The comparison of greenhouse gases emission by closed chamber and eddy covariance technique in paddy rice field in Japan

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The comparison of greenhouse gases emission by closed chamber and eddy covariance technique in paddy rice field in Japan

(クローズドチャンバー法と渦相関法による日本の水田からの温室効果ガス排出の比較)

BY

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Dissertation

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Abstract

The comparison of Greenhouse gases Emission by Closed Chamber and Eddy Covariance technique in Paddy Rice field in Japan

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The global is being dramatically affected by environmental changes such as alterations to the composition of the atmosphere, associated shifts in climate and reductions in biological diversity. The increase of greenhouse gases in the atmosphere plays a prominent role in global warming. In addition to carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are also potent greenhouse gases, accounting for an estimate 19% and 7% of global warming, respectively. The problem is caused by anthropogenic activities like industrial process and burning of fossil fuels. The management of agricultural can also increase atmospheric greenhouse gases. Rice is the most important agricultural staple for more than half of the world's population and is grown in 114 countries over a total area of around 153 million ha. However, rice cropping systems are considered to be among the major anthropogenic sources of GHGs. Although the study of GHGs emissions from soil to atmosphere, it is still difficult to measure it accurately because of its great temporal and spatial variability and dependence on many environmental characteristics. A variety greenhouse gases measurement strategies exist, each with their own strengths and weaknesses. So, the accurate measurement, supporting well-inform the pattern tendency of such landscape-based

emission, is critical in order to understand the driver of climate change as well as to identify mitigation opportunities.

The goal of the present study is to understand the GHHs flux pattern in rice paddy field. Compare by using the widely used method, closed chamber (CC) method and eddy covariance (EC) method. The second objective was to find out the relationship between GHGs production mechanism in soil and environmental factors for the emission. Futhermore, to combine the output form CC and EC method for a more detail description for upscaling point data to large area and longer time series of GHGs emission.

In this study, greenhouse gas flux was conducted by CC and EC technique in flooded rice paddy field during June to October, 2014. Intensive monitoring using conducted at 30, 60, 90 days after transplanting (DAT) and after harvest (AHV). The EC method measurement was conducted GHGs flux continuous measurements during the rice cropping season. It was found that spatial-temporal variation in GHGs flux among rice growing stage was observed. The variation of CH_4 flux pattern was similar for all growing stage. Methane flux was lower in early growing stage (30 DAT) and became highest in 60 DAT. Due to the increased of environmental factors including net radiation, air temperature and soil temperature. Diurnal variation of CH_4 flux from CC and EC method showed similar emission pattern for all growing stage. The CC method resulted in CH_4 flux average that were 58%, 81%, 94%, and 57% higher than those measured by the EC method at 30, 60, 90 DAT and AHV, respectively. The results found that, depending on the particular atmosphere condition make the over or underestimated by both methods. The overestimate by CC method due to the inclusion of optimally grown rice plants at high temperature for flux measurements, and the EC method aggregated different sourced and masked the individual process behind the fluxes at each point. With the analysis of continuous measurements that show the general trend of a large area and homogeneous terrain, the EC method has a strong advantage. The different strengths and

weakness of the CC and EC methods can complement each other, and the use of both methods together leads to more understanding of GHGs emissions from paddy fields.

Key words : greenhouse gases flux, rice paddy fields, closed chamber method, eddy covariance technique.

クローズドチャンバー法と渦相関法による日本の水田からの温室効果ガス排出の比較

本研究では、クローズドチャンバー法(CC)と渦相関法(EC)を用いて日本の水田からの温室効果ガス排出の比較を行った。その結果、イネの生育初期の排出量は低く、中期に最高に達し、収穫後は減少した。季節変動は総太陽放射、気温、水温、土壌温と相関があった。本研究の結果は、どちらの方法とも特定の気象環境条件により過大あるいは過小評価があることを示した。CC 法による過大評価は、測定が生長状態のよいイネ個体をチャンバーで密閉することによって生じる高温条件というメタンフラックスに適した条件での測定によるものと結論づけられた。CC 法の長所は、ガスの測定と土壌・環境の測定の調査地点・時点が類似しているため、フラックスの測定データを土壌環境要因と直接関連付けられる点である。EC 法の欠点は、測定が異なる放出源を含んだ値となることで、各地点における放出プロセスをマスクした平均値を示すことである。一方、その長所は、連続測定と比較的広い範囲を測定することにより、全体的な傾向と平均を出すことである。両方法の違いは、主にそれぞれの測定の対象の違いにあり、、放出源となっている範囲（フットプリント・エリア）が異なるためであり、その範囲における放出源の空間変動が大きいことにあることが判明した。２つの方法にはそれぞれ長所、短所があり、これらを併用することで温室効果ガスのより正確な測定が可能となることが明らかとなった。

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Thank you

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List of Abbreviations

AHV	=	After Harvest
CH_4	=	Methane
CO_2	=	Carbon Dioxide
GHG_S	=	Greenhouse Gases
N_2O	=	Nitrous Oxide
DAT	=	Days After Transplanting
EC	=	Elctrical Conductivity
Eh	=	Redox Potential
SOM	=	Soil Organic Matter
TC	=	Total Carbon
TN	=	Total Nitrogen
CC	=	Closed Chamber
EC	=	Eddy Covariance technique

Chapter :1 General Introduction

1.1 .Background

The changes in climate parameters are being felt globally in the form of change in temperature and rainfall pattern. The global atmospheric concentration of carbon dioxide (CO_2), a greenhouse gas (GHGs) largely responsible for global warming, has increased from a pre-industrial value of about 280 ppm to 387 ppm in 2010. Similarly, the global atmospheric concentration of methane (CH_4) and nitrous oxide (N_2O), other important GHGs, has also increased considerably resulting in the warming of the climate system by 0.74 °C between 1906 and 2005 (Intergovernmental Panel on Climate Change; IPCC, 2007). Increasing temperature and changes in rainfall pattern are also impacting the agricultural sector. Predicted change in the amount and frequency of rainfall at both season and annual scales will affect the variation in soil moisture and the plant soil process.

Understanding the contributions of both human activities and natural system to radiative properties of the atmosphere is an area of critical importance as we strive to mitigate anthropogenic contributions to the greenhouse effect. In addition to CO_2, N_2O, and CH_4 are also potent greenhouse gases accounting for an estimated 7% and 19% of global warming, respectively, with the majority of emissions coming from landscape sources (Thomson et al., 2013). The range from manage system such as agricultural fields, rice paddy, and landfills, to natural system such as forest floors, wetlands, and termite mounds. Accurate measurement, supporting well-informed of such landscape-based emissions is critical in order to understand of climate change as well as to identify mitigation opportunities.

1.2. Global warming and greenhouse gas emission

The global is being dramatically affected by environmental changes such as alterations to the composition of the atmosphere (e.g. CO_2, CH_4, and N_2O concentration), associated shifts in climate and reductions in biological diversity (Brooker et al., 2010).

Methane is a potent greenhouse gas that has 25 times higher global warming potential than CO_2. It contribution to the greenhouse effect is about 1.7 W m^{-2} (Purkait et al., 2007) that accounts for 15 to 20% of global warming (IPCC, 2007). Moreover, global concentration of greenhouse gas CH_4 has been increasing at the rate of ~1% each year (IPCC, 2007). If the current rate of increase is maintained, the next 50 years, it is estimated to contribute an additional 0.5 W m^{-2} in radiative heating (Purkait et al., 2007). Thus, global warming due to increasing greenhouse gases emission is current great environmental concern.

Soils are of particular importance in the atmospheric CO_2 budget for a number of reasons (Raich and Potter, 1995). In terrestrial ecosystem, natural process of carbon transformation occur mainly in the soil, where biogeochemical activities and abiotic factors, such as climate, regulate the internal cycles and flow of the organic and inorganic forms of these elements. Also indicated that CO_2 emissions from the amount of atmospheric C, fixed through photosynthesis and stored in soil as organic matter, and the amount of soil C oxidized to CO_2 during a given periods (Muñoz et al., 2010). The CO_2 emitted from soil is result of root respiration and physiological process of the microorganisms involved in the decomposition of organic material. The rate of CO_2 emission showed in highly variable in heterogeneous soil micro-site, and they are influenced by the activity of roots, microbial processes, crop residue and litter content, microclimate and catalytic properties of clay colloids (Muñoz et al., 2010).

1.3. The impact of climate variability in agricultural sector

Agriculture is highly dependent on the climate. Increases in temperature and CO_2 can increase some crop yield in some place. But the realize these benefit, nutrient levels, soil moisture, water availability, and other conditions must also be met. An increasing in ambient CO_2 is usually considered beneficial as it results in increased photosynthesis in several crops, especially those with C3 mechanism of photosynthesis. However, despite these beneficial effects, the combined increase in temperature and variability of rainfall would considerably affect food production. Some studies indicated a probability of 10-40% loss in crop production in India with increase in temperature by 2080-2100 (Aggarwal and Mazumdar, 2007).

Rice cultivation period is the basic condition for planting rice production which is decided by the climate conditions and the rice variety. In Korea, the average temperature of 21-23 °C during ripening period is favorable for the production of high quality rice. If that period the average temperature is higher than that rang, rice cannot ripen fully. As result, grains weigh less, contain more protein and become less tasty and nutritious. The temperature higher than the average temperature during the ripening period results in the production of poor quality rice (Dabi and Khanna, 2018). Europeans country, low temperature is a major factor limiting rice growth and yield, and seedling is the one of the developing stage. Chilling stress changes in physiological and molecular process. According to a study, drought stress affects rice production at morphology, physiology, biochemical, and molecular levels and thereby affects its yield (Pandey and Shukla, 2015). And it also, inhibits processes such as another dehiscence, pollen shedding, pollen germination, and fertilization.

1.4. Factors affecting greenhouse gas emission

The area under agricultural land has increased. Couple with the greater demand for food is expected to enhance annual greenhouse gases emission from agriculture (Benbi, 2013). The increasing of CO_2 is attributed to the anthropogenic activities like agriculture and land use changes, burning of fossil fuel, deforestation, emission from automobiles, forest, etc. (Rahman et al., 2012). The emission of CO_2 from soil to the atmosphere is influenced by the mineralization of soil organic carbon (SOC) through microbial processes that use carbon as a source of energy and combine it with O_2, leading to the release of CO_2 and H_2O (Raich and Potter, 1995). Soil disturbance such as tillage is another carbon emission driver because tilling can cause soil to be more susceptible to breakdown and make it possible for the organic material to easily decompose because of aeration and soil temperature (Rastogi et al., 2002). The micrometeorological factors such as air temperature are driving force in increasing soil carbon emissions. The increasing of temperature simulates microbial decomposition of organic matter and root respiration in soils (Rastogi et al., 2002; Chevallier, 2015). Precipitation is correlated with CO_2 emission, Raich and Potter (1995) found that less than 2 cm per month of precipitation rate decreased soil CO_2 fluxes to less than 50% of their potential in non-wet land site. Soil texture was predominantly important in regulating CO_2 emissions, as spatial variation of other controlling properties associated with soil water conditions tended to decrease after an irrigation event. Lee et al. (2006) also, found water and Water-Filled Pore Space (WFPS) had significant impacts on CO_2 emissions at non tillage soils. Rustad et al. (2000) reported the critical factors to influence rate of soil respiration include (1) temperature (2) soil moisture (3) vegetation and substrate quality (4) net ecosystem productivity (NEE) (5) the relative allocation of net productivity production above and belowground (6) population and community dynamics of the above ground vegetation and belowground flora and fauna, and (7) land use and/or disturbance regimes, including fire. Rastogi et al. (2002) concluded that the main sources of CO_2 emission from agriculture soil are decay of organic matter, forest fires, eruption of volcanoes, burning of fossil fuels, deforestation and land-use changes. Agriculture is also a contributor to CO_2 emission but is not considered as a major source of this important GHG. Within agriculture, soil is the main contributor with factors such as soil texture, temperature, moisture, pH, available C and N, influencing CO_2 emission from soil. Emission of CO_2 is more from a tilled soil than from undisturbed soil (no till). Temperature has a marked effect on CO_2 emission from soil by influencing the root and soil respiration and also on CH_4 by effecting anaerobic carbon mineralization and methanogenic activity. It may be mentioned that plant, ocean and atmospheric reactions are the major sink of CO_2.

Atmospheric CH_4 originates from both natural and anthropogenic sources. The natural sources of CH_4 include wetland, oceans, forests, wildfires, termites, geological sources and gas hydrate. The major anthropogenic emissions of CH_4 originate from agriculture (mainly enteric fermentation rice cultivation, animal waste, and savanna burning) (Benbi, 2013). In ruminant animal, CH_4 is produce as a by-product of the digestion of feed in the rumen under anaerobic condition. Methane emission is related to the composition of animal diet (grass, legume, grain and concentrates). Methane is also formed in soil through the metabo (Pathank et al., 2013).

Rice plants are an important role in the flux of CH_4. Methane formed in the soil, diffuse from the reduced layer through the aerenchyma to the atmosphere. The production and transport of CH_4 to the atmosphere depend on properties of the rice plant. Root exudates and degrading roots are also important sources of CH_4 production. So, the number of tillers, root mass, rooting pattern, total biomass, and metabolic activity also influence gas fluxed (Neue et al., 1995)

1.5. Rice Production in the world

Rice is among the three most important grain crops in the world, and it has a major contribution to fulfill the food needs across the global. Rice is staple food of an estimated 3.5 billion people worldwide (Chauhan et al., 2017). Rice production has steadily increased during the Green Revolution, but recently its growth has been substantially slowed down. Moreover, crop intensification during the Green Revolution has exerted tremendous pressures on natural resources and the environment. On the other hand, under the globalization of world economy, rice produces are exposed to competition not only among themselves but also with the producers of other crops. The future increased rice production, therefore, requires improvement in productivity and efficiency (Food and Agriculture Organization; FAO, 2018).

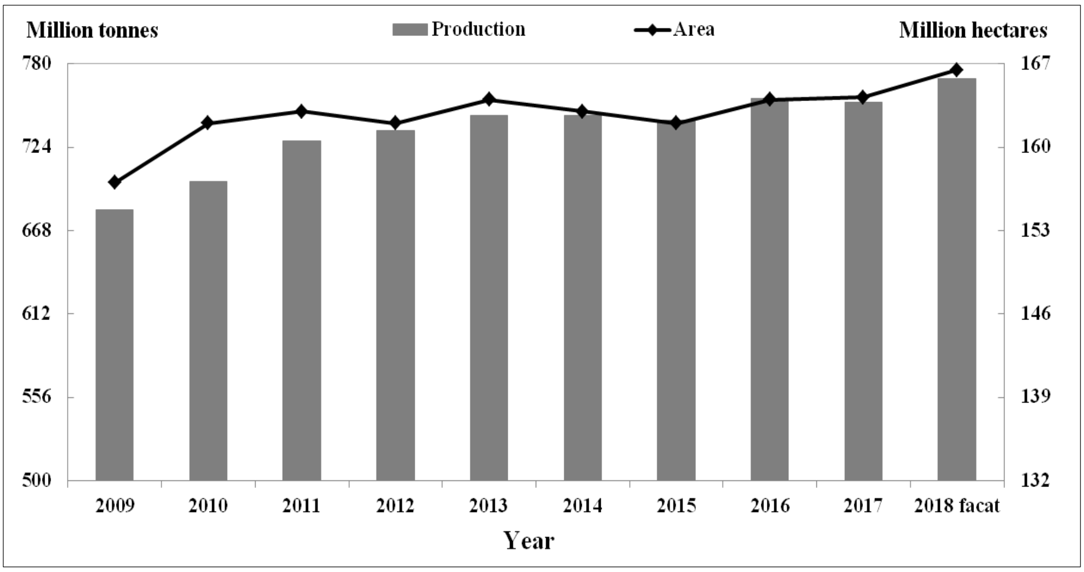

Figure 1 The Global paddy production and area in 2017 (FAO, 2018)

The global rice production in 2017 raised by 759 million tones (Mt), FAO has raised forecast area expansion to raise world paddy production by 10.3 Mt in 2018. Much of the forecast growth would reflect improved yield outcomes and concentrate in Asia, even of the pace of production expansions in that region was restrained by a combination of floods and drought (FAO, 2018).

Global rice consumption (including component) in 2018/19 is forecast at a record 490.3 million tons, up 0.7 million tons from the previous forecast and 2 percent larger than 2017 (Unites State Department of Agriculture; USAD, 2019). The Organization for Economic Co-operation and Development; OECD and the Food and Agriculture Organization; FAO, 2018) reported that the global rice production is expected to grow by 6.4 Mt to reach 562 Mt in 2027. While production in developed countries is projected to increasing marginally. Asia contributes the majority of the additional global production accounting for 54 Mt of the increase during the outlook period. The highest growth is expected in the world's second largest rice producer India, followed by Indonesia, Thailand and Viet Nam.

1.6. Greenhouse gas emission from Paddy Fields

Paddy rice fields are identified as one of the major sources of global warming greenhouse gas (IPCC, 2007). Carbon dioxide (CO_2) emitted from soil to atmosphere is defined as the CO_2 efflux from the soil surface or the outcome of the production of CO_2 by both plant root (autotrophic respiration) and micro-organism (heterotrophic respiration) in soil surface (Hanson et al., 2000). Generally, source of CO_2 in the soil which derived from (1) growth and maintenance respiration by root (true root respiration) (2) rhizomicrobial respiration, (3) decomposition of fresh organic matter (surface and root litter), (4) decomposition of old soil organic matter, (5) priming of soil organic matter decomposition by substrate input from live root or plant litter, and (6) weathering of soil carbonates.

In recent years, many studies have focus on understanding the relationship between specific sources of CO_2 and the environmental factors controlling them. Several researchers have reported contribution of autotrophic and heterotrophic respiration to total soil respiration in various ecosystems. Since, Hanson et al. (2000) indicated that root/rhizosphere respiration could account for more little as 10% to great than 90% of total *in situ* soil respiration depending on vegetation type and season of the year. The contribution of root respiration to total soil respiration also varies with 39% during the wet season and 41% during the dry season (Tang and Baldocchi, 2005). Jiang et al. (2005) found that rhizosphere respiration accounted for 25% to total soil respiration in old forest and 65% in the young forest. In different evergreen ecosystem also found annual autotrophic respiration accounts from 16-56% of total soil respiration in the seven different evergreen ecosystems and data observation shows a decrease of annual autotrophic respiration at increasing availability of soil nitrogen (Rodeghiero and Cescatti, 2006).

However, the relative contribution of root/rhizophere and microbial to total soil respiration is difficult to determine, as report by a wide range of estimating for soil. The factors controlling autotrophic and heterotrophic respiration are influenced by the complex interaction of environmental and biotic factors. Autotrophic respiration is influenced by the amount and activity of plant and reflects changes in environmental condition that control plant growth and development, photosynthesis and carbon allocation patterns (Han et al., 2007). While, heterotrophic respiration is dependent on the supply of respiratory substrates (primary from plant litter, plant root exudates, plant root) as well as environmental conditions that control microbial growth and development, and supply and quality of respiratory substrate provided by plant, particularly plant root(Ngao et al., 2007; Raich and Schlesinger, 1992). Thus, autotrophic and heterotrophic respiration will respond differently to change in environmental conditions, it is crucial to get insight into both components of soil respiration.

Methane is produce under anaerobic environments by obligate anaerobic microorganisms through either CO_2 reduction or transmethylation process (Hou et al., 2000). There are two main sources for CH_4 production; anthropogenic sources and natural sources. More than 50% of global CH_4 is related to human activities (United State Environmental Protection Agency; US EPA, 2006). Anthropogenic sources include fossil fuel production, animal husbandry (enteric fermentation in livestock and manure management), rice cultivation, biomass burning, and waste management, etc. Among the anthropogenic sources, rice field occupied 10% of global anthropogenic CH_4 emission because of the flooding condition required for the rice cultivation (IPCC, 2007). However, there are several factors influencing upon CH_4 emission in paddy fields such as soil type, climatic conditions, agronomic practices including water and fertilizer management, organic matter amendment, and application of pesticides, etc. (Xiong et al., 2007; Yan et al., 2005; Zou et al., 2005)

Methane production and emission from rice paddy field shown in Figure 2. Emission mechanism starting by methanogenesis, the scientific term for methane production, occurs primarily in anaerobic conditions because of the lack of availability of other oxidants. In these conditions, microscopic organism call archaea use acetate and hydrogen to break down essential resources in a process called fermentation. Acetoclastic methanogenesis, certain archaea cleave acetate produced during anaerobic fermentation to yield methane and carbon dioxide.

$$H_3C\text{-}COOH \longrightarrow CH_4 + CO_2 \quad (1)$$

Hydrogenotrophic methanogenesis-archaea oxidize with carbon dioxide to yield methane and water.

$$4H_2 + CO_2 \longrightarrow CH_4 + CO_2 \quad (2)$$

Flooding of rice fields cuts off oxygen supply from the atmosphere to the soil, which leads to anaerobic fermentation of organic matter in the soil, resulting in the production of methane (Ferry, 1992) and much of it escapes from the soil into the atmosphere.

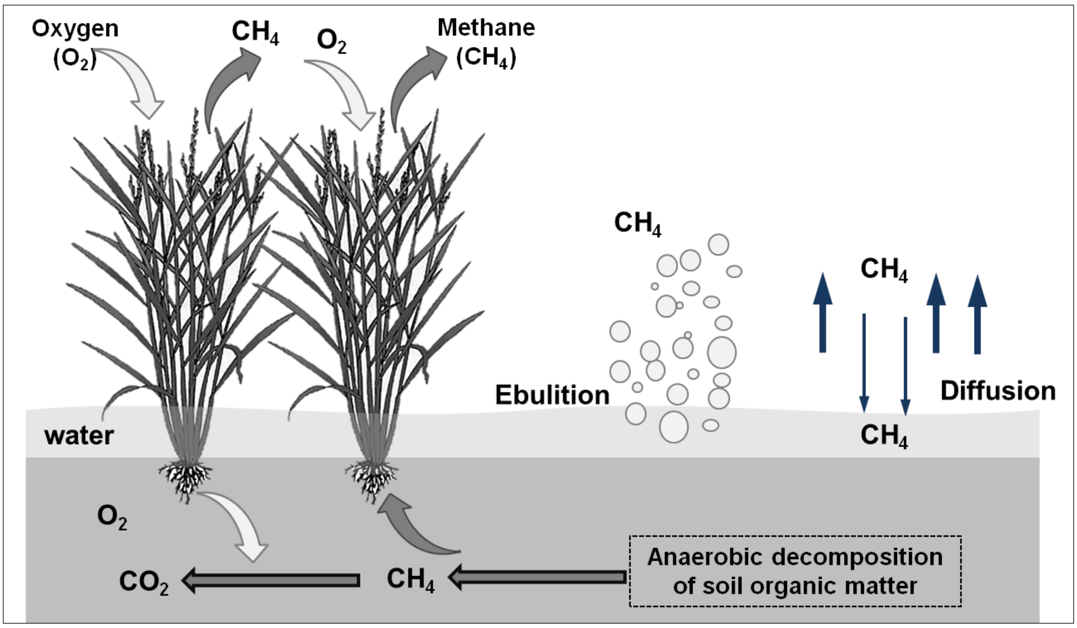

Figure 2 Mechanism of methane emission from paddy rice field

Source: Modify from Hansan (2013)

1.7. Greenhouse gas flux measurement

Understanding greenhouse gas sources, emission, measurements, and management is essential for capture utilization, reduction, and storage of greenhouse gas, which plays a crucial role in issues such as global warming and climate change. Several method exist for trace gases measurements, each of each has its own assumption, spatial and temporal measurement scales, complexity, and expense.

