Doctoral Thesis

Mechanism of Greenhouse Gases Emission from Paddy Field with Environmentally Sustainable Rice Growing Method
(温室効果ガス排出から見た環境保全的稲作法のメカニズム)

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Dedication

This work is dedicated to my late father, Lal Bahadur Pun, my mother Mrs. Jani Pun, my uncle and aunt Mr. Yam Bahadur Pun and Mrs. Chhaya Pun, my elder brother Mr. Tul Prasad Pun and younger brother Mr. Prem Pun and whole Pun families.

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My words are not enough to thank my family; especially my mother Mrs. Jani Pun, my uncle Mr. Yam Bahadur Pun and my elder brother Mr. Tul Prasad Pun for their patience and moral support in the due course of my research. In the absence of my late father Mr. Lal Bahadur Pun and my illiterate mother, my uncle and brother extended all the support that guardians could extend to help me grow and glow. While my struggle was inevitable, I would have lost my track and proper direction to move forward without their guidance. Therefore, I will always remain indebted to their love, care and sacrifice to make me who I have become today.

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Abstract

About Ninety percent of rice production and consumption takes place in Asian countries. Not only the consumption of rice in Asian countries is higher but also rice is inter-connected with feast and festival. The quality of rice taste varies with location, topography, cultivation system, irrigation facilities. Especially, lowland rice is considered as good quality in taste and have higher demand in the market. But because of untimely precipitation, drought, deforestation, urbanization leading to lowering the water resources can cause rice production fluctuating. After the green revolution, the per capita rice consumption is increased in Asia from 85 kg to 103 kg and at the same time global per capita rice consumption is increased from 50 to 65 kg (Mohanty, S. 2013)[44]. On one hand, the increased in rice consumption along with population increment is challenging the sustainable rice production.On the other hand, climate change is also hindering the rice production and its adaptability. To overcome these issues, several mechanisms were developed not only to increase rice production but also to ensure the sustainability from viewpoints of environment, economic and social.Some of the mechanisms developed to cope with climate change and limited resources were AWD (alternative wetting and drying) irrigation, development of drought tolerance rice cultivators, and newly disseminating processes, synergy for the both climate and production system, SRI (System of Rice Intensification) methods. In this study, from the viewpoints of mechanism of GHGs (Greenhouse Gases), the consecutive experiments were performed starting from the lysimeter environment to real farmer's paddy field, adopting one of SRI key elements with irrigation application in Chiba prefecture and Fukushima prefecture, Japan from 2013 2015 in rice growing seasons.

In this study, one of the main objectives is to understand the rice plant development under SRI and non-SRI method. Second objective is to investigate the soil layer condition of paddy field under the different water treatment and final one is to understand mechanism of GHGs emission with respect to soil layer in depth-wise condition.

The method in this study is experimental based. Data collections are adopted in various ways. The soil pH and ORP are recorded manually in situ condition. The soil moisture (soil water content), temperature are measured for every sixty minutes by sensors throughout the experiment. The gas data are also collected by closed chamber method and transferred in air tight bial in situ conditions. The laboratory experiment are conducted to analyze the GHG by gas chromatography and post-harvest measurements are conducted for rice plant height, tiller, leaves, grain yields and total biomass by dismantling and oven drying processes. The data recording and computing process are done using excel and graphical/statistical analysis tool R.

For the first objective, we found that on rice plant development under the SRI method and non-SRI method, the structural development of rice plant in the flooding plot is significantly greater than the SRI plot. Young single seedlings are used in both plots, and there is no difference in grain yield. Dry root weight is greater in the flooding plot but no difference is observed for root length. The difference in result is because the same number of rice seedlings are transplanted in both plots. In other to further understand the structural development in SRI and non-SRI methods, we investigated the SRI method by seedling densities and it is found that the grain yield is significantly higher for transplantation treatment with three and four seedlings rather than one seedling, validating the farmer's confidence in their way of applying the SRI method suggesting that farmers can transplant more than one seedling in lowland areas. In the farmer's field, it is found that by same methodology applied in lysimeter environment, the grain yield (14% moisture level) is also insignificant difference, indicating the value 55.54 gms./hill in SRI method and 59.81 gms./hill in local method. It suggests that SRI method and non-SRI method near our study area, the rice yields do not differ between two methods.

For the second study, the soil layer condition in growing and non-growing seasons, it is found that the soil moistures are fluctuating with same pattern of ponding depth (water availability in paddy field) and the temperatures also have similar trend with the average temperature obtained from meteorological agency. The soil ORP (Oxygen Reduction Potential) is measured in lysimeter experiment at different depths, shows positive for depth at 20 cm.We supposed that lower depth should be more reducing in nature of paddy field soil. Henceforth, it is also validated in real farmer's field in Iwaki-shi, Fukushima, measuring ORP at 5 cm, 10 cm, 15, 20, and 30 cm depths, in two paddy fields (Paddy field A is with intermittent irrigation and B is Iwaki-Shi local method). It is found that 30 cm depth showed similar results as lysimeter experiment. It is found that up to 20cm depth, ORP is negative and 30 cm depth is not responsible for the GHGs emission.

For the final objective, to investigate mechanism of GHG emission with respect to soil layer conditions in depth-wise, the higher correlation between methane flux and ORP value at 10 cm and 15 cm is found with lysimeter environment, reducing the 50% methane in comparison between SRI and non-SRI methods. In case of paddy field, intermittent irrigation method (Paddy field A) has shown higher correlation among methane flux and ORP at 15, 20, and 30 cm depths, while in local method (Paddy field B) it shows negative correlation at the depth of 5, 10, 15, and 20 cm. It indicates that different phenomenon is observed in GHG emission in intermittent irrigation method and continuous flooding method.

Finally, the SRI method is now spreading in more than 50 countries in all over the world. In case of Japan, still the SRI method is on the process of adoption and have less practices in farm level. Other factor for slow adoption of SRI method is that Japanese rice already have higher yield among the Asian countries, so from the viewpoints of Japanese farmer's, they think SRI method is not very important to adopt. The results achieved from our experiment, suggests that intermittent irrigation method (One of SRI key elements) have importance to contribute reduction in GHG emission from rice farming in Japan.

Key words: Mechanism, GHGs, Environmentally sustainable, SRI, Lysimeter, paddy field,

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Acronyms and Abbreviations

SRI: System of Rice Intensification

AWD: Alternate Wetting and Drying

GHGs: Greenhouse Gases

CIFAD: Cornell International Institute for Food, Agriculture and Development

Chapter 1

Introduction

1.1 General Background

After the green revolution (1960 onwards), to solve the food shortage with increase in world population, rice production is increased due to development of high yielding variety of rice and high input of chemical fertilizer and water. Eventually, it causes heavy burden on environment because of excessive use of chemical fertilizer and agriculture pesticides. It also requires high consumption of irrigation water. In long run, the yield of rice production have slowed and scarcity of water resources occur because of overuse of chemical fertilizers and pesticides in soil and irrigation water.These rice cultivation methods added greenhouse gases in the atmosphere which was already loaded with anthropogenic gas CO_2, CH_4, N_2O , since industrial revolution. The increase of greenhouse in the atmosphere of earth for long time, now causes the the issues of "climate change". The global emission of CO_2, CH_4, and N_2O account for 76%,16%, and 6% respectively and rest is emitted by fluorinated gases (EPA, 2016)[1]. From the agriculture sector, total non-CO_2 emission from enteric fermentation and agricultural soil account for 70%, rice cultivation (7-11) %, biomass burning (6-12) %, and manure management (7-8) % according to Smith, P. et al.,(2014)[35]. In order to improve the the rice productivity as well as to have sustainable environment, many scientist and researcher looked for methods which can mitigate greenhouse gases for rice cultivation. Detail study of various parameters and several mechanism are tried to invent the new methods. Low water input like alternative wetting and drying irrigation (AWD) is one of the measures to reduce greenhouse gases which is recommended by IRRI (International Rice Research Institute). The other effective method, system of rice intensification (SRI) was introduced by Fr. Henri de Laulani.J.[2](1970-1980) in Madagascar in order to improve rice productivity in farms of poor farmers to alleviate poverty.

Later, in 1993, Professor Uphoff[3] from Cornell University confirms the effectiveness of SRI method and it was disseminated by him worldwide. Which also is synergies with organic rice farming. The basis of SRI method is to increase yield of paddy in per unit area even for local rice variety by optimizing seeds, chemical fertilizer and use of water, which leads to reduction in use of agro-chemical fertilizer and irrigation water during rice growing season, which finally reduced rice production cost as well as greenhouse gas emission. After the several experiments conducted in worldwide for adopting SRI method, key elements of SRI are established in 2009 by Uphoff et al.[4]. These key elements of SRI consist of young seedlings, single seedlings, wider spacing, aerobic soil conditions, active soil erosion and use of organic manures (Guideline of SRI Practices for Tropical Countries)[6]. To make aerobic soil condition, intermittent irrigation method is applied in order to keep the paddy soil moist but not continuously saturated to avoid the lack of oxygen, depending on topography of rice farms. However, young and single seedling contributes higher SRI yield but water management is also important for reducing greenhouse gas emission without affecting the higher yield. Now by 2015, more than ten millions farmers use SRI methods in various countries which is environmentally sustainable and because of low input of fertilizer and low environmental, high production, and enable to feed the growing population.

1.2 Literature Review

1.2.1 Greenhouse Gas Emission from Paddy Fields

Rice, as one of the most important cereals; has a long history in the Asian countries. The demand for rice is rising with the increase of population. However, more agriculture activities can also affect directly and indirectly to environmental loads. Paddy fields are thought to be a major emitter of GHGs (Greenhouse Gaseous) such as methane, nitrous oxide and carbon dioxide (Zhang et al. 2013)[7]. There are several techniques to increase the rice production by controlling resources like water and fertilizers. However, there are few paddy field and lysimeter experiments are conducted to estimate the methane emission with and without water management or utilization of SRI methods. Yagi et al.(1998)[8] have shown percolation of soil organic and nutrients can make low CH_4 gas emission by draining the water from the rice fields.

It is considered that continuous flooding of paddy field during rice growing seasons is considered as higher emission of greenhouse gas, because of lack of oxygen in the soil. It is found that water management in rice field, mid-season drainage which is in practices in traditional method in several countries, is effective measures to reduce CH_4 flux from rice fields (Hadi et al. 2011)[9]; (Li et al. 2002)[10]; (Berger et al. 2013)[11]; (Nishimura et al. 2004)[12]. The sustainable rice practice, system of rice intensification (SRI) has already been introduced in Madagascar. It is a new technique to improve the rice production by controlling water, soil nutrient and plants in the Paddy fields. It is proved to have higher yields and it has saved the water utilization and leads to reduce use of fertilizer in comparison to conventional rice practices (Hasan et al. 2007)[13]; (Chapagain et al. 2010)[14]. Alternate wetting and drying irrigation (AWD) is one of the key element of SRI method in which rice field are not kept in a ponding situation always but water management is performed by alternatively wet and dry during rice growing seasons.

The recent experiments conducted in the paddy field shows that methane emission rate can be differed with soil types, compost application, water management, and intermittent drainage. Hence, various factors can be used as option to reduce the greenhouse gas emission from paddy fields (Hadi et al. 2010)[9]; (Yagi et al. 2012)[15]. Moreover, some researchers has suggested that methane emission from the paddy field occurs through the ebullition and low atmospheric condition (Tokida et al. 2005)[16]. The recent lysimeter experiment by Kudo et al. (2014)[17] has showed that GHG is reduced when intermittent irrigation is applied. But there is still limited knowledge regarding the soil layer condition at various depth in paddy field environment and its effect on GHGs emission.

1.2.2 System of Rice Intensification (SRI)

As mentioned earlier, the system of rice intensification (SRI) was originated in Madagascar in 1983 by father Henri de Laulanie, S. J.[2] and later disseminated by Prof. Uphoff[3], Cornell University in more than 50 countries. The basic definition of SRI is an agro-ecological methodology to increase the productivity of irrigated rice by optimal the management of transplantation, soil, water and nutrients (CIIFAD report)[6]. Moreover, SRI method also suggests single seedling transplantation which leads to 90 % reduction in seed requirement, and (20-100) % increase in yield, and 50 % water saving according to CIIFAD report[6]. However, there are several issues to adopt SRI with local farming practices from region to region in worldwide. The rice production is largely depends on the topography, climatic condition and soil nutrients. However, SRI method have shown positive synergies in various countries. Sato et al. (2005)[27] has reported that, it is the method of water saving, cost saving and high yield in Indonesia for rice production. SRI method from India have shown almost 67 % higher yield than conventional methods (Singh & Talati, 2006)[18]. Similarly, SRI method can save the water upto (25-50) % than conventional practices in Japanese rice farming (Chapagain & Yamaji, 2010)[14]. Study of the rice plant development in China (Defeng, et al. n.d.)[20] have shown that wider space transplanting method can lead to higher root number than conventional close transplanting method. As single seedling transplanting of baby nursery in wider space is most important key element of SRI method. Chapagain et al. (2011)[19] have shown that SRI method leads to higher development of roots like 30 % greater in root number and 25 % more in tillering and also early flowering from the paddy field experiment in Japan. Similarly, from experiments in India, SRI method has shown significantly higher development in physiological and plant development characteristics (Thakur et al. 2009)[21]. Stoop et al.(2002)[22] have reviewed the SRI method practiced around the world, explaining how high yields are achieved through SRI's key principles, depending on a range of environmental factors and agronomic management practices including rice variety selection. However, there are lacks of studies, particularly in Japan, for SRI dissemination by replacing the local methods. According to CIIFAD report[6], SRI has disseminated in more than 57 countries as shown in Figure 1.1. The present status of SRI has disseminated in 6 countries in East Asia/Pacific island, 6 countries in South Asia, 9 countries in Southeast Asia, 5 countries in Southwest Asia, 22 countries in sub-Saharan Africa, and 9 countries in Latin America/ Caribbean.

1.2.3 Water Management in the Paddy Fields

Based on the water rice cultivation practices in lowland rice, two kinds of water is prevailing in general practices of water management. According to IRRI[5], one is continuous flooding and other is intermittent or AWD irrigation. Continuous flooding is considered typically provides the strength and weed controls into the paddy field. The local methods used in this study area, Iwaki-shi irrigation method, in Japan, generally there is modification of water management, the local farmer's practices adopt in the mid of vegetative phase, which is called mid-season/(nakaboshi) drainage. AWD irrigation is the method of water management in paddy field after (1-2) weeks of transplantation of water wet and dry alternatively, except during flowering condition. Field water tube is used to monitor ponding condition. Intermittent irrigation is used in SRI methodology after (3-4) weeks of baby rice nursery transplantation. According to the SRI manual[6], wetting and drying cycle is determined by observing crack formation into soil surface. To avoid the water loss near bund, the hole is needed to plug carefully. Further irrigation management is determined after the first irrigation upto 3-5 cm ponding depth to get dry condition and observe shallow crack formation, this time interval is used as the reference for the intermittent irrigation. However, water holding capacity of soil, land preparation, and climatic condition may have affect to determine the intermittent irrigation, 2-3 times, wetting and drying cycles time should be calculated as mentioned above method. Apart from high yield by introducing two main key elements of SRI, single seedling in wider space, water management, the greenhouse gas emission can also be reduced. Several methods of water management in paddy fields are practiced in recent years in lowland rice farming. The water management plays a vital role for formation of CH_4 emission from the paddy field. Some of the practices of water management are AWD (alternative wetting and drying) irrigation, intermittent irrigation, mid-season drainage (nakaboshi/mizukiri in traditional Japanese rice farming methods). The previous research have shown that AWD irrigation can effectively saves the water without reducing the rice production system in comparison to conventional practices (Chapagain et al. 2011[19]; Choi J et al. 2014[23]).

1.2.4 Sustainability of Rice Production

Sustainability is defined as improvement of production levels along with protection of natural resources, within the context of economic viability and social acceptability (Greenland, D.J., 1997)[24]. The world population is growing in exponential way, while the food production has in a linear growth. After the industrial revolution, the world population is getting centralized in the city area, which leads to destroying of agricultural land for settlement of human habitants. Because of high income generation, the eating habits of city population also changed which even results in elimination of some local cereal crops cultivation. The unplanned urbanization, deforestation, and over population density in certain area causes destruction of resources which has direct connection with natural ecosystem. The unbalance in ecosystem results in the issues of climate change.

The rice one of the staple cereal crops around the world. However, more than 90 % of rice production occurs in Asian countries. Among various cereals, rice is one of major component of meal for Asian people. The dense population is also increasing in many Asian countries, which still have developing economy, for many poor families,rice is main dietary for them. The natural calamities related to the climate change, flooding, untimely precipitation etc. limit the rice productivities in these countries. Among the other cereal crops, rice cultivation requires much water. The insufficient untimely precipitation and lack of irrigation infrastructure leads to reduction in yield and sometimes destroying the rice fields. The rice varieties which are possible to grow in upland and lowland differ in taste, hence, among them mostly lowland rice is preferred in the market. But, the cultivation of lowland rice by traditional methods need more water and it increases environmental loads. Therefore, exploring of environmentally sustainable rice production method is required. For the sustainable of rice production, the discussion is made from farmers' view points (local level sustainability) and global sustainability in the following sections.

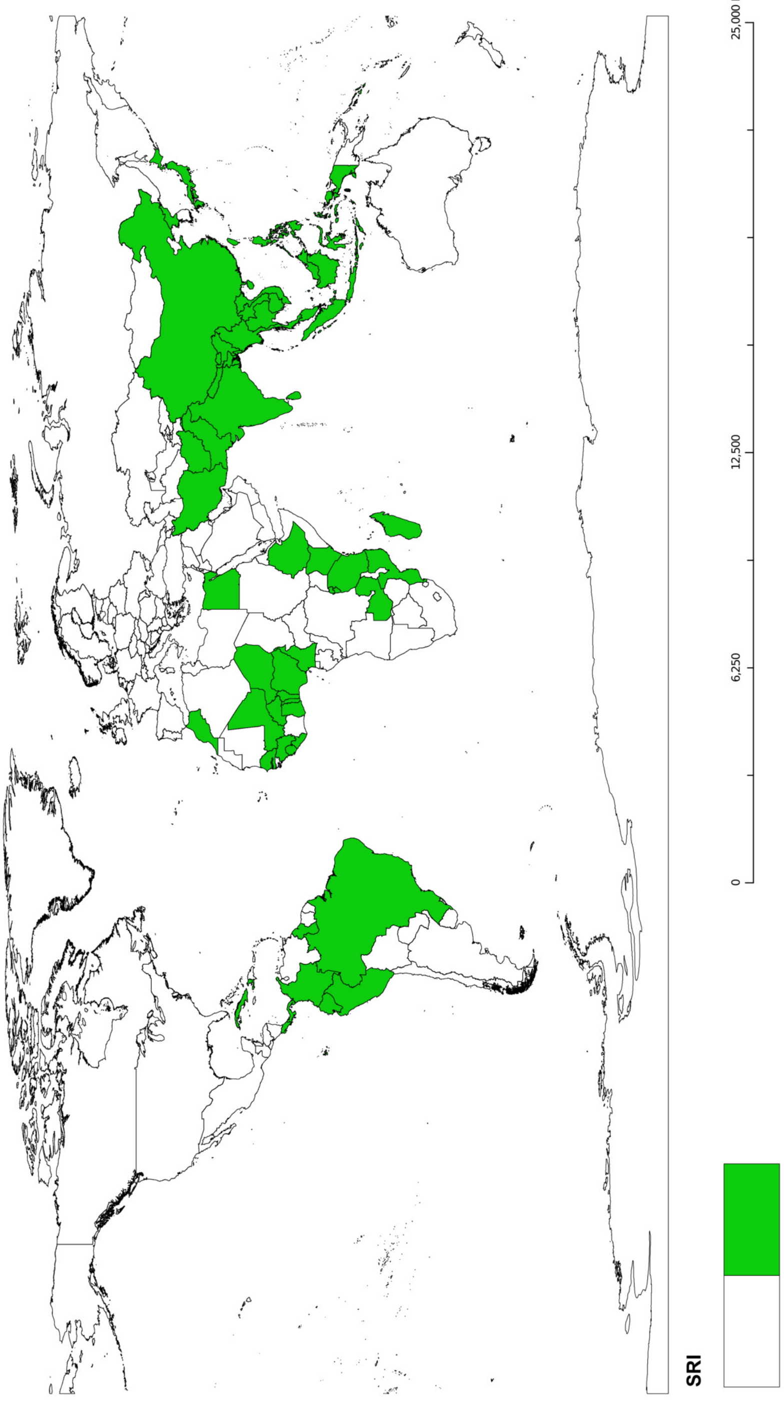


Figure 1.1: SRI dissemination (source: Raw data obtained CIIFAD[6] and map created by author)

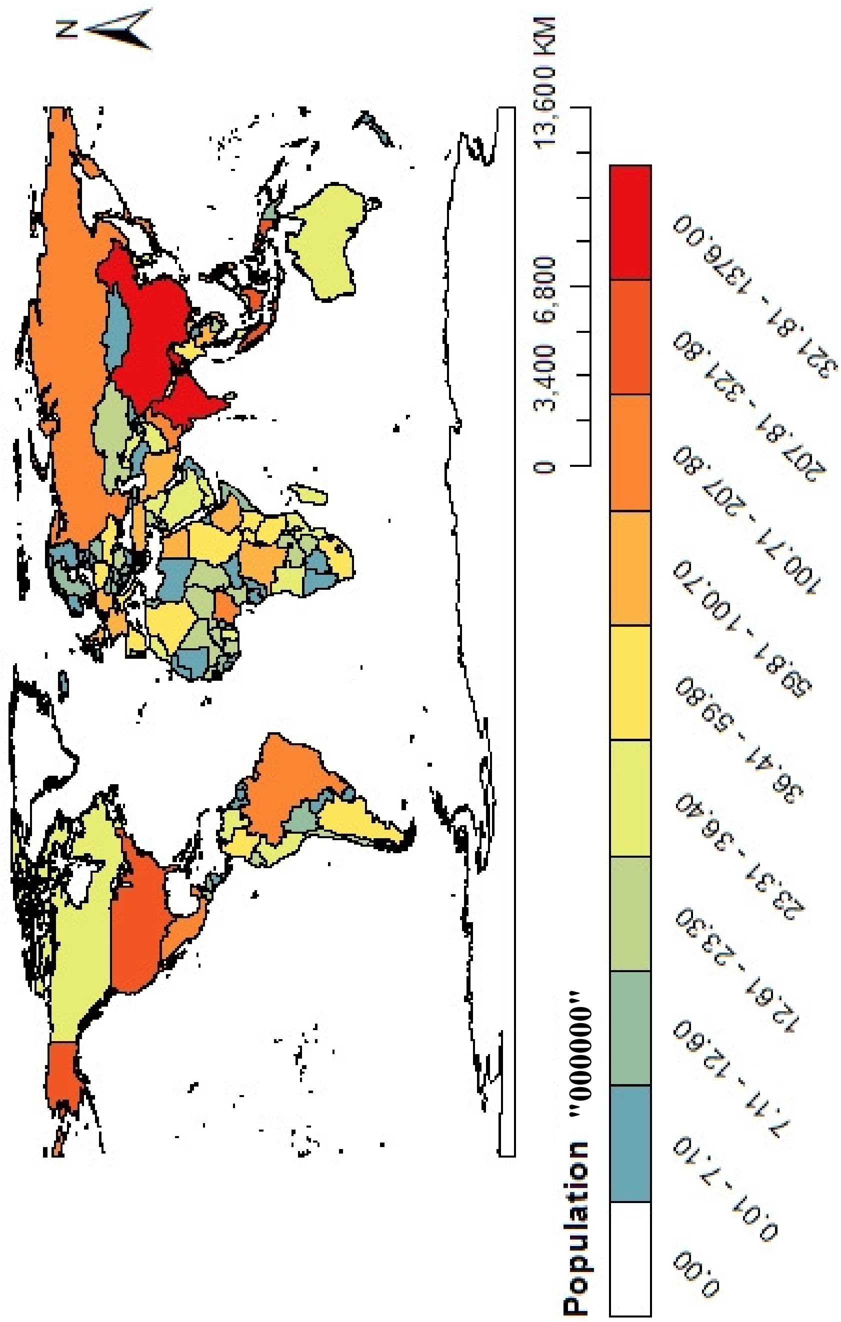


Figure 1.2: Population distribution: worldwide (source: The World Bank[25] and and map created by author)

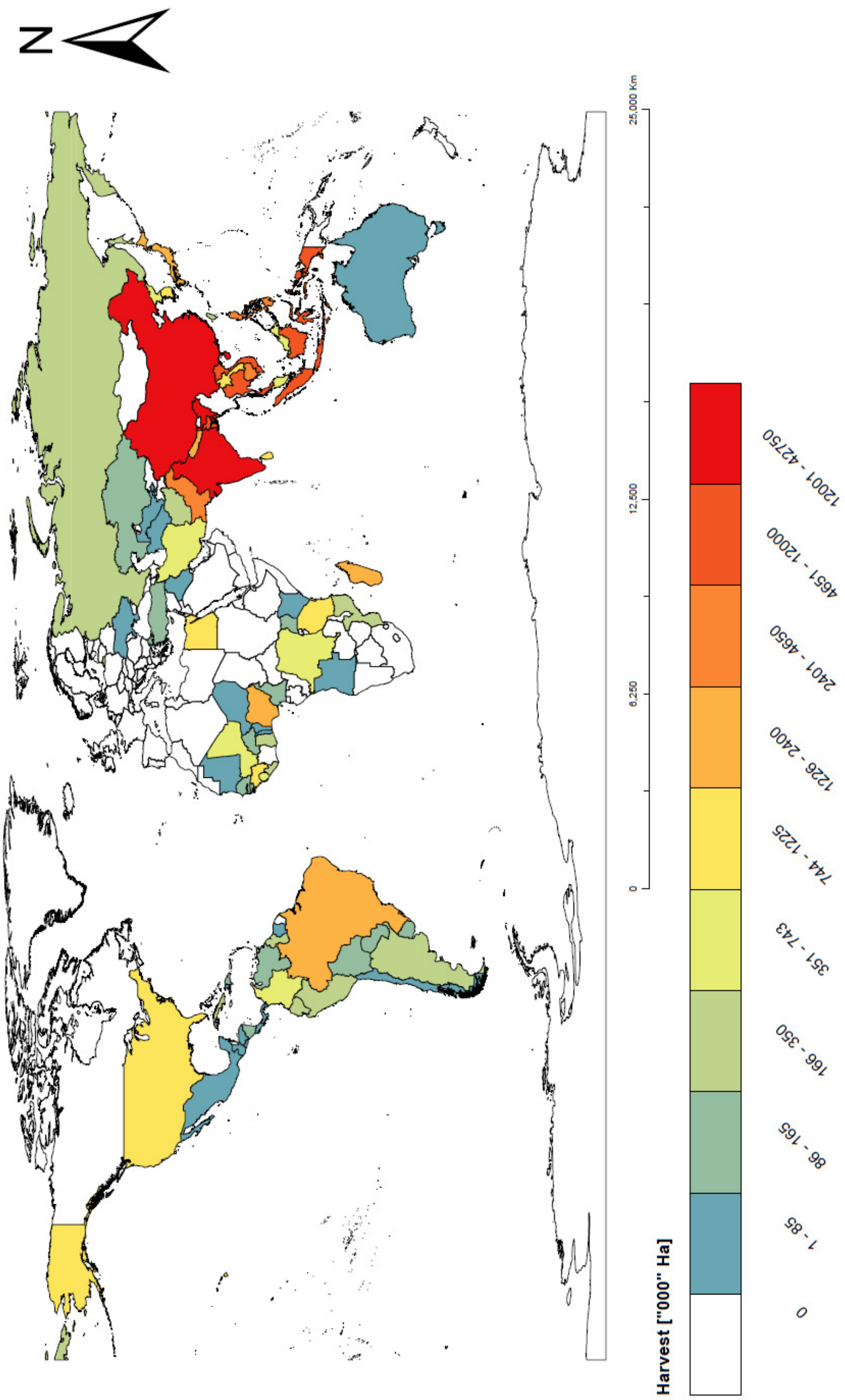


Figure 1.3: Rice harvesting: Worldwide (source: Raw data obtained from IRRI[26] and map created by author)

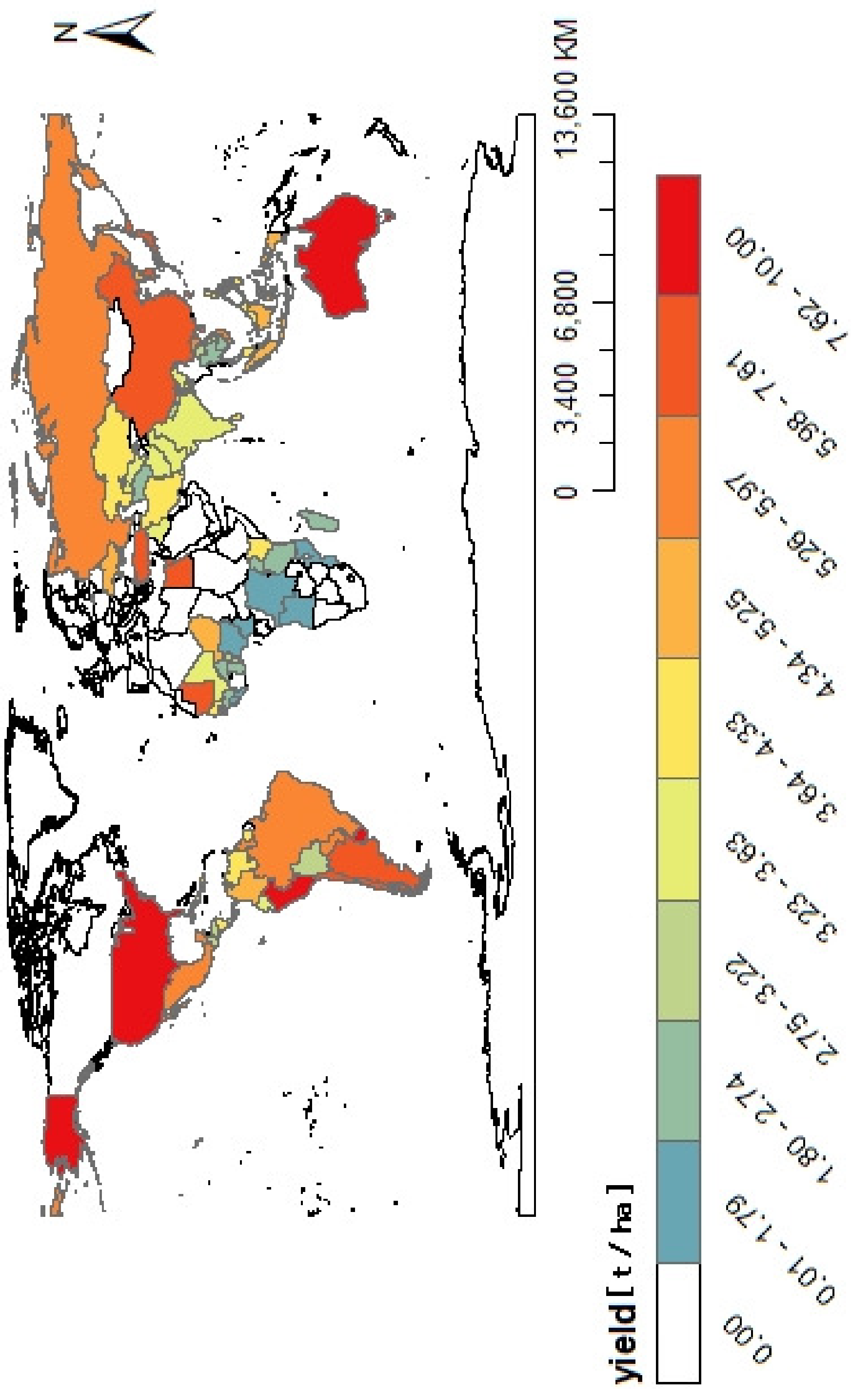


Figure 1.4: Rice yield: worldwide (source: Raw data obtained from IRRI[26] and map created by author)

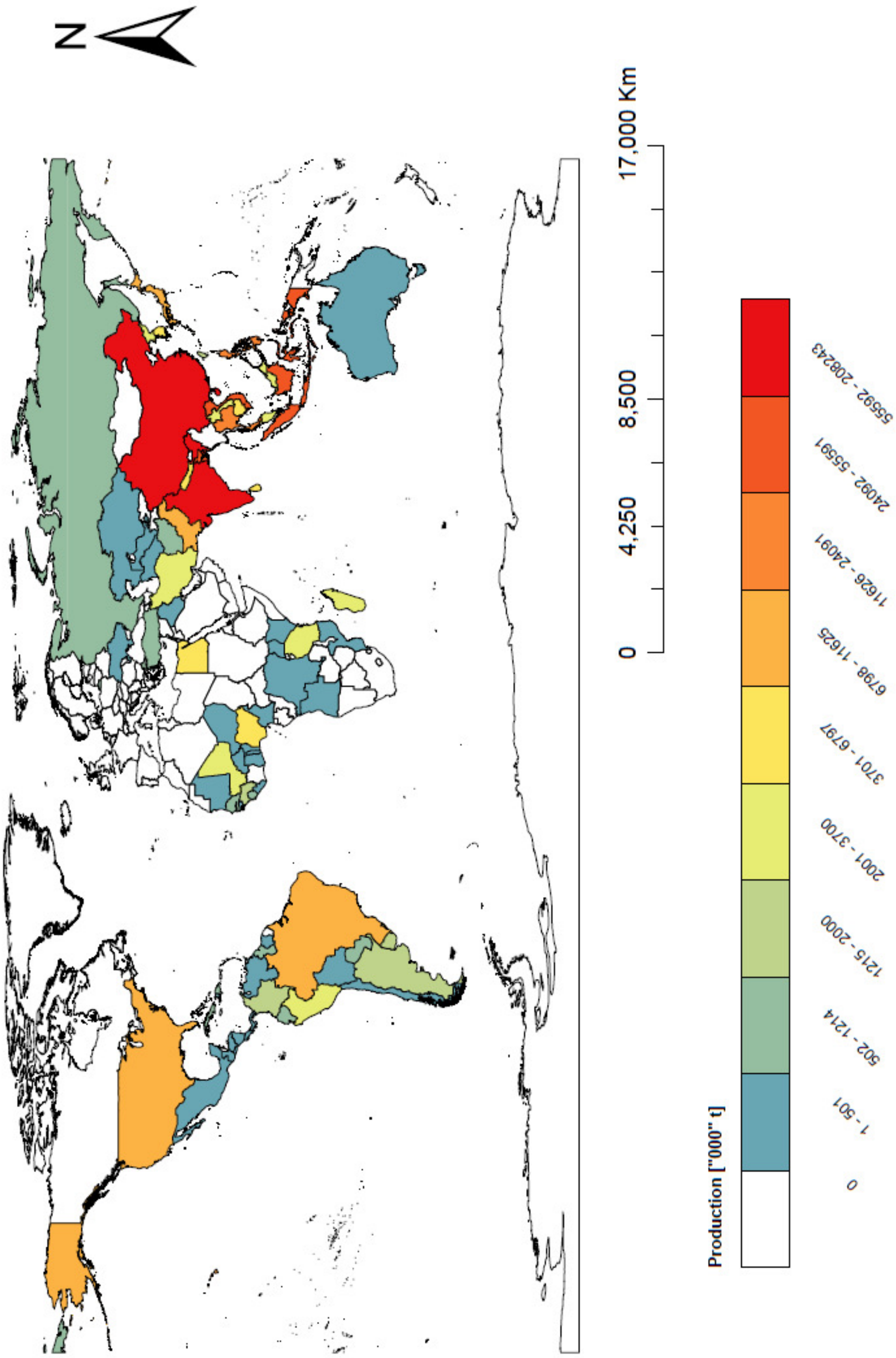


Figure 1.5: Rice production: worldwide (source: Raw data obtained from IRRI[26] and map created by author)

