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AND SCIENTIFIC PUBLICATION

DEVELOPING SRI PADDY FIELDS INFORMATION SYSTEM FOR GREEN AGRICULTURE

1ST YEAR OF 3 YEARS

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SUMMARY

Currently, the issues of food safety, water scarcity and global warming became the focus of attention among people in the world including in Indonesia. Utilization of water irrigation for paddy fields by continuous flooding has been increased fresh water use in agricultural sector. However, continuous flooding irrigation is not always associated with the increasing of land productivity. Indeed, this irrigation has been decreased water productivity because less efficient in water use causing large amounts of surface runoff, seepage and percolation Also, this irrigation regime contribute to negative impact to environment by releasing higher amount of global warming potential (GWP) particularly methane gas that caused the increasing of global warming.

System of rice intensification (SRI) is proposed as an alternative of rice farming with more efficient water use for producing more rice and reducing greenhouse gas emissions by applying intermittent irrigation. With the proper water management, SRI is promising practice for developing green agriculture with three benefits, i.e. 1) enhancing yield, 2) increasing water productivity and 3) reducing greenhouse gas emission. However, there is no information regarding the optimal SRI water management by the objective to implement green agriculture in achieving those three benefits.

The current research is proposed to develop SRI paddy fields information system for green agriculture in order to optimize water management for enhancing yield and water productivity and reducing greenhouse gas emissions simultaneously. To achieve the goals, three years research collaboration between Bogor Agricultural University and the University of Tokyo is proposed. In the first year (2015), SRI paddy fields information system will be developed by implementing advance field monitoring technology in the paddy fields. SRI information website will be developed in order to present daily field monitored data from the fields. Also, study on the development of greenhouse gas emission model will be conducted in the first year to characterize gas emissions under different weather and water managements. In the second year (2016), crop model of SRI paddy rice will be developed according the planting seasons in the first and second years in both fields to identify plant growth under different seasons. Then, optimization model will be performed with the objective function to enhance yield and water productivity and reduce GWP simultaneously. In the last year (2017), irrigation and drainage control system for SRI paddy fields will be designed using fuzzy logic control system. Finally, SRI information system website will be improved by providing the historical data such as yield, water productivity and greenhouse gas emissions before applying control system and predicting results during applying control system.

In the first year (2015), we developed advance field monitoring system in three locations. The system was effective, efficient and reliable in monitoring SRI paddy field in three locations in Indonesia during one cropping season. The actual field conditions were monitored well in term of image, numeric and graphic data acquisition. Although this monitoring did not send real-time data, the data were stored in the field data loggers. By adopting quasi-real time monitoring, it was more power saving and Internet cost effective than the real time monitoring. The data were then used for further analyses to optimize SRI water management in Indonesia. For security and accessibility, field monitored database management system was developed using integrated website. For accessing the database, only authorized user can access the data.. From the data we can easily interpret the data and their trend.

Based on field monitored data and manual measurements, greenhouse gas model, water productivity, crop coefficient and nitrogen uptake were developed and investigated in different fields. Artificial Neural Network (ANN) model can be used to estimate CH_4 and N_2O emissions from paddy fields using soil moisture, soil temperature and soil EC with R^2 of

0.93 and 0.70. It was indicated that the model can used to predict CH_4 and N_2O emissions from paddy field.

Crop coefficient (Kc) of SRI and continuous flooding (FL) regimes in terrace paddy fields were well determined by water balance analysis with Excel Solver estimation. SRI regime has lower Kc values than that FL regime in all growth stages. Average Kc values for SRI regime were 1.00, 0.96, 1.02 and 1.04 for the initial, crop development, reproductive and late growth stages, respectively. Meanwhile, average Kc values for FL regime were 1.01, 1.02, 1.09 and 1.05 in the initial, crop development, reproductive and late growth stages, respectively. Although has lower Kc values, however, SRI regime produced more grain yield than that FL regime. The main reason was probably due to aerobic condition under SRI regime which provided optimal water and oxygen availability. Accordingly, with less irrigation water, SRI regime has higher water productivity than that FL regime. We recorded water productivity for SRI and FL regimes were 1.55 and 1.42, respectively.

Nitrogen uptake is a product of soil nitrogen availability and evapo-transpiration. High nitrogen uptake is usually a result of high evapo-transpiration that brings soil nutrition to leaves. However the available-N in soil act as limiting factors for nitrogen uptake. Slight difference in available-N for SRI and Common field and its respective crop yields confirms the hypothesis. It is still unknown the effect of shifting from anaerob-aerob or shrinking-swelling combine with biochar application to nitrogen availability.

The outputs in this year (2015) are three papers were presented on PAWEES-INWEPF Joint International Conference 2015, 9-21 August, 2015 at Kuala Lumpur, Malaysia. Those papers were reviewed and selected to be published in Special Issue of Jurnal Teknologi (Science and Engineering - ISSN: 21803722, 01279696 (SCOPUS INDEX)) “Solution for Sustainable Water and Environmental Management”. The outcomes of this year were undergraduate and master thesis that conducted based on this project. There were leven students were involved this research from Bogor Agricultural University and University of Jenderal Soedirman.

For future planning, we will focus on 1) development of crop model based on field monitored data and 2) optimize SRI water management to increase land and water productivities and reduce greenhouse gas emission with schedule presented in next chapter.

PREFACE

Alhamdulillah, all of praise to Allah SWT who gives us opportunity to conduct research continuously through program of Collaboration Research and International Publication Competitive Grant funding by Directorate Higher of Education, Ministry of Education, Indonesia. Our title is “Developing Sri Paddy Fields Information System For Green Agriculture”

In this first year, we could reach the targets completely, which were installed advance field monitoring system in three locations, develop field monitored database management system and develop greenhouse gas emission model. The outputs in this year (2015) are three papers were presented on PAWEES-INWEPF Joint International Conference 2015, 9-21 August, 2015 at Kuala Lumpur, Malaysia. Those papers were reviewed and selected to be published in Special Issue of Jurnal Teknologi (Science and Engineering - ISSN: 21803722, 01279696 (SCOPUS INDEX)) “Solution for Sustainable Water and Environmental Management”. The outcomes of this year were undergraduate and master thesis that conducted based on this project. There were leven students were involved this research from Bogor Agricultural University and University of Jenderal Soedirman.

In the second year (2016), we will focus on 1) development of crop model based on field monitored data and 2) optimize SRI water management to increase land and water productivities and reduce greenhouse gas emission.

We are grateful the Directorate of Higher Education, Ministry of National Education, Republic of Indonesia for partial funding support through grant of International Research Collaboration and Scientific Publication in 2015 with number project of 475/IT3.11/LT/2015.

Bogor, October 2015

Chief researcher

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Dr. Chusnul Arif, STP, MSi.

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I. INTRODUCTION

A. Background

Rice (*Oryza sativa* L) is the most important staple food in Indonesia, and it covers the largest agricultural area. The total harvested area and rice production in 2013 were 13.8 million ha and 71.2 million tons, respectively (Statistics Indonesia 2013). Commonly in Indonesia, irrigated rice is cultivated under continuous flooding irrigation by maintaining the depth of water between 2 and 5 cm above the soil surface. As the result, agriculture is the largest consumer of fresh water especially for irrigation. The data in 2010 showed that water used for irrigation was 89% following by fisheries (7%), domestic and industrial (4%) and livestock (0.2%) (Radhika et al. 2012). However, this irrigation is not always associated with the increasing yields and biomass production (Lin et al., 2011; Sato et al., 2011; Zhao et al., 2011), even it threatens the sustainability of rice farming since competition of water resource for rice production increased as affected by climate change (De Silva et al., 2007). Also, continuous flooding irrigation is less efficient and causing large amounts of surface runoff, seepage and percolation (Bouman, 2001).

In addition, paddy fields with the application of continuous flooding irrigation contributes to negative effect to the environment by releasing greenhouse gas emissions particularly methane gas (CH_4) (Cicerone et al., 1992; Setyanto et al., 2000). The increase of methane concentration in the atmosphere contributes to global warming. Methane is produced by methanogens during organic matter decomposition, under an environment where the oxygen and sulfate are scare such as in flooded condition. Another greenhouse gas emission, nitrous oxide (N_2O), also releases from paddy fields by microbial processes, nitrification and denitrification in soil. Both N_2O and methane are two of contributors to global warming and they can be represented in one parameter called Global Warming Potential (GWP).

One alternative strategy of rice farming that is regarded more productive with more efficient in water use is the System of Rice Intensification (SRI). SRI is well-known as a set of crop management practices for raising the productivity of rice by changing the management of plants, soil, water, and nutrients. Although some critics were dismissed to SRI, its benefits have been validated in 42 countries of Asia, Africa and Latin America (Uphoff et al., 2011). In SRI paddy fields, intermittent irrigation is applied in which the field is allowed to dry during particular time instead of keeping them continuously flooding (Van der Hoek et al., 2001). Intermittent irrigation is also known as a mitigation strategy for greenhouse gas emission from paddy fields (Li et al., 2011; Tyagi et al., 2010). Therefore, SRI is promising practice for rice production by the implementation of green agriculture with three benefits, i.e. 1) enhancing yield, 2) increasing water productivity and 3) reducing greenhouse gas emissions.

However, there were some limitations in disseminating SRI particularly in Indonesia, such as determining optimal irrigation regime and developing irrigation water control (Gani et al., 2002). Few farmers in Indonesia are interested in applying SRI in their fields because there is no reference of optimal SRI water management according to the weather condition in achieving three benefits of SRI. SRI with intermittent irrigation is vulnerable to water shortage particularly when the field in dry condition that decreases the yield significantly.

Therefore, optimizing water management for SRI paddy fields is a key factor to obtain those three benefits of SRI simultaneously. For optimizing water management, there are many factors to be considered, such as crop water requirement, production function of irrigation water, precipitation, soil water balance including irrigation water, plant growth stage, etc (Zhang et al., 2008). Precise data set such as water, soil and meteorological data are important to be considered in optimizing water management of SRI paddy fields. In addition, field monitoring is required to prevent water shortage in the fields. So, information system is needed in providing precise field data through the continuous measurements by implementing field monitoring technology.

The current research collaboration is proposed to develop field information system for SRI paddy fields in different fields with the main objective to optimize SRI water management with three goals, i.e. 1) enhancing yield, 2) increasing water productivity, and 3) reducing GWP simultaneously. By optimal SRI water management, yield can be increased as maximally, water resource can be utilized optimally and greenhouse gas emissions can be reduced significantly. To achieve the goals, some specific studies will be conducted such as develop SRI information website, greenhouse gas emissions model to characterize the emissions under different weather and water managements, SRI paddy rice model based on field data, optimize SRI water management and design irrigation and drainage control system. This research will be conducted under the collaboration between Bogor Agricultural University (IPB) and the University of Tokyo (UT).

B. Track Record of Research Collaboration

Research collaboration between Department of Civil and Environmental Engineering, Bogor Agricultural University and Department of Global Agricultural Sciences, the

University of Tokyo has been started in 2008 when Department of Civil and Environmental Engineering was established. In this year, collaboration was initiated to develop real-time field monitoring system for some agricultural fields such as paddy fields, forest plantation and Cibodas National Park. For this monitoring, we used Field Server (FS) that is an automatic monitoring system consisting of a CPU (a Web server), an analog-to-digital converter, an Ethernet controller; sensors to measure air temperature, relative humidity, solar radiation, soil moisture, soil temperature and electrical conductivity; and a CCD camera. However, there was problem limiting its stability. From our field experiences, the Field Server broke down after only half a year when the heat and ultraviolet light weakened their acrylic poles. The stability depends on the field solar power supply, the antenna, the local electrical power supply, and the Internet connection. If any of them has a problem, the data will be lost because the Field Server does not have any data logging function.

In the end of 2009, new field monitoring system was introduced adopted quasi real-time monitoring using FieldRouter (FR). The advantages of FR are small power source (6W solar panel), easy set up, cost-effectiveness (using mobile line), can check battery level from the remote lab, no data loss because the data secured by data logger and stored in data center. In case, there are some problems related to internet connection and electrical power, the data will be saved and stored in data loggers. Research collaboration was continued using this system specially for monitoring SRI paddy field in the SRI training center in Indonesia using first generation of FR with limited sensors. Under this collaboration, PI of this proposal have opportunity to pursue PhD degree in the University of Tokyo started the end of 2009 and finished on March 2013 supported by the directorate higher education scholarship (beasiswa DIKTI 2009-2013)

During study at the University of Tokyo, PI focus studied on the developing quasi real-time field monitoring system for SRI paddy field in Nusantara Organic SRI Center (NOSC) at Sukabumi, West Java, Indonesia. However, it was first generation of field monitoring system that can be connected with limited sensors. Although SRI information website can be developed by presenting single field image and raw data, the website was simple and there is no detail information regarding the water status in the field. By the available data, PI developed optimal SRI water management model with only two objectives, i.e., enhancing the yield and water productivity. Three scientific papers were published in three international journals during the study.

After finished study, research collaboration is being tried to be continued through this proposal in developing SRI paddy fields information system using the advance field monitoring technology to optimize SRI water management for green agriculture with three main benefits as explained previously. Also, SRI information website will be improved based on the advance of FR that can be connected with more data loggers and cameras using field network adapter. The website will be improved by including more field images and water status based on environmental data. The University of Tokyo will support the equipments of advance field monitoring system through the project of Green Network of Excellence environmental information (GRENE-ei) with the topic of climatic changes and evaluation of their effects on agriculture in Asian monsoon region supported and funded by the Japanese Ministry of Education.

C. Research Urgencies

Recently, the issues of food safety, water scarcity and global warming became hot issues and they are to be the main focus discussion among people in the world including in Indonesia. Utilization of water irrigation for paddy fields by continuous flooding has been increased fresh water use in agricultural sector. Data from UNESCO showed that 70% of fresh water was used for irrigation. However, continuous flooding irrigation is not always associated with the increasing of land productivity. Even, this irrigation has been decreased water productivity because less efficient in water use causing large amounts of surface runoff, seepage and percolation Also, this irrigation regime contribute to negative impact to environment by releasing higher amount of greenhouse gas emissions caused the increasing of global warming. Climate change is occurred by global warming indicated by the change of seasons in which long dry season occur and flooding in wet season with high rain intensity.

Therefore, the current research is very urgent to find optimal SRI water management with the application of field information system in enhancing yield and water productivity and reducing greenhouse gas emissions simultaneously. By this research, it is expected that the concept of green agriculture with three main benefits can be implemented for sustainable rice farming and adaptive strategy against climate change can be obtained for rice farming by considering environmental parameters.

II. LITERATURE REVIEW

A. Fields Information System

Since 2007 fields information system to collect real-time precise environmental data have been developed through ubiquitous field monitoring for agricultural production using field monitoring system involving the Field Server (FS), under the "Database-Model cooperation system" project of the Ministry of Agriculture, Forestry and Fisheries of Japan (Honda et al., 2008). The FS is an automatic field information system in monitoring the field consisting of a CPU as a web server, an analog-to-digital converter, an Ethernet controller; sensors to measure air temperature, relative humidity, solar radiation, soil moisture, soil temperature, and electrical conductivity; and a charge-coupled device camera. It can transfer high-resolution pictures of fields and sensing data through Wi-Fi broadband networks.

However, there was problem limiting its stability. From the field experiences, the FS broke down after only half a year when the heat and ultraviolet light weakened their acrylic poles (Mizoguchi et al., 2009). The stability depends on the field solar power supply, the antenna, the local electrical power supply, and the Internet connection. If any of them has a problem, the data will be lost because the FS does not have any data logging function.

Therefore, the new generation of field information system is being developed by using FieldRouter (FR) since the end of 2009 (Mizoguchi et al., 2011) adopted quasi real-time monitoring. The differences between FS and FR can be seen in **Table 1**. FR has capability to send the daily data through Internet connection. It consists of 3G/GSM modem, mini PC, camera, battery and timer then all of those components are kept in a water proof and dust tight box. FR is equipped with network camera and connected to the data loggers. Although this monitoring did not send real-time data, the data were stored in the field data loggers and sent daily to the server. The daily field image is useful to observe plant growth, while the daily field numeric data, i.e., meteorological and soil moisture data.

The first generation of FR only can be connected to the limited sensors and it has been tried to monitor SRI paddy field particularly in SRI training center in West Java Indonesia (Arif et al., 2011) as presented in **Figure 1**. Single field image and raw data are presented in that information website. There is no detail information regarding the water status in the field. The current study is proposed to improve SRI paddy fields information system for two different paddy fields using advance of FR that can be connected with more data loggers and cameras using field network adapter. The website will be improved by including more field images and water status based on environmental data.

Table 1. Comparison of FS and FR (Mizoguchi et al., 2011)

No	Items	Field Server	FieldRouter
1	Monitoring	Real-time and continuous	Daily monitoring/ quasi real-time
2	Operation	All day	A half hour/day
3	Power	High power consumption by using big solar panel (100 W size: 1m x 2m	Lower power consumption by using 6 W solar panel
4	Internet line	Internet with static IP address	Mobile phone Internet (3G/GSM)
5	Internet cost	More expensive	Cheaper
6	Data logger	No data logger function, data are directly and continuously sent to the server	Any data loggers can be connected
7	Set up process	Difficult system set up: Phone setting, Internet modem setting, IP cam, WiFi AP and sensors	Easy set up: - Device name, mobile name company - Automatic data logger detection
8	Collecting data	Data lost when power or Internet fails	Data secured in each data logger. However, the data will be lost immediately if the sensor cable unplugged and the battery depleted.

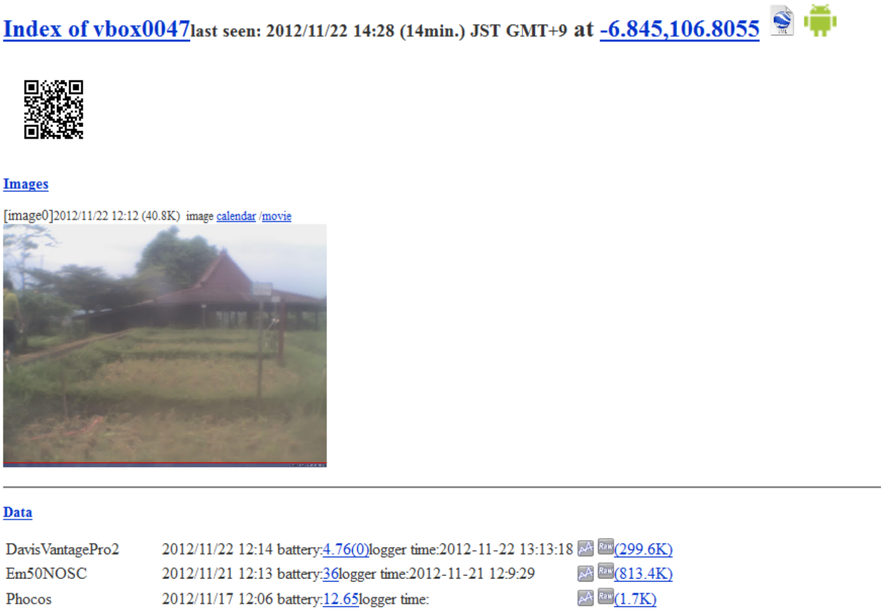

Figure 1. First SRI paddy field information system in West Java, Indonesia

B. System of Rice Intensification

SRI was introduced firstly by Fr. Henri de Laulanié in the early 1980s in Madagascar. Recently, SRI became popular over the world by effort of Prof. Norman Uphoff from Cornell University. SRI is a set of crop management practices with six basic elements summarized by following points:

1. Transplant young seedling while still at the 2–3 leaf stage, before the start of the 4th phyllochron of growth to retain most of the rice potential for roots and shoots growing.
2. Transplant quickly and carefully to avoid trauma to the roots within 15-30 minutes at a transplanted depth only 1-2 cm.
3. Single transplanting with wider spacing for better shoot and root growth according to soil quality.
4. Carefully controlled water management by avoiding continuous flooding.
5. Early and regular weeding as consequently of applying AWDI.
6. Apply compost to enhance soil organic matter as much as possible.

SRI represents an integrated and agro-ecological approach to irrigated rice allowing farmers to realize yields of up to 15 ton/ha with reduced irrigation water and mineral fertilizers' inputs demonstrated by participatory on-farm experiments conducted in

Madagascar (Stoop et al., 2002). However, inverse results were obtained and concluded that SRI has no inherent advantage over the conventional system. Thus, it has been dismissed by vehement criticism and controversy like an ‘‘unidentified flying object’’ (UFO) or “unconfirmed field observation” (Sinclair and Cassman, 2004).

The controversy of SRI motivates the researchers to investigate its elements including water management. Many studies have been conducted to investigate water saving regimes through intermittent irrigation in several countries. The key to save water is to keep soil moist enough to sustain plant growth, not too much water input by avoiding continuous flooding that the plants suffocate. However, any study on different irrigation regimes under intermittent irrigation with different ground water level is not found yet. This study is important to find the optimal water management by determining ground water level to enhance yield and water productivity and reduce greenhouse gas emissions at the same time based on field monitored data.