1.7.1 Chamber- methods

Chamber methods have been widely used for soil cover techniques to measure trace gas fluxes, and numerous chamber configurations have been developed. Closed Chambers (CC) generally employ an open bottom enclosure that is inserted into the soil surface. Flux measurements are determined by estimating the rate of change of gas concentrations within the enclosure. The samples are then analyzed in laboratory using gas chromatography technique. Spatial variability in the measured greenhouse gas fluxes in a major drawback of the chamber approach, particularly for highly diverse smallholding farm systems. Another drawback is that imposition of artificial chambers may disturb the microclimate such as creating significant difference with the ambient environment in terms of temperature and obstruction in natural wind flow, thereby introducing errors in the measured fluxes. Also, to adequately represent the temporal variability or when eddy-night trend is to be monitored, chamber method becomes cumbersome and often impractical due to the requirement of more number of trained laboratory staff, instruments and chemicals (Rochette et al., 1997). The cost of closed chamber is low, simplicity of design and operation, closed chambers are commonly used to determine fluxes of many gases component from soil (Collier et al., 2014).

1.7.2 Micrometeorological techniques

Micrometeorological methods can broadly be divided into two categories, including vertical flux profile or flux gradient and eddy covariance techniques. Micrometeorological techniques are nondestructive to the local environment and enable determination of fluxes without perturbations included by covering the soil (Collier et al., 2014). These methods can also allow for continuous measurement. Flux measurements obtained by this method are time averaged point measurements which, if sufficient fetch is available, can represents temporal and spatially integrated estimates (Baldocchi, 2003).

1.7.2.1 Vertical Gradient Methods

There are two types of this method, the aerodynamic gradient method and Bowen Ratio-energy balance (EREB) method. Both methods, measure gradients of atmospheric variables in the determination of fluxes. In each case, a time-averaged estimate is produce, representing typically a half-hourly or hourly average flux. The aerodynamic gradient method utilized the near surface logarithmic wind profile, while the BREB method assumes short-term closure of the surface energy balance and does not require explicit calculation of a turbulence coefficient. The BREB method is a low cost technique, does not require power supply and is primarily designed for measuring energy fluxes i.e. latent and sensible heat, rather than measuring trace gas fluxes. It requires more assumptions to be fulfilled than the aerodynamic gradient method. The aerodynamic gradient method is more suited for barren or low-vegetation surface and is difficult to apply over complex vegetation due to the fact that greenhouse gas concentration gradient such as that of CO_2 is often small in such ecosystems (Saha et al., 2018).

1.7.2.2 Eddy Covariance Methods

Eddy Covariance is a micrometeorological method that is currently popular to directly observe the exchange of gas, energy, and momentum between ecosystems and the atmosphere (Baldocchi, 2003). This technique provide a long-term measure of greenhouse gases exchange between vegetated canopies and the atmosphere from hourly to inter-annual time scale (Foken and Wichura, 1996).

The first eddy covariance measurements of carbon dioxide exchange occurred in the early 1907s. This study was performed over corn fields. Currently, the eddy covariance method is being used at over 900 site world are operating on long-term and continues basis. Vegetation under study includes temperate conifer and broadleaved (deciduous and evergreen) forest, tropical and boreal forests, crop, grassland, chaparral, wetland, and (Baldo Baldocchi et al., 2001; van der Horst et al., 2019)

The principles and concepts of eddy covariance allow relating the observed fluxes to spatial region of the underlying surface. Position and extent of the footprint can be optimized to fit the target surface by adjusting tower position and measurement height, respectively (Burba and Anderson, 2007; Schimid, 2002). The measurement point in atmosphere contains turbulent motions of upward and downward moving air that transport trace gases such as CO_2, CH_4, and H_2O. The eddy covariance technique samples these turbulent motions to determine the net difference of material moving across the canopy-atmosphere interface (Figure 3) (Baldocchi, 2003). The air flow was shown to consist of numerous eddies. The closely at the eddies at a single point on the tower shown in Figure 4. At one moment (time 1), eddy number 1 moves air parcel C_1 downward with the speed W_1. At the next moment (time 2) at the same point, eddy number 2 moves air parcel C_2 upward with speed W_2. Each air parcel has its own characteristic, such as gas concentration, temperature, humidity, etc (Burba and Anderson, 2007). In practice, this task is accomplished by statistical analysis of the instantaneous vertical mass flux density ($F = w\rho_{c'}$ µmol m^{-2} s^{-1}), using Reynolds' rules of averaging, which are described below. The product of this operation is a relationship that expresses the mean flux density of parcel average over some time span (such as an hour) as the covariance between fluctuations in vertical velocity (w) and the parcel mixing ratio ($c = \rho_c / \rho_a$ where ρ_a is air density and ρ_c is parcel density)

$$F = \rho_a\,(\overline{w'c'})$$

In this equation, the overbars denote time averaging and primes represent fluctuations from the means. A positively signed covariance represents net gases transfer into the atmosphere and a negative value denotes the reverse (Baldocchi, 2003).

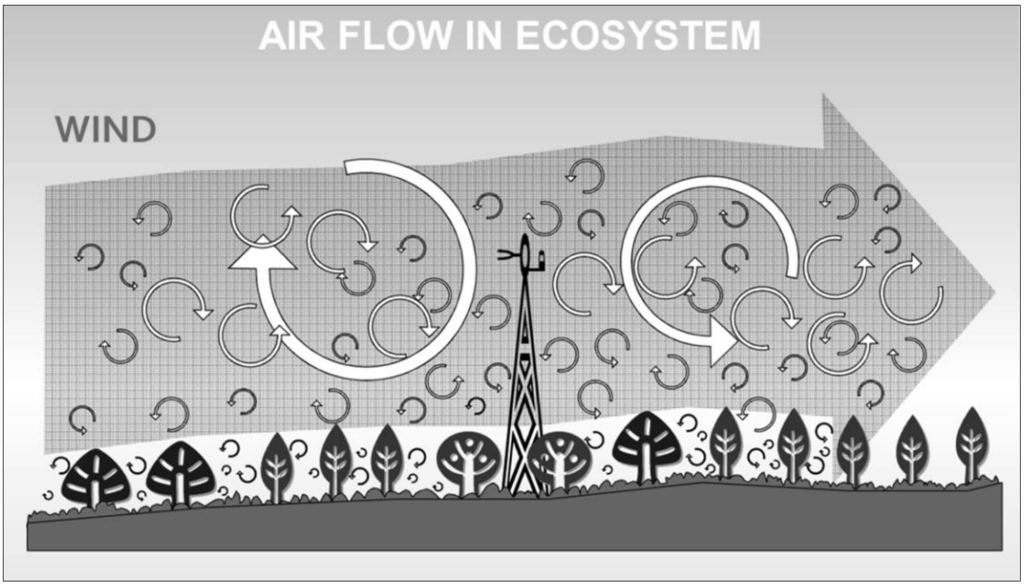

Figure 3 The imagined air flow of numerous rotating eddies pass through the tower
Source: Burba and Anderson (2007)

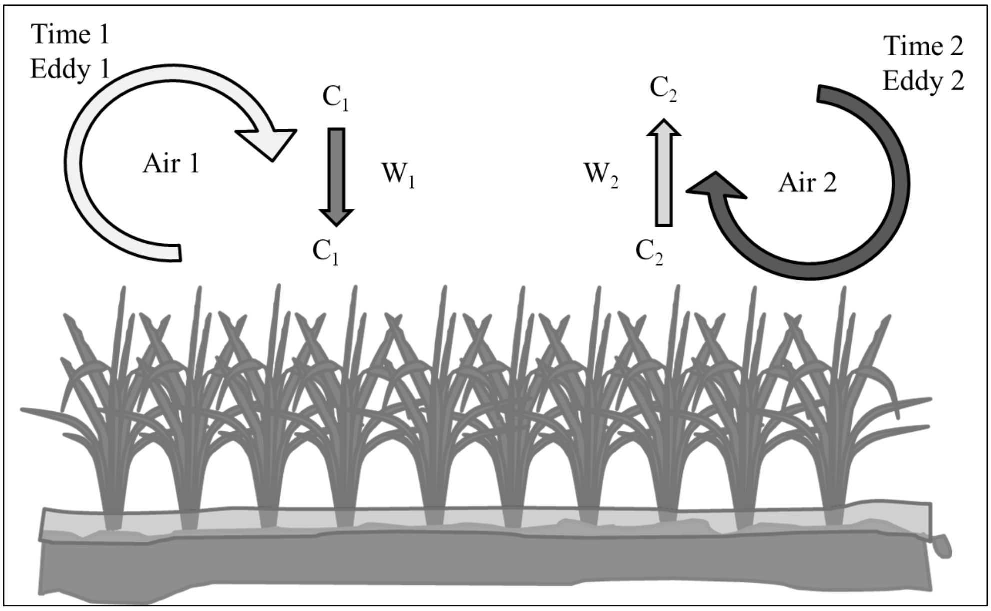

Figure 4 The characteristic of the eddies at a single point on the tower over plant canopy
Source: Modify from Burba and Anderson (2007)

An eddy covariance (EC) system essentially consists of fast response sensors that are capable of measuring the vertical wind speed and simultaneously some other properties of the turbulent eddies, as stated above, at a very high frequency (e.g. 10 Hz or more). The method of measurement is mathematically complex and requires a lot of care in setting up and processing the data (Riederer et al., 2014). The accuracy of eddy covariance depends on several factors and it is most accurate in steady atmosphere, homogeneous underlying vegetation and when it is situated on flat terrain (Reth et al., 2005).

To compare the different methods with respect to applicability (spatial variability, observable area, continuous monitoring, analyzing processes), the aspects of accuracy and precision (bias, e.g., influence on soil structure) and of costs and workload involved need to be taken into account. There is no single best technique out there. Ideally, investigations would allow for multiple method approaches such as a combination of chamber systems with eddy covariance and remote sensing (Oertel et al., 2016). The scale of measurement, relative advantage and limitations of closed chamber techniques in comparison of eddy covariance technique are presented in Table 2. Nowaday, the most important meteorologist for determining greenhouse gas from soil and discuss their individual strengths and weakness. In general, greenhouse gas emissions from soils are being directly measured in both field and laboratory (chamber method and micrometeorological method), obtained through space and airborne measurements, and calculate with empirical and process-oriented model.

Table 2 Comparison of different measuring techniques to determine greenhouse gas emission from rice soil

Measuring technique	Measuring Scale	Area (m^2)	Analyzer	Advantage	Disadvantage
Closed chamber (manual)	Small	<1	GC-FID[*]	- Can measure small fluxes - No or limited energy required - Easy to handle - Good for short duration collection sampling periods - Low manufacturing cost	- Build up gases concentration in chamber, alter the atmospheric, temperature etc. which may inhibit the normal emission rate of soil - Labor costly
Closed chamber (automed)	Small	<1	GC-FID	- Easy to handle - Environmental conditions similar to ambient fields - It is effective for continuous long-term monitoring	- Soil distribution during installation - Pressure deficit inside chamber can cause artificially gas flux - Automated sampling is required - Expensive as compared to closed chamber
Eddy Covariance	Large	>100	IRGA[**]	- No or minimum distribution - Can measure fluxes of ecosystem basis - Useful for monitoring diurnal and seasonal variations	- High cost, Data analyzing in difficult - Required continuous energy supply, assumption and correction level high - Dependence on atmospheric conditions

* GC-FID: Gas Chromatography-Flame Ionizing Detector.

** IRGA: Infar-Red Gas Analyzer.

Source: Modify from Malyan et al., 2016

A number of studies have compared the flux rate measured with chamber and eddy covariance measurement (Schrier-Uijl et al., 2010; Wang et al., 2010). They found that the chamber method produced slightly higher values than EC method by approximately 4.5% and 13.6% during 2001 and 2002 but respiration rates measured by both techniques showed very similar seasonal pattern of variation in 2001-2002 (Flanagan and Johnson, 2005). (Myklebust et al., 2008) compared measurements of soil respiration using (1) soil chamber, (2) the soil gradient technique and (3) ecosystem respiration using the eddy covariance (EC) method from a surface. The result showed agreement between nocturnal EC and soil respiration measurement over an un vegetated surface, but soil gradient technique measured overall 7% greater values (R^2 = 0.71) than automated chamber method.

Comparisons of eddy covariance and chamber based methods have previously been made for net ecosystem exchange of CO_2 (balance between respiratory and assimilatory process). Wang et al (2010) pointing that future studies are required as sources of error from the two techniques are not clearly understood. Schrier-Ujil et al. (2010) compares CH_4 fluxes measured with both methods in a peat-land and concluded that fluxes were comparable when all the land-scape elements involved in the EC flux were considered in the scaling up from chamber measurements. Other results also performed a similar comparison in a rice paddy field, during a short campaign of one week, resulting in great differences between measurement techniques (Werle and Kormann, 2001).

1.8 Objectives of this study

The goal of this study was to understand the greenhouse gas flux pattern compare by using closed chamber (CC) method and eddy covariance (EC) method in rice paddy field. The second objective was to find out the relationship between greenhouse gas production mechanism in soil and environmental factors for the emission. Futhermore, the objective of this study was to combine the output from CC and EC method for a more detail description for upscaling point data to large areas and a longer time series of greenhouse gas emission.

Chapter 2: Evaluation of greenhouse gas emission from rice paddy field by using Closed Chamber (CC) and Eddy Covariance (EC) method.

2.1. Introduction

The Food and Agriculture Organization of the United Nation (FAO) recently revised information on trends in global greenhouse gases emissions from agriculture, forestry and other land use. More than 90% of rice is produced and consumed in Asia, because of its favorable warm and humid climate (Fairhurst and Dobermann, 2015). The increased of rice production while world population increased. About 48% of rice production growth has been attributed to modern farming technologies that have produced. Rice paddy fields are a source of the CH_4, CO_2, and N_2O. The total greenhouse gas emissions from paddy fields mainly depend on a number of microbial-mediated processes in soils e.g. CH_4 production, CH_4 oxidation, and on numerous pathway of gas transport, e.g. plant-mediated transport (through the aerenchyma), molecular diffusion, and ebullition (Frenzel and Karofeld, 2000; Wang et al., 2017). Soil also provide carbon substrate to microbe for mediating greenhouse gas production and enhancing plant growth that in turn governs more than 90% of CH_4 transport (Komiya et al., 2015). Plant characteristic e.g. biomass and root exudate are also important regulators of greenhouse gas metabolism in soil. Other environmental variable, including soil temperature, pH, redox potential (Eh), and soil salinity also influence greenhouse gas metabolism (Wang et al., 2017).

The development of regional and global climate model has increased the understanding of terrestrial GHGs exchange at large scales (Riederer et al., 2014). There are many researches throughout the world assessing the environmental constraints on carbon and water vapor exchange of well-watered ecosystems including forest and grasslands. A number of investigations have taken place on the fluxes of water and CO_2 from drought strass in forest and grass land (Baldocchi, 2003) As large networks of ecosystem studies has been organized (e.g. FLUXNET, AmeriFlux, AsiaFlux, JapanFlux, ChinaFLUX), there has been increased recognition of a lack of information of carbon dioxide, water vapor and energy between terrestrial ecosystem and the atmosphere, especially agriculture ecosystem.

The methods for monitoring greenhouse gas from soil tend to use either chamber-based measurement or micrometeorological approach. Chamber-base is most widely used technique, since it can be applied at low cost and without power supply at a remote site to allow measurement of greenhouse gas exchange between soil and atmosphere (Butterbach-Bahl, 2016). The static closed-chamber technique relies on the diffusion theory and provides the enclosed of a known volume of air above a portion of soil surface for precise period. During enclosure, greenhouse gas molecules migrate by diffusion along a natural concentration gradient from soil pore air, where they are produced by specific microorganism e.g. methanogens in the case of CH_4, to the air enclosed with the chamber headspace, eventually through the flooding water or the plant aerenchyma. The concentrations of the greenhouse gas within the chamber headspace increased over time, and occurrence of the increases provides for flux estimate (Bertora et al., 2018). Chambers offer both advantage and disadvantages for dealing with spatial heterogeneity of fluxes. Where variation within the landscape is recognizable, chamber deployment can be stratified to measure the important of that variability (Davidson et al., 2002). The disadvantage of the CC method is the disturbance of the measurement point and the limitation of site and time periods, which theoretically requires more than 100 replications for a representative of one site (Katayanagi and Hatano, 2005).

The EC method can measure continuously without disturbing the environment and can cover a few hectares, up to a large scale (Komiya et al., 2015; Pakoktom et al., 2013). The disadvantage of the EC method is that this method requires a flat and homogeneous manage area according to canopy height and wind speed (Baldocchi, 2003). The measured values are an average of that area, which makes it difficult to identify the site-specific source and process of greenhouse gas production (Liu et al., 2012; Wang et al., 2013). The control of steady-stage conditions, flat and homogeneous terrain and turbulent exchange conditions are achieved by applying data quality tools (Riederer et al., 2014).

Previously, comparison between experiments between chamber data and EC data can be found. Comparison between CC and EC measurement are available for other trace gases (Riederer et al., 2014). The challenging of the compare data from CC and EC method are EC method measures an integrated signal from a large flux footprint area (Rannik et al., 2015), the way of target reasonable representativeness with the CC method on ecosystem scale (Reth et al., 2005). Anyway, both CC and EC method must be reviewed for inaccuracies and due to the fact that real fluxes are always unknown under field conditions, it is impossible to validate flux measurements by any technique (Davidson et al., 2002)

2.2. Material and Methods

2. 2.1 Study site descriptions

The field experiments were carried out from May, 2014 to October, 2015, during 2 rice cropping season. The experimental site (35° 39' 56.2" N, 139° 28' 17.7" E) was located in Field Museum Honmachi Field Science Centre, Tokyo University of Agriculture and Technology, Fuchu, Tokyo, Japan (Figure 5). The studies area is located in temperate to sub-tropic. Winters are mild and summer is hot and humid. The rainy season comes in early summer with 1,808 mm rainfall in 2014 (Japan Meteorological Agency, 2016). The soil is gray lowland soil (Fluvisol). The layout of the paddy rice field experimental site showed in Figure 6. The experimental site containing 13 individually irrigated fields. At the beginning of May, 2014, basal fertilize with 30 kg N ha^{-1} was applied before rice transplanted. Japonica rice variety Ikuhikari was used in experimental area. Rice seedlings were transplanted at 8 May, 2014 by using rice planting machine. From transplanting date, the rice paddy was flooded at 10-15 cm water depth. Mid-season drainge was conducted from 12^{th} to 19^{th}, July, 2014. Except that period the field was continuously flooded until harvest on October 15, 2014.

Figure 5 The experimental site, Paddy rice field at Fuchu Honmachi, Fuchu, Tokyo, Japan.

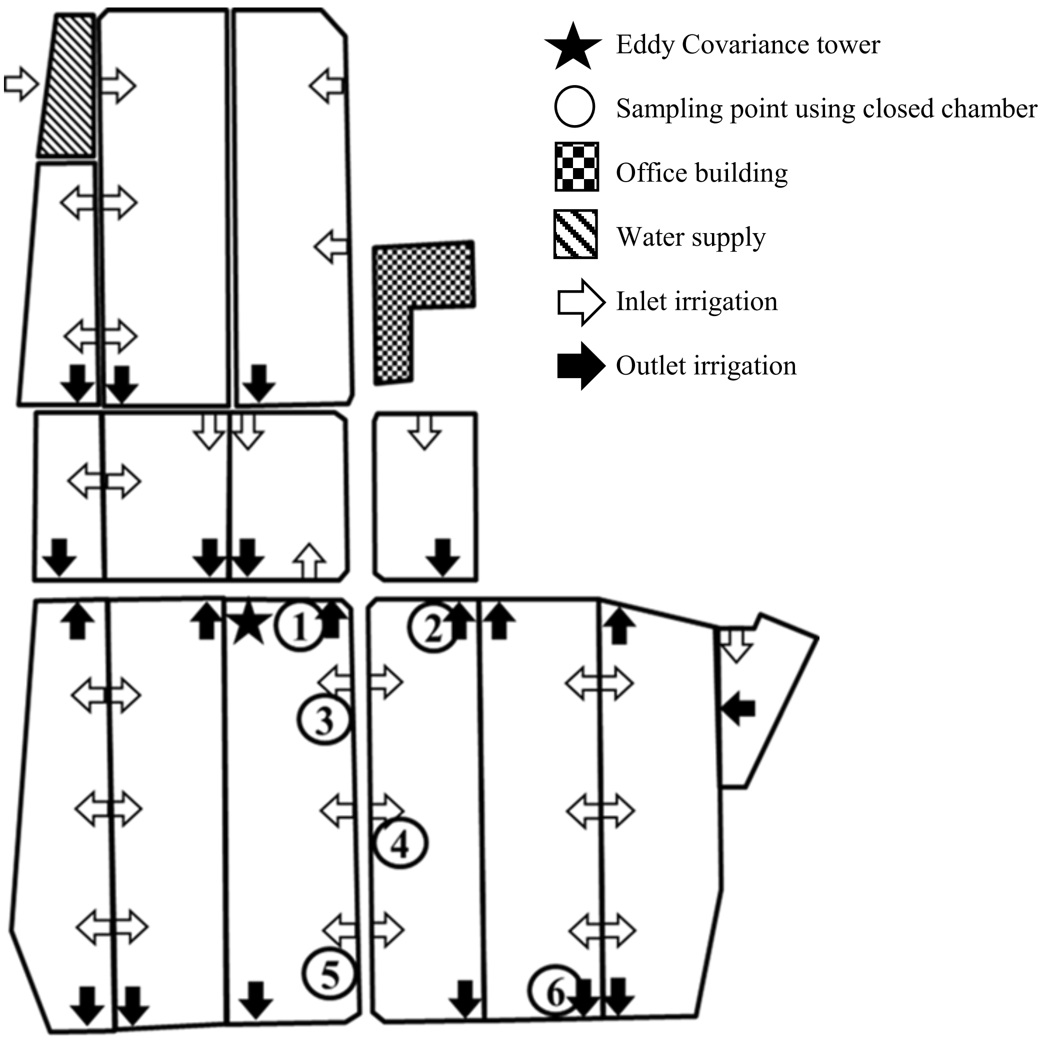

Figure 6 Lay out of the paddy rice field experimental site containing individual irrigated fields. The black star indicates the location of the eddy covariance tower, and the circle numbers indicate closed chamber sampling points. The empty and black arrows show inlet and outlet irrigation systems, respectively.