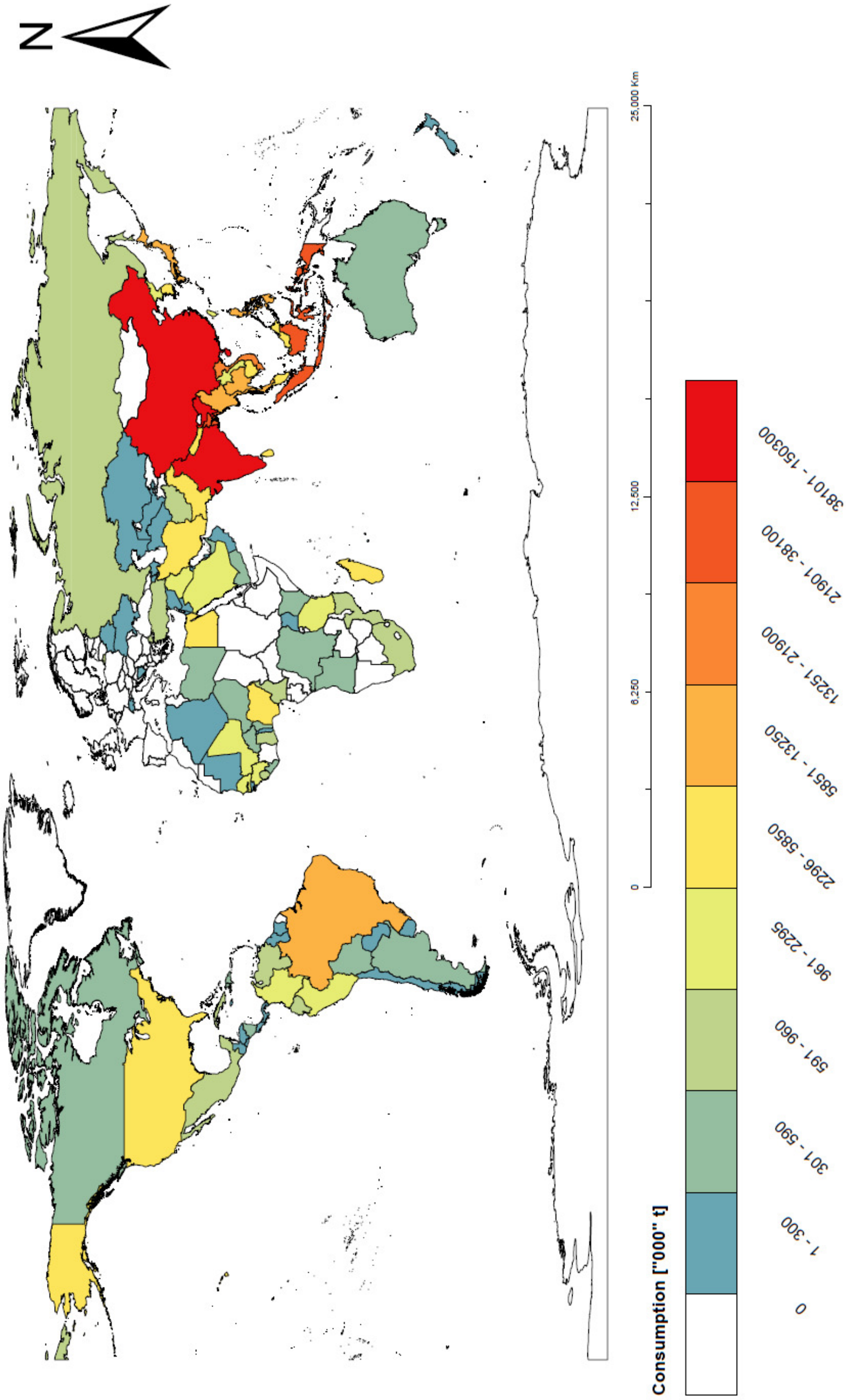


Figure 1.6: Rice consumption: worldwide (source: Raw data obtained from IRRI[26] and map created by author)

1.2.5 Local Level Rice Sustainability

The improvement in rice production at farm plays vital role in global rice sustainability. Because of poor agricultural practices (long time over use of chemical fertilizer and water) in some regions and climate change, the rice production have lower yield in farmer's level in recent days. The rice production in farm level can be improved either by improving production technology or the efficiency (high yield in per unit area) of rice production. The research conducted at farm level to improve the production and efficiency in Nigeria shows the rice yield can be increased by educating farmers and by forming farmers association and cooperative societies (Idiong, I.C, 2007)[28] so that best practices can be applied and shared with other farmers. In case of Nepal, improved rice technology is adopted in higher degree where the irrigation facilities existed (Shakya, P.B. and Flinn, J.C, n.d.)[29]. There are also other issues in developing countries , e. g. fertile agriculture land are urbanized because of water availability and less fertile land is abandoned due to lack of water resources. The new technology for rice production find difficulties to be adopted by farmers because of lack of support from government and irrigation facilities as well as low education level in farmers. SRI is one of the technology which can lead to higher yield with limited resources. One of the main difficulties behind the dissemination of improved new technology is farmer's hesitation. Because of lesser education in Farmer's and insufficient subsidy and promotion from government leads to dilemma in farmers mind to shift from conventional agricultural practices to new improved methods. To have a sustainable rice production at local level, it requires to improve the rice yield, with reduce in environment load in higher producing countries as well as it is also requires to improve eating behavior of higher rice consuming countries. Although, it may be difficult to improve this without economic rise of farmers and consumers.

1.2.6 Global Sustainability of Rice

The global population is already over 7 billion. Asian countries like China and India are densely populated as shown in Figure 1.2. Although rice production and harvest areas are also wider in China and India as shown in Figure 1.5 & Figure 1.3. But from the view point of rice yield, larger populated countries except China, other South Asian countries are still hindering as shown in Figure 1.4. One of the reason is vulnerability of water resources because of climate change and low technological advancement, which results in south Asian countries having problem of low rice production. The rice consumption per capita is also higher in Asian and African countries (as shown in Figure 1.6). It has been predicted that the rice consumption will increase 116 million ton worldwide by 2035, in which 77 million tons in Asia, 30 million tons in Africa from 2010 rice consumption to feed the growing population. Which is almost 130% increment of rice consumption from the year 2010 (Sect, P.A et al., 2012)[30]. From the view point of total consumption by country-wise data from IRRI (world rice statistics, 2013) showed higher consumption in Asian countries (Figure 1.6) except China, even though rice yield is lower as shown in Figure 1.4. For the global sustainability of rice production, it is better to improve the rice yield without damaging the environment.

1.3 Research Objective

The traditional rice farming practices in lowland are considerably higher emitter of greenhouse gases. Reduction of greenhouse gases emission by applying SRI key elements such as intermittent irrigation and organic fertilizers are already in practice. However, quantification of reduction in greenhouse gases in various regions and the mechanism of its dependence of deeper soil layers are not understood properly. Some researches are performed for soil ORP measurements with methane flux at certain depth up to 5 cm to 10 cm. And there are very few researches examining the mechanism of greenhouse gases emission with wide ranges of soil layer (depth-wise) conditions. Hence, it is required to study the deeper soil layer characteristics with implementation of SRI key elements to understand the mechanism of GHGs emission reduction. Further, the implementation of SRI method is under progress in Japan, hence, it is also important to know the effectiveness of SRI key elements on rice yield and GHGs emission than local faming practices in Japan, which already have higher yield among Asian countries. By keeping the above in mind, the current study focuses on the following objectives:

1. Comparative study of rice plant development and yield component from two rice cultivation methods applying intermittent irrigation and Iwaki-shi local irrigation practices.

2. Understanding the soil layer conditions in a depth-wise direction during rice plant developments.

3. Clarify the mechanism of greenhouse gases emission with respect to soil layer condition in overall rice growing season.

1.4 Research Hypothesis

To achieve the above research objectives, we formulated following hypothesis:

1. The intermittent irrigation may have higher rice productivity and better plant development than Iwaki-shi local irrigation method.
2. The soil layer conditions may change at various depths in paddy field especially with movement of ponding water depth.
3. Greenhouse gases emission may be highly dependent on physiochemical condition of soil layer, hence it may have different characteristics in the applied two method of intermittent irrigation and Iwaki-shi local irrigation method.

Chapter 2

Study Area

To achieve the research objectives, four experiments are conducted in various rice growing seasons. Three experiments are conducted at the roof top of environmental building at the University of Tokyo, Kashiwa campus as shown in Figure 2.1. The fourth experiment is conducted in the farmer field in Iwaki Shi, Fukushima prefecture.

In the first experiment, GHG is investigating from lysimeter environment by applying AWD irrigation year 2013. In the second experiment, greenhouse gas emission and structural development of rice plant by adopting SRI and non-SRI method at lysimeter environment in the year 2014. The third experiment is different seedling densities are compared again in lysimeter experiment in the year 2015. It is to be noted that first, second, and third experiments are conducted in lysimeter environment at the University of Tokyo, Environment building. Lysimter experiment are popular in agriculture experiment to investigate the effectiveness of various treatments while controlling other parameters. In most of the studies, lysimeter experiments are conducted before adopting in real paddy field, because paddy fields have several characteristics; soil types, irrigation and so on. Hence, the fourth experiment is conducted in real paddy field to validate the results from lysimeter environment.

2.1 Lysimeter Experiments

Lysimeter is located at the rooftop of the environmental building, in the University of Tokyo, Kashiwa campus, Chiba Japan as shown in Figure 2.2. Lysimeter is facilitated with irrigation inlet and drainage outlet. In every year, lysimeter setting is different depending on purpose of experiment. The size of lysimeter is $(500 \times 160)\ cm^2$. For the study of greenhouse gas impact by adopting AWD irrigation method, the experiment are conducted in a small Lysimeter

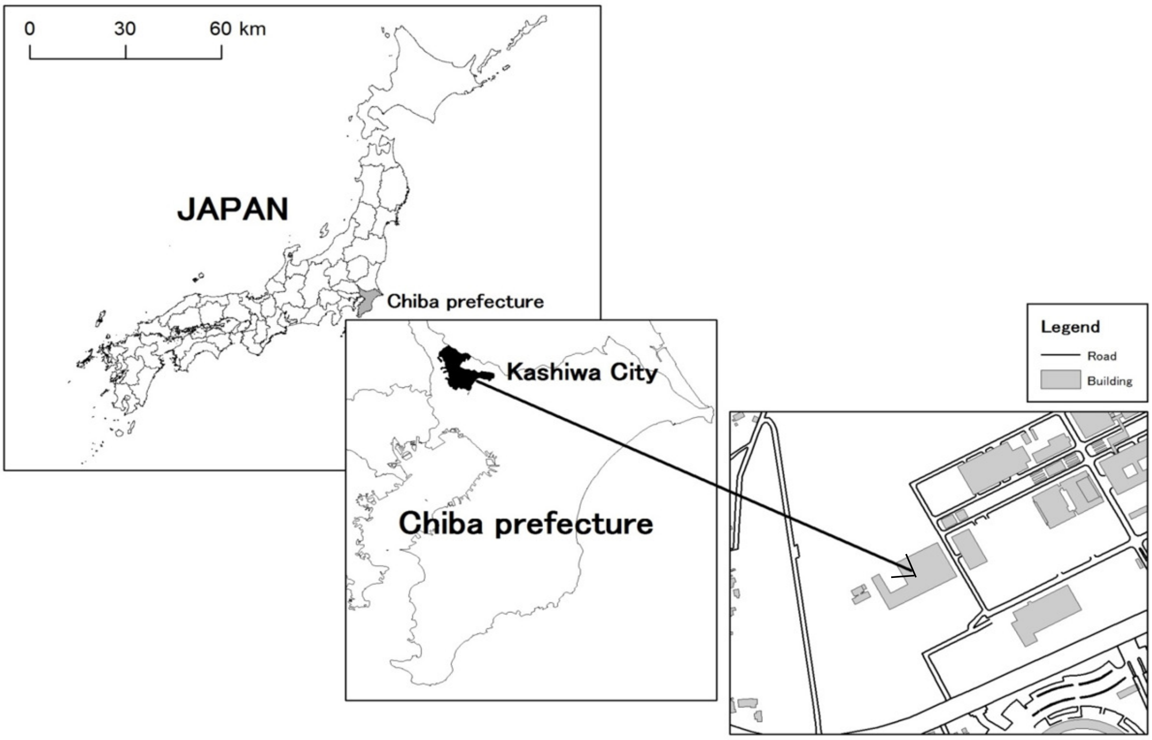


Figure 2.1: Lysimeter located in the University of Tokyo, Kashiwa campus, Japan

during beginning of May till the end of December 2013. The rice variety called Koshihikari (Japanese famous rice) is transplanted on May 29, 2013. Based on the size of Lysimeter, 80 seedlings are transplanted (Figure 2.4). No fertilizer are applied during the experiment; gas sampling is also performed during rice growing season as well as after the harvest to observe the pattern of methane emission change with rice roots, decay in fallow land. The rainy season in Japan mostly starts from early June to August. While, rice cultivation starts in summer with high rate of humidity. The total rainfall during the rice farming season was 171.0 mm by June, 2013 and maximum daily rainfall was 60.5 mm as shown in Figure 2.3. The average maximum temperature was on August 2013, i.e. 27.2 degree Celsius and daily maximum is also recorded in the same month. The maximum sunshine hours are recorded in August, 2013 (May month have longer sunshine but just rice plantation started on May 29 according to Abiko Meteorological Station, Chiba, Japan).

In year 2014, the experiment is conducted at the roof top of environmental building of the University of Tokyo, Chiba prefecture in the rice growing season, starting from May to end of October, 2014. The size of lysimeter consists of $(500 \times 160)\ cm^2$. The lysimeter is facilitated with drainage system on the right border and irrigation tap on the left border (Figure 2.6). The soil is puddled homogeneously at the time of land preparation. The 800 gram organic

Figure 2.2: Photo of lysimeter

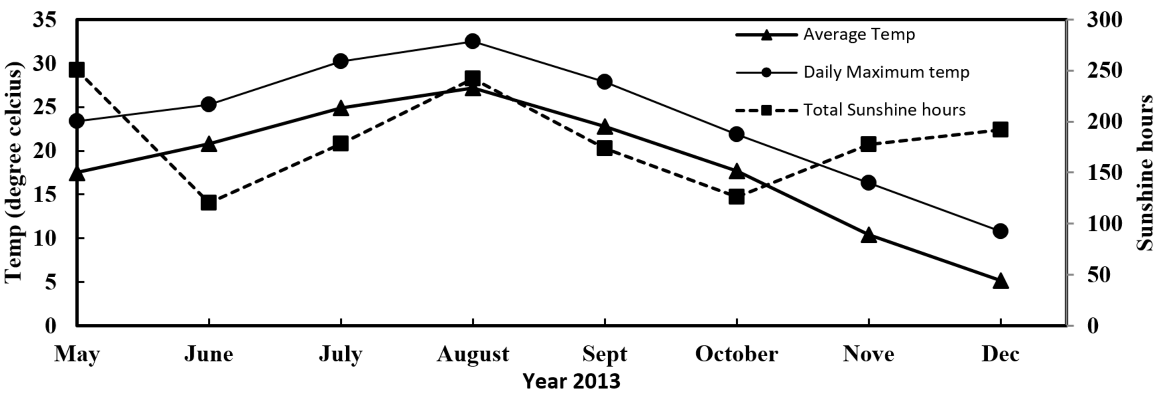


Figure 2.3: Meteorological condition of study area in the year 2013 (Source: Abiko meteorological agency, Chiba, 2013)

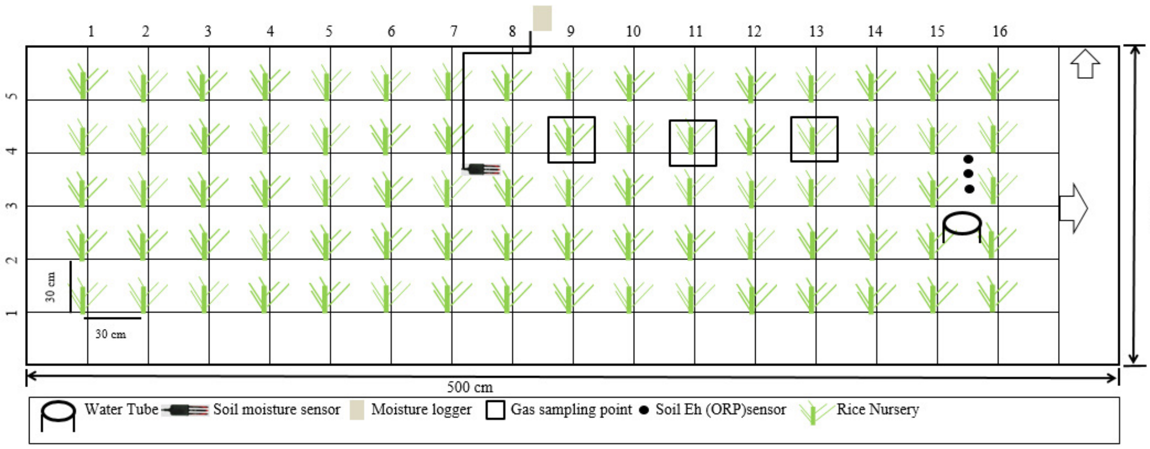


Figure 2.4: Experimental design and instrumental set up in the 2013

fertilizer is applied homogeneously. The composition of used fertilizer is 1.3% nitrogen, 0.6% phosphorus and 1.8% potassium with C/N ratio of 22. The lysimeter is divided into two plots by using plastic sheet from the center. Plot A is named SRI plot and plot B is named flooding plot. Two water tubes of length 25 cm and diameter 13.5 cm are installed to monitor the ponding depth on each plots. The water tubes consist of fixed measure aluminum scale to observe the water level in the lysimeter. Japanese rice variety (Koshihikari), at the age of 12 days single nursery is transplanted. The local farmer is asked to prepare that nursery. On May 23, total 32 nurseries are transplanted in each plot. The space between each hill is (30×25) cm^2. The Soil Eh (ORP) sensors are set up in the both plots at the depths of 5 cm and 10 cm. The data of soil Eh is recorded by (EH-120; Fujiwara Scientic Co. Ltd., Tokyo, Japan). The meteorological condition of study area in 2014 are also observed, maximum temperature is recorded in July and average maximum temperature is in August. The longest sunshine hours are observed in July according to the nearest meteorological station, Abiko, Chiba, Japan (Figure 2.5).

In the year 2015, the lysimeter experiment are conducted in the same location during the rice growing season. The meteorological condition of study area is observed, the maximum average temperature is recorded in August. The maximum daily temperature is recorded in both July and August. July month have the longest sunshine hours during the rice growing season as shown in Figure 2.8. Although, the longest sunshine hour occurred in May but it happens before May 12 on the rice transplantation day. The study aimed to verify the difference in rice plant development by different transplanting densities. The size of lysimeter was 495 cm in length and 158 cm in width. The lysimeter consist of a drainage valve on the right border and an irrigation facility from tap water on the left border (Figure 2.7). The soil is puddled homogeneously for two weeks before transplanting. The organic fertilizer (2,200

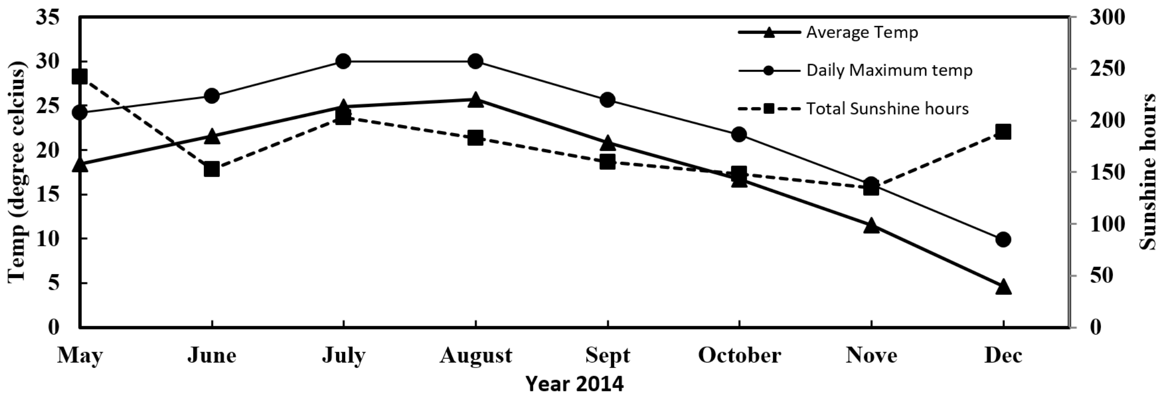


Figure 2.5: Meteorological condition of study area in the year 2014 (source: Abiko meteorological agency, Chiba, 2014)

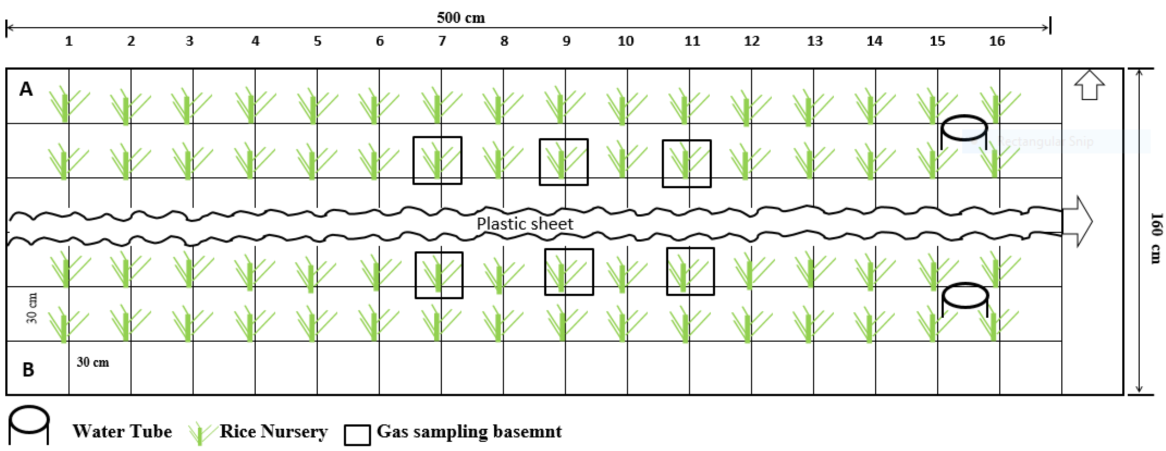


Figure 2.6: Experimental design and instrumental set up in the 2014

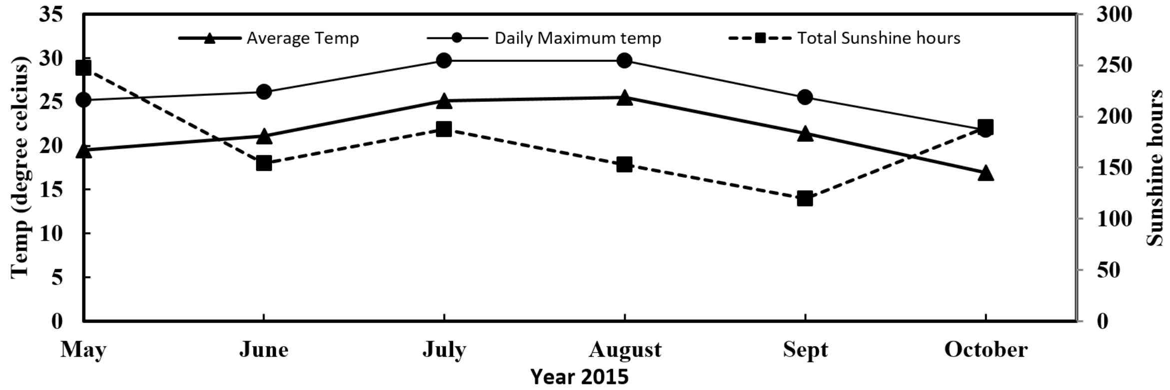


Figure 2.7: Meteorological condition of study area in the year 2015 (source: Abiko meteorological agency, Chiba, 2015)

gram) is also mixed homogeneously into the entire soil. The composition of organic fertilizer is 1.3 % nitrogen 0.6 % phosphorus, and 1.8 % potassium, with C/N ratio of 22. The water tube with 13.5 cm diameter and 25 cm length are set up to measure the ponding depth. Ponding depth is measured using data logger LR5042 (Hioki E.E. Corporation, Japan) over the course of the experiment. The water depth sensors inside the water tube are fixed at 15 cm depth from the soil surface. Data logger LR5042 measures water pressure in voltage ranging from -5.000 V to 5.000 V which is converted to the height of water in lysimeter with a calibrated equation. Water pressure data is also collected every sixty minutes. The transplanted rice nursery are 24-days old Japanese rice variety koshihikari. A total of 160 rice nurseries are transplanted on May 12 2015. A single factor experiment method is utilized for this experiment, in which a single factor varied (density of rice seedlings while other factors remained constant (e.g. fertilizer, water management). The experiment followed the completely randomized design (CBD) with four treatments (number of rice seedlings per hill) with two replications. The randomization is done as shown in Figure 2.7. The numbers indicated in Figure 2.7 is a) SRI method with one seedling per hill, 2) SRI method with two seedlings per hill, 3) SRI method three seedlings per hill, and 4) SRI method four seedlings per hill.

2.2 Farmer's Field Experiment

The study area is located in Iwaki city, Southern part of Fukushima Prefecture, Japan. The experiment is conducted in 2015, starting from May to end of September 2015. This region was affected by tsunami in March 11, 2011. The major productions in Fukushima are vegetables and rice. Consumers believe that it has good taste of rice because of spring

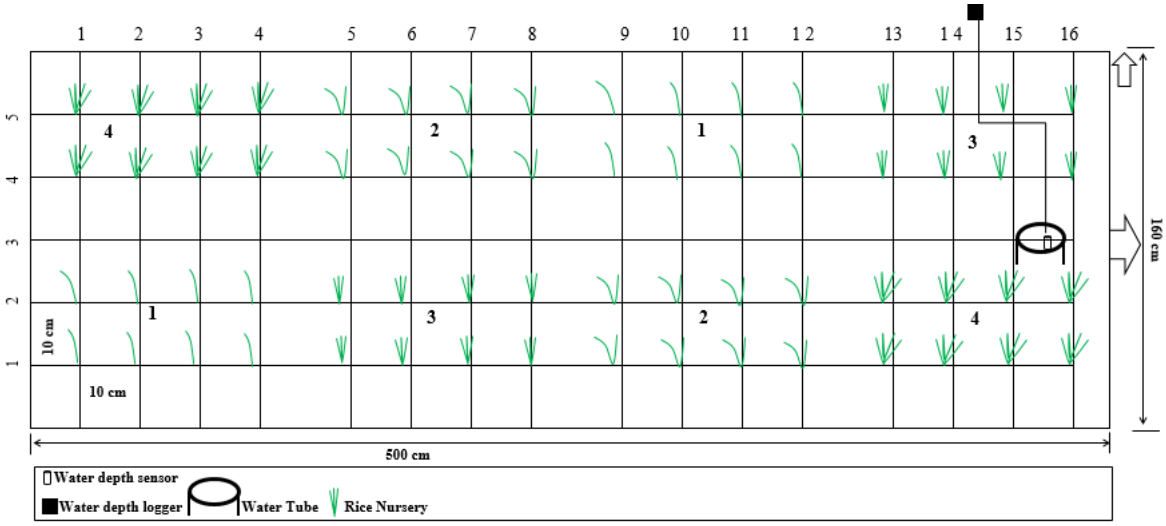


Figure 2.8: Schematic diagram of the lysimeter in the 2015

water supplied from mountains and forest. The study is carried out in local farmer's field. In the paddy fields experiments, two methods are practiced as intermittent irrigation and Iwaki-shi local method. The two paddy fields are selected. Paddy field A is adopted for intermittent method (one of SRI key elements) and paddy field B is adopted for farmer's local method. The size of paddy field A (intermittent irrigation) is $(44.9 \times 34.8)\ m^2$ and paddy field B (Iwaki-shi local method) is $(44.5 \times 17.70)\ m^2$ as shown in Figure 2.9. Both fields are facilitated with irrigation and drainage outlets. The climatic condition during the rice growing season is recorded from the Yumoto, meteorological agency in the year 2015. The maximum temperature is recorded in July as 26.2 degree Celsius. The average higher temperature is noted 20.9 degree Celsius in July (Figure 2.10). The total maximum sunshine hours are lower here than in Chiba prefecture. According to the local farmers, the lower temperature will leads to decrease in rice productions.

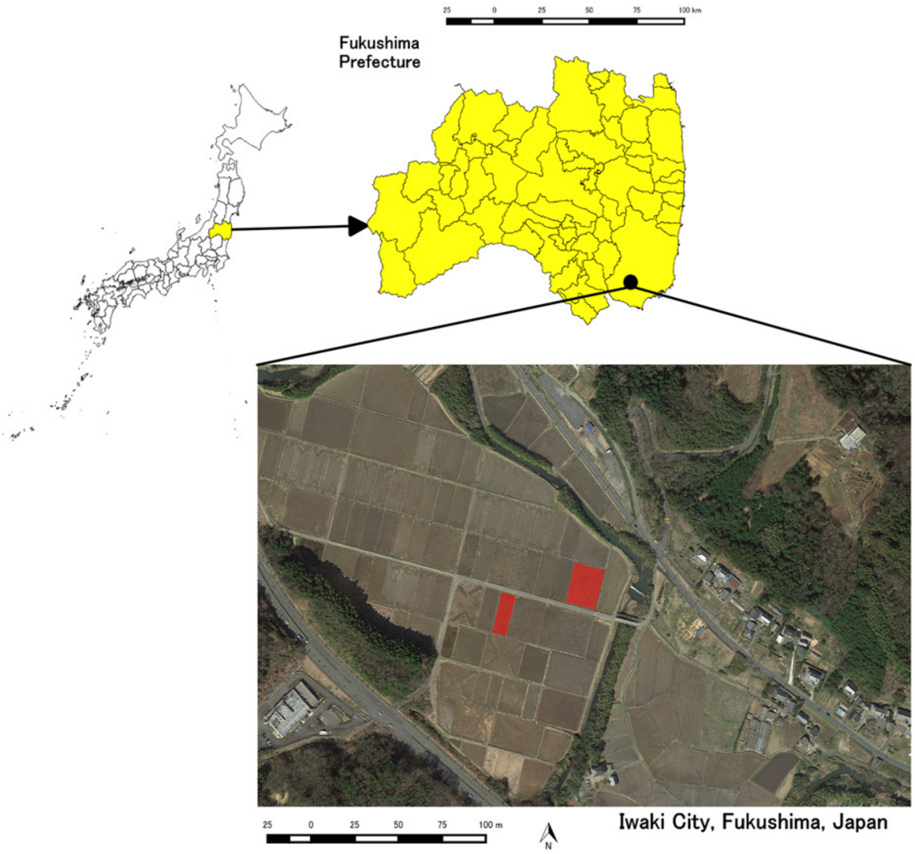


Figure 2.9: Study area in Iwaki Shi, Fukushima Prefecture in the year 2015

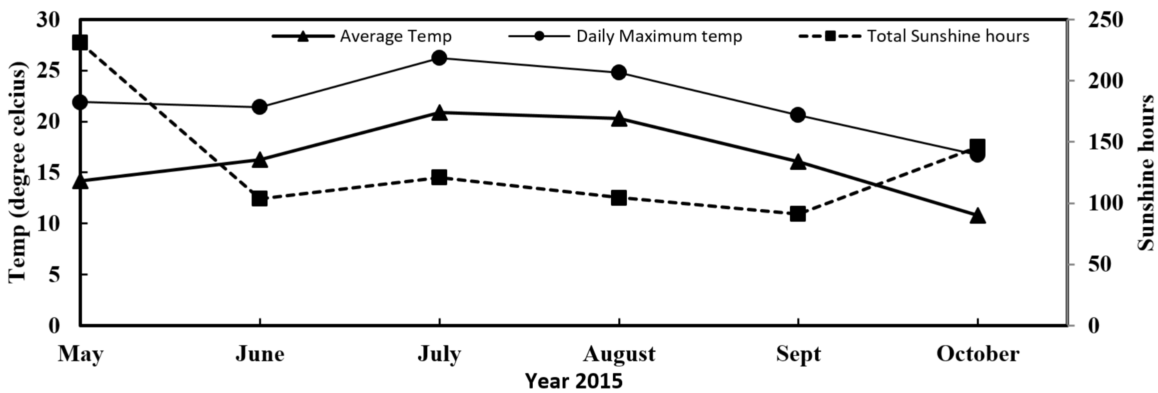


Figure 2.10: Meteorological condition of study area in the year 2015 (source: Iwaki meteorological agency, Fukushima, 2015)

Chapter 3

Research Methodology

Four consecutive experiments are conducted to achieve our research objectives of this study. Initial experiments are conducted in the year 2013 at lysimeter facility, located in Environmental building of the University of Tokyo, have objectives to understand soil layer conditions based on AWD irrigation method. In year 2014, the second experiment is conducted in lysimeter facility to compare the structural development of rice plants by SRI method and flooding method. Finally, in 2015, two experiments are conducted. The first experiment is conducted in real paddy field at Iwaki Shi, Fukushima prefecture by adopting intermittent irrigation methods and Iwaki-shi local farmer's methods. And the other experiment is conducted at lysimeter facility to compare grain yield with different transplanted densities of young seedlings. Both the field study and laboratory experiments are performed to carry out the research and the data are obtained both manually and instrumental bases. The equipments used in these study and method adopted are discussed in this chapter.