C. Greenhouse Gas Emissions from Paddy Fields

Global warming and climate change are hot topics of considerable scientific debate and public concern. GWP concept has been introduced to allow the comparison of the ability of each greenhouse gas emission to trap heat in the atmosphere relative to carbon dioxide (CO_2) over a specific time horizon. This is called the carbon dioxide equivalent (CO_2 eq) value and is calculated by multiplying the amount of gas by its associated GWP (Smith and Wigley, 2000). Methane (CH_4) and nitrous oxide (N_2O) are two greenhouse gases contributing to GWP at 23 and 296 times greater than carbon dioxide, respectively (Snyder et al., 2007). Thus, these gases attracted considerable attention during the last decades because of their contribution to global warming.

Paddy field is a major source of greenhouse gas emissions particularly methane (Cicerone et al., 1992; Setyanto et al., 2000). Although an early study found that nitrous oxide emission from paddy field to be negligible, however, recent study suggested that paddy field is important source not only methane but also nitrous oxide (Cai et al., 1997). Methane is produced by methanogens during organic matter decomposition, under an environment where the oxygen and sulfate are scare such as in flooded condition. Meanwhile, nitrous oxide is primarily produced from microbial processes, nitrification and denitrification in soil.

A trade-off effect between methane and nitrous oxide is clearly observed (Cai et al., 1997). The nitrous oxide flux is very small when paddy field is flooded, but its flux reaches a peak at the beginning of the disappearance of flooding water. In addition, its flux rises dramatically when fertilizer N induced to the field. In contrast, methane flux reaches a peak during flooding and is significantly reduced by water drainage (Setyanto et al., 2000). Therefore, water management is one of the most important factors in rice production and most promising option for methane and nitrous oxide mitigation. Many researchers have been conducted the experiments to find the optimal water management for mitigating of greenhouse gas emissions from paddy fields. They found that mid-season drainage irrigation may be an effective option to reduce greenhouse gas emissions (Akiyama et al., 2005; Towprayoon et al., 2005). However, the experiments were conducted under conventional crop management. Therefore, further study is needed to find effective option for mitigating gas emissions from paddy fields particularly under SRI.

III. RESEARCH OBJECTIVES AND BENEFITS

A. Research Objectives and Targets

This research aims to develop SRI paddy fields information system using the advance of field monitoring technology in collecting precise environmental data to optimize water management for green agriculture with three benefits, i.e. 1) enhancing yield, 2) increasing water productivity, and 3) reducing greenhouse gas emissions simultaneously. Furthermore, in-depth studies will be conducted to obtain the target in each year as follow:

First year:

1. Develop SRI information website for different paddy fields
2. Develop fields monitored database management system
3. Develop greenhouse gas emission model using artificial neural network model
4. Paper presented at PAWEES (International Society of Water and Environment Engineering) 2015 International Conference (Malaysia)
5. Paper submitted to International Journal Indexed by Scopus

Second year:

1. Develop SRI paddy rice model based on field monitored data
2. Optimize SRI water management according to the previous models
3. Paper presented at PAWEES (International Society of Water and Environment Engineering) 2016 International Conference (South Korea)
4. Paper submitted to Paddy and Water Environment Journal (Indexed by Scopus) (http://link.springer.com/journal/10333)

Third year:

1. Develop computer program for irrigation and drainage control system based fuzzy logic system
2. Design irrigation and drainage control system for SRI paddy fields
3. Improve website of SRI information system
4. Paper submitted to Paddy and Water Environment Journal (Indexed by Scopus) (http://link.springer.com/journal/10333)
5. Paper presented at PAWEES (International Society of Water and Environment Engineering) 2017 International Conference (Taiwan)

B. Research Benefits

There are two benefits of this research, i.e., direct and indirect. Direct benefits can be felt by institution, researcher and students. Meanwhile, indirect benefits of this research is expected can contribute to the development sustainable agriculture by utilizing more efficient water in paddy field to enhance yield, increase water productivity, and reduce greenhouse gas emissions simultaneously.

Institution:

- Continuous mutual research collaboration with one of the best university in Asia
- Increasing of number publications

Researcher:

- Adding international network
- Updating new method and technology in monitoring system
- Enhancing teaching material
- Increasing capacity and knowledge

Students:

- Supporting research experiment for their thesis (2015: IPB: 6 undergraduate students and 1 master stundet, Unsoed: 3 undergraduate students; 2016: IPB: 3 undergraduate students, Unsoed: 3 undergraduate students; 2017: IPB: 3 undergraduate students, Unsoed: 3 undergraduate students)

Farmers:

- Information regarding optimum water management for SRI paddy field in increasing yield, water productivity and reducing greenhouse gas emissions

IV. RESEARCH METHODOLOGY

A. Time and Location

This collaboration research will be conducted in three years (2015-2017). In the first year field, advance field monitoring technology will be installed in the SRI paddy fields in lab scale and field scale belong to the local farmers at Bogor, Purwokerto and Wonogiri (**Figure 2**). For the second field, the team member from Jenderal Soedirman University will be in charge for installing and maintaining second field monitored. During installing field monitoring system, soil samples will be collected and analyzed at the laboratory of Water Resource Engineering, Department of Civil and Environmental Engineering, Bogor Agricultural University. For the third field, we will collaborate with the local researcher from Gadjah Mada University. During planting season, greenhouse gas emissions will be sampled in the field and then bring the samples to the laboratory of Gas Rumah Kaca, Balai Penelitian Lingkungan Pertanian, Jakenan Pati, Central Java to be further analyzed.

Figure 2. Location of this research experiment: 1) Bogor, 2) Purwokerto, 3) Wonogiri

B. Methodology

This research collaboration will be conducted in three years in which the flow chart of research stages can be seen in **Figure 3**. As previously mentioned, field information system has been initiated during 2010-2013 by adopting quasi real-time monitoring especially for monitoring SRI paddy field in SRI research center at Sukabumi, West Java, Indonesia. During at that time, initial web based SRI information system has been developed for only one field. In addition, the technology of field monitoring was the first generation in which it only can be connected to limited sensors and data loggers. The research was conducted during pursue PhD program by PI with the outputs such as initial web based SRI information system, estimation model for non-measurable parameters, crop coefficient model and optimal water management model with simple objective function that have been presented in some International conferences and published in some International Journal (Arif et al., 2012a; Arif et al., 2012b; Arif et al., 2012c).

Currently, advance quasi real-time monitoring system is being developed in which it equipped with field network adapter that can be connected to more sensors and data loggers as well as network cameras. Therefore, the current collaboration research is proposed to develop SRI paddy fields information system using advance technology of quasi real-time monitoring technology for two different paddy fields in Indonesia with the specific objective to optimize water management in order to implement green agriculture with three benefits as previously mentioned.

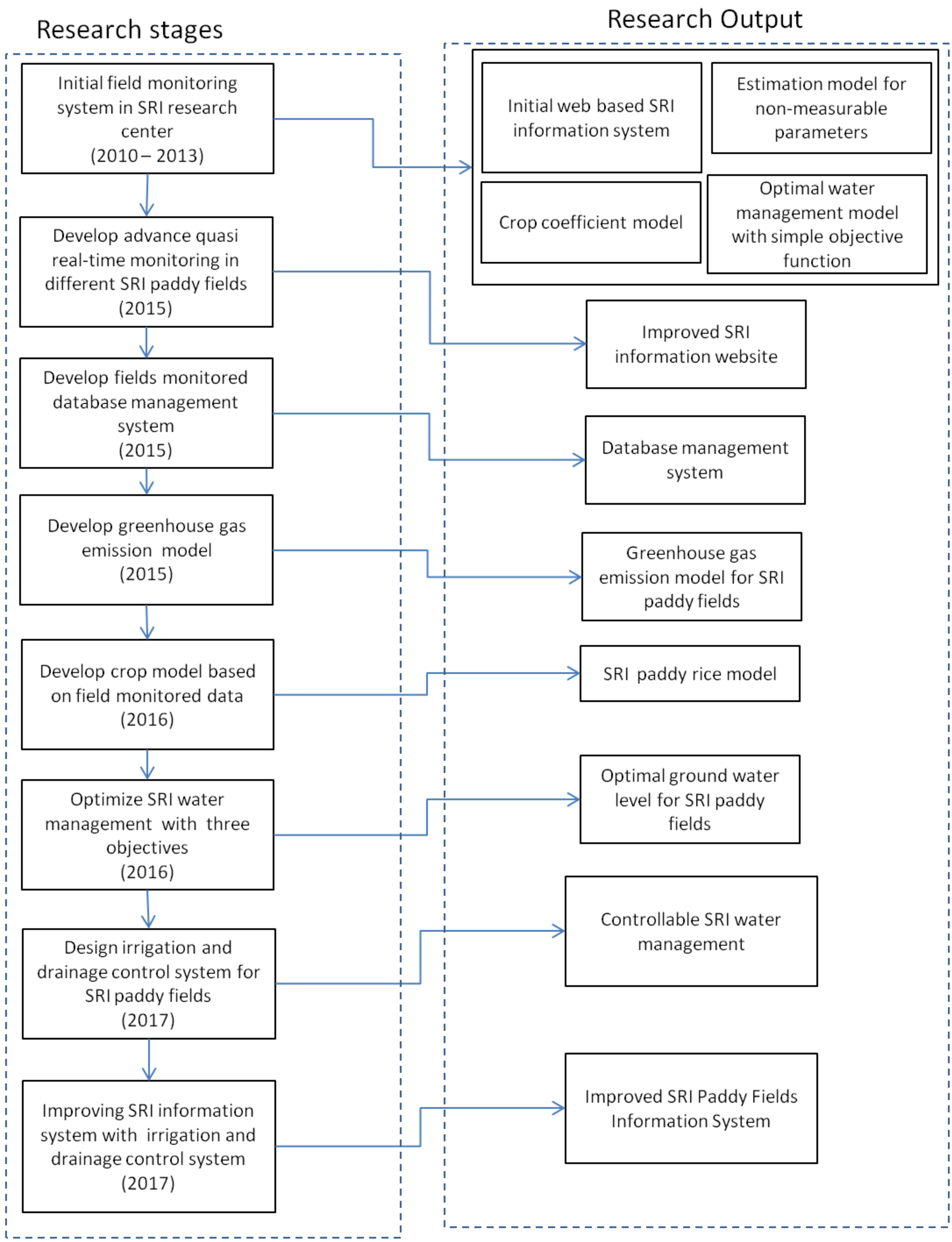

Figure 3. Flow chart of research stages during three years

During next three years, detail research stages can be explained as follow:

First year (2015):

1. Setting advance quasi real-time monitoring in three different SRI paddy fields
   The advance quasi real-time monitoring will be installed in Bogor, West Java and Purwokerto, Middle Java as well as Wonogiri. Here, FieldRouter equipped with field network adapter will be used and connected to meteorological and soil data loggers (**Figure 4**). The weather sensors consisted of solar radiation, air temperature, relative humidity, wind speed, and precipitation sensors connected to the datalogger. Meanwhile as the soil data logger, we used an Em50 data logger developed by Decagon Devices, Inc., USA. The Em50 was connected to three soil moisture and soil temperature sensors (GS-3) installed at the 10 cm depths from the soil surface in each plot and water level sensor (e-Tape). The output of this stage is SRI information website that will be improved for paddy fields.

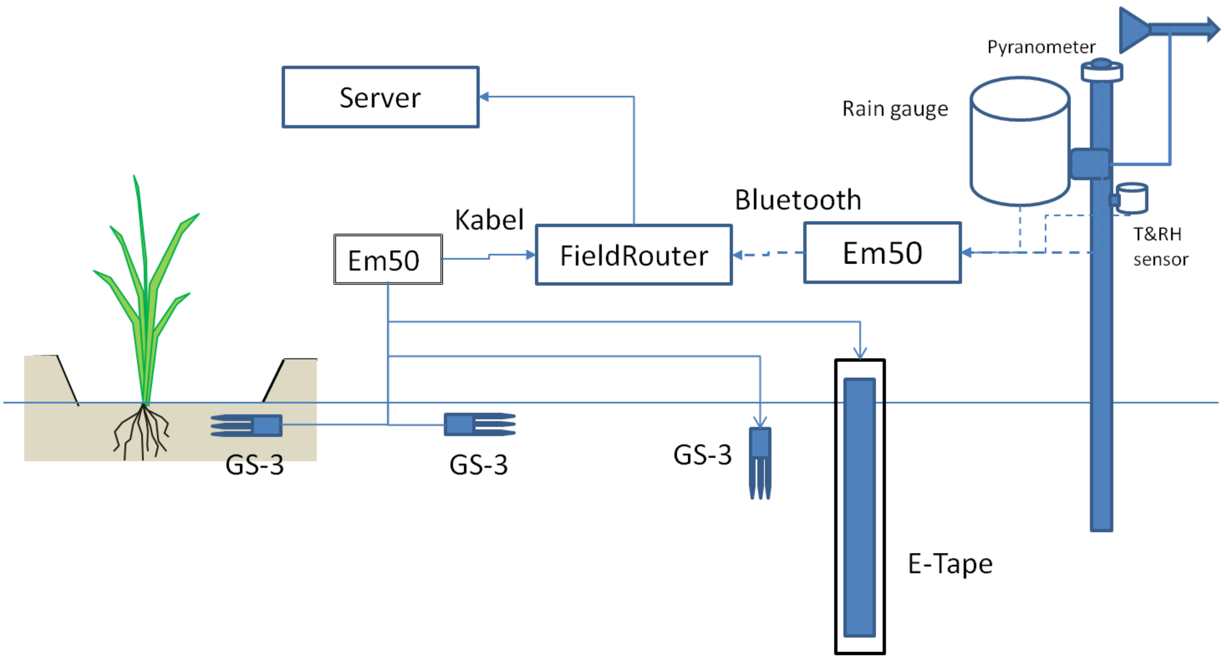

Figure 4. Connection of SRI paddy fields information system in Indonesia

2. Develop field monitored database management system
   By advance quasi real-time monitoring, the data will be automatically sent to the server daily. To access the data, we will develop database management system. All of data from both the fields can be accessed from the official website. In addition, field conditions including water status can be monitored daily.

3. Develop greenhouse gas emission model

To optimize SRI water management, some studies of identification processes will be conducted based on the research framework presented in **Figure 5**.

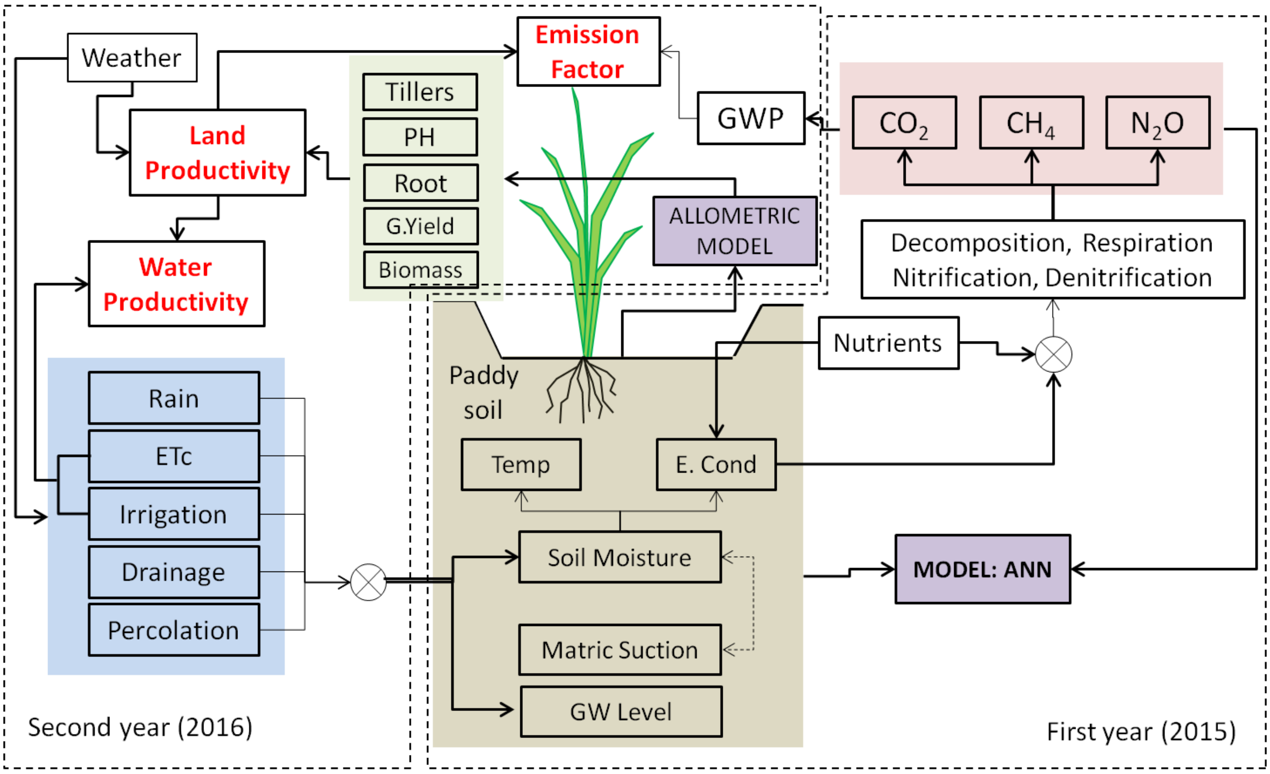

Figure 5. Research framework to identify plant-water-soil interaction

The first study to identify plant-water-soil interaction is developing greenhouse gas model. Since the advance quasi real-time monitoring is not connected yet with greenhouse gas measurements, it will be measured manually in the field. We will use the closed chamber with the size of 30 cm in wide, 60 cm in long and 100 cm in high to measure GHG emissions from paddy fields. The sampling gas is analyzed using a gas chromatograph. The fluxes of the gases are calculated from temporal increase/decrease of gas concentration inside of the chamber per unit time. The total emissions are calculated by integrating the fluxes for the period of cultivation using Simpson's role numerical analysis described by the following equation:

$$\int_a^b f(x)dx \approx \frac{b-a}{6}\left[f(a) + 4f(\frac{a+b}{2}) + f(b) \right] \qquad (1)$$

where a and b are time points in the cultivation period (d)

Then, an Artificial Neural Network (ANN) model will be developed to find interrelationships between GHG emission (CH_4 and N_2O) interacting with soil moisture (VWC), soil temperature, and soil EC.

Second year (2016):

1. Develop crop model based on field monitored data
   Using monitored data, SRI paddy rice model will be developed according the planting seasons in the first and second years at both locations. The model will be developed according to the schema in **Figure 5**.
2. Optimize SRI water management
   After identification process is developed by the crop model and greenhouse gas model, the next step is to optimize SRI water management. Optimization will be carried out according to the objective function to enhance yield and water productivity and reduce greenhouse gas emissions. The next model is more complex than optimal water management developed previously. Optimal SRI water management represented by optimal ground water level in each growth stage will be searched by Genetic Algorithms model in maximizing the objective function.

Third year (2017):

1. Design irrigation and drainage control system for SRI paddy fields
   After optimum ground water level to be founded in the previous year, the next step is to design irrigation and drainage control system for SRI paddy fields. The control system will be simulated first by fuzzy logic control system. Then, it will be tested to the monitored SRI paddy fields
2. Improve SRI information system with irrigation and drainage control system.
3. Finally, SRI information system website will be improved by providing the historical data such as yield, water productivity and greenhouse gas emissions before applying control system and predicting results during applying control system.

V. RESULTS AND DISCUSSION

A. Advanced Field Monitoring System

Advanced field monitoring system was installed in two different topographies, i.e., flat and terrace fields. Flat fields were located in farmer's field in Cikarawang, Dramaga, Bogor and farmer group's field in Piasa Kulon, Somagede, Purwokerto – Banyumas. Meanwhile, terrace paddy field was located in farmer's field in Gemawang village, Girimarto, Wonogiri (**Figure 6**).