2.2.2 Measurement of Environmental parameters

Along with the EC tower, standard meteorological and soil parameters were measured continuously with array of sensors. The environmental parameters including Net radiation (Rn) was measured with Net radiometer (Q-7.1, Campbell Sci. Inc., North Logan, UT, USA). Air temperature (Ta) and relative humidity (RH) were measured using humidity and temperature probe (HMP60, Vaisala Inc., Helsinki, Finland). Water and soil temperature (Tw and Ts) were measured with thermos couple-T, copper and constants) at depths of 0, 5, 10 and 20 cm. and soil heat flux (G) was measure with soil heat flux sensor (PHF-02, PRED Inc., Tokyo, Japan). meteorological data were sampled at 30 min intervals using data logger software (CR3000, Campbell Scientific, Inc., North Longan, UT, USA).

2.2.3 Measure of greenhouse gas fluxes using the closed chamber method

Six sampling point of CC method and soil gas sampling tube placed at 6 individually irrigated fields (Figure 6). Greenhouse gases fluxes monitoring were conducted during the paddy rice cropping season from June to October, 2014. The Sampling points of CC method and soil gas sampling tubes were established in the field in duplicates. Greenhouse gases fluxes and soil gas were conducted at 30 days after transplant (30 DAT), 60 days after transplant (60 DAT), 90 days after transplant (90 DAT) and after harvested (AHV). At each growing stage, 3 days continuously sampling was conducted by CC method and soil gas, except at 30 DAP, where only 2 days were successful sample. The transparent chambers used were 30 cm in length, 30 cm in width and 100 cm in height. To prevent leakage and soil disturbance, a chamber base was installed in the soil 1 day before sampling date. The air inside each chamber was homogenized and reduces the negative effect of air temperature by an electric fan operated by battery, which was installed at the top of the chamber. The temperature inside the chamber was recorded using a micro-temperature thermometer (PC-9125, AS ONE Co., Tokyo, Japan) fitted with rubber septum insert into the small hole of the chamber. The air inside the chamber was thoroughly mixed before collecting gas samples by flushing the syringe 3 times. Approximately 50 mL of gas samples were taken with the 50 mL plastic syringe, adjusted to 45 mL and then transferred into a 20 mL vacuumed glass vial. Daily gas sampling was carried out at 8:00, 12:00 and 16:00 for the three days continuously. Methane and CO_2 concentration were analysed in the laboratory by using a gas chromatograph equipped with a flame ionization detector (GC-8A, Shimadzu Corporation, Kyoto, Japan). The detector and column were operated at 180 °C and 80 °C, respectively. The oven temperature was set at 50 °C. Helium (99.9%) was used as the carrier gas for greenhouse gases at a flow rate of 60 mL min^{-1}. Using values recorded by the CC method, GHGs emission rates were calculated from the increase in GHGs concentration per unit surface area of the chamber within a specific time interval. The amount of GHGs flux was calculated using the following equation

$$F = \rho \times \left(\frac{V}{A} \times \frac{\Delta c}{\Delta t} \times \frac{273}{K}\right)$$

Where F: GHGs flux (mg CH_4 m^{-2} h^{-1})

ρ: gas density of CH_4 gas (0.174 mg cm^{-3})

V: volume of the chamber (m^{-3})

A: surface area of the chamber (m^{-2})

$\frac{\Delta c}{\Delta t}$: rate of gas concentration increase in the chamber (mg m^{-3} h^{-1})

K: Kelvin temperature of the air inside the chamber

Figure 7 Transparent closed chamber cover rice for gases sampling on rice paddy field at 90 DAT

2.2.4 Measure of greenhouse gas fluxes using the eddy covariance technique

Fluxes of carbon dioxide and methane were continuously measured using EC method (Figure 8). During the paddy rice growing season from June to October, 2014. The flux system was mounted at 1.8 m. The distance from the tower to the edge of the field in the south direction was nearly 200 m., which is large enough to cover up to approximately 100 times the tower's height. The EC tower consisted the vertical and horizontal wind velocities and sonic temperature (Tsv) were measured at 10 Hz interval using a three dimensional sonic anemometer-thermometer (SAT-540, SONIC Co., Tokyo, Japan) installed at 2 meter high over rice canopy. The gas sampling tube

CH_4/H_2O fluctuation was measured at 10 Hz interval by closed-path EC method using CH_4/H_2O closed path gas analyzer (G2301-f, Picarro Inc., Santa Clara, CA, USA). Air sampling from the vicinity of the sonic is drawn through a sampling tube to the closed path gas analyzer, where set up at an instruments box (Figure 9 and 10).

Figure 8 Eddy Covariance set up consisted with open-path CO_2/H_2O gas analyzer and closed-path CH_4/H_2O sampling tube set up with a three dimensional sonic anemometer

Eddy covariance method calculates the GHGs fluxes by measured turbulent fluctuation in vertical wind velocities and concentration of gas (Baldocchi, 2003). Greenhouse gases flux was determined using the following equation

$$F = \rho\ (\overline{w'c'})$$

Where F : the turbulent fluxes

ρ : the density of the air (g m^{-3})

w' : the mean values instantaneous deviation of the vertical wind velocity (m s^{-1})

c' : the gas concentration (μmol mol^{-1}) from mean values

The EC raw data were processed and quality controlled using EddyPro software (LI-COR Biosciences, Nebraska, USA). Steps for post-processing of the 10Hz raw data will include spike detection, double rotation procedure, spectral loss correction and density fluctuation correction. Data quality control includes the basic test for the steady stage test, and the integral turbulence characteristics test (Foken et al., 2012). The data gaps of gas flux could be filled with linear interpolation mean diurnal variation, light, respiration response equation (Qun and Huizhi, 2013)

Figure 9 Eddy Covariance system set up with eddy covariance tower and an instruments box at 5 m far from the EC tower

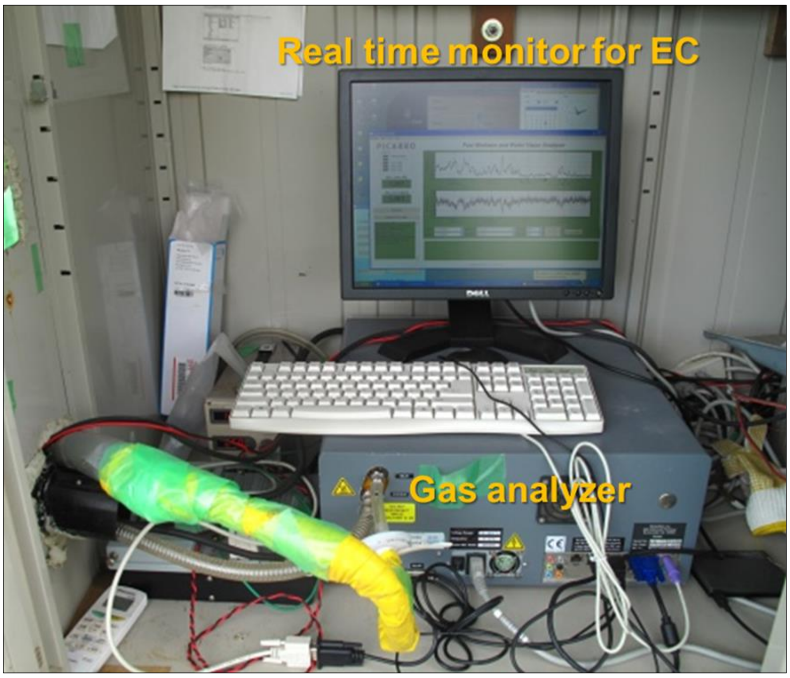

Figure 10 The closed-path eddy covariance system, the CH_4/H_2O closed-path gas analyzer and the real time monitor located inside an instrument box at 5 m far from EC tower

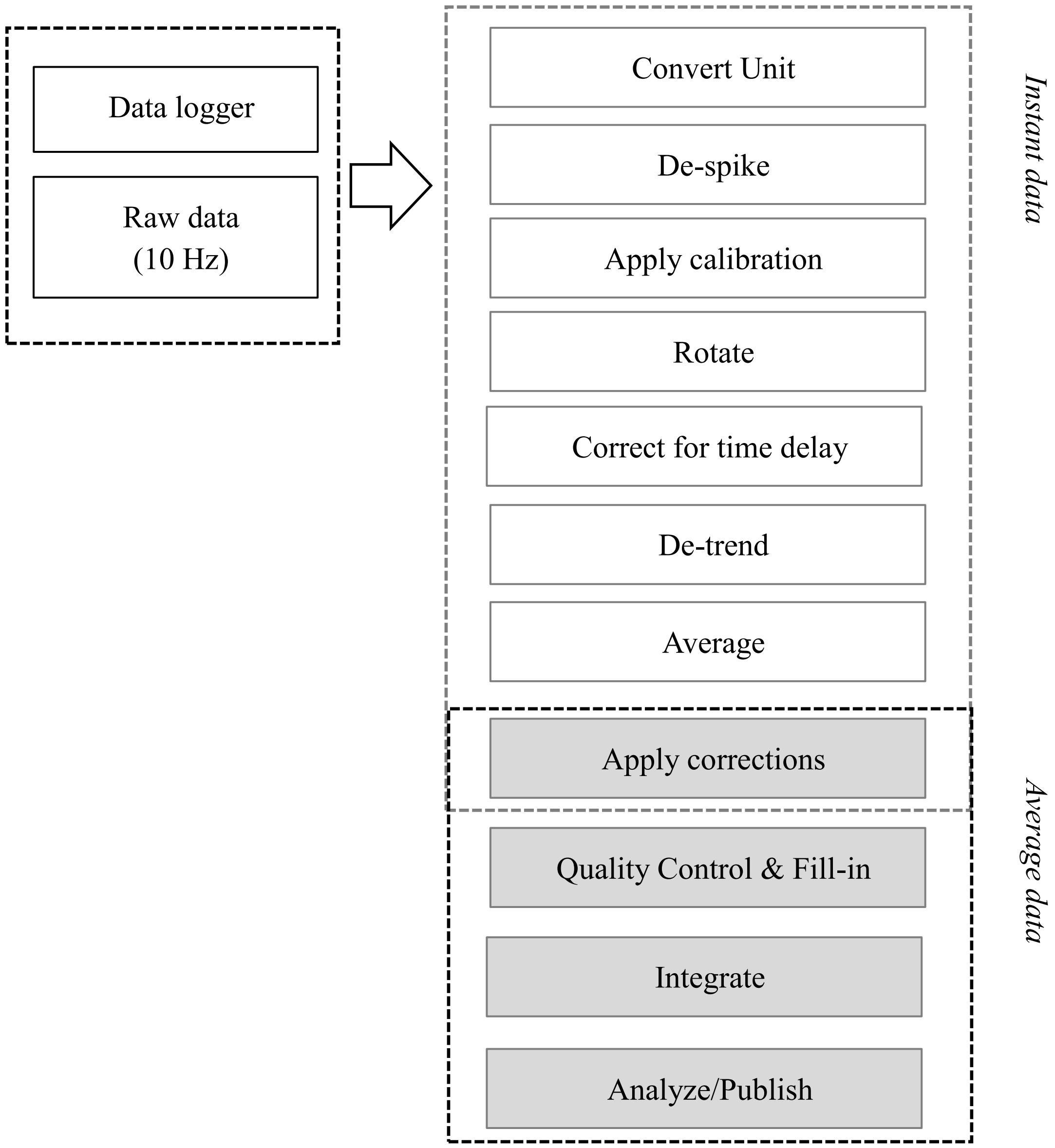

Figure 11 Processing scheme for eddy covariance data
Source: Modify from Burba and Anderson (2007)

2.2.5 Measure of greenhouse gas concentration using soil gas sampling tubes

The greenhouse gas concentration in soil layer was sample by soil gas sampling tubes (Kusa et al., 2010). Each soil sampling tube was closed with the stopper at one end, while the other end was connected to 30 cm long iron tube equipped with a three-way cock for gas sampling. The silicon tube was buried in the paddy field soil at 0, 5 and 10 cm depths at the six CC method sampling point (Figure 12 and 13). A 30 mL gas sample were taken from the three-way cock location with a syringe and then transferred to a 10 mL vacuum glass vial. The greenhouse gas concentration was analysed in the laboratory using a gas chromatograph equipped with the flame ionization detector (GC-8A, Shimadzu Corporation, Kyoto, Japan)

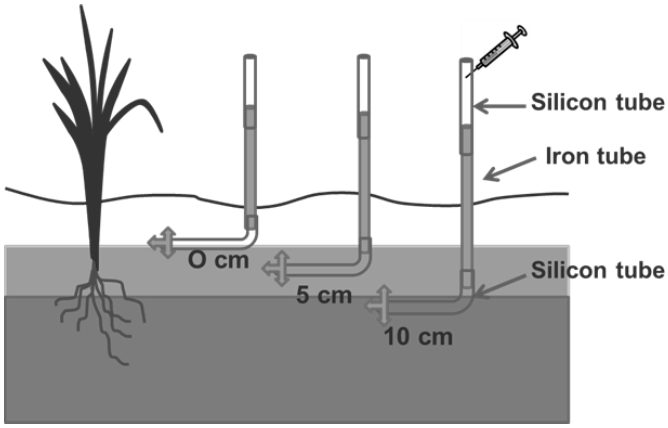

Figure 12 Schematic of site setup the soil gas sampling tube buried in the paddy field at 0, 5 and 10 cm depths in duplicated at the six CC method sampling points

Figure 13 Site setup the soil gas sampling tube buried in the paddy field in duplicated at the six CC method sampling points

2.2.6 Measure of soil parameters

In paddy field, soil sampling was performed at 6 CC sampling point with two replications at each growing stage. Soil pH, electrical conductivity of soil water (mS m^{-1}), total nitrogen (TN; g kg^{-1}) contents in soil, soil organic matter (SOM; %), ammonium ion concentration (NH_4^+; mg N kg^{-1}) and nitrate ion concentration (NO_3^-; mg N kg^{-1}) were measured before flooding. Soil pH was measured in the supernatant suspension of a 1:2.5 soil:water mixture using a portable pH meter equipped with a combined electrode (glass: Ag/AgCl, Horiba, Japan). Electrical conductivity of the soil water was measured in the supernatant suspension of a 1:5 soil:water mixture using EC meter (OM-51, Horiba, Japan). Total nitrogen (TN) and total carbon (TC) contents were analyzed by using a NC analyser (Sumigraph NC-80; Sumika Chemical Analysis Service Co., Japan). Soil organic matter was determined from the loss in weight caused by digesting in the soil with hydrogen peroxide (the hydrogen peroxide method). The concentration of NH_4^+ and NO_3^- were determined by extracting mineral N from the soil with a 2 mol L^{-1} KCl solution, filtering through Whatman #42 filter paper and analysing using a colorimetric method. The absorbance of soil-extracted solutions were measured using a UV-VIS spectrophotometer (Shimadzu UV mini, Shimadxu Corporation, Kyoto, Japan). Measured absorbances st 635 nm and 220 nm determined the concentrations of NH_4^+ and NO_3^-, respectively.

2.2.7 Measure of plant growth

Plant growth parameters, including plant height, leaf number and tiller number were determined from two hills at each growing stage. Plant height (cm) measured from ground level to the tip of the longest leaf, tiller number and leaf number counted for each hill. Phenological stages of paddy rice are generally divided into the vegetative, from transplanting to panicle initiation (0-60 days after transplanting). Reproductive from panicle initiation to heading (61-90 days after transplanting), and maturation, from heading to maturity (91-120 days after transplanting) (Hardke, 2014).

2.2.8 Statistical analysis

All data were statistically analyzed by analysis of variance (ANOVA) using R 2.13.2 (R Development Core Team; https: cran.r-project.org). To determine the significance of the difference among the mean of the sampling point, least significant differences (LSD) at $p = 0.05$. The stepwise regression of CH_4 emissions with environmental parameters were done using the SPSS software program; Statistical Package for the Social Sciences, Version 16.0 (IBM Crop. Armonk, NY, USA).

2.3. Results

2.3.1 Environmental condition at experimental site

The net radiation was increased after the sunrise and reached maximum at noon along growing stage. The average net radiation from June to October 2014 range from -69 to 747 Wm^{-2} (Figure 14). The average net radiation variation range from -48 to 747, -54 to 610, and -60 to 419 Wm^{-2} at 60 DAT, 90 DAT, and AHV, respectively (Figure 15, 16, 17 and 18).

One of the most important factors that in flounces plants development is the solar radiation intercepted by the crop. The solar radiation brings energy to the metabolic process of the plants. The principal process is the photosynthetic assimilation that makes synthesize vegetal components from water, CO_2 and the light energy possible. A part of this, energy is used in the evaporation process inside the different organs of the plant, and also in the transpiration through the stomas. It is well known that incident radiation is related to growth duration. Rice yield can be increased by increasing biomass production. Biomass production is the product of intercepted solar radiation by the canopy and radiation use efficiency (Huang et al., 2016; Zhang et al., 2009) .

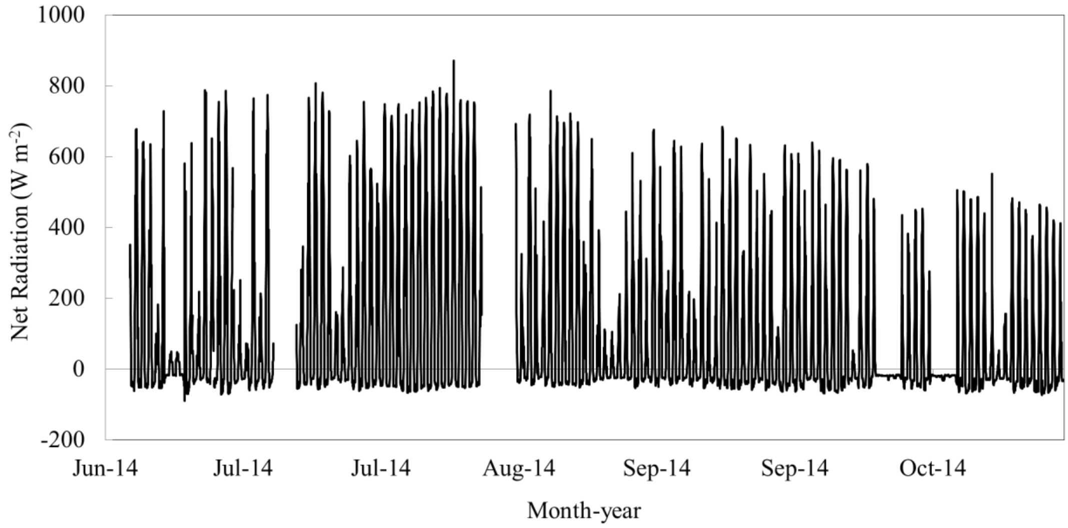

Figure 14 Net radiation (Rn) of experimental site during rice growing season (June–October, 2014)

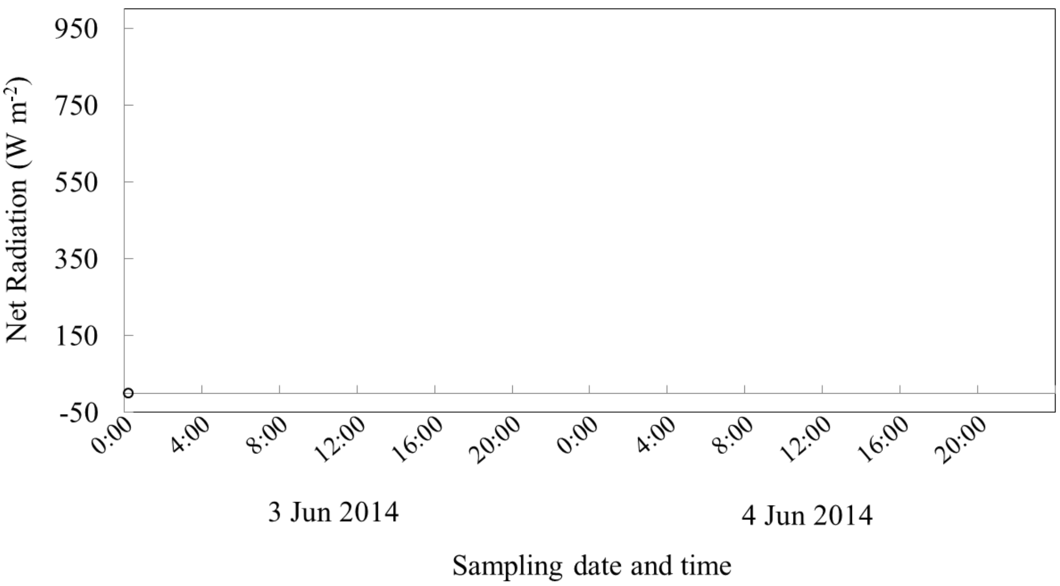

Figure 15 Net radiation (Rn) of experimental site during 3-4 June, 2014 (30 DAT).

