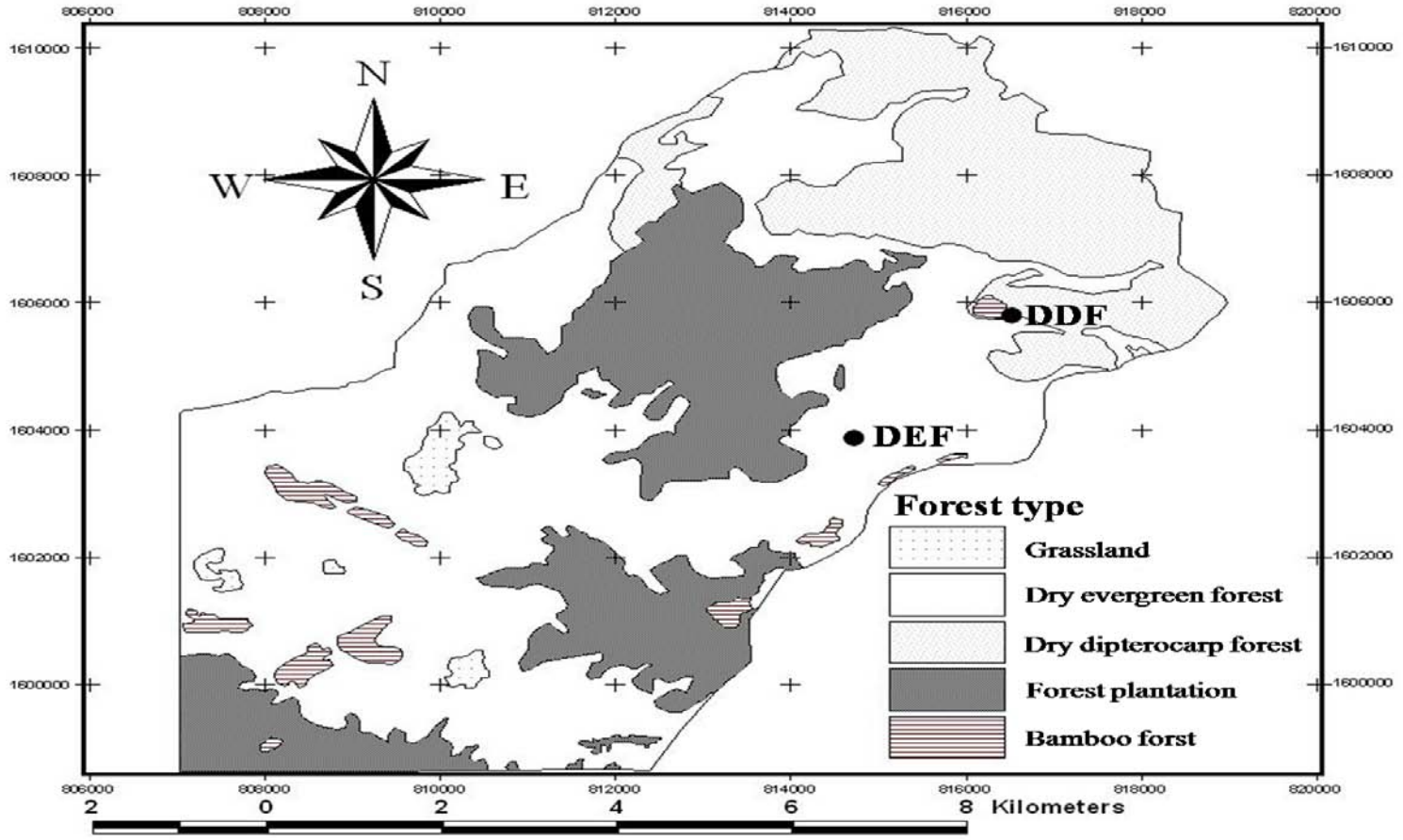

Figure 3.4 The location of different study sites at Sakaerat Environmental Research Station (SERS, 2009).

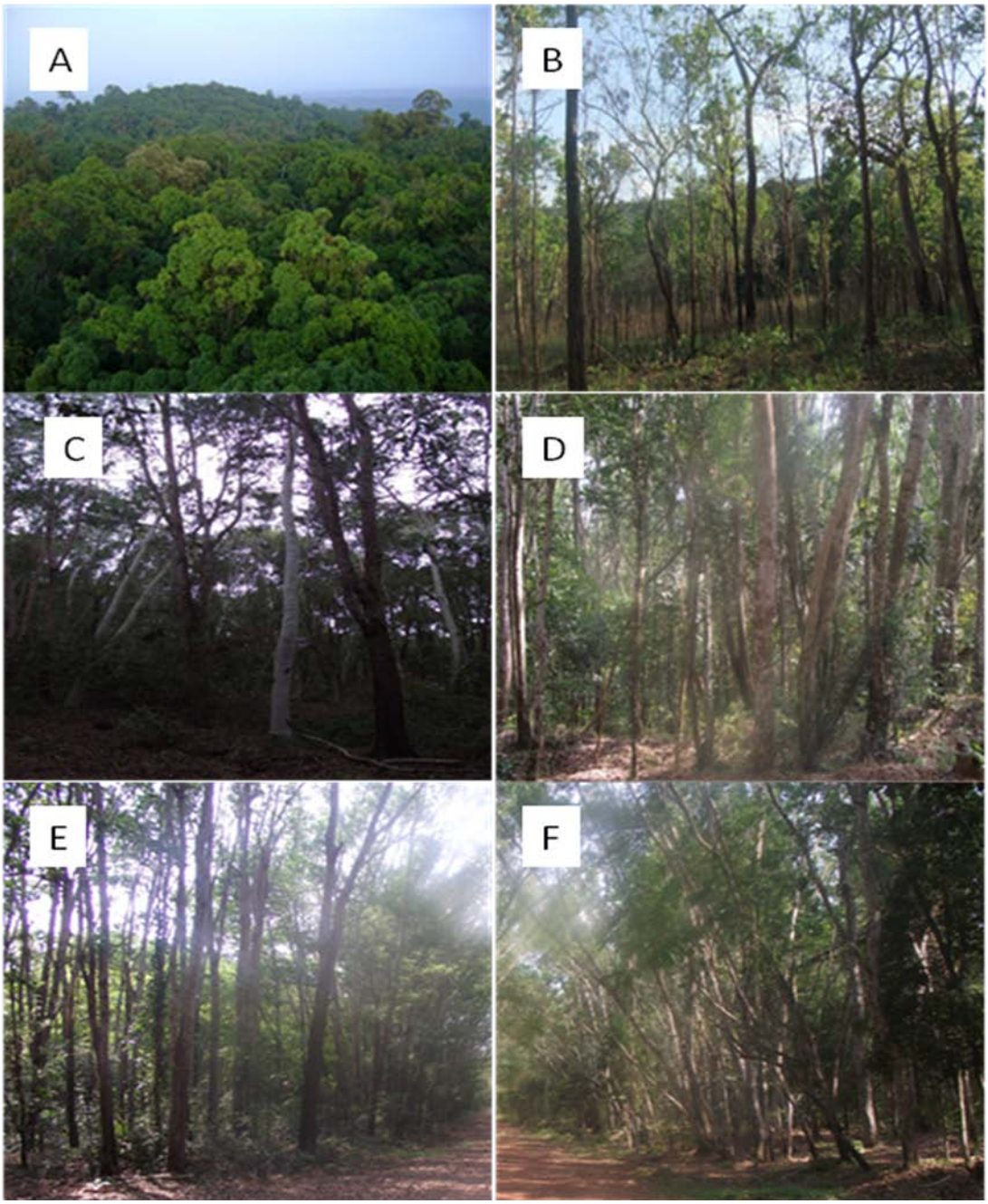

Figure 3.5 Pictures of study sites in SERS and SSRS.

A: dry evergreen forest, B: dry dipterocarp forest, C: *Eucalyptus camaldulensis*, D: *Dalbergia cochinchinensis*, E*: Acacia auriculiformis* and F: *Acacia mangium*.

The upper stories of dry evergreen forest are 21-40 m high, dominated by *Hopea ferrea* Pierre, *Hopea odorata* Roxb., *Shorea sericeiflor* Fisch and Hutch and *Irvingia malayana* Olive. Ex A. Ben. The middle story is 15-20 m high and consisted of dominant species such as *Hydnocarpus ilicifolius* King.,*Memecylon ovatum* Smith and *Walsura trichosatemo* Mig. The lower stories are about 4-14 m high consisting of *Baccaurea sapida* Muell. Arg., *Apodytes dimidate* E. Mey. Ex Arn. and *Olea salicifolia*. The undergrowth consists of sapling and shrubs of 4 m high and bamboo is also found in higher elevation (Somniyam, 2008).

The dry dipterocarp forest generally has open stand characteristic, composing of three stories. The upper stories are of 21-35 m high, dominated by *Shorea obtuse* Wall., *Shorea siamensis* Miq., *Dipterocarpus tuberculatus* Roxb. The middle stories of 11-20 m high dominated by *Quercus kerrii* Craib, *Gardenia sooptepensis* Huch., *Gardenia obtusifolia* Roxb., and *Randia tomentosa* Hook.F. The ground cover consists of grasses such as *Arundinaria pusiilla* Cheval. *Arundinaria camus* and *Imperata cylindrical* Beauv (Somniyam, 2008).

3.1.3 Sakaerat Silvicultural Research Station

SSRS is located at Sakaerat, Pak Thong Chai district, Nakhon Ratchasimma. It shared the same area as SERS but more dealing with forest plantation. SSRS was established in 1980 under the assistance of Japanese International Cooperation Agency (JICA) to rehabilitate the degraded lands through reforestation. The total area of SSRS is 1325.88 ha which is divided into two site A (894.57 ha) and site B (431.31 ha). In 1985, both native and exotic plant species were planted in SSRS. Now, more than nine tree species have been planted in SERS (Table 3.1).

The study sites here consist of about 30 years old *Acacia auriculiformis* Cunn (Aa), *Acacia mangium* Willd (Am), *Dalbergia cochinchinensis* Pierre (Dc) and *Eucalyptus camaldulensis* (Eu2) (Figures 3.5 and 3.6).

Table 3.1 Types of tree species planted with their area coverage at SSRS (SSRS, 2009).

Tree species	Area (ha)
1. Acacia mangium	430.67
2. Acacia auriculiformis	268.69
3. Leucaena leucocepphala	195.85
4. Pterocarpus macrocarpus	108.47
5. Eucalyptus sp.	87.06
6. Dalbergia cochinchinensis	47.60
7. Peltophorum plerocarpum	31.95
8. Melia azedarach	31.95
9. Others	123.64
Total	1325.88