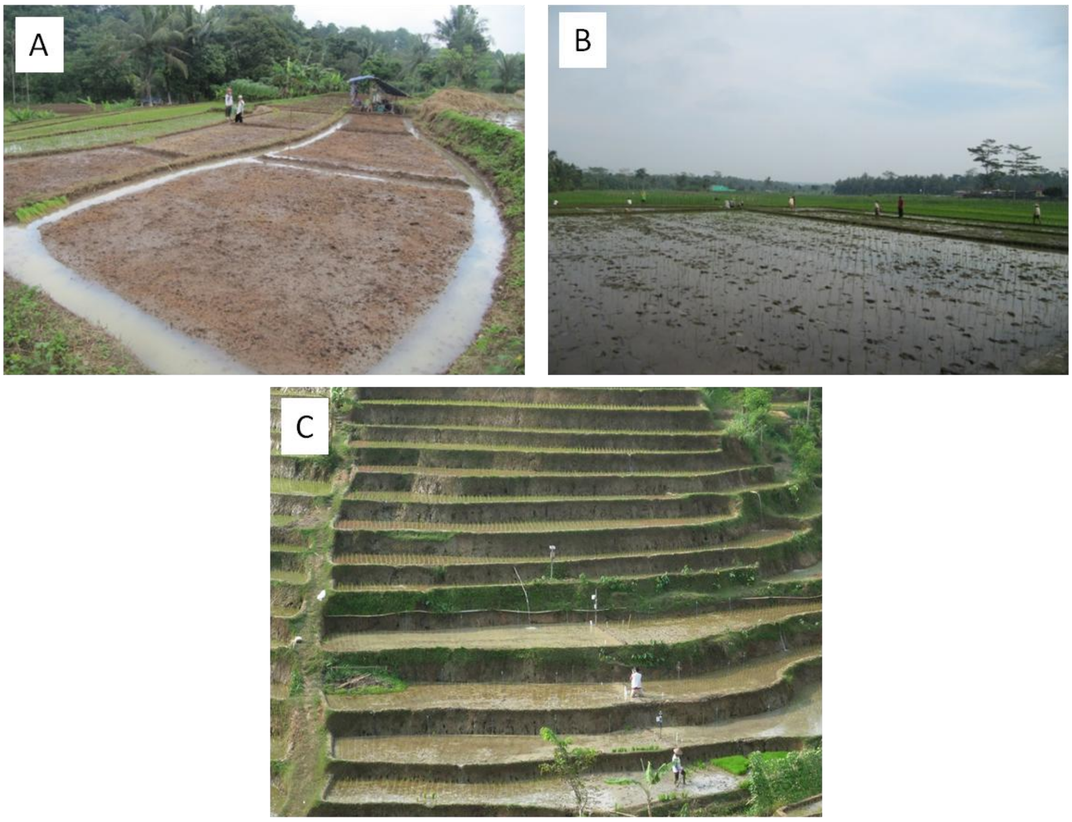

Figure 6. Fields location in this research: A) Bogor, B) Purwokerto, C) Wonogiri

Advance field monitoring system is adopted quasi real-time monitoring. This system is suitable for applying in paddy fields in Indonesia. As shown in **Figure 6** that paddy fields are commonly in the open area and far from the farmer's house. Thus, it is difficult to find electrical source for field monitoring. Real-time monitoring using Field Server has been installed in SRI paddy field in Indonesia as reported in the previous studies (Gardjito et al., 2008; Setiawan et al., 2010) were not suitable applied in Indonesia because it is difficult to get electrical power and Internet connection continuously.

By this study, we initiated advance field monitoring system for SRI paddy field in Indonesia by adopting quasi real-time monitoring using FieldRouter. Some instruments of field monitoring system were used as shown in **Figure 7**. All environmental parameters including weather and soil parameters were measured by some particular sensors and all data were stored in dataloggers. Then, FieldRouter will send the data as well as image data to the server. The users can collect all data through official website.

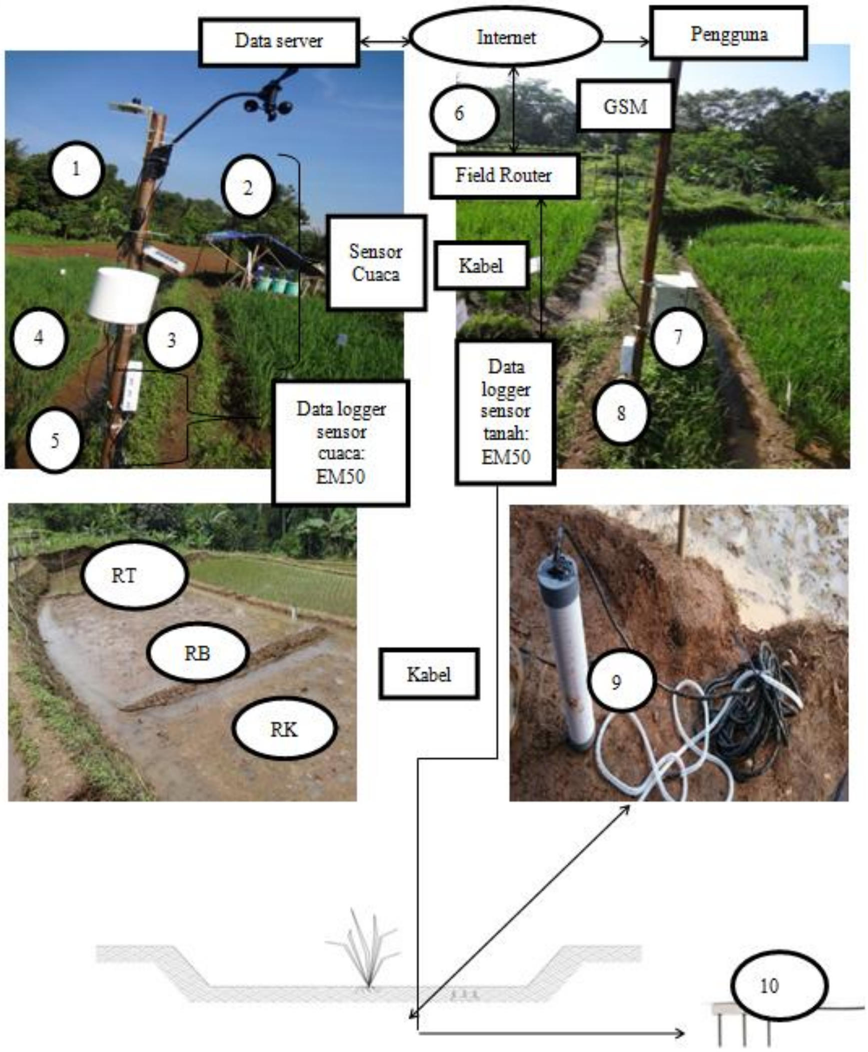

Figure 7. Instrument of advance field monitoring system installed in Bogor

During one cropping seasons, hourly, daily, and monthly of field conditions were monitored properly by the developed field monitoring system connected to the meteorological and soil data loggers. Although this monitoring did not send real-time data, the data were stored in the field data loggers and sent daily to the server. Daily field image was useful to observe plant growth, while the daily field numeric data, i.e., meteorological and soil moisture data, were required as basic information to optimize SRI water management (**Figure 8**). From this experiment revealed that quasi real-time monitoring was more power saving and Internet cost effective than the real time monitoring by using the Field Server developed in the previous study (Manzano et al., 2011; Mizoguchi et al., 2008).

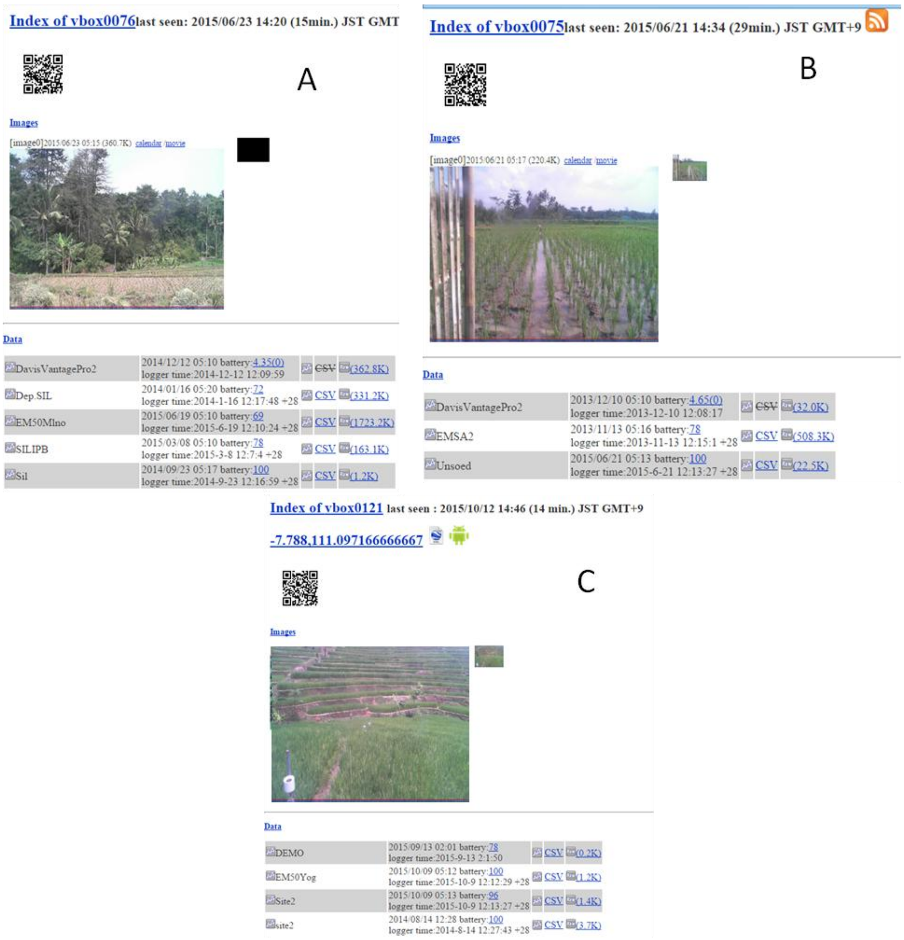

Figure 8. Access data from each location: A) Bogor, B) Purwokerto, C) Wonogiri.

The data and field image can be accessed from the following website:

a. Bogor: http://x-ability.jp/FieldRouter/vbox0076/
b. Purwokerto: http://x-ability.jp/FieldRouter/vbox0075/
c. Wonogiri: http://data01.x-ability.jp/FieldRouter/vbox0121/

The data in those official website are raw data. The raw data for both meteorological and soil parameters are presented graphically and are located below the field images on the websites. The raw data are then converted first by particular software before further analysis.

From the field image, it was relatively easy to determine each plant growth stage (**Figure 9**). In addition, the numeric data showed the reasonable values for both the meteorological and the soil parameters. For example solar radiation data that shown in **Figure 10**, their values were maximum in the noon day, and minimum on the night time. The data are important for further analyses particularly to evaluate effects of irrigation regime on yield and water productivity, and then to determine the optimal regime to maximize yield and water productivity.

Figure 9. Plant growth monitoring from information system website in Bogor paddy field

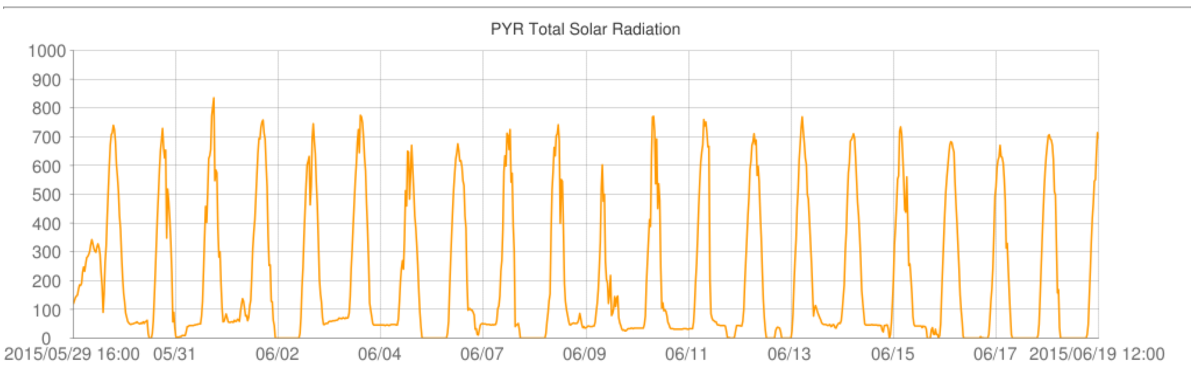

Figure 10. Solar radiation data from Bogor paddy field in June 2015

However, the stability of FieldRouter depends on the field solar power supply and the Internet connection. In case there are any problems in the coverage of the Internet connection within the data transmitting time, the plant images data are lost as shown in **Figure 9**. Moreover, data were also lost when the data logger battery was depleted or the sensor cable was unplugged from the logger or the sensor was broken.

B. Field Monitored Database Management System

All data from the field can be accessed from each official website as previously mentioned. For security and accessibility, database management system was developed. Database management system was developed based on single website. Only authorized user can access the data. We collaborate with professional database management corporate called 100Integrity (http://www.100integrity.com/).

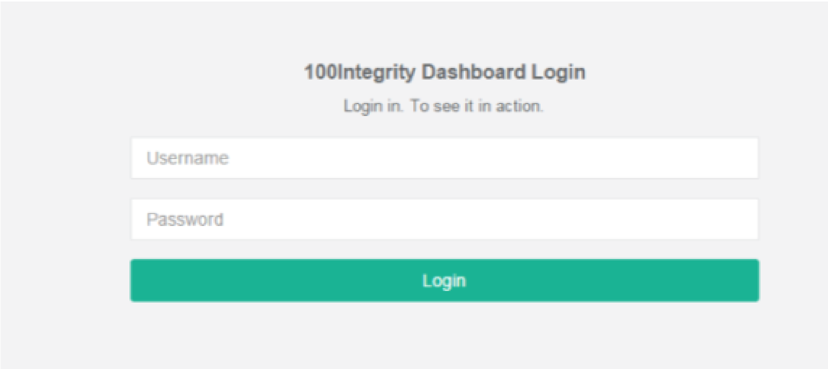

Figure 11. Authorizing to field monitored database management system

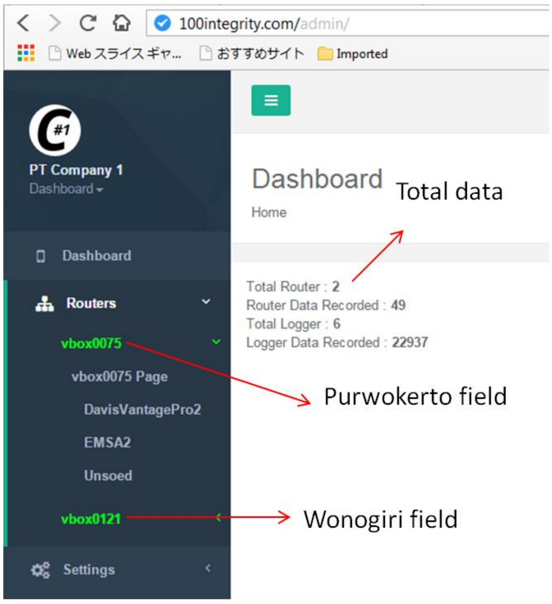

Figure 12. Accessing field data in the field monitored database management system

In that database, we can choose the Field Router in each location as well as the data (**Figure 12**). We can see the Field Router number on the interface, e.g., vbox0075 is the Field Router for Purwokerto field, and vbox0121 is for Wonogiri field. In each field, there are some notes such as vboxxxx page for field image in the calendar format, Em50xxx for accessing meteorological and soil data. For example in the Wonogiri field, vbox0121 page is for accessing field image in the calendar format (**Figure 13**).

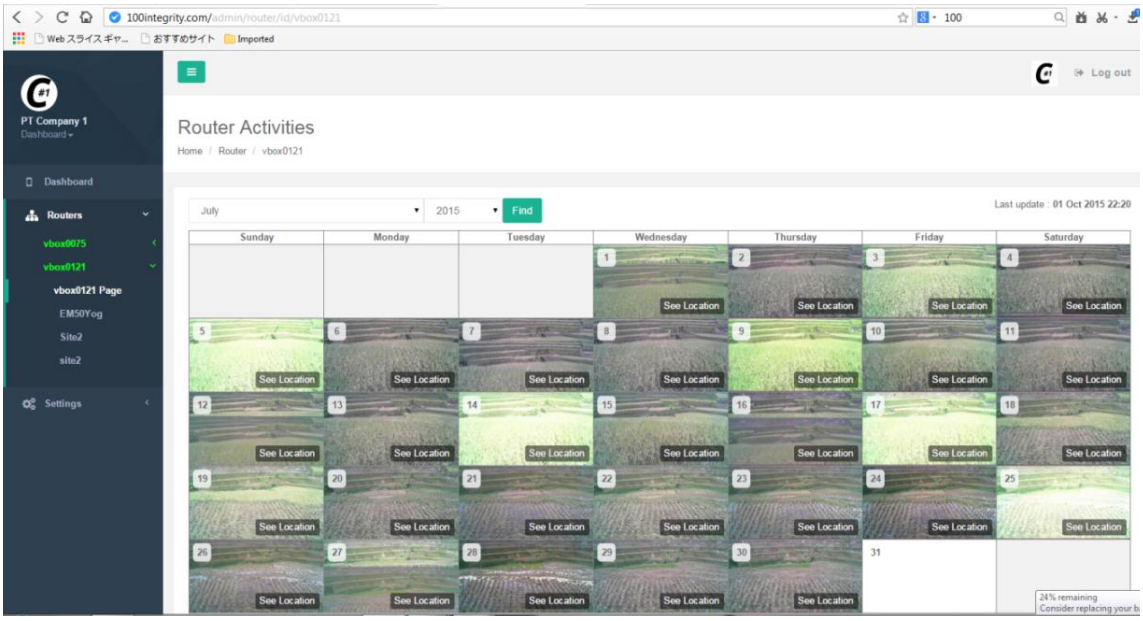

Figure 13. Field image in the calendar format

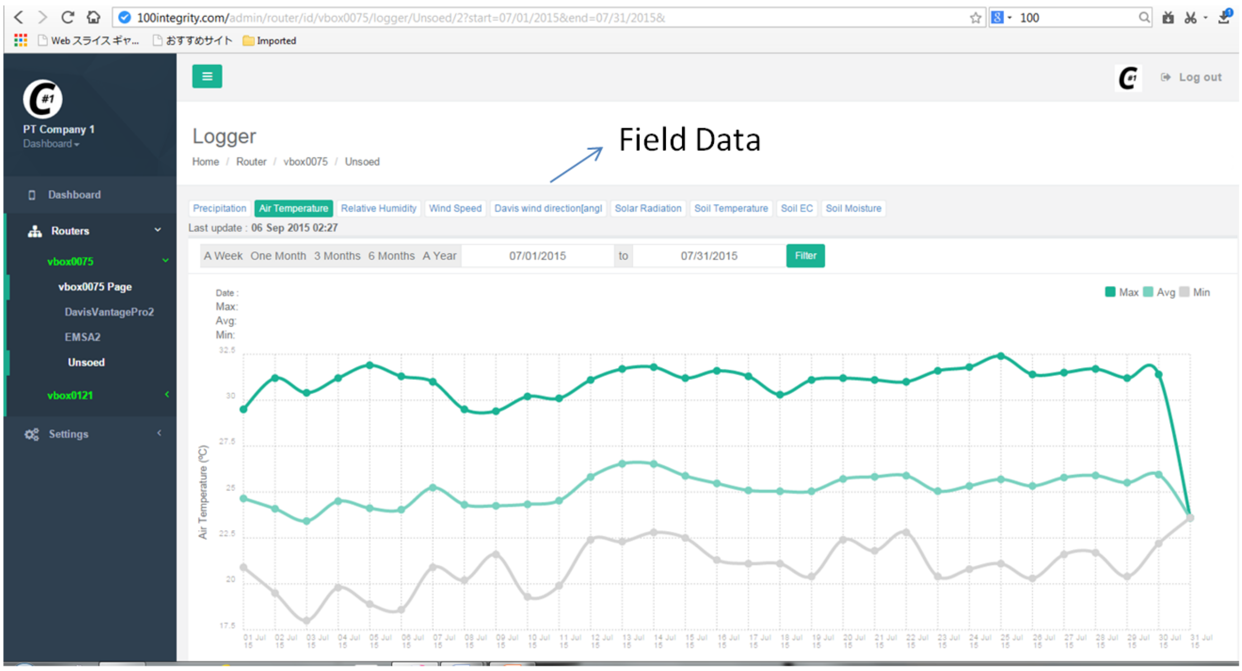

Figure 14. Daily field data in field monitored database management system

For the field data, the data are presented in the graphic that showed daily data consisted of precipitation, air temperature, relative humidity, wind speed, solar radiation, soil moisture, soil temperature and soil EC. From the data we can easily interpret the data and their trend.

C. Greenhouse Gas Emission Model

Greenhouse gas emission model was developed using Artificial Neural Network (ANN) model. The model consisted 3 layers, i.e., input layer, hidden layer and output layer (**Figure 15**). Since soil type and climatic condition in the pot and paddy field experiments were totally different, we developed two kinds of ANN models. The first model was developed for the pot experiment to find interrelationships between CH_4 and N_2O emissions with soil moisture, soil temperature and soil EC. Meanwhile, since there is no N_2O gas analyzer for the paddy field experiment, the second model was developed to estimate only CH_4 emission.