3.1 Soil pH, ORP

The pH measures the acidity or alkalinity of soil. Soil pH plays important role to understand soil and water quality in paddy fields. The soil ORP (Oxygen reduction potential, Eh), measures indirectly the oxygen level inside the soil layer. The positive value means the oxidizing condition inside soil depth while negative value (minus) means the reduction condition of soil layer. The value of soil ORP shows the methanogens condition inside the soil also. The soil pH and ORP at various depth level are measured to identify the soil physiochemical condition of soil. In the lysimeter experiment (in 2013), the soil Eh (ORP) sensors are set up at 5 cm, 10 cm, 15cm and 20cm depths. The pH and ORP are measured by using PRN-41, product from Fujiwara Company, Tokyo as shown in Figure 3.4. Before using pH meter, the sensors are calibrated by using standard solution of pH 6.86 and pH 4.01. The pH and Eh of soil and ponding water depth are recorded once a day as shown in Figure 3.4. In the lysimeter experiment (in 2014), the Soil Eh (ORP) sensors are set up in the both plots at the depths of 5cm and 10 cm. The data of soil Eh was recorded by (EH-120; Fujiwara Scientic Co. Ltd., Tokyo, Japan). The soil pH and ORP are measured every day to understand the soil physiochemical condition from the both plots (Figure2.6). During the field experiment in 2015, the soil ORP sensors are fixed at the depth of 5 cm, 10 cm, 15 cm ,20 cm, and 30 cm in both the paddy fields at Iwaki-shi. The measurements are performed in every two weeks intervals during the field visit. Soil pH is measured only on the fixed date as depth-wise pH measurement does not fluctuates in lysimeter experiment, done in 2013. Table 3.1 shows various values of ORP (Redox potential) in soil, showing microbial metabolism process.

Table 3.1: Redox potential in soil and sediment, showing microbial metabolism process

Anaerobic							Aerobic	Sediment Condition
Highly Reduced			Reduced	Moderately Reduced			Oxidized	Redox Condition
CO_2		SO_4^{-2}	Fe^{3+}		Mn^{4+}	NO_3	O_2	Electron Acceptor
Anaerobic		Facultative				Aerobic		Microbial Mechanism
−300	−200	−100	0	+100	+200	+300	+400 ∼ +700	

Source: Delaune, R.D. and K.R. Reddy (2005)[31]

3.2 Water Management

Both lysimeter experiment and farmer field experiment are conducted in open environment. There is no control of rainfall, hence, irrigation is supplied based on rainfall in lysimeter and farmer field experiment. The two kinds of water management in these experiments are performed as continuous flooding or intermittent flooding. In 2013 lysimeter experiment, ponding condition is observed by water tubes of diameters of 11 cm and 13.5 cm. During the initial phase of this experiment, intermittent irrigation is applied but after the middle of September till end of November there was no AWD irrigation application, because of frequent rain. After that, the ponding condition does continue until the end of December. Irrigation is performed in accordance with rainfall and ponding condition of lysimeter. The driest condition at -20 cm below the surface and the highest ponding depth is around 5 cm above the surface.

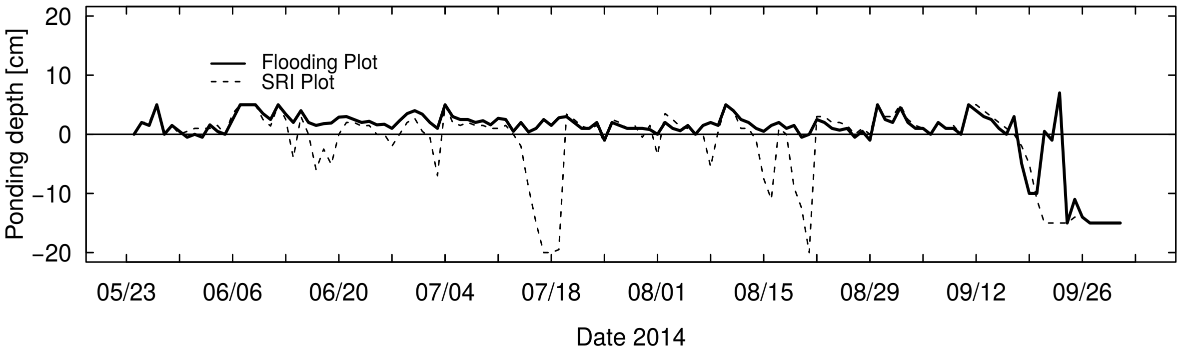


Figure 3.1: Ponding condition in lysimeter 2014

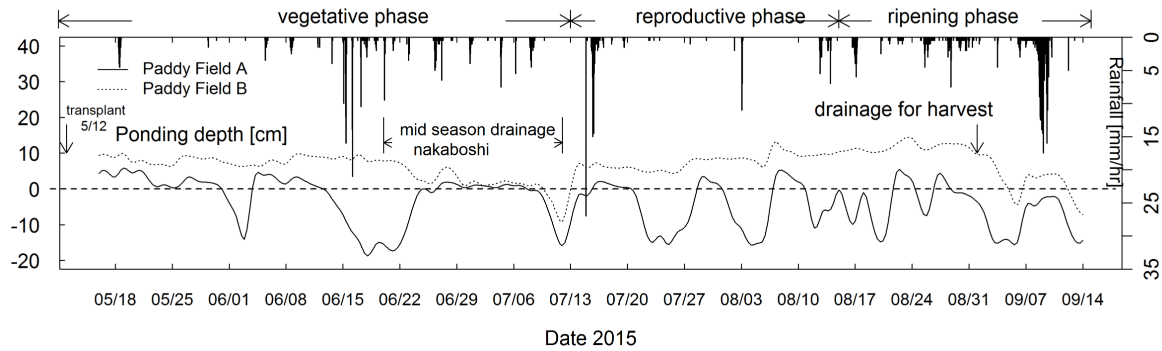


Figure 3.2: Ponding condition in farmer field 2015

In 2014 lsyimeter experiment, two kinds of water managements are applied. One is AWD (Alternate Wetting and Drying) irrigation for SRI plot and another is continuous flooding for flooding plot. The first two weeks after the transplantation, shallow ponding condition is maintained in both plots until the young rice nursery tends to get strong. Then, SRI plot is maintained by alternatively wetting and drying irrigation method (Figure 3.1). In case of excess rainfall, water is drained by pumping tubes. Flooding plot is continuously kept the stagnant water in the vegetative phase.

In 2015, farmer paddy field experiment at Iwaki Shi, two kinds of water management are applied. One is alternate wetting-drying cycle which is applied in intermittent irrigation method and another one is farmers Iwaki-shi local water management method (Japanese local practices). Water level in paddy field A fluctuates drastically whereas water in paddy B fluctuates only in mid-season drainage (nakaboshi/mizukiri). Mid-season drainage is the traditional water management method applied by Japanese farmers (Figure 3.2).

3.3 Crop Measurements

Crop measurements mean measurement of rice plants development. Plant height, number of tillers and number of leaves are measured. The purpose of crop measurement is to understand the rice plant development during vegetative phase, reproductive phase, and post-harvest yield. In 2013, lysimeter experiment, crop measurement is done by measuring rice plant height, number of tillers and leaves at every 7-10 days. Similarly, in 2014 lysimeter experiment, the rice plant height, tiller (stem) and leaves are counted to study the structural development of rice plant. During this experiment period, the measurements are performed fourteen times in both the plots. The first measurement is done on June 6 and final measurement on September 12. The height is measured by using simple measuring tape and for tillers and leaves, their numbers are counted. During the reproductive phase, lower parts of rice leaves are decayed and some of small new tillers are emerging out. The decayed leaves are not counted but new tillers are included in counting. After the rice harvest, the samples of rice roots are dried and the elongation and dry weight are measured.

In 2015 lysimeter experiment, rice plant height and the number of tillers and leaves are recorded once every week during the vegetative phase. During the reproductive phase, the plants are covered with a net to protect from birds, and crop measurements are performed twice a month. The rice is harvested on September 23 in this experiment and the detailed study of post-harvest measurement is completed.

To perform crop measurements in farmer field at Iwaki-shi. Five sampling points of every six rice plants are chosen in both paddy field A and paddy field B. The height of rice plant, numbers of tiller, and leaves are noted in two weeks interval depending on the field visit survey. The details post-harvest study is showed in later Chapters.

3.4 Soil Temperature, Moisture

Soil moisture is measured in various depth in 2011 lysimeter experiment and paddy field experiment in 2015. The soil moisture and temperature at the different depths of 5 cm, 10 cm, 15 cm and 20 cm are measured by ECH2O-5TE sensors made by DECAGON DEVICES.The sensors are inserted horizontally at 5 cm, 10 cm, 15 cm, and 20 cm depths from upper soil surface. The soil temperature and moisture ata are recorded in every one hour intervals in lysimeter experiment. In paddy field experiments, the temperature and moisture sensor are set at 30 cm depth also to understand the irrigation effects. The moisture sensors measure the volumetric water content (m^3/m^3). Based on the other soil investigation, researchers use it not only for volumetric water content but also to understand the structure of soil as clay, sandy, loamy. Temperature and moisture are measured in both experiment (lysimeter 2013 and paddy field 2015) after the rice transplantation until the date of harvest. The observed data of temperature and moistures are calibrated with standard equation obtained from lab experiment.

3.5 Gas Sampling

The development of gas sampling method varies on different techniques. The techniques depend on the point source and non-point sources of gas emission. In this study, point source technique is used. Hence, close chamber method is applied which is simple method to collect the gas from paddy fields as shown in Figure 3.10 and this method has been already practiced by Yagi, K. and Minami, K. (1991)[32].

The close chamber is made of hard plastic of length one meter in height, length and breadth is 30 cm each. The chamber is well equipped with small fan, thermometer, vent hole, gas sampling port, and air buffer bag. The small fan is run by battery. Fan is fixed in the mid part of chamber. The gas accumulated inside the chamber may have disturbed by the rice plant. So, fan is used to mix the air homogeneously throughout the chamber area. Thermometer is used to measure the temperature changes. The vent hole, air buffer bag are fixed on the lid of chamber. The top part of chamber is designed to seal the water with lid. The bottom part of chamber is fixed with basement of same area. The basement is made from aluminum, 30 cm in length and breadth is used. The basement which is made of aluminum and have 30 cm length and breadth is used. The base has sufficient space for water sealing to ensure the gas exchange from the bottom. The paddy condition during the growing season is different in ponding depth, so scale is used to read the effective depth from real depth of chamber. The thermometer is used to measure the soil temperature outside of chamber also. The glass vial with plastic screw cap and butyl rubber is needed to collect the gas. Before injecting gas into the vial, the glass should be evacuated from the air. This means the evacuation of air disturbance inside the vial is in a homogeneous. The gas is collected in every plot at three locations, starting from zero to thirty minute in each replication. From each replication, the gas is collected in every three minute interval but 10 minute interval for individual chamber. The four gas samples are collected from each chamber. The plastic syringe is used to collect the gas from chamber to vial. The collected gases are brought in the agro-engineering laboratory and CH_4 is analyzed using GC-14A and N_2O gas is analyzed using GC-2014 (Shimadaju).

3.6 Land Leveling

The homogeneity of rice production in a field depends on the leveling of land. If the land surface is smooth and homogeneous, the distribution of water, nutrient are equally available to the plants. Also, the working efficiency is higher in good land leveling. The study of land leveling is important to understand the crop production from different rice fields. In our study, the plant development and rice yield from two rice fields are compared, so, land leveling accuracy in paddy field experiment is important. The grid survey is conducted after the rice harvest on September 26, 2015. The size of paddy field A is $44.5 \times 34.8m$ in length and breadth and paddy field B is $44.5 \times 17.70m$ in length and breadth. Based on the paddy field sizes, Paddy field A is divided into 14 columns and 11 rows and the data is taken at every 3 meter interval grid points. Similarly, in case of paddy field B, grid points are divided into 14 columns and 5 rows in three meters interval. From both paddy fields, elevation points are recorded using surveying equipment (Sokkia). The well-scaled stake is used to take the each grid points moving forward and backward. In the paddy field A, total 154 grids points and in paddy field B, 60 grid points are noted. By comparing the micro-elevation of paddy fields, the smoothness of paddy is studied.

3.7 Data Collection Process

Some of images of data collection process in the year 2013, 2014, and 2015 in lysimeter experiment as well as in paddy field are shown in Figures 3.3, 3.4, 3.5, 3.6, 3.7, and 3.9. The data is collected in both situ condition and continuous measurement. In situ condition, soil ORP, pH are measured while soil temperature and moisture are measured continuously at every one hour time interval. Gas is collected and taken to the agro-environmental laboratory for further analysis of CH_4 and N_2O by Gas chromatography (GC).

Figure 3.4 shows the data collection process in lysimeter experiment in 2013, at Kashiwa campus, the University of Tokyo. The GHGs emission in rice growing and non-growing season are also measured. Similarly, Figure 3.5 shows the sampling process through the starting of rice transplantation to harvest, compares the structural development of rice plant development along with rice yield. Figure 3.6 and 3.7 show the rice plant growing process along with measurement both in vegetative phase and ripening phase. Finally, Figure 3.9 and 3.13 show the rice plant measurement in pre-harvest and post-harvest phases, respectively. For the soil physiochemical measurements, Figures 3.10, 3.11, and 3.12 represent the whole processes conducted during data collection process.

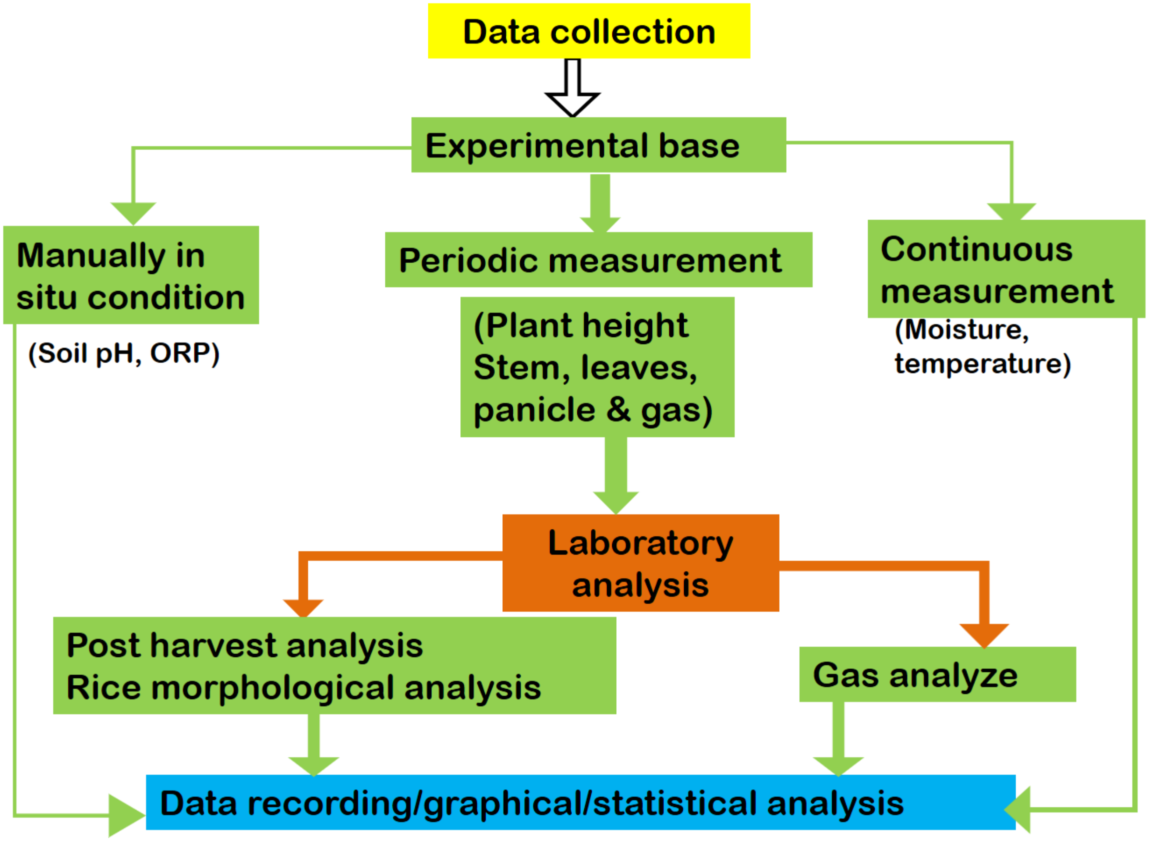


Figure 3.3: Methodology for data collection

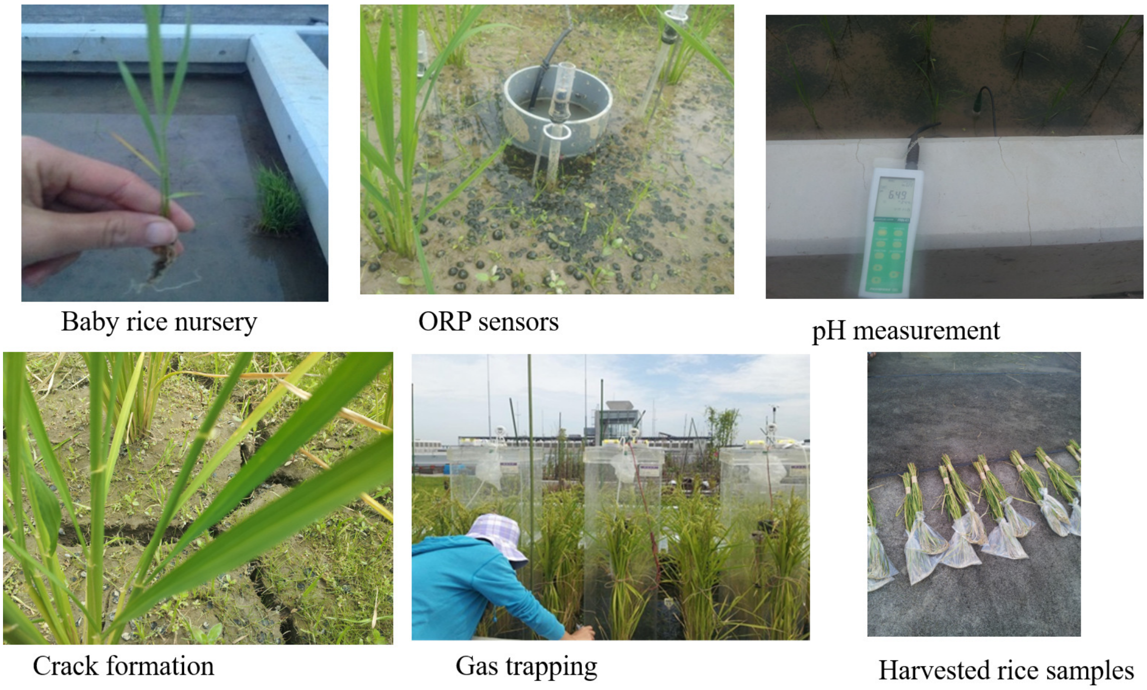


Figure 3.4: Rice growing and sampling process in the year 2013, lysimeter

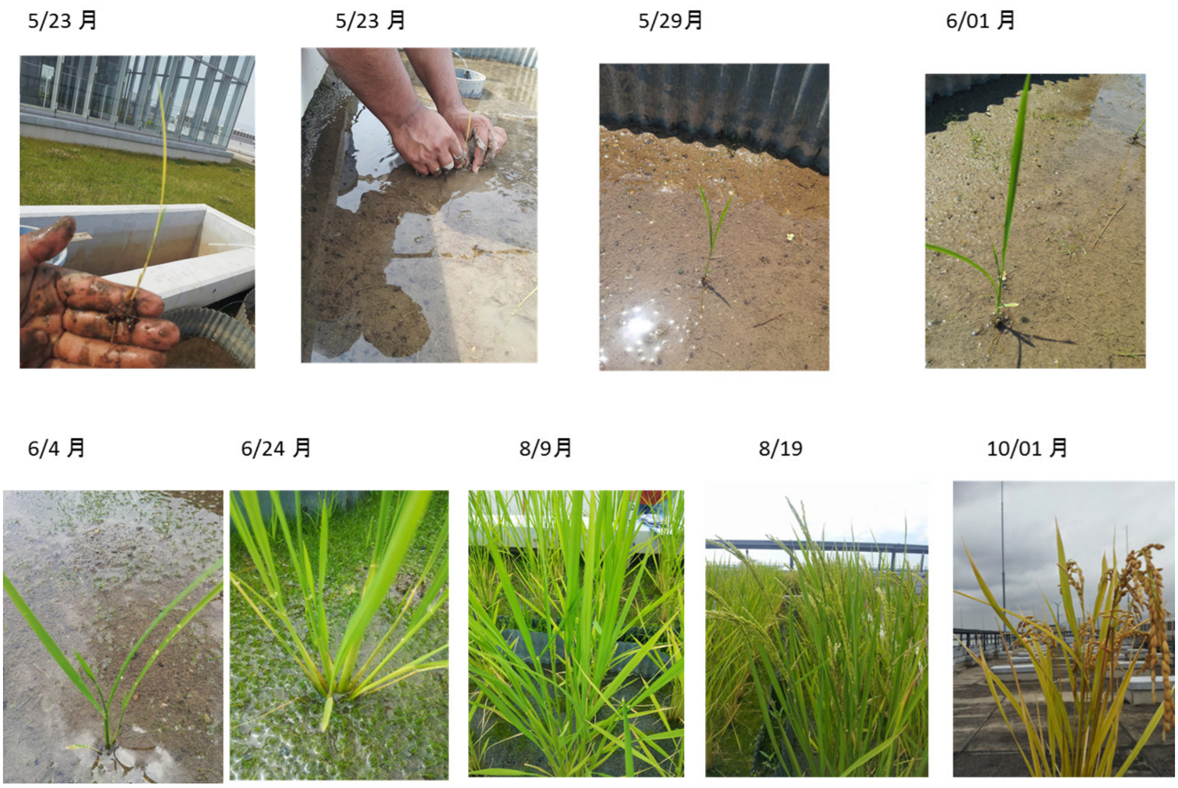


Figure 3.5: Rice growing process in the year 2014, lysimeter

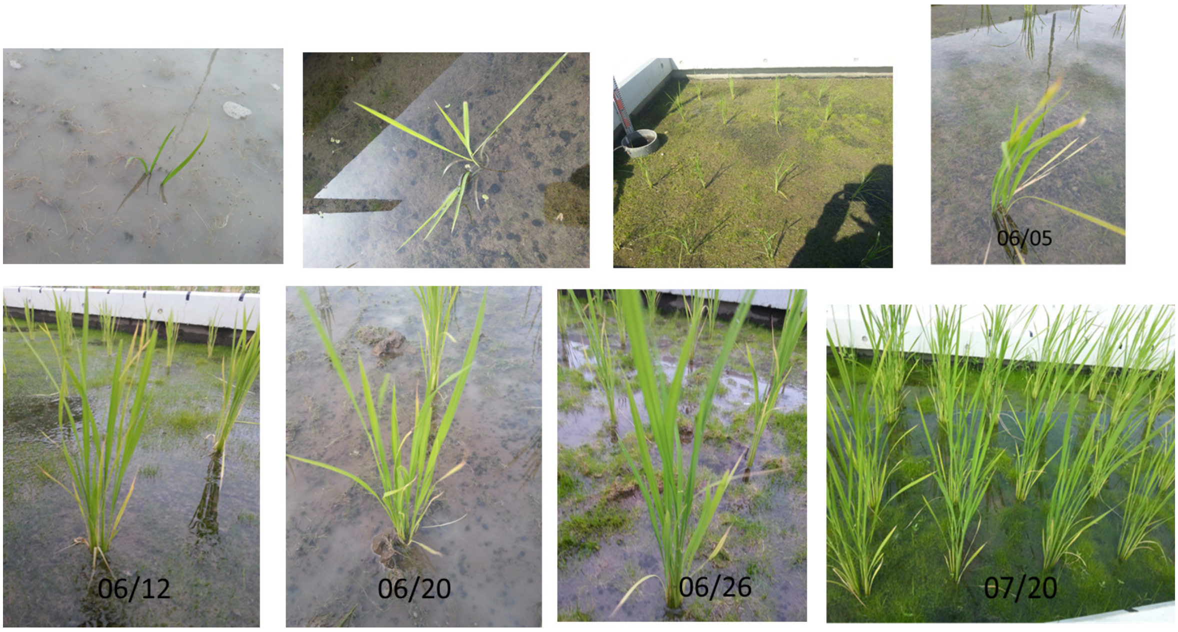


Figure 3.6: Rice growing process in the year 2015, lysimeter

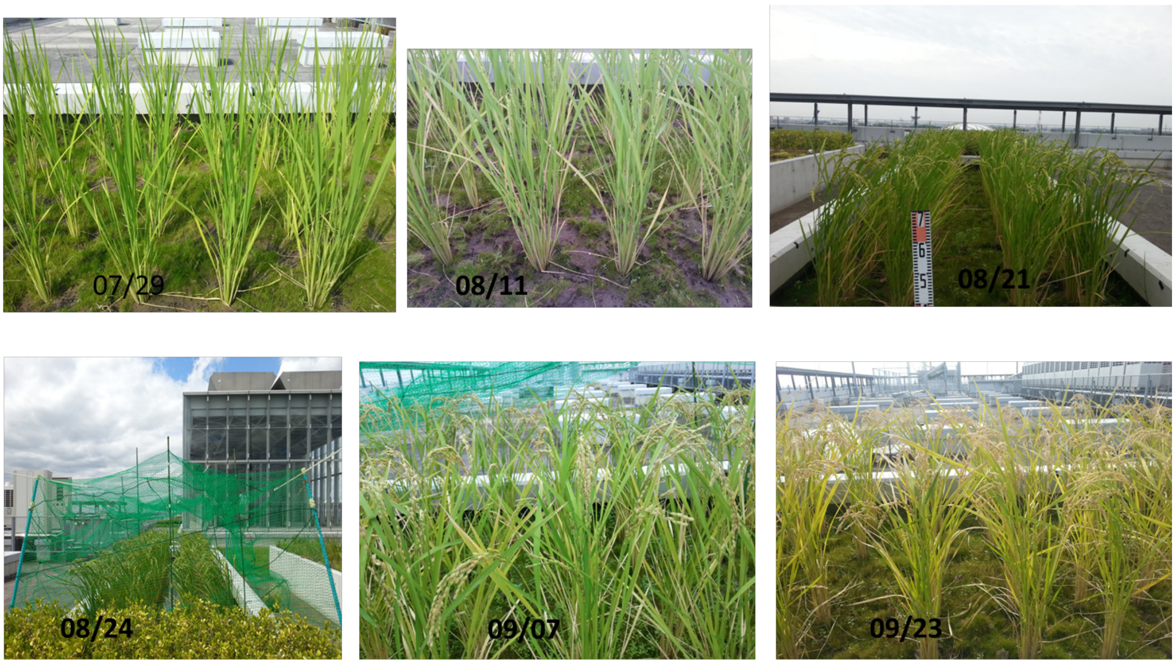


Figure 3.7: Rice growing process in the year 2015, lysimeter

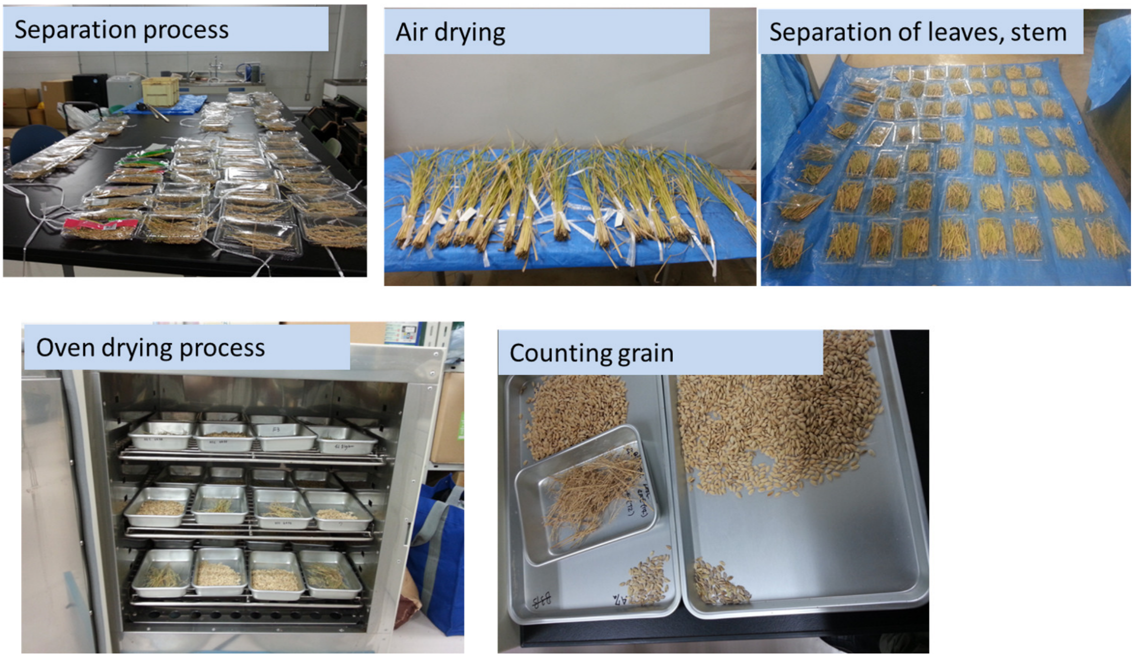


Figure 3.8: Post-harvest measurement process in the year 2015, lysimeter

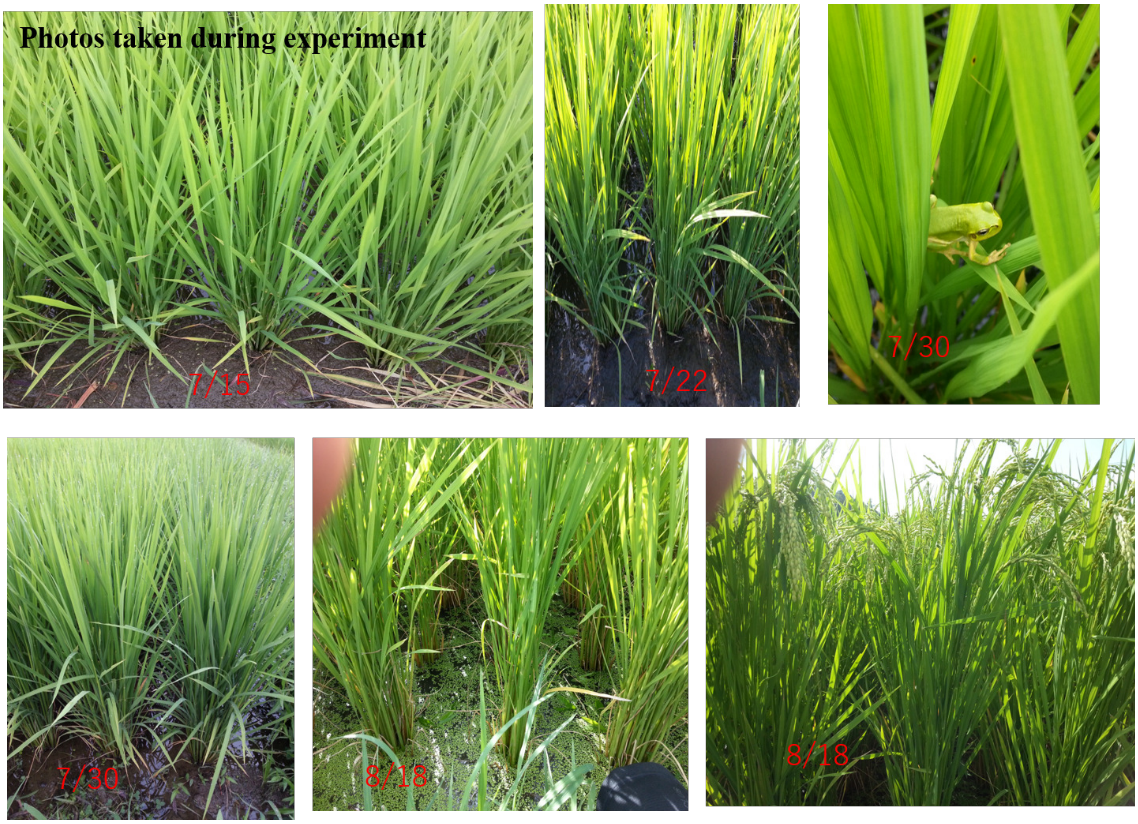


Figure 3.9: Sampling process in the year 2015, paddy field, Iwaki, Fukushima

Figure 3.10: Gas sampling process in the year 2015, paddy field, Iwaki, Fukushima

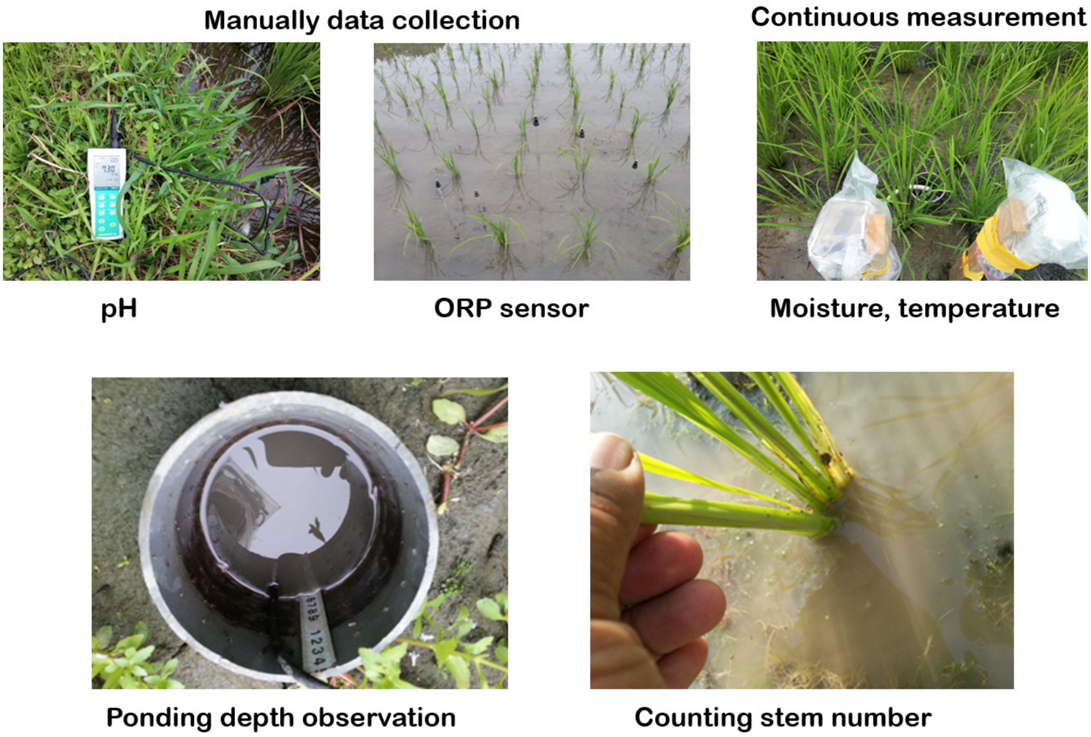
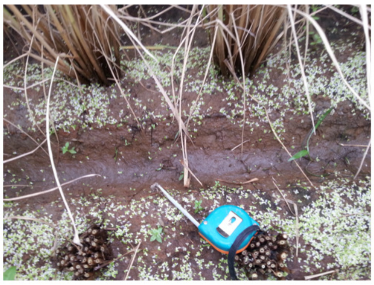
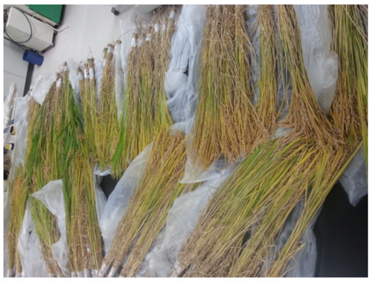


Figure 3.11: Measurement of soil physiochemical in the year 2015, paddy field, Iwaki, Fukushima

Figure 3.12: Laboratory analysis using gas chromatography paddy field samples, 2015



Rice harvest



Drying process in room temp.