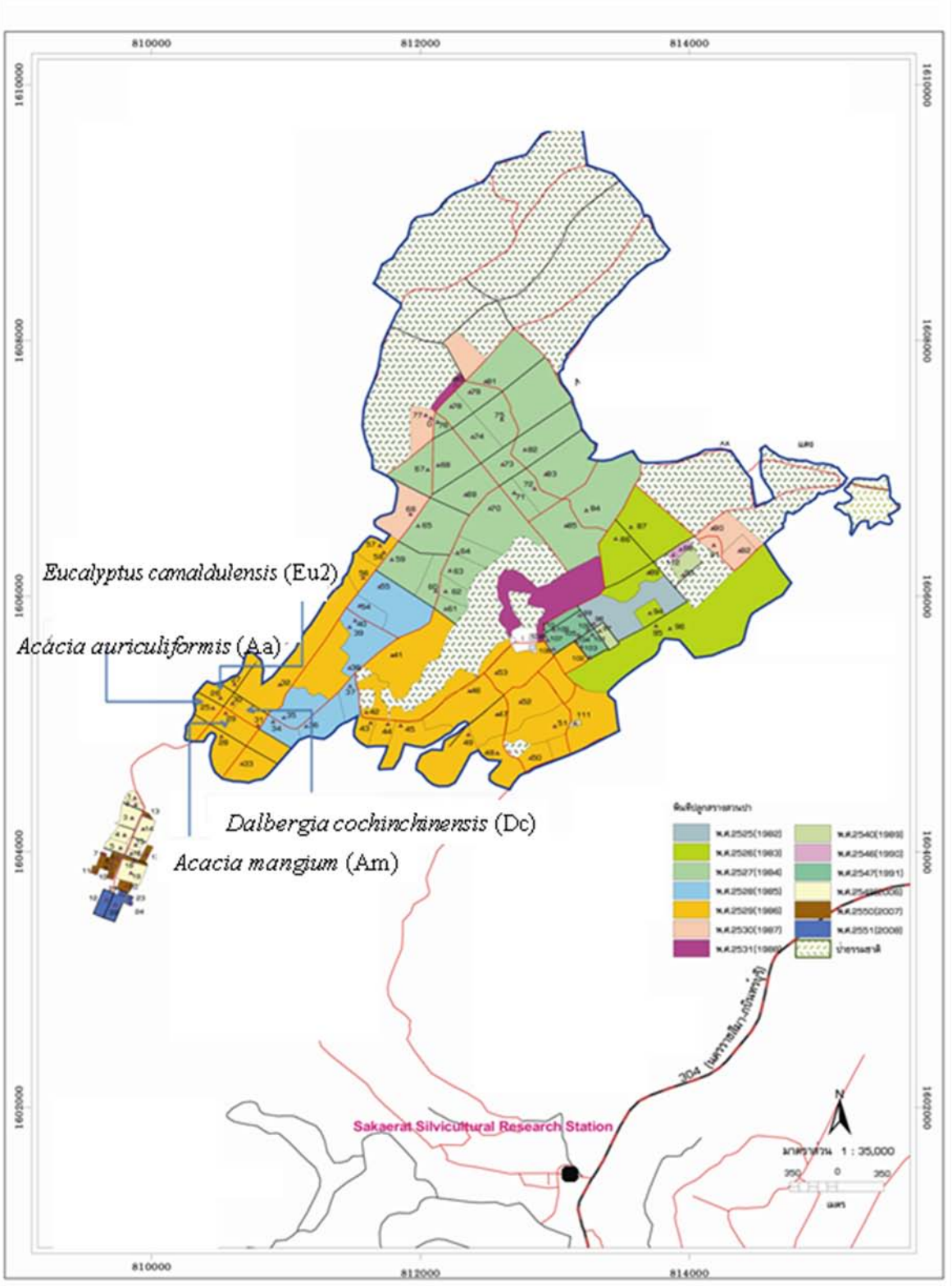

Figure 3.6 The study sites at Sakaerat Silvicultural Research Station (SSRS) (SSRS, 2009).

3.2 Field CO_2 efflux measurements

3.2.1 Field CO_2 efflux measurement of different ecosystems in SUT

In each site, two 40 m parallel line transects were laid randomly with 15 m apart and three plastic chambers (15 cm diameter and 15 cm height) were fixed in each line by inserting 5 cm into the soil at 20 m interval (Figure 3.7). Each site has six replications. The chambers were fixed a few days before the CO_2 measurements by using alkali-absorption method (Duiker and Lal, 2000).

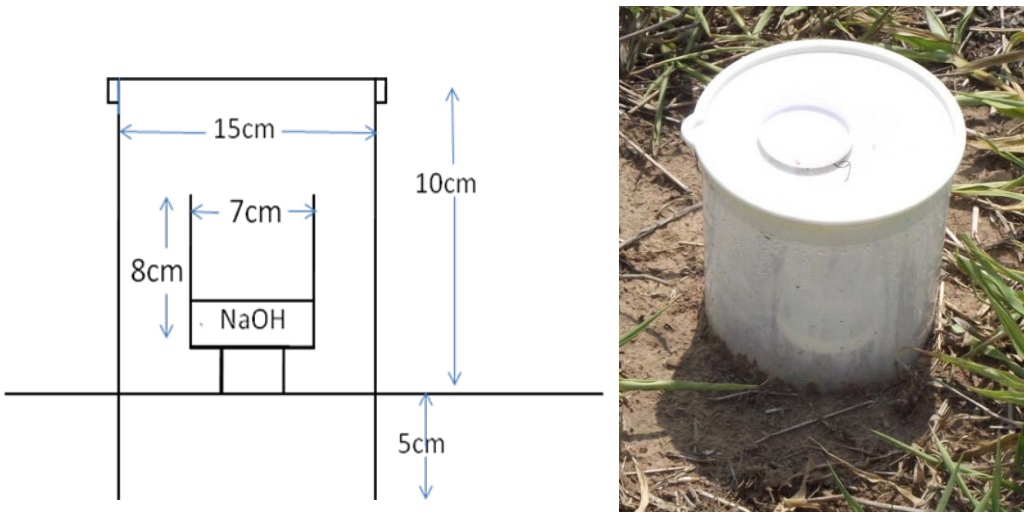

Figure 3.7 Static chamber set-up for field CO_2 measurement (A: schematic diagram, B: field static chamber).

Two plastic cups filled with 40 ml of 1M sodium hydroxide were used to determine the amount of CO_2. One was placed in the chamber while the other was closed and kept in the laboratory. The chamber was then covered by a plastic lid with rubber bands wrapped around to ensure proper sealing. After 24 h, the cups were

removed from the chambers, closed with lids and transported to the laboratory for titration.

Excess NaOH was titrated to pH 8.2 in the presence of excess $BaCl_2$ using 1M HCl and phenolphtalein as an indicator. The respiration rates were calculated using following formula;

$$X(gCO_2m^{-2}d^{-1}) = \frac{C\text{-}T*M*E*24}{A*h*1000}$$

Where, X is soil respiration rate, C is the volume of HCl used in control, T is the volume of HCl used in the field, M is the molarity of HCl, E is the Equivalent, A is the area of cylinder, and h is the hour of NaOH placed in the chamber.

The field CO_2 efflux measurements were carried out once a month from January to April, 2010. The field temperature of the soil and air were also measured at the time of chamber placing and at collection (average value used). A soil sample near each chamber was collected each time to measure water contents. For soil organic carbon, total nitrogen and pH analyses, only soil samples from January were used.

3.2.2 CO_2 efflux measurement of different ecosystems at SERS and SSRS

A 40 m line transect was laid randomly in two natural forests, dry evergreen forest (DEF) and dry diterocarp forest (DEF) in SERS and four forest plantations, *Acacia auriculiformis* Cunn (Aa), *Acacia mangium* Willd (Am), *Dalbergia cochinchinensis* Pierre (Dc) and *Eucalyptus camaldulensis* (Eu2) in SSRS . Three plastic chambers were placed at 20 m interval in each transect. Soil CO_2 efflux were measured once a month from January to April, 2010 within a few days after the

CO_2 measurement at SUT. Soil samples, one each nearby chambers, were collected for organic carbon, total nitrogen and pH analyses in January. Field air and soil temperatures and soil moistures were also measured during each sampling time.

3.3 Soil respiration under laboratory conditions

3.3.1 The respiration of soils from different ecosystems

During the first week of March 2010, a 40m line transect was laded in each ecosystem site at SUT (C, S, G, R and Eu1), SERS (DEF and DDF) and SSRS (Aa, Am, Dc and Eu2) then three soil samples were collected by soil cores at 20m interval. The soils at 0-5 and 5-15 cm depths were collected, put in plastic zip bags and transported to SUT laboratory. The roots and stones were removed by filtering the soil through 2 mm mesh and then put 100 g of soil into 500 ml conical flasks, covered with parafilm to prevent water loss but allow diffusion of gases and then incubated under 25°C for ten days (Figure 3.8 and 3.9). Soil respiration was measured at the 4^{th} and 10^{th} day using LI-820 CO_2 analyzer (LI-COR, USA). Soil water content (WC), organic carbon (C), total nitrogen (N), pH and texture were also analyzed.

3.3.2 The influence of water and temperature on soil respiration

From the previous incubation experiment, I selected soils from DEF, cornfield and *Eucalyptus camaldulensis* to investigate the effect of water and temperature on soil respiration. Hundred gram soils was put into a conical flask and adjusted to 50 and 75% of its water holding capacity (WHC) by adding de-ionized water. The flasks were closed with paraflim and then incubated under 25, 30 and 35°C. The soil respiration was measured at day 1, 4, 6, 9 and 12. To ensure the peak

date of respiration, soils from DEF and C were incubated and measured respiration at day 1, 2, 3, 4, 5, 6, 9 and 12.

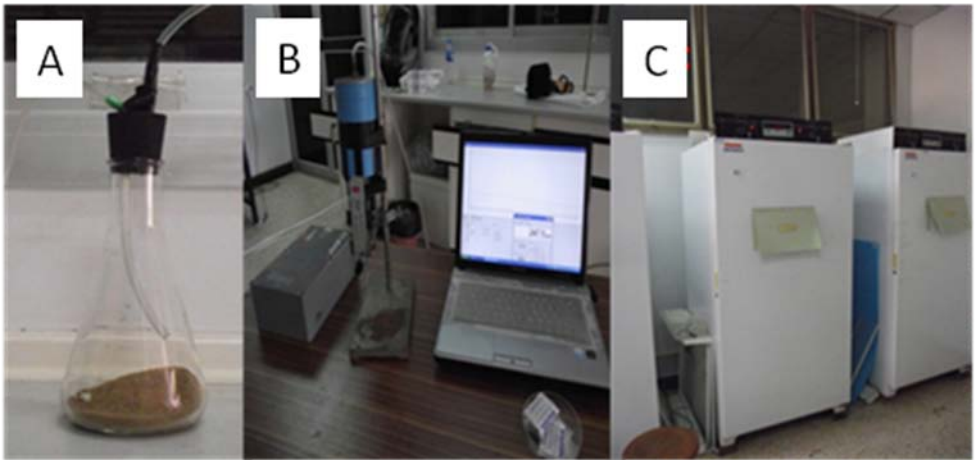

Figure 3.8 Laboratory equipments setup for CO_2 efflux measurements from soil samples. A: soil sample in conical flask, B: LI-820 connection to computer, C: incubation chambers.

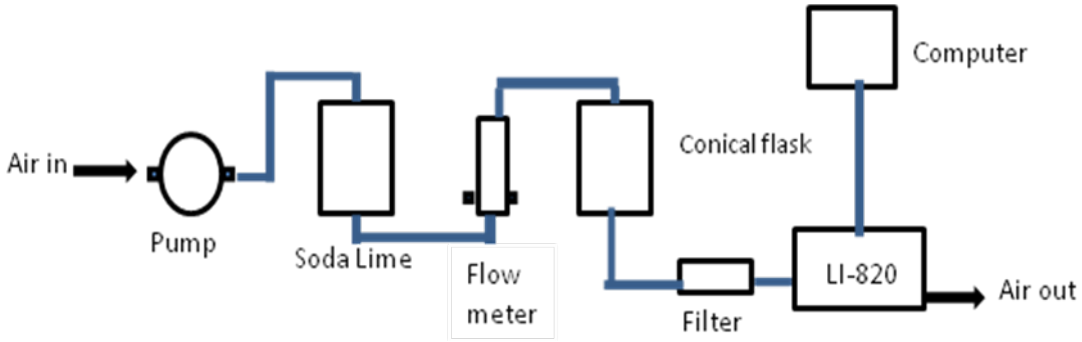

Figure 3.9 Schematic diagram of laboratory equipments setup for CO_2 efflux measurements from soil samples.

3.4 Soil analysis

Soil samples were air-dried inside the laboratory room by spreading on the tray for about 48 h. Soil lumps was gently crushed. Gravels and roots were separated by hand and finally sieved through 2 mm sieve to remove rocks and roots. Then soils were analyzed by methods according to Gupta (2007).

1) Soil pH was measured by suspending soil sample in water and potassium chloride (KCl) at soil-water ratio 1:1.

2) Organic carbon was determined by Walkley-Black method.

3) Total nitrogen was measured by Kjeldahl method.

7) Soil texture was determined by hand.

8) The water content was measured from the weight loss of the known amount of the soil samples after drying at 105°C for 24 h.

3.5 Data analysis

The analysis of variance, ANOVA and MANOVA were used to compare the different of soil respiration and properties among sites. The t-tests were used to compare the differences in soil respiration between soil depths. The relationship between soil respiration and environmental factors were tested using Pearson's correlation coefficient. The statistical analysis was performed by using SPSS 16.0 for windows.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Field CO_2 efflux measurements results

4.1.1 Field results of Suranaree University of Technology sites

4.1.1.1 Soil respiration rates of SUT ecosystems

The soil respiration, temperature and water content were significantly different among ecosystems sampling time (month) and ecosystem x month interaction at $p<0.01$ (Table 4.1). The soil respiration rate was found highest in cornfield followed by sunflower, grassland, rubber plantation and eucalyptus plantation, respectively (Table 4.2 and Figure 4.1).

The monthly soil respiration rates of cornfield, grassland, *Eucalyptus* sp. and rubber plantations were highest in January except for sunflower in February (Figure 4.2). The monthly soil respiration of cornfield, sunflower and grassland were significantly different among the sampling month ($p<0.01$).

Table 4.1 The MANOVA results soil respiration, temperature and water content of different ecosystems in SUT.