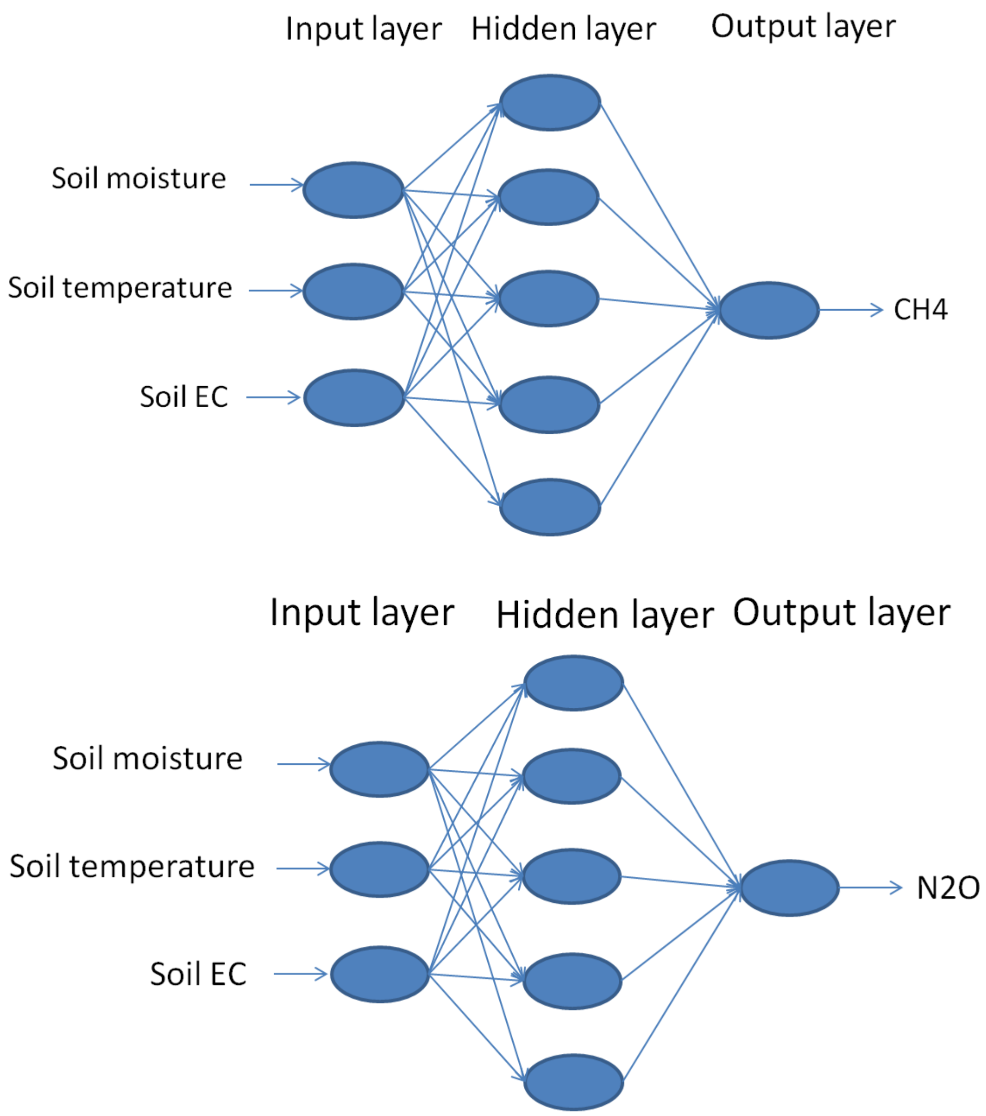

Figure 15. ANN model for green house gas emissions

The ANN model was constructed based on the model developed previously (Setiawan, et al., 2013) with some modification and improvement. MS. Excel 2007 with Visual Basic Application (VBA) and Solver were used to optimize ANN parameters with the objective function to minimize root mean squared error (RMSE) between measured and calculated outputs. Then, the characteristic curves of CH_4 emission were produced based on the ANN model.

Before perform the model, we investigate the effects of greenhouse gas emission under different water managements. We use 3 regimes called wet, medium and dry regimes. A negative correlation between CH_4 and N_2O emissions was found (**Table 2**). The dry regime released the lowest amount of CH_4, while flux of CH_4 in the wet regime was the highest than others. This was supposed due to the availability of oxygen and sulfate in the soil under dry regime, thus methanogens, methane producers, should have limited activity of organic matter decomposition (Bouwman, 1990; Cicerone and Oremland, 1988). On the other hand, dry regime released more N_2O gas than that wet regime. It was indicated that aerobic condition under dry regime promote more microbial processes i.e., nitrification and denitrification in soil, in producing N_2O. For the mitigation strategy in the pot experiment, the dry regime was the best among the regimes, however, this regime produced a grain yield lower than the wet regime.

Table 2. Effects of irrigation regime on greenhouse gas emissions

Parameters	Irrigation regimes		
	Wet	Medium	Dry
CH_4 (kg/ha/season)	18.32	4.68	-0.56
N_2O (kg/ha/season)	3.61	6.86	5.00
GWP (kg/ha/season)	1488.98	2138.50	1467.29
Plant Height (cm)	82.5 ± 2.83a	85 ± 2.83a	81.05 ± 0.64a
Tillers/hill	41 ± 5.66a	27 ± 3.54b	29 ± 4.24b
Root weight (g/hill)	165.58	189.50	214.98
Straw yield (g/hill)	150 ± 0a	100 ± 14.14b	100 ± 14.14b
Grain yield (g/hill)	92.54 ± 3.98a	57.86 ± 12.45b	58.95 ± 8.53b

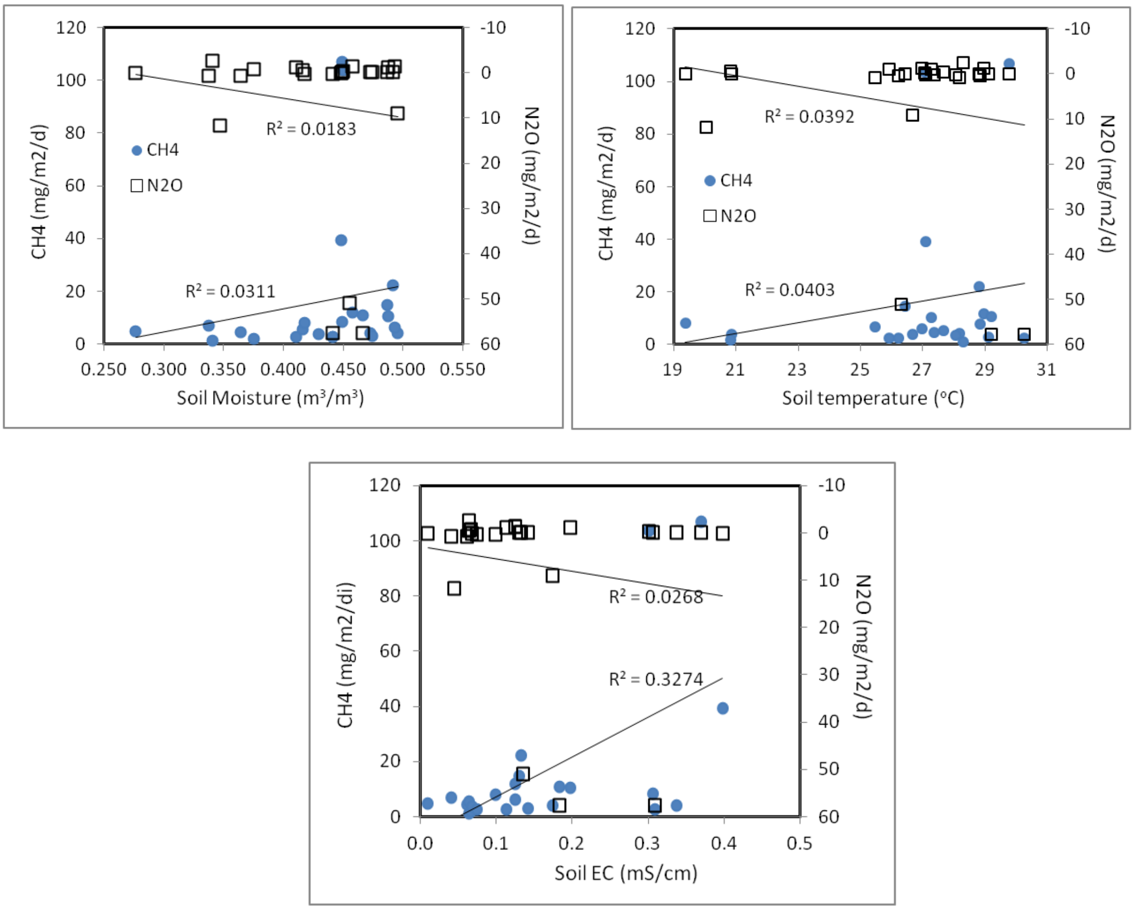

Figure 16. Relationship between greenhouse gas emission and soil parameters

Figure 16 showed linear correlation CH_4 and N_2O emission with soil parameters consisted of soil moisture, soil temperature and soil EC. From the figure it showed that greenhouse gas emission has non-linear correlation since R^2 was very low (< 0.33). CH_4 emission reached the peak when soil moisture in between 0,45-0,50 m^3/m^3. It was indicated that higher soil moisture will affect on the increasing CH_4 emission. Therefore, paddy fields with flooded condition will increase soil moisture, so CH_4 emission will increase as well. For soil temperature, CH_4 emission reached the peak when soil temperature in between 25-30 ^oC. Soil temperature became important factor affected on microorganism activities. Metanogenic microorganism that release CH_4 emission has optimum activities when soil moisture on 30^oC (Vogels et al. 1988). Meanwhile for soil EC, CH4 emission reach peak when soil EC in between 0,3-0,4 mS/cm.

N_2O emission also is affected by soil moisture, soil EC and soil temperature. However, the slope of correlation was little bit lower than CH_4 emission (R^2<0.05). It was indicated that it was not clear the correlation between N_2O emission and soil parameter and N2O was less responsive than that CH_4 emission.

For the validation model, the ANN model can learn well the correlation between CH_4 and N2O emissions with soil parameters as indicated with high R2 values 0.93 and 0.70. The regression coefficient nearly 1 ($R^2 \approx 1$) indicated that good agreement between the model with the observed data, thus the proposed method was reliable (Kim et al., 2009). However, it was difficult to gain higher R^2 for N_2O because it was less responsive that than CH_4 emission. It was probably caused by over estimation when N_2O emission was consider as to be output model since insignificant differences of N_2O emission was observed by previous study (Setiawan, et al. 2013).

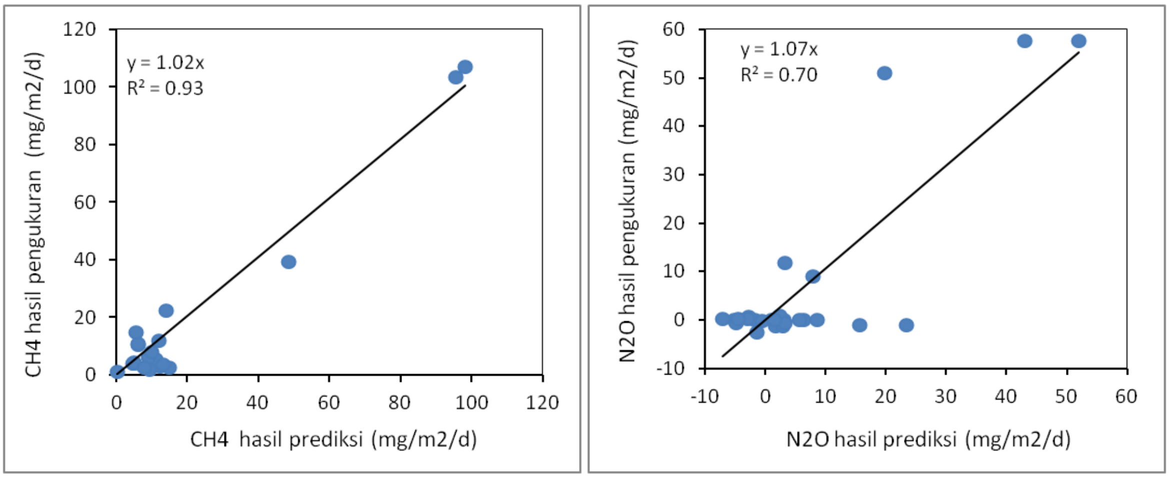

Figure 17. Validation ANN model for prediction CH_4 and N_2O emissions

Validation model also was supported by comparing results between observed greenhouse gas emission and estimated one (**Figure 18**). From the figure showed that although over and underestimation occurred, however, the trend between observed and estimated model was fit. It was indicated that the model can predict greenhouse gas emission accurately based on soil parameter, i.e., soil moisture, soil temperature and soil EC.

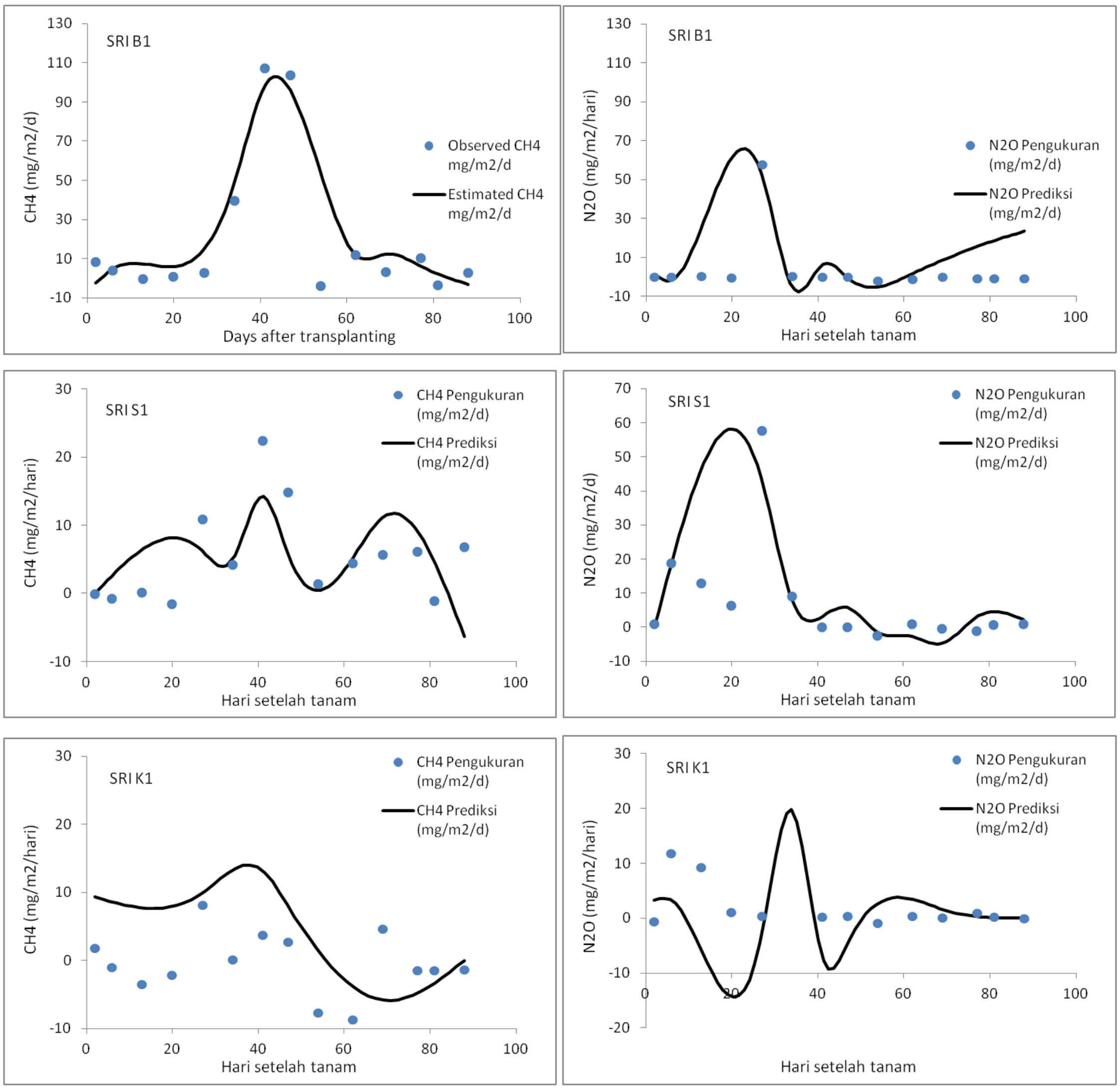

Figure 18. Comparing between observed greenhouse gas emissions and estimated ones.

D. Water Productivity and Crop Coefficient

Study on water productivity and crop coefficient was focused on third field in Wonogiri with rice terrace. Here, we prepared two different water irrigation regimes with three replication, i.e., SRI regime (SRI) and Continuous Flooding (FL) for conventional rice cultivation practice. During initial and crop development (vegetative) stage, water level was kept at 1-2 cm above soil surface for FL regime and it was kept at very shallow water level near soil surface for SRI regime. Then, during reproductive (mid-season) stage, water level was kept at approximately 1 cm above soil surface for FL regime, while aerobic soil condition was developed for SRI regime. Irrigation was done through the upper terrace and overflowed to the next terrace. All plots were planted with a rice variety (Oryza sativa L.), IR64, one of the mega rice varieties suitable for cultivation in Indonesia.

Crop coefficient is affected by the local climate as well as the change of water storage at the field (Doorenbos dan Kassam, 1979). Water storage in the field is commonly represented water level. Higher water level above soil surface indicates flooded condition and soil moisture is in saturated level. On the other hand, lower water level (probably below soil surface) shows less water storage and drier condition. Thus, it is important to consider the actual water level in studying crop coefficient between each regime. Figure **19** shows the daily average water level between SRI and FL regimes during planting period.

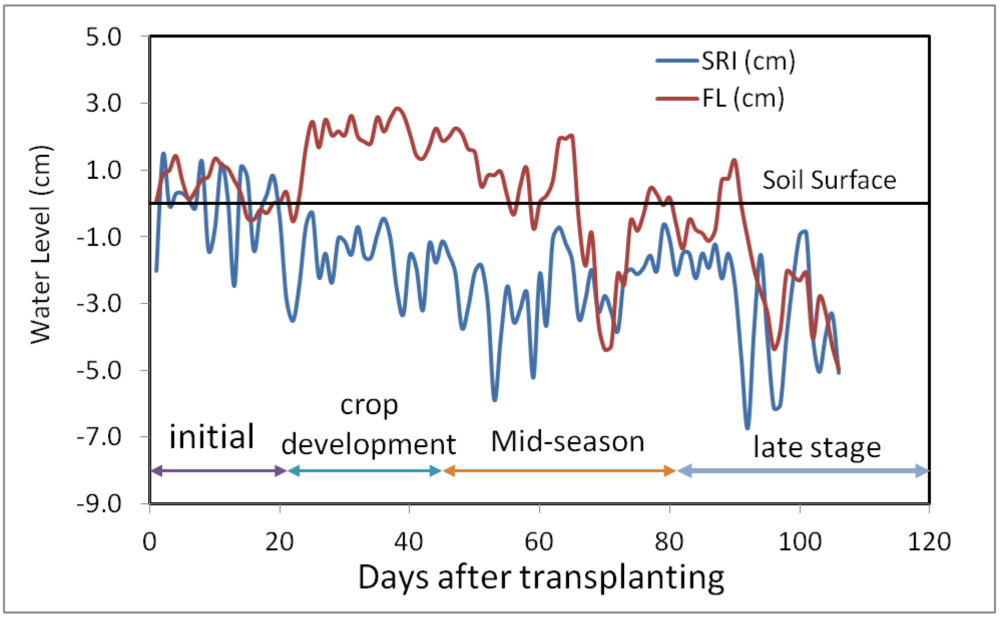

Figure 19. The daily average water level between SRI and FL regimes during planting period.

The daily average water levels for both regimes were little bit different with the expected water level. In the crop development stage, it was expected the water level at very shallow water level near soil surface for SRI regime, however, the daily average water level was at 1-3 cm below soil surface indicated that the field was drier than expected one. The same situation also occurred in the flooded regime in which water level was expected at 1 cm above soil surface in the mid-season stage, but it was dropped at 4.5 cm below soil surface. The occurrence was indicated that it was not easy to control water level in the terrace rice field manually without automatic water control system.

The daily crop coefficient (Kc) fluctuated widely throughout most of the planting period as presented in Figure **20** and Figure **21**. The Kalman filter method smoothed the data and provided continuous lines during the planting period for both regimes.

In the FL regime, when water level was at 1-3 cm above soil surface in the initial and crop development stages, Kc value was at the interval of 0.9 – 1.05. Then, it was rapidly increased in mid-season stage with maximum value of 1.18. Finally, it was declined rapidly in the late season stage with minimum value of 0.93. Its value declined when the plant focused on grain development in which the field became drier starting in the end of mid-season stage as shown in Figure **19**.