Remark: No net radiation data for this growing stage due to sensor defect

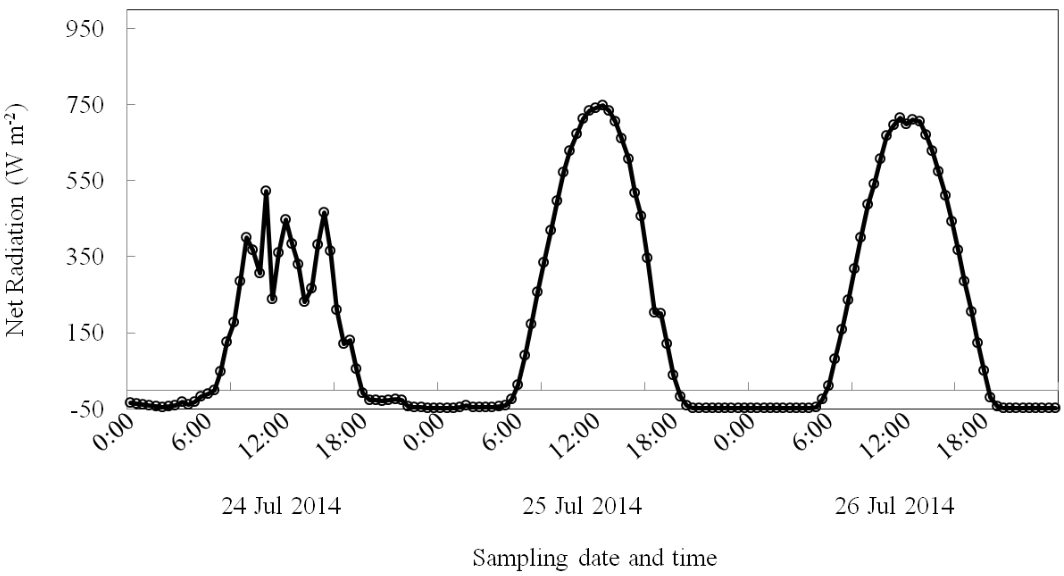

Figure 16 Net radiation (Rn) of experimental site during 24-26 July 2014, (60 DAT)

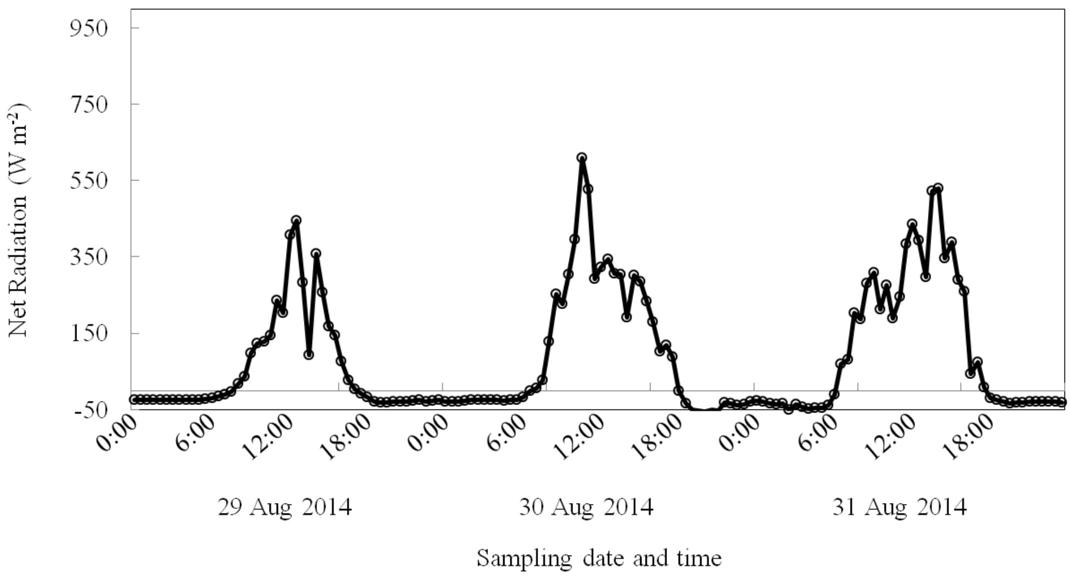

Figure 17 Net radiation (Rn) of experimental site during 29-31 August, 2014 (90 DAT)

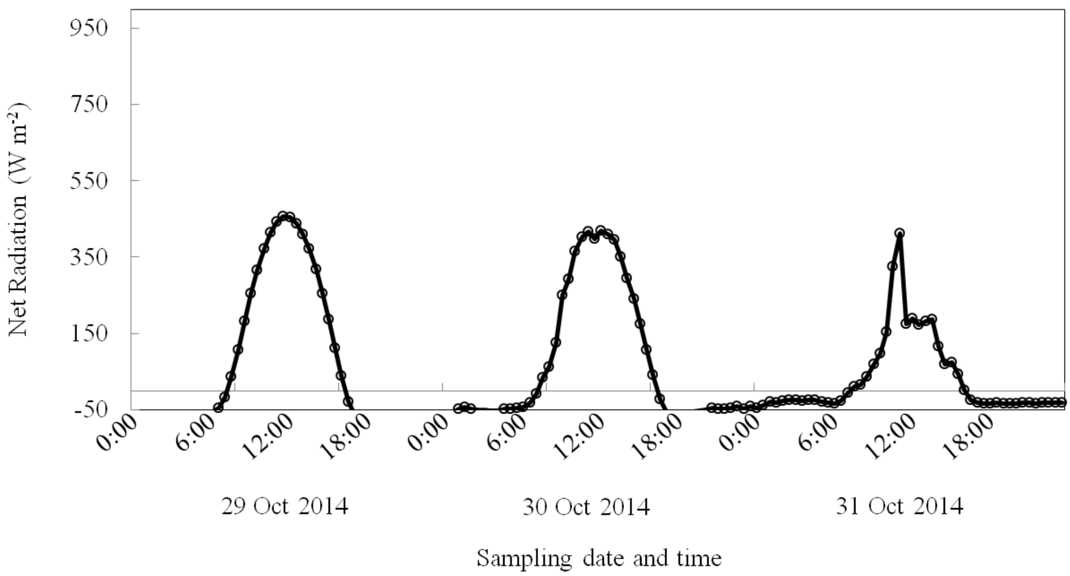

Figure 18 Net radiation (Rn) of experimental site during 29-31 October, 2014 (AHV)

Air and water temperatures showed similar patterns on the net radiation pattern (Figure 21, 22, 23 and 24). Air temperature varied from 7.5 to 35.5 °C during the experimental period. The variation during growing season mainly occurred due to the variation of net radiation. The highest air temperature value of 35.3 °C was observed at 60 DAT and the lower air temperature was 7.5 °C observed at AHV. The water temperature in paddy rice field during experiment period range from 6.7 to 46.0 °C. During flooding condition, the average water temperature was 22.9, 29.9, 21.5 and 13.7 °C at 30 DAT, 60 DAT, 90 DAT and AHV, respectively. The lower and higher water temperature was observed at AHV and 60 DAT, respectively.

The diurnal variation of soil temperature at 0, 5, 10, and 20 cm depths showed a similar temporal pattern (Figure 25, 26, 27 and 28). Soil temperatures were lower in night time and early morning, then increased become highest at noon. Soil temperature increased from 30–60 DAT with maximum 36.4, 32.3, 31.1, and 29.3 °C at 0, 5, 10, and 20 cm depth of soils, respectively. In this study, found the daily variation difference in soil temperature in each profiles. The difference between minimum and maximum soil temperature in each sampling time showed big difference at 0 cm depth, on the other hand small difference was found at 20 cm depth of soil. The big difference of soil temperature was observed 7.36, 10.79, 2.06, and 6.3 °C at 30, 60, 90 DAT, and AHV, respectively. The soil temperature difference between the 0 and 20 cm depths ranged from 0.3 to 1.9 °C during crop growth and 0 to 2.5 °C at AHV.

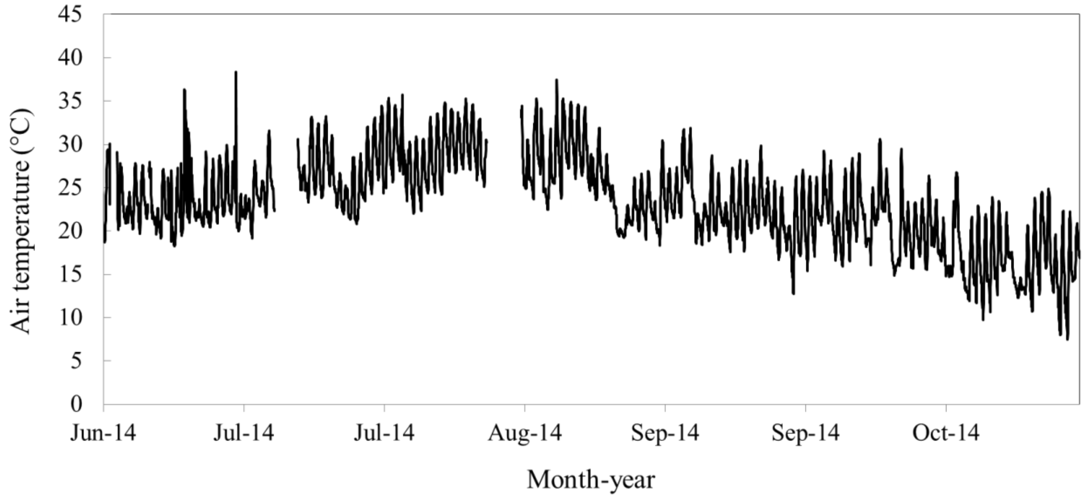

Figure 19 The average of air temperature (Ta) of experimental site during rice growing season (June to October, 2014)

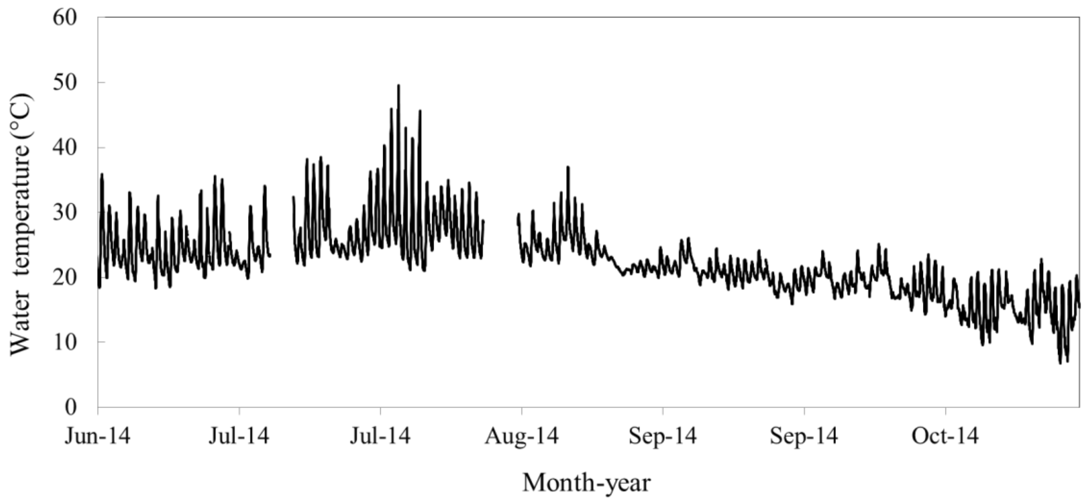

Figure 20 The average of water temperature (Ta) of experimental site during rice growing season (June to October, 2014)

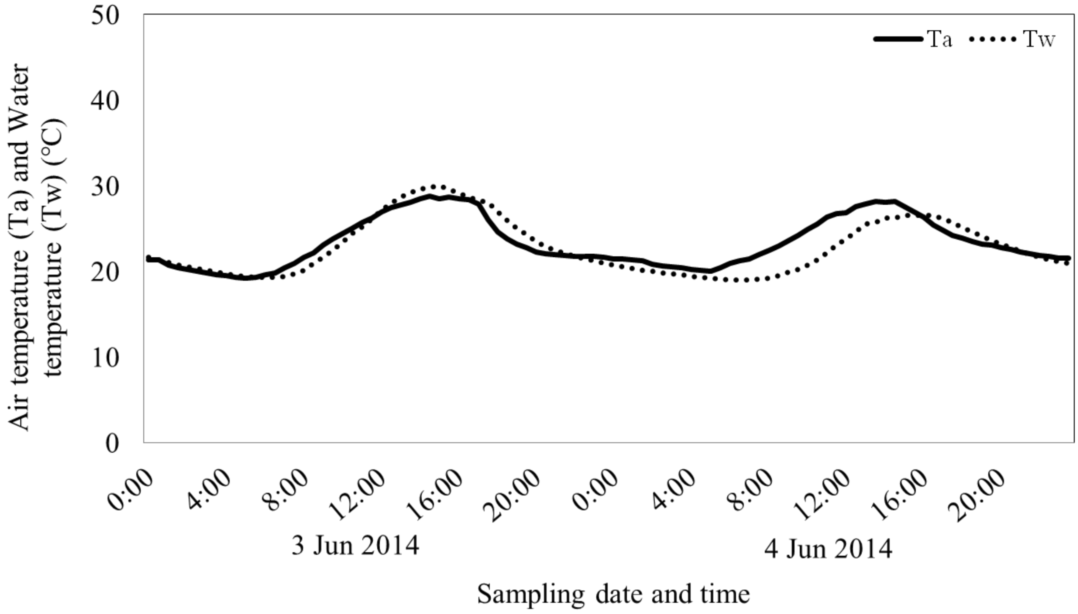

Figure 21 The average of air temperature (Ta) and water temperature (Tw) of experimental site at 3-4 June, 2014 (30 DAT)

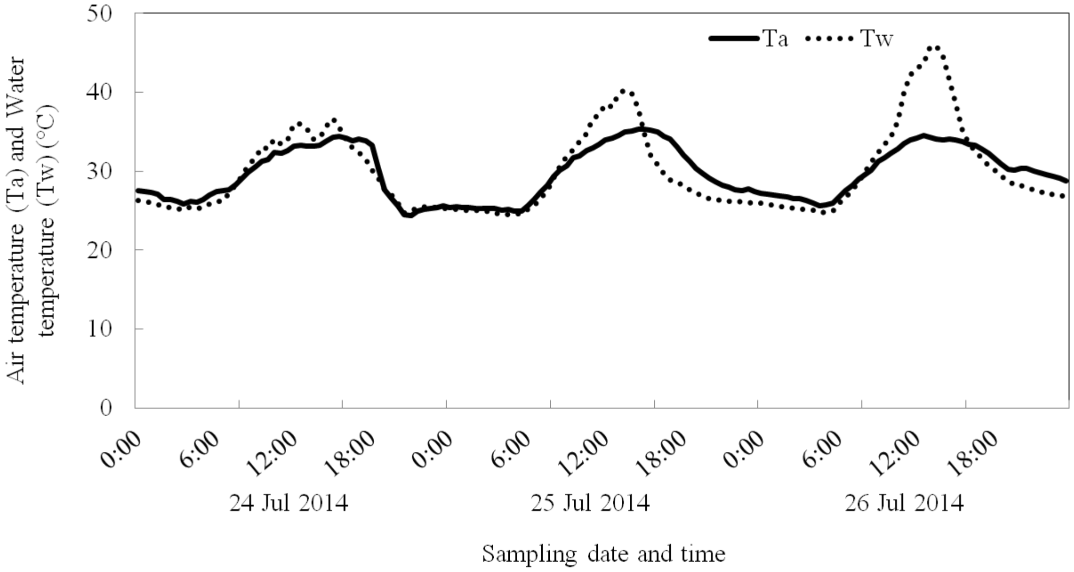

Figure 22 The average of air temperature (Ta) and water temperature (Tw) of experimental site at 24-26 July, 2014 (60 DAT)

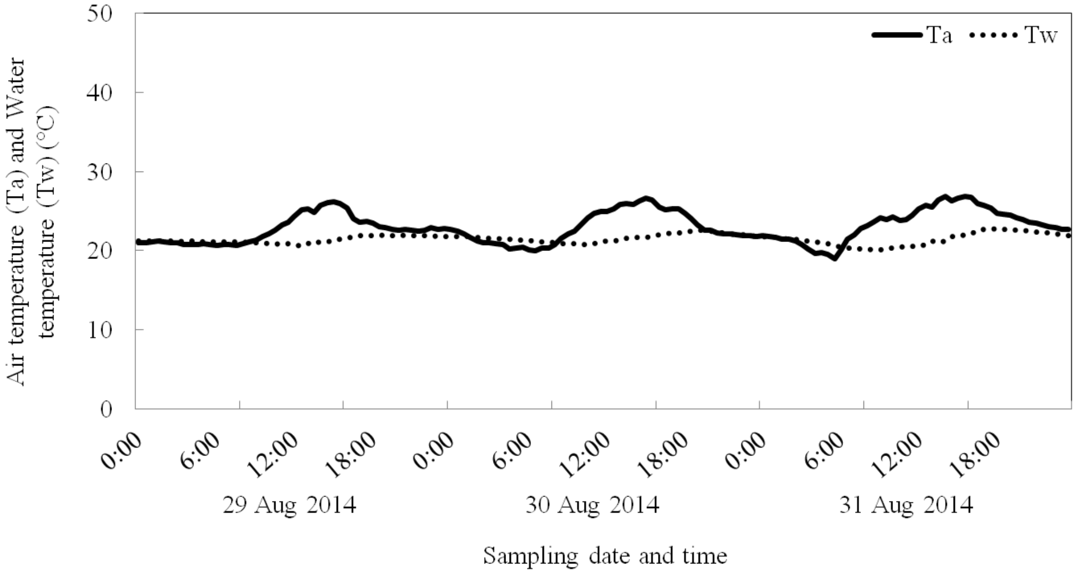

Figure 23 The average of air temperature (Ta) and water temperature (Tw) of experimental site at 29-31 August, 2014 (90 DAT).

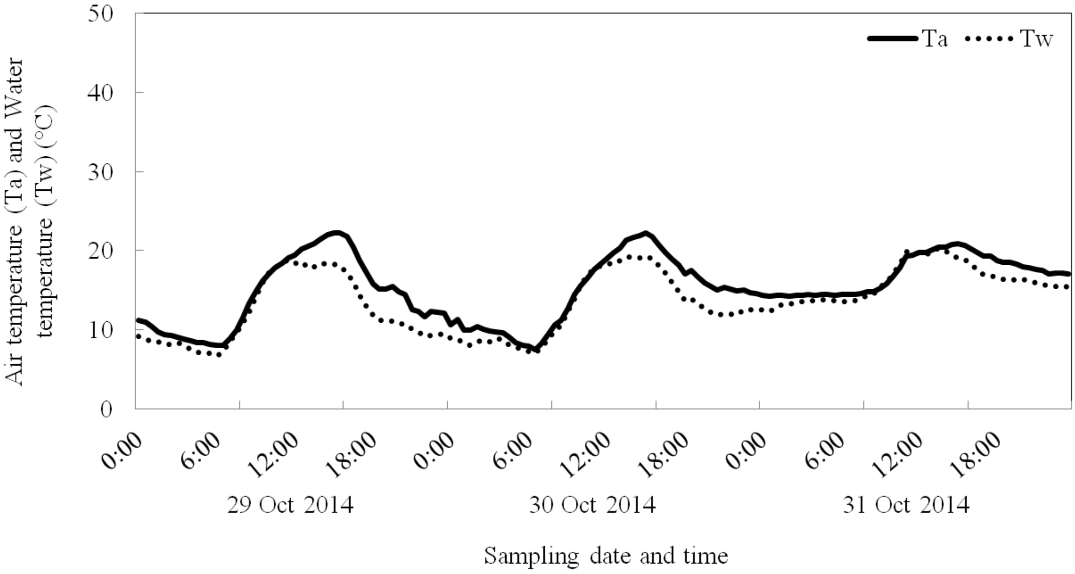

Figure 24 The average of air temperature (Ta) and water temperature (Tw) of experimental site at 29-31 October, 2014 (AHV).

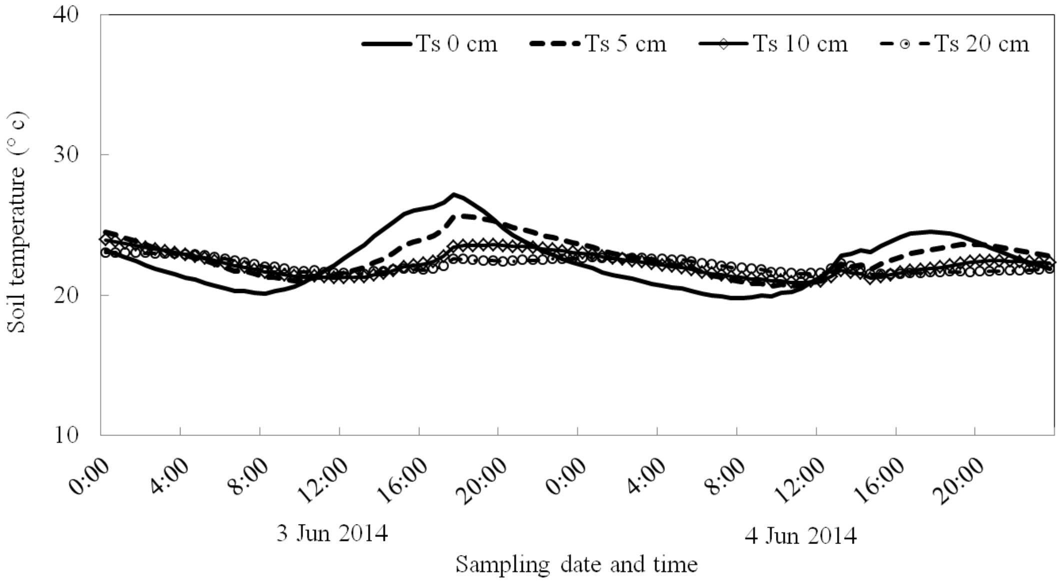

Figure 25 The average of soil temperature (Ts) at 0 cm, 5 cm, 10 cm, and 20 cm depth of soil at a sampling point during 3-4 June, 2014 (30 DAT)

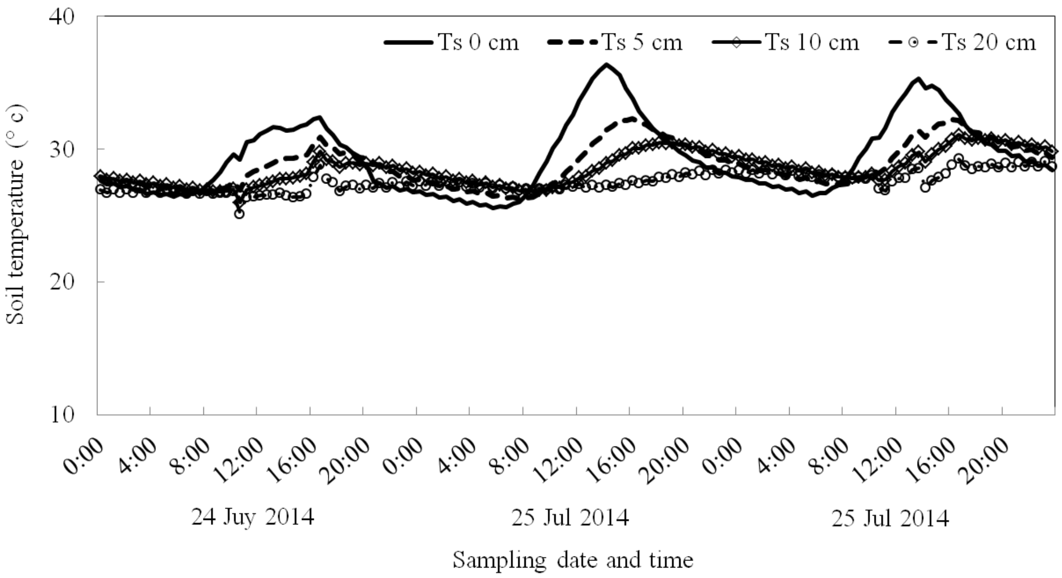

Figure 26 The average of soil temperature (Ts) at 0 cm, 5 cm, 10 cm, and 20 cm depth of soil at a sampling point during 24-25 July, 2014 (60 DAT).