Source	Dependent Variable	df	F	p-value
Corrected Model	SR	19	40.21	*
	ST	19	1077.43	*
	SW	19	74.27	*
Intercept	SR	1	8211.34	*
	ST	1	423752.70	*
	SW	1	2541.58	*
Ecosystem	SR	4	129.48	*
	ST	4	1585.62	*
	SW	4	210.70	*
Month	SR	3	26.02	*
	ST	3	3827.14	*
	SW	3	86.48	*
Ecosystem x month	SR	12	14.00	*
	ST	12	220.61	*
	SW	12	25.74	*
Error	SR	100		
	ST	100		
	SW	100		
Total	SR	120		
	ST	120		
	SW	120		

SR: soil respiration, ST: soil temperature and SW: soil water content.

*****$p<0.01$

Table 4.2 The mean field soil respiration rates and soil parameters (n=24) of SUT ecosystems from January to April, 2010.

Soil parameters	C	S	G	Eu1	R	p-value
Respiration rate ($gCO_2\ m^{-2}\ d^{-1}$)	4.20a	3.75b	3.35c	1.89e	2.79d	<0.01
Water content (%)	16.98a	15.30a	6.76b	2.31c	7.00b	<0.01
Temperature (°C)	21.63c	24.50b	27.88a	21.96c	19.67c	<0.01
Organic carbon (%)	1.20b	0.90c	1.73a	0.70d	0.48e	<0.01
Total nitrogen (%)	0.08b	0.07bc	0.12a	0.06c	0.03d	<0.01
C:N ratio	14.28bc	12.56cd	16.94a	10.96d	15.51ab	<0.01
pH	7.06ab	7.31a	6.73b	5.38c	5.57c	<0.01
Texture	Clay	Clay	Clay loom	sand	Loomy sand	

C: cornfield, S: sunflower, G: grassland, Eu1: *Eucalyptus* sp. and R: rubber plantation. Soil organic carbon, total nitrogen, pH and texture were analyzed from January soils only (n=3).

Different letters show significant differences among ecosystems at $p<0.01$ (Duncan's test).

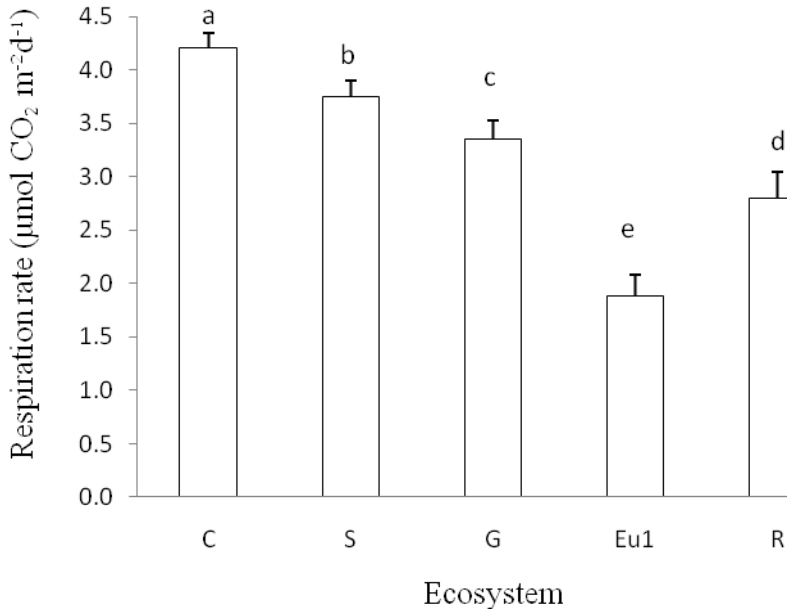

Figure 4.1 Mean soil respiration of cornfield (C), sunflower (S), grassland (G), *Eucalyptus* (Eu1) and rubber plantation at SUT (n=24). Different letters show significant differences among the ecosystems at $p<0.01$ (Duncan's test).

4.1.1.2 Soil environment

The mean soil water content was found highest in cornfield followed by sunflower due to constant watering but lowest in *Eucalyptus* sp. (Table 4.2). Cornfield, grassland and *Eucalyptus* sp. had highest water content in April while sunflower in February and rubber plantation in January (Table 4.3). The lowest soil moisture was observed in February for all ecosystems except sunflower which was found lowest in March.

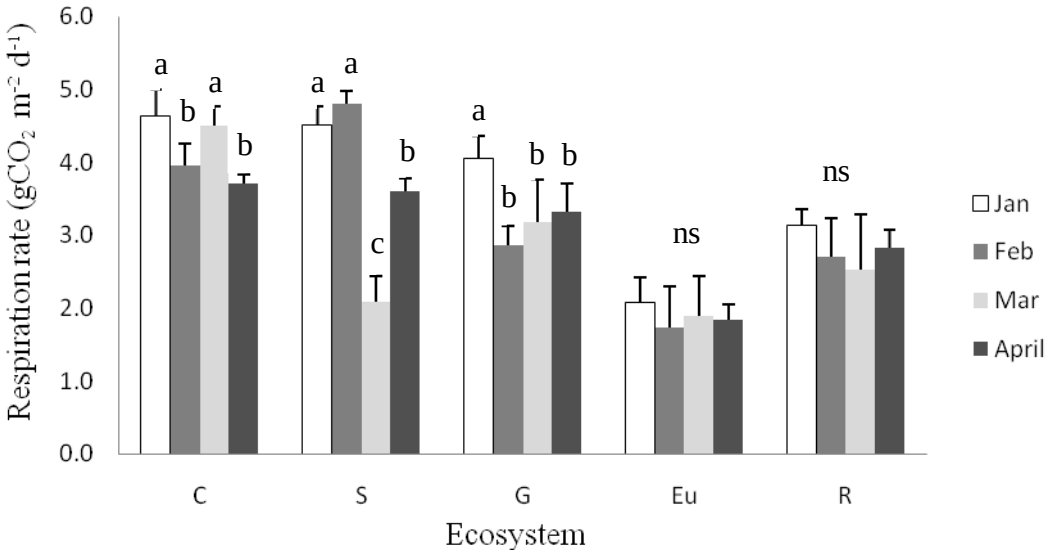

Figure 4.2 Variation of the monthly mean soil respiration rates of different ecosystems in SUT from January to April 2010. (n=6). C: cornfield, S: sunflower, G: grassland, Eu1: *Eucalyptus* sp. and R: rubber plantation. Different letter on bars of each ecosystem shows significant difference of each month at $p<0.05$ (Duncan's result). ns= not significantly different.

The overall soil temperature was highest in grassland, followed by sunflower, *Eucalyptus* sp., cornfield and rubber plantation, respectively (Table 4.4). April generally had the highest soil temperature except for grassland and sunflower which were in March.

Soil organic carbon and nitrogen were highest in grassland followed by cornfield, sunflower, *Eucalyptus* sp. and rubber plantation, respectively. While C: N ratio was highest in grassland followed by rubber, cornfield, sunflower and *Eucalyptus* sp., respectively. However, pH of cornfield, sunflower and grassland were neutral but pH of *Eucalyptus* sp. and rubber soils were acid (Table 4.2).

Table 4.3 The monthly mean of soil water content of different SUT ecosystems from January to April 2010. (n= 6)

Ecosystem	Water content (%)				p-value
	January	February	March	April	
C	19.35a	13.21c	15.16b	20.19a	<0.01
S	17.57b	22.75a	2.26c	18.63ab	<0.01
G	11.08a	1.30b	1.50b	13.14a	<0.01
Eu	1.76b	1.32b	1.50b	4.66a	<0.01
R	9.50a	4.52b	5.18b	8.79a	<0.01

C: cornfield, S: sunflower, G: grassland, Eu1: *Eucalyptus* sp. and R: rubber plantation.

Table 4.4 The monthly mean of soil temperature of different SUT ecosystems from January to April 2010. (n= 6)

Ecosystem	Temperature (˚C)				p-value
	January	February	March	April	
C	19.23c	17.21d	23.75b	26.35a	<0.01
S	20.28c	17.79d	31.71a	28.22b	<0.01
G	22.59d	23.63c	36.31a	29.00b	<0.01
Eu	19.51c	18.50d	24.12b	25.72a	<0.01
R	19.51c	16.83d	21.37b	22.40a	<0.01

C: cornfield, S: sunflower, G: grassland, Eu1: *Eucalyptus* sp. and R: rubber plantation.

4.1.1.3 The relationship between soil respiration and environmental factors

Soil respiration was positively significant correlated ($p<0.01$) with soil pH, water content, organic carbon and nitrogen, respectively (Table 4.5 and Figure 4.3). Although not significant, it had a negative correlation with soil temperature.

Table 4.5 Pearson correlation coefficient of soil respiration with soil temperature, water content, organic carbon, total nitrogen and pH of SUT ecosystems (n= 120 for soil temperature and water content but n= 30 for soil organic carbon, nitrogen and pH)

	Temperature	Water content	Carbon	Nitrogen	pH
Soil respiration	-0.156	.792**	.471**	. 465**	.805**

**Correlation is significant at $p<0.01$ level.

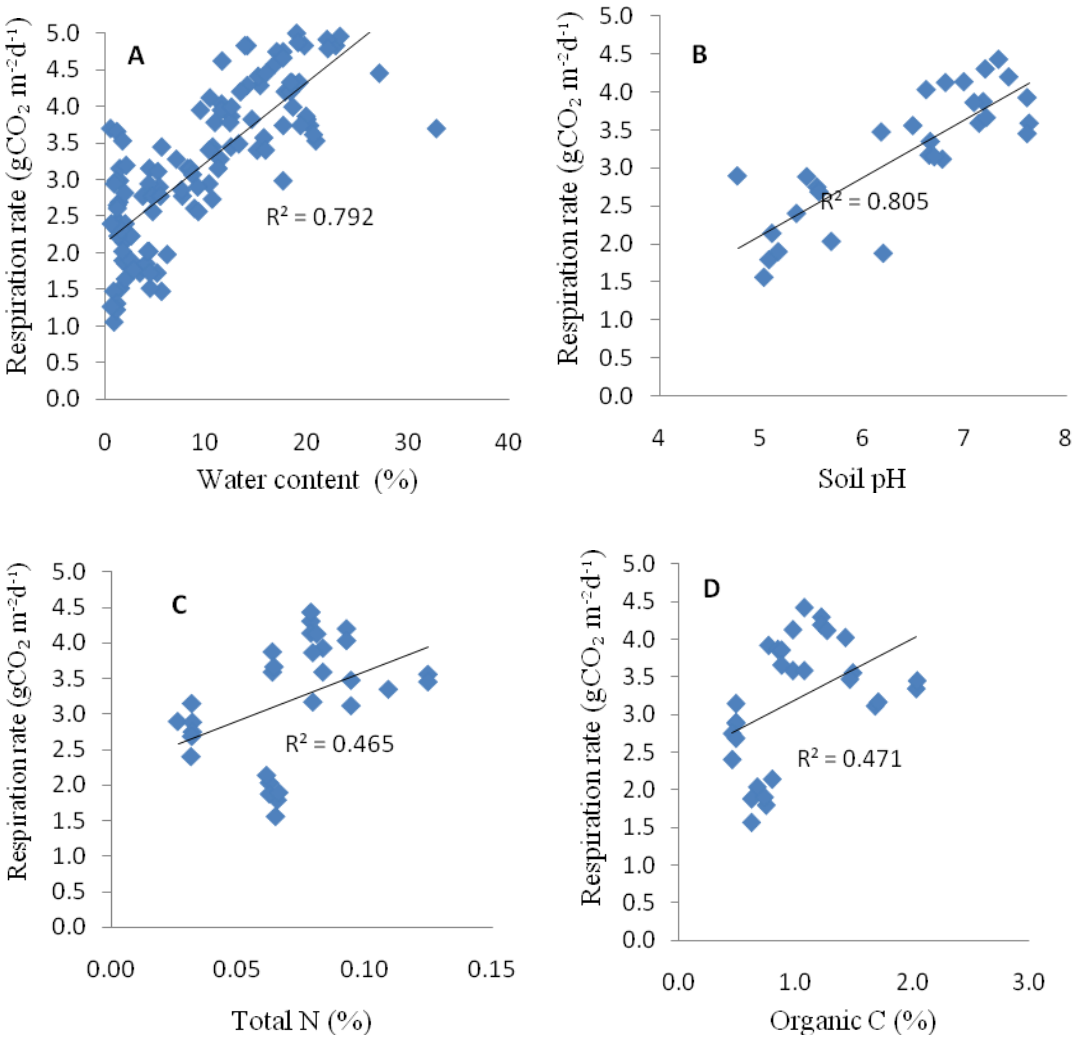

Figure 4.3 The relationship of soil respiration with other soil properties. A: soil water content, B: soil pH, C: soil organic carbon and D: soil total nitrogen of SUT ecosystems. (n = 120 for soil water content and n = 30 for soil pH, total nitrogen and organic carbon).