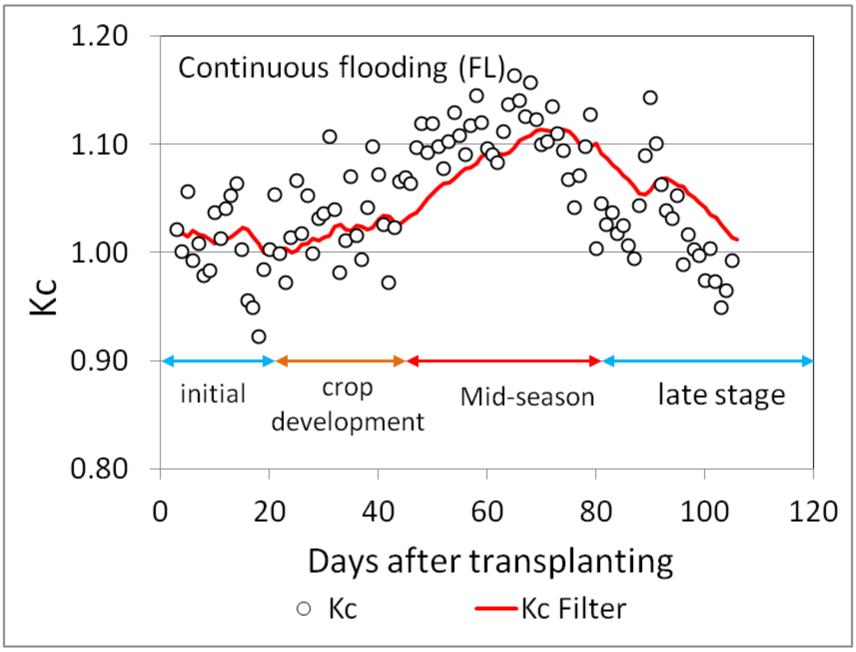

Figure 20. Daily crop coefficient curve of FL regime

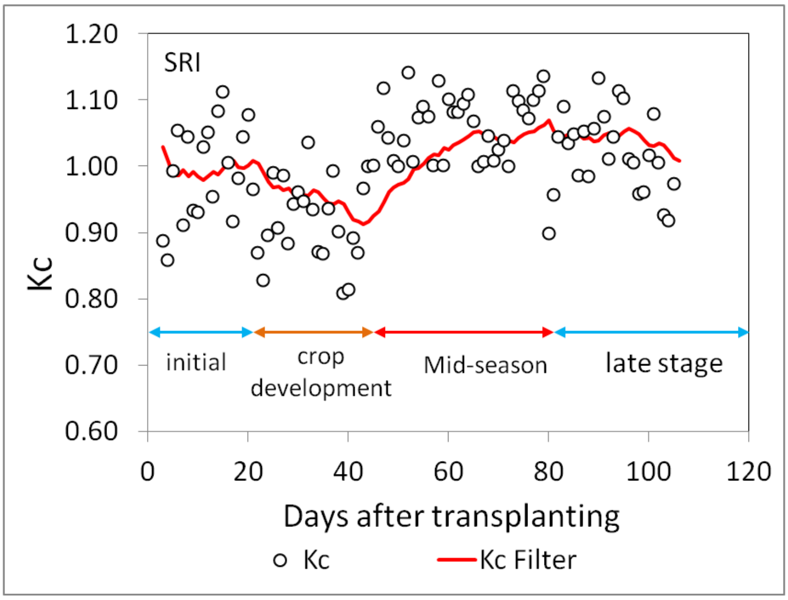

Figure 21. Daily crop coefficient curve of SRI regime

Meanwhile, in the SRI regime, Kc value was slightly decreased in the initial and second stages as responses of the decreasing of water level during this period with minimum Kc value was 0.8. The water level was dropped from 1 cm above soil surface to be 5 cm below soil surface in the end of crop development stage (Figure **21**). Then, it was gradually increased in the mid-season stage when the plant initiated generative phase in development of tillers and panicles. Finally, it was declined gradually with minimum Kc value was 0.90 in the late stage. Commonly, in the late stage when water was drained and the plant exhibited full senescence, Kc value declined as responses of water availability in the fields (Arif et al., 2012a).

Table 3. Crop coefficient and water productivity in each irrigation regime

Parameter	**Irrigation regimes**		**FAO's Kc Value**
	FL	**SRI**	
Average crop Coefficient in each growth stage:			
Initial Stage	1.01	1.00	1.10 - 1.15
Development Stage	1.02	0.96	1.10 - 1.15
Mid-season Stage	1.09	1.02	1.10 - 1.30
Late Stage	1.05	1.04	0.95 - 1.05
Water input:			
Precipitation (mm)	0	0	
Irrigation water (mm)	536	518	
Crop evapotranspiration (mm)	517	496	
Grain Yield (ton/ha)	7.63	8.05	
Water Productivity (g grain/kg water)	1.42	1.55	

Table **3** record the comparison of the average Kc values for both regimes compared and the typical ranges reported by the FAO for rice cultivation under the standard conditions (Doorenbos and Kassam, 1979). In the initial stage, both average Kc values for the SRI and FL regimes were lower than the FAO value since the actual field conditions were drier than the FAO standard conditions. The minimum Kc value of SRI regime indicated minimum levels of both evaporation and transpiration rate.

The same could occur in the crop development stage when average Kc value for the SRI regime was also lower than that for the FL regime. Water stress (drying period) has affected on lower Kc value over several days (Figure **19**). In this growth stage, Kc value varies depending on crop type and frequency of soil wetting (Allen et al., 1998). Therefore, drier field also should have corresponded to the decreased Kc value in this stage. Commonly, in the initial and crop development stages water used is directly proportional to transpiration, as a result when the field became drier, the most effective response of the plant is to reduce the transpiration (Heinemann et al., 2011).

In the mid-season and late stages, SRI regime has also lower Kc values than that FL regime when the water availability in the field less than FL regime represented by lower water level (Figure **19**). Particularly in the late stage, Kc values for both regimes were comparable and their values were within FAO's Kc value. With lower Kc values in most growth stages, therefore, total crop evapotranspiration of SRI regime was lower than that FL regime.

Interestingly, although has lower Kc values during planting period, however, SRI regime produced more grain yield than that FL regime (Table **3**). It was indicated that SRI regime more effective in the development of number of tillers and panicles. The key of SRI regime was aerobic condition particularly in mid-season stage in which this condition was effective to avoid spikelet sterility particularly around the flowering time. In addition, SRI regime provided provides optimal water and oxygen availability with alternate wetting and drying irrigation system.

SRI regime with drier condition than that FL regime need less irrigation water (Table **3**). Accordingly, with more grain yield and less irrigation water, SRI regime has higher water productivity than that FL regime. We recorded water productivity for SRI and FL regimes were 1.55 and 1.42, respectively. It was indicated that SRI regime more efficient in water use than that FL regime. Thus, SRI regime has more benefit or value derived from use of water.

E. Nitrogen Uptake

Study on water productivity and crop coefficient was focused on the second field in Purwokerto. Here, plot experiments were conducted to observe nitrogen uptake in SRI field and Common field. Soil nitrogen dynamic during crop growth were also observed. Three SRI plots (S1, S2, S3) and three common plots (K1, K2, K3) were given the same amount of organic fertilizer and three different biochar amount. In SRI field, S1 were plot with 5 ton/ha biochar application, S2 were plot with 10 ton/ha biochar application, and S3 were plot with 20 ton/ha biochar application. Similarly, in common paddy field, K1, K2, and K3 were plots with 5 ton/ha, 10 ton/ha, and 20 ton/ha biochar application. Mineral fertilizer were not used in this research. Soil nutrient were analyzed from soil samples taken in the field during crop growth. Total nitrogen (Total-N) and available nitrogen (available-N) were determined in the laboratory. Plant parameters observed were nitrogen content in biomass, crop yield, and grain weight.

Figure 22 shows nitrogen uptake per gram of dry mass for three treatments of both SRI field and Common field. Visually, it appears that plant biomass in Common field has more nitrogen content than SRI field. Nitrogen content in straw seems to be a "difference maker", that influence total nitrogen uptake for both field type. Average of total N-uptake from Common field (323 mg/g_dry mass) is larger than SRI field (262 mg/g_dry mass). Straw, root and leaves are biomass formed in vegetative stage, thus it shows that in Common field, vegetative growth is higher than SRI field.

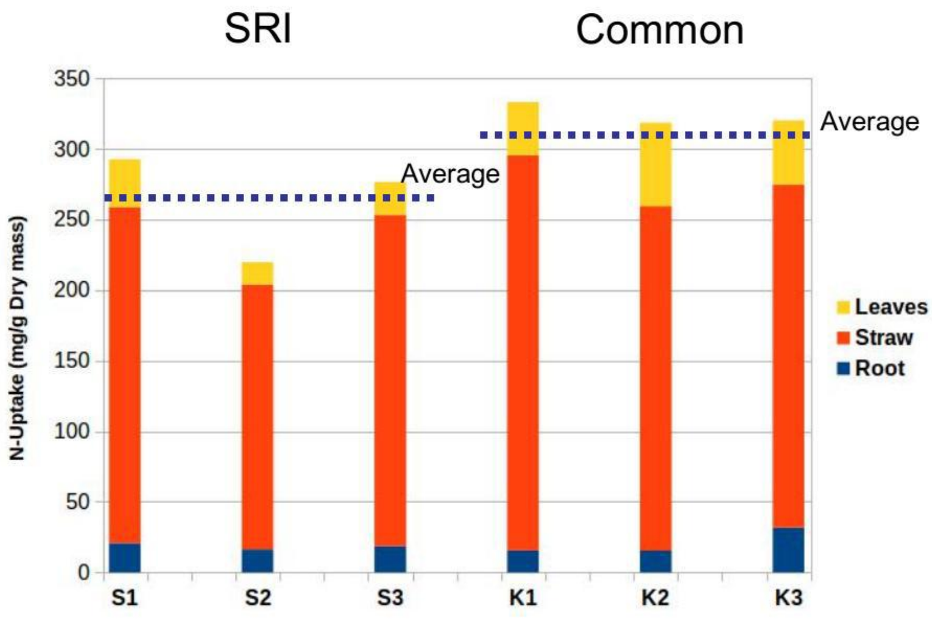

Figure 22. Nitrogen uptake in SRI field and Common field.

Weight of 1000 paddy grain shows that grain from SRI field is more weight (average of 20.7 g) than Common field (average of 19.0 g), as in Figure 23 . Total-N and available-N measured from soil samples were observed on each of growth stage. Total-N is the amount of nitrogen that need to decompose to make it available for plant. It range from 0.26 to 0.42 %. Available-N is amount of nitrogen that is ready for plant uptake. It range from 73.46 to 135.2 ppm in this research. Comparison of nitrogen dynamics of common field and SRI field is given in . The dynamics of nitrogen in soil is a result of decomposition of organic-N, plant nitrogen uptake and nitrogen loss through volatilization and leaching (Ardiansyah, et.al. 2012). Either in Figure 24a.(total-N) or Figure 24b.(available-N), amount of nitrogen in common field were slightly higher than SRI field. Total-N is increasing in S3 field after fertilizer application, however it decreases below common field in the next stage.

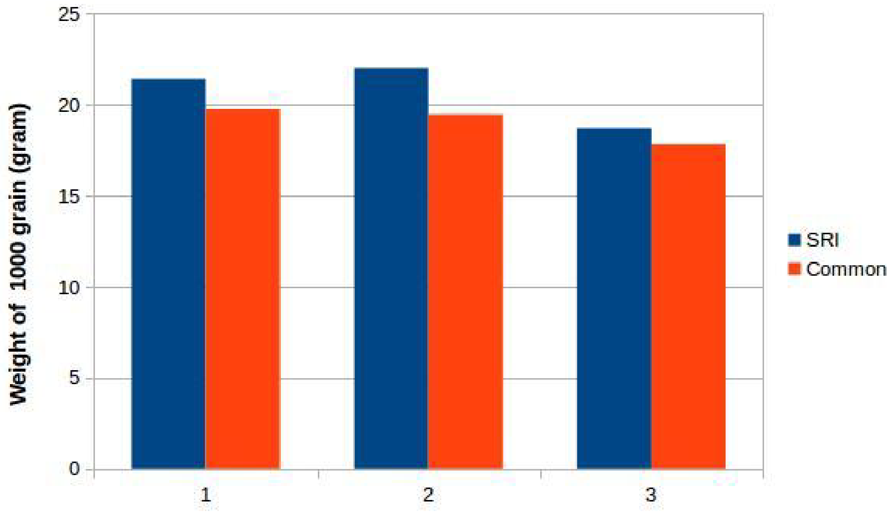

Figure 23. Comparison of 1000-grains-weight for SRI and Common field

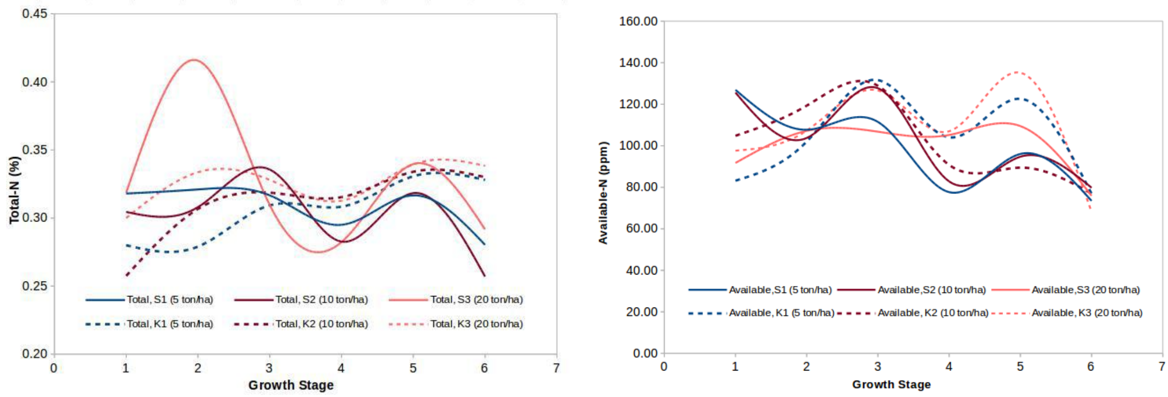

Figure 24. (a) Soil Total Nitrogen (Total-N) and (b) Available Nitrogen (Available-N) on: 1.Before fertilizer application; 2.After fertilizer application; 3.Day 14; 4.Day 57; 5.Day 85; 6.Day 96(Before harvesting)

Crop yield in this experiment shows almost no difference for both SRI field (3.6 ton/ha) and Common field (3.7 ton/ha), but still, Common field shows higher result. Visual observation in root shows that SRI paddy develops good rooting system than common paddy. It implies that SRI paddy was supposed to have more space for higher nutrient uptake. However, the opposite were happened. The yield itself were unlike many other research that showed dramatic increase in biomass and crop yield for SRI field. Comparison for some items observed in both SRI and Common field showed in Table **4**. The only item that SRI field is higher than Common field is Weight of 1000 grains.

Table 4. Comparison of items, observed for SRI field and Common Field

Items Observed	SRI field	Common field
Nitrogen content per gram of dry mass		v
Weight of 1000 grains	v	
Soil Available-N		v
Vegetative stage of Evapo-Transpiration		v
Crop Yield		v

Observing Available-N and ET in above data, it can be concluded that both parameters interact simultaneously to create uptake process for paddy. Available-N act as stock factor which determine how much maximum nitrogen can be absorbed by plant root, while ET act as pulling factor which the uptake energy is provided from. Simple if-then conclusion could be made such as ; if available-N is enough, and ET is high, than Nitrogen uptake is also high. Conversely, lower available-N and lower ET resulting low nitrogen uptake. Hence, filling the gap between low-high ET and low-high Available-N, the possibilities of nitrogen uptake are presented in Table **5**.

Table 5. Possibility of Nitrogen Uptake considering Available-N and Evapotranspiration

	Available-N Low	**Available-N medium**	**Available-N high**
Evapo-traspiration low	low	low	low
Evapo-traspiration medium	low	medium	medium
Evapo-traspiration potential	low	medium	high

Available-N is suspected to be the result of aerobic microbial activity. It provides more available-N to soil by decomposing organic-N. The only factor that suspiciously limiting available-N in soil is decomposition rate or mineralization, as the amount of total-N is abundant in soil.

Generally, N mineralization decreases in lower soil moisture especially in dry-air soil (Abera, et;.al, 2012). It restrains microbial activities for decomposing organic matter. However, alternate wetting-drying irrigation in SRI field don't create dry-air soil. Soil were drying to certain level of moisture content that still tolerable for plant to grow well. The possibility is now lies on biochar application. Biochar application to soil were reported to reduce N_2O emissions. In addition to biochar application, soil aeration may also contribute to the suppression of N_2O release (Abera et al., 2012). In the nitrogen cycle, N_2O emission comes from mineralized Organic-N that finally released into air. Reducing N_2O emissions means decreasing in nitrogen mineralization.

Soil in SRI field develop cracks when drying, which means it shrinking. The shrinking causes void ratio reduces and makes the air difficult to enter (low aeration) (Ardiansyah, et.al, 2008). Different from soil without shrinking-swelling properties, reducing moisture content still maintain it void ratio and spare some pore spaces for aeration. Thus, the soil condition in SRI field is soil with biochar application and low aeration. There is challenging question to understand aerob-anaerob or shrinking-swelling condition in SRI field related to available-N.

Evapo-Transpiration is always in potential value during vegetative stage, because soil is sufficiently wet for paddy to grow. However, there is a difference in ponding and non-ponding evaporation for Common and SRI field. There is also possibility of difference in fraction of Evaporation and Transpiration for both SRI and Common field that make most SRI practice resulting higher biomass and yield. Although evapo-transpiration in Common field higher during vegetative stage, this research shows only slight difference in crop yield.

VI. OUTPUT AND OUTCOMES

A. Outputs

1. Three papers were presented on PAWEES-INWEPF Joint International Conference 2015, 19-21 August, 2015 at Kuala Lumpur, Malaysia.
2. Those papers were reviewed and selected to be published in Special Issue of Jurnal Teknologi (Science and Engineering - ISSN: 21803722, 01279696 (SCOPUS INDEX)) "Solution for Sustainable Water and Environmental Management". The link: http://www.jurnalteknologi.utm.my/index.php/jurnalteknologi/issue/view/213
   The titles are:
   a. Crop Coefficient And Water Productivity In Conventional And System Of Rice Intensification (Sri) Irrigation Regimes Of Terrace Rice Fields In Indonesia
   b. Nitrogen Uptake Of Sri Paddy Field Compare To Common Field
   c. Optimizing Irrigation And Drainage Rates In Sri Paddy Fields
3. Greenhouse gas emission model

B. Outcomes

Eleven students were involved this research for their thesis. They are:

1. IPB:
   Master student: - Nurfaijah (NIM: F451130051), title: "Otomatisasi Irigasi pada Berbagai Rejim Air Padi Sawah Budidaya SRI
   Undergraduate:
   - Ulya Rufako (NIM: F44110028)
   - Dyan Manggandari (NIM: F44110040)
   - Briza Sibarani (NIM: F44110050)
   - Aulia Azizah (NIM: F44110086)
   - Rilsan Malkhi Pandapotan (NIM: F44110077)
   - Chau Abdoul Cariem (NIM: F44118001)

2. Universitas Jenderal Soedirman:
   Undergraduate:
   - Azam Ibnu Pamungkas (NIM: A1H011037)
   - Annastasia Leony (NIM: A1H011039)
   - Barkah Ifandi Putra (NIM: A1H011079)
   - Nur Fajri Fatoni Rahmat (NIM: A1H011014)

VII. FUTURE PLANNING

As previously mention in methodology, in the second year we will focus on 1) development of crop model based on field monitored data and 2) optimize SRI water management to increase land and water productivities and reduce greenhouse gas emission. The schedule of future planning is shown in **Table 6**.

1. Develop crop model based on field monitored data

   The model will be developed based on field experiment that was performed in this year and will perform next year. For this purpose, we will do experiment in the lab scale to investigate effect of different environmental biophysics on yield, water productivity and greenhouse gas emission. The models consist of hydrological and allometric model. The model will be developed using Artificial Neural Network model and others model. The purpose of the model is to identify relationship between environmental biophysics condition and plant response

2. Optimize SRI water management

   Optimization will be carried out according to the objective function to enhance yield and water productivity and reduce greenhouse gas emissions. The next model is more complex than optimal water management developed previously. Optimal SRI water management represented by optimal ground water level in each growth stage will be searched by Genetic Algorithms model in maximizing the objective function.