Height measurement

Dismantling process of rice plants

Oven drying process

Weighting process

Figure 3.13: Post-harvest measurement process of paddy field samples

Chapter 4

Rice Plant Development in Lysimeter Environment

The implementation of system of rice intensification results in enormous yield from other countries, e.g. India, Indonesia, Nepal, and other tropical countries. Japan has already better rice yield among the other Asian countries. However, there are very few studies for structural development of rice plants by SRI method in Japan, Chapagain and Yamaji et. al., (2010)[14] have shown that there is no significant difference in yield by adopting SRI method in comparison to traditional method, while conducting experiment in paddy field at Kashiwa Tanaka, Chiba Prefecture. However, the paddy field environments is affected by various controllable and non-controllable factors. In order to reduce the various effects on the result output, in this study, initially experiments are conducted in Lysimeter environment by adopting SRI methods.The experiments are conducted to study the structural development of rice plants using SRI and non-SRI (traditional method) in lysimeter environment during 2014 and 2015 at the roof top of Environmental building, the University of Tokyo, Kashiwa Campus. In both years, the key elements of SRI method, water management is performed while keeping the other factors same. Hence, in this chapter, the results for structural rice plant development are discussed by adopting SRI and non-SRI method in 2014. Further, the result for the effect of seedling densities have also been discussed for which experiment was conducted in 2015.

4.1 Rice Development by SRI and non-SRI Methods

The comparative study for rice plant development by adopting SRI and non-SRI method in lysimeter facility is conducted at the roof top of Environmental building, the University of Tokyo, Kashiwa, Chiba, Japan, in 2014. Our main objectives of this study is to examine the structural development of rice plant and its yield by adopting two kinds of method: SRI method (AWD irrigation/intermittent irrigation) and non-SRI method (continuous flooding). As it is widely found in various regions of the world that SRI method should have higher yield than comparing to non-SRI (traditional method). It is expected that by adopting SRI method, higher grain yield, biomass, and root elongation should be observed as stated in many previous studies.The experiment in lysimeter environment are conducted in two plots, one with alternative wetting and drying as SRI method and another with continuous flooding as non-SRI method by transplanting single seedlings. The rice plant development can be divided in three phases: Vegetative, Reproductive, and Ripening phase. The time interval between transplantation to panicle formation is vegetative phase, further from panicle initiation to flowering (formation of spikelet) is considered as reproductive phase. The time interval after reproductive phase to before harvest when maturity of rice grains occur is called ripening phase. The rice plant height, number of tillers, number of leaves, and flowering numbers are measured and counted to study the structural development of rice plants during this whole experiment period in 2014. Total fourteen observations are conducted for all the rice plants from both the plots. The first observation is conducted on June 6 and the final is conducted in September 12. During each observation, the rice plant height is measured by simple iron tape and number of leaves, tillers, and flowers are counted. The observed data is shown in Figure 4.1 for both the water management methods and discussed as below.

4.1.1 Vegetative Phase

By definition, vegetative phase is considered the time interval between transplantation to maximum number of tillers. From the results it can be seen that flooding plot has vegetative phase upto DAT (days after transplantation) 57, however, for SRI plot, the vegetative phase can be considered upto DAT 71 (Figure 4.1b). Although the precise number of days according to maximum tillers in late vegetative phase is difficult to judge in SRI method because of slight fluctuation from DAT 43 to DAT 71 because some dried tillers are excluded from counting. It can be seen in the plot that maximum number of tillers is higher for flooding plot than SRI plot in late vegetative phase. The rice plant height shows almost same values for SRI and non-SRI methods (Figure 4.1a) in vegetative phase. The number of leaves during first

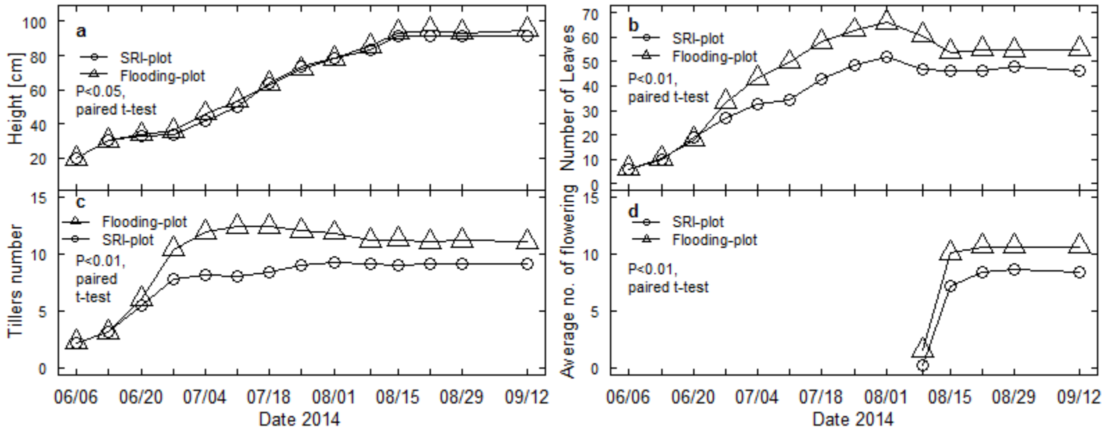


Figure 4.1: Rice plant development :(a) plant height, (b) leaves numbers, (c) tiller number, and (d) flowering number

three weeks are almost similar in both the plots, however, in late vegetative phase, flooding plot has higher number of leaves (Figure 4.1c). The slight fluctuation in number of tiller and leaves for SRI plot is because of water management slightly dried leaves and tillers are excluded from counting.

4.1.2 Reproductive Phase

After vegetative phase, the reproductive phase is considered when most of the rice plants have starting of panicle formation. By DAT 92, in both the plots, the significant numbers of plants have panicle formation, hence, the reproductive phase can be considered from end of vegetative phase to DAT 92 (August 22). During the reproductive phase, because of AWD irrigation in SRI plot, some rice leaves are decayed and small new tillers are emerged out in the counting, decayed leaves or tillers are always excluded in new leaves or tillers are always included in counting for every observations. In Figure 4.1a, the plant height is slightly higher in flooding plot than in SRI plot. This may be because, plant growth is higher in without any water stress in flooding plot. In the starting of reproductive phase, after DAT 57, the number of tillers slightly decreased till the end of reproductive phase in flooding plot and in SRI plot it is slightly fluctuates but remains almost constant after DAT 71 (Figure 4.1c). The number of leaves continue to increase in middle of reproductive phase for both the plots while slightly decrease in the end of reproductive phase (4.1b). The first panicle are observed on DAT 79th. Further, the lower number of panicles are observed in SRI plot because of less tiller number in compare to flooding plot. The numbers of panicles and tillers are almost same near the end of ripening phase before harvest (Figure 4.1d). Further, to estimate the effect of SRI and non-SRI methods on rice yield, the grain yield and biomass is discussed in next section.

4.1.3 Grain Yield and Biomass

Table 4.1: Comparison between number of grains, branches and rice root

Measurement Indicator (average data from 10 plants)	Significance Level★	SRI plot		Flooding Plot	
		Mean	SD	Mean	SD
Grain Numbers	–	1086.10	395.49	1198.30	383.15
Grain weight (gms.)	–	21.03	6.82	21.97	5.95
Panicle branches (number)	∗∗	95.50	36.08	117.30	39.19
Panicle weight without grain (gms.)	∗	1.09	0.41	1.34	0.49
Root length (cm.)	–	19.20	2.53	20.60	2.63
Dry root weight (gms.)	∗ ∗ ∗	5.07	2.21	7.62	3.23

★Significance Level: ∗ at 0.1, ∗∗ at 0.05 , ∗ ∗ ∗ at 0.01, –: Not Significant

After the rice harvest, to investigate the effect of SRI method on overall rice plant development, various parameters are compared with non-SRI method. The rice plant samples are taken as 10 from each plot. The rice roots made dried and the elongation and dry weight are measured. During the sampling, the rice plants are selected from both sides borders of the plots. The border sides rice plants are observed with larger panicle formation than in the middle. The number of grains, panicle branches, and root length are measured from all 10 rice samplings plants. In table 4.1, various measured and counted parameters are compared with mean and standard deviation for SRI and flooding plot. Statistical significance level is also indicated for all these parameters. The average grains number and grains weight are found higher slightly higher than the flooding plot. However, there is no statistical significance difference in between these two. The higher numbers of panicle branches are found in SRI plot than flooding plot with significance difference. The dried panicle weight without grain also have moderate significance difference between these two plots. The root length does not seems very difference between these two plots. however, dry root weight is significantly higher in flooding plot than compare to SRI plot. Thakur et al. (2009) [21] showed the higher elongation and better distribution of root system in SRI methods. There are several reports on SRI high yielding and water saving method in comparison to particular local farming methods, however, in this study, there is no significance difference in terms of grain yield by using SRI method in lysimeter environment in Japan.

4.2 Different Transplanting Density

Among various SRI key elements, the effect of alternate wetting and drying (AWD) without changing any other parameters, is investigated in 2014 in lysimeter environment and there is no significant differences in terms of rice yield. Also, overall rice plants development shows better result in flooding method than in SRI method. In SRI and flooding plots, single seedlings are used. Hence, it may be because one SRI key elements (single seedling) along with water management may not affect the yield in lysimeter environment. Hence, in 2015, the rice plant development by different transplant densities under SRI practice is studied. The various rice development parameters are measured and counted during rice growing season as well as post-harvest for single seedling to four seedlings in four different plots in lysimeter environment. The objective of this study is to provide adequate recommendations to farmers who are generally hesitant to transplant single seedlings in low land as well as uplands.

4.2.1 Plant Development

In 2015, to understand the effect of seedling densities in rice planting development, rice plant height, number of tillers and number of leaves are measured once in a every week during vegetative phase. However, during reproductive phase, the above measurements are taken once in a month because the lysimeter was covered with the net to protect the rice from birds. Figure 4.2, 4.3, and 4.4 show rice plant height, number of tillers, and number of leaves, respectively for one seedling to four seedlings. In 2015, the rice transplantation is done on May 12 and the measurement and counting is performed on May 22 (DAT 11). The average height of rice plant on DAT 11, for two, three, and four seedlings per hill are 16.34 ± 1.21 cm, 16.03 ± 1.34 cm and 16.03 ± 1.53 cm, respectively, but the average height for one seedling per hill is only 15.69 ± 2.26 cm as shown in Figure 4.2. The variation in average number of tillers, which are observed in every seedling density after the 29th of May are shown in Figure 4.3. In Figure 4.4, the average number of leaves during rice growing season is shown, where the maximum number of leaves is observed in four seedlings, followed by three, two, and one seedling. During the vegetative phase, numbers of leaves is similar in three and four seedlings.

In Figure 4.2, it can be seen that the rice plant height almost remain similar in all seedling densities, however, single seedling rice plant have slight higher height than other seedling densities, and it can be said that higher seedling density leads to lower the rice plant height. The number of tillers are found higher in every observations for three and four seedlings than compare to one and two seedlings (Figure 4.3). The number of tillers increases with increase

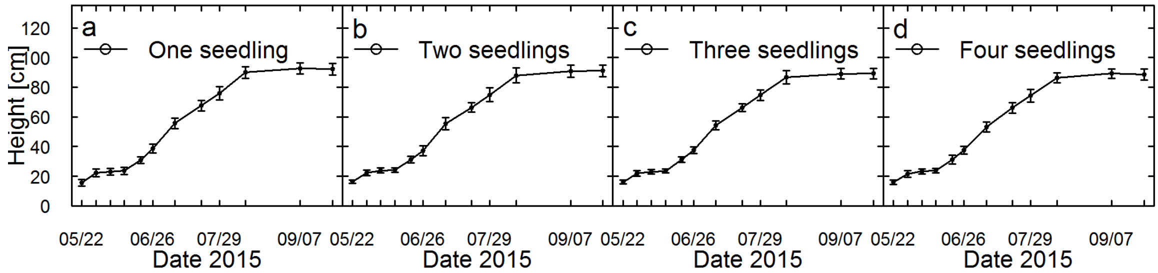


Figure 4.2: Rice plant height development in all treatments

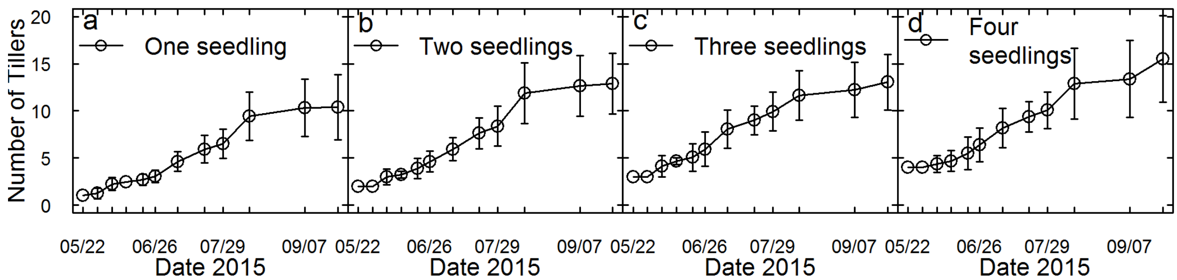


Figure 4.3: Rice tillers development in all treatments

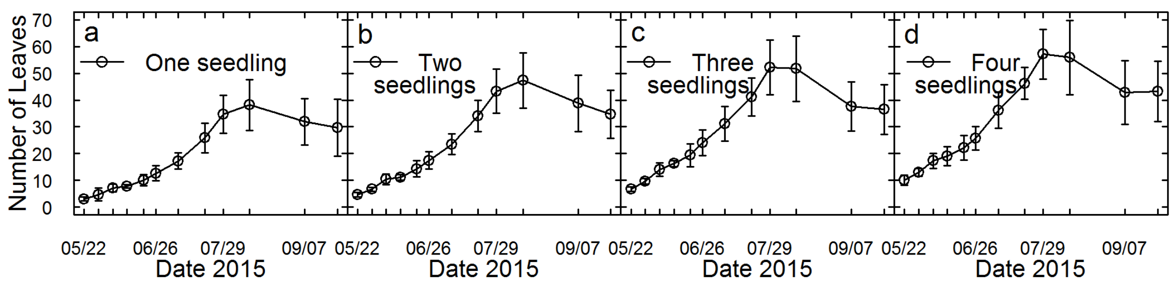


Figure 4.4: Rice plant leaves development in all treatments

in seedling densities. The number of tillers have increased in the end of vegetative phase because of emergence of small branches in three and four seedlings, however, there is no panicle formation is observed from these small emergence of tillers. The maximum number of leaves are observed in four seedling, followed by three to one seedling (Figure 4.4). During vegetative phase, number of leaves are similar in three and four seedlings. The maximum number of leaves are achieved in three and four seedlings on DAT 90, however, in seedling one and two, the maximum number of leaves observed on DAT 103. After that, number of leaves decrease because some of the lower leaves have decayed and not included in counting.

The main observation from this study for the effect of seedlings densities on rice plant development can be summarized as 1) the higher seedling densities may lead to reduce height of rice plant, 2) the higher seedling densities may lead to higher number of tillers, 3) the number of leaves can also increase with increase in seedling densities. However, the effect of seedling densities on grain yield and biomass is discussed in next section.

4.2.2 Post-harvest Measurement

Table 4.2: Details of the post-harvest measurements

Measured Variables	1 T Treatment		2 T Treatment		3 T Treatment		4 T Treatment	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Height (cm.)	92.13	2.88	91.00	89.25	89.25	2.63	88.56	2.19
Stem (Number)	10.38	2.36	12.88	2.15	13.06	1.45	15.25	2.41
Green Leaves (Number)	29.69	7.21	34.63	6.44	36.50	4.64	43.25	6.69
Dead Leaves (Number)	13.44	2.26	19.56	2.99	20.13	3.52	20.81	3.40
Panicle (Number)	9.75	1.67	11.94	2.35	11.94	1.32	13.25	2.62
Dry Stem (gms.)	9.61	0.89	13.04	0.74	13.39	2.35	14.39	2.04
Dry Leaves (gms.)	4.14	0.41	5.55	0.51	5.76	0.86	5.84	0.73
Good Grain (Number)	647.75	162.97	798.00	64.39	752.88	85.18	681.13	75.21
Bad Grain (Number)	8.50	1.08	16.75	8.45	15.75	1.50	13.00	9.88
Dry Spikelet (gms.)	0.95	0.15	1.03	0.15	0.98	0.13	1.07	0.20
Grain Weight (gms.)	15.89	2.31	18.20	3.15	19.83	2.55	20.49	4.39

In 2015, the rice is harvested on September 23. The rice plant height, number of stems, green leaves, dead leaves, and panicles are measured and counted at the end of harvest for total 64 rice plants (8 rice plants in each replication, Figure 2.8) for one to four seedling densities. To study the grain yields and total biomass development within four treatments (2 replication for each seedling treatment), four rice plants are selected from the middle of each treatment replication (total 32). Moreover, in order to study the details of rice plants, the number of grains (good and bad), dry stems and leaves, and spikelets are counted from these selected 32 plants. Table 4.2 shows details of post-harvest measurements for all the four seedlings treatments with average and standard deviation data. The grain weight is measured at 14% moisture level from all rice selected 32 rice plants.

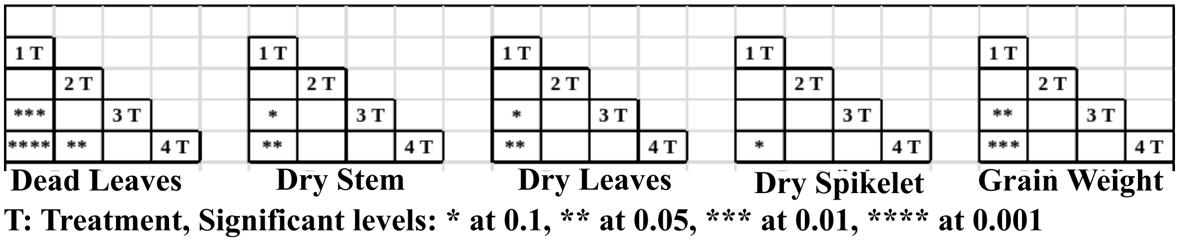


Figure 4.5: comparison between using T-test

The average height of rice plant shows higher for single seedling among all the treatments but there is no significant difference. The average number of stems are higher for four seedlings and lowest for single seedlings. Similarly, the number of leaves and dead leaves have ordered as least for single seedling than higher for two seedlings, further higher in three seedlings, and highest in four seedlings. The dry stem and dry leaves weight also show similar trend, increases with increase in number of seedlings. After that the average number of good grains are found in two seedling treatments and then slightly lower in three seedlings and further lower in four seedlings and lowest in single seedlings. Similar trend is found in number of bad grains also. The average grain weight is observed highest in four seedlings and slightly lower in three, further lower in two and lowest in single seedling.

Figure 4.5 shows comparison for dead leaves, dry stems, dry leaves, dry spikelet and grain weight by using T-test. It is found that three seedlings show significantly higher level of dead leaves as compared to single seedling treatment ($p < 0.01$). The four seedling also have higher number of dry leaves than two seedlings ($p < 0.05$). The number of dry stems and leaves are higher for four seedling treatment than for one seedling treatment ($p < 0.05$). For other comparison, the difference in dry stems and dry leaves are not significance. The dry spikelet is significantly higher for four seedlings than compare to single seedling ($p < 0.1$). The measured grain weight (i.e. yield) at 14% moisture level is higher for three seedlings

($p < 0.05$) and four seedlings $p < 0.01$) compared to one seedling. However, there is no significant difference in grain weight (yield) between one and two seedling treatments.

4.3 Discussion

To study the effects of SRI key elements on structural development of rice plants, two experiments are conducted in two lysimeter plots in 2014, one with alternate wetting and drying and another with flooding water management for single seedling and further in 2015 another experiment is conducted by varying seedling densities with alternate wetting and drying in lysimeter environment. In 2014, it is found that in lysimeter environment the structural development of rice plant is significantly greater during vegetative and reproductive phase for flooding plot (non-SRI method) than compare to SRI plot. However, the post-harvest measurements shows no significant differences in grain yield. This may be because young single seedlings are used in both plots, and dry root weight is greater in the flooding plot but no difference is observed for root length. However, earlier study in India have shown higher elongation of roots for SRI method and better distribution of root system (Thakur et al., 2009)[21]. The indicators panicle branches, panicle weight (without grain) and dry root weight show significantly higher in flooding plot than compare to SRI plot. SRI method itself is a new environment-friendly method, and while several researchers produced higher yields than conventional their regional conventional rice cultivation method. In this study, the yield from SRI method does not significantly change in Japan. The dissemination of SRI method is still a work in progress, where basic key elements are being identified by particular local areas, since different areas have different climate conditions and resource availability. As there is no significant differences in yield by alternative wetting and drying water management than continuous flooding condition in this study, it leads to further study the effect of seedling densities because in 2014, same number of rice seedling is transplanted in both plots. Hence, experiment is conducted in following year 2015 for single seedling to four seedling in lysimeter environment to clarify the difference in rice plant development under the SRI practices.

The common method of rice transplanting by SRI is single young rice seedling. However, farmers in some lowland areas hesitate to transplant single seedlings for SRI method because of the threats from birds, flood, insects, etc., it causes a dilemma for the farmers over the implementation of the SRI method. Hence, study of different seedlings in lysimeter environment can also clarify the optimum use of number of seedlings for higher yield.

It is found that the rice plant height is higher among the one seedling than two, three and four seedlings in vegetative phase. The number of tillers (stems) and leaves is lower in single seedling than two, three, and four seedlings. The post-harvest measurement of rice plant development measures and counts the height, stem, green leaves, dead leaves, panicle number, dry stem, dry leaves, good grains (not decayed, filling with grain), bad grains (without filling and decayed ones), dry spikelet and grain weight (14% moisture level). The statistical significant differences is observed in dead leaves, dry stem, dry leaves, dry spikelet and grain weight. The final production (rice yield) is important indicator in our research. Grain yield is significantly higher for transplantation treatment with three and four seedlings rather than one seedling, validating the farmers' confidence in their way of applying the SRI method. This study thus suggests that farmers can transplant more than one seedling in lowland areas. The study used a Japanese koshihikari rice nursery. It is highly recommended to test with the local rice variety, climatic condition, and agronomical practices for a more precise confirmation of optimal seedling densities.

Chapter 5

Methane Emission in Lysimeter Experiment

Two experiments are conducted to investigate the methane emission from rice cultivation in lysimeter environment by measuring various parameters and adopting AWD water management (in 2013) and further in 2014 by comparing the methane flux from lysimeter by using two kind of water management (AWD irrigation and continuous flooding). The aim of first experiment is also to investigate the soil condition at various depth by managing AWD irrigation and second experiment is to study the change in GHGs by SRI method (AWD/irrigation) and conventional method(continuous flooding). Previous paddy fields experiment have shown that the flux of methane emission varies because of soil types, compost application as well as water management such as mid-season drainage. Mid-season drainage can be an appropriate option for reducing the greenhouse gas emission from paddy fields (Hadi et al. 2010[9]; Yagi et al. 2012[15]). Moreover, some researchers have suggested that methane emission from the paddy fields occurs through ebullition and low atmospheric condition (Tokida et al. 2005)[16]. The lysimeter experiment by Kudo et al. (2014)[17] have shown that GHG is reduced by intermittent irrigation. Nonetheless, the mechanism of methane emission (parameters responsible for high and low methane emission) is not completely identified with respect to water management and physiochemical properties of the soil at different depths. During the first experiment, the methane flux patterns and physiochemical properties of the paddy soil during and after the rice growing season is investigated.

5.1 Water Management

During lysimeter experiments, ponding depth is observed by a water tube. The ponding depth during the rice growing and non-growing season as shown in Figure 5.1c, 5.2c. However, in 2014, methane emission is compared between SRI (alternate wetting and drying, AWD) and non-SRI method (continuous flooding). Ponding depth for these two plots in lysimeter is shown in Figure 3.1.

In 2013, during the rice growing season (Figure 5.1c), AWD irrigation is adopted but after harvesting (Figure 5.2c) frequent rainfall is observed from mid September to the end of November. Tap water is supplied for irrigation whenever the water level drops below the soil surface in rice growing season. The water level in the driest condition is at 20 cm below the soil surface and the highest ponding level is at 5 cm above the surface in rice growing season. In post-harvest, the lysimeter is in flooded condition until the end of December. Water in the lysimeter was not managed after harvest.

In 2014 (Figure 3.1), in the flooding plot water level is managed by supplying water without drainage so that, the water level should always be above the soil surface except before harvest, drainage is applied. Also in SRI plot, the water level is managed by alternate irrigation and drainage. The maximum water level above the surface is kept approximately 5 cm while in drainage, water level can go upto 20 cm.

5.2 Soil Condition during Pre-harvest

It is important to know various soil conditions (e.g. soil pH, ORP, temperature, water content) during the rice growing seasons and relate it with the methane emission. In this section, the data observed in 2013 experiment is discussed for rice growing season. Soil moisture and temperature data are recorded in every 60 minutes throughout the experiment and soil ORP and pH are measured manually once a day. Figure 5.1 shows soil pH, soil ORP, ponding depth, soil water content and soil temperature at various depth during vegetative phase, reproductive phase, and ripening phase for rice growing season.

As alternate wetting and drying irrigation is applied in 2013 experiment, which may affect the soil characteristics at the upper layer. The temperature and moisture measurements are performed at 5 cm, 10 cm, 15 cm, and 20 cm, however, soil pH and ORP measurements are performed at three various depth because of limited number of sensors. Soil moisture content at 5 cm and 10 cm depth are greatly affected by AWD irrigation in Figure 5.1d, it can be seen that moisture at surface layer percolated faster in a drier condition. In Figure

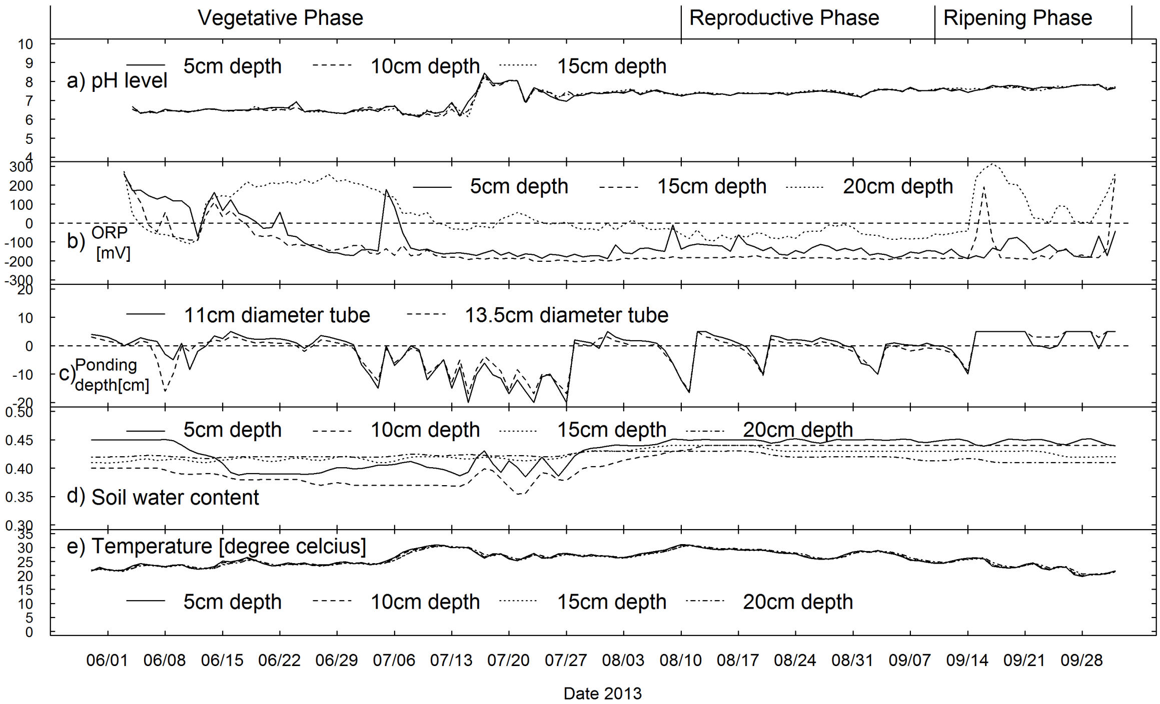


Figure 5.1: Physiochemical condition of lysimeter experiment, in year 2013

5.1c, the ponding depth is below the surface from starting of June to starting of August, in this period, soil water content also drops down. However, there is not much effect on deeper layers at 15 cm and 20 cm depths. During the wet season, when the ponding depth is above the surface, the soil water content at every depth increased and almost stayed constant even with application of short time drainage. Much of the lowland rice field soil is clayey with higher water holding capacity compared to other soil types. Water retention capacity of soil may be the reason for the smaller soil moisture fluctuations at deeper depths of 15 cm and 20 cm depths. In addition, temperature is slightly fluctuating up and down with ponding depth and upper layer soil water content in opposite direction. However, the atmospheric temperature may also affect the soil temperature and in between water layer may offer resistant in heat transfer from atmosphere to soil. There is no significant difference in temperature at various depths. Figure 5.1e shows that the temperature increased at every depth during the initial phase when the moisture content decreased in accordance with the ponding depth. Temperature started to drop when the moisture content increased.

After the transplantation of rice on May 29 during the initial phase, the pH value remained constant until middle of July (Figure 5.1a). Soil pH value steadily increases toward alkaline condition afterwards during lesser ponding depth. At various depths of 5 cm, 10 cm and 15 cm, the soil pH values do not have significant differences and vary in similar same pattern.

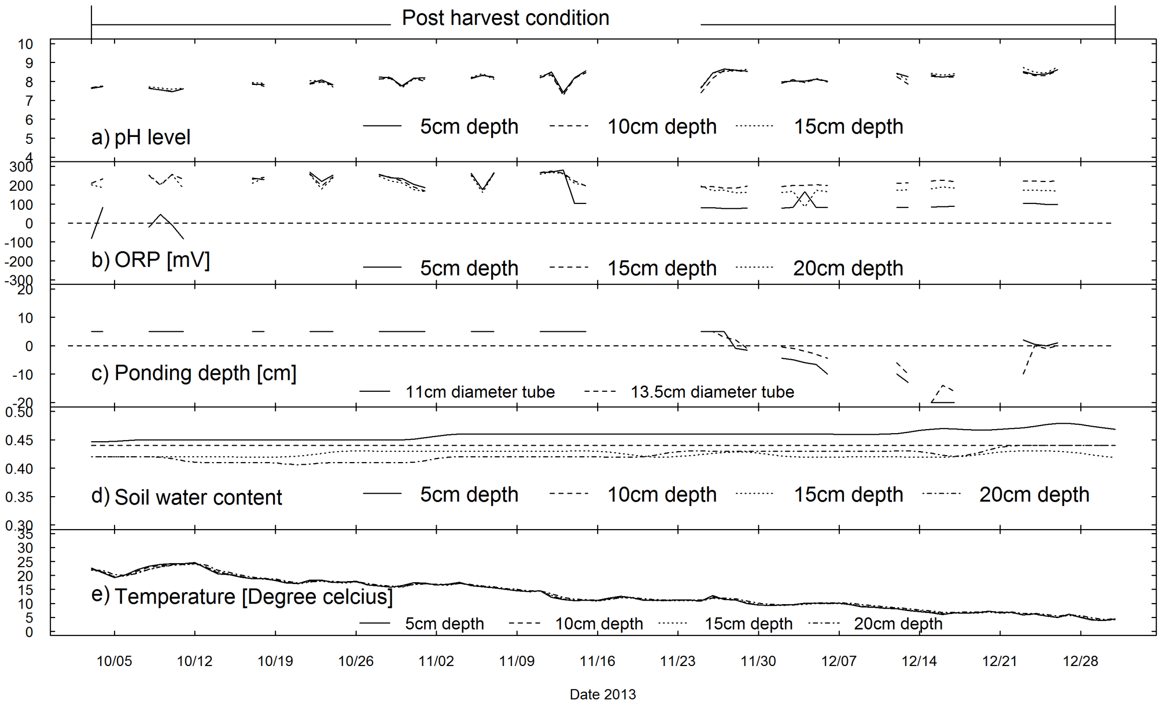


Figure 5.2: Physiochemical condition (non-rice growing season), in year 2013

The soil ORP value at 5 cm, 15 cm, and 20 cm are highly fluctuating during the initial phase because of soil puddling in the plow layer, which causes frequent changes in oxidation ability of rice roots. In later phase, lysimeter is ponded after mid-July due to the rain and irrigation. The ponding condition causes the soil ORP to gradually drop in reduction condition as shown in Figure 5.1b. The exchange of oxygen gas from atmosphere to the soil is reduced under the ponding condition in lysimeter, hence, the soil ORP indicates reduction condition for ponding. However, the soil ORP at 20 cm depth shows positive value, in oxidation condition,even when the upper layer are in reduction condition. It may be cause because of concrete base of building may have impact on lysimeter environment. Hence, to understand the deeper layer soil oxidation and reduction characteristics, the measurements in actual paddy fields are required which is discussed in next chapter.