4.1.2 Field CO_2 efflux measurement results of Sakaerat Environmental Research Station and Sakaerat Silvicultural Research Station

4.1.2.1 Soil respiration rates of SERS and SSRS ecosystems

Soil respiration, temperature and water content were significantly different among ecosystems, month and ecosystem x month interaction (Table 4.6). The average respiration rate was highest in DEF followed by Aa, Dc, Eu2, Am and DDF, respectively (Table 4.7 and Figure 4.4).

The monthly soil respiration rates of DEF, Eu2, Aa and Dc were highest in April while DDF and Am were in January (Figure 4.5). The lowest respiration rates were observed in February for DEF, DDF, Eu2, and Am and in March for Aa and Dc. Only respiration rates of DEF and DDF in February were significantly different ($p<0.01$) from other months.

Table 4.6 The MANOVA results of soil respiration, temperature and water content of different ecosystems in SERS and SSRS.

Source	Dependent Variable	df	F	p-value
Corrected Model	SR	23	6.17	*
	ST	23	53.22	*
	SW	23	15.14	*
Intercept	SR	1	3869.0	*
	ST	1	129425.1	*
	SW	1	1512.42	*
Ecosystems	SR	5	17.69	*
	ST	5	149.93	*
	SW	5	11.92	*
Month	SR	3	10.70	*
	ST	3	127.65	*
	SW	3	52.12	*
Ecosystems x month	SR	15	1.42	0.176
	ST	15	6.10	*
	SW	15	8.82	*
Error	SR	48		
	ST	48		
	SW	48		
Total	SR	72		
	ST	72		
	SW	72		

SR: soil respiration, ST: soil temperature and SW: soil water content.

*$p<0.01$

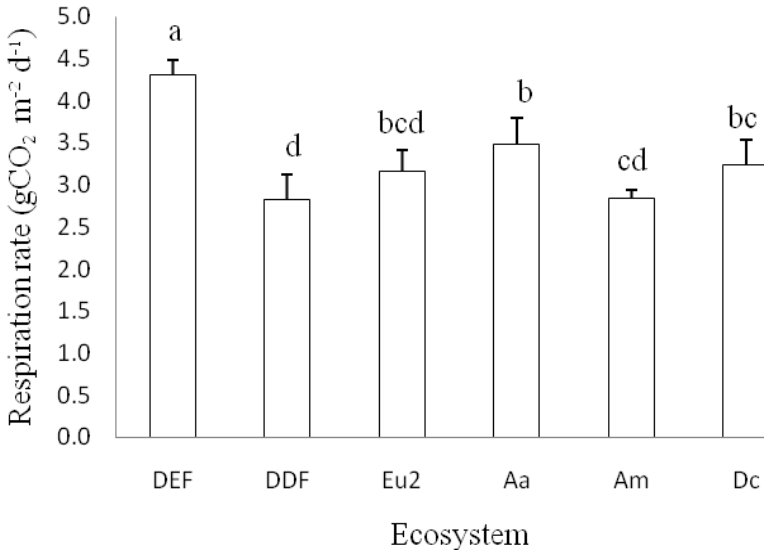

Figure 4.4 Field soil respirations of different ecosystems in SERS, SSRS from January to April 2010. DEF: dry evergreen forest, DDF: dry dipterocarp forest, Eu2: *Eucalyptus camaldulensis*, Aa: *Acacia auriculiformis*, Am: *Acacia mangium*, Dc: *Dalbergia cochinchinensi.* (n=12). Different letters show significant differences among ecosystems at $p<0.01$ (Duncan's test).

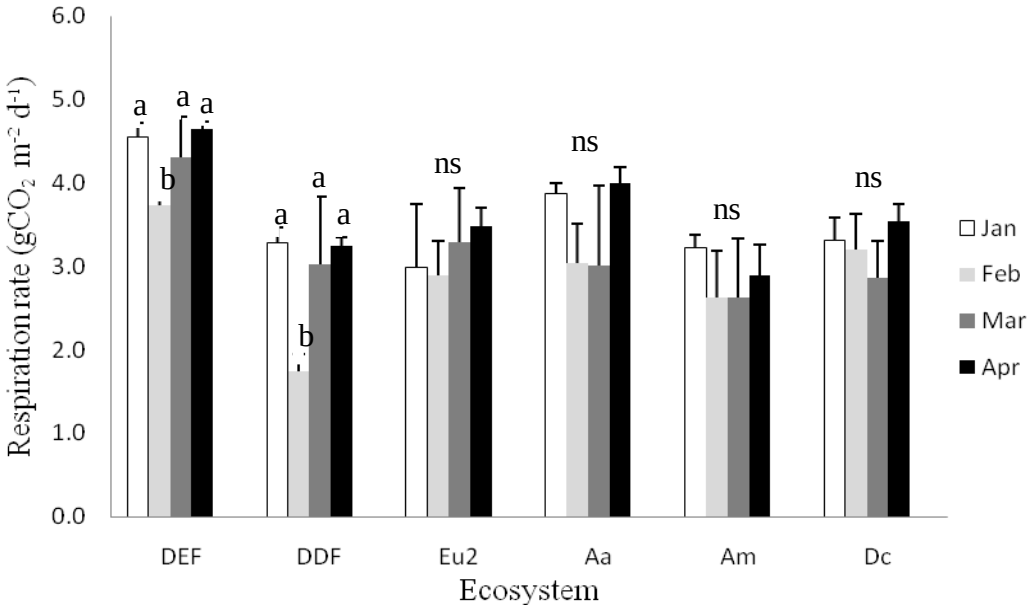

Figure 4.5 Variation of the monthly mean soil respiration rates of different ecosystems in SERS and SSRS from January to April 2010. (n=3). DEF: dry evergreen forest, DDF: dry dipterocarp forest, Eu2: *Eucalyptus camaldulensis*, Aa: *Acacia auriculiformis*, Am: *Acacia mangium*, Dc: *Dalbergia cochinchinensi*. Different letter of each ecosystem is significantly different at $p<0.05$ (Duncan's test) and the letter ns shows not significantly different.

4.1.2.2 Soil environment

Soil water content was highest in DEF followed by Dc, DDF, Eu2, Am and Aa, respectively (Table 4.7). The soil water content was highest in January for Aa and Am but in April for other ecosystems. The lowest soil water content was observed in February except for Dc, in March. The average temperature of DDF was significantly different from rest of the ecosystems ($p<0.05$) which was highest in DDF and lowest in Ac with 21.01 and 17.19°C. Mean monthly soil temperatures of

Table 4.7 The mean field soil respiration rates and soil parameters (n=12) of SERS and SSRS ecosystems from January to April 2010.

Ecosystem	DEF	DDF	Eu2	Aa	Am	Dc	p-value
Respiration rate ($g\ CO_2\ m^{-2}\ d^{-1}$)	4.31a	2.83d	3.16bcd	3.48b	2.85cd	3.23bc	<0.01
Water content (%)	13.76a	10.37b	8.5c	8.27c	8.39c	11.56b	0.05
Temperature (°C)	17.44b	21.01a	17.33b	17.33b	17.19b	17.45b	<0.01
Organic carbon (%)	3.21a	1.74b	1.89b	2.14b	1.92b	2.17b	<0.01
Total nitrogen (%)	0.45a	0.16b	0.08b	0.15b	0.17b	0.16b	<0.01
C:N ratio	7.61b	12.96c	21.38a	13.11b	11.62b	14.86b	<0.01
pH	4.26b	5.23a	4.48b	4.43b	4.43b	4.53b	0.002
Texture	Clay	Sandy clay loom	Silky clay	Loam	Clay	Clay	

DEF: dry evergreen forest, DDF: dry dipterocarp forest, Eu2: *Eucalyptus camaldulensis,* Aa: *Acacia auriculiformis,* Am: *Acacia mangium,* Dc: *Dalbergia cochinchinensi.* Soil organic carbon, total nitrogen, pH and texture were analyzed from January soils only (n=3).

Different letters show significant differences among ecosystems at $p<0.01$ (Duncan's test).

ecosystems were found highest in February except for Am in April and lowest values were recorded during March.

DDF had the highest soil temperature while those in other ecosystems were similar. Soil organic carbon and nitrogen were highest in DEF followed by Dc, Aa, Am, Eu2 and DDF, respectively. Whereas, C: N ratio was highest in Eu2, Dc, Aa, DDF, Am and DEF, respectively. However, pH of all soils was acidic.

4.1.2.3 The relationship of soil respiration with environmental factors

The mean soil organic carbon, total nitrogen and water content were highly positive correlated ($p<0.01$) with the soil respiration rates. Although significantly correlated ($p<0.05$), soil temperature had a negative correlation with soil respiration (Table 4.8).

Table 4.8 Pearson correlation of soil respiration rates with the soil factors.

	Temperature	Water content	Carbon	Nitrogen
Soil respiration	-0.296*	.501**	.727**	.704**

* Correlation is significant at $p<0.05$.

**Correlation is significant at $p<0.01$.

4.2 Laboratory soil incubation experiments

4.2.1 Incubation experiments of soils from eleven ecosystems in SUT, SERS and SSRS.

The eleven different ecosystems are confield (C), sunflower (S), grassland (G), *Eucalyptus* sp. (Eu1) and rubber plantation (R) in Suranaree University of Technology (SUT), dry evergreen forest (DEF) and dry dipterocarp forest (DDF) in Sakaerat Environmental Research Station (SERS) and *Acacia auriculiformis* (Aa), *Acacia mangium* (Am), *Dalbergi cochinchinensis* (Dc) and *Eucalyptus camaldulensis* (Eu2).

4.2.1.1 Soil respiration rates of different ecosystems in SUT, SERS and SSRS

Soil respiration was significantly different ($p<0.01$) among ecosystems and soil depth (Table 4.9). However, the soil water content was significantly different only among the ecosystems. The ecosystems x soil depth interaction were not significantly different for both soil respiration and water content. The mean incubated soil respiration rates were highest in sunflower, followed by cornfield but very low for other ecosystems (Table 4.10 and Figure 4.6). In general, the respiration rates of 0-5cm soil layers of most ecosystems were higher than those of 5-15cm soils except in sunflower and DDF (Table 4.11).

Table 4.9 MANOVA results of the treatments effects on soil respiration of eleven different ecosystems at SUT, SERS and SSRS.

Source	Dependent Variable	df	F	p-value
Corrected Model	WC	21	24.09	*
	SR	21	32.13	*
Intercept	WC	1	1200.39	*
	SR	1	197.34	*
Soil depth	WC	1	27.46	0.722
	SR	1	0.13	*
Forest type	WC	10	46.58	*
	SR	10	66.68	*
Soil depth x forest type	WC	10	1.27	0.278
	SR	10	0.78	0.651
Error	WC	44		
	SR	44		
Total	WC	66		
	SR	66		

WC: soil water content, SR: soil respiration.

*$p<0.01$

Table 4.10 The mean incubated soil respiration rates and other parameters from eleven ecosystems of SUT, SERS and SSRS (n=3)

Ecosystem	Eu1	R	C	S	G	DEF	DDF	Eu2	Aa	Am	Dc
Respiration rate (µmol CO_2 $g^{-1}h^{-1}$)	0.005c	0.009c	0.327b	0.868a	0.024c	0.036c	0.017c	0.039c	0.027c	0.032c	0.033c
Water content (%)	1.24d	4.06d	16.91ab	16.23a	3.25	13.96b	4.28d	10.87c	9.85c	9.66c	10.03c
Organic C (%)	0.391fg	0.325g	0.672ef	0.625fg	0.921de	2.622a	1.167cd	1.297bcd	1.823b	1.361bcd	1.481bc
Total N (%)	0.048cd	0.043d	0.075bcd	0.087bcd	0.076bcd	0.202a	0.088bc	0.112bcd	0.130b	0.130b	0.142b
C:N ratio	7.623b	11.470b	11.601b	5.601b	11.149b	15.574b	14.856b	10.539a	10.425b	9.786b	9.641b
Soil pH	5.18d	5.63d	7.09b	7.68a	6.13c	5.22e	4.16e	4.59e	4.41e	4.55e	4.58e

C: Confield, S: sunflower, G: grassland, Eu1: *Eucalyptus* sp. R: rubber plantation, DEF: dry evergreen forest and DDF: dry dipterocarp forest, Aa: *Acacia auriculiformis,* Am: *Acacia mangium,* Dc: *Dalbergi cochinchinensis* and Eu2: *Eucalyptus camaldulensis.* Different letters show significant differences among ecosystems at $p<0.01$ (Duncan's test).