Table 6. Schedule for future planning

No	Activities	Year 2											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Cultivate SRI paddy rice : - Bogor - Purwokerto - Wonogiri												
2	Improve SRI information website												
3	Greenhouse gas measurements												
4	Validate greenhouse gas model												
5	Develop SRI paddy rice model												
6	Optimize SRI water management												
7	Attending International Conference												
8	Preparation of articles												
9	Submitting the paper to International Journal												
10	Progress report												
11	Annual Report												

VIII. CONCLUSION AND RECOMMENDATION

A. Conclusion

1. The developed advance field monitoring system was effective, efficient and reliable in monitoring SRI paddy field in three locations in Indonesia during one cropping season. The actual field conditions were monitored well in term of image, numeric and graphic data acquisition. Although this monitoring did not send real-time data, the data were stored in the field data loggers. By adopting quasi-real time monitoring, it was more power saving and Internet cost effective than the real time monitoring. The data were then used for further analyses to optimize SRI water management in Indonesia.
2. For security and accessibility, field monitored database management system was developed using integrated website. For accessing the database, only authorized user can access the data. The data are presented in the graphic that showed daily data consisted of precipitation, air temperature, relative humidity, wind speed, solar radiation, soil moisture, soil temperature and soil EC. From the data we can easily interpret the data and their trend.
3. Based on field monitored data and manual measurements, greenhouse gas model, water productivity, crop coefficient and nitrogen uptake were developed and investigated in different fields. Artificial Neural Network (ANN) model can be used to estimate CH_4 and N_2O emissions from paddy fields using soil moisture, soil temperature and soil EC with R^2 of 0.93 and 0.70. It was indicated that the model can used to predict CH_4 and N_2O emissions from paddy field
4. Crop coefficient (Kc) of SRI and continuous flooding (FL) regimes in terrace paddy fields were well determined by water balance analysis with Excel Solver estimation. SRI regime has lower Kc values than that FL regime in all growth stages. Average Kc values for SRI regime were 1.00, 0.96, 1.02 and 1.04 for the initial, crop development, reproductive and late growth stages, respectively. Meanwhile, average Kc values for FL regime were 1.01, 1.02, 1.09 and 1.05 in the initial, crop development, reproductive and late growth stages, respectively. Although has lower Kc values, however, SRI regime produced more grain yield than that FL regime. The main reason was probably due to aerobic condition under SRI regime which provided optimal water and oxygen availability. Accordingly, with less irrigation water, SRI regime has higher water productivity than that FL regime. We recorded water productivity for SRI and FL regimes were 1.55 and 1.42, respectively.

5. Nitrogen uptake is a product of soil nitrogen availability and evapo-transpiration. High nitrogen uptake is usually a result of high evapo-transpiration that brings soil nutrition to leaves. However the available-N in soil act as limiting factors for nitrogen uptake. Slight difference in available-N for SRI and Common field and its respective crop yields confirms the hypothesis. It is still unknown the effect of shifting from anaerob-aerob or shrinking-swelling combine with biochar application to nitrogen availability.

B. Recommendation

1. For maintaining advance field monitoring, we should involve local people in order to disseminate the current technology and transfer knowledge as well
2. Greenhouse gas emission model should be validated under different location and climate. So, more SRI paddy cultivations are needed for future planning in order to achieve this purpose
3. Soil texture and chemical in specific location should be sampled and analyzed to identify their relationship with greenhouse gas emissions.

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APPENDIX

Appendix 1. Instrumentation that are being used in this research

No	Laboratories	Locations	Equipments	Function
1	Water resources engineering	Dept of Civil and Environmental Engineering -IPB	Oven	Measuring soil water content
			T4 Soil tensiometers	Measuring soil matrix potential
			DL6-te data loggers	Stored measured data
			Computer server	Stored monitored data
			Li-Cor 8100	Measuring CO2 emission
			Weather and Soil sensors	Monitoring weather and soil parameters
			Soil physical properties	Measuring soil bulk density, water content, permeability
2	Environmental Engineering	Dept of Civil and Environmental Engineering -IPB	7890A GC system Agient Technologies	Analyzing greenhouse gas emissions: methane and nitrous oxide
			Memmert Oven	Measuring soil water content of soil sampling
3	Agricultural Mechanization	Dept of Agricultural Engineering – Jenderal Soedirman University	Weather station: Davis vantage vue	Monitoring weather conditions
			pH meter	Measuring soil pH
			Pyranometer	Measuring solar radiation
4	Soil Physics and Chemistry	Soil Research Office, Deptan, Bogor	Soil properties measuring apparatus	Measuring soil physical and chemical properties: bulk

No	Laboratories	Locations	Equipments	Function
				density, permeability, water retention, water content, fertility, etc.
5	International Agro-Informatics	Department of Global Agricultural Sciences, The University of Tokyo	Web server	Database management
			Field monitoring instruments	Monitored field data
			Decagon soil moisture and environmental monitoring	Monitoring soil parameters

Appendix 2. Curriculum vitae of research team

Chief of Researcher: Dr. Chusnul Arif, STP.MSi

A. Personal Identity

1	Full name (with title)	Dr. Chusnul Arif, STP.MSi
2	Gender	M/F
3	Functional position	Lecturer (Lektor)
4	NIP/NIK/Others ID	198012062005011004
5	NIDN	0006128003
6	Born	Bojonegoro, 6 December 1980
7	Email	chusnul_ar@yahoo.com
8	Telephone number/HP	0251-8374645/62-8777-0397-307
9	Office address	Kampus Fateta IPB, Darmaga 16680, Bogor, West Java Indonesia
10	Telephone number/Fax	0251-8627225
12	Number of graduated student	S-1 = - students; S-2 = - students; S-3 = - students
13	Courses	1. Environment Control Engineering (Undergraduate)
		2. Environment Biophysics Engineering (Undergraduate)
		3. Soil and Soil Water Pollution (Undergraduate)
		4. Engineering Construction Drawing (Undergraduate)
		5. Mathematical Modeling in Civil and Environmental Engineering (Master)
		6. Research Methodology (Master)
		7. Structure and Environment (Master)

B. Educational Background

	S – 1 (undergraduate)	S-2 (Master)	S-3 (Doctoral)
Name of University	Bogor Agricultural University	Bogor Agricultural University	The University of Tokyo
Major	Agricultural	Agricultural	Global Agricultural

	Engineering	Engineering	Sciences
Entrance – graduates year	1999 - 2003	2004 - 2008	2010 -2013
Title of thesis	Scheduling the Supply of Nutrient Solution in a Hydroponics System for Cucumber (Cucumis sativus L) Plant Using Artificial Neural Network and Genetic Algorithms	Optimization of EC Values of Nutrient Solution on Hydroponics System For Tomato Fruits	Optimizing Water Management in System of Rice Intensification Paddy Fields by Field Monitoring Technology
Name of advisors	- Prof. Dr. Ir. Herry Suhardiyanto, MSc - Dr. Ir. Suroso, MSc	- Prof. Dr. Ir. Herry Suhardiyanto, MSc -Prof. Dr. Ir. Budi Indra Setiawan, M.Agr	Prof. Dr. Masaru MIZOGUCHI

C. Research Experiences (last 5 years)

No	Year	Research Title	Funding source	
			Source/Sponsors	Total(IDR)
1	2013 - 2014	Designing Local Frameworks for Integrated Water Resources Management	RIHN- Japan	386,816,000,-
2	2014	Water Productivity and Emission Factor of Paddy Fields under Different Cultivation Systems	RIHN- Japan	190,473,000,-
3	2009-2010	Thermal environmental modification of Nutrient Solution for Tomato Plant in Hydroponics Cultivation System	DIKTI	50,000,000,-
4	2009	Developing Water Zoning System in Industrial Plant Forestry	DIKTI	94.000.000,-

D. Extensions experiences (last 5 years)

No	Year	Extensions title	Funding source	
			Source/Sponsors	Total(IDR)
1	2014	Program Pengembangan Desa Binaan	PT.PGN (Persero)	
2				
3				

E. Publication in the Journal (last 5 years)

No	**Title of paper**	**Journal name**	**Volume/No/ Year**
1	Effects of Groundwater level on CH4 and N2O Emissions under SRI Paddy Management in Indonesia	Journal of Taiwan Water Conservancy	Vol.61, No. 4. 2013
2	Enhanced Water Use Efficiency by Intermittent Irrigation for Irrigated Rice in Indonesia	Journal of Islamic Perspective on Science Technology and Society	Vol.1, No.1. 2013
3	Quantitative Use of Luminosity-normalized Grayscale Image of Greenness, Redness and Yellowness of Rice Canopy Derived from Multi-temporally Acquired Digital Photographs	International Journal of Agriculture and Biology	Vol.15, No.4. 2013
4	Estimating Crop Coefficient in an Intermittent Irrigation Paddy Field using Excel Solver	Rice Science	Vol. 19, No.2. 2012
5	Estimation of water balance components in paddy fields under non-flooded irrigation regimes	Journal of Agronomy	Vol.11, No.2.2012
6	Estimation of soil moisture in paddy field using Artificial Neural Networks	International Journal of Advanced Research in Artificial Intelligence (IJARAI)	Vol. 1, No.1.2012
7	Speaking Plant Approach for Automatic Fertigation System in Greenhouse	International Journal of Signal Processing,	Vol. 4, No.3. 2011

No	Title of paper	Journal name	Volume/No/ Year
		Image Processing and Pattern Recognition	
8	Aplikasi Jaringan Syaraf Tiruan (JST) untuk Pendugaan Suhu Larutan Nutrisi yang Disirkulasikan dan Didinginkan Siang-Malam pada Tanaman Tomat Hidroponik	Jurnal Keteknikan Pertanian	Vol.24, No.3.2010
9	Simulasi Komputer Penerapan Teknik Kendali Fuzzy Sederhana untuk Pengaturan Muka Air Tanah di Lahan Padi SRI	Jurnal Irigasi	Vol.4, No.2.2009
10	Optimization of EC Values of Nutrient Solution for Tomato Fruits Quality in Hydroponics System Using Artificial Neural Network and Genetic Algorithms	ITB Journal Science	Vol.41A, No.1.2009

F. Conference (oral presentation) for last 5 years

No	Name of seminar/conference	Title of paper	Time and Location
1	GRENE-ei CAAM THIRD INTERNATIONAL WORKSHOP	Land and Water Productivities of Paddy Fields with Different Water Management Regimes under System of Rice Intensification (SRI) in Indonesia	BALI, 17-19 March 2014
2	APAN 37th Meeting: Effects of climate change on the major crops in Asia	Performance of Quasi-Real-Time Paddy Field Monitoring Systems in Indonesia	Bandung, 20-24 January 2014
3	the 12th Conference of International Society of Paddy and Water Environment	Determining Optimal Soil Moisture for Irrigated Rice in Indonesia with System of Rice Intensification	Cheongju, South Korea, 30 October - 1

No	Name of seminar/conference	Title of paper	Time and Location
	Engineering (PAWEES)		November 2013
4	International Conference on Sustainable Rural Development 2013	Enhanced Water Use Efficiency for Irrigated Rice in Indonesia with System of Rice Intensification (SRI)	Purwokerto, 25-26 August 2013
5	GRENE 2nd International workshop,	Optimizing Water Management of System of Rice Intensification for Climate Change Adaptation Strategy Based on Field Monitored Data	Baguio, Philippine, 4-6 March 2013
6	PAWEES 2012 International Conference	Optimizing Non-flooded Irrigation Regime under System of Rice Intensification Crop Management using Genetic Algorithms	Bangkok, Thailand, 27-28 October 2012
7	Agro-Informatics Conference 2012	Field monitoring system for decision support of SRI practice as a climate change adaptation strategy in Indonesia.	Tokyo, 15-16 May 2012
8	Soil Moisture Workshop 2011	Water Management Evaluation of Alternate Wetting and Drying Irrigation in Paddy Fields by Considering Monitored Soil Moisture	Tokyo, December 2011
9	PAWEES 2011 International Conference on “Capacity Building for Participatory Irrigation and Environmental Management	Estimation of Water Balance Variables in the SRI Paddy Field by Considering Soil Moisture	Taipei, Taiwan 27-28 October 2011
10	CIGR 2011 conference on	Field Network System to Monitor	Tokyo, 19-23

No	**Name of seminar/conference**	**Title of paper**	**Time and Location**
	Sustainable Bioproduction,	Paddy Fields in the System of Rice Intensification in Indonesia	September 2011
11	National Seminar of Perteta	Appication of Genetic Algorithms for Optimization of Nutrient Solution for on Hydroponics System for Tomato Plant	Mataram, 8-9 August 2009
12	National Seminar of Perteta	Heat Transfer Modeling on Day-Night Cooling of Nutrient Solution on Hydroponics NFT for Tomato Plant	Mataram, 8-9 August 2009
13	National Seminar of HIPI	Monitoring System for Plant Growth and Micro Environmental under Greenhouse using Field Server	Bogor, 6-7 August 2009

G. Book for last 5 years

No	Title of Book	Year	Number of pages	Publisher

H. Intellectuals properties (Patent) during last 5-10 years

No	Title of Patent	Year	Categories	ID number

I. Experiences on public policy for last 5 years

No	Title	Year	Location	Public responses

J. Awards

No	Awards categories	Institution	Year

All of data filled in the curriculum vitae are true and accountability to the law. If in the future, there is a discrepancy with reality, I could accept sanctions.

The curriculum vitae is filled with the true data as a requirement to propose grant of International Research Collaboration and Scientific Publications

Bogor, 25 October 2015

(Dr. Chusnul Arif, STP, MSi)

Appendix 5. Continued…

Member-1: Prof. Dr. Ir. Budi Indra Setiawan, M.Agr

A. Personal Identity

1	Full name (with title)	Prof. Dr. Ir. Budi Indra Setiawan, M.Agr
2	Gender	L/~~P~~
3	Functional position	Guru Besar
4	NIP/NIK/Others ID	196006281985031102
5	NIDN	0028066007
6	Born	Tasikmalaya, 28 Juni 1960
7	Email	budindra@ipb.ac.id; budindra@yahoo.com
8	Telephone number/HP	0251-8425583/08129321108
9	Office address	Kampus Fateta IPB, Darmaga 16680, Bogor, West Java Indonesia
10	Telephone number/Fax	0251-8627225/8627225
12	Number of graduated student	S-1 = 58 students; S-2 = 31 students; S-3 = 17 students
13	Courses	1. Introduction of Civil and Environmental Engineering
		2. Water Resource Engineering
		3. Integrated Water Resource Management
		4. Advance Irrigation and Drainage Engineering
		5. Environmental Biophysics Engineering
		6. Research Methodology
		7. Colloqium on Wireless Automatic Irrigation to Enhance Water Management in SRI Paddy Field

B. Educational Background

	S – 1 (undergraduate)	S-2 (Master)	S-3 (Doctoral)
Name of University	Bogor Agricultural University	The University of Tokyo	The University of Tokyo
Major	Agricultural Mechanization	Biological and Environmental Engineering	Biological and Environmental Engineering
Entrance – graduates	1979-1983	1988-1990	1990-1993

year			

C. Research Experiences (last 5 years)

No	Year	Research Title	Funding source	
			Source/Sponsors	Total(IDR)
1	2013 - 2014	Designing Local Frameworks for Integrated Water Resources Management	RIHN- Japan	386,816,000,-
2	2014	Water Productivity and Emission Factor of Paddy Fields under Different Cultivation Systems	RIHN- Japan	190,473,000,-
3	2014	Pengembangan Solar Power Irrigation di Lahan Kering dengan Menggunakan Disc Irrigation System (Development of Dry Land Solar Power Irrigation using Disc Irrigation System) (KKP3N)	Balitbang, Kementan	
4	2013	Pengembangan Solar Power Irrigation di Lahan Kering dengan Menggunakan Disc Irrigation System (Development of Dry Land Solar Power Irrigation using Disc Irrigation System) (KKP3N)	Balitbang, Kementan	151.311.000
5	2012	Designing Local Framework for Integrated Water Resource Management. Collaboration with Research Institute fo Human dan Nature (RIHN), Kyoto, Japan. Japanese Government	RIHN- Japan	
6	2012-2014	Anaysis on Carbon Budget of Forest Plantation in Ogan Komering Ilir, South-Sumatra. Collaboration research between Bogor University and Sinarmas Forestry. Sinarmas Forestry	Sinarmas Forestry	
7	2012	Developing Environmental Monitoring System on the Advancement of the System of Rice Intensification in Asian Countries (EMSA-SRI).	DP2M-DIKTI Ministry of National Education	145.000.000
8	2011	Developing Environmental Monitoring System on the Advancement of the System of Rice Intensification in Asian Countries (EMSA-SRI).	DP2M-DIKTI Ministry of National Education	96.157.000
9	2010	Developing Environmental Monitoring System on the Advancement of the System of Rice Intensification in Asian Countries (EMSA-SRI).	DP2M-DIKTI Ministry of National Education	120.000.000
10	2009	Perancangan Sistem Zonasi Air di Hutan Tanaman Industri Lahan Basah di Kabupaten Ogan Komering Ilir,	DP2M-DIKTI Ministry of National	

		Sumatera Selatan (Water zoning system in Forest Plantation in Wetlands).	Education	
11	2008-2012	Stability of Rainforest Margins in Indonesia (STORMA). Group D5. Collaborative Research Centre 552. German Research Foundation.	German Research Foundation	
12	2007-2009	Permodelan Hidrologi untuk Analisa Potensi Sumber Daya Air DAS Singkil Propinsi Nanggroe Aceh Darussalam (Hydrological modeling to analize water resource potential). Program Insentif (Insentive Program). State Ministry for Research and Technology.	State Ministry for Research and Technology	

D. Extensions experiences (last 5 years)

No	Year	Extensions title	Funding source	
			Source/Sponsors	Total(IDR)
1	2013	Reviewer Policy Brief: program peningkatan peran dalam perumusan kebijakn pertanian (Policy Interfacing)	IPB	
2	2013	Aboveground Carbon Stock Assesment of the Scientific Studies for the Rehabilitation and Management of the Tripa Peat-Swamp Forest.	Unsyiah	
3	2012	Tenaga Ahli Penelaahan Data Statistik dan Kajian Ekonomi untuk Pemeriksaan Kinerja atas Upaya Pemerintah dalam rangka Pencapaian Swasembada Beras.	BPK RI	
4	2012	Bantuan Tenaga Ahli Bareskrim untuk Kasus Hukum Danau Gunung Putri	Fateta-IPB	
5	2012	Pendampingan Kunjungan Kerja Komisi IV DPR-RI dan Dirjen BUK Kementerian Kehutanan ke HTI	Dir. Bina Usaha tanaman pangan	

		Lahan Gambut si Sumatera Selatan, 18-20 Des 2012		
6	2012	Tim Penilai dalam rangka Pengukuran, Pelaporan dan Verifikasi (MRV) terhadap Kegiatan Pengelolaaan Ekohidro yang dilaksanakan oleh IUPHHK-HTI PT.RAPP pada Lahan Gambut di Pulau Padang Kabupaten Kepulauan Meranti, Provinsi Riau.	Kemenhut RI	
7	2012	Tim Verifikasi Kerentanan Lingkungan dan Gambut di Areal IUPHHK-HT PT.RAPP di Pulau Padang, Kab.Kepulauan Meranti, Provinsi Riau	Kemenhut RI	
8	2011	Tim Penilai dalam rangka pengukuran, pelaporan dan verifikasi (MRV) terhadap kegiatan pengelolaan ekohidro yang dilaksanakan oleh IUPHHK-HTI PT RAPP di lahan gambut HTI-Ring Semenanjung Kampar. Riau, 9 Agustus 2011	Kemenhut RI	
9	2009	Tim Penilai dalam rangka pengukuran, pelaporan dan verifikasi (MRV) terhadap kegiatan pengelolaan ekohidro yang dilaksanakan oleh IUPHHK-HTI PT RAPP di lahan gambut HTI-Ring Semenanjung Kampar, Riau	Kemenhut RI	
10	2009	Tim Pakar Independen Post Evaluation terhadap Rencana dan Implementasi Pengelolaan Ekohidro	Kemenhut RI	

		di Areal PT. RAPP di Lahan Gambut HTI-Ring Semenanjung Kampar Riau		

E. Publication in the Journal (last 5 years)

No	Title of paper	Journal name	Volume/No/ Year
1	Effects of Groundwater level on CH4 and N2O Emissions under SRI Paddy Management in Indonesia	Journal of Taiwan Water Conservancy	Vol.61, No. 4. 2013
2	Enhanced Water Use Efficiency by Intermittent Irrigation for Irrigated Rice in Indonesia	Journal of Islamic Perspective on Science Technology and Society	Vol.1, No.1. 2013
3	Quantitative Use of Luminosity-normalized Grayscale Image of Greenness, Redness and Yellowness of Rice Canopy Derived from Multi-temporally Acquired Digital Photographs	International Journal of Agriculture and Biology	Vol.15, No.4. 2013
4	Optimalisasi Diversifikasi Pangan guna mewujudkan Ketahanan Pangan Nasional yang Berkelanjutan	Majalah Komunikasi dan Informasi. Lembaga Ketahanan Nasional	Edisi 94, tahun 2012
5	Peningkatan Resapan Air Tanah dengan Saluran Resapan dan Rorak untuk meningkatkan Produktivitas Belimbing Manis (*Increasing Soil Water Storage with Storage Channel to Icrease Starfruits Productivity*)	Jurnal Irigasi	Vol.7, No.1. 2012
6	Pintu Sorong Tinjol berbahan Fiberglass sebagai Inovasi Alat Ukur Debit dalam Operasi Irigasi	Jurnal Sumber Daya Air.	Vol.8, No.1, Mei 2012
7	Estimating Crop Coefficient in an Intermittent Irrigation Paddy Field using Excel Solver	Rice Science	Vol. 19, No.2. 2012
8	Estimation of water balance components in paddy fields under non-flooded irrigation regimes	Journal of Agronomy	Vol.11, No.2.2012
9	Estimation of soil moisture in paddy field using Artificial Neural Networks	International Journal of Advanced Research in Artificial Intelligence (IJARAI)	Vol. 1, No.1.2012
10	Interpretasi Kandungan Air Tanah untuk Indeks Kekeringan: Implikasi untuk Pengelolaan Kebakaran Hutan. *Interpretation of soil water content into dryness index: inplication for forest fire management*	Jurnal Manajemen Hutan Tropika.	Vol.XVIII (1):31-38, April 2012.
11	Analisis Perubahan Iklim Likal dan Debit Sunagi di DAS Cidanau (*Analysis of Local Climate*	Jurnal Agromet Indonesia.	Vol XXV, No.1, Juni