5.3 Soil Condition during Post-harvest

In year 2013, after the rice harvest the lysimeter is left in natural condition and it's physio-chemical properties are observed by measuring the same parameters in pre-harvest season.The soil pH, soil ORP, and ponding condition are measured irregularly while soil temperature and moisture are measured every 60 minutes as before (Figure 5.2). The ponding depth is positive until the end of November and turned negative through December. Because of anaerobic condition of soil, the ORP values are positive upto November but decrease slightly in December. The soil water content is neutral throughout the post-harvest seasons since the ponding depth in lysimeter is constant upto November, as shown in Figure 5.2c and even reduction in ponding depth does not change soil water content in December. The temperature at every depth decreases in same pattern as winter has arrived. Further, it is important to relate methane emission data measured during pre-harvest and post-harvest with the soil characteristics to understand the increase or reduce emission rate by adopting water management. In next section, methane emission from 2013 experiment with soil characteristics is discussed as well as compared in 2014 experiment when SRI and non-SRI methods are adopted.

5.4 Methane Emission

In 2013 experiment, lysimeter is flooded for first weeks after the transplantation, and AWD irrigation is applied afterwards in accordance with amount of rainfall while the rice nursery is still strong. Figure 5.3 shows methane flux data measured on four dates before harvest and three dates after harvest during 2013 experiment. The first gas sampling is conducted on July 23 when the ponding water is 15 cm below the surface, given that methane flux should be less when ponding depth is dropped. On this date, methane flux is observed below zero and soil ORP values are also negative at 5 cm and 15 cm depths and slightly positive in 20 cm depth. The second and third gas sampling is performed on August 4 and 10 respectively. The positive methane flux is observed in these two dates with higher value in third sampling date. It can be said that methane flux increase with the rapid development of rice plants during the end of vegetative phase. In the next sampling on August 24, the methane flux again decreases. If the irrigation can be controlled without inducing water stress in a rice plant then AWD irrigation is an appropriate measure for mitigating CH_4. Methane flux is less during the reproductive phase where rice plant height, tillers, and leaves develop and panicles reach maturity slowly. The total average grain weight per hill in a dry condition was 19.66 gms, equivalent to 1.57 t of rice per hectare. During the post harvest measurements, the flux at three dates are below the zero in this study, the similar result are observed by Nishimura et al. (2004)[12]. It means that fallow paddy field in Japan without cultivation left after the rice harvest is irresponsible for methane emission.The global warming potential during rice growing and non-growing seasons from total methane emission, is 7.30 and -6.13 $gms.CO_2/m^2$, respectively.

In 2014, the experiments are conducted in lysimeter environment by adopting SRI method

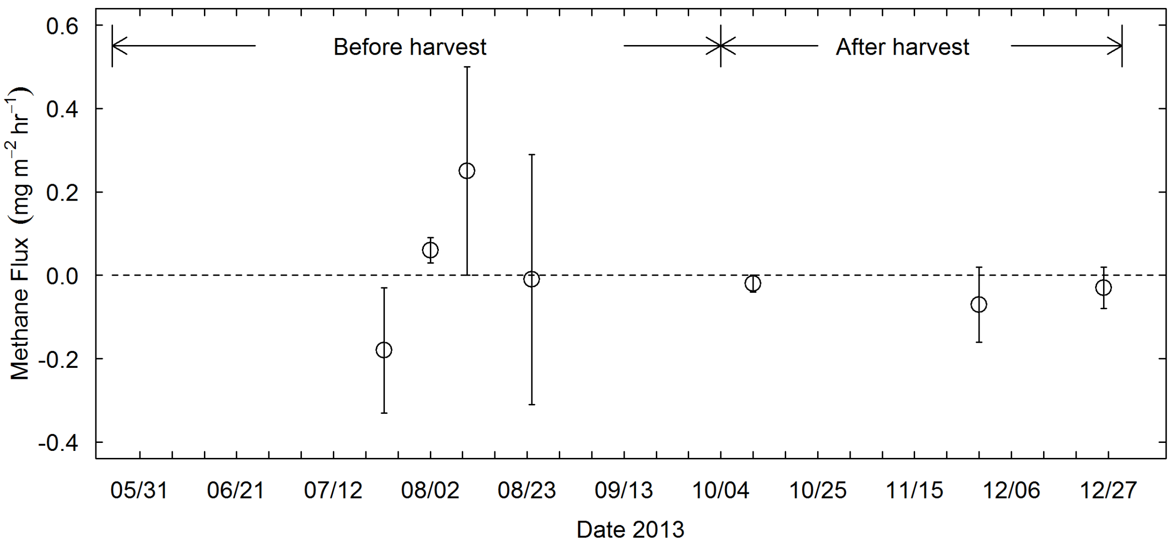


Figure 5.3: Methane emission from lysimeter, in 2013 (vertical bar is SD: standard deviation)

(AWD irrigation) and non-SRI method (continuous flooding) to study the effectiveness of SRI method on methane emission. Although the measurements are performed for soil characteristics but because of issues of sensors, only methane emission data is presented here and during discussion in next section, available data is plotted to find correlation. The methane emission data in 2014 experiment is sufficient to give preliminary information on methane emission in various rice development phases. Further, in details studies are performed in actual paddy field and discussed in next chapter. In the previous literature, the methane gas emission from SRI method is found typically lower than flooding plot. The methane gas reduction process by AWD irrigation is already known by many researchers (Hadi, A.et al. 2010[9], Kudo, K. et al. 2014[17]). Figure 5.4 shows methane emission measurement in SRI and flooding plots during rice growing season at four dates. In both the plots, the pattern of methane emission shows increased emission in vegetative phase and further decreased in reproductive phase. The rapid development of rice plants in vegetative phase and longer application of irrigation causes the higher emission of methane. Even though, during this experiment, same amount of fertilizers is mixed with soil before transplantation in both the plots, but the methane emission is significantly reduced by adopting water management using AWD than compare to continuous flooding condition. By computing total cumulative methane flux during the rice growing season, methane emission is reduced nearly 50% in SRI plot than in flooding plot. Total methane flux emitted from SRI plot is 50.41 $gms.CO_2/m^2$ and flooding plot is 100.53 $gms.CO_2/m^2$ per rice growing season. Another anthropogenic gas N_2O emission is occurred with the disappearance of flooding water from paddy field and fertilizer application

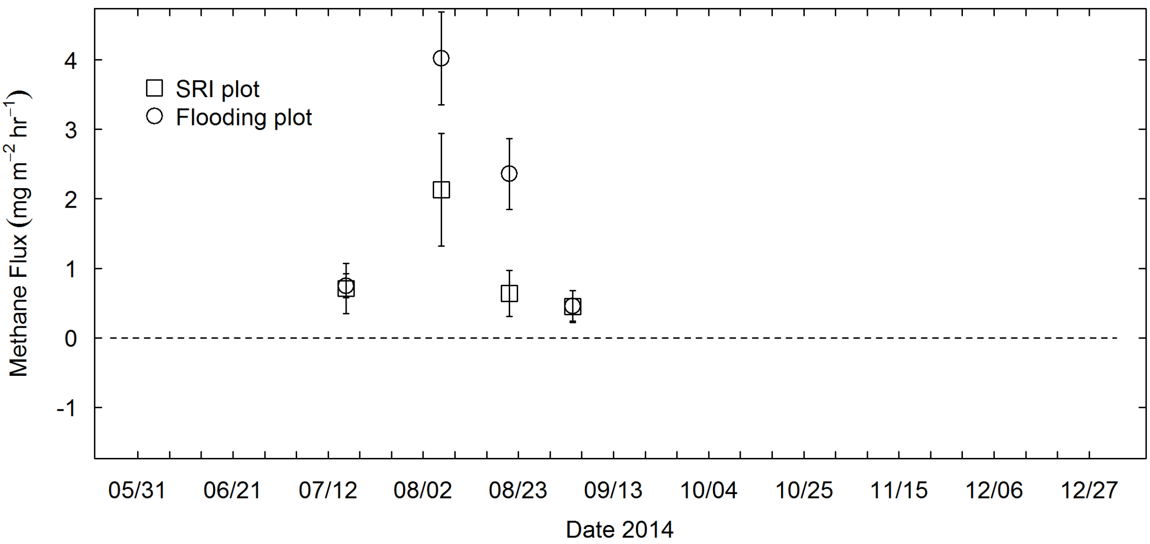


Figure 5.4: Methane emission in SRI plot and flooding plot, in 2014

(Cai, Z. et al., 1997)[34], which is measured in actual paddy field experiments later.

5.5 Discussion

It should be noted that experiments are conducted in 2013 with AWD irrigation and depth-wise measurement of soil ORP, pH, temperature, soil water content in rice growing and non-growing seasons, however, during rice non-growing season, the fallow land does show any methane emission. Similarly, in 2014, comparison of methane flux from lysimeter in two plots naming SRI plot and non-SRI plot is performed. In 2014, due to some issue of the sensors, the correlation between methane flux and soil ORP (soil Eh) is only discussed in this section at 5 cm and 10 cm depths (Figure 5.6). However, for experiment conducted in 2013, the correlations between methane flux with soil ORP, soil pH, water content and soil temperature are discussed in this section (Figure 5.5).

In the experiment conducted in lysimeter in 2013, it is identified that higher methane flux occur near the end of vegetative phase or starting of reproductive phase. Methane flux is also greater in presence of active soil microorganism during the rapid development of rice plant height, leaves, and tillers. Moreover, the experiment has also shown that methane is being released whenever soil ORP is negative in the soil layer (reduction condition), while higher value of ORP indicates oxidation condition in soil which results in lower methane emission. In this study, the temporal measurement of ORP is performed upto 20 cm soil depth, while many previous studies have measured soil ORP only upto 5 to 10 cm depths. Figure 5.5a shows

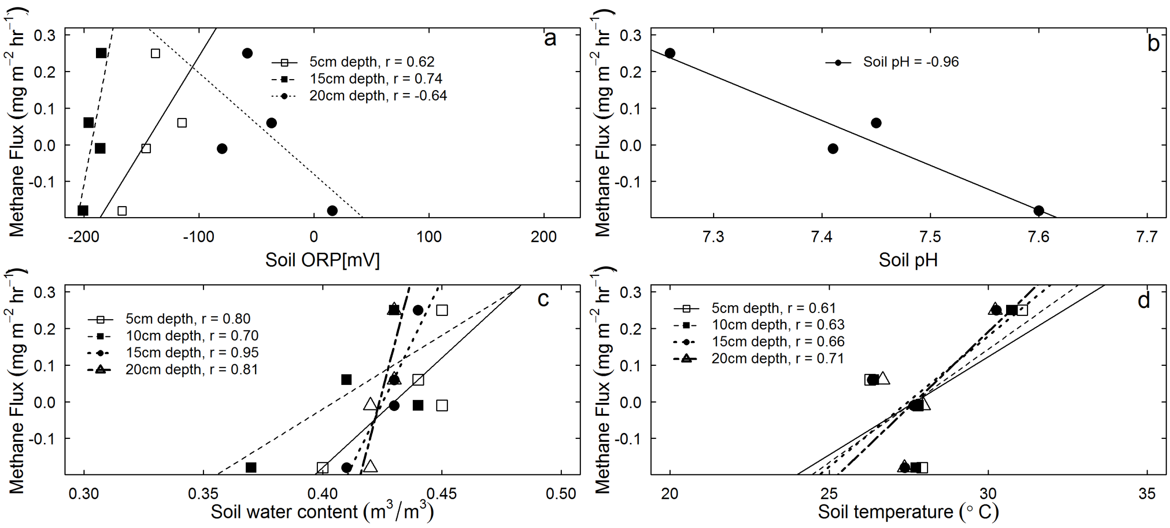


Figure 5.5: Relation between methane flux, soil water content, soil temperature, and ORP, in 2013

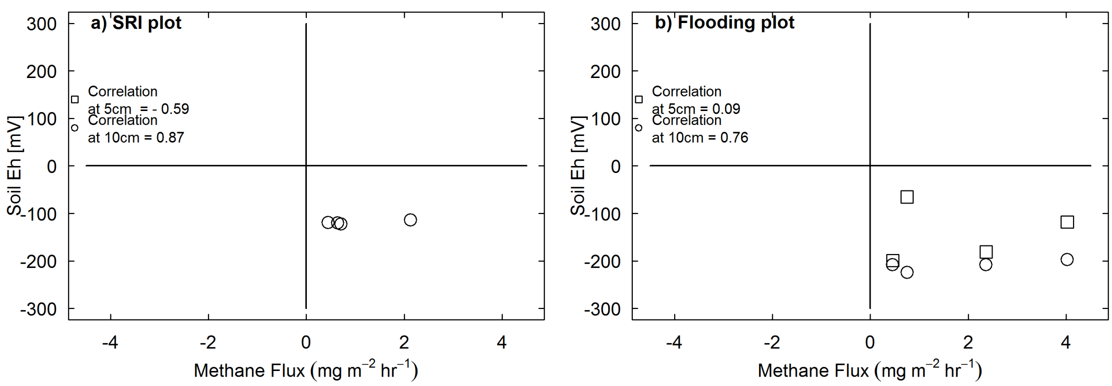


Figure 5.6: Relation between methane flux and ORP, a) SRI plot, b) flooding plot, in 2014

negative correlation even at 20 cm depth where slight oxidation condition is observed. When the soil ORP value is positive, the methane emission is lower. The Figure 5.5a also shows positive correlation between CH_4 flux and ORP at 5 cm and 15 cm depths while the ORP values are always negative (reduction condition) at this depths during methane emission measurements. Hence, the methane emission may increase by slight change in reduction conditions, methane emission may also depend on other soil characteristics. Further, it may be required to have more data points for upper layer of soil to exactly predict the correlation. The moisture and temperature shows higher positive correlation with methane flux (Figures 5.5c and 5.5d). During the experiment, soil water content increasing and decreasing with ponding depth with the lysimeter. Similarly, methane flux is also increasing and decreasing with the ponding condition of lysimeter which leads to positive correlation between methane flux and soil water content. The increase in soil water content leads to increase in reduction condition in soil which may be responsible for higher methane flux. The soil temperature increases during pick summer weather, hence, methane emission flux also increases in the summer and shows similar pattern to soil water content. The ORP result shows that maximum negative ORP do not fall below in -201 mV during gas measurement process. Decreasing ORP may be affected by water management. However, this is a lysimeter experiment conducted on the roof of a concrete building, and there may be some heating effect at the lower, 20 cm depth, which is different from a paddy field environment. To better understand the mechanism of methane flux with respect to soil physiochemical properties, experiments on real paddy fields are required.

The experiment conducted in year 2014 for comparing methane emission from SRI and non-SRI plots, the methane flux in SRI method is significantly lower than the flooding plot, with almost 50% reduction in emission. The methane flux peak is mainly observed during the vegetative and pre-reproductive phases. The Figures 5.6a and 5.6b show the correlations between methane flux and soil ORP (soil Eh) in two different depths at 5 cm and 10 cm for SRI and non-SRI methods, respectively. Soil Eh is measured as an indicator of methane gas emission from both plots. To understand the mechanism of methane gas flux with soil layer condition, depth-wise measurement of soil Eh are performed. In both plots, 10 cm depths shows moderately positive correlation between methane flux and soil Eh (Figure 5.6a and Figure 5.6b). However, in 5cm depth, SRI plot shows higher negative correlation (Figure 5.6a). In the SRI plot, the AWD irrigation supply kept the soil wetting and drying the soil surface results in soil Eh (ORP) increase and low methane formation. The aerobic conditions of soils also make the low emission in SRI plot. In case of flooding plot, continuous stagnant of water, soil Eh shows the lower negative value in every depths of 5 cm and 10 cm and emits higher methane flux. During the continuous flooding soil gets reduction condition and emits the more methane gas. In flooding plot, every depth of 5 cm and 10 cm are responsible for the methane flux formation. But in case of SRI plot, the reduced methane flux formation shows only at 5 cm depth but 10 cm depth shows slight increasing methane flux with slight fluctuation in ORP negative values. If the water could be managed without stress to the plant, then SRI method can be the appropriate method for reducing global warming potential. Although, the experiment in 2014 are also conducted on concrete made lysimeter, and the heat from the concrete may have affected the measurements for soil temperature and soil ORP (Eh). Hence, comparison of methane emission by adopting SRI and non-SRI methods, to clearly understand the relation between soil ORP (Eh) and methane emission at various depths, tests in real paddy fields environment are needed.

Chapter 6

Mechanism of GHGs Emission from Paddy Field

6.1 Introduction

After the green revolution, rice production was increased due to the high use of chemical fertilizers and water but it also causes the heavy burden in environment. Because of new fertilizer based rice cultivation methods, the environment get affected from anthropogenic gases CO_2, CH_4, N_2O emitted from rice field which changes changes the ecosystem of earth and now becoming a serious issue of climate change. To overcome the problems of climate change, scientists and researchers have looked for rice cultivation methods which can be environmental friendly and have sustainable rice production to feed the masses. Many researchers have tried several mechanisms in order to achieve the same. Low water input like alternative wetting and drying irrigation (AWD) is one of the measures to reduce the GHG emission which is recommended by IRRI[5]. In 1980s new rice cultivation innovative method was (System of Rice Intensification) was discovered by Fr. Henri de Laulanié, S.J.[6] and later this method was disseminated worldwide by Professor Uphoff[3] from Cornell University with the synergy of the organic rice farming. After the several experiments conducted in worldwide regarding the SRI, they set up the key element of SRI as follows. After the several experiments for SRI conducted at various topographical and climate locations worldwide, the key elements of SRI are established[6]. The four key elements for SRI are as follows: 1) Early, quick an healthy plant establishment, 2) Reduced plant density, 3) Improved soil conditions through enrichment with organic matter, and 4) Reduced and controlled water application. One of the key elements in SRI by practicing intermittent irrigation depends on many factors from region to region. In general the adaptation of SRI depends on the climate, topography and farmer's cultivation cultures.

In case of Japan, the effectiveness of SRI for Japanese rice cultivation is started by the Japan Association of the System of Rice Intensification (J-SRI) and its adaptability is being in progress to set the basic SRI key elements for various rice farm location's in Japan. In initial researches, it is found that the traditional Japanese rice cultivation methods have lesser GHGs emission as reported by Nishimura, S. et al. (2004)[12]; Minamikawa, K. and Sakai, N. (2006)[36] because conventional water management and mid-season drainage is already in practice in Japan. However, there is still scope to improve current traditional methods towards SRI in Japan.

Methane gas is formed during rice cultivation because of anaerobic condition of soil, which largely depend on water management in paddy fields (Wang et al. 2000)[38]; (Wassmann et al., 2009)[37].The global warming potential of CH_4 is 34 times higher than CO_2 in 100 year time span (IPCC, 2013)[53].

Another major greenhouse gas, N_2O is also produced as a byproduct of nitrification during rice cultivations and also because of application of fertilizer type. Especially upland fields are recognized as higher N_2O emitter rather than paddy field (Akiyama et al., 2000)[40]. The global warming potential of N_2O is 296 times higher than CO_2 in 100 year of time span(IPCC, 2013)[53]. However, till now very few paddy field experiments have been conducted to understand the mechanism of GHGs emission by observing the soil layer conditions in deep depths.

In previous chapters the results from two consecutive experiments in 2013 and 2014 in the lysimeter facility by applying SRI basic component like young seedling, single seedling and water management (intermittent irrigation / AWD) are discussed. However, the lysimeter conditions and paddy conditions may have different environment.To validate the results of greenhouse gases emissions, observed in lysimeter experiment with the actual paddy field further experiments were conducted in Iwaki-shi, paddy fields as explained in chapter 2.The main objectives of this experiments are to understand the mechanism of GHGs emission from the soil, investigating the soil layer condition in a depth-wise and as well as assessing the improvement in rice yield with intermittent irrigation methods.

As intermittent irrigation is one of the basic key SRI principles, hence experiments are conducted in Iwaki city, Fukushima prefecture in cooperation with local farmers. Two rice fields are selected for rice cultivations, the farmers are asked to adopt the intermittent irrigation method according to our requirements in one paddy field, which is named as Paddy Field A and to continue local method of rice cultivation of Iwaki-shi in another paddy field, which is named as Paddy Filed B. The similar measurements are done in both paddy rice fields to achieve objectives of this study. The size of paddy field A is $44.9m \times 34.8m$ and paddy field B is $44.5m \times 17.70m$. Initially same fertilizers applied in both the rice fields as 30 kg/10 acre which has composition of 10% nitrogen, 24% phosphorus, 18% potassium and 4% magnesium. Further additional fertilizer is applied in both the fields as 6.25 kg /10 acre which has a composition of 16% nitrogen, 0% phosphorus and 16% potassium.Shallow intermittent irrigation method according to SRI key applied in paddy field A while local irrigation method according to Iwaki-shi is applied in paddy field B as shown in Figure 6.11. Both the methods had only one thing is common as during the vegetative phase mid-season drainage was employed and both paddy fields are dried two weeks before the paddy harvest.

6.1.1 Rice Plant Development

During the paddy field experiment, the first rice transplantation is done by tractor on May 8, 2015. The transplanted density of rice nursery is done with $3 \sim 4$ seedlings per hill with spacing between one hill to another hill as $21cm \times 18cm$. The measurements of rice plant height, counting of stems and leaves are performed regularly. One week after the transplantation rice plant growth is observed.The sampling locations are chosen based on the random sampling method considering rice plant on the border sides (outer parts) may have higher development because of near by plant density, direct exposure of sun light, and more nutrients of plant intra-competition. As shown in Figure 6.1,the four places are chosen to measure plant development from each field. The rice plant development measurements are taken eleven times during vegetative and reproductive phases, while two times measurements are taken during ripening phase.

6.1.2 Vegetative Phase

Among different phases of rice plant development, vegetative phase has longest time interval in rice growing season. In general, vegetative phase is defined as time interval from germination to panicle initiation (maximum number of tillering), which is approximately 87 days in total. In current experiment, the transplanted young seedlings have age of 25 days on the day of rice transplantation (May 8, 2015). Hence the vegetative phase observed in rice field have approximately 62 days (ends on July 15, 2015). During the pre-harvest phase, the rice plants

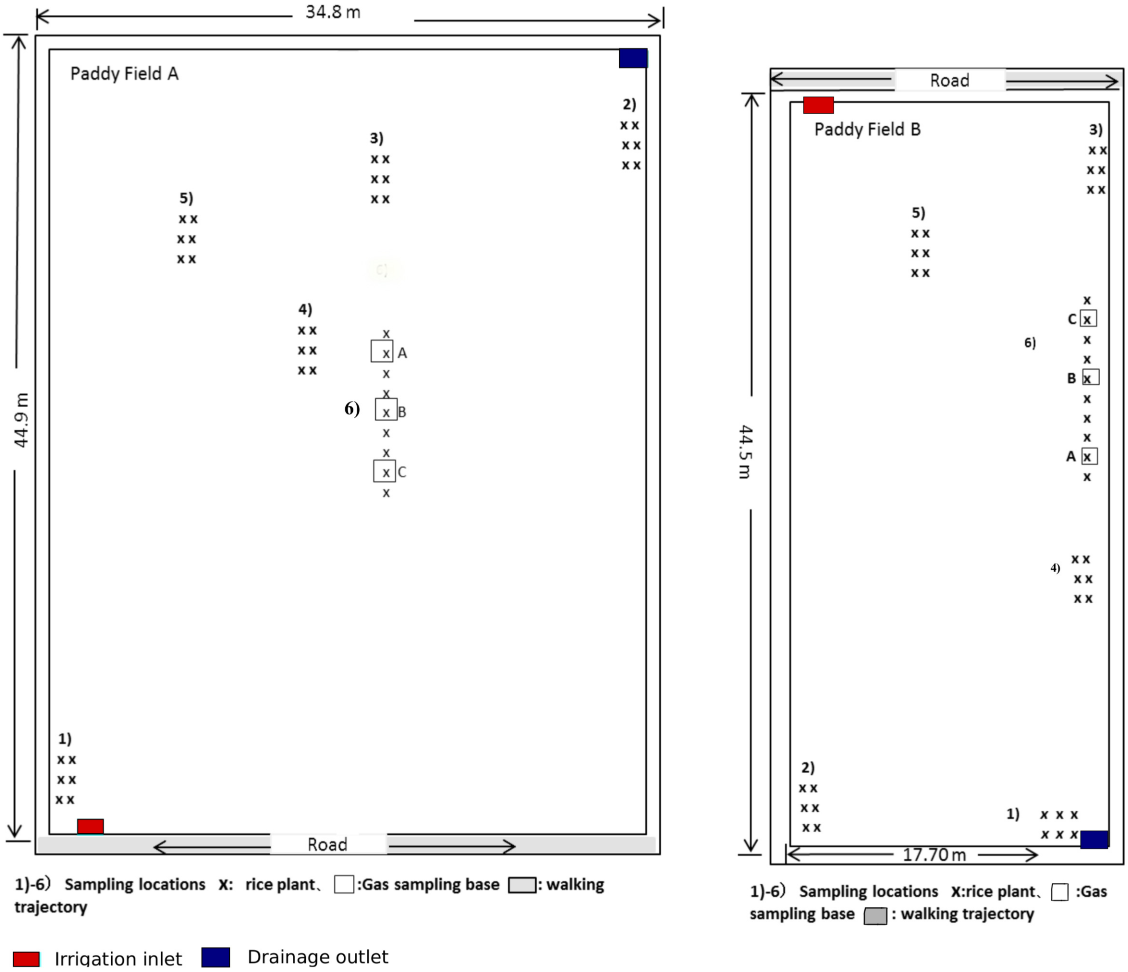


Figure 6.1: Sampling points in paddy field A and paddy field B

development are measured in May (three times on 16, 23 & 28); in June (three times on 6, 13, & 23); in July (four times 2, 15, 22, & 30) and in August (two times on 18 & 28). Figure 6.2 shows variation in height of rice plant and numbers of tillers and leaves during pre-havest phase. As Figure 6.2a shows that the height of rice plant is increasing continuously after the transplanting in both the fields during vegetative phase and there is no significant difference in overall height of rice plants in both the fields. In paddy field B where local irrigation method of Iwaki-shi is implemented, the tillers and leaves have shown slower growth until May 28 as compared to paddy field A where intermittent irrigation method is implemented (Figure 6.2b). In both the paddy fields, the growth of tillers is slower until May 28, however, number of tillers are slightly higher in observed rice plants of paddy field A. After May 28 to June 23, rapid increase in numbers of tillers is observed in both the paddy fields, number of tillers are always higher in paddy field A. From July 23 onwards, the growth in tiller is very slow and reached maximum on July 2 for paddy field A and July 15 for paddy field B. The

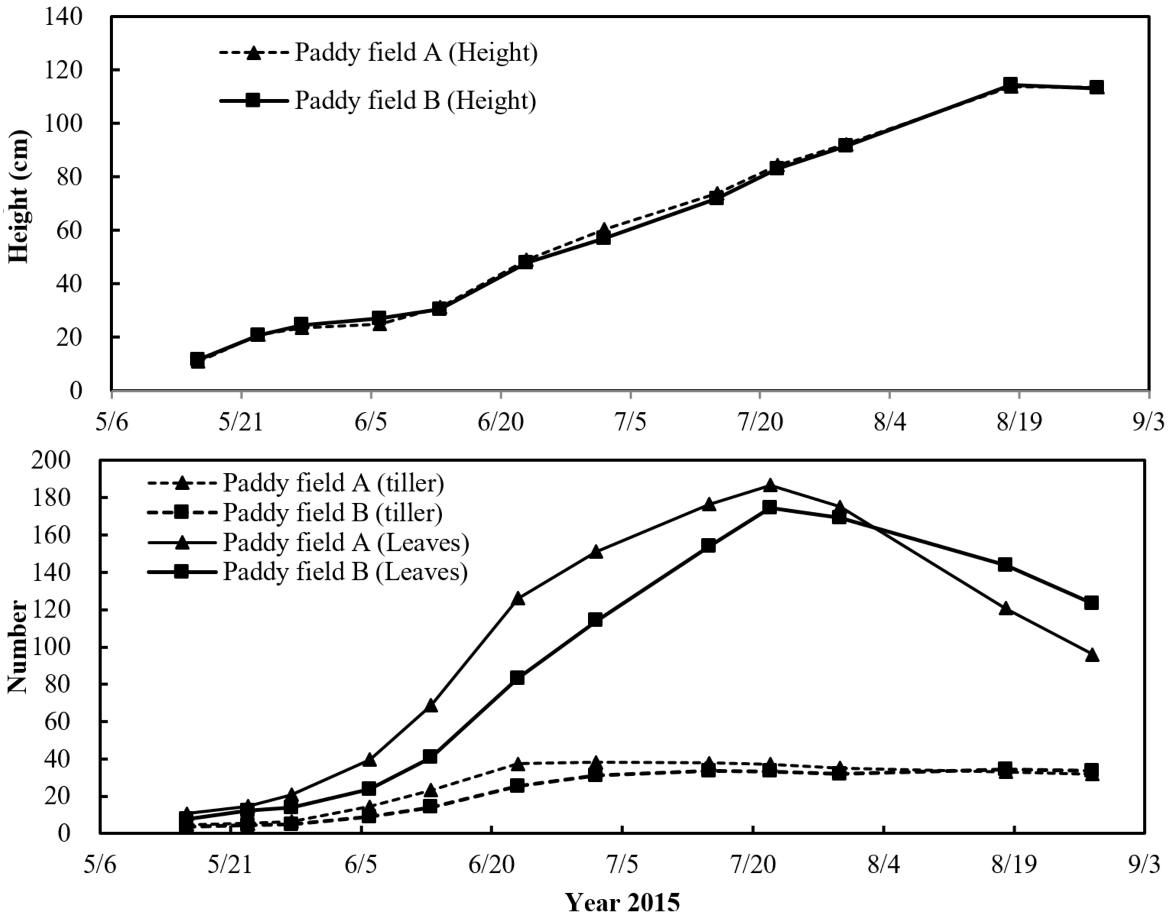


Figure 6.2: Rice plant development in pre-harvest phase (vegetative and reproductive)

difference between maximum number of tillers slightly decreased for both the paddy fields, having paddy field A more number of tillers than paddy field B. In both the paddy fields, the number of leaves have slow start upto May 28 and rapid growth in number of leaves can be observed in both the paddy fields until end of vegetative phase (July 15), however, maximum number of leaves have not reached yet. The paddy field A always have higher number of leaves than paddy field B in during vegetative phase. From July 15 onwards, the start of panicle initiation from the base of tiller is observed in both the fields.

6.1.3 Reproductive Phase

In rice plant development, vegetative phase is followed by reproductive phase. In general, the reproductive phase is defined as time interval after the maximum tillering stage to flowering stage (panicle initiation) to flowering stage. In current study, the reproductive phase is observed for approximately days (from July 15 to August 10). The reproductive phase can be divided into three sub-stages; booting, heading and flowering. In booting stage, the basement of tiller is getting swelled to be ready for panicle initiation. The booting stage as observed from July 15 onwards. Booting stage followed by heading stage in which, panicle started emerging out from covering sheath leaves after initiation. Heading stage is observed in both the fields in July 30. Further flowering stage shows the formation of spikelet (which is development of anthers) which is responsible for pollination.

During the reproductive phase, height of rice plants continuously increases after vegetative phase. However, number of tillers remained almost constant and there is slight decrease in number of tillers because lower part of baby emerged tillers are excluded from counting as they decay. The number of leaves reaches maximum just after vegetative phase (July 22) in both the fields and further decay in number of leaves as observed in later reproductive phase, even number of leaves in paddy field A decreased in comparison to paddy field B. The reason for decrease in number of leaves in paddy field A in later stage of reproductive phase in because the dried leaves in paddy field A are excluded from counting.

6.1.4 Ripening Phase

Ripening phase is the last stage of rice plant development. It is defined as time interval after flowering all panicles to the time each individual spikelet gets riped grain filling. In current study, the ripening phase observed between August 10 to September 14 (day of harvesting). During the ripening phase, at first the grain started as milky substance. Later milky substance will turn into solid hard grains. During the milky stage there is chance of attacks by birds or insects,however, with solid hard grain birds and insects do not used to attack. To avoid the attacks from birds and insects, some local methods e.g. netting are done in paddy fields. In current study, the flowering of rice plants is observed in August 18, grain filling with milky substance is completed by August 28 in both the fields. Finally, rice have been harvested on September 14 from paddy field A and B.

6.2 Soil Physiochemical Characteristics

The soil physiochemical characteristics have the important impact on the output of agriculture production and it may also vary on the method adopted for farming. In general, paddy soil characteristics are different in various topography e.g. they are different in normal upland and paddy field soil. In general, upland soils are in oxidation condition whereas paddy soils have reduction condition because of flooding condition and land preparation for rice cultivation. According to the Yamazaki (1988)[52], paddy soil layers can be divided into three layers. However, above the soil ponding water condition occur in rice cultivation where water level is added by irrigation or rainfall. This ponding water layer interrupts oxygen exchange from atmosphere to the soil surface because of stagnant water level. The first soil layer is called plow layer where the rice transplantation is performed and the soil nutrients (fertilizers) are mixed with soil. In rice cultivation, plow layer is important part for the rice plant growth and in this layer soil environment have in general reduction condition. The second layer is plow sole below the plow layer, which is not plowed and the organic matters may not reach into this layer, hence, this layer can be considered in oxidation condition. The third and last layer is subsoil which lies under the groundwater table and may have oxidation and reduction condition depends on reaching of micro-organism in this soil layer. Based on the above phenomenon and hypothetical assumptions the soil physiochemical characteristics are also investigated by in different depths in this study. The discussions on soil pH, ORP, soil moisture and temperature measurement are performed in the following sections.