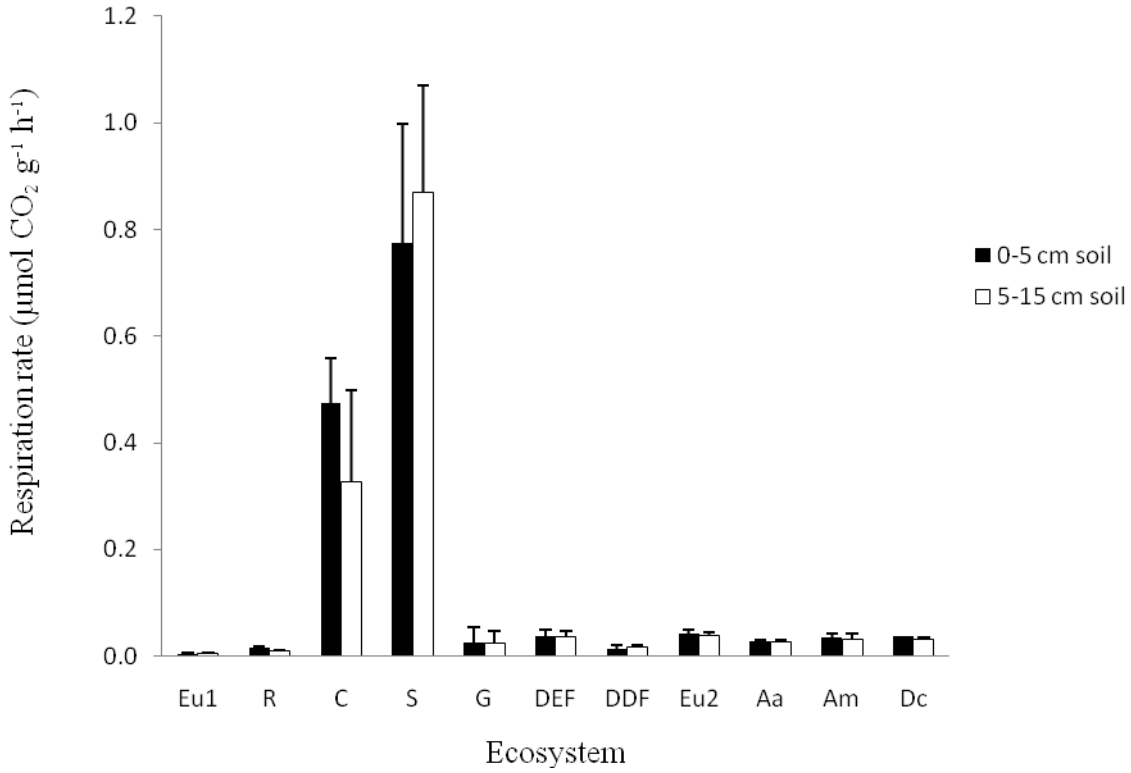

Figure 4.6 Mean soil respiration rates of incubated soils at 0-5 and 5-15 cm depth from eleven different ecosystems of SUT, SERS and SSRS. Soil respirations were measured after four days of incubation at 25°C (n=3). Eu1: *Eucalyptus* sp. R: rubber plantation, C: Confield, S: sunflower, G: grassland, DEF: dry evergreen forest and DDF: dry dipterocarp forest, Eu2: *Eucalyptus camaldulensis,* Aa: *Acacia auriculiformis,* Am: *Acacia mangium* and Dc: *Dalbergi cochinchinensis.*

4.2.1.2 Soil environment

Soil water content was very high in cornfield and sunflower followed by DEF, SSRS plantations, DDF, rubber, grassland and Eu1, respectively (Table 4.10). However, soil organic carbon was highest in DEF, followed by DDF, and SERS plantations, grassland, cornfield and sunflower, Eu1 and rubber, respectively. DEF

Table 4.11 Mean soil respiration rates and soil characteristics of two soil depths (cm) of different ecosystems of SUT, SERS and SSRS (n=3)

Site	Respiration rate (µmol CO_2 g^{-1} h^{-1})		Water content (%)		Organic C (%)		Total N (%)		Soil pH	
	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15	0-5	5-15
Eu1	0.005	0.005	0.67	1.24	0.679	0.391	0.064	0.048	5.27	5.18
R	0.015	0.009	2.17	4.06	0.488	0.325	0.030	0.043	5.64	5.63
C	0.475	0.327	12.36	16.91	1.288	0.672	0.088	0.075	7.08	7.09
S	0.775	0.868	17.59	16.23	0.862	0.625	0.070	0.087	7.47	7.68
G	0.025	0.024	1.35	3.25	1.543	0.921	0.105	0.076	6.48	6.13
DEF	0.039	0.036	10.27	13.96	3.208	2.622	0.445	0.202	4.26	5.22
DDF	0.015	0.017	2.67	4.28	1.742	1.167	0.161	0.088	5.23	4.16
Eu2	0.043	0.039	7.19	10.87	1.888	1.297	0.078	0.112	4.48	4.59
Aa	0.028	0.027	6.97	9.85	2.139	1.823	0.154	0.130	4.43	4.41
Am	0.036	0.032	6.49	9.66	1.921	1.361	0.172	0.130	4.43	4.55
Dc	0.037	0.033	6.26	10.03	2.174	1.481	0.156	0.142	4.53	4.58

Eu1: *Eucalyptus* sp., R: rubber plantation, C: Confield, S: sunflower, G: grassland, , DEF: dry evergreen forest and DDF: dry dipterocarp forest, Eu2: *Eucalyptus camaldulensis,* Aa: *Acacia auriculiformis,* Am: *Acacia mangium,* and Dc: *Dalbergi cochinchinensis.*

also had the highest soil nitrogen but Eu1 and rubber had very low. C: N ratio was highest in DEF followed by DDF but lowest in sunflower.

Generally, soil water content was higher in 5-15 cm soil than in surface soil but soil organic carbon and nitrogen were higher in surface soil (Table 4.11) while soil pH did not show much different between soil depths.

4.2.1.3 Soil respiration and environmental factors

In general, soil pH and water content showed a very strong positive correlation ($p<0.01$) with soil respiration (Table 4.12).

Table 4.12 Pearson correlation coefficient of soil respiration rates with soil water contents and pH of eleven different ecosystems of SUT, SERS and SSRS (n=33)

	Water content	pH
Soil respiration	0.660**	0.752**

. Correlation is significant at the 0.01 level (2-tailed).**

4.2.2 Effect of temperature and water content on cornfield, dry evergreen forest and *Eucalyptus camaldulensis* soils

4.2.2.1 Respiration rates of the ecosystem soils

Soil respiration was significantly different among ecosystems and incubation dates. The treatments of water and temperature also significantly affected ($p<0.01$) soil respiration (Table 4.13).

Overall soil respiration was highest in cornfield, followed by DEF and Eu, respectively (Table 4.14 and figure 4.7). Increasing soil water content generally

stimulated more soil respiration in *Eucalyptus camaldulensis* and DEF but not in cornfield. However, increasing soil temperature had mix effects on soil samples. Though not significantly, it increased soil respiration in cornfield at 50%WHC but decreased in soil respiration in *Eucalyptus camaldulensis* at both soil water contents.

In general, soil respiration increased after incubation, reached the maximum in day four, and then declined over 50% at the end of the experiments (Figure 4.8).

Table 4.13 MANOVA results used to investigate the treatments effects on soil respiration of dry evergreen forest, cornfield and *Eucalyptus camaldulensis* incubated soils.

Source	df	F	p-value
Corrected Model	89	11.70	*
Intercept	1	3070.95	*
Water (WC)	1	73.02	*
Temperature (T)	2	8.50	*
Days (D)	4	162.27	*
Ecosystem (E)	2	24.80	*
WC x T	2	1.11	0.333
WC x D	4	2.44	0.049
WC x E	2	22.90	*
T x D	8	4.57	*
T x E	4	10.71	*
D x E	8	4.37	*
WC x T x D	8	1.43	0.188
W x T x E	4	0.86	0.486
W x D x E	8	1.84	0.072
T x D x E	16	1.23	0.251
W x T x D x E	16	1.96	0.018
Error	180		
Total	270		

*$p<0.01$

Table 4.14 Average soil respiration rate ($\mu molCO_2\ g^{-1}h^{-1}$) of *Eucalyptus camaldulensis* (Eu), dry evergreen forest (DEF) and cornfield (C) soils incubated under different temperatures and water contents for twelve days (n=15).

Ecosystem	Water content (%WHC)	Incubation temperature (°C)			p-value
		25	30	35	
Eu	50	0.960a	0.971a	0.370b	0.001
	75	1.898a	1.732ab	1.122b	0.050
DEF	50	1.366	1.113	1.133	0.663
	75	1.732	1.810	1.603	0.672
C	50	1.411	1.656	1.789	0.454
	75	1.426	1.781	1.591	0.498

Different letters show significant differences at given p-value (Duncan's test). The mean soil respiration rates of DEF and cornfield were not significantly different.

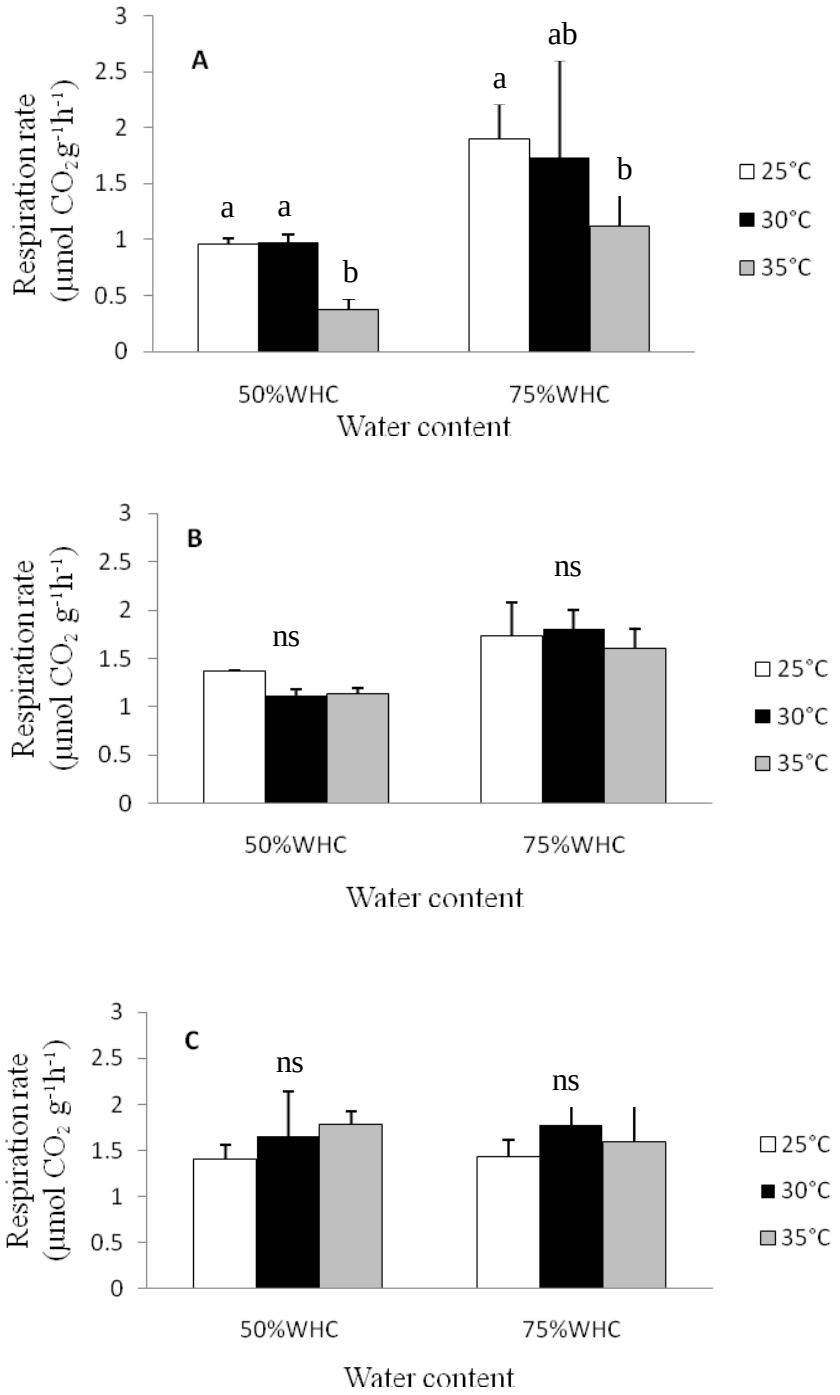

Figure 4.7 The average soil respiration rates from *Eucalyptus camaldulensis* (A), dry evergreen forest (B) and cornfield (C) at different incubation temperature and water content treatments. Different letters on bars of same water content treatments show significantly different ($p<0.05$). (n=15). ns= no significant difference.