No	Title of paper	Journal name	Volume/No/ Year
	Change and Discharge in Cidanau Watershed).		2011
12	Analisis Dimensi Bangunan Overflow untuk Pengelolaan Air Rawa Pasang Surut di Hutan Tanaman Industri, Sumatera Selatan (*Dimension Analysis of Overflow Structure for Tidal Lowland Water Management in Wood Forest Industry, South Sumatra*)	Jurnal Irigasi.	Vol 6,No 1. 2011
13	Pengembangan Sistem Irigasi Terkendali menggunakan Jaringan Nirkabel (*Development on Automated Irrigation Sstem using Wireless Network*)	Jurnal Irigasi.	Vol.6,No 1. 2011
14	Peluang untuk mengurangi Bahaya Kebakaran di HTI Lahan Basah: Model Pendekatan Pengelolaan Air.	Jurnal Hidrosfir Indonesia	Vol.5, No.2, Agustus 2010.
15	Pengembangan Pintu Air irigasi GFRP (Glass Fiber Reinforced Plastic) . *The Development of GlFRC Water Gates*).	Jurnal Irigasi	Vol.5, No.1, Juni 2010
16	Model Perencanaan irigasi berdasarkan Kesetimbangan Kadar Air (*Planning of Irrigation based on Water Content Balance*).	Jurnal Irigasi,	Vol.5, No.1, Juni 2010,
17	Productivity Analysis of Organic Rice Farming Intensification.	Jurnal Irigasi,	Vol.5, No.1, Juni 2010
18	Potential Water Supply to support Rice Field Practices: A Case Study of Cicatih-Cimandiri Watershed, West-Java.	Jurnal Irigasi,	Vol.5, No.1, Juni 2010
19	Economic Valuation for Cidanau Watershed Area, Indonesia.	Journal of Tropical Forest Management.	Vol.XVI, No.1, April 2010
20	Characterizing Spatial Variability of Saturated Hydraulic Conductivity in a Paddy Field Based on Dielectric Dry Bulk Density Data in Accordance to Subsurface Percolation.	Journal of Paddy and Water environment,	Vol 8, No 2, June 2010.
21	Numerical modeling of soil moisture profiles under pitcher irrigation application.	CIGR Journal,	Vol 12, No 2. 2010
22	Climate change effect on paddy field thermal environment and evapotranspiration.	Paddy and Water Environment,	Vol.7 Number 4. 2009
23	Mathematical Modeling On Water Level And Soil Water Concentration Estimation In Non-Water Ponding Paddy Field.	Jurnal Irigasi,	Vol 4,No 1. 2009
24	Simulasi Komputer Penerapan Teknik Kendali Fuzzy Sederhana untuk Pengaturan Muka Air Tanah di Lahan Padi SRI	Jurnal Irigasi	Vol.4, No.2.2009
25	Optimization of EC Values of Nutrient Solution for Tomato Fruits Quality in Hydroponics System Using Artificial Neural Network and	ITB Journal Science	Vol.41A, No.1.2009

No	Title of paper	Journal name	Volume/No/ Year
	Genetic Algorithms		

F. Conference (oral presentation) for last 5 years

No	Name of seminar/conference	Title of paper	Time and Location
1	Konteks 7: Peran Rekayasa Sipil dan Lingkungan dalam Mewujudkan Pembangunan yang Berkelanjutan.	Sistem Zonasi Air Terpadu Untuk Mendukung Hti Lestari Di Lahan Gambut (*Integrated Water Zoning System for Sustainable Forest Industrial Plantation in Peatland*)	Solo, 24-26 Oktober 2013.
2	the 11th International Conference the East and Southeast Asia Federation of Soil Science Societies Land	Patterns of CO2 Flux in a Bared Tropical Peatland	Bogor, 21-24 October 2013
3	International workshop for co-designing local wisdom of land and water management for IWRM. Research Institute for Humanity and Nature	Water Availability & Productivity in the Context of Climate, Landuse and Socio-economic Changes in Saba & Jeneberang Watersheds	Kyoto, March 28, 2013.
4	FGD Gambut 04: “Metodologi Analisis, Pengukuran dan Pemantauan Biomass dan Karbon di Lahan Gambut. Kerjasama Fateta-IPB, HGI dan Sinarmas Forestry.	Biomass & Carbon Accumulation of Acacia Trees in Tropical Peatlands	Bogor, 22 February 2013.
5	FGD Gambut 03: “Metodologi Analisis, Pengukuran dan Pemantauan Biomass dan Karbon di Lahan Gambut. Kerjasama Fateta-IPB, HGI dan Sinarmas Forestry.	Analysis Of CO2 Flux Using Artificial Neural Network. *Analisis CO2 Flux Menggunakan Jaringan Syaraf Tiruan*	Bogor, 22 February 2013
6	GRENE 2nd International workshop,	Paddy growth and GHG emission under various ground water levelsData	Baguio, Philippine, 4-6 March 2013
7	GRENE the first International workshop	Online Environmental Monitoring System On The Advancement Of The System Of Rice Intensification In Indonesia [EMSA-SRI]	Bangkok, 3-5 March 2012.

G. Book for last 5 years

No	Title of Book	Year	Number of pages	Publisher

H. Intellectuals properties (Patent) during last 5-10 years

No	Title of Patent	Year	Categories	ID number
1	Sistem Resirkulasi dan Sistem Penghangatan Air untuk Pembenihan Ikan (*Water Resirculation and Warming Systems for Fish Hatchery*)	2010	Paten	P00200500007. Granted No.ID P0024637
2	Filtrasi Konsentris untuk Akuakultur (*Concentrical Filtration for Aquaculture*)	2007	Patent	Patent Application
3	Kolektor Surya Penghangat Bangsal Pembenihan Ikan Terkendali (*Controlled Solar Colector for Warming Room of Fish Hatchery*)	2007	Patent	Patent Application
4	Akuarium Multiguna (*Multipurpose Aquarium)*	2005	Patent registered	No.P00200500746

I. Experiences on public policy for last 5 years

No	Title	Year	Location	Public responses

J. Awards (for last 10 years)

No	Awards categories	Institution	Year
1	The Most Inspirative Lecturer. Fateta 2013	Faculty of Agricultural Technology	2013
2	Visiting Scholar in Research Institute for Humanity and Nature (RIHN)	Kyoto, Japan	April-July 2013
3	Best Lecturer 2012 in the Department of Civil and Environmental Engineering, Bogor Agricultural University	Department of Civil and Environmental Engineering	2012

4	Micro Oasis. Prasetya Mulya Businnes School. Global Finalist of Global Social Venture Competition.	University of California, Berkeley	2012
5	103 Inovasi Paling Prospektif 2011: Akuarium Multiguna	Menteri Negara Riset dan Teknologi, Republik Indonesia	2011
6	PAWEES International Award	The International Society of Paddy and Water Environment Engineering	2010
7	Sistem Resirkulasi dan Sistem Penghangatan Air untuk Pembenihan Ikan (*Water Resirculation and Warming Systems for Fish Hatchery*)	Rektor IPB	2010
8	102 Inovasi Paling Prospektif 2010: Sistem Irigasi Kendi	Menteri Negara Riset dan Teknologi, Republik Indonesia	2009
9	101 Karya Inovasi Indonesia Paling Prospektif 2009	Rektor IPB	
10	101 Inovasi Paling Prospektif 2009: Sistem Resirkulasi Air Terkendali	Menteri Negara Riset dan Teknologi, Republik Indonesia	2009
11	Adhicipta Rekayasa, PII Enginering Award	Persatuan Insinyur Indonesia (Association of Indonesian Engineers)	2008
12	Temporary Visiting Professor: Agriculture in Monsoon Countries, Master course	Ibaraki University	2009
13	Fateta Alumni Awards	Fateta Alumni Assosiation	2008
14	Temporary Visiting Professor: Agriculture in Monsoon Countries, Master course	Ibaraki University	2008
15	Temporary Visiting Professor: Agriculture in Monsoon Countries, Master course	Ibaraki University	2007
16	Dosen Berprestasi Nasional II (*National Outstanding Lecturer*)	DGHE, Ministry of National Education	2007
17	Dosen Berprestasi I IPB (*Outstanding Lecturer*)	Bogor Agricultural University	2007
18	Dosen Berprestasi I Fateta-IPB (*Outstanding lecturer*)	Faculty of Agricular Technology	2007
19	Dosen Berprestasi I (*Outstanding Lecturer*)	Department of Agric.Engineering	2007
20	Visiting Professor, Environmental Soil Physics and Hydrology in Sweden Agriculrural University and Wagenigen UR, Master course in European Forestry	Third Country Mobility Program Erasmus Mundus Sweden and the Netherlands	2007
21	Travel Awards to 7th International Micro Irrigation Congress: Advance on microirrigation for optimum crop production and resource conservation. International Committee on Irrigation and Drainage. Kualalumpur, 10~16 September 2006.	SEARCA	2006

22	Visiting Professor, Environmnetal Soil Physics and Hydrology in Sweden Agriculrural University and Wagenigen UR, Master course in European Forestry	Third Country Mobility Program Erasmus Mundus Sweden and the Netherlands	2006
23	Satyalancana Karya Satya (*20 years of public services*)	President of the Republic of Indonesia	2006
24	Dosen Berprestasi II (*Outstanding Lecturer*)	Faculty of Agriculural Technology	2005
25	Dosen Berprestasi I (*Outstanding Lecturer*)	Department of Agric.Engineering	2005

All of data filled in the curriculum vitae are true and accountability to the law. If in the future, there is a discrepancy with reality, I could accept sanctions.

The curriculum vitae is filled with the true data as a requirement to propose grant of International Research Collaboration and Scientific Publications

Bogor, 25 October 2015

(Prof. Dr. Ir. Budi Indra Setiawan, M.Agr)

Appendix 2. Continued…

Member-2: Dr. Ardiansyah, STP.MSi

A. Personal Identity

1	Full name (with title)	Dr. Ardiansyah, STP.MSi
2	Gender	M/F
3	Functional position	Asisten Ahli
4	NIP/NIK/Others ID	197701222005011002
5	NIDN	0022017902
6	Born	Palembang, 22 January 1979
7	Email	ardi.plj@gmail.com
8	Telephone number/HP	+6285764379752
9	Office address	Teknik Pertanian, Universitas Jenderal Soedirman (UNSOED) Jl. Dr.Soeparno, Karangwangkal, Purwokerto 53123
10	Telephone number/Fax	+62281621094
12	Number of graduated student	S-1 = 30 students; S-2 = 1 students; S-3 = 0 students
13	Courses	1. Soil-Water-Plant System
		2. Irrigation and Drainage
		3. Hydrology
		4. Agriculture System Modeling (Post-Graduate Course)

B. Educational Background

	S – 1 (undergraduate)	S-2 (Master)	S-3 (Doctoral)
Name of University	Bogor Agricultural University	Bogor Agricultural University	The University of Tokyo
Major	Agricultural Engineering	Agricultural Engineering	Biological and Environmental Engineering
Entrance – graduates year	1996 – 2000	2002 - 2004	2005 - 2008

Title of thesis	Design of Fuzzy-Logic Temperature Control System using Multi-Step Set-Points for Anesthesia of Tiger Shrimp (*Penaeus monodon* Fab.) (in Bahasa Indonesia)	Modeling Controlled Filtration System in Fish Hatchery Recirculating System (in Bahasa Indonesia)	Estimation of Evapotranspiration in Cultivated and Uncultivated Paddy Field in Tropical Watershed
Name of advisors	1. Dr. Sam Herodian 2. Prof. Dr Budi I. Setiawan	1. Prof. Dr. Budi I. Setiawan 2. Dr. I Dewa Made Subrata	Prof. Dr. Sho Shiozawa

C. Research Experiences (last 5 years)

No	Year	Research Title	Funding source	
			Source/Sponsors	Total (IDR)
1	2013	Karakteristik Emisi Gas Rumah Kaca CH_4 dan N_2O pada Lingkungan Mikro Tanaman Padi Metode SRI (System of Rice Intensification)	DIKTI	
2	2013	Permodelan Matematika dan Pemrograman Komputer untuk Rekomendasi Pemupukan Kompos-Arang Sekam pada Lahan Padi Metode SRI (System of Rice Intensification)	DIPA UNSOED Tahun Anggaran 2013	
3	2012	Optimalisasi Sistem Aeroponik dalam Rangka Peningkatan Produksi Benih Kentang Bebas Patogen (Kajian Lanjut Hasil SIDa Jawa Tengah)	Riset Unggulan Daerah (RUD), Litbang Propinsi Jawa Tengah	
4	2011	Pengembangan Teknologi Tepat Guna	DIPA UNSOED	

		dalam Sistem of Rice Intensification (SRI) untuk Mewujudkan Ketahanan Pangan dan Mengurangi Efek Perubahan Iklim	Tahun Anggaran 2011	

D. Extensions experiences (last 5 years)

No	Year	Extensions title	Funding source	
			Source/Sponsors	Total(IDR)
1	2013	Counseling (in RRI): "Menjaga Air Tanah Kita"		
2	2013	IbM Pondok Pesantren	DIKTI	42,000,000.-
3	2012	Farmer Field School untuk Penanaman Padi Metode SRI	DIPA-UNSOED	10,000,000.-
4	2012	Penyuluhan di Serang , Penanaman Kentang dalam Greenhouse		
5	2012	Penyuluhan Penanaman Padi Metode SRI dan Pembuatan Kompos		
6	2011	Alih Teknologi Budidaya Jamur Tiram Putih di Desa Kalisogra Wetan, Kecamatan Kalibagor, Kabupaten Banyumas		

E. Publication in the Journal (last 5 years)

No	**Title of paper**	**Journal name**	**Volume/No/ Year**
1	Thermal Properties and Shrinkage-Swelling Characteristic of Clay Soil in a Tropical Paddy Field	Journal of the Japanese Society of Soil Physics	Vol.110, November 2008
2	Nitrogen Budget and Gaseous Nitrogen Loss in a Tropical Agricultural Watershed (Second Author)	Biogeochemistry. 2008;87(1):1-15.	2008;87(1):1 -15.

F. Conference (oral presentation) for last 5 years

No	Name of seminar/conference	Title of paper	Time and Location
1	Seminar Nasional Pengembangan Sumber Daya Pedesaan dan Kearifan Lokal Berkelanjutan III	Karakteristik Emisi Gas Rumah Kaca CH4 dan N2O pada Lingkungan Mikro Tanaman Padi Metode SRI (System of Rice Intensification)	Purwokerto, 2013
2	International Conference on Sustainable Rural Development 2013	Study of Rice Growth and Yield as well as the Available of N, P, K Soil Content Given by Local Micro Organisms in System of Rice Intensification Rice Fields in the Cilacap District	Purwokerto, 25-26 August 2013
3	PAWEES 2012 International Conference on "Challenges of Water & Environmental Management in Monsoon Asia"	Soil Macro Nutrient (N, P, K) during Growth Stages under Conventional and SRI (System of Rice Intensification) Practices in Tropical Soil	Bangkok, Thailand, 27-28 October 2012
4	Seminar Nasional Teknologi Berkelanjutan	Pengamatan Jarak Jauh Iklim Mikro Sawah Daerah Cimanggu, Kabupaten Cilacap dengan Stasiun Cuaca Mini dan Teknologi Field Router	Purwokerto, 2011

G. Book for last 5 years

No	Title of Book	Year	Number of pages	Publisher

H. Intellectuals properties (Patent) during last 5-10 years

No	Title of Patent	Year	Categories	ID number

I. Experiences on public policy for last 5 years

No	Title	Year	Location	Public responses

J. Awards

No	Awards categories	Institution	Year

All of data filled in the curriculum vitae are true and accountability to the law. If in the future, there is a discrepancy with reality, I could accept sanctions.

The curriculum vitae is filled with the true data as a requirement to propose grant of International Research Collaboration and Scientific Publications

Bogor, 25 October 2015

(Dr. Ardiansyah, STP, MSi)

Appendix 3. Publications

1. Arif, C., K. Toriyama, B.D. A. Nugroho., M. Mizoguchi. 2015. Crop Coefficient And Water Productivity In Conventional And System Of Rice Intensification (Sri) Irrigation Regimes Of Terrace Rice Fields In Indonesia. Jurnal Teknologi 76:15 (2015) 97–102

Jurnal Teknologi

Full Paper

Crop Coefficient and Water Productivity in Conventional and System of Rice Intensification (SRI) Irrigation Regimes of Terrace Rice Fields in Indonesia

Article history
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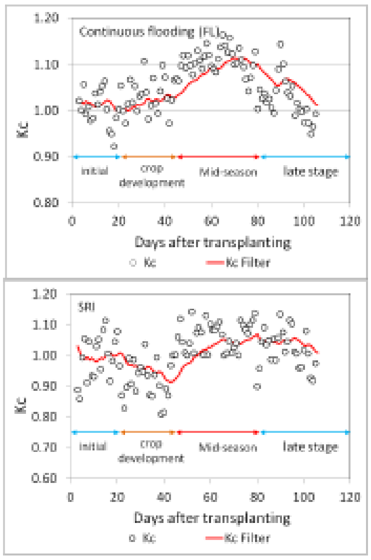
Graphical abstract



Abstract

The current study initiated to investigate crop coefficient (Kc) and water productivity between conventional and System of Rice Intensification (SRI) irrigation regimes of terrace rice fields in Indonesia. Kc value represents plant responses to available water in the fields and its information is very important to determine crop evapotranspiration. The field experiments were conducted in the terrace rice fields belong to the local farmer located in Wonogiri, Central Java (S 7°47'18.66", E 111°5'51.26") during 21 July – 7 November 2014 in the dry season. Here, there were two irrigation regimes with three replications, i.e. conventional flooding (FL) regime and SRI with intermittent irrigation (II) regime. Water level in each regime was measured by pressure sensor, while weather parameters such as solar radiation, air temperature, precipitation, etc were measured by particular sensors and connected to the developed field monitoring system. Based on weather and water level data, we estimated the average Kc values for FL regime were 1.01, 1.02, 1.09 and 1.05 in the initial, crop development, reproductive and late growth stages, respectively. Meanwhile, the average Kc values under SRI regime were a little bit lower than that FL regime. Their values were 1.00, 0.96, 1.02 and 1.04 for the initial, crop development, reproductive and late growth stages, respectively. The reason was probably due to minimum soil evaporation under the drier soil condition. However, lower Kc values were not corresponded to the production of grain yield. Although it was not significant difference, we recorded that SRI regime produced 8.05 ton/ha grain yield, while FL regime was 7.63 ton/ha. Accordingly, with less irrigation water, SRI regime has higher water productivity than that FL regime.

Keywords: Crop coefficient, rice terrace, system of rice intensification, water management, water productivity

1.0 INTRODUCTION

Since introduced in 1999, System of Rice Intensification (SRI) has been widespread in some areas in Indonesia. However, paddy fields in Indonesia have various topographies such as terrace fields, so it is not easy to apply the SRI elements particularly in the water management. So, although many farmers have been trying to achieve high yield by SRI, yet accomplishment is not as desired.

In the SRI, paddy fields are not continuously flooded as common irrigation regimes in Indonesia, but conditioned dry during particular time, a practice called intermittent irrigation [1]. Many studies were carried in the different countries evaluating between SRI irrigation regime and conventional practice. SRI regime saved irrigation water significantly as reported previous studies. For example, SRI regime saved 26% water input in Indonesia [2], 28% in Japan, 38.5% in Iraq [3]. However, all experiments were conducted in the flood plain fields.

The current study initiated to investigate crop coefficient (Kc) and water productivity between conventional and System of Rice Intensification (SRI) irrigation regimes of terrace rice fields in Indonesia. Kc is commonly use for studying plant responses to available water in the fields whether in the dry or wet conditions. In addition, it is needed for irrigation scheduling and water resource allocation, management and planning [5]. Meanwhile, water productivity is important parameter to obtain the value or benefit derived from the use of water input [6].

The objectives of this study, therefore, were 1) determining crop coefficient of two different irrigation regimes, i.e., SRI irrigation regime and continuous flooding regime as representation of conventional rice cultivation practice in the terrace paddy fields, 2) comparing water productivity of those two irrigation regimes.

2.0 EXPERIMENTAL

2.1 Field Experiment

The experiment was conducted in Gemawang village, Giriwarto, District of Wonogiri, Middle-Java Indonesia with GPS position of S 7°47'18.66", E 111°5'51.26" during 21 July – 7 November 2014 in the dry season.