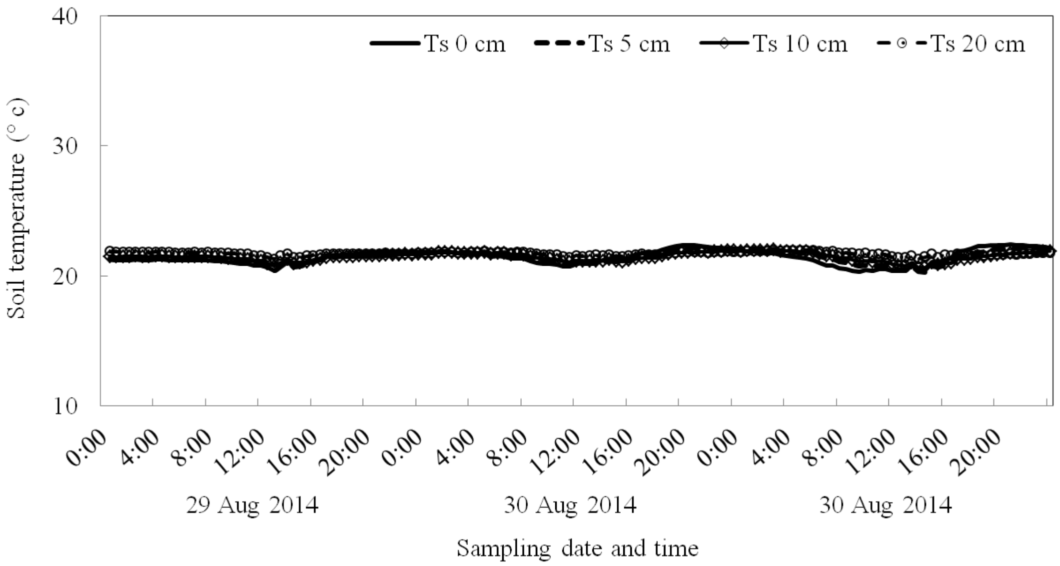

Figure 27 The average of soil temperature (Ts) at 0 cm, 5 cm, 10 cm, and 20 cm depth of soil at a sampling point during 29-31 August, 2014 (90 DAT)

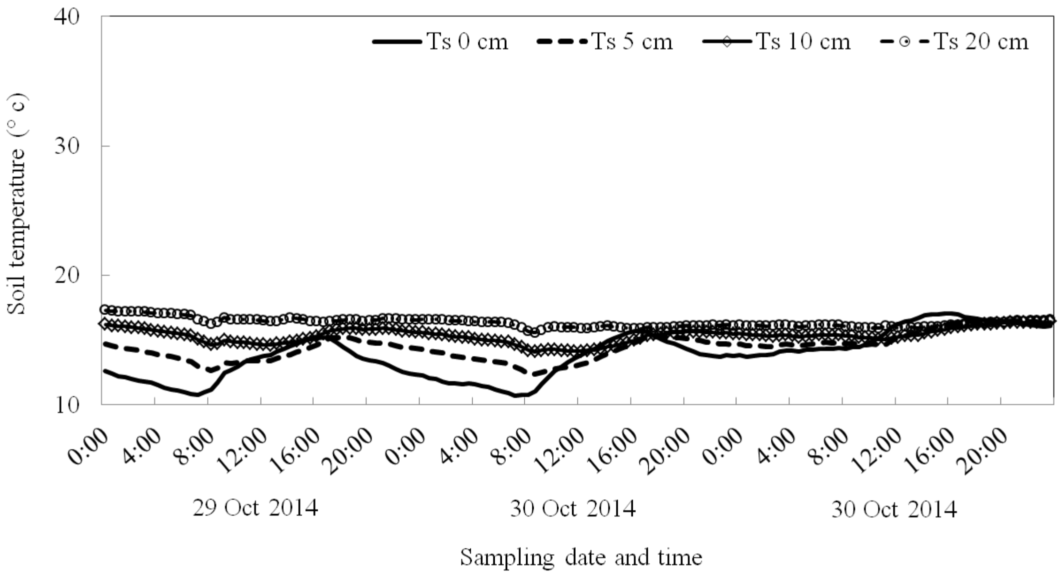

Figure 28 The average of soil temperature (Ts) at 0 cm, 5 cm, 10 cm, and 20 cm depth of soil at a sampling point during 29-31 October, 2014 (AHV).

Table 3 Chemical properties of soil at different soil sampling points at the experimental site during June to October, 2014.

Sampling point	**Soil pH**	**Electrical conductivity ($mS\ m^{-1}$)**	**TC ($g\ kg^{-1}$)**	**TN ($g\ kg^{-1}$)**	**C/N**	**SOM (%)**	**NH_4^+ ($mg\ N\ kg^{-1}$)**	**NO_3^- ($mg\ N\ kg^{-1}$)**
1	6.2	9.8 ab	41.3 b	3.7	11.0	11.1	0.1	13.5
2	6.4	6.2 c	40.6 b	4.2	10.3	10.2	0.1	15.0
3	6.4	11.6 a	46.7 a	4.0	11.6	10.0	0.1	14.0
4	6.5	8.7 b	43.3 ab	3.9	11.3	9.8	0.1	14.2
5	6.6	8.0 bc	43.2 ab	3.8	12.0	9.8	0.1	9.2
6	6.4	7.7 bc	39.8 b	3.6	11.2	9.7	0.1	8.7
p-value	0.08	0.002**	0.05*	0.55	0.16	0.79	0.72	0.14

Note: Letters that are the same indicated no significant difference at the $p < 0.05$ level. * and ** indicated significant at the $p < 0.05$ and $p < 0.001$, respectively. Significant differences were found were found only for electrical conductivity and TC.

Soil chemical properties varied significantly among six sampling points. Soil pH, TN, C/N, SOM, NH_4^+, and NO_3^- was not significantly different amoung sampling point. The values of electrical conductivity and TC were significantly different between sampling points. The average values of electrical conductivity from different sampling positions were 8.7 mS m^{-1}. When comparing different sampling positions, the values of electrical conductivity was highest in sampling point no. 3 with 11.6 mS m^{-1}, and lowest observed in sampling point no. 2 with 6.2 mS m^{-1}. The average of the values of TC contents was significant higher in sampling point no. 3 with 46.7 g kg^{-1}, followed by sampling point no. 4 and 5 with 43.3 and 43.2 g kg $^{-1}$, respectively. In six sampling points the results like electrical conductivity were also found for TC contents. The average of TN ranged from 3.6 to 4.2 g kg^{-1} in six sampling points. The higher TN value was found in sampling point no. 2 than the others. High C/N ratio was observed in sampling point no. 5 followed by sampling point no. 3, 4, 6 and 1. The values of soil organic matter contents ranged from 9.7 to 11.1 (%) among the sampling points with high content in sampling point no. 1 and the lowest content with 9.7 % in sampling no. 6. The sampling point no. 6 showed lower NO_3^- than that other position. The higher NO_3^- content was observed in sampling point no. 2 with 15.0 mg N kg^{-1}.

2.3.2 Plant growth

2.3.2.1 Plant Height

Plant height was increased gradually from stating the measurement at 30 DAT as shown in Figure 29. Non-significant ($p<0.05$) differences in plant height among the six sampling point were observed in this experiment. The average of plant height was 40.1, 88.3, and 113.1 cm at 30 DAT, 60 DAT, and 90 DAT, respectively. After transplanting 30 days, the tallest found at sampling point no. 6 was 52.0 cm. The taller at 60 DAT was 103.5 and 103.0 cm at sampling point no. 1 and 6, respectively. At 90 DAT, the tallest was 125.5 cm at sampling point no. 2.

2.3.2.2 Tiller number

Non-significant ($p<0.05$) differences were identified in tiller number among six sampling points. The number of rice tiller was increased from the measurement at 30 DAT as shown in Figure 30. Tiller number at 30 DAT range from 2 to 9 culms per hill. The highest value was 9 culms per hill at sampling point no. 6. After transplanting 90 days, the highest number showed at sampling point no. 2 and 5. The highest number of tiller at 90 DAT was 22 culms per hill at sampling point no. 5

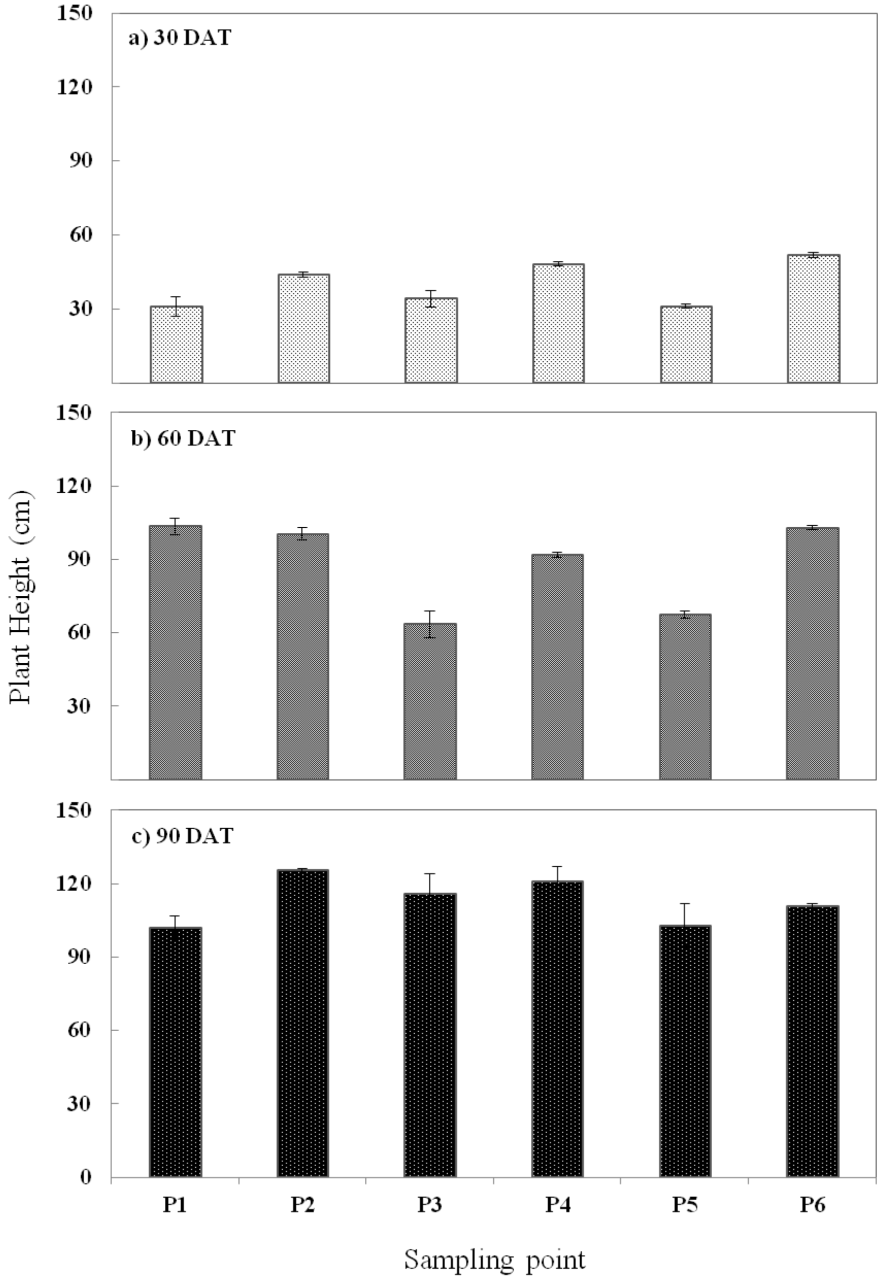

Figure 29 Plant height of rice on 6 sampling point at a) 30 DAT, b) 60 DAT, and 90 DAT

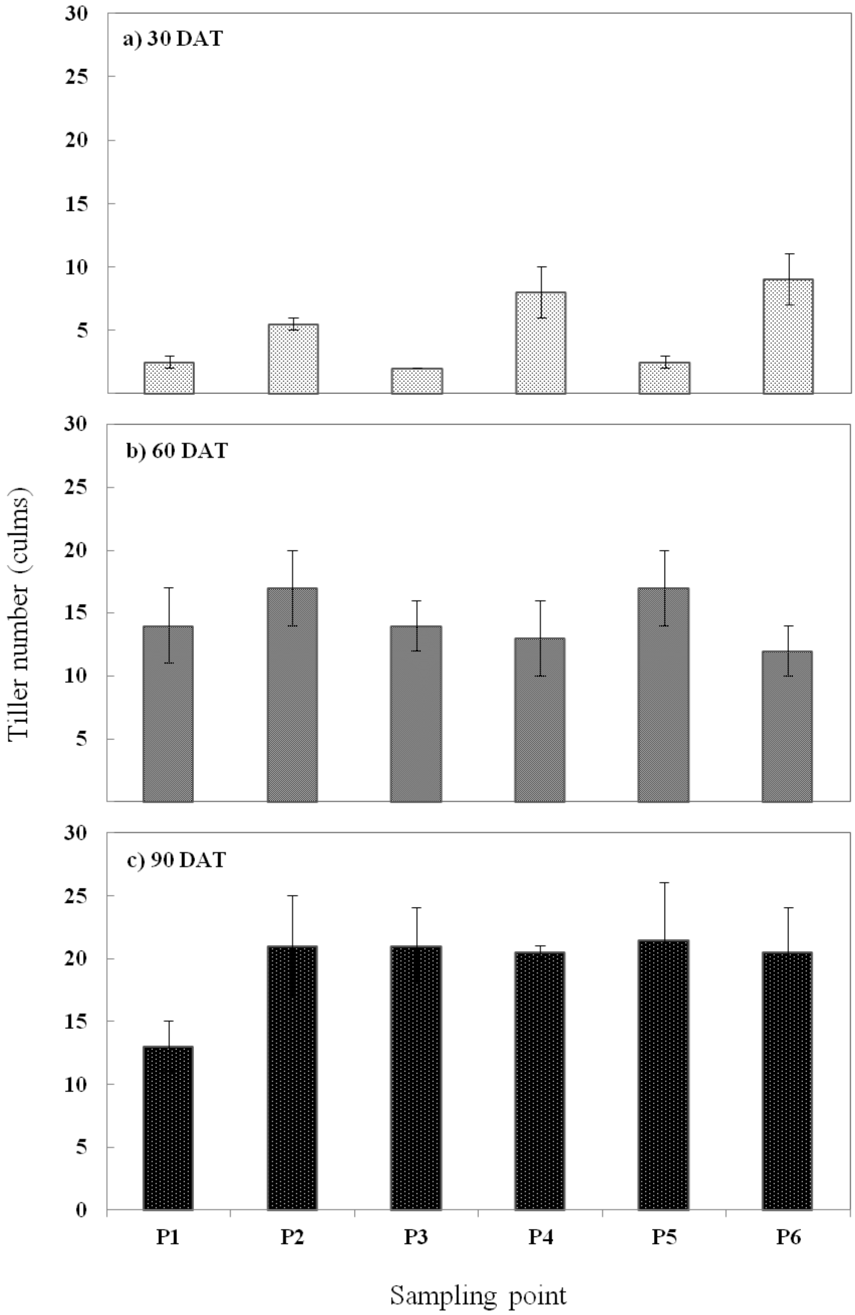

Figure 30 Tiller number (culms) of rice on 6 sampling point at a) 30 DAT, b) 60 DAT, and 90 DAT

2.3.3 Greenhouse gas concentration in soil

Methane concentration in paddy soil increased until 90 DAT and decreased after harvest at all soil depths (Figure 31). The concentration of CH_4 in soil at 90 DAT was significantly higher than rice in the other periods ($p<0.01$) (Figure 32). The average concentrations at 90 DAT were 23.7, 32.8 and 30.5 ppm at 0, 5 and 10 cm soil depths, respectively. After harvested, the average CH_4 concentrations decreased to 5.5, 10.3 and 9.2 ppm at 0, 5 and 10 cm soil depths, respectively. At 5 cm soil depth, the concentrations of CH_4 were higher than at the 0 and 10 cm soil depths during the irrigation period. The lower value was found at 0 cm soil depth. At 30 DAT, 60 DAT and AHV, CH_4 concentrations at the 5 and 10 cm soil depths were significantly higher than those at 0 cm.

Figure 33 shows the average CO_2 concentration in which sampling point during rice growing season. Carbon dioxide concentration in paddy soil during rice growing season ranged from 596-1,935, 1,223-3,054, 3,299-4,494, and 536-820 ppm at 30, 60, 90 DAT, and AHV. The concentration of CO_2 in paddy field increased from 30 DAT to 90 DAT, and then decreased at AHV (Figure 34). At 60 DAT, CO_2 concentration at 0 cm soil depth was higher than at 5 and 10 cm soil depth. Unlike at 90 DAT, CO_2 concentration was higher at 5 and 10 cm soil depth.

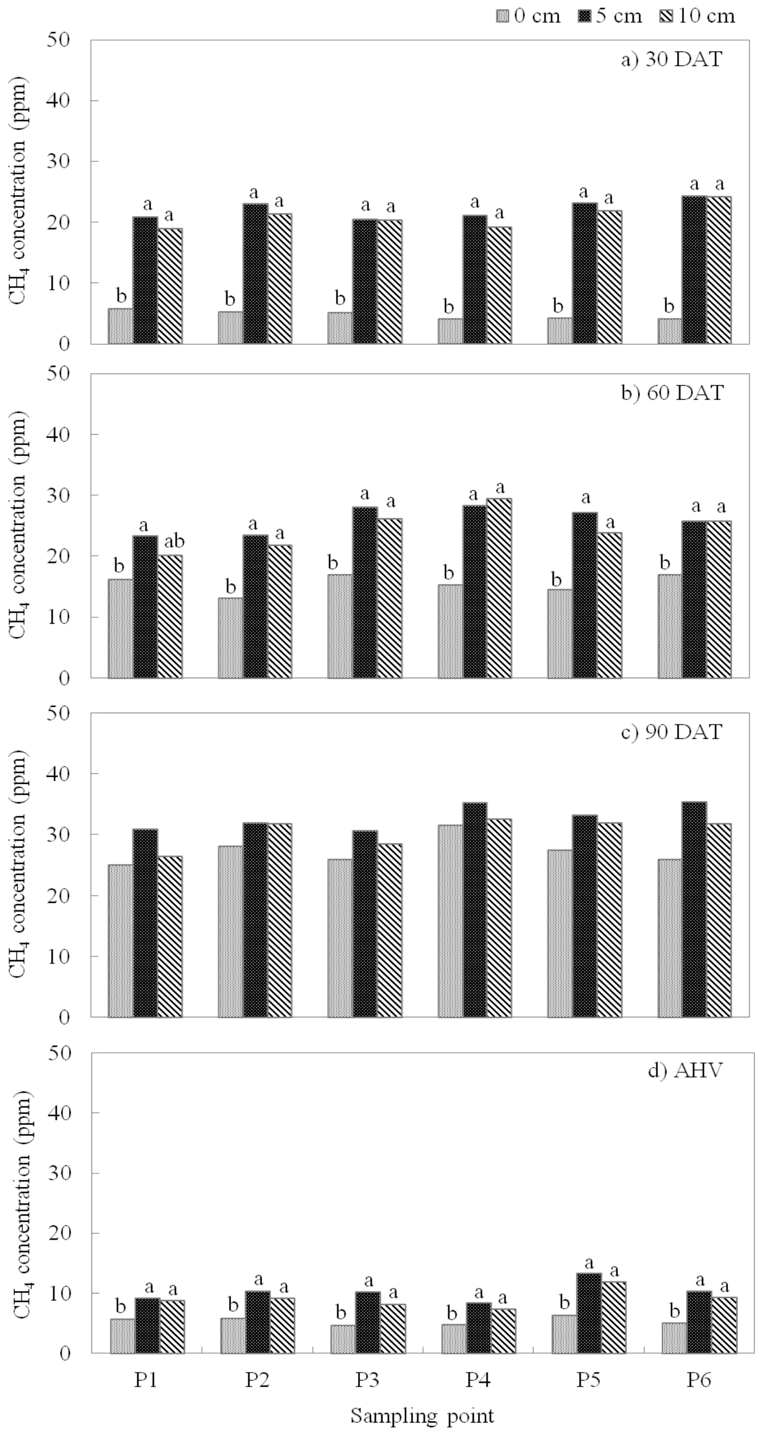

Figure 31 The average of CH_4 concentration at 0, 5 and 10 cm depths from 6 sampling points in each growing stage by using soil gas sampling tubes. Different letters indicated significant differences between measurement depths

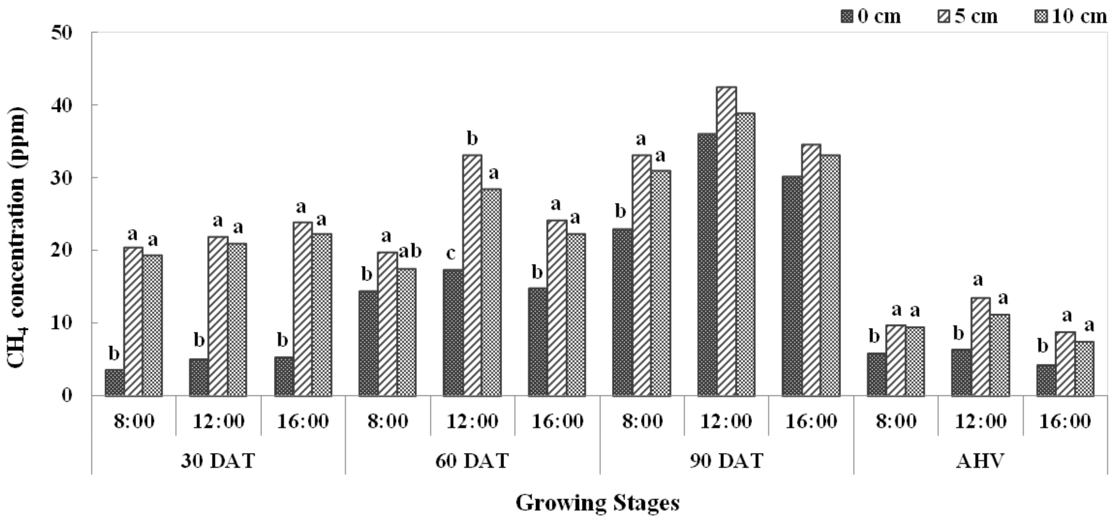

Figure 32 The average of CH_4 concentration from 6 sampling point at 0, 5 and 10 cm depths in each growing stage by using soil gas sampling tubes. Different letters indicated significant differences