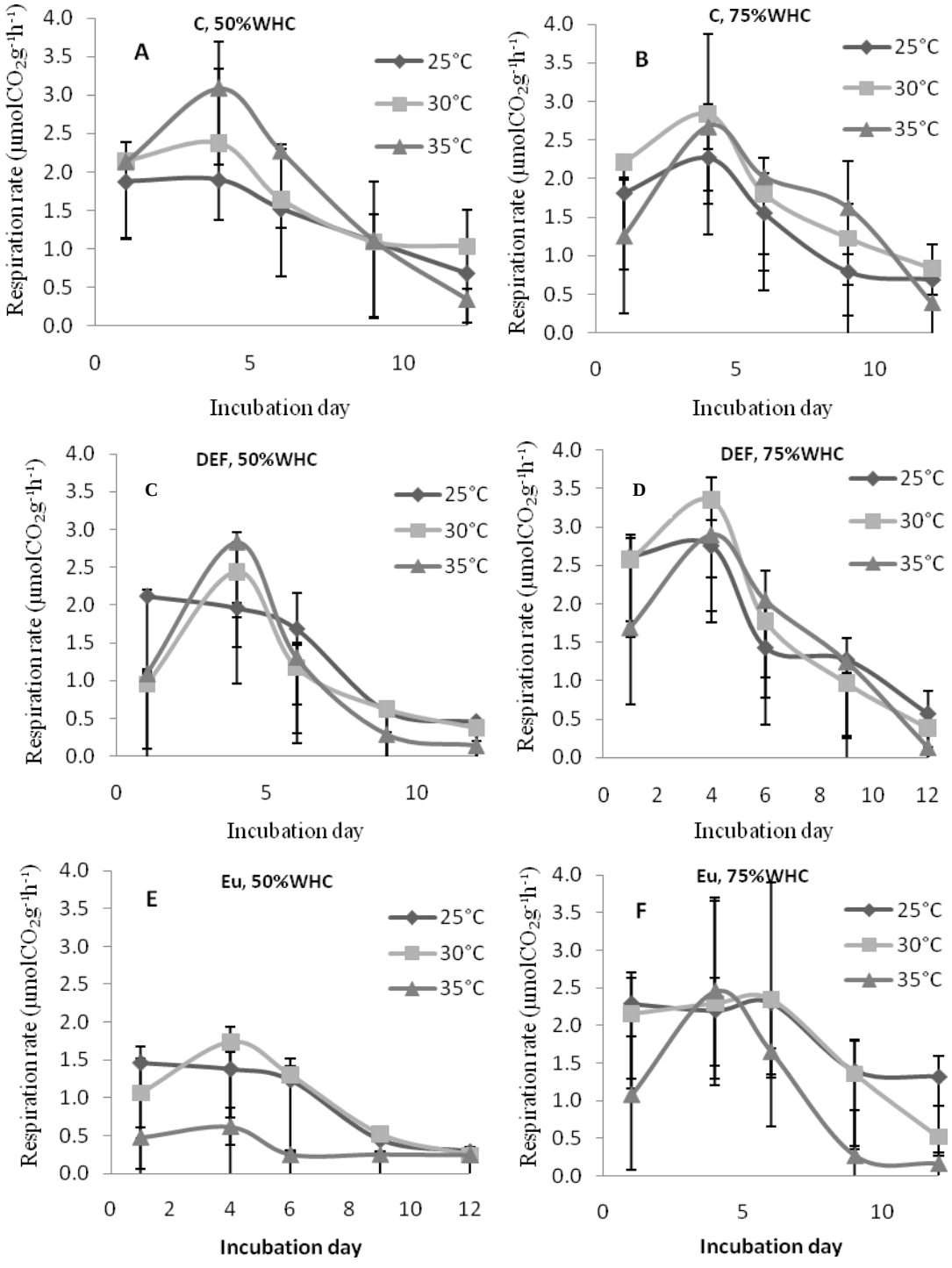

Figure 4.8 The mean respiration rates of incubated soils of cornfield (A and B), DEF (C and D) and *Eucalyptus camaldulensis* (E and F) at different incubation days under different temperature and water treatments (n=3).

The highest soil respiration rate of cornfield incubated under 50% WHC water content was on day four which was significantly higher at 35°C, followed by 30°C and 25°C with 3.09, 2.373 and 1.896 µmol CO_2 $g^{-1}h^{-1}$, respectively ($p<0.01$). The respiration rate of DEF and eucalyptus of 50% water treatments were also higher at 35°C, followed by 30°C and 25°C, respectively on incubation day six but differences were not significant for both the ecosystem. Under 30°C and 75% WHC, cornfield soils had highest respiration rates on day four but on day six and nine, the respiration rates were higher for 35°C, followed by 30°C and 25°C, respectively (Figure 4.8).

The DEF soils of both, 50 and 75% WHC had highest respiration rates on incubation day four. Soils containing 50% WHC, had higher respiration rates 35°C, followed by 30 and 25°C with 2.83, 2.44 and 1.96 µmol CO_2 $g^{-1}h^{-1}$, respectively ($p<0.01$). But DEF soils with 75% WHC, incubated under 30°C had highest respiration rates (3.347 µmol CO_2g^{-1} h^{-1}).

The mean respiration rate of *Eucalyptus camaldulensis* plantation soils were significantly higher under temperature treatment of 25 and 30°C than 35°C ($p<0.01$) (Table 4.13). Under 75% WHC, the soil respiration of *Eucalyptus camaldulensis* was higher at 35°C, followed by 30°C and 25°C with 2.456, 2.292 and 2.198 µmol CO_2 $g^{-1}h^{-1}$, respectively and but not statistically significant ($p<0.05$).

4.2.2.2 Soil environment

The soil organic carbon was found highest in cornfield followed by DEF and *Eucalyptus camaldulensis* with 3.56, 3.12 and 0.63%, respectively. The soil total nitrogen was highest in *Eucalyptus camaldulensis* but lowest in DEF with 3.1 and 0.09%. The C:N ratio was significantly different among the all the ecosystems with

highest in cornfield followed by DEF and *Eucalyptus camaldulensis* soils. The pH of cornfield soils was neutral but DEF and *Eucalyptus camaldulensis* were acidic (Table 4.15).

Table 4.15 Overall mean soil chemical properties of *Eucayptus camaldulensis*, dry evergreen forest and cornfield soils (n=3).

	Eu	DEF	C	p-value
Organic carbon (%)	0.634c	3.123b	3.561a	<0.01
Total nitrogen (%)	0.312a	0.085c	0.163b	<0.01
C/N ratio	10.007b	7.467c	21.892a	<0.01
pH	4.27c	4.48b	7.08a	<0.01
Texture	Silt clay	clay	clay	-

Different letters show significant differences at given p-value (Duncan's test).

4.2.3 Incubation experiment of soils from cornfield and dry evergreen forest

To ensure the peak date of respiration, soils from cornfield and dry evergreen forest were incubated under same temperature (25, 30 and 35°C) and water treatments (50 and 75% WHC) and measured respiration at day 1, 2, 3, 4, 5, 6, 9 and 12.

4.2.3.1 Respiration rates of cornfield and dry evergreen forest soils

Soil respiration is still significantly different ($p<0.01$) among ecosystems, incubation day, soil water content and temperature (Table 4.16). The average soil respiration rate of cornfield was significantly higher than DEF at $p<0.01$ (Figure 4.9). The respiration rates of DEF and cornfield were higher in 75% WHC than 50% WHC (Table 4.16).

Table 4.16 The MANOVA results of soil respiration, water content and temperature of DEF and cornfield incubated soils.

Source	df	F	p-value
Corrected Model	95	25.56	*
Intercept	1	6129.94	*
Days (D)	7	197.58	*
Water content (WC)	1	29.70	*
Temperature (T)	2	42.94	*
Ecosystem (E)	1	491.27	*
D x WC	7	3.55	0.001
D x T	14	3.82	*
D x E	7	10.05	*
WC x T	2	12.63	*
WC x E	1	66.42	*
T x E	2	31.91	*
D x WC x T	14	1.62	0.076
D x WC x E	7	4.22	*
D x T x E	14	3.88	*
WC x T x E	2	7.30	0.001
D x WC x T x E	14	0.92	0.541
Error	192		
Total	288		

*$p<0.01$

More water content increased soil respiration in DEF soil (Table 4.17 and Figure 4.9) but there was no effect on cornfield soils and respiration rate even got reduced at 30°C condition. The respiration rate of cornfield on day two was highest under incubation temperature 35°C followed by 30°C and 25°C with 2.732, 2.239 and 2.093 µmol CO_2 $g^{-1}h^{-1}$, respectively for 50% WHC and 2.903, 2.483 and 1.377 µmol CO_2 $g^{-1}h^{-1}$, respectively for 75% WHC (Table 4.17). The cornfield incubated soils had higher respiration rates from incubation day one to four for both 50% and 75% WHC treatments but after day four, they were significantly reduced at $p<0.01$ (Figure 4.10). In both 50% and 75% WHC treatments, respiration rates were highest on day two for all temperature treatments.

Table 4.17 Mean soil respiration rate (mean value of day 1, 2, 3 and 4) of dry evergreen forest and cornfield soils incubated under different temperature of 25, 30 and 35°C and water contents of 50 and 75% WHC (n=12).

Ecosystem	Water content (% WHC)	Incubation temperature (°C)			p-value
		25	30	35	
DEF	50	0.908a	1.236a	0.844a	0.117
	75	1.351b	1.69a	1.563ab	0.050
C	50	1.923c	2.097bc	2.376a	0.014
	75	1.221c	2.142b	2.584a	0.000

Different letters show significant differences at $p<0.01$ (Duncan's test).

In both the water treatments, DEF soil respiration was highest under 30°C incubation than 35°C and 25°C, peaking at day three for 50% WHC and day four for 75% WHC with 2.016 and 1.908 µmol CO_2 $g^{-1}h^{-1}$. DEF soils incubated at 35°C, 30°C and 25°C with water content of 50% and 75% WHC showed their higher respiration rates from incubation day two to four.

In this experiment, increasing temperature significantly ($p<0.01$) promoted the more respiration only in cornfield soils but not in DEF.

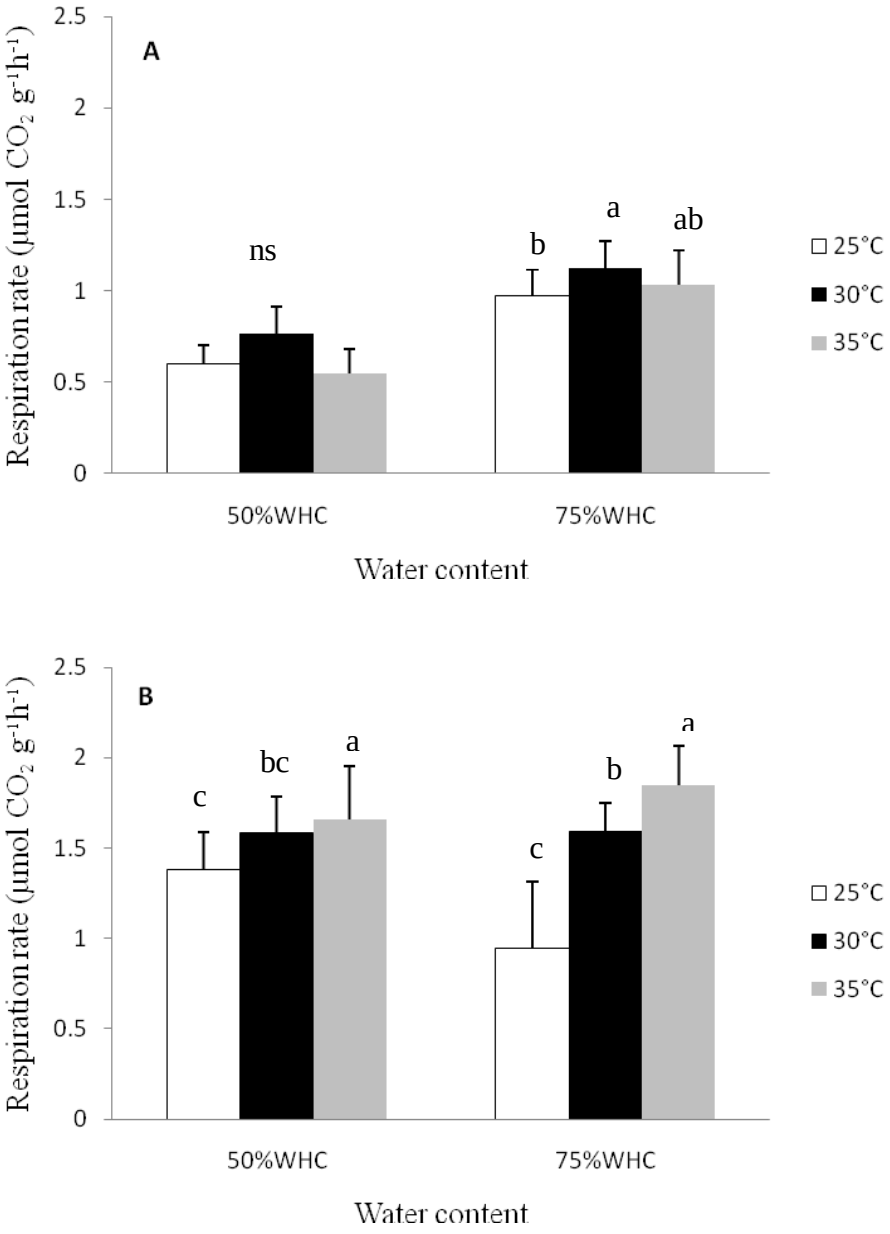

Figure 4.9 The overall average soil respiration rates of dry evergreen forest (A) and cornfield (B) at different incubation temperature and water treatments. Different letters on bars of same water content treatments show significant difference at $p<0.05$ (Duncan's test) (n=24). ns = no significant difference.