Here, we prepared two different water irrigation regimes with three replication, i.e., SRI regime (SRI) and Continuous Flooding (FL) for conventional rice cultivation practice. During initial and crop development (vegetative) stage (Figure 1), water level was kept at 1-2 cm above soil surface for FL regime and it was kept at very shallow water level near soil surface for SRI regime. Then, during reproductive (mid-season) stage, water level was kept at approximately 1 cm above soil surface for FL regime, while aerobic soil condition was developed for SRI regime. All plots were planted with a local rice variety (*Oryza sativa* L.), Ciherang, a current rice variety suitable for cultivation in Indonesia.

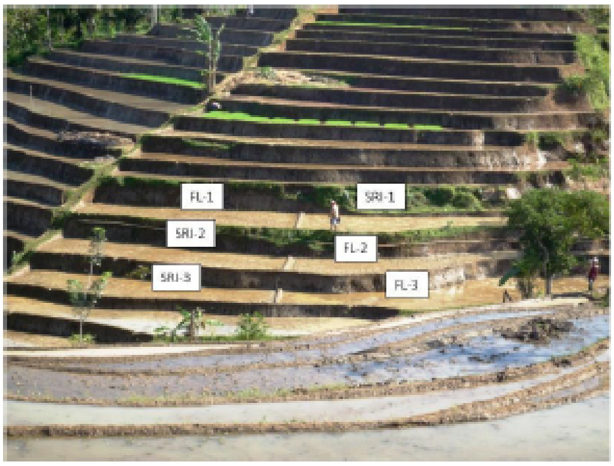


Figure 1 Experimental Paddy Fields in this study

2.2 Field Measurement

We used some sensors and data loggers to measure environmental biophysics parameters consisted meteorological and soil parameters. For meteorological parameters, we used *ECRN-100* rain gauge, *PYR* pyranometer, *EHT RH/Temp* sensors to measure precipitation, solar radiation and air temperature and relative humidity, respectively. Meanwhile for soil parameters, *5-TE* and *Hobo water level* sensors were used to measured soil moisture and water level in each plot. All sensors except Hobo water level sensor were connected *Em50 data logger* and the data were sent daily by *FieldRouter*.

2.3 Data Analysis

All environmental biophysics parameters were measured every 30 minutes, however, for data analysis we used daily data during planting period. Solar radiation and air temperature data were used to determine reference evapotranspiration (ETo) according to Hargreaves model [7, 8] as follow:

$$ET_o = 0.0135(T_{mean} + 17.78)Rs\left(\frac{238.8}{595.5-0.55T_{mean}}\right) \quad (1)$$

Where, ET_o is reference evapotranspiration (mm/d), T_{mean} is average air temperature (°C) and Rs is solar radiation (MJ/m²/d).

Then, water balance analyses were performed to estimated crop evapotranspiration (ETc) using Excel Solver [9] according the following equation:

$$S_m(t) = S_m(t-1) + \Delta S(t) \quad (2)$$

$$\Delta S(t) = P(t) + I(t) + Gw(t) - Qr(t) - DP(t) - ETc(t) \quad (3)$$

Where, Sm is estimated water storage equivalent water depth(mm), ΔS is the change of water storage equivalent water depth (mm), P is precipitation (mm), I is irrigation water (mm), Gw is groundwater (mm), Qr is runoff/drainage (mm), DP is deep percolation (mm), ETc is estimated crop evapotranspiration (mm) and t is the time (day). Groundwater was assumed to be zero because its rate was negligible.

Sm was determined using water level data by the following equation:

Flooded:

$$S_m(t) = Z_r * \theta + WL(t) \qquad \text{for WL(t)} > 0 \quad (4)$$

Non-flooded:

$$S_m(t) = Z_r * \theta \qquad \text{for WL(t)} < 0 \quad (5)$$

Where, WL is water level (mm), Zr is effective soil depth layer (mm), and θ is volumetric water content (m^3/m^3). Here, we assume that effective soil depth layer is equal with root zone depth (approximately 300 mm)

Then, ETc was then used to determine crop coefficient by the following equation:

$$Kc = \frac{ETc}{ETo} \quad (6)$$

Where Kc is crop coefficient (unit less). Showing the trend in each growth stage, Kc value was filtered using Kalman Filter equation [10, 11]. Kalman filter is useful to show the trend when the daily change of crop coefficient is fluctuated with irregular trend. Average Kc value was then calculated based on FAO growth stage, that is divided into 4 stages namely, initial, crop development, mid-season and late stages.

Meanwhile, water productivity with respect of total water input [12] in each regime was calculated by the following equation:

$$WP = \frac{Y}{\sum (I + P)} \quad (7)$$

where Y is grain yield (ton/ha), WP is water productivity (g grain/kg water).

3.0 RESULTS AND DISCUSSION

3.1 Weather Condition During Planting Period

Figure 2 shows daily changes in air temperature and relative humidity during planting period. The trend of daily maximum air temperature was significantly increased (R^2 = 0.7) in which it value was approximately 30°C in the early period and 35°C in the late period. However, the trend was not followed by the trends of average and minimum air temperature as well as relative humidity. These trends were slightly stable in 20°C, 25°C and 80% for minimum air temperature, average air temperature and relative humidity, respectively.

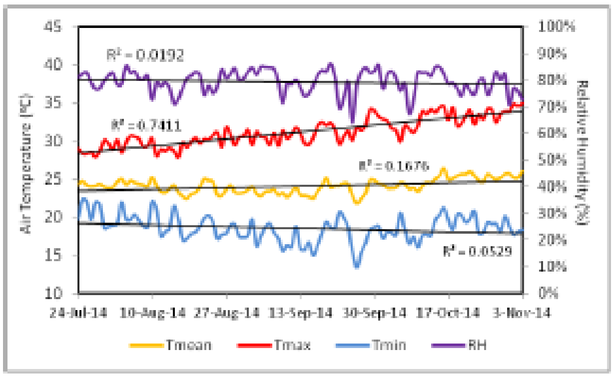


Figure 2 Daily changes in air temperature and relative humidity

The increasing maximum air temperature was supposed affected by increasing solar radiation as shown in Figure 3. Daily solar radiation was also significantly raised (R^2 = 0.35) from 15 MJ/m²/day on 24 July 2014 to be 25 MJ/m²/day on 3 November 2014. It was indicated that dry season was occurred during July – November 2014. Consequently, evapotranspiration was also increased significantly (R^2 = 0.43) from 3.5 mm/day in the early planting period to 6 mm/day in the late period. Therefore, the increasing evapotranspiration will also raised plant water requirement and irrigation.

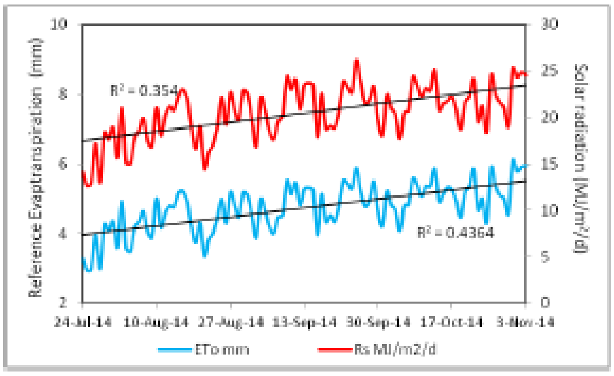


Figure 3 Reference evapotranspiration and solar radiation during planting period

3.2 Actual Water Level in the Fields

Crop coefficient is affected by the local climate as well as the change of water storage at the field [14].

Water storage in the field is commonly represented water level. Higher water level above soil surface indicates flooded condition and soil under saturated level. On the other hand, lower water level (probably below soil surface) shows less water storage and drier condition. Thus, it is important to consider the actual water level in studying crop coefficient between each regime (Figure 4).

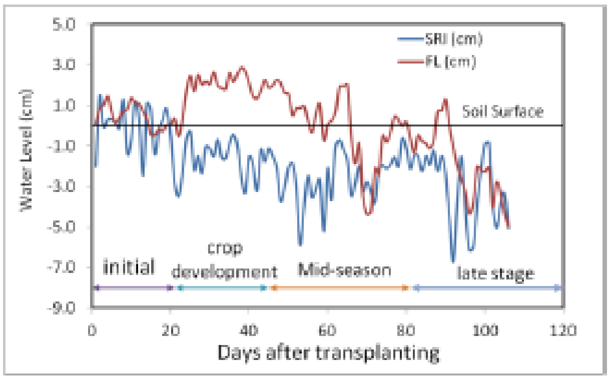


Figure 4 Actual water level between SRI and FL regimes during planting period

The actual water levels for both regimes were little bit different with the expected water level. In the crop development stage, it was expected the water level at very shallow water level near soil surface for SRI regime, however, the actual water level was at 1-3 cm below soil surface indicated that the field was drier than expected one. The same situation also occurred in the flooded regime in which water level was expected at 1 cm above soil surface in the mid-season stage, but it was dropped at 4.5 cm below soil surface. The occurrence was indicated that it was not easy to control water level in the terrace rice field manually without automatic water control system.

3.3 Crop Coefficient and Water Productivity

The daily crop coefficient (Kc) fluctuated widely throughout most of the planting period as presented in Figures 5 and 6. The Kalman filter method smoothed the data and provided continuous lines during the planting period for both regimes.

In the FL regime, when water level was at 1-3 cm above soil surface in the initial and crop development stages, Kc value was at the interval of 0.9 – 1.05. Then, it was rapidly increased in mid-season stage with maximum value of 1.18. Finally, it was declined rapidly in the late season stage with minimum value of 0.93. Its value declined when the plant focused on grain development in which the field became drier starting in the end of mid-season stage as shown in Figure 4.

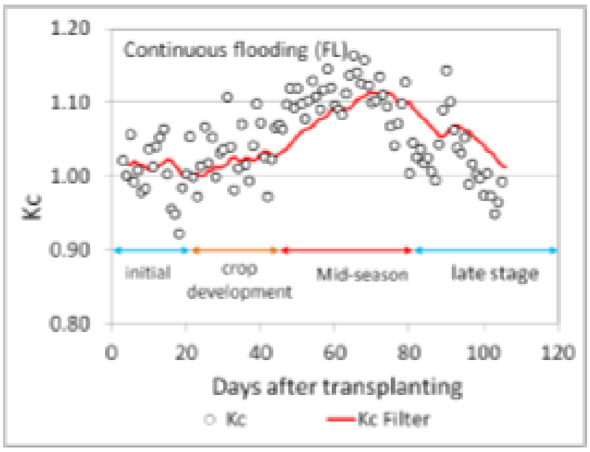


Figure 5 Daily crop coefficient curve of FL regime

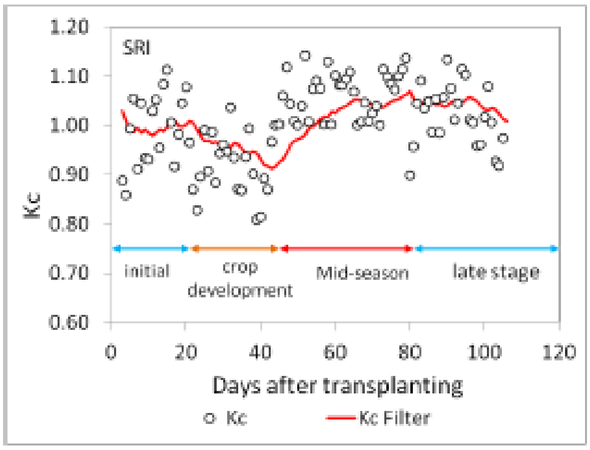


Figure 6 Daily crop coefficient curve of SRI regime

Meanwhile, in the SRI regime, Kc value was slightly decreased in the initial and second stages as responses of the decreasing of water level during this period with minimum Kc value was 0.8. The water level was dropped from 1 cm above soil surface to be 5 cm below soil surface in the end of crop development stage (Figure 6). Then, it was gradually increased in the mid-season stage when the plant initiated generative phase in development of tillers and panicles. Finally, it was declined gradually with minimum Kc value was 0.90 in the late stage. Commonly, in the late stage when water was drained and the plant exhibited full senescence, Kc value declined as responses of water availability in the fields [9].

Table 1 Crop coefficient and water productivity in each irrigation regime

Parameter	Irrigation regimes		FAO's Kc Value
	FL	SRI	
Average crop Coefficient in each growth stage:			
Initial Stage	1.01	1.00	1.10 - 1.15
Development Stage	1.02	0.96	1.10 - 1.15
Mid-season Stage	1.09	1.02	1.10 - 1.30
Late Stage	1.05	1.04	0.95 - 1.05
Water input:			
Precipitation (mm)	0	0	
Irrigation water (mm)	536	518	
Crop evapotranspiration (mm)	517	496	
Grain Yield (ton/ha)	7.63	8.05	
Water Productivity (g grain/kg water)	1.42	1.55	

Table 1 record the comparison of the average Kc values for both regimes compared and the typical ranges reported by the FAO for rice cultivation under the standard conditions [13]. In the initial stage, both average Kc values for the SRI and FL regimes were lower than the FAO value since the actual field conditions were drier than the FAO standard conditions. The minimum Kc value of SRI regime indicated minimum levels of both evaporation and transpiration rate.

The same could occur in the crop development stage when average Kc value for the SRI regime was also lower than that for the FL regime. Water stress (drying period) has affected on lower Kc value over several days (Figure. 4). In this growth stage, Kc value varies depending on crop type and frequency of soil wetting [14]. Therefore, drier field also should have corresponded to the decreased Kc value in this stage. Commonly, in the initial and crop development stages water used is directly proportional to transpiration, as a result when the field became drier, the most effective response of the plant is to reduce the transpiration [15].

In the mid-season and late stages, SRI regime has also lower Kc values than that FL regime when the water availability in the field less than FL regime represented by lower water level (Figure 4). Particularly in the late stage, Kc values for both regimes were comparable and their values were within FAO's Kc value. With lower Kc values in most growth stages, therefore, total crop evapotranspiration of SRI regime was lower than that FL regime.

Interestingly, although has lower Kc values during planting period, however, SRI regime produced more grain yield than that FL regime (Table 1). It was indicated that SRI regime more effective in the development of number of tillers and panicles. The key of SRI regime was aerobic condition particularly in mid-season stage in which this condition was effective to avoid spikelet sterility particularly around the flowering time [12]. In addition, SRI regime provided provides optimal water and oxygen availability with alternate wetting and drying irrigation system [16].

SRI regime with drier condition than that FL regime need less irrigation water (Table 1). Accordingly, with more grain yield and less irrigation water, SRI regime has higher water productivity than that FL regime. We recorded water productivity for SRI and FL regimes were 1.55 and 1.42, respectively. It was indicated that SRI regime more efficient in water use than that FL regime. Thus, SRI regime has more benefit or value derived from use of water.

4.0 CONCLUSION

Crop coefficient (Kc) of SRI and continuous flooding (FL) regimes in terrace paddy fields were well determined by water balance analysis with Excel Solver estimation. SRI regime has lower Kc values than that FL regime in all growth stages. Average Kc values for SRI regime were 1.00, 0.96, 1.02 and 1.04 for the initial, crop development, reproductive and late growth stages, respectively. Meanwhile, average Kc values for FL regime were 1.01, 1.02, 1.09 and 1.05 in the initial, crop development, reproductive and late growth stages, respectively. Although has lower Kc values, however, SRI regime produced more grain yield than that FL regime. The main reason was probably due to aerobic condition under SRI regime which provided optimal water and oxygen availability. Accordingly, with less irrigation water, SRI regime has higher water productivity than that FL regime. We recorded water productivity for SRI and FL regimes were 1.55 and 1.42, respectively.

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Full Paper

OPTIMIZING IRRIGATION AND DRAINAGE RATES IN SRI PADDY FIELDS

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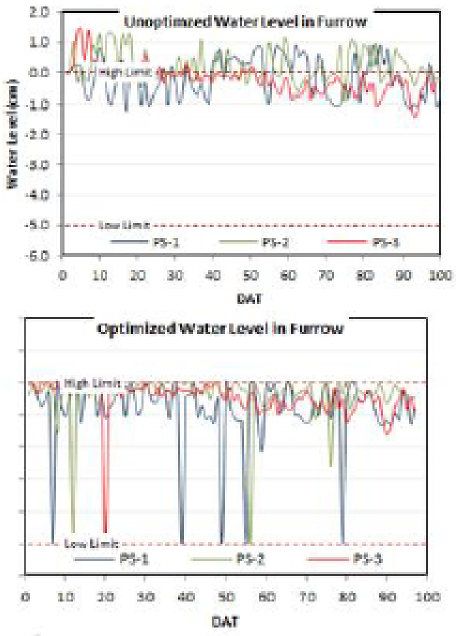
Graphical abstract



Abstract

A quantified study to optimize furrow irrigation and drainage rates for SRI paddy fields has been carried out over three different planting seasons. It is very crucial to maintain soil conditions where the water level sustains soil moisture at around saturation and air-entry values. In the present study we report on a simulator program which applies a saturated water flow equation in one dimension for which boundary conditions at both ends formed water rates (Neumann type). A spreadsheet optimization using an imbedded Solver in MS Excel was employed alongside the simulation. Daily rainfall, evapotranspiration and percolation rates as sink-source functions were incorporated into the equations. Our study shows that optimizing irrigation and drainage rates gives an effective water level for SRI paddy fields within a range of -5 to 0 cm for all planting seasons. The highest value for irrigation rate within the furrow was about 6 mm per day, while the optimizing drainage rate was about 0.5 mm per day. Water table profiles are significantly affected by planting season. Our study confirmed that conserving drained water from one planting season is desirable to provide sufficient irrigation water for the next planting season.

Keywords: SRI paddy field, water level, water table, irrigation, drainage, optimization

1.0 BACKGROUND

Water management in SRI paddy fields is crucial to maintain the water level within a proper soil moisture range. Soil moisture conditions should be kept around or between the soil's saturation and air-entry values. [To condition the water level simply, as it becomes a standard procedure, paddies are planted in a short ridge between two furrows or waterlines [1, 2] – this I cannot understand]. There is no standard number of paddy plants in a specific ridge but commonly there are about 4 to 5 plants with a wider spacing (25 cm x 25 cm) in between compared to the conventional paddy fields [3]. The furrow itself could be the width of an unplanted row. In Indonesia, this practice is well-known as *Jajar Legowo*, called *Jarwo* for short. This practice is also for the plants to intercept more sunshine [4, 5]. Typically, the space between two adjacent furrows ranges from 100 cm to 125 cm, and the width is about 25 cm.

Furrow irrigation [e.g., 6] is commonly applied to moisten the surrounding soils through the process of lateral infiltration. In some occasion the furrow is fully filled with water at the earlier growth stage but in the later stages, the water level is lower than the soil surface [7]. Lowering the water level gradually with time as the root growth has also been introduced to put the water level continually below the root zones [7]. Irrigated water flows down gravitationally in the furrow in which its speed is determined by the slope length of the furrow [8, 9]. It is not uncommon to find a slope of paddy field in the magnitude of 10-4 (in example, 5 cm-height different in 100 m-length). It turns out that furrows are also effective as drainage channels to draw excessive rainwater out of the fields [10].

The water may be supplied through a water gate from a tertiary irrigation box continuously, or intermittently vis-à-vis to the determined purposes or special treatments of irrigation [11]. An alternate wetting and drying (AWD) through surge irrigation practice [12] is also common to acquire more water use efficiency and to condition aerobic-anaerobic dynamics in the root zone which is very important to propagate microorganism activities [13] and to control soil respiration [14].

This study intends to build a simulator program for maintaining water level in the furrows that can minimize irrigation and drainage rates. Herewith, we applied a saturated water flow equation in one dimension over which boundary conditions at both ends formed water rates (Neumann type). A simulation program was built, by using the imbedded Solver of MS Excel with the target of optimization is to minimize irrigation and drainage rates while maintaining water level in the furrows at a certain range. Hence, we employ daily rainfall, evapotranspiration and percolation rates as sink-source function that was incorporated to the equation.

2.0 THEORETICAL APPROACH

Water flow in saturated porous medium follows the Darcy's Law that can be written in the following equation [15].

$$q = -K_s \frac{dh}{dx} \quad (1)$$

Where, q is water flux (m d^{-1}); Ks is saturated hydraulic conductivity (m d^{-1}); h is static pressure head (m H_2O); and x is distance (m).

In the form of the unsteady state, Equation 1 can be transformed into the following continuity equation [e.g., 16].

$$S\frac{\partial h}{\partial t} = T\frac{\partial^2 h}{\partial x^2} + s \quad (2)$$

Where, S is storativity; s is water sink and source (m d^{-1}); t is time (d); and T is transmissivity (m^2 d^{-1}) in which was defined by the following equation.

$$T = K_s h \quad (3)$$

The water sink and source herewith is in the form of the following equation.

$$s = re - et \quad (4)$$

Where, re is effective rainfall intensity (m d^{-1}); et is evapotranspiration rate (m d^{-1}).

The effective rainfall intensity denotes rainwater that is potential to percolate into the soil layer.

$$re = \begin{cases} r & r \le p \\ p & r > p \end{cases} \quad (5)$$

Where, p is percolation rate of the soil layer (m d^{-1}).
Excessive water