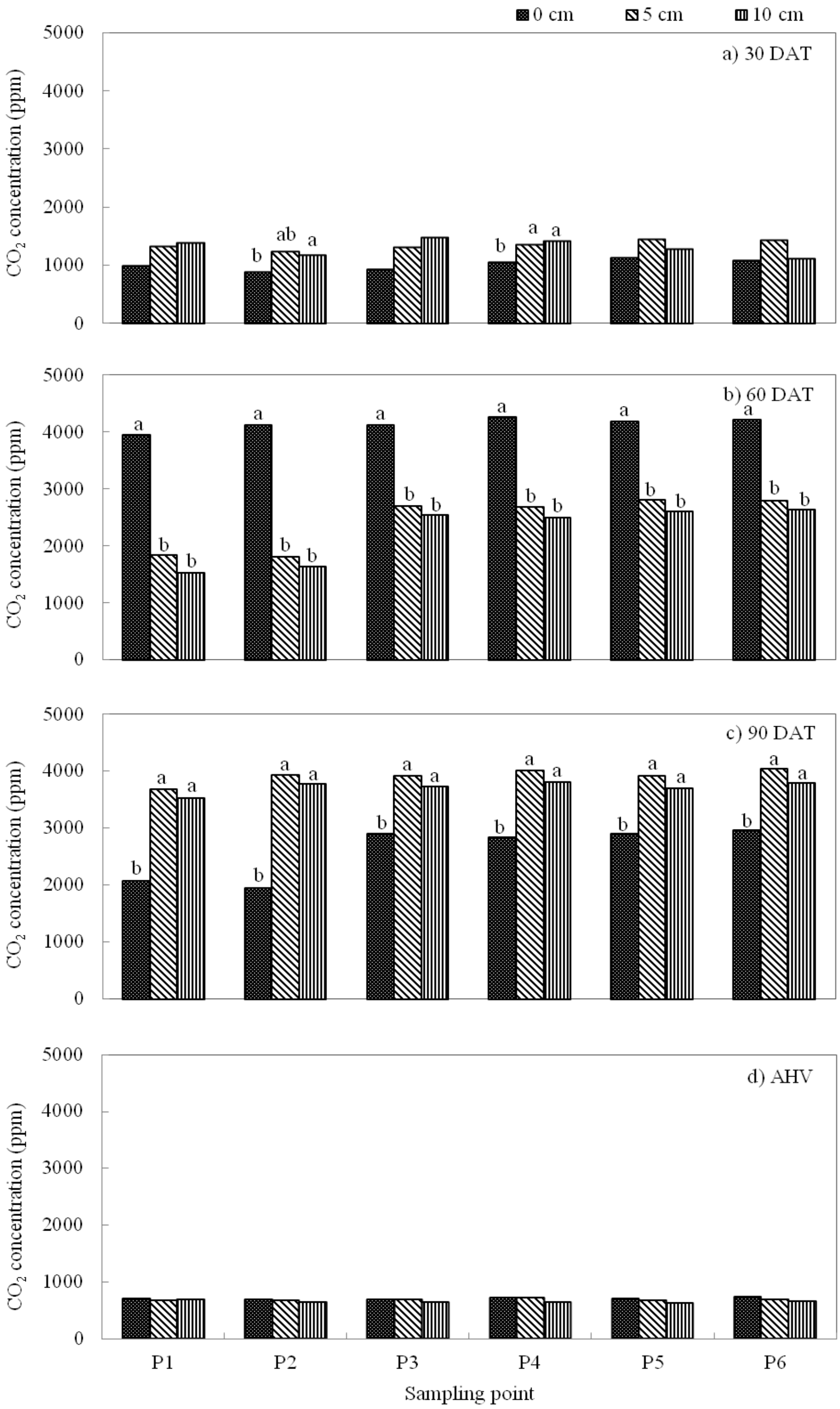

Figure 33 The average of CO_2 concentration at 0, 5 and 10 cm depths from 6 sampling points in each growing stage by using soil gas sampling tubes. Different letters indicated significant differences between measurement depths

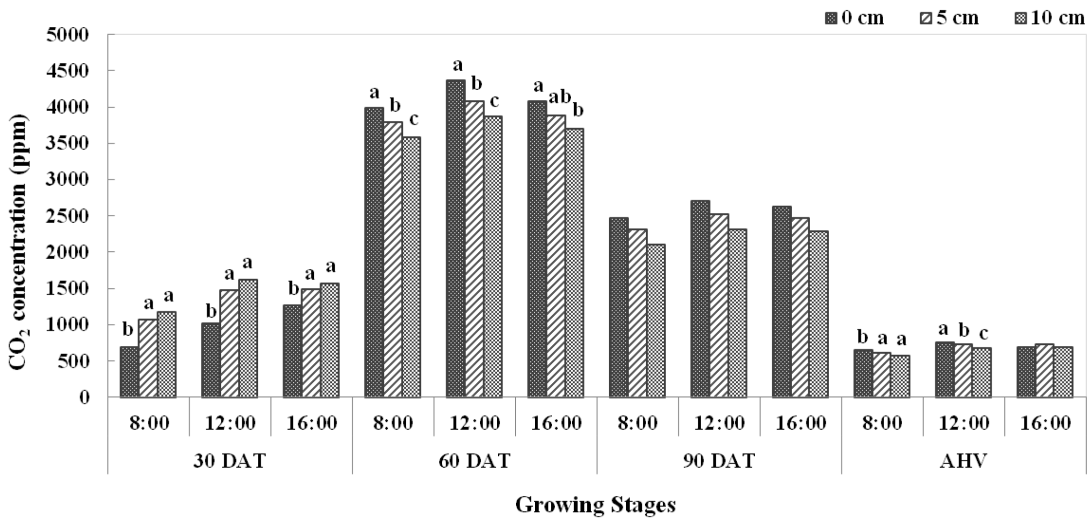

Figure 34 The average of CO_2 concentration at 0, 5 and 10 cm depths in each growing stage by using soil gas sampling tubes. Different letters indicated significant differences.

2.3.4 Greenhouse gas fluxes from soil surface by using CC method

The daily pattern of CH_4 flux start with low values in the early morning and increased gradually until 12:00, then it decreased again in the evening (Figure 35-38). Significant differences ($p < 0.05$) in CH_4 fluxes among the six sampling points were found at 12:00 on 26 July 2014 ($p < 0.01$), 12:00 on 29 August 2014 ($p<0.01$) and 12:00 on 31 August 2014. The highest CH_4 flux value, 47.36 mg CH_4 m^{-2} h^{-1}, was found at sampling point no. 2 at 12:00 at 60 DAT, and the lowest CH_4 flux value, 0.31 mg CH_4 m^{-2} h^{-1}, was found at sampling point no. 5 at 16:00 on 29 October 2014. The mean CH_4 flux values measured by the CC method at 30 DAT, 60 DAT, 90 DAT and AHV were 4.27, 15.27, 16.84 and 1.63 mg CH_4 m^{-2} h^{-1}, respectively.

The variation of CO_2 flux for sampling days from June to November, 2014 are shown in Figure 39-42. The daily pattern of CO_2 flux unlike with the daily pattern of CH_4 flux. By the CO_2 showed high value in early morning and then decreased at noon in all growing season. At 30 DAT, CO_2 fluxes showed maximum in early morning, the minimum (negative values) appears at noon. During the early season (30 DAT) CO_2 flux was small. The CO_2 flux increased and reach highest 90 DAT and then decreased after harvested. The highest CO_2 flux value, 59.11.36 mg CO_2 m^{-2} h^{-1}, was found at sampling point no. 6 at 8:00 at 90 DAT, and the lowest CO_2 flux was -9.87 mg CO_2 m^{-2} h^{-1}, was found at sampling point no. 3 at 12:00 on 4 June 2014. The mean CO_2 flux values measured by the CC method at 30 DAT, 60 DAT, 90 DAT and AHV were 2.25, 25.82, 39.02 and 7.69 mg CO_2 m^{-2} h^{-1}, respectively.

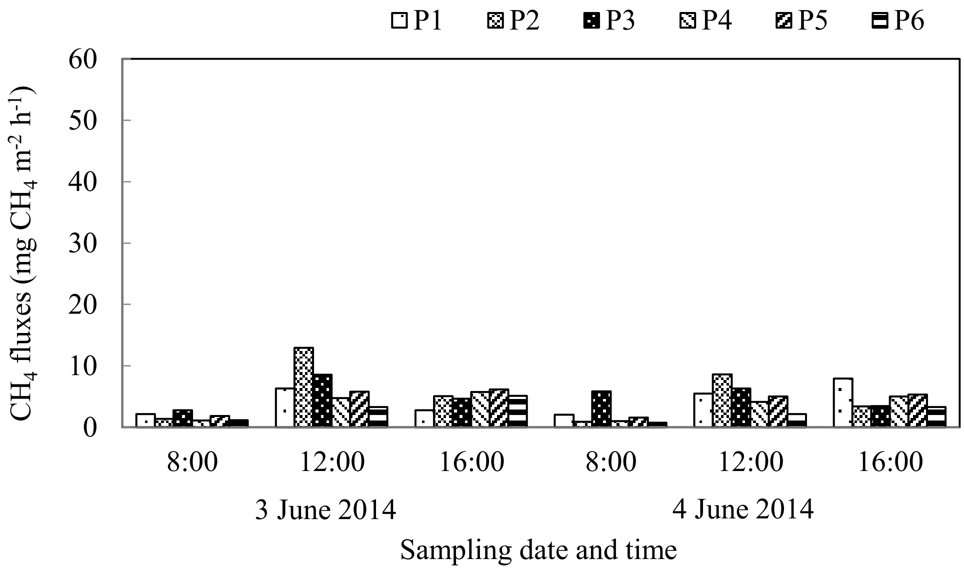

Figure 35 Methane fluxes measured with the closed chamber method (P1-P6) on 3-4 June, 2014 (30 DAT)

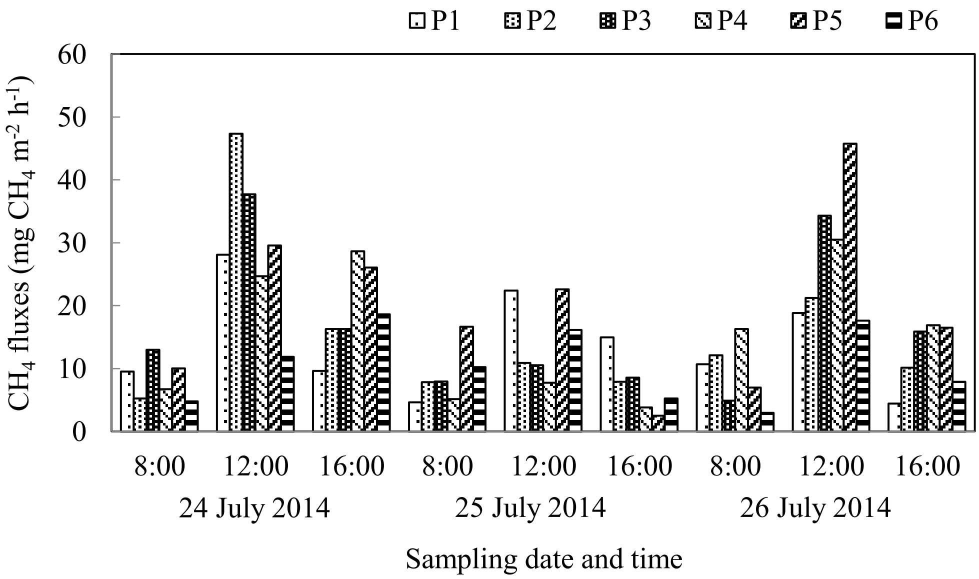

Figure 36 Methane fluxes measured with the closed chamber method (P1-P6) on 24-26 July, 2014 (60 DAT).

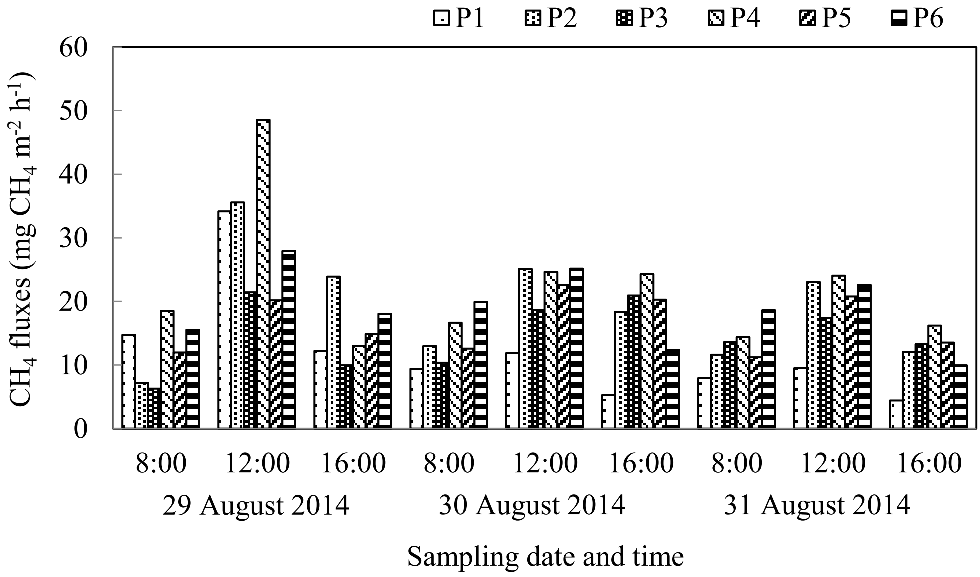

Figure 37 Methane fluxes measured with the closed chamber method (P1-P6) on 29-30 August, 2014 (90 DAT)

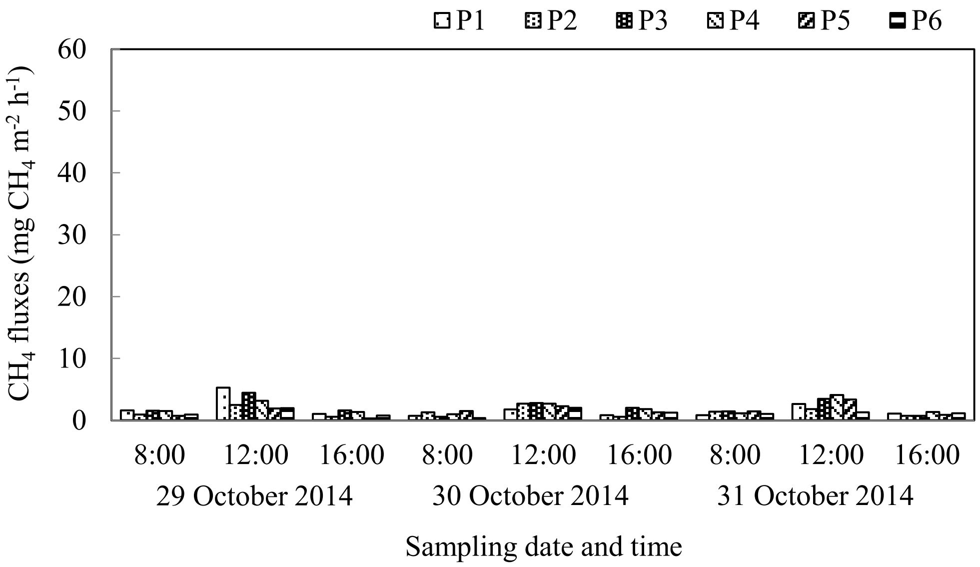

Figure 38 Methane fluxes measured with the closed chamber method (P1-P6) on 29-30 October, 2014 (AHV).

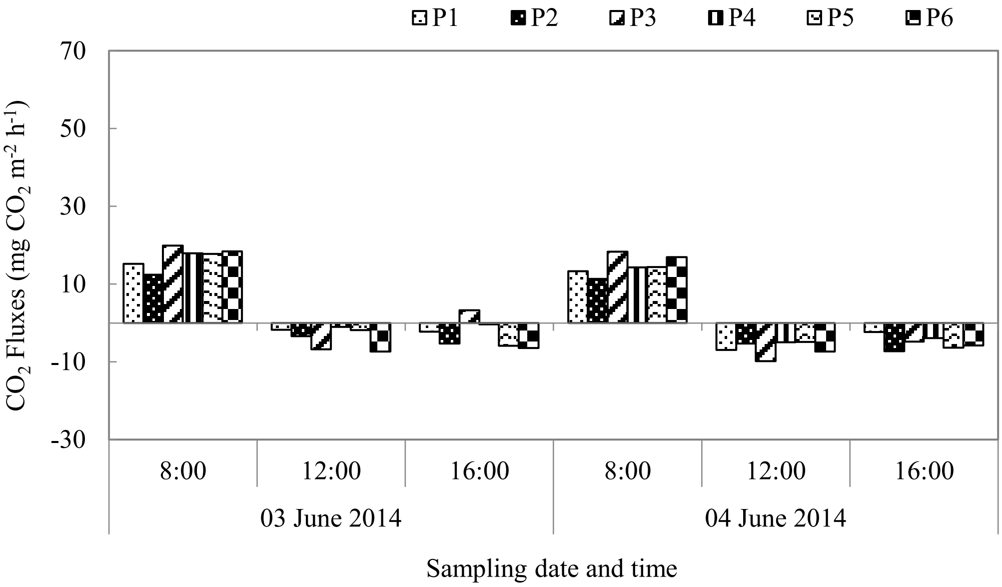

Figure 39 Carbon dioxide fluxes measure with closed chamber method from six sampling point on 3-4 June, 2014 (30 DAT)

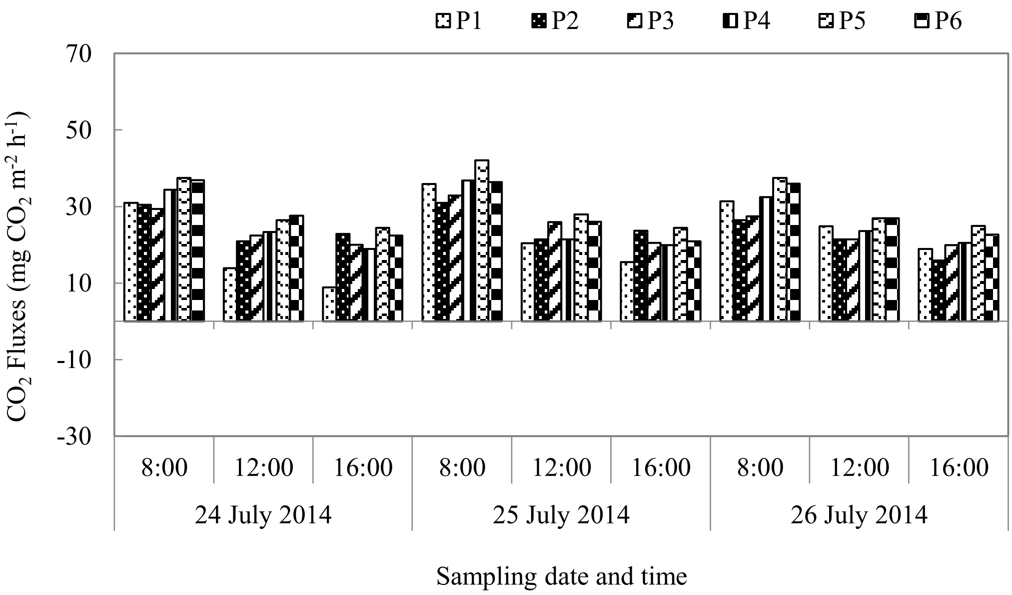

Figure 40 Carbon dioxide fluxes measure with closed chamber method from six sampling point on 24-26 July, 2014 (60 DAT)

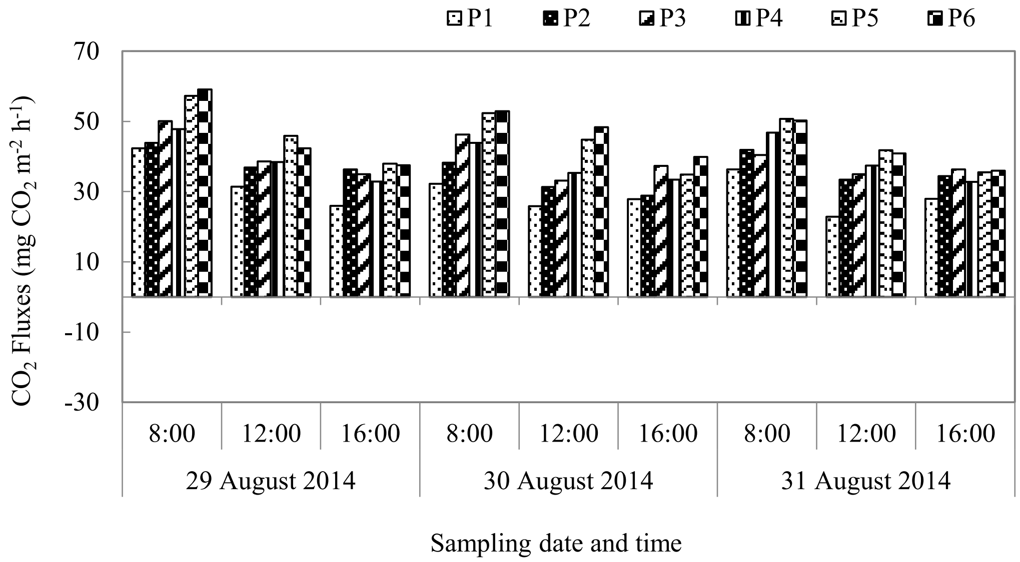

Figure 41 Carbon dioxide fluxes measure with closed chamber method from six sampling point on 29-31 August, 2014 (90 DAT)

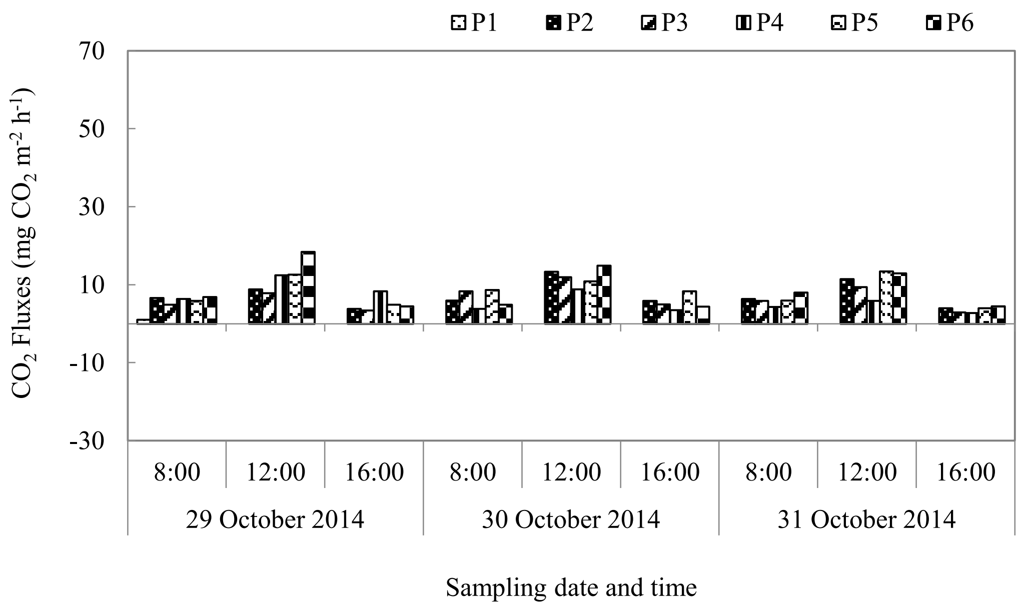

Figure 42 Carbon dioxide fluxes measure with closed chamber method from six sampling point on 29-31 October, 2014 (AHV)

2.3.5 Greenhouse gas fluxes from soil surface by using EC method

Over the course of the rice growing season, the variations in CH_4 flux depend on growing stage and micrometeorological conditions. The CH_4 flux observed in duplicated CC method sampling day shows in Figure 43, 44, 45 and 46. Diurnal pattern of CH_4 flux not same as CC method and difference among sampling day. The average CH_4 flux range from 0.04 to 4.07 mg CH_4 m^{-2} h^{-1}. The amount of CH_4 emitted from paddy field gradually increased from 30 DAT, and reach maximum at 60 DAT. The highest value of CH_4 flux observed was 4.07 mg CH_4 m^{-2} h^{-1} at 8:00 at 60 DAT. The lowest CH_4 flux found at 8:00 at AHV with 0.0 mg CH_4 m^{-2} h^{-1} during dry condition and early winter time.