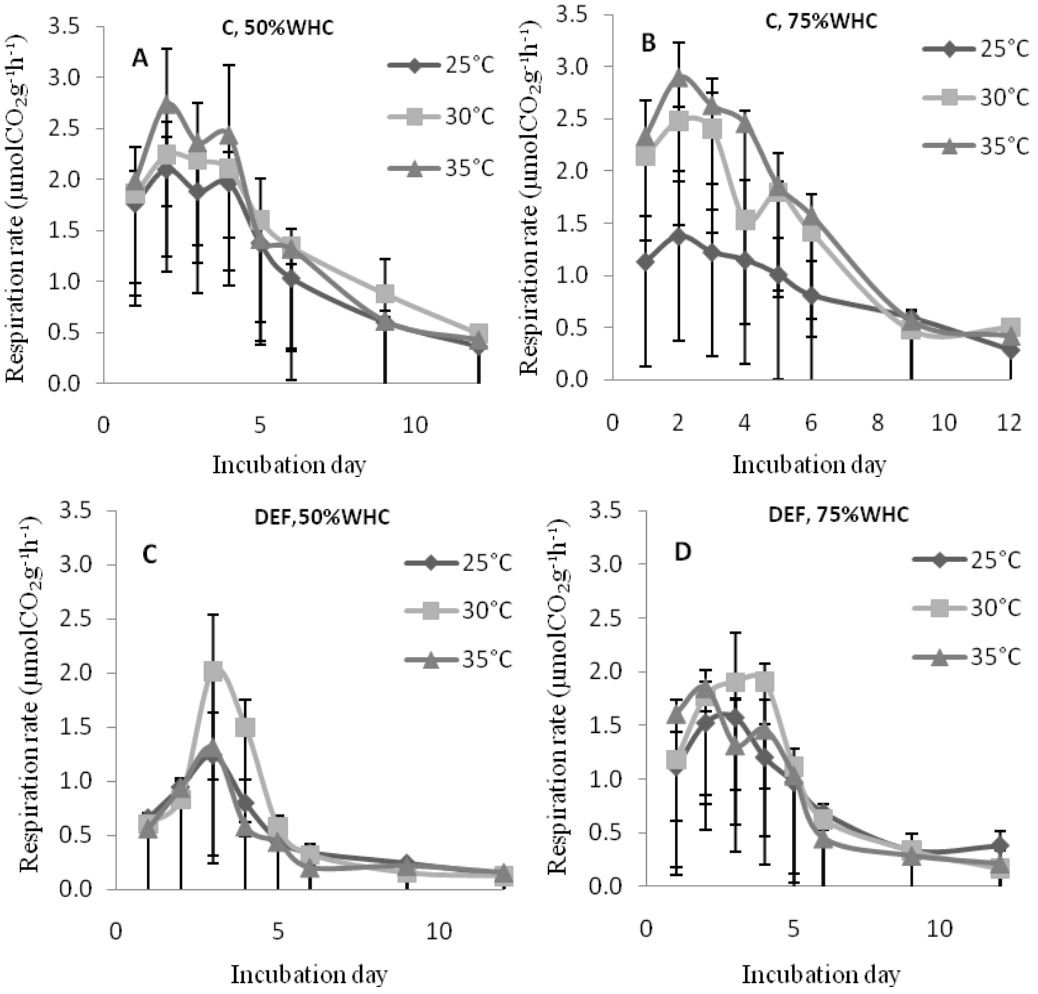

Figure 4.10 Mean respiration rates of incubated soils from cornfield (A and B) and dry evergreen forest (C and D), at different incubation days and with different water and temperature treatments (n=3).

4.2.3.2 Soil environment

The soil respiration rates in this experiment were positively correlated with soil pH at $p<0.01$. The soil organic carbon and total nitrogen were found higher in DEF soils than cornfield with 3.61% and 0.60%. The soil pH of cornfield was neutral and that DEF was acidic (Table 4.18). The C: N ration was significantly higher in cornfield than DEF ($p<0.01$).

Table 4.18 T-test result of the mean chemical properties of dry evergreen forest (DEF) and cornfield (C) soils (n=3).

Ecosystem	DEF	C	p-value
Organic carbon (%)	3.611	0.628	<0.01
Total nitrogen (%)	0.604	0.086	<0.01
Soil pH	4.257	7.083	<0.01
C/N ratio	5.979	7.302	<0.01
Texture	Clay	Clay	

Finally, using the highest current soil respiration data from 25 and 30°C incubation temperature at 50% WHC treatments, we calculated the amount of carbon that could approximately add up by cornfield, dry evergreen forest and *Eucalyptus camaldulensis* plantation soils, if there is a rise of 1°C soil temperature. The approximate increase of CO_2 gas addition by cornfield, DEF and *Eucalyptus camaldulensis* plantation soils were approximately 12.15, 10.02 and 7.58 g C $kg^{-1}y^{-1}$, respectively (Table 4.20). The agricultural land was found to contribute significantly more, followed by natural forest and lowest by Eucalyptus plantation soils.

Table 4.19 Increase in soil respiration rates of cornfield, DEF and *Eucalyptus* sp. sites with 1°C rise in soil temperature. (Approximate)

Ecosystem	Current respiration rate (µmol CO_2 $g^{-1}h^{-1}$)		1°C temperature rise (g C $kg^{-1}y^{-1}$)
	25°C	30°C	
Cornfield	1.896	2.473	12.15
Dry dipterocarp forest	1.965	2.441	10.02
Eucalyptus camaldulensis	1.377	1.737	7.58

4.3 Discussion

4.3.1 Measurement of field CO_2 efflux of different tropical ecosystems at SUT, SERS and SSRS

In order to find the differences in field soil CO_2 efflux in the tropical land use types, I carried out soil CO_2 flux measurements of natural forests (dry evergreen forest and dry dipterocarp forest), agricultural fields (cornfield and sunflower), grassland and plantation areas (*Eucalyptus* sp., rubber , *Acacia auriculiformis, Acacia mangium, Dalbergi cochinchinensis* and *Eucalyptus camaldulensis*). The CO_2 efflux from sunflower, cornfield and dry evergreen forest were (3.8, 4.2 and 4.3 g CO_2 $m^{-2}d^{-1}$) significantly higher than other ecosystems (Table 4.1 and 4.5) which agrees with the values of Campos (2006) who obtained the value of corn–potato–corn rotation plot and tropical cloud forest to be 1.58-11.25 and 1.98-8.1 g CO_2 $m^{-2}d^{-1}$ respectively using alkali-absorption method. There were no significant differences in average CO_2 efflux between cornfield and DEF. The high CO_2 efflux of DEF soil was due to its high organic carbon, total nitrogen and water contents. While high CO_2 efflux of cornfield and sunflower, despite its comparatively lower soil carbon and nitrogen contents than DEF, was attributed by their higher water contents from constant field watering and its neutral pH. Miao et al. (2004) also found increased in soil respiration rates within the water content limits of 21 to 37% but decreased above that limit. The higher soil CO_2 efflux with higher water content was also supported by many studies (Hashimoto et al., 2004; Miao et al., 2004; Haper et al., 2005; Keith et al., 1997; Kosugi et al., 2007; Hanpattanakit et al., 2008; Schaefer et al., 2009; Takahashi et al., 2009). The plant and microbial activity increases in response to soil water content increase (Lee et al., 2002; Luo and Zhou, 2006).

The soil pH was positively correlated with soil respiration ($p<0.01$), which was supported by Reth et al. (2005). The acidity of ecosystem soils other than cornfield and sunflower might have lead to lower soil respiration rate found by Kemmitta et al. (2006) who observed reduction in soil respiration with increasing acidity in agricultural soil.

A few soil respiration researches have been done in Thailand before. Both Panuthai et al. (2005) and Hashimoto et al. (2004) found higher soil respiration in dry evergreen forest at SERS and tropical monsoon evergreen forests of Kog-Ma Watershed than my observation due to more advance equipment as IRGA and a whole year study period. Adachi et al. (2006) also got higher CO_2 efflux than this study in tropical primary and secondary forest with 19.94 and 20.11g CO_2 $m^{-2}d^{-1}$ in Malaysian Peninsula (Table 2.3). The static chamber method gave lower values compared with dynamic chamber methods (Nay et al., 1994). However, Wiriyatangsakul (2004) obtained slightly lower value (3.082 g CO_2 $m^{-2}d^{-1}$) in tropical dry evergreen forest in Phanom Sarakarm district in dry season as well.

Iqbal et al. (2008) measured soil respiration rates in sesame–peanut rotation site and paddy field in subtropical China and obtained the value of 1.52 and 2.47 g CO_2 $m^{-2}d^{-1}$much lower than the values of cornfield and sunflower in this study due to its subtropical climatic condition where respiration rate is lower than tropical areas. The higher soil respiration rates in agricultural fields in the present study compared with other ecosystems were supported by Miao et al. (2004) and Adachi et al. (2006) (Table 2.3).

The soil temperatures at SUT, SERS and SSRS were negatively correlated with soil respiration rates but found significant at $p<0.05$ only for SERS and SSRS

sites which were the same as the results of Hanpattanakit et al. (2008) who studied DDF site in Chombung District, Ratchaburi province. But some researchers like Mo et al. (2008) observed positive exponential relationship between soil respiration and soil temperature in tropical forest in China. Iqbal et al. (2008) also observed soil temperature as an important variable controlling 26-59% of soil CO_2 flux variability. Increasing in soil temperature over the time may cause reduction of soil water and thickness of the soil water films and also the temperature above 35°C may cause protoplasm system to start breaking down (Luo and Zhou, 2006).

The yearly CO_2 efflux was found highest in DEF, cornfield followed by sunflower and lowest in Eucalyptus sp. with 4.21, 4.19, 4.11 and 1.84 t C $ha^{-1}y^{-1}$ (Table 4.20). The values were lower than many other studies like Keith et al. (1997) who measured soil respiration of Eucalyptus pauciflora in Brindabella Range, Australia for a year using soda lime method and obtained 7.11 t C $ha^{-1}y^{-1}$. The reason behind is that we measured only during dry season where as they have data for full year.

Table 4.20 Daily and yearly field soil CO_2 efflux from different ecosystems in SUT, SERS and SSRS calculated based on present study from January to April 2010 (n=24) for SUT ecosystems but n=12 for SERS and SSRS ecosystems.

	Respiration rate		
Ecosystem	$gCO_2\ m^{-2}\ d^{-1}$	$gC\ m^{-2}\ d^{-1}$	$tC\ ha^{-1}\ y^{-1}$
Cornfield	4.201	1.15	4.105
Sunflower	3.748	1.023	3.663
Grassland	3.351	0.915	3.275
Eucalyptus sp.	1.885	0.515	1.842
Rubber	2.794	0.763	2.730
Dry evergreen forest	4.308	1.176	4.210
Dry dipterocarp forest	2.825	0.771	2.761
Eucalyptus camaldulensis	3.164	0.864	3.092
Acacia auriculiformis	3.479	0.950	3.400
Acacia mangium	2.846	0.777	2.781
Dalbergia cochinchinensis	3.231	0.882	3.157

4.3.2 The respiration of incubated soil from eleven different tropical ecosystems

Soils of 0-5 and 5-15 cm depth from different ecosystems, including agricultural land (cornfield and sunflower), natural forests (dry evergreen and dry dipterocarp forests), grassland and plantation forests (*Eucalyptus* sp. rubber plantation, *Acacia auriculiformis*, *Acacia mangium*, *Dalbergi cochinchinensis* and *Eucalyptus camaldulensis*) were incubated under 25°C for four days and measured their respiration rates with their field water content.