6.2.1 Soil pH and ORP

The soil pH is measurement of soil acidity or alkalinity in soil. ORP (oxygen-reduction potential) of soil measures electrochemical potential in soil in millivolt (mV) unit. Figure 6.3 shows ORP measurement in paddy field A and paddy field B and soil pH measurements during rice growing seasons between rice transplant to rice harvest. In previous experiments in lysimeter environment in 2013 and 2014, the soil pH did not fluctuate in various depths measurement. Hence, in both paddy field experiments, the soil pH is measured at one fixed depth approximately at 5 cm. The ORP is measured at five depths in both the fields as 5 cm, 10 cm, 15 cm, 20 cm, and 30 cm below the soil surface. As shown in Figure 6.3c, soil pH value fluctuates slightly in vegetative phase and reproductive phase of rice plants but mostly remains in normal acidic range of pH in paddy soil for both the paddy fields. Figure 6.4 shows depth-wise profile of soil ORP at different depths. The ORP values in paddy field A fluctuates more wider range than paddy field B. The positive ORP values in paddy field A indicates that GHGs formation is not responsible at respective depths showing in paddy field A (mostly generating oxidation layer) while in paddy field B, ORP values remain mostly in negative (mostly generating reducing layer).

To understand the oxygen level at different depths in soil layers, the ORP set up was introduced in both the paddy fields on May 28. Initial measurement on May 28 shows

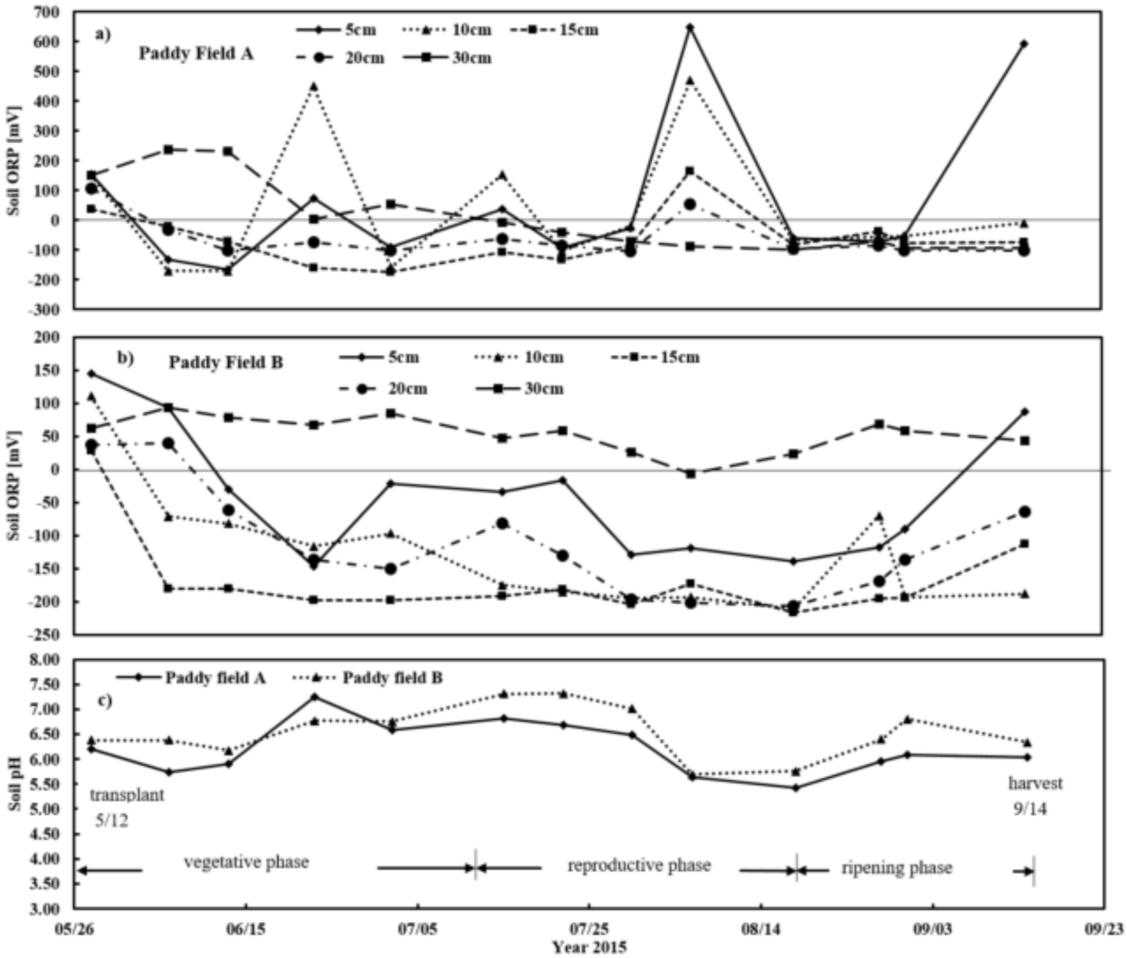


Figure 6.3: Soil pH and ORP: a) paddy field A, b) paddy field B, and c) soil pH

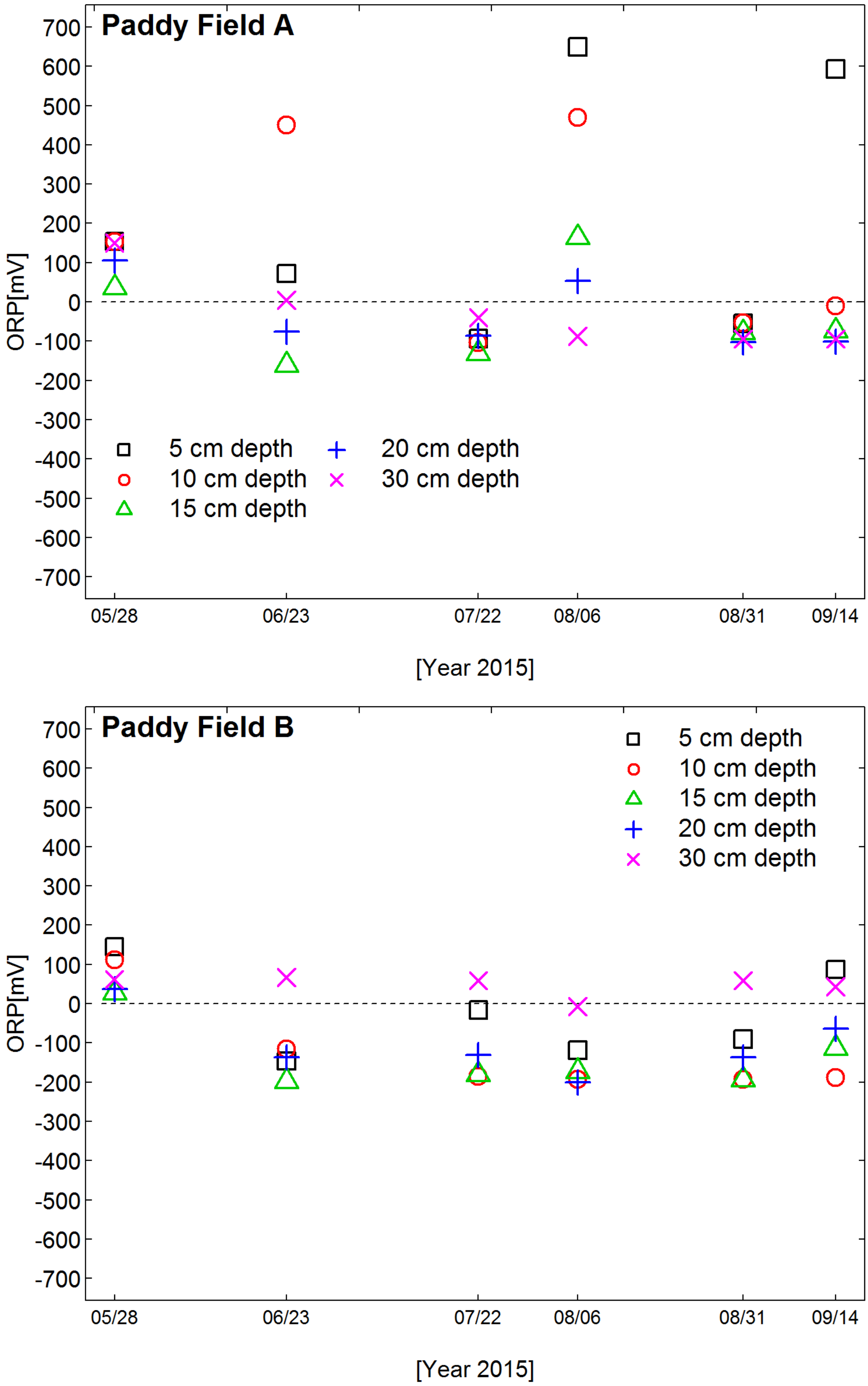


Figure 6.4: Depth-wise profile of ORP in paddy field A (upper) and field B (lower)

positive ORP values in both the fields at all depths level. It may be because the aeration of soil is occurring and disturbed soil during transplantation and instruments set up may be settling down at this point of time, which causes soil oxidation although, in both the fields there is standing ponding depth at this measurement time. Further on June 6,the ORP in paddy field A become negative except 30 cm. However, in paddy field B, ORP values become negative in 10 cm and 15 cm depths. Throughout the experiment, ORP value increases with reduction and ponding depth and vice-versa. The shallow intermittent irrigation in paddy field A leads to fluctuations in oxygen level inside the plow layer as the depths of 5 cm, 10 cm, 15 cm, and 20 cm shows similar pattern in ORP values in Figure 6.3a. However, 30 cm depth does not show much fluctuation. In paddy field B, stagnant water is kept throughout the experiment except mid-season drainage (mizukiri/nakaboshi according local method), the soil condition maintained in reduction state (Figure 6.3b). However, the deep soil depth 30 cm shows oxidation condition in paddy field B whereas in general lower depth of paddy soil should be in reduction condition. During the dry condition of soil when ponding depth is lower, paddy field A shows higher fluctuation in ORP value at 5 cm, 10 cm depths, while paddy field B shows higher negative ORP values at 10 cm, 15 cm, and 20 cm depths. This ma be because paddy field A has developed some small cracks in the surface while paddy field B almost in saturation condition (no formation of cracks).

6.2.2 Soil Moisture and Temperature

Soil temperature and volumetric water content are also important physiochemical conditions of paddy soil for its characteristics. Soil moisture (volumetric water content) gives information regarding water available inside the deep soil and soil temperature provides the information of soil nutrient (energy) regulation inside the paddy soil. The main objective of measuring the soil water content in this study is to understand difference in movement of water during shallow intermittent irrigation (paddy field A) and and Iwaki-shi local method of water management (continuous flooding) except short term mid-season drainage. Water holding capacity of soil will also provide the understanding of soil type and oxygen-reduction condition of soil in various depths. In this study, continuous measurement of soil water and temperature are recorded in every 60 minutes interval at depths of 5 cm, 10 cm, 15 cm in both the paddy fields. Because of availability of two more moisture and temperature sensors in paddy field A, these sensors are set up at 30 cm and while in paddy field B at 20 cm. This is done because in paddy field A with intermittent irrigation, the movement of water content may go deeper while in paddy field B with continuous flooding, there may be saturation of water in paddy field B may lead to not much fluctuation water content between 20 cm and 30 cm depths.The

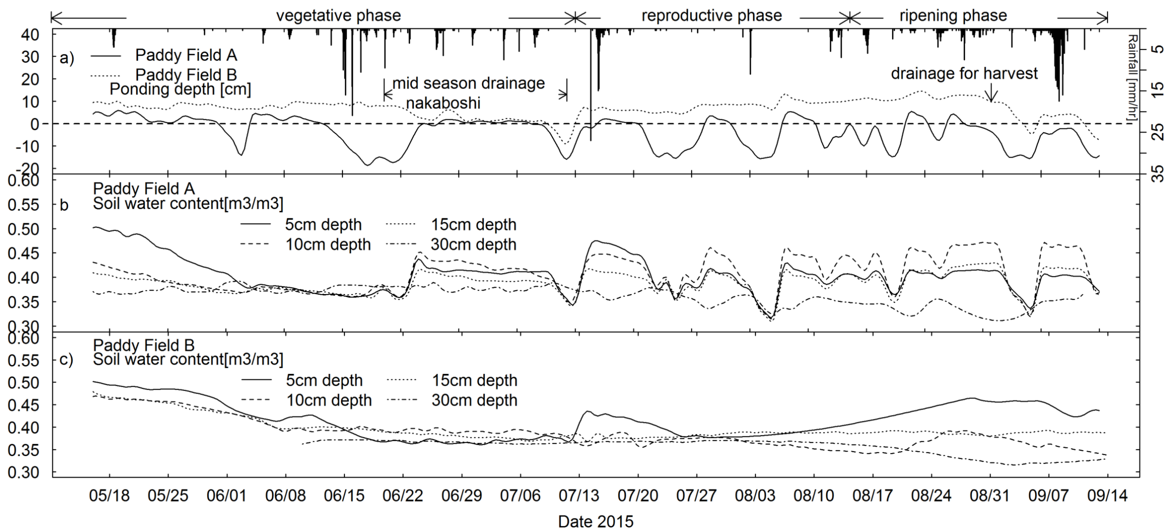


Figure 6.5: Spatiotemporal variation of soil water content in different depths

aim of intermittent irrigation (paddy field A) is to provide optimum saturation of water in paddy soil, hence,water content is measurement to measure during rice growing season.

Figure 6.5 and 6.6 show spatiotemporal soil water content and soil temperature, respectively along with ponding depth and rainfall during vegetative, reproductive, and ripening phases. Soil water content in both paddy fields A and paddy field B are moving in the same pattern as ponding depth (water management). In Figure 6.5c, paddy field B shows fluctuation of soil water content only in the mid July when mid-season drainage (nakaboshi / mizukiri) is applied in Iwaki-shi local method. Before the harvest in both paddy fields, ponding water was reduced by drainage and irrigation is also stopped. In Figure 6.5b, 5 cm, 10 cm, and 30 cm depths shows fluctuation in soil water content with change in ponding depths, however 15 cm depth shows lesser fluctuation as compare to other depths. It may be because at 15 to 20 cm, there is rice plant root location, which may stabilize the water content at this depth by taking excess water during higher ponding depths.

As shown in Figure 6.6, the fluctuation in temperature occurs according to atmospheric temperature, however, paddy field A shows lesser temperature than paddy field B. It can be considered that lesser exchange of heat occur to the atmosphere and paddy field B, because of stagnant water condition. However, in paddy field A, soil surface can get dried because of practicing intermittent irrigation and there can be direct exchange of sun heat. It is also observed that the overall pattern of temperature change have similar trend as meteorological temperature data from Iwaki station.

Temperatures were increasing with the rise of temperature in summer and vice versa.

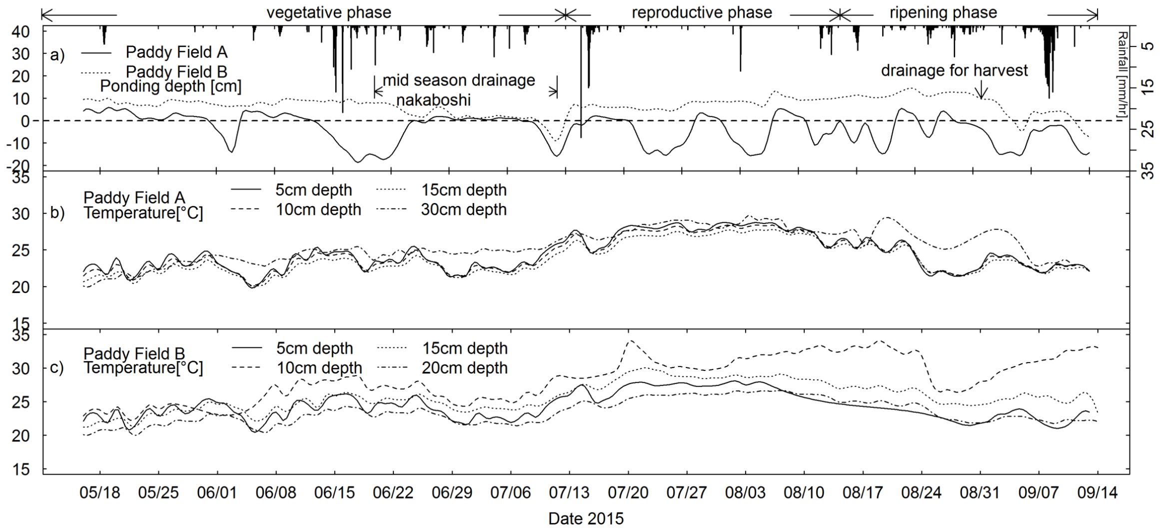


Figure 6.6: Spatiotemporal variation of soil temperature in different depths

In comparison to paddy field A and paddy field B, paddy A showed less temperature than paddy field B. Considering that less exchange of outside heat in paddy field B because of stagnant water condition. But in paddy field A, soil surface was dried practicing intermittent irrigation and could be direct exchange of sun heat. The pattern of temperature showed similar structure to the outside meteorological temperature data from Iwaki station (Figure 2.10).

6.3 Post-harvest Studies

The previous section discussed about rice plant development results during in two paddy fields, one is intermittent irrigation method and another one is local irrigation method, traditionally used by farmers in Iwaki-shi. To understand the effectiveness of SRI methods in comparison to traditional rice cultivation method or rice yield needs to be studied and compared. In the current study, the rice yield and plant biomass is measured by random sampling method. Also, land leveling is measurement also performed after the harvesting. So that, surface flow of water during irrigation and drainage while rice development should be accessed. The following section discuss two result in details.

6.3.1 Rice Yield and Plant Biomass

To analyze the difference in rice yield and quality for post-harvest measurements, initially, 39 rice plants from six different places are randomly selected from each field. These selected rice plants are further dismantled in various parts for detail study in soil culture laboratory. In first step, the height of rice plants are measured, number of stems, dead lives, live leaves, and panicle numbers are counted. Dead live are the leaves which are totally dried in paddy fields just before harvest and live leaves are the leaves which have even partial green color at the time of harvest. Stems are counted as number of tillers and panicles are the tillers with spikelet formation. After doing the above measurements, the rice plants are dried for one week at room temperature to further measure the biomass of different parts. After drying for one week, the body of rice plants are separated into 1) stems, 2) leaves, 3) panicles. To get the accurate weight of stems and leaves, these were oven dried by maintaining the oven temperature 110 degree Celsius for 24 hours. Panicles are further separated into good grains, bad grains (without grain filling), spikelet. The number of grains are counted from those 6 different places and the processed in oven to make them dry by maintaining 110 degree Celsius for 24 hours. The grain weight were calculated in 14 % moisture level after the above process.

Table 6.1: Relation between post-harvest indicators

Measured parameters	Paddy field A		Paddy field B		Relation
	Mean	SD	Mean	SD	
Height (cm)	112.17	2.92	106.89	5.20	***
Stem (number)	26.00	6.42	29.00	3.46	-
Panicle (number)	25.67	6.42	28.56	3.40	-
Live leaf (number)	43.44	9.02	74.56	10.42	***
Dead leaf (number)	99.33	36.24	79.11	11.36	-
Dry stem (gram)	29	4.15	32.46	3.62	-
Total dry leaves (gram)	13.00	2.49	13.22	1.24	-
Good grain (number)	2194.56	378.79	2323.56	132.46	-
Dead grain (number)	70.89	33.05	76.33	33.97	-
Others (spikelet in gram)	1.97	0.41	2.17	0.15	-
Grain weight (gram)	55.54	10.72	59.81	3.69	-

In the initial samplings of 39 rice plants from each paddy field, the locations of 12 rice plants in paddy field A and 24 rice plants in paddy field B are located in the border side of each field. Hence, the initial sampling provides unexpected results because the border side rice plants are directly exposed sun heat and may not get optimum water for their proper growth. Hence, further random samples of total 9 rice plants from each fields are taken near the center of paddy fields. Six rice plants are taken from sampling location number 5, and three rice plants are taken from the sampling location 6 (these three plants are also used for gas sampling) in each field as shown in Figure 6.1.Total 9 plants from each paddy field A and B, data are used to analyze to study the post-harvest condition of rice plants. The average values of different parameters of post harvest measurements for rice yield and biomass from both the paddy fields are shown in Table 6.1 and their relation is also indicated.

As it can be seen Table 6.1, the average height of rice plants is significantly higher in paddy field A as compared to paddy field B. However, number of live leaves (green leaves) are higher in paddy field B but dead leaves are higher in paddy field A. Although the average of total number of leaves (live and dead) are almost same in both the fields. It indicates the higher height of rice plants in paddy field A may be a result of optimized water management (by intermittent irrigation). The difference in live and dead lives in paddy field A and paddy field B is obviously because of control of water levels during rice growing season. Other parameters dry stem weight, good grain number, bad grain number, spikelet weight (without grain), and grain weight (14% moisture level) do not show the significant statistical difference.

6.3.2 Land Leveling

In post harvest measurement, land leveling measurement provides information of accuracy and smoothness of surface water movement inside the paddy fields. Also the smoothness of the land leveling plays greater role in the equal distribution of soil nutrient and water throughout the paddy fields. In the current study, the land leveling is measured in both the paddy fields by using popular " plane method ", which is already in practice by USDA and also in Japan[42]. In order to utilize this method, the grid points at every three meter interval along length and width direction are constructed as shown in Figure 6.7 and 6.8 and further land leveling survey is conducted at each grid point. During the survey, the data of micro elevation is measured at grid data points of every square.

Method

Paddy field A is divided into eleven columns and fourteen rows with grid square size by $3m \times 3m$, similarly, paddy field B is divided into five columns and fourteen rows with same grid square size. The paddy field A and paddy field B was divided into grids as shown Figure 6.7 and 6.8, the sampling points are indicated as rows by alphabet X and column by alphabet R. The micro-elevation data is measured by surveying equipment (Sokkia, Japan). During the measurement, well-scaled stake is moved from one point to another point handled by person. The standard point (elevation) was fixed and measured all the points by moving

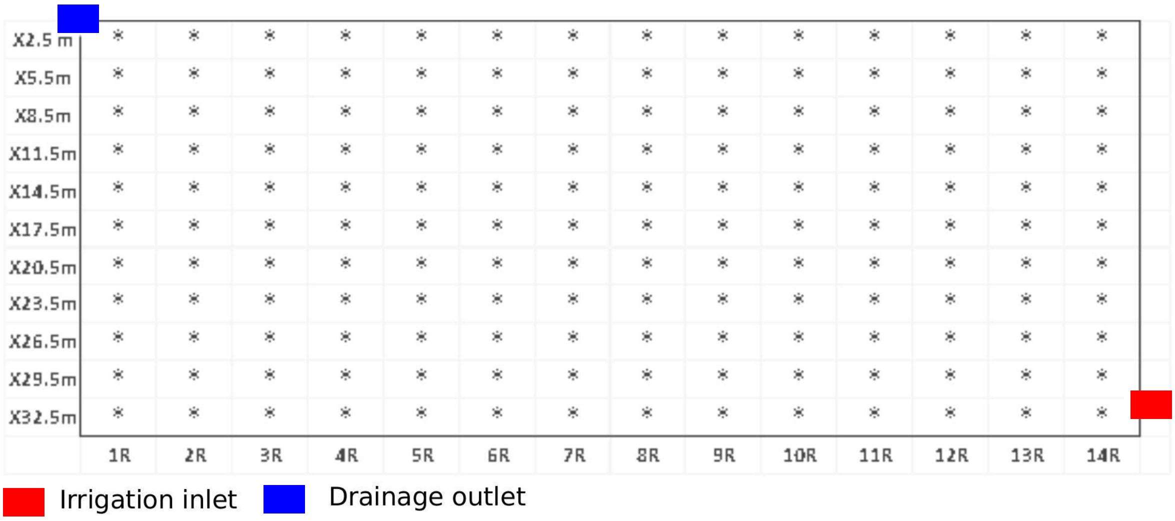


Figure 6.7: Observed elevation points in paddy field A

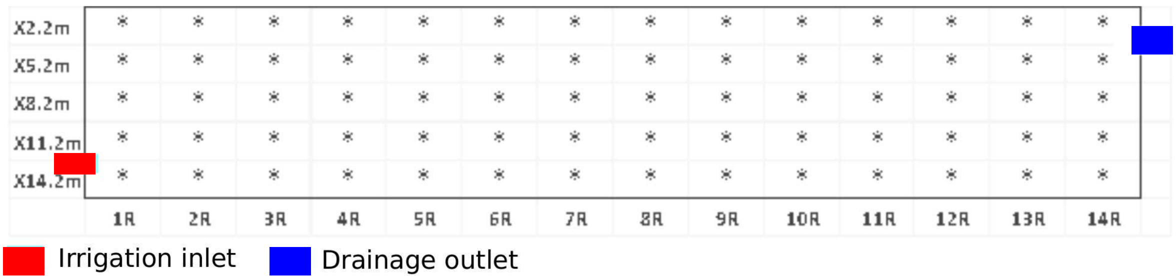


Figure 6.8: Observed elevation points in paddy field B

forwards and backward direction.

Result and Discussion

The average micro elevation is calculated for every square by averaging data from all four corner points obtained by method explained. Further, the micro-elevation data at each grid point is calculated by subtracting the average value. Further, contour map for micro-elevation is established for paddy field A and Paddy field B. The variation of micro-elevation is shown in Figures 6.9 and 6.10 for each paddy field. In this contour plot, lowest points is shown in black grey color and highest elevation is shown in white grey color. The range of micro-elevation of paddy field A is found to be 73 mm with standard deviation of 12 mm. In case of paddy field B, the micro-elevation range is 75 mm and standard deviation is 15 mm. This indicates both paddy fields have acceptable standard land leveling as reported by (Yamaji, 1989)[41]. The similar cases are also reported by Anbumozhi, V. et al., (2001)[42]; Shoji, K. et al., (2005)[43].

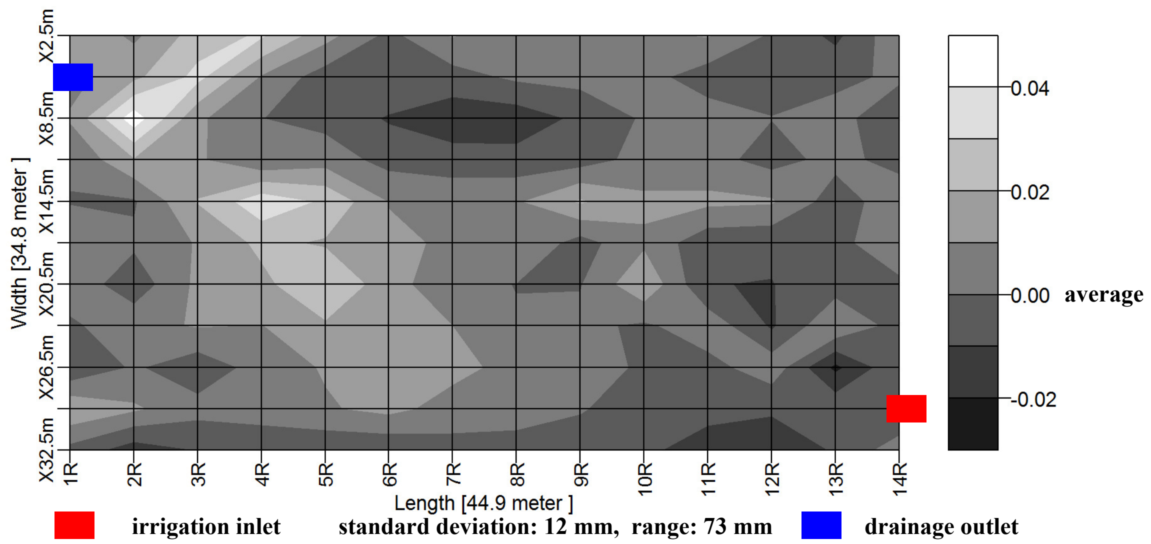


Figure 6.9: Topographical map of paddy field A, micro-elevation (mm)

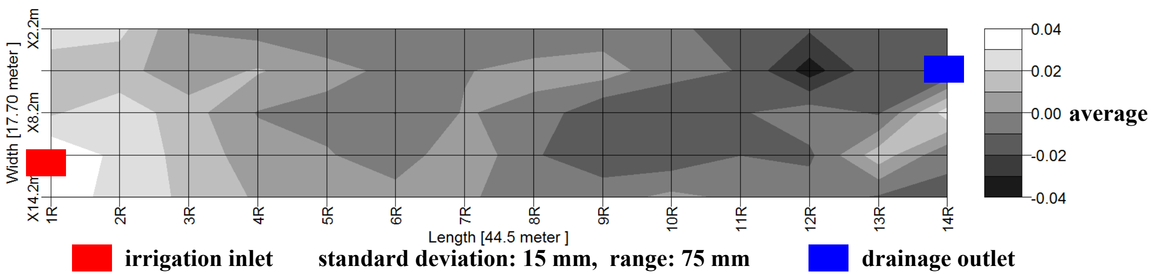


Figure 6.10: Topographical map of paddy field B, micro-elevation (mm)

In case of paddy field A, in Figure 6.9 shows maximum range of micro-elevation undulation in second and third rows. which shows heterogeneity of water distribution. Irrigation channel in paddy field A is located near the lower right corner and drainage channel is located at the upper left corner. It is found there is unevenness of surface areas in paddy field A, which can be noticed from black gray color in contour plot. The ponding depth or water availability is recorded every sixty minutes and is shown in Figure 6.11. As paddy field A has intermittent irrigation method for water management. Hence, there is fluctuation in ponding depths. In paddy field A while irrigation and drainage is performed, distribution of water remains uneven because of unevenness of soil surface. The higher range of micro-elevation surface area gets drier and lower elevation gets wet soon whenever there is water distribution into paddy fields.

In paddy field A, the irrigation water supply is from the right lower corner (X32.5, 14R) and drainage is from left upper corner (X2.5, 1R) in Figure 6.7. However, the sensors for

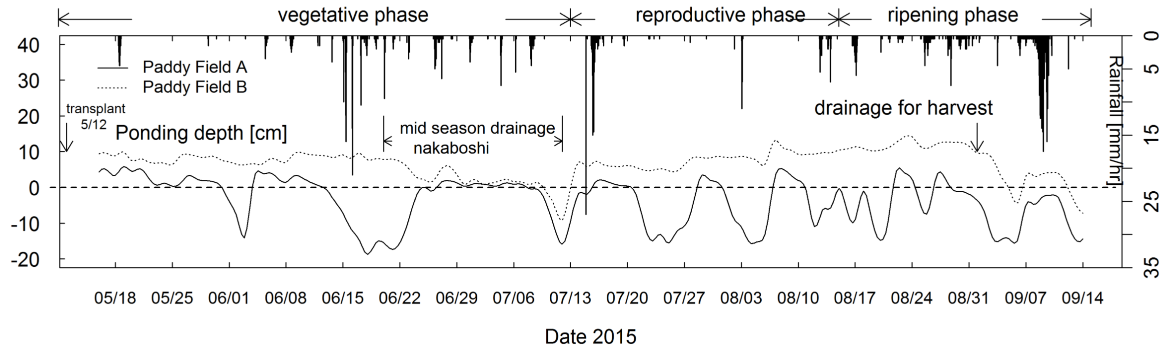


Figure 6.11: Irrigation management in paddy field A and paddy field B in rice growing season

ponding measurement is located at approximately middle of paddy field A. The location of ponding depth sensor from topographical map (Figure 6.9) shows higher micro-elevation from the ground level. Hence, it may not able to get equal water distribution during intermittent irrigation water management. The rows near the irrigation location (11R, 10R, 9R, and 8R) have lower micro-elevation and their ranges are 27.90 mm, 34.50 mm, 34.90 mm, and 33.10 mm, respectively. After seven rows (7R) to first row (1R), the micro-elevation surface ranges are fluctuating and the range values are 42.80 mm, 34.80 mm, 44.20 mm, 30.20 mm, 67.20 mm, 43.90 mm, and 46.10 mm, respectively. Micro-elevation fluctuation is occurred in paddy field A, because of soil disturbance during the time of rice transplantation. Further, the rows located 1, 2, 3, 5, & 7 pass through the higher elevation in paddy field A.

In paddy field B, irrigation channel is located in the lower left corner (X14.2, 1R) and drainage channel is located near right upper corner (X2.2, 14R) as shown in Figure 6.8. In this paddy field B, the elevation of irrigation channel location is higher than paddy field. The micro-elevation variation as can be seen from topographical map of paddy field B (Figure 6.10), has less fluctuation as compared to paddy field A. And micro-elevation varies from high near irrigation channel to low in drainage channel. In paddy field B, micro-elevation shows ranges for first, second, third, fourth, and fifth rows 47.50 mm, 48.30 mm, 44.80 mm, 57.00 mm, and 46.70 mm, respectively. The irrigation was applied in the paddy field B is Iwaki-shi local methods, followed by mid-season drainage and drainage before harvest time. The sensor for the ponding depth measurement in paddy field B is fixed in the middle of upper corner. Except during mid-season drainage and before harvest, the paddy field B is always in a positive ponding condition as shown in Figure 6.11.

By comparing between two paddy fields in terms of equal irrigation distribution, paddy field B has better land leveling than paddy field A. However, irrigation method,which is used in paddy field A as intermittent irrigation. Many times water supply and drainage in paddy field A may lead to water accumulation in pits and not complete drainage because of uneven leveling, while, for paddy field B only once mid-season drainage followed by irrigation in Iwaki-shi local method leads to better water management because of proper leveling of surface. Hence, it is necessary that the land level preparation of paddy field should be focused for distribution of equal water and nutrients as well as according to drainage and irrigation plans. If the soil surface is not smooth, some rice plants may get water stress, some may get late ripening and even uneven harvest loss. One of the factor regarding the uneven ripening stage within rice plants of same paddy field is the land smoothness and water distribution.