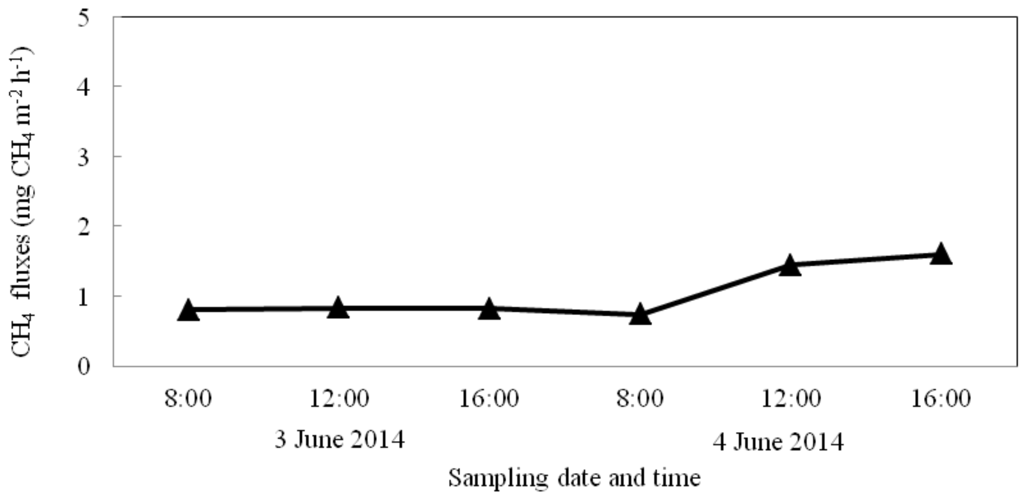

Figure 43 Methane fluxes measure with eddy covariance method in duplicated sampling day with CC method during 3-4 June, 2014 (30 DAT)

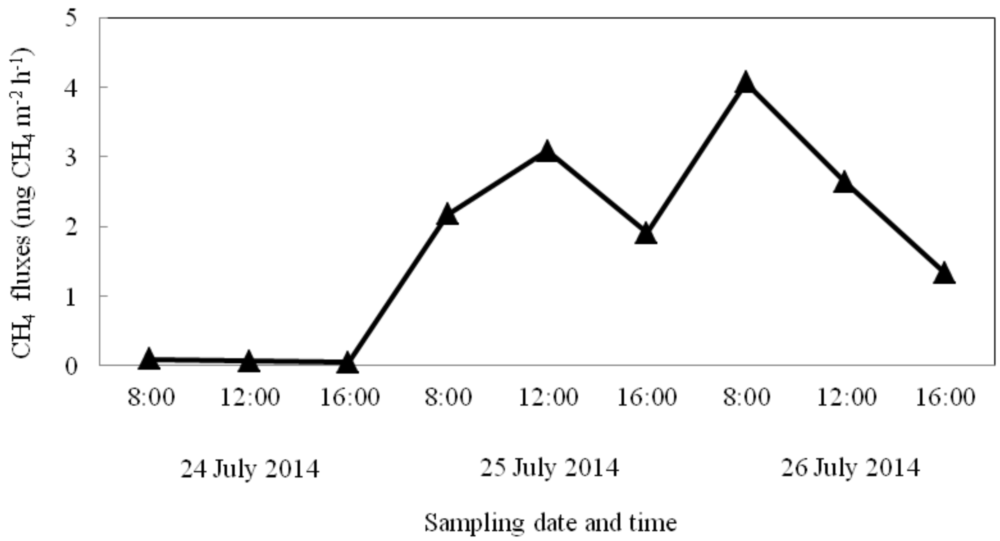

Figure 44 Methane fluxes measure with eddy covariance method in duplicated sampling day with CC method during 24-26 July, 2014 (60 DAT)

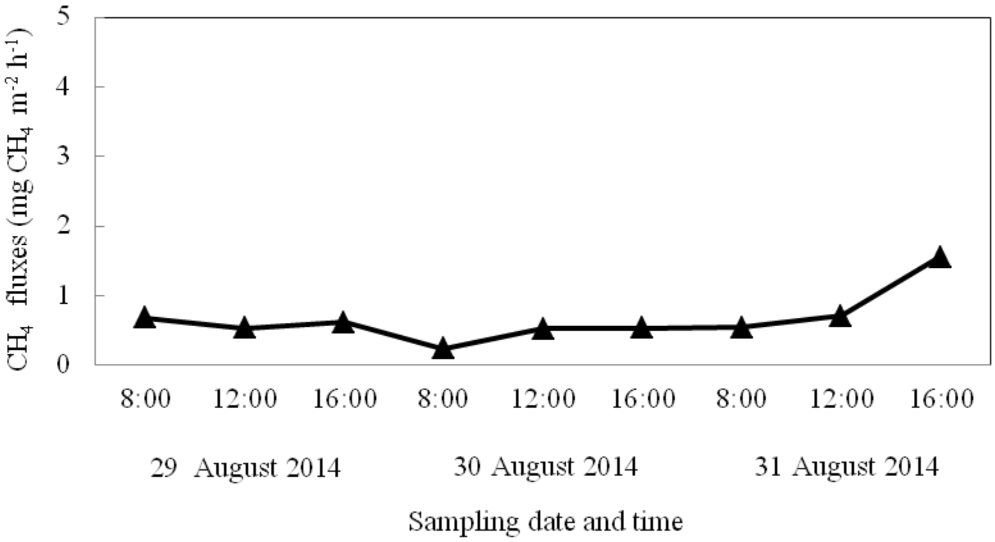

Figure 45 Methane fluxes measure with eddy covariance method in duplicated sampling day with CC method during 29-31 August, 2014 (90 DAT)

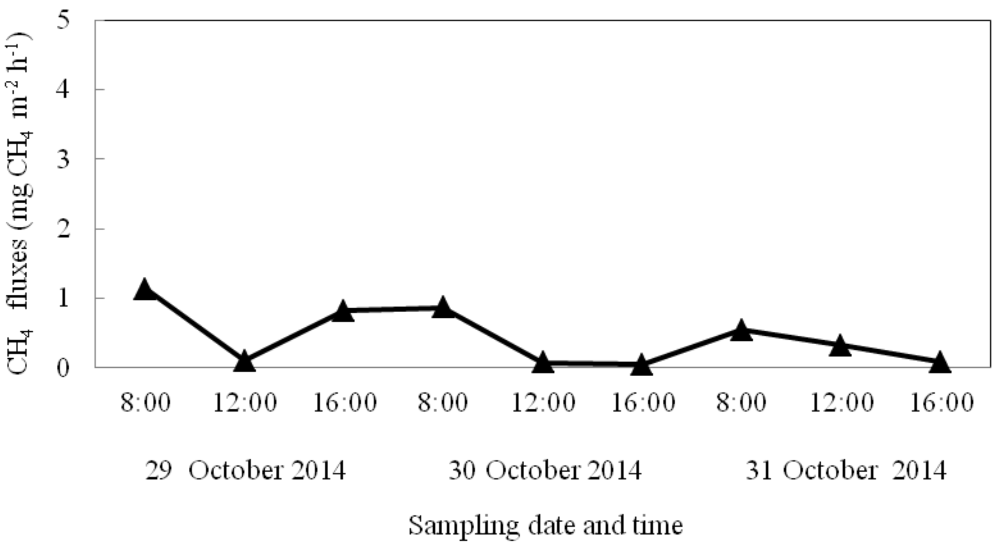

Figure 46 Methane fluxes measure with eddy covariance method in duplicated sampling day with CC method during 29-31 October, 2014 (AHV)

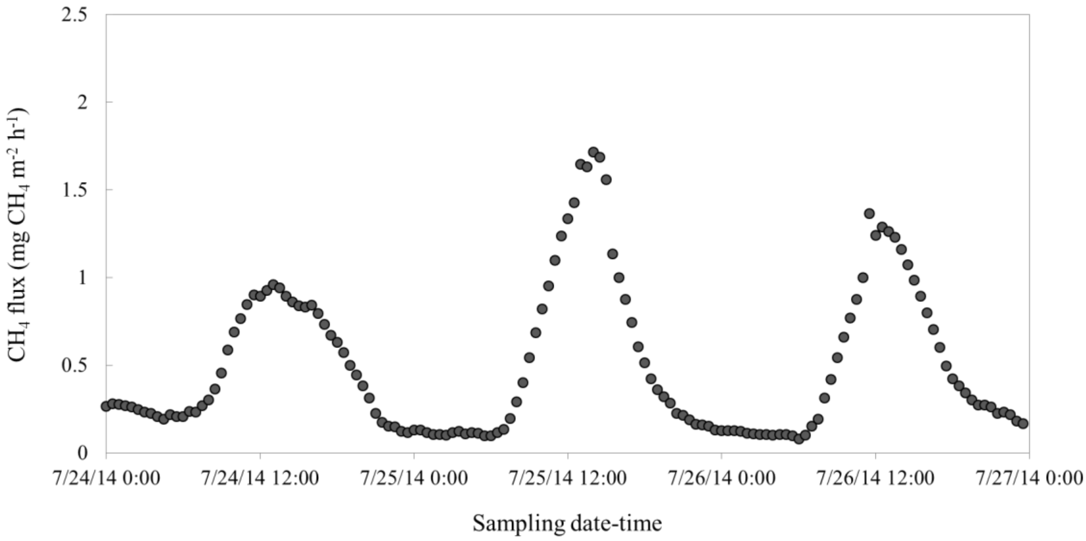

Figure 47 The daily pattern of CH_4 fluxes measured with the eddy covariance method from experimental site at 24-26 June, 2014

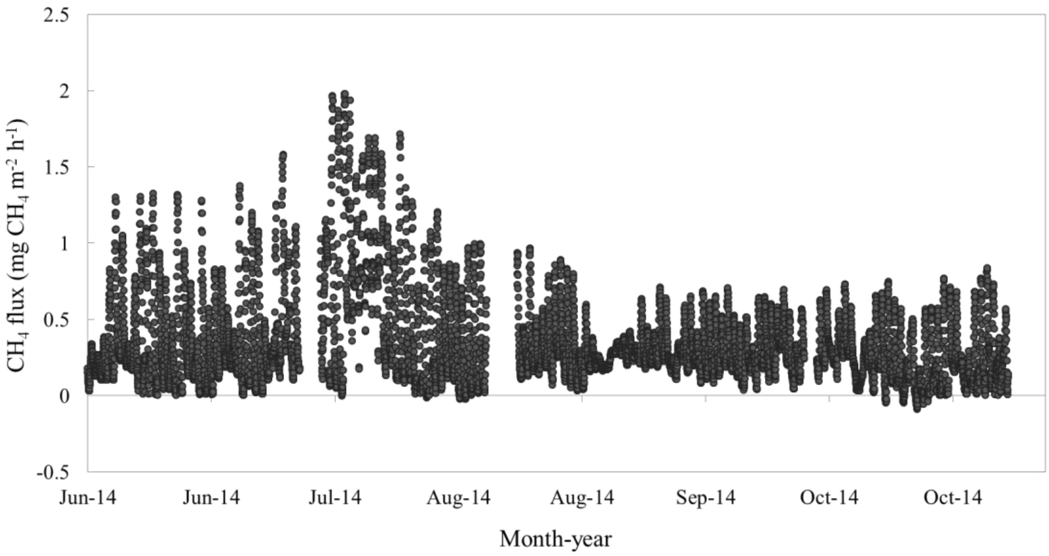

Figure 48 The seasonal pattern of CH_4 fluxes measured with the eddy covariance method from experimental site during June to October, 2014

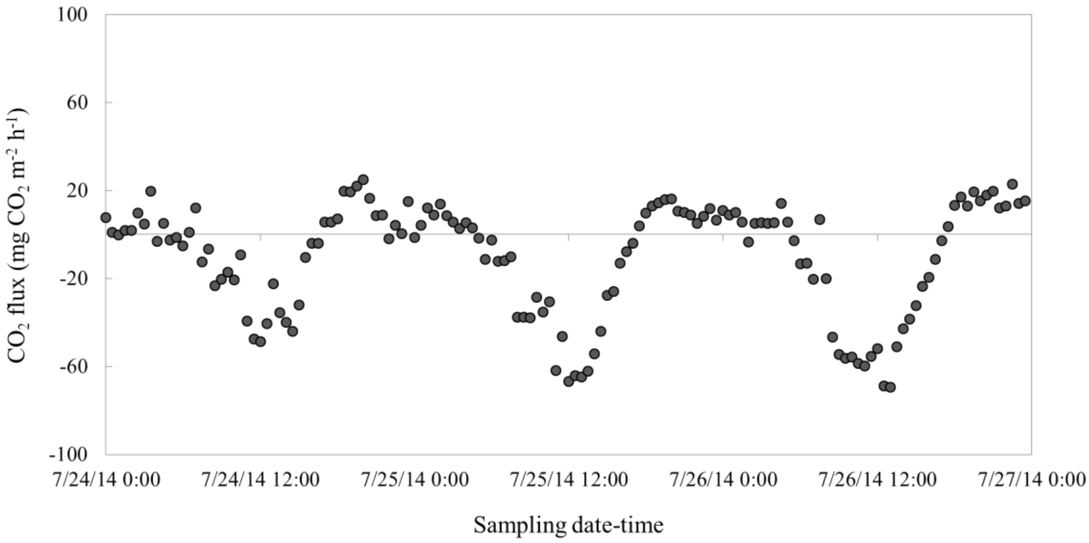

Figure 49 The diurnal trend of CO_2 fluxes measured with the eddy covariance method from experimental site at 24-26 June, 2014

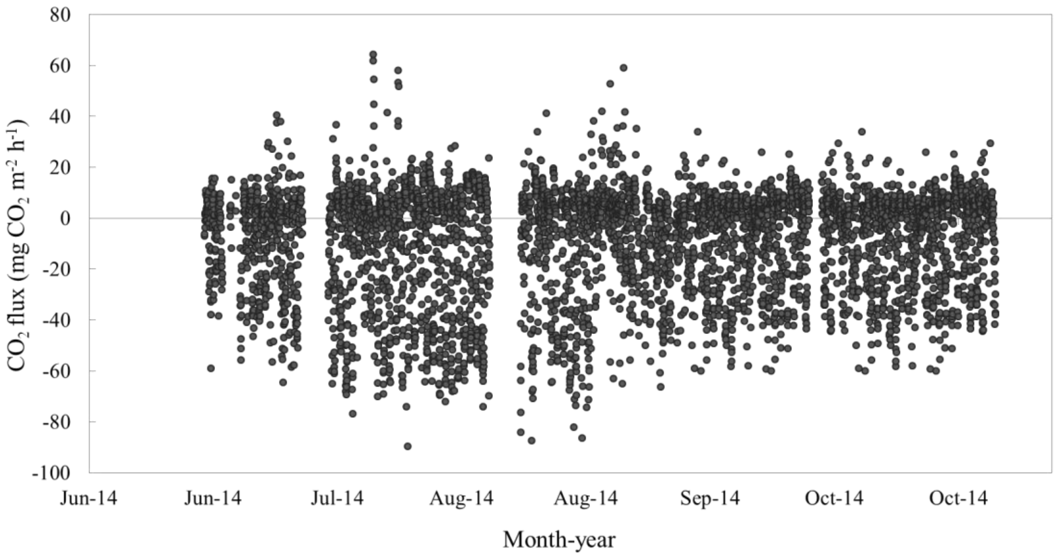

Figure 50 The seasonal pattern of CO_2 fluxes measured with the eddy covariance method from experimental site during June to October, 2014

2.3.6 Influence of environmental factors on greenhouse gas fluxes

To evaluate the collective role of environmental factors on CH_4 flux, stepwise multiple regression analysis was used for the CH_4 fluxes as measured by the CC method (Table 4). The correlation equation coefficient and coefficient of determination were calculate as $R = 0.67$ and $R^2 = 0.44$, respectively. The obtained f value was significant at $p < 0.001$ level. The environmental factors together explained 44% of the CH_4 flux. The results relationship between the environmental factors showed that there was a significant relationship between CH_4 flux and pH, Ta_Eco, Ts_20 cm and the RH variable. Moreover, pH, EC, TC, SOM, NH_4^+, NO_3^-, plant height, tiller number, Rn, Ta_Eco, Tw_Eco, Ts_10 cm, Ts_CC, G, RH and WS had positive effects on the variable of increasing CH_4 flux. There results showed that CH_4 flux was mainly driven by Ta_Eo ($\beta = 2.960$) and Ts_10 cm ($\beta = 2.536$), followed by RH ($\beta = 1.252$).

Table 4 Stepwise multiple regression analysis with environmental factors for surface CH_4 flux as measured using the CC method

Predictors	Stepwise regression ($R = 0.67$, $R^2 = 0.44$, $F = 7.370$, $p < 0.001$)			
	B	SE	β	p
Constant	-2929	1179	-	0.140
pH	365	131	0.465	0.006
Electrical conductivity (EC)	3.14	4.44	0.056	0.481
Total Carbon (TC)	4.81	7.45	0.175	0.519
Total Nitrogen (TN)	-96.2	116	-0.304	0.410
C/N ratio	-41.1	21.7	-0.303	0.059
Soil Organic Matter (SOM)	18.9	14.6	0.207	0.199
Ammonium ion concentration (NH_4^+)	517	581	0.356	0.376
Nitrate ion concentration (NO_3^-)	1.08	13.6	0.016	0.937
Plant height	0.26	1.15	0.046	0.823
Tiller number	3.67	1.99	0.161	0.067
Net radiation	0.18	0.07	0.308	0.016
Air Temperature inside CC	-0.30	1.47	-0.018	0.840
Soil Temperature inside CC	7.34	3.47	0.265	0.036
Air temperature in ecosystem	66.8	18.3	2.960	0.000
Soil temperature at 0 cm depth	-78.0	20.3	-3.995	0.000
Soil temperature at 5 cm depth[a]	-	-	-	-
Soil temperature at 10 cm depth	72.2	46.7	2.536	0.124
Soil temperature at 20 cm depth	-87.8	46.5	-2.502	0.061
Water temperature in ecosystem	13.1	6.67	0.879	0.051
Ground heat flux	4.17	1.93	0.754	0.033
Relative humidity	12.1	3.65	1.252	0.001
Wind speed	27.6	26.8	0.149	0.303

Note: β = standardized regression coefficients, B = unstandardized regression coefficients, SE = standard error. A Percent of variance in the predictor that cannot be accounted for by the other predictors.

2.3.7 Influence of rice growth characteristic on greenhouse gases fluxes

During rice cropping season plant height and tiller number was increasing after transplanting date. When plant height and tiller number was increased which was significantly related with high CH_4 emission rate according to linear regression analysis (Figure 51 and 52). The plant height and tiller number showed significantly positive correlation with CH_4 fluxes with $R^2 = 0.4739$ and 0.6596, respectively.

The correlation between plant height and tiller number of rice and CO_2 flux in paddy field shown in Figure 53 and 54, respectively. The plant height and tiller number were significantly and positive related with CO_2 flux by a simple linear regression model ($R^2 = 0.7643$ and 0.7777). The average daily CO_2 flux in each growing stages increased systematically with increasing plant height and tiller number.