Soil respiration rates of corn field and sunflower were significantly high but other ecosystems were relatively very low (Figure 4.6 and Table 4.9). The higher soil respiration of cornfield and sunflower were attributed by their higher water

content which agreed with previous studies (Bowden et al., 2004; Tang et al., 2006; Schaefer et al., 2009; Deng et al., 2010). Other reason of higher soil respiration in sunflower and cornfield is due to its neutral pH which agrees with Reth et al. (2005).

The very low CO_2 efflux from DEF was contradictory with the field measurements besides its relatively higher soil organic carbon and nitrogen contents than those of other ecosystems. The soils from natural forests and plantation areas were collected and keep for three days in room temperature (about 28°C) whereas the agricultural soils were keep for only one and half days before being transferred to laboratory for storage under 5°C. During those days, lots of CO_2 efflux would have already one, reducing soil organic matter and microorganisms, subsequently leading to lower respiration rates in all the ecosystems compared to current field studies and other studies.

The DEF soil CO_2 efflux of this study (0.864 µmol CO_2 $g^{-1}d^{-}1$) was also much lower than that obtained by Wiriyatangsakul (2004). The mistakes of the experimental setup above might be the cause of much lower respiration rates of ecosystems other than cornfield and sunflower. But the higher soil respiration rates of agricultural cornfield and sunflower compared to other ecosystems were consistent with Campos (2006) who obtained soil respiration to be 1.5 times greater in the corn–potato–corn rotation than in the tropical cloud forest of Mexico.

The agricultural fields had neutral pH and other ecosystems had acidic soils which might have lowered their microbial respiration as observed by Kemmitta et al. (2006) and Rastogi et al. (2002).

The respiration rates were significantly different between soil depths. The higher soil respiration of 0-5 cm soil depth of cornfield than 5-15 depth soils is

due to significant higher carbon content in upper soil which agrees with Wiriyatangsakul (2004).

4.2.3 The effect of soil temperature and water on agricultural, natural forest and plantation soils

To study the effect of these factors, soils from cornfield, dry evergreen forest and *Eucalyptus camaldulensis* plantation were incubated under 25, 30 and 35°C with water content of 50 and 75%WHC for 12 days. The average soil respiration rate was highest in cornfield, followed by DEF and *Eucalyptus camaldulensis* (Table 4.9). These results contradict with the field study at SUT, SERS and SSRS ecosystems where soil respiration of DEF and cornfield was not significantly different which may be due to significant higher nitrogen content in present DEF soil than during field measurement times. The higher soil respiration of cornfield was due to higher soil organic carbon and C : N ratio contents. The neutral pH of cornfield may be another reason of higher CO_2 efflux because acidic soil reduces microbial activities (Rastogi et al., 2002). The lower respiration rates of Eucalyptus camaldulensis, besides its higher nitrogen contents may be due to acidic soil and lower carbon contents. The higher soil respiration of cornfield than DEF was supported by findings of Wiriyatangsakul (2004) who incubated soils from tropical uplands in Thailand for a month. The average value she obtained are much higher (Table 2.5) than the present study, maybe due to different measurement methods of which she used chromatography technique and I used IRGA analyzer. Another reason could be the difference in total incubation times.

The mean soil respiration rates (mean of day 1 and 4) of all three ecosystems were higher under 75% WHC for all temperature treatments, suggesting

that water is the main controlling factor for CO_2 efflux. This result of increase in soil respiration with water is in line with our field CO_2 efflux measurement at SUT, SERS and SSRS where soil water content had high positive correlation with respiration rates which are in line with other studies (Kosugi et al., 2007; Hanpattanakit et al., 2008; Schaefer et al., 2009; Takahashi et al., 2009).

The soil respiration rate of both DEF and cornfield, incubated under 50%WHC water content were significantly highest at 35°C, followed by 30 and 25°C, respectively on the forth date of incubation (Figure 4.8). This increase of respiration rates were also observed from *Eucalyptus camaldulensis* soils on incubation day four and cornfield soils on day six and nine at 75% WHC, which was in line with Jian-fen et al. (2009) incubated soils from fir forest in Nanping, China and obtained highest mean soil CO_2 efflux at 35°C, followed by 25 and 15°C, since increase in temperature activates the metabolic activity of microorganisms. But the *Eucalyptus camaldulensis* soils had highest respiration rates at 25°C and gradually decreased with increasing temperatures which was in line with the results of (Miao et al., 2004) from incubation of dark coniferous forest soils. This optimum temperature of *Eucalyptus camaldulensis* soil may be 25°C or lower as the respiration rates decrease above the optimum temperature. Flanagan and Weum (1974) found the maximal soil microbial respiration at 23°C. The acidic pH of *Eucalyptus camaldulensis,* besides its higher carbon and nitrogen contents, might reduce the respiration rate.

Further incubation experiment was carried out using cornfield and DEF soils to find out the peak respiration rates with the same water and temperature treatments. The mean soil respiration rates of cornfield were significantly higher than DEF in all the temperature and water treatments beside its significantly lower carbon

and nitrogen content than DEF. The neutral pH of cornfield was the main reason for its higher soil respiration since the soil textures of both the ecosystems were clay.

The soils of cornfield in both water contents showed significant increased in their respiration rates with temperature (Table 4.16), which was also supported by other studies like Miao et al. (2004) who used soil samples from broadleaved/Korean pine forest, Changbai Mountain, China and Jian-fen et al. (2009) who used soils from Chinese fir for the incubation experiments. DEF soils of both water treatments, showed increased in their respiration rates from 25 to 30°C but the rates was lower with 35°C which is same with the studies of Wiriyatangsakul (2004).

In both incubations, respiration rates of cornfield, dry evergreen forest and *Eucalyptus camaldulensis* soils increased very fast after the beginning and achieved their highest rates within day four and decreased drastically beyond it, which was also observed by Wiriyatangsakul (2004). The sudden increase in soil temperature might enhance fast microbial growth and speed up decomposition processes resulting in rapid CO_2 efflux. Reichstein et al. (2005) observed faster decreased in carbon mineralization rates with incubation time. Pohhacker and Zech (1995) also observed the decreasing respiration rates with increasing time while labile substrate was relatively low.

So, this study suggested that soil CO_2 efflux depends on number of factors like soil water, temperature, pH, carbon, nitrogen and C : N ratio and it greatly differ with ecosystems.

CHAPTER V

CONCLUSION

The soil respiration rates of eleven tropical ecosystems and the effect of soil temperature and moisture on soil respiration rate were investigated.

5.1 Soil respiration in the field

The field CO_2 efflux measurements were carried out in eleven ecosystems at SUT, SERS and SSRS once a month from January till April, 2010. There was a significant difference ($p<0.01$) in mean soil respiration rates among SUT ecosystems with highest in cornfield (C) followed by sunflower (S), grassland (G), rubber (R) *Eucalyptus* sp. (Eu1) and plantation sites with 4.20, 3.75, 3.35, 2.79 and 1.89 g CO_2 m^{-2} d^{-1}, respectively. The soil pH had a significant positive correlation with soil respiration rate ($p<0.01$). The cornfield and sunflower had neutral soil pH but the plantation and natural forest soils were acidic. The significant higher water content and neutral soil pH of cornfield and sunflower soils might be the cause of higher soil respiration rates than other ecosystems in SUT.

In SERS and SSRS, the mean respiration rate was significantly different ($p<0.01$) among the ecosystems with highest in dry evergreen forest (DEF), followed by *Acacia auriculiformis, Dalbergia cochinchinensi, Eucalyptus camaldulensis, Acacia mangium* and dry dipterocarp forest (DDF) with the value of 4.31, 3.48, 3.23, 3.16, 2.85 and 2.83 g CO_2 m^{-2} d^{-1}, respectively. The significant higher ($p<0.01$) soil organic carbon, total nitrogen and water content of DEF soil might contribute to its

higher respiration rates. However, soil respiration of DEF and cornfield were not significantly different. The mean soil respiration rates of SUT, SSRS and SERS were strongly correlated ($p<0.01$) with soil water, pH, carbon and nitrogen contents.

As per this study, the annual carbon emission from dryevergreen forest, sunflower, cornfield, *Acacia auriculiformis*, grassland, *Dalbergia cochinchinensis*, *Eucalyptus camaldulensis*, *Acacia mangium*, Dry dipterocarp forest, Rubber and *Eucalyptus* sp. were 4.21, 4.11, 3.66, 3.40, 3.26, 3.16, 3.09, 2.78, 2.76, 2.73 and 1.84 tC $ha^{-1}y^{-1}$, respectively.

5.2 Soil respiration in incubation

In order to study the differences in CO_2 efflux, soil samples, of 0-5 and 5-15 cm depths from eleven different ecosystems were collected and incubated under 25°C for four days and measured their respiration rates. The highest soil respiration rate was found in sunflower, followed by cornfield, *Eucalyptus* sp., dry evergreen forest, *Dalbergia cochinchinensis*, *Acacia mangium*, *Acacia auriculiformis*, grassland, dry dipterocarp forest and *Eucalyptus camaldulensis* and rubber plantations with 0.868, 0.327, 0.039, 0.036, 0.033, 0.032, 0.027, 0.024, 0.017, 0.009 and 0.001 µmol CO_2 $g^{-1}h^{-1}$, respectively. Soil respiration rates were significantly different ($p<0.01$) between two soil depths in some ecosystems. Soil water content and pH had significant positive correlation ($p<0.01$) with soil respiration rates and was the main cause of higher respiration in sunflower and cornfield soils.

5.3 The effect of temperature and water on incubated soils

The incubation experiments were carried out to study the effect of soil warming and different water content treatments on soil respiration rates of natural forest (dry evergreen forest), agricultural land (cornfield) and from plantation area (*Eucalyptus camaldulensis*). The temperature of 25, 30 and 35°C and water content of 50 and 75% WHC treatments were used. The soil respirations were measured on incubation day 1, 4, 6, 9 and 12, respectively for the first incubation experiments.

The treatments of water and temperature significantly affected ($p<0.01$) soil respiration. Increasing soil water content generally stimulated more soil respiration in *Eucalyptus camaldulensis* and DEF but not in cornfield. However, increasing soil temperature had mix effects on soil samples. Though not significant, the soil respiration of cornfield increased with temperature in 50%WHC treatments but decreased in *Eucalyptus camaldulensis* soils at both soil water contents. The soil respiration rates of both DEF and cornfield soils, incubated under 50%WHC were highest ($p<0.01$) at 35°C, followed by 30°C and lowest in 25°C on incubation day four, respectively. These increased in soil respiration rates with increasing temperature is due to increased metabolic activities of soil microorganisms.

To find out the actual peak respiration rates of incubated soils, another experiment was carried out using only soils from dry evergreen forest and cornfield then measured their respiration rates on day 1, 2, 3, 4, 5, 6, 9 and 12, respectively.

In this experiment, increasing temperature significantly ($p<0.01$) promoted the respiration only in cornfield soils. whereas water content significantly increased soil respiration only in DEF. in both the water treatments, DEF soils respiration was highest under 30°C incubation than 35°C and 25°C, peaking at day three for 50% HC

and day four for 75% WHC. The soil respiration rate of cornfield on day two was highest under incubation temperature 35°C, followed by 30°C and 25°C for 50% The average soil respiration rate of cornfield was significantly higher ($p<0.01$) than DEF. The respiration rates of DEF and cornfield were higher in 75% WHC than 50% WHC. More water content increased soil respiration in DEF soil but there was no effect on cornfield soils. The respiration rate of cornfield on day two was highest under incubation temperature 35°C followed by 30°C and 25°C for 50% and 75% WHC.

In both soil incubation experiments under different temperatures and water contents treatments, soil respiration increased rapidly from day one, achieving the highest value during day two to four but decreased sharply after that. This suggests that CO_2 efflux would increase very fast by global warming effect. This study also shows that the increase in soil temperature from 25 to 35°C increase soil respiration rates of some soils but decreases for some under higher temperature at given water contents. The soil water content, temperature, pH, carbon and nitrogen contents were major driving forces for tropical soil respiration.

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