6.4 Greenhouse Gases Emission

As one of the main objective of this study is to estimate the environmental load because rice farming. Hence, in this section the results of greenhouse gas emission caused by rice farming are presented and discussed. In Chapter 3, the method of gas sampling is explained, hence, the gas is collected by chamber method from paddy fields. The collected gas is injected into vial through the syringe. The sampling is performed six times during rice growing seasons depending on ponding condition of paddy fields and one time in non-rice growing seasons.In rice growing seasons, the gas is sampled on May 28, June 23 (vegetative phase), July 22, August 6 (reproductive phase), August 31, and September 14 (ripening phase. The last gas sample is performed on February 12 (bare land). The results are discussed to understand the greenhouse gas emission mechanism with respect to two different water management methods, one in paddy field A intermittent irrigation and second in paddy field B, Iwaki-shi local irrigation method. During rice farming, two gases mainly causes environmental load methane and nitrous oxide,therefore, their result are discussed in the following sections.

6.4.1 CH_4 and N_2O flux

The gas is first collected from paddy fields and then taken to the the laboratory of agro-environmental engineering, the University of Tokyo to determine the quantity of methane and nitrous oxide emission. The equipments used to measure methane gas is Shimadzu GC-14A and nitrous oxide is Shimadzu GC 2014A. Shimadzu GC-14A uses the gas chromatography which has a flame ionization detector (FID) and uses a hydrogen flame to detect the ionized hydrocarbons (HCs) which is suitable for the detection of CH_4. Shimadzu GC-2014 has electron capture detector (ECD) gas chromatography which uses the carrier gas as CH_4 5%

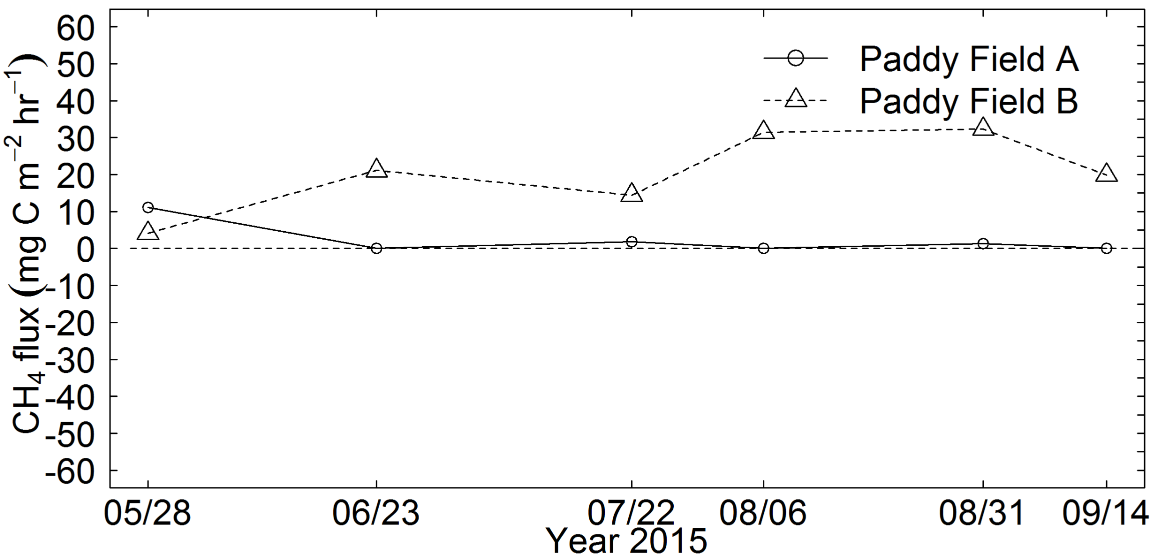


Figure 6.12: Methane CH_4 flux from paddy field A and paddy field B

and Argon balance.

As mentioned in data collection process in Chapter 3.5, the gases are collected using close chamber method at three locations in each field and further analyzed an average data of CH_4 and N_2O flux is presented in Figures 6.12 and 6.13. After getting the concentration of CH_4 and N_2O from the gas sampling, the following equation is used to calculate each gas flux.

$$GasFlux = \frac{\Delta C}{\Delta t} \times \frac{V}{A} \times \rho \times \frac{273}{273 + T} \tag{6.1}$$

where, $\Delta C/\Delta t$ is change in concentration of CH_4 and N_2O over the time of measurement; V is gas chamber volume; A is the are of chamber; and ρ is gas density and T is atmospheric air temperature.

The measured methane flux in paddy field A and paddy field B during the rice growing season is compared in Figure 6.12. Almost after two weeks (May 28), the first measurement of CH_4 flux is performed, at this time the ponding ponding depth is positive in both fields. The methane flux can be seen positive in both fields and have higher methane emission in paddy field A. The value of methane flux in paddy field A is 14.80 $mg/m^2/hr$ whereas, in paddy field B, it is 5.54 $mg/m^2/hr$. During the same time, the soil ORP sensor indicates the positive value which is opposite to higher methane gas emission as ORP should be negative (in reduction condition) to have higher methane emission. The reason for positive ORP at the same time may be as ORP sensors are set near around the dates which might have disturbed the soil. The first data for ORP may not be correct,but later data should be fine.

The second gas sampling (June 23) shows higher methane gas emission in paddy field B while in paddy field A, it decreases significantly. After second gas sampling, the further data for paddy field A shows negligible methane gas emission, where water management is performed by intermittent irrigation. The values for methane gas flux emission in paddy field A from first sampling to last sampling during the rice growing season and non-rice growing season are tabulated with standard deviation in Table 6.2. However, paddy field B shows higher methane emission from second gas sampling onwards except slight decay during mid-season drainage and pre-harvest drainage and during and reproductive and ripening phases, it has highest methane emission. The values of methane emission in paddy field B are tabulated with standard deviation in Table 6.2. It can be concluded that higher methane emission in paddy field B is because of stagnant water which may lead to reduction condition in soil layer. It is observed during non-rice growing season (February 02, 2016), the methane emission is not significant in both the paddy fields. However, the values of fluxes are slight positive and negative, for paddy field A and B, respectively. It indicates the main source of higher methane emission from the paddy field is rice plantations.

Table 6.2: Methane flux from paddy fields in Iwaki Shi, Fukushima

	Paddy field A		Paddy field B	
Date	CH_4 flux ($mg/m^2/hr$)	SD	CH_4 flux ($mg/m^2/hr$)	SD
2015/5/28	14.80	6.50	-5.54	3.58
2015/6/23	0.01	0.24	28.31	3.69
2015/7/22	2.52	1.69	19.30	7.13
2015/8/6	0.04	0.69	41.88	8.93
2015/8/31	1.75	0.92	43.13	26.25
2015/9/14	0.06	0.04	26.54	22.30
2016/2/12	0.30	0.27	-0.59	0.51

Table 6.3: Nitrous oxide flux from paddy fields in Iwaki Shi, Fukushima

	Paddy field A		Paddy field B	
Date	N_2O flux ($\mu g/m^2/hr$)	SD	N_2O flux ($\mu g/m^2/hr$)	SD
2015/5/28	-7.60	17.05	-87.06	154.88
2015/6/23	-8.48	49.99	-38.94	31.54
2015/7/22	17.65	12.15	18.47	35.73
2015/8/6	22.89	27.32	25.81	28.30
2015/8/31	-35.69	50.77	-60.24	72.48
2015/9/14	12.96	9.79	17.77	5.12
2016/2/12	12.00	30.21	-0.02	105.42

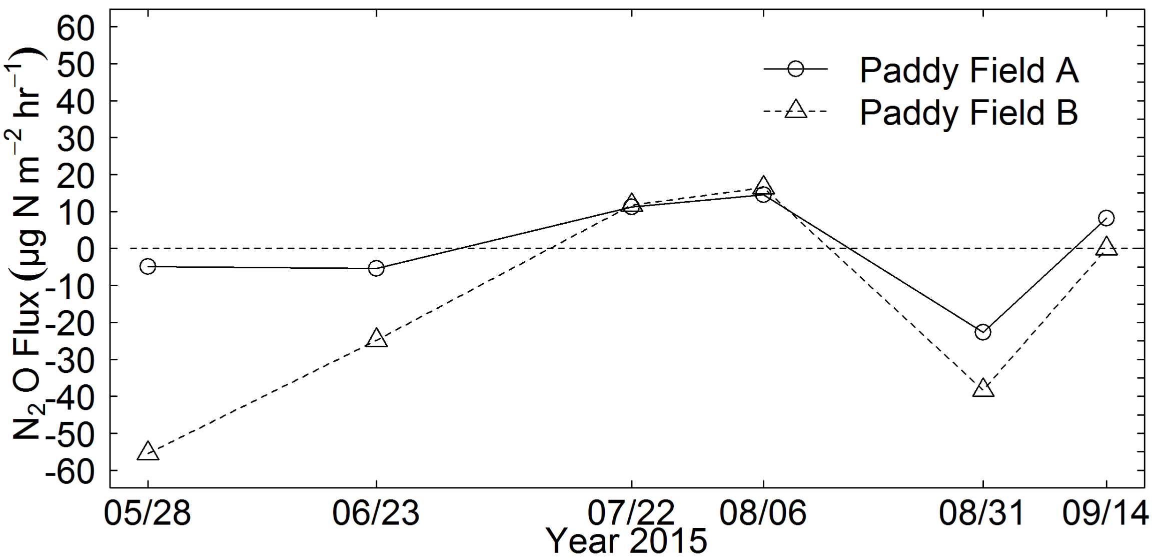


Figure 6.13: Nitrous oxide N_2O flux from paddy field A and paddy field B

Along with CH_4, N_2O is also one of the GHGs, contributor for environmental loads. The Measurement of N_2O flux is performed along methane fluxes and plotted in Figure 6.13. The values of N_2O flux in $\mu g/m^2/hr$ unit with standard deviation is presented with Table 6.3 for both the paddy fields. The positive or higher N_2O flux in only seen in reproductive phase for both the paddy fields along with pre-harvest drainage. For other times, rest of the gas data shows negative N_2O flux (sink into paddy field). In general, it is considered that N_2O emission can be more in non-flooding rice fields, however, paddy field A where intermittent irrigation is performed, does not show any significant difference from paddy field B. During non-rice growing season, however, paddy field A shows slight higher N_2O flux in compare to paddy field B, but there may be many factors. It should be noted that the emission data for N_2O flux is $\mu g/m^2/hr$ and CH_4 flux is in $mg/m^2/hr$ units, hence, from paddy fields CH_4 has higher environmental load as compare to N_2O.

6.4.2 Cumulative Emission of Greenhouse Gases

It is important to know the total emission of greenhouse gases from paddy field to understand the effectiveness of SRI-method (intermittent irrigation) in comparison to traditional methods, hence, from the measurement of fluxes in previous sections, daily flux is calculated by multiplying 24 for CH_4, N_2O both. To compute cumulative GHGs emission during rice growing seasons, trapezoidal rule integration is implemented from this daily emission flux data by following equation.

$$Area = \int_a^b f(x)dx \approx (b-a)\left[\frac{f(a)+f(b)}{2}\right] \tag{6.2}$$

where "a" is the initial measurement day, and "b" is the consecutive measurement day. Finally,the total emission for CH_4, and N_2O is computed for paddy field A and B. The calculation performed is as shown in Tables 6.4, 6.5, 6.6, 6.7. The last row shows cumulative emission between two samples collection dates and finally total emission in rice growing season is calculated by summation.

Table 6.4: Cumulative methane emission in paddy field A

Paddy field A	Sampling date						Total emission CH_4 $(g/m^2) =$ 7.16
Date	5/28	6/23	7/22	8/6	8/31	9/14	
DAT	20	46	75	90	115	129	
Flux/mg/hr	14.80	0.01	2.52	0.04	1.75	0.06	
One day flux/mg	355.22	0.26	60.48	0.84	41.96	1.49	
Cumulative emission	355.22	4621.34	880.79	459.9	535.00	304.14	

Table 6.5: Cumulative methane emission in paddy field B

Paddy field B	Sampling date						Total emission CH_4 $(g/m^2) =$ 75.36
Date	5/28	6/23	7/22	8/6	8/31	9/14	
DAT	20	46	75	90	115	129	
Flux/mg/hr	5.54	28.13	19.13	41.88	43.13	26.54	
One day flux/mg	132.98	675.12	463.20	1005.01	1035.16	636.86	
Cumulative emission	132.98	10505.35	16505.64	11011.56	25502.10	11704.11	

However, the time interval between two sampling dates is almost one month, but this method of computing total emission during rice growing season provides adequate information for comparing greenhouse gas emission between intermittent irrigation and Iwaki-shi local irrigation method. Tables 6.4 and 6.5 show cumulative and total methane emission from paddy field A and B. For both the fields, CH_4 emission is positive during all the time interval. The cumulative emission for paddy field A is highest during vegetative phase than comparing to reproductive and ripening phase. It can be seen, CH_4 emission decreases with decrease in ponding depth because soil reduction condition is also changing based on water level in paddy field A. For paddy field B, cumulative emission between various time intervals is always significantly higher in comparison to paddy field A. The maximum methane emission can be seen in reproductive phase because in Iwaki-shi local method, there was continuous stagnant water during 7/12 to 9/6. Hence, it can be said that stagnant water in paddy field plays strong role in cumulative methane emission. To reduce the methane emission in paddy field, AWD or intermittent irrigation method is appropriate for mitigation. During rice growing season, total methane emission in paddy field A is 7.16 g/m^2 whereas, in paddy field B is 75.36 g/m^2. The total methane emission is reduced more than ten times by adopting intermittent irrigation method.

Table 6.6: Cumulative nitrous oxide emission in paddy field A

Paddy field A	Sampling date						Total emission N_2O $(mg/m^2) = -2.37$
Date	5/28	6/23	7/22	8/6	8/31	9/14	
DAT	20	46	75	90	115	129	
Flux/ μg/hr	-7.60	-8.48	17.65	22.89	-35.69	12.96	
One day flux/ μg	-182.40	-203.52	423.54	549.33	-856.44	311.10	
Cumulative emission	-182.40	-5016.96	3190.23	7296.48	-3838.90	-3817.35	

Table 6.7: Cumulative nitrous oxide emission in paddy field B

Paddy field B	Sampling date						Total emission N_2O $(mg/m^2) = -58.02$
Date	5/28	6/23	7/22	8/6	8/31	9/14	
DAT	20	46	75	90	115	129	
Flux/μg/hr	-87.06	-38.94	18.47	25.81	-60.24	17.77	
One day flux/μg	-2089.44	-934.56	443.28	619.36	-1445.86	426.36	
Cumulative emission	-2089.44	-39312.00	-7123.56	7969.8	-10331.3	-7136.53	

Tables 6.6 and 6.7 show similar calculation for N_2O emission in paddy field A and B. It can be seen that mainly positive cumulative N_2O emission occur during post vegetative and reproductive phase in paddy field A while only in reproductive phase in paddy field B, the total N_2O emission because of two kind of water management is -2.37 mg/m^2 in paddy field A and -58.02 mg/m^2 in paddy field B. It can be concluded higher ponding water depth leads to lesser N_2O emission in paddy field.

6.4.3 Global Warming Potential (GWP)

To study the global warming potential (GWP), the total cumulative methane emission is converted to CO_2 equivalence for both the paddy fields. In this study, IPCC report of Myhre et. al., 2013[46] is used to calculate GWP. GWP value is calculated for climate-carbon feedback for a 100-year time horizon. 1 g of CH_4 emission is equivalent to 34 g of CO_2 and 1 g of N_2O is equivalent to 298 g of CO_2. The total methane emission in paddy field A is 7.16 g/m^2/growing season. In case of paddy field B, total methane emission is 75.36 g/m^2/growing season. When it is converted to CO_2 equivalent, paddy field B has higher emission more than ten times as compared to paddy field A, indicating 2562.30 g equiv.CO_2/growing season and 243.32 g equiv.CO_2/growing season for paddy field A and B, respectively. For total cumulative emission from paddy field A and B, the data are converted from N_2O to total equivalent CO_2 in gram from paddy field A is -0.34 g/growing season and paddy field B is -17.29 g/growing season.

6.4.4 Mechanism of Greenhouse Gases Emission from Paddy Fields

There are several researches, where mechanism of GHGs emission from paddy field is studied for various parameters and most of the studies are performed at soil layer depth upto 20 cm. In this study, greenhouse gas emission are estimated form the lysimeter and actual paddy field by controlling water management and performing measurement upto 30 cm. Hence,it is important to explain greenhouse gas emission by combining all the findings of this study from paddy field. Generally anaerobic condition in paddy soil are responsible for methane emission. Methane (CH_4) is produced by methanogenesis process in rice field.The other GHGs, nitrous oxide (N_2O) is produced through nitrification process. As it can be seen from the previous sections in this chapter, intermittent irrigation practice of water management in paddy field leads to higher emission of N_2O than flooding condition of paddy fields[47] ,[48].

The mechanism of formation of methane its emission in paddy fields occur through the process of ebullition, diffusion, and transport through the rice plant as discussed by Wassmann et al. 2000[45]. About (88 —90)% methane is transported through the arenchyma in vegetative and reproductive stage of rice plant development[49].

Our measurement is performed under the intermittent irrigation method (one of SRI key elements) which already showed the higher yield and lowering the GHGs and examined the formation of soil condition under the intermittent irrigation and Iwaki-shi local method, at the depths 5 cm, 10 cm, 15 cm, 20 cm, and 30 cm using ORP sensors. In the current depth-wise study of soil ORP with the paddy soil structure, the paddy soil structure can be considered having plow layer, followed by plowsole and subsoil according to Yamazaki, F. 1988[52]. Further,plow layer is divided into oxidation layer and reduction layer. The desirable depth of plowlayer is upto 15 cm to 20 cm from surface during paddy field land preparation.

The general phenomena of methane emission and soil ORP have opposite relation. Same pattern in each depth except 30 cm is observed in paddy field B in Figure 6.12 in this study, which has almost stagnant water condition. The intermittent irrigation applied in paddy field A shows fluctuation of soil ORP in between (0-20) cm depth. But lower depth 30 cm which is near to subsoil remained almost unchanged. Applying shallow intermittent irrigation

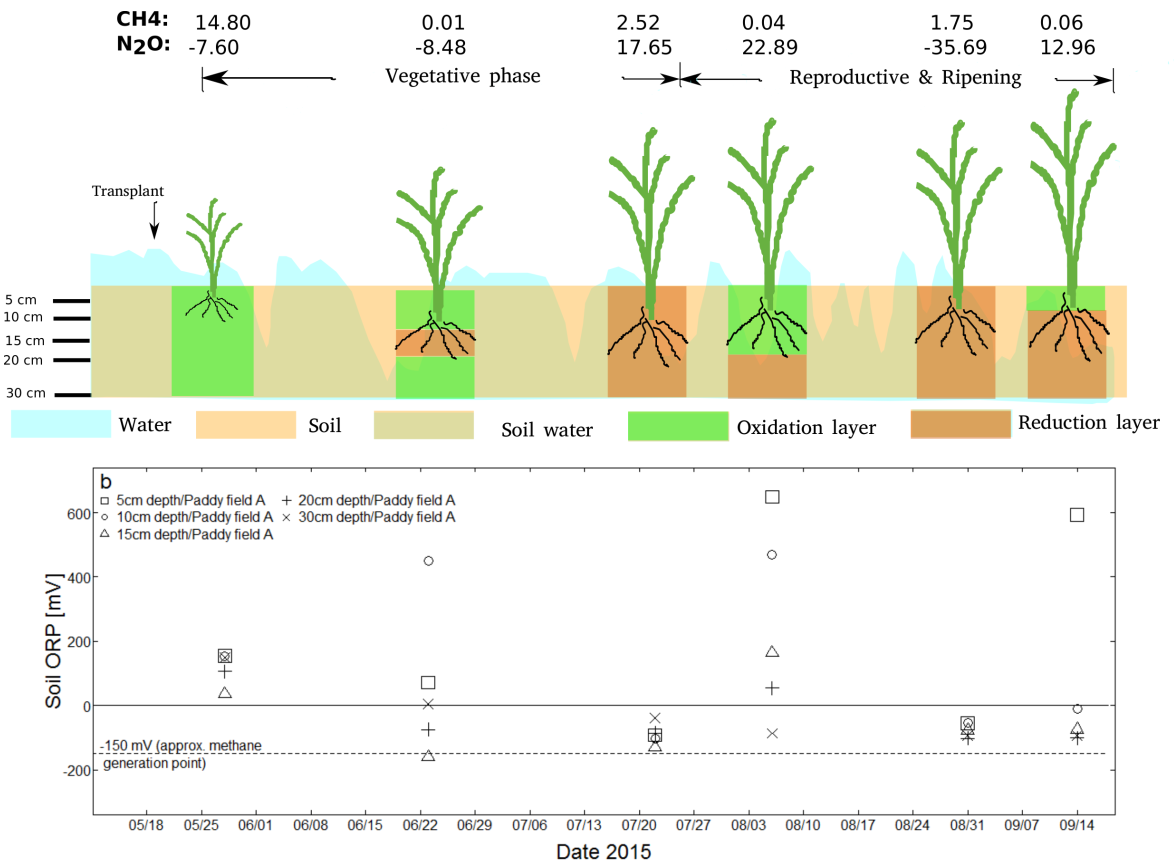


Figure 6.14: Methane flux with soil ORP and ponding depth for paddy field A

method reduces the reduction condition of soil. The movement of ponding depth (increasing and decreasing) in paddy field through out the rice growing season may be effective for soil nutrients and organic matter movement in vertical direction.

To have reduced methane flux from intermittent irrigation, soil ORP should have negative value in each depth measured. In initial phase after rice transplantation, soil is disturbed during land preparation, until one month, there may be exchange of oxygen by diffusion and unsaturation state of soil that caused the positive soil ORP at each depth. One month after rice transplantation, paddy soil will be saturated and settled down the puddling soil, based on the lower and higher ORP values, methane emission can be predicted.

The temporal changes of soil reduction and oxidation condition (soil ORP) throughout the rice growing season, methane flux and ponding depth for paddy field A with schematic of various conditions of soil layers upto 30 cm is shown in Figure 6.14. Further, same data with schematic of soil layer conditions for paddy field B is shown in Figure 6.15. During paddy fields experiments, CH_4 emission contributes higher to GWP than N_2O emission, hence, both the figures only methane emission is shown for the discussions.

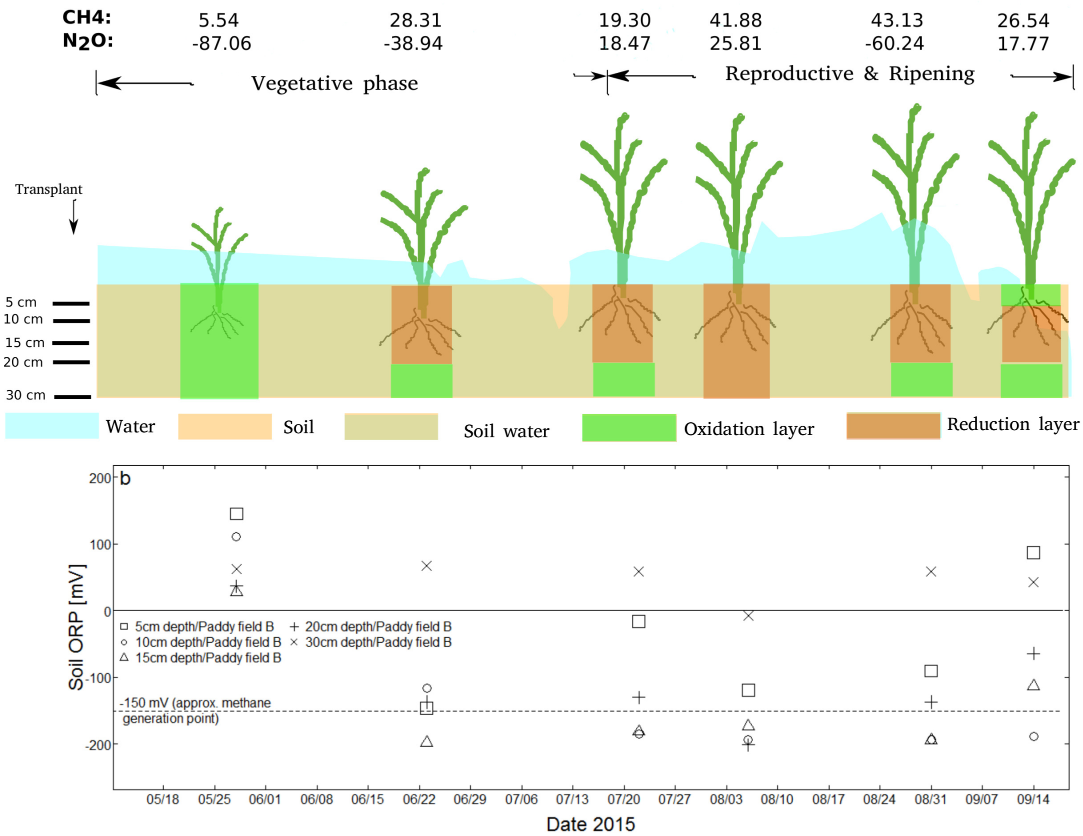


Figure 6.15: Methane flux with soil ORP and ponding depth for paddy field B

To explain the mechanism of GHGs emission, the findings from paddy field A and paddy field B experiments can be discussed together. In both the methods, the rice growing season can be divided in vegetative phase, reproductive and ripening phases. The intermittent irrigation leads to fluctuation in ponding depth which causes changes in soil ORP at various depths. The change in soil ORP from mainly reduction condition to oxidation condition can lead to reduced methane formation and can result in reduced over all GHGs emission. However, higher oxidation condition may have opposite effect on N_2O emission, but the quantity of N_2O is lesser than CH_4, hence it is more important to control CH_4 emission. The following explanations can be provided for GHGs emission mechanism from the findings of intermittent irrigation method (in paddy field A) and Iwaki-shi local method (in paddy field B):

- During vegetative phase, initially after transplantation, the water level in each paddy field is managed almost stagnant for plant growth, however, the soil is also settling during initial 20 - 30 days after transplantation, which leads to initially oxidation condition at each depth for both the paddy field.

- After transplantation, during initial days, the water level is still higher in paddy field B than paddy field A, and slightly fluctuating in paddy field A. This may cause resistance in paddy field B for change in soil condition from oxidation to reduction, while in paddy field A, the change in soil layers from oxidation to reduction condition can occur faster than paddy field B. This leads to higher methane emission in paddy field A on the measurement on DAT 20 than compare to paddy field B.

- After 20 days (DAT 20-46), it may be possible the soil layer in paddy field B start having reduction condition in upper layer while deep layers are still in oxidation condition. In case of paddy field A, due to change in water level leads to upper layer in oxidation, middle in reduction and deeper layer in oxidation conditions. Because of this, this paddy field B have higher methane flux. Paddy field A have significant reduction in methane emission, because of dominant oxidation layers near upper surface.

- After DAT 46 to 75 (near end of vegetative phase), mid-season drainage is performed for paddy field B, which can lead to slight change in soil ORP in the upper layer. Because of that, there is slight reduction in DAT 75. In case of paddy field A, the fluctuation in the water level leads to reduction condition in all the soil layers which causes slight increase in methane emission flux but still have significantly lower emission than paddy field B.

- Between DAT 75 to DAT 90, reproductive and ripening phase have started. Because of stagnant water condition in paddy field B, all the soil layers have reduction condition which increase methane emission flux significantly. But in case of paddy field A, because of frequent drainage and irrigation, the upper layers become in oxidation condition with higher soil ORP values except deepest layer of 30 cm. Hence, at DAT 90,very less methane emission occurred.

- In between DAT 90 to DAT 115, the stagnant water condition in paddy field B causes reduction to continue in upper layers, however, the deepest layer had moderately oxidation condition which may be because of reduction in microorganism in deepest layer. The lower soil ORP in upper layers leads to higher methane emission on DAT 115. In case of paddy field A, due to intermittent irrigation, all the layers have very moderate reduction condition, which leads to slight increase in methane emission on DAT 115 than compare to DAT 90. However, the methane emission in paddy field A is significantly less than paddy field B may be because of frequent oxidation condition in paddy field A with ponding depth change.

- DAT 129 is pre-harvest time, when drainage is performed for both the paddy fields, which leads to mixed layer of oxidation and reduction in paddy field B, cause slight reduction in methane emission than DAT 115. In case of paddy field A, the upper layer has oxidation condition and the methane emission is significantly lesser than paddy field B.

To summarize the above discussion, it can be said that the ponding water condition leads to more reduction condition in soil layer and also offer resistance in change in soil layer conditions. In case of intermittent irrigation, the upper soil layers upto 20 cm have frequent change between moderate reduction and higher oxidation condition which leads to significant reduction in methane emission with ponding depth change. The previous result of N_2O emission does not change significantly with water depth change. And the higher N_2O emission is only observed in reproductive and ripening phase in both the paddy fields. However, it can be considered that with oxidation condition in soil layer, N_2O emission can be higher with use of nitrogen based fertilizers. In order to reduce overall GHGs emission in rice farming, it is recommended to utilize the optimized water management during rice growing season by intermittent irrigation method, so that, methane emission can be significantly reduced, N_2O emission should not increase significantly, and plant development should not be affected by water stress.

6.5 Discussion

It is important to know that the experiments are carried out in the paddy fields based on water management / irrigation management, whereas other parameters are kept same in both the paddy fields A and B. The idea behind this experiment is to validate the greenhouse gas emission based on soil layer condition in depth-wise and to find effectiveness of intermittent irrigation method by shallow water management practice in Southeast Asian countries.

While observing the rice plant development, the higher number of leaves and tillers are found that during vegetative phase for paddy field A in comparison to paddy field B. The average height of rice plant is also higher during this phase in paddy field A. However, in next reproductive and harvesting phase, some of the leaves gets dried because of intermittent irrigation in paddy field A and are removed from counting. In paddy field, because of almost all the time stagnant water condition, less number of dry leaves are observed during pre-harvest phase. At the time of harvest in both paddy fields A and B, number of tillers and height of rice plant are almost in same condition.

The details study of post-harvest measurement of rice yield and plant biomass is conducted and rice plant height is found significantly higher in paddy field A. However,insignificant relation between stem numbers, panicle numbers and dead leaves is found between in both the paddy fields. Live leaves are also significantly higher numbers in paddy field B as compared to paddy field A in post harvest measurements. The average grain weight from paddy field A and B are 55.54 g and 59.81 g, respectively, which is slightly higher number in paddy field B but insignificantly related within in 10% margin.

Further, in post harvest measurement, in paddy field A and B, micro-elevation measurement are performed. In case of paddy field A, range of micro elevation is 73 mm and standard deviation 12 mm, and in paddy B was 75 mm and standard deviation 15 mm. The paddy field condition is acceptable in Japanese standard (Yamaji, 1989)[41]; Anbumozhi, V. et al., (2001)[42]; Shoji, K. et al., (2005)[43]. By comparing the surface elevation of paddy field A and B, with irrigation channel and drainage channel locations, it is found that Paddy B has effective elevation from irrigation to drainage point, followed by higher to lower. this means easy water movement during irrigation and drainage whenever it is needed. But in case of paddy field A, the drainage corner is found to have higher micro-elevation than irrigation point. It means during application of AWD irrigation/intermittent irrigation, heterogeneous dryness of soil surface may have been caused because of spatial variation of micro-elevation throughout the paddy field A. Hence, paddy field A should have been leveling properly before rice transplantation. Which can lead to equal water distribution and rice yield throughout

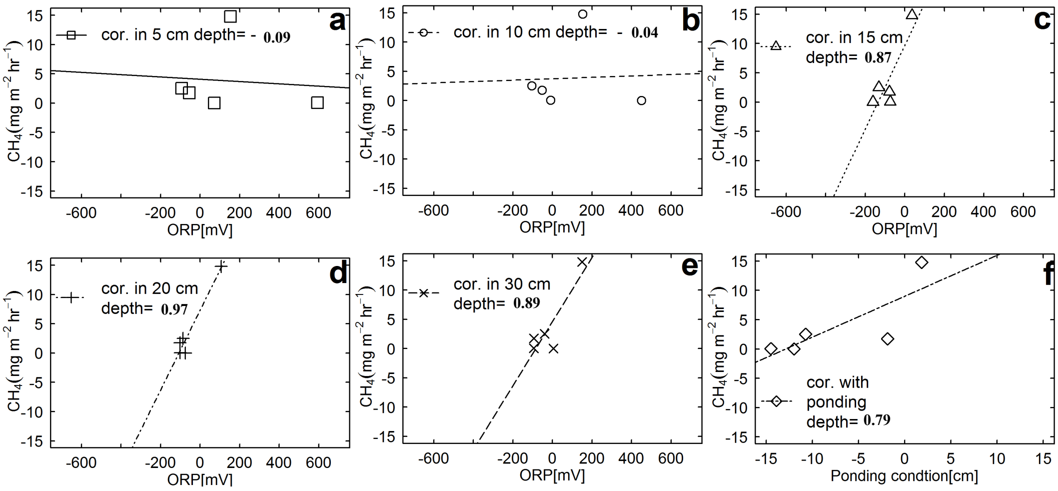


Figure 6.16: Correlation between methane flux and ORP in paddy field A

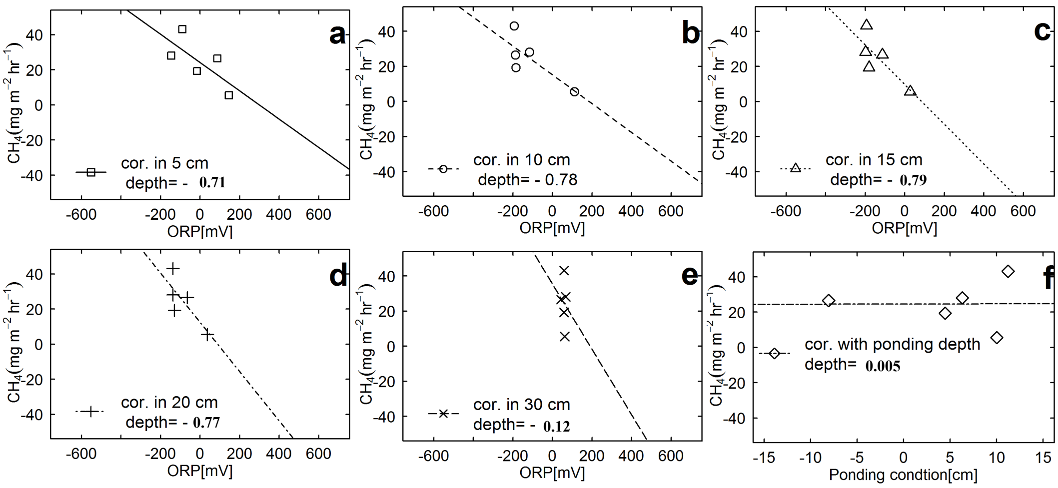


Figure 6.17: Correlation between methane flux and ORP in paddy field B

the field. However, as range of micro-elevation is acceptable, this may not have significant effect on the results of this study.