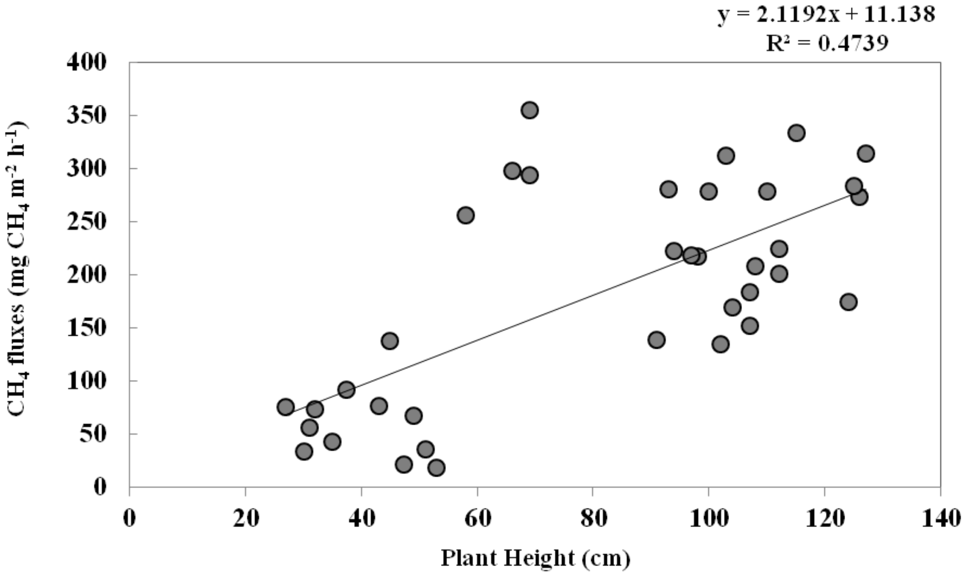

Figure 51 The correlation between CH_4 fluxes measure by CC method and plant height during growing season (June to October, 2014)

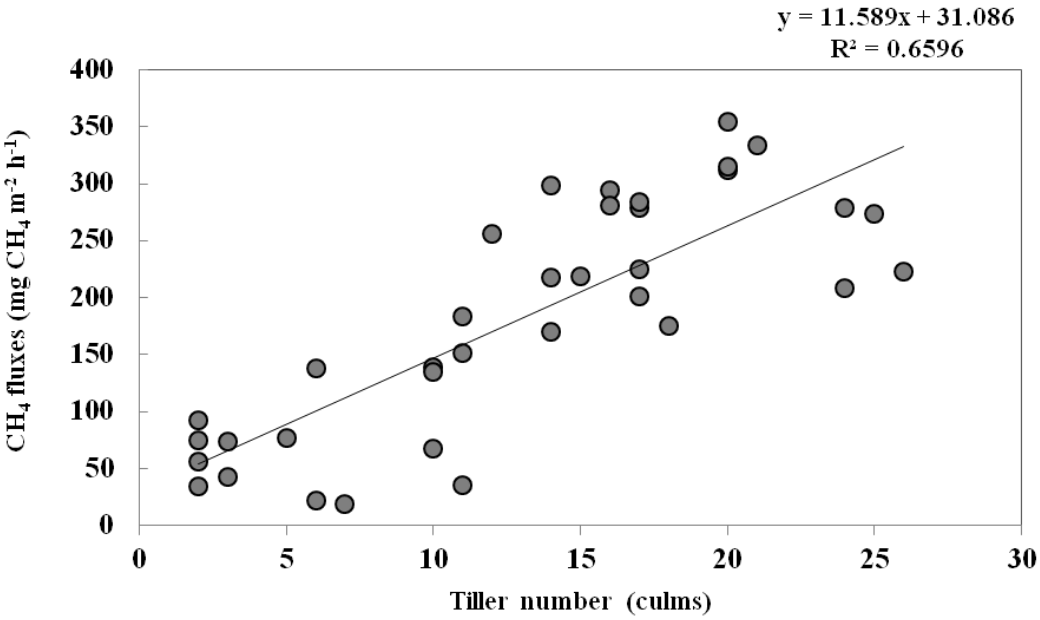

Figure 52 The correlation between CH_4 fluxes measure by CC method and tiller number during growing season (June to October, 2014)

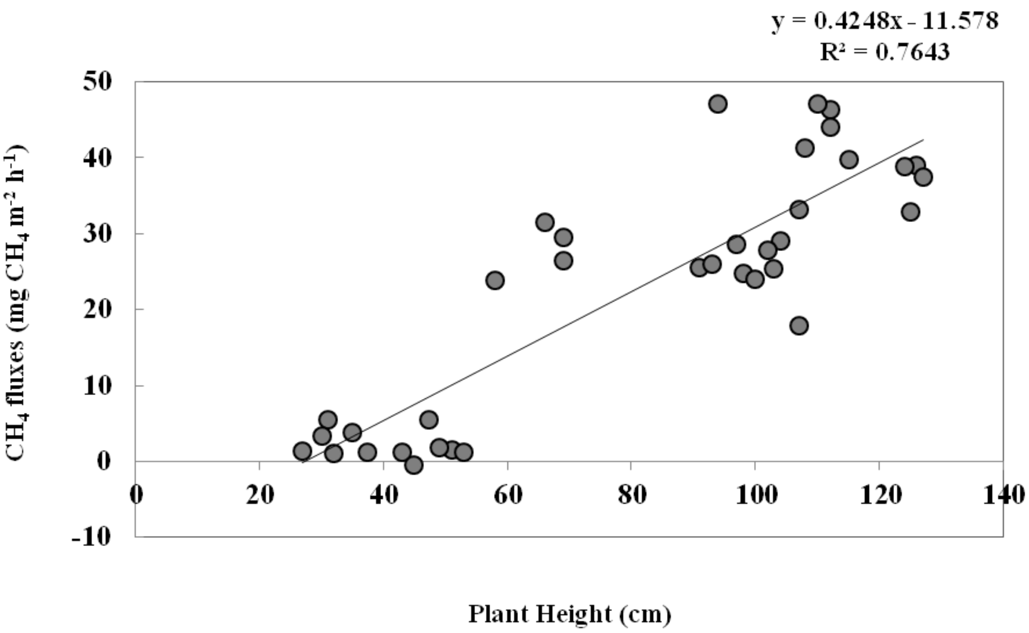

Figure 53 The correlation between CO_2 fluxes measure by CC method and plant height during growing season (June to October, 2014)

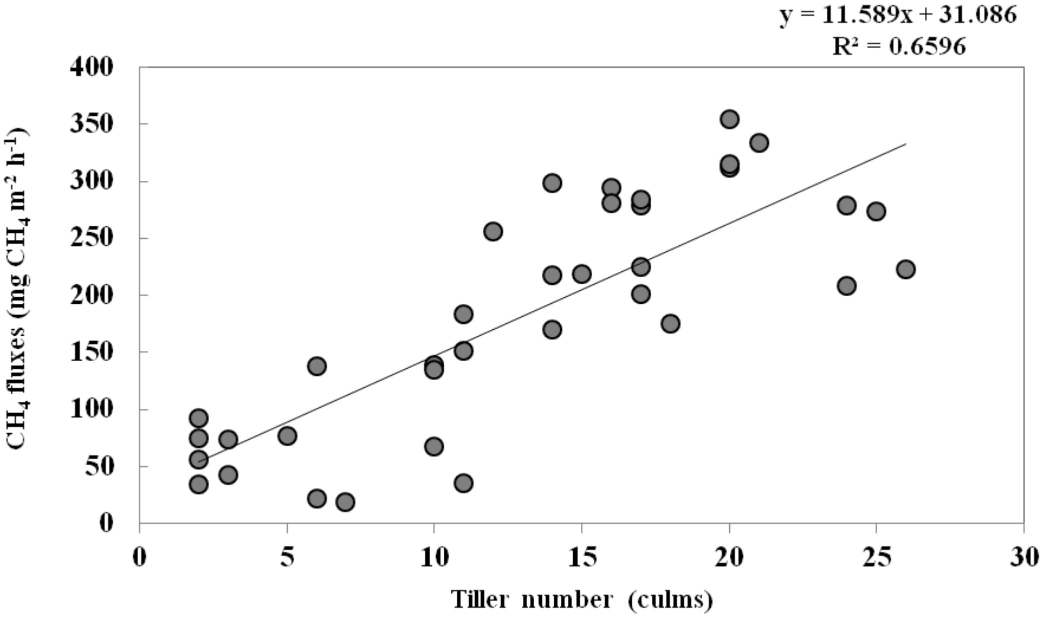

Figure 54 The correlation between CO_2 fluxes measure by CC method and tiller number during growing season (June to October, 2014)

2.3.8 Comparison of greenhouse gas emission by using closed chamber and eddy covariance method

During rice growing season, the mean CH_4 fluxes values measured by the CC method at 30 DAT, 60 DAT, 90 DAT, and AHV were 4.27, 15.27, 16.84, and 1.63 mg CH_4 m^{-2} h^{-1}, respectively (Figure 55, 56, 57 and 58). The CH_4 fluxes measured using the CC and EC method were compared throughout the rice growing season. The CC flux values were significantly greater ($\alpha = 0.05$) than the EC flux values at 30 DAT, 60 DAT, 90 DAT and AHV with *p*-values = 0.013039, 0.00147, 0.00004, and 0.00338, respectively. The mean CH_4 fluxes values as measured by the EC method were 1.09, 1.71, 0.66 and 0.04 mg CH_4 m^{-2} h^{-1}, respectively. The average CH_4 fluxes calculated from the CC method were 58%, 81%, 94%, and 57% higher than those of the EC method at 30 DAT, 60 DAT, 90 DAT and AHV, respectively. The CH_4 fluxes measurements using the CC and EC methods were compared during the cropping season. CC flux was significantly greater ($\alpha = 0.05$) than the EC flux at 30 DAT, 60 DAT, 90 DAT, and AHV. However, the results showed the highest CH_4 fluxes at 90 DAT, corresponding to the heading stage of rice production.

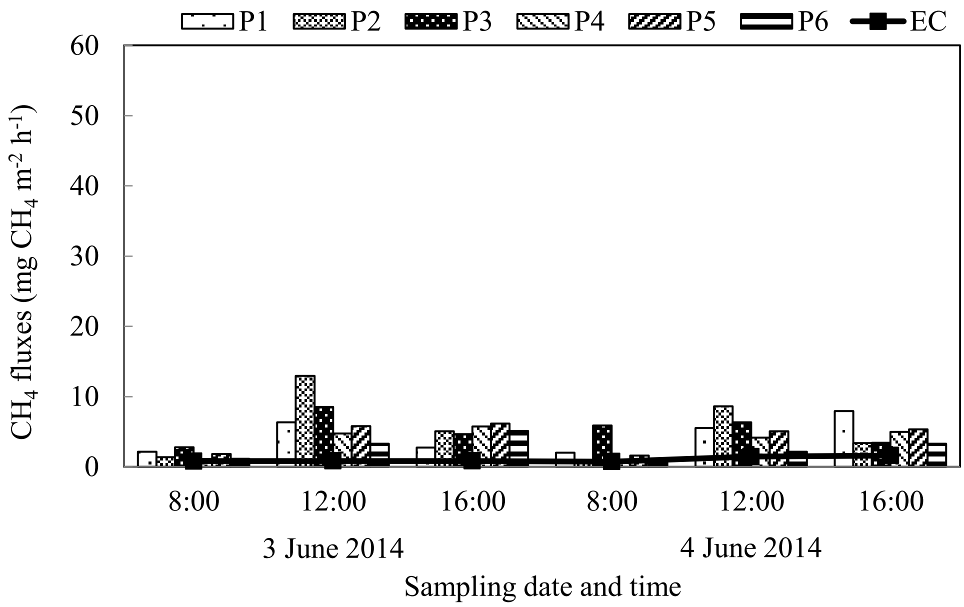

Figure 55 Methane fluxes measure with the CC method (P1-P6) and EC technique at 3-4 June, 2014 (30 DAT)

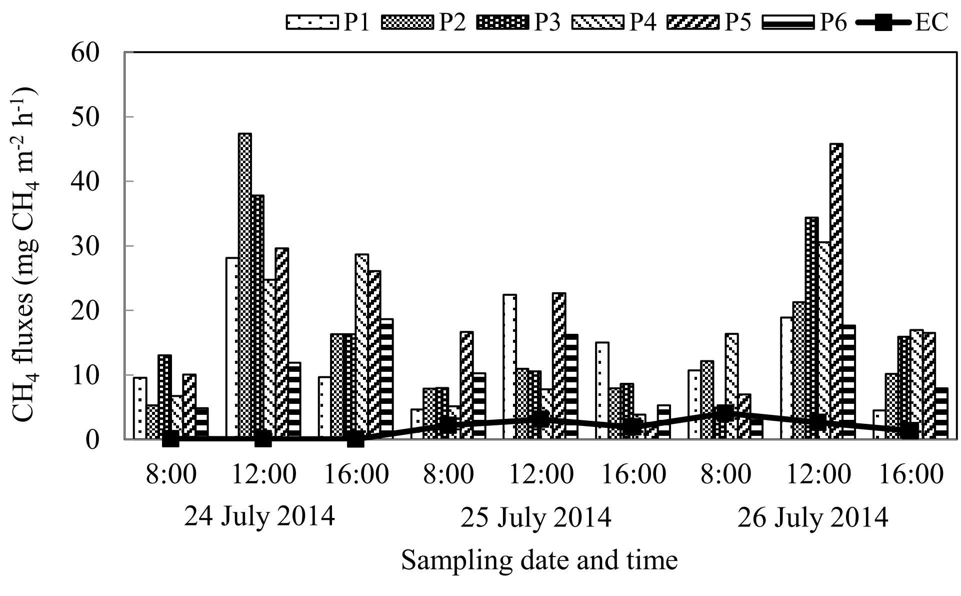

Figure 56 Methane fluxes measure with the CC method (P1-P6) and EC technique at 24-26 July, 2014 (60 DAT)

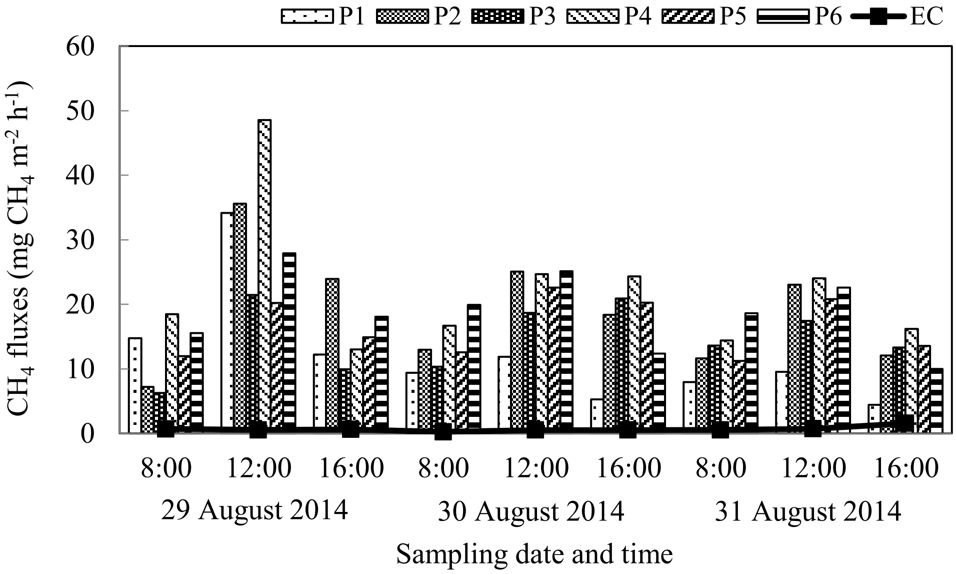

Figure 57 Methane fluxes measure with the CC method (P1-P6) and EC technique at 29-31 August, 2014 (90 DAT)

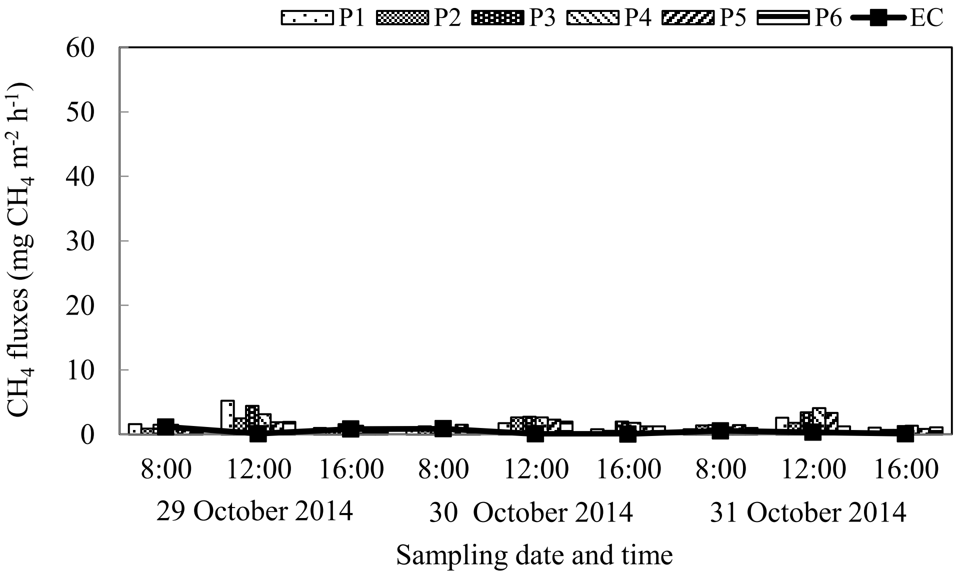

Figure 58 Methane fluxes measure with the CC method (P1-P6) and EC technique at 29-31 October, 2014 (AHV)

2.4 Discussion

2.4.1 Diurnal and seasonal variation in greenhouse gas emission

From the results we found CH_4 flux was lower in the early morning and highest at noon, then decreased again in the evening (Figure 35, 36, 37 and 38). Daily variations of CH_4 flux showed similar emission pattern for all growing stage. The diurnal pattern of CH_4 flux was similar to those of net radiation, air temperature, water temperature and soil temperature, which increased from the morning to the afternoon and decreased in the evening (Figure 21, 22, 23 and 24). Multiple regression analysis showed that air temperature, water temperature and soil temperature had influence on CH_4 concentration in soil and CH_4 flux (Table 4). This because increased net radiation increased the air, water and soil temperatures. Higher temperature accelerates CH_4 production by promoting methanogenic bacteria activity in soil and substrate availability. High temperatures increased CH_4 sources and capacity of CH_4 transport (Neue et al., 1997). The maximum transpiration rate on midday coincided with the midday CH4 flux maximum and air and leaf temperatures and that transpiration rate was driven by the temperature difference between leaf and atmosphere, in accordance with changing of light density (Chanton et al., 1997; Dacey, 1980).

Methane flux was low in early growing stage, increased and became highest in the middle of the growing season, and then decreased after harvest (Figure 35, 36, 37 and 38). Flux dynamics throughout the day were also higher at 60 DAT and 90 DAT compare to those at 30 DAT and after harvest. Due to the development process of rice, high root exudate and root litter are available as substrate for methanogenic bacteria, and allow transport through the rice plant to the atmosphere (Nouchi et al., 1994). The number of methanogenic bacteria increased with plant growth (Bosse and Frenzel, 1997). Previous studies indicated that the total amounts of CH_4 production at the mid-season stage ripening stage range from 76-92% (Yang and Chang, 1999). High root exudate and high metabolic activity due to high soil temperature favoured methane emission, and in this study, the developed rice plant induced CH_4 transport more easily than did the other growing stage. Not only soil condition but also meteorological condition favoured methane emission at 60 DAT and 90 DAT.

Molecular diffusion and ebullition of CH_4 are increased as soil temperature increased (Alberto et al., 2014). The variation in solar radiation drove the differences in air-leaf temperature and humidity and are associate with convection flow in plants. Methane emissions from soil to the atmosphere are related to stomatal opening or convection flow in plants (Wang and Han, 2005). The strong radiation and high temperature conditions influenced CH_4 flow through the rice plant. Additionally, tiller number was found to be positive correlation with CH_4 flux (Table 2) because CH_4 is released from pores connection in the junction of the leaf sheath and the culm (Neue et al., 1997).

Although a mid-season drain during the growing season can improve aeration of the soil, it interferes with anaerobic conditions, thus leading to a decrease in CH_4 emission (Zhang et al., 2012). The finding in this study indicated that after the mid-season drain the CH_4 flux was slightly higher than before the mid-season drain (Figure 35, 36, 37 and 38). This might be related to the short period of the mid-season drain and the fact that some moisture still existed in the soil, even after drain. Thus methanogen formation resumed (Tariq et al., 2017).

However, the results indicated that air temperature in the ecosystem and soil temperature at 0 cm soil depth should have had a regression correlation with CH_4 flux. Both parameters were highly significant factors, with coefficient and standard effects being the most pronounced. This was similarly observed in paddy rice fields (Meijide et al., 2011), and these results showed a strong correlation between soil temperature and CH_4 flux during the vegetative period.

2.4.2 Influence of sampling position on greenhouse gas flux

Previous study, observed that average CH_4 flux was lower at positions closed to the irrigation channel ant that high emission rate occurred at the end of the paddy rice cascade in the summer season (Oo et al., 2013). Different sediment deposition pattern influenced physical and chemical properties of soil depending on field position. In this study, no significant trend in CH_4 flux were found for inlet or outlet positions (Figure 19). This may be due to the low water flow velocity in our experiment field, since the slope differences between inlet and outlet position within the field was very low. Thus only EC and soil TN differed among the positions and had no influence on the CH_4 emission rate as well as soil CH_4 concentration (Figure 16). The variability in the sampling CH_4 fluxes points were within the range of individual chamber difference (Bosse and Frenzel, 1997).

2.4.3 Comparison between the CC and EC in this study

CH_4 flux measured by CC method resulted from direct CH_4 emission from the soil and rice plant, the large increase in gas concentration with minor influences from atmosphere outside the chamber (Yang and Chang, 1999). The chamber completely covers the ecosystem during the measurement. Weak development of stratification results in higher fluxes compare to EC (Riederer et al., 2014). On the other hand, EC method measures mixed fluxes from a wide area which are influenced by atmospheric turbulence (Alberto et al., 2014). The different scale and low-frequency flow pattern of turbulent may cause differences between CH_4 fluxes measured by CC and EC method (Wang and Han, 2005). The CH_4 fluxes measured by EC method are substantially lower than CC method, especially at measurements at high gas emission rates (Zhang et al., 2012).

In this study, CC fluxes showed 58 to 90% higher CH_4 flux values than EC method (Figure. 55, 56, 57 and 58). The percentage of difference between CC method and EC method in this study was larger than previous studies that showed 30% (Meijide et al., 2011) or 7.6% higher values for CC compared to EC (Yu et al., 2013). The large percentage different between this study to previous studies can be attribute to the higher air and soil temperature in this study site, hence higher CH_4 fluxes using CC method. In addition, the chambers in this study were located at 3, 48, 20, 55, 90 and 123 m from the EC tower, whereas Meijide et al. (2011) place in two groups at 25 and 45 m from EC tower. Even though, no clear trend was found for the field position, the heterogeneity of the sampling points was much higher in our study compare to (Meijide et al., 2011), even though our field was uniformly managed.

Reth et al. (2005) reported that the footprint analysis was useful to show the influence of assimilation processes on the EC tower and the differences between CC and EC method due to the internal boundary layer effects, which occur when the wind flow over the different surface properties. The possible reason for the mismatch of the observation between CC and EC method, is that the CC method measure fluxes from a plot with optimal develop of plant, while EC method combines fluxes from area of the field where the vegetation might not be homogeneously developed (Meijide et al., 2011). Lewicki et al. (2008) reported that the fluxes from CC method are not possible to characterize spatial-variations in source fluxes on the time scale of EC method. While no correlation was found for average CH_4 flux from CC and EC method, the scale up CH_4 flux using CC method according to Sachs et al. (2010) showed strong correlation with the EC flux (R^2 = 0.95; p-values = 0.02), showing that both methods are useful to show the seasonal trend. While daily fluxes are 21.1 g CH_4 m^{-2} h^{-1}, seasonal fluxes are 12.5 g CH_4 m^{-2} h^{-1}. The diurnal changes in environmental condition driven by daily fluxes in solar radiation, air temperature, soil temperature (Meijide et al., 2011).

Chapter 4: Conclusions

Monitoring the variation of the greenhouse gas fluxes from rice paddy field by using closed chamber method and eddy covariance technique to understanding the variation of greenhouse gas exchange from paddy fields. The conclusions of this research are following:

1. Spatial-temporal variation in greenhouse gas among rice growing stage was observed in this study. The variation of CH_4 concentration and CH_4 flux pattern was similar for all growing stage. There was significantly difference in greenhouse gas flux between rice growing season. Methane flux was lower in early growing stage (30 DAT), increased and became highest in the middle of the growing season (60 DAT), and then decreased after harvest. Due to the increased of micrometeorological factor including net radiation, air temperature and soil temperature. Carbon dioxide flux monitored was higher in early morning then deceased at noon due the plant photosynthesis. The growth stage of rice modifies significantly the response of CO_2 flux.

2. Greenhouse gas flux results were conducted by CC and EC method to understand how both methods deviate and how the results can be harmonize. When compare both methods, the daily variation in CH_4 flux from both methods showed similar emission pattern for all growing stage. The variation in CH_4 flux during growing season showed significant correlation, as both methods scale up to the same spatial scale. The results from the CC method was much higher than that of the EC method and tended to overestimated due to the inclusion of optimally grown rice plants at high temperature for flux measurements, and the EC method aggregated different sourced and masked the individual processes behind the fluxes at each point. To capture the heterogeneity with in

the field, the CC method is predicated on its mobile facility and direct link to measurement point. With the analysis of continuous measurements that show the general trend of a large area, the EC method has a strong advantage. The different strengths and weakness of the CC and EC methods can complement each other, and the use of both methods together leads to more understanding of CH_4 emissions from paddy fields.

Chapter 4: References

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