The indicators for the GHGs formation, soil ORP, soil water content, pH, temperature, ponding depth are measured in both paddy fields. The GHG emission in Paddy field A remained very low compare to the paddy field B. ORP is the main indicator for the methane formation inside the paddy soil, which is measured in various depth of 5 cm, 10 cm, 15 cm, 20 cm, and 30 cm from the upper soil surface in a vertical direction.

In this section, relation between different parameters (soil ORP, soil water content, temperature) with methane flux have been discussed in both the paddy fields. Figure 6.16 and 6.17 shows correlation between methane flux and soil ORP in paddy field A and B, respectively. At the depth of 5 and 10 cm, it shows very weak correlation in paddy field A, indicating the values -0.09 and -0.04. However, at the depth 15 cm, 20 cm, and 30 cm, it shows strong positive correlation between methane flux and soil ORP. It means methane flux increases with increase in soil ORP values at theses inner depths and vice-versa in paddy field A. It can be concluded the reduction in methane flux is caused by more oxidation in soil layers. As paddy field A is treated with intermittent irrigation throughout the rice growing seasons, movement of water in soil layer because of intermittent irrigation increases the chances of higher oxidation in soil layer. In paddy field B, Iwaki-shi local irrigation management practice is adopted in which mid-season drainage and just before harvest drainage is performed. The correlation between methane flux and soil ORP in paddy field B (in Figure 6.17) shows strong negative correlation at depths 5, 10, 15,and 20 cm, except 30 cm. It means the decrease in ORP value leads to increase in methane emission and vice-versa. The increase in reduction condition leads to higher methane flux because of almost stagnant water condition in paddy field B. The correlation between ponding depth and methane flux in paddy field B does not have any significance.

In this study, N_2O flux shows higher values only in reproductive phase in both paddy fields A and B (in Figure 6.13). Rest of the sampling data do not show positive N_2O emission as reported by Yan et al., (2000)[50]. It was already studied that N_2O flux increases by application of higher nitrogen based fertilizer. The maximum amount of ammonium sulphate fertilizer increases the higher emission of N_2O (Cai et al. 1997)[34]. In this study, although the nitrogen based fertilizers applied in both the fields in same amount but there is no significant N_2O in comparison to CH_4 flux. Hence, methane accounts for higher global warming potential reduction in rice farming. Xing et al, (2009)[51] have also showed N_2O flux is very lower in comparison of CH_4 flux.

The temperature and soil water content in paddy soil also shows conductivity of soil nutrients and water holding capacity of paddy soil. Moreover, soil water content shows about water availability for the rice plants. Figure 6.18 and 6.19 show the correlation of methane flux and soil water content in paddy field A and B, respectively. In paddy field A, positive correlation is observed only at 5 cm and 30 cm depths and negative weak correlation is observed at 10 cm and 15 cm depths. In general, methane emission should have positive correlation with soil water content as increasing soil water may lead to reduction condition, which causes higher methane emission. By application of intermittent irrigation, the pattern of soil water content gets affected at various depths in paddy field A. As shown in Figure 6.19, the correlation between methane flux and soil water content is weakly negative at 5 cm depth while always negative at rest of the depths in paddy field B. As paddy field B have stagnant

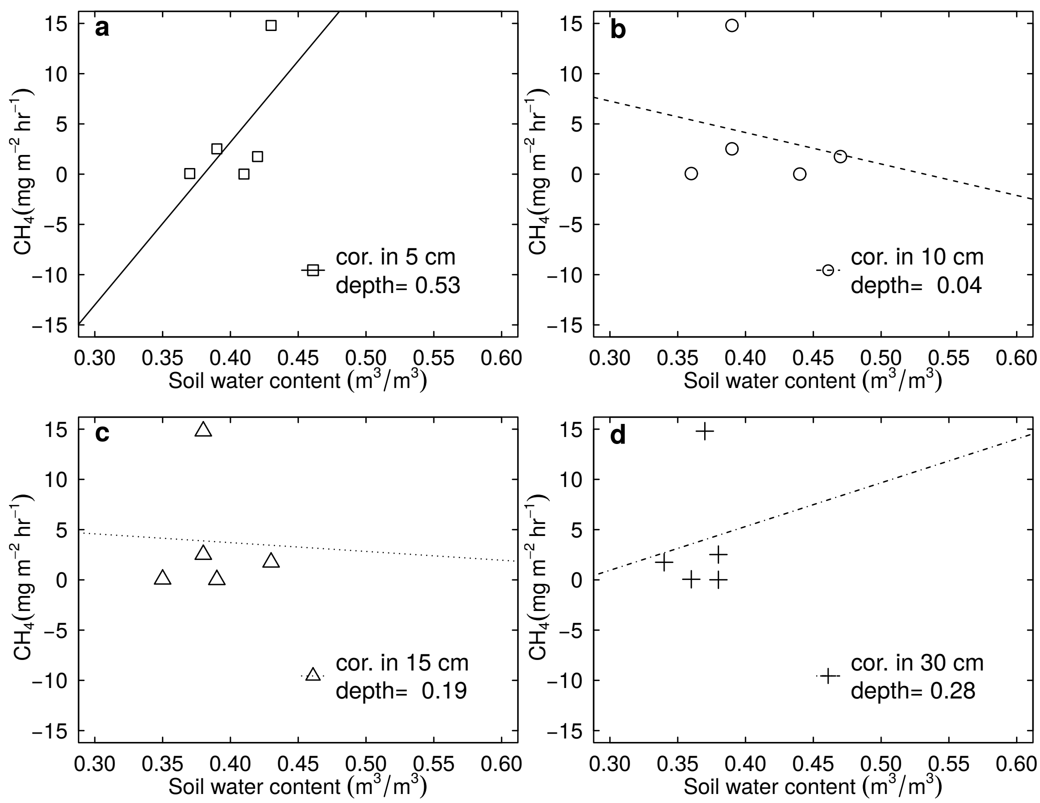


Figure 6.18: Correlation between methane flux and soil water content in paddy field A

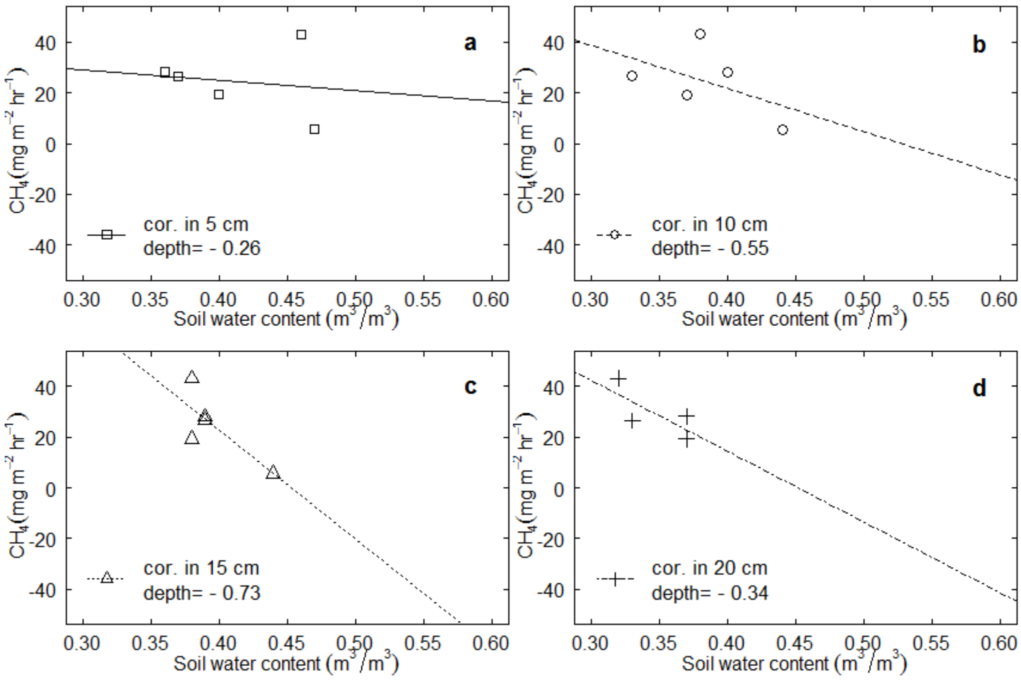


Figure 6.19: Correlation between methane flux and soil water content in paddy field B

water most of the time, soil surface of paddy field B is softer and deeper than paddy field A. However, in this study, soil texture is not measured but during frequent visits, it is observed clay loamy soil is dominated in paddy field B whereas, sand loamy soil is observed in paddy field A. As paddy field B have ponding condition from time of rice transplantation, it can be said that soil water content should be similar at various depth throughout the rice growing season in paddy field B and methane flux is always high in case of paddy field B, however, there is a negative correlation found with soil water content which is not very conclusive for paddy field B.

The correlation between soil temperature and methane flux is plotted in Figure 6.20 and 6.21 at various soil depths in paddy field A and B, respectively. Soil temperature changes with weather pattern as hot in summer or initial rice growing phase to cold in winter near harvesting phase. The soil temperature might have its influenced on methane emission from paddy soil, however, in this study temperature does not fluctuate significantly in the depth of the soil. In paddy field A and B, the range of soil temperature fluctuation is maximum between 20 to 30 degree Celsius. The correlation between temperature and methane flux shows weak negative at 5 cm depth and moderately negative at other depths. In paddy field B, the soil temperature shows weakly negative at 20 cm and 30 cm depths and slight negative at 5 cm depths, however, at 10 cm depth, it shows positive correlation. In general, increasing

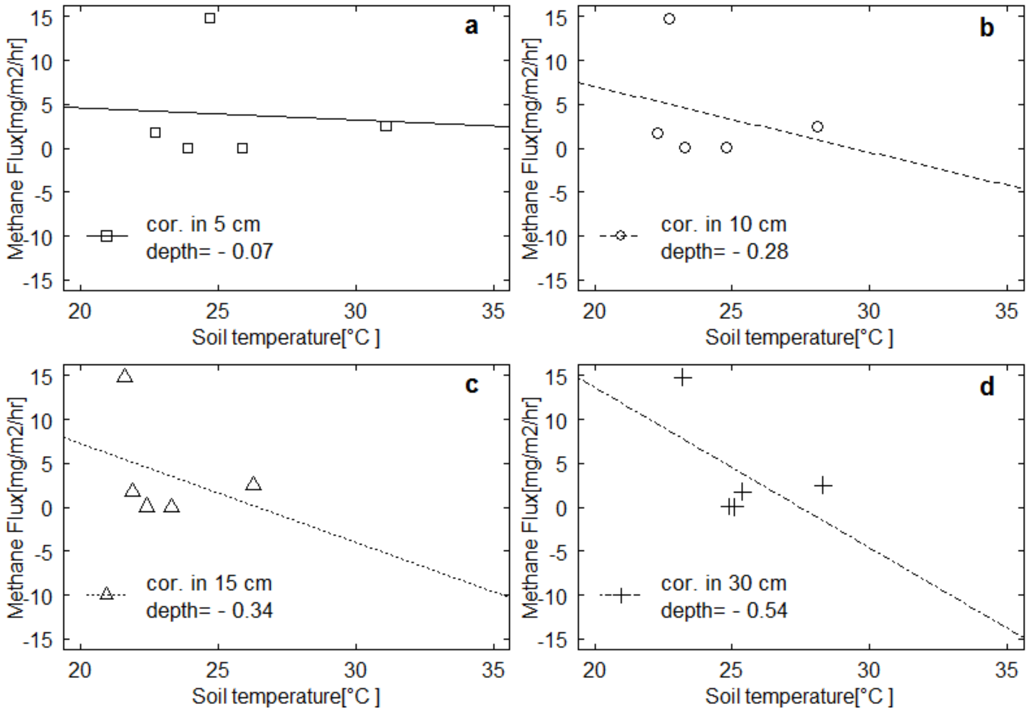


Figure 6.20: Correlation between methane flux and temperature in paddy field A

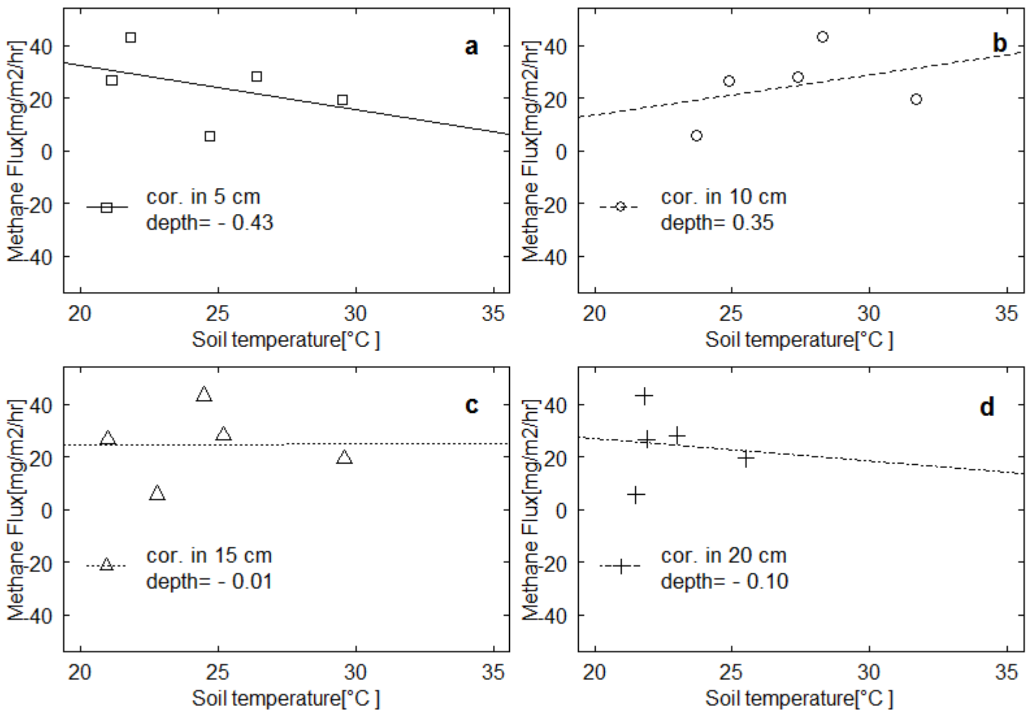


Figure 6.21: Correlation between methane flux and temperature in paddy field B

temperature may lead to reduction of organic matter in the soil which may cause higher methane emission. But in this study,the correlation between soil temperature and methane flux are inclusive. Because of lesser temperature fluctuation.

In this study, slightly higher rice yield per hill was observed in paddy field B than paddy field A but without significant difference. The rice yield varies per hill with the condition of micro-elevation which defines the accuracy of water distribution and soil nutrients. Paddy field A has slightly poor homogeneity in terms of surface level. Methane flux varies with the strong indicator of ORP in soil layer. If the soil ORP is lower (in negative), the higher emission of methane flux occur. In the paddy field A, where the water management was done by intermittent irrigation, the methane formation occurs at 15 to 30 cm depths rather than at 5 and 10 cm depths. The soil reduction condition is controlled by intermittent irrigation in paddy field and strong correlation is observed at 15-30 cm depths. Because of stagnant ponding condition in paddy field B, the methane flux is higher. In case of paddy field B, active methane formation is observed at 5 to 20 cm depths. However, at 30 cm depth, the reduction condition soil should be dominated but in this study, it shows different condition in comparison in comparison to paddy field A (30 cm depth). Further investigation of soil texture, ground water table, and plow layer is needed for greenhouse gas emission. It can be summarize that the Intermittent irrigation method practiced in farm level in Japan can reduce environmental loads significantly (more than ten times) without reducing the rice grain yields.

Chapter 7

General Discussion and Conclusions

7.1 Introduction

The major contributors of global warming potential are three greenhouse gases: CO_2, CH_4 and N_2O contributing 60%, 15% and 5%, respectively according to the IPCC results 2007[53]. The agriculture report of fifth assessment[35] showed that agriculture is the major emitter of global anthropogenic non-CO_2, accounting 56%, categorizing the agricultural soils, enteric fermentation, manure management systems, and rice cultivation. Among them, enteric fermentation and agricultural soils account for 70%, following by 12% from rice cultivation (Smith, P. 2011)[35]. To overcome the problems, scientists and researchers had looked for the rice cultivation methods which are environmental friendly and may have sustainable rice production. They have tried several mechanisms to invent the methods. Organic fertilization, AWD irrigation, intermittent irrigation, mid-season drainage, system of rice intensification, are overwhelming for the mitigation of GHGs emission in agriculture practices. Environmentally sustainable means low input of fertilizer, low environmental load, high production, enable to feed the growing population. In this study, we investigated the intermittent irrigation method and it's effect in reducing the GHGs emission. Moreover, detailed investigation of paddy field soil condition for depth-wise is performed under different water management and compared with Iwaki-shi local method of irrigation. Initial experiments are performed in lysimeter environment and then results are validated in farmer's field in Iwaki-shi, Fukushima prefecture. The key elements set in SRI method varies from region to region. It largely affected by climate, topography and farmers cultivation cultures. But in case of Japan, there are lack of data or practices in order to set the basic SRI key elements. In this research, in

Chapter 4, the studies about the structural development of rice plants by SRI and non-SRI method in lysimeter environment are performed. In Chapter 5,the study about methane emission during rice growing season and non-growing season in lysimeter environment is performed. Then in chapter 6, the mechanism of GHGs emission from paddy fields are validated and final conclusions for greenhouse gases from paddy fields are drawn.

7.2 Structural Development of Rice Plants

The experiments are conducted to measure methane emission and the structural development of rice plant by SRI and non-SRI methods in Chapter 4. The structural development of rice plant in the flooding plot is significantly greater than the SRI plot. Young single seedlings are used in both plots, and there is no difference in grain yield. Dry root weight is greater in the flooding plot but no difference is observed for root length. SRI method itself is a new environment-friendly method, and while several researchers have produced higher yields than conventional rice cultivation method. The results from this study was different. The dissemination of SRI method is still a work in progress, where key basic elements are being identified by particular local areas, because different areas have different climate conditions and resource availability. Hence the difference in result was because the same number of rice seedling are transplanted in both plots. In order to further understand the structural development in SRI and non-SRI methods, we investigated the SRI method by changing seedling densities.

The lysimeter experiment are conducted to clarify the difference in rice plant development by different transplanting density under the SRI practices. The common method of rice transplanting by SRI is single young rice seedling. However, farmers in some lowland areas hesitate to transplant single seedlings by the SRI method because of the threats from birds, flood, insects, etc., causing a dilemma for the farmers over the implementation of the SRI method. It is found that the grain yield is significantly higher for transplantation treatment with three and four seedlings rather than one seedling, validating the farmer's confidence in their way of applying the SRI method. This study thus suggests that farmers can transplant more than one seedling in lowland areas. The study used a Japanese koshihikari rice nursery. It is highly recommended to test with the local rice variety, climatic condition, and agronomical practices for a more precise confirmation of optimal seedling densities.

Chapter 6.3.1 shows the rice plant development in farmer's field in Iwaki-shi, Fukushima prefecture, comparing intermittent irrigation method and Iwaki-shi local irrigation method treating water management and keeping other parameters constant. The result shows that rice plant height is significantly higher in intermittent irrigation method than Iwaki-shi local method. The numbers of live leaves are significantly higher in Iwaki-shi local method. The other indicators stem number, panicle, dead leaves, good grains numbers, dry grains numbers are not statistically much different. The most important part of rice, the difference in grain yield (14% moisture level) is also insignificant indicating the values 55.54 gms. in intermittent irrigation method and 59.81 gms. in Iwaki-shi local method. Moreover, the land surface of paddy fields A and B are investigated. Paddy field B has better micro-elevation surface from higher elevation to lower elevation, followed by irrigation channel to drainage channel. But in case of paddy field A as shown in Figure 6.9, the irrigation channel to drainage channel, the surface elevation around the drainage channel is not smooth, which means cutting and filling process should be done properly to keep the smoothness.

7.3 Paddy Soil Condition during Rice Growing Season

Chapter 5 shows the paddy soil condition during the growing and non-growing seasons. The parameters used are soil pH, ORP, moisture, temperature in different depths. The methane flux in SRI method is significantly lower than the flooding plot, with almost 50% reduction in emission. The methane flux peak is mainly observed during the vegetative and pre-reproductive phases. If the water could be managed without stress to the plant, then SRI method can be the appropriate method for reducing global warming potential. The higher correlation between soil Eh and methane flux are found at 10 cm depth in both plots. The experiments are conducted on the rooftop, and the heat from the concrete may have affected the measurements for soil temperature and Eh. To clearly understand soil Eh in relation to depth, tests in real paddy fields are needed.

Data obtained during vegetative and reproductive phases are used to evaluate the methane flux pattern in AWD irrigation by observing the soil physiochemical properties during the rice-growing and non-rice growing seasons. The methane flux with soil ORP, pH, soil moisture content, and temperature are analyzed using a simple correlation process. The correlation between soil ORP and methane flux should be negative, which means suppression of oxygen reduction process in the soil leads to increase in methane flux. Measurements are taken at fixed depths of 5, 15, and 20 cm. ORP values at 5 and 15 cm are lower at the beginning of the sampling process, and later it increases to a level where methane flux with ORP is positive at 5 and 15 cm depths, and negative at 20 cm depth. It suggests that AWD irrigation is an effective method for reducing methane emission. Many studies, including Yagi et al. (1998)[8] and Minamikawa et al. (2006)[36], checked the soil ORP only at 5 cm depth and methane emission was observed whenever soil ORP decreased to -150 mV. While soil ORP in this study were similar to that of the past studies at 5 cm and 15 cm depths, ORP was higher at 20 cm depth. The soil water content and temperature show a positive correlation with methane flux (Figure 5.5c), even though soil water content depends largely on ponding condition and soil types. In a non-rice growing season, soil ORP was positive and methane flux was negative, which is consistent with the observations by Kudo et al. (2016)[38].

The experiment conducted in lysimeter environment identified methane flux during the vegetative phase. Methane flux was also greater with the presence of active soil microorganism during the rapid development of rice plant height, leaves, and tillers. Moreover, the experiment shows that methane is being released whenever ORP is low in the soil layer. When the ORP value is higher, the methane emission is lower. This study has also shown that the temporal measurement of ORP varies at each soil depths. While many studies measured soil ORP only at 5 cm depth, the results from this study shows a negative ORP correlation even at 20 cm depth, which is logical for the methane emission mechanism. The positive correlation between CH_4 flux and ORP at 5 cm and 15 cm depths shows that methane flux increases as ORP slightly decrease, and vice versa. The moisture and temperature at each depth shows a positive correlation with methane flux. The result shows that maximum ORP does not fall below -201 mV during gas measurement process. A decrease in ORP may be affected by water management. However, this was a lysimeter experiment conducted on the roof of a concrete building, and there may have been some heat effect at the lower, 20 cm depth, which is different from a paddy field environment. Hence an experiments on real paddy fields are needed to better understand the mechanism of methane flux with respect to soil physiochemical properties.

Chapter 6.2.1 and 6.2.2 show the paddy soil characteristics both physical and chemical. With the intermittent irrigation in paddy field A, the soil condition is measured by indicator ORP which shows higher fluctuation in 5 cm and 10 cm depths. At 15 cm and 20 cm depths, there are lower fluctuations in ORP values and even further lesser fluctuations are seen at 30 cm depth. Before draining (7-10 days before harvest), At each depth the similar negative ORP are observed, except 5 cm depth. At the 5 cm depth there are oxidation which may be highly affected because of the crack formation on the surface. The others indicator as soil water content have similar movement with water management by ponding depth. Temperatures are also have similar pattern with average temperature observed by Japan meteorological agency, Yumoto, Iwaki-shi, 2015[54].

The water management in paddy field A is done by intermittent irrigation and in paddy field B is done by continuous flooding, except during mid-season drainage and both the fields are drained before harvest. The ORP values in every depth showed negative values except the 30 cm depth. In general, for paddy field A, the ORP value at 30 should be negative but in this study it shows the lower depth in oxidizing condition, which should be further investigated for soil water property and groundwater table. The other indicator of soil water content is only affected by mid-season drainage, comparing the data with ponding conditions (Figure 6.5a, b, & c).

7.4 GHG Emission and Environmental Load

The major study of this research is investigation of GHGs emission and environmental load. The best mechanism practiced in rice farming and on-going research, like intermittent irrigation method (One of SRI key elements) is adopted for one paddy field. Another method of Japanese farmer's local method (considerably having higher yield among the Asian countries) is adopted for other paddy field. Methane is major contributing gas from the paddy field. So, measurement of methane emission from paddy field is investigated along with another important contributer N_2O.

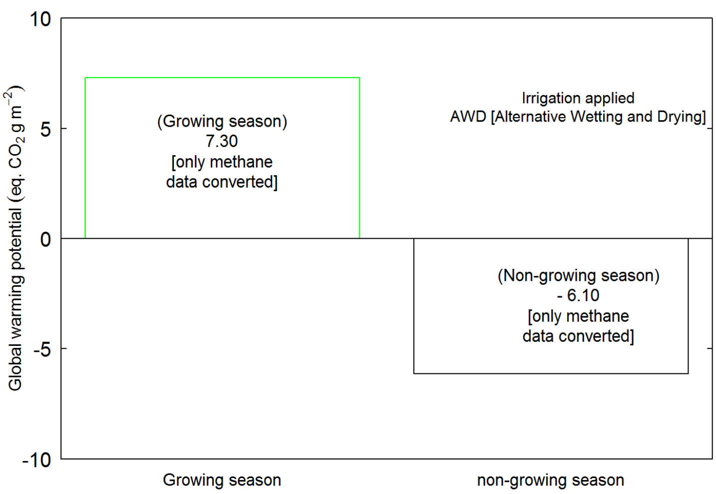


Figure 7.1: Global warming potential (GWP) in rice growing and non-growing seasons

In Chapter 5, methane gas is obtained from lysimeter experiment and it is converted to measure the environmental load (GWP with the climate carbon feedback for a 100 year time horizon. 1 g of CH_4 is equal to 34 g of CO_2). During the experiment conducted in lysimeter environment in 2013, for rice growing season and non-growing season by applying

AWD irrigation, the total GWP values equivalent to CO_2 are 7.30 and -6.10, respectively (Figure 7.1). This means, it can be concluded that if the fallow land is left after the rice growing period, there is effect in environmental load.

The second experiment in lysimeter environment is conducted in 2014 by comparing the methane emission in SRI and non-SRI methods. It shows that the methane emission is significantly lower in SRI method without reducing the grain yields. The GWP data have also shown that methane emission can be reduced more than half by using SRI method as shown in Figure 7.2.

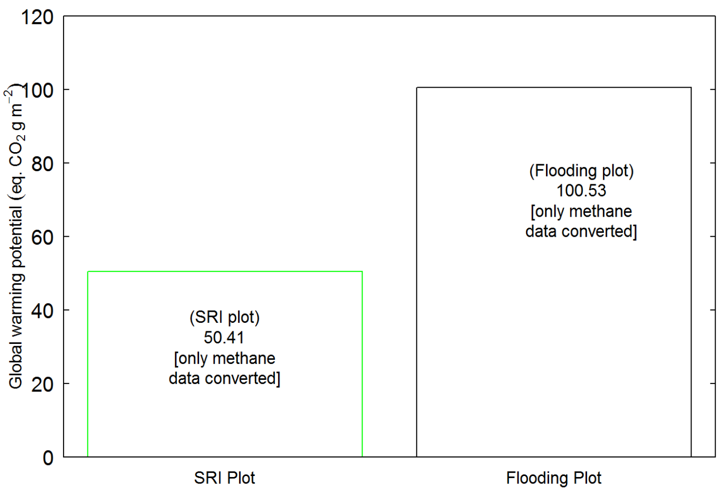


Figure 7.2: Global warming potential (GWP) in intermittent plot and conventional plot

To validate the two experiments conducted in lysimeter environments, the investigation of GHGs emission in paddy field was conducted in 2015. The methane gas emission from intermittent irrigation method adopted paddy field A and Iwaki-shi local method adopted paddy field B is measured by applying the different water treatments (intermittent and continuous flooding). The GWP data based on methane emission shows that global warming potentials can be reduced ten times lower by using intermittent irrigation method as compared to Iwaki-shi local method. In the N_2O emission data from both paddy fields, usually there is no significant change except two small peaks are observed after mid-season drainage. However, water management and drainage performance depend on the land surface (micro-elevation) in the paddy field. From the view points of Japanese standard of land leveling is both paddy fields are in precision recommended by Japanese scientist standard deviation and range. But from the view points of facilities, the paddy field B is better location of irrigation inlet and drainage outlet. In paddy field B, irrigation inlet is located in upper elevation than drainage

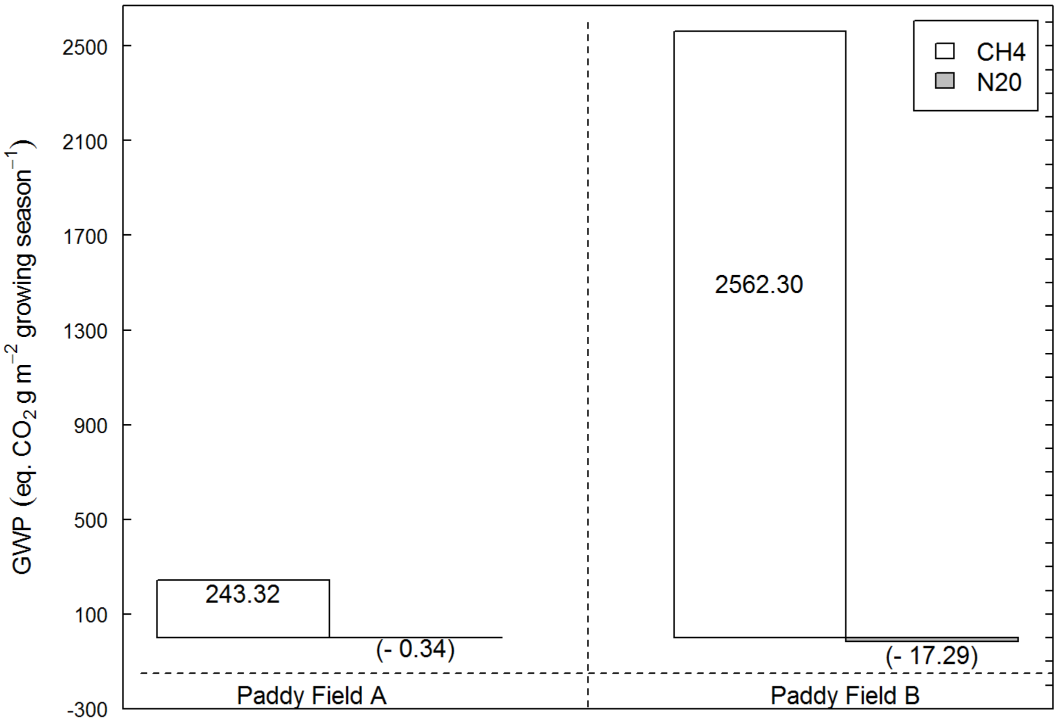


Figure 7.3: Global warming potential (GWP) in paddy field A and paddy field B

outlet. This enables the better water management performance whenever, intermittent irrigation is adopted. While paddy field A, in terms of micro-elevation, paddy field A has unequal distribution of micro-elevation. The irrigation inlet in paddy field A is lower than drainage outlet. The micro-elevation located near drainage outlet, higher elevated surface are observed. It means during intermittent irrigation applied in paddy field A, heterogeneous water distribution are observed. Some of the surface elevation near lower elevation are stilled observed water ditches and some of higher elevation surface are observed dryness. But it is important to note the methodology of gas sampling, in both paddy field A and B, lower chamber basement are sealed by using tap water to avoid gas leakage from chamber. The replication is applied three times. It means from the viewpoints of GHGs measurement, the variability of data accuracy are similar. Figure 7.2 shows the global warming potential contribution from intermittent irrigation method and Iwaki-shi local method.

7.5 Conclusions

Excess use of irrigation and stagnant condition of lowland paddy field leads to reduction condition (opposite to oxidation) of soil layer inside the paddy field. This causes the anthropogenic GHG emission to the atmospheric environment. This study has exhibited the mechanism of GHGs emission by investigating soil layer condition for paddy field adopted SRI key element; intermittent irrigation. The soil layer conditions change with the water management practices. From the paddy field experiment, the result has shown that from the upper surface level to vertical lower direction, soil have reduction condition mainly up to 20 cm depth (Figure 6.3a & b). Hence, maintaining the soil dry condition during the water management, with large crack formation is recommendation to break down the soil reduction condition without getting any water stress by plants. In paddy field A, the ORP values have shown slight fluctuations and negative values. However, in paddy field B, the ORP values have shown slight positive values but not so high. From the viewpoints of GHG emission between intermittent irrigation and Iwaki-shi local method, the intermittent irrigation mechanism of SRI methods can reduced the GWP more than ten times as compared to Iwaki-shi local method based on methane and nitrous oxide. However, the grain yield did not differ in both the cases. Although Japanese rice yield is higher among the Asian countries. It means if intermittent irrigation is applied widely, it can lead to significant reduction in GWP without reducing the grain yields.

7.6 Limitation of Research and Future Needs

One of the main objectives of this study is investigating the soil layer condition in depth-wise. For the GHG emission, ORP is the main indicators for getting information methane formation checking. Our result have shown methane formation upto 20 cm depth from upper soil surface. However, the water management in paddy field upto formation of big surface crack and along with plant water stress level should be studied in future. In this study, soil treatment is controlled by water management, in future the effect of other factors should also be studied. By applying the intermittent irrigation method, the GHG was reduced tremendously in this study. Further GHGs emission with different treatment of fertilization, plant density (based on the constituents) are also needed to investigate along with applying intermittent irrigation method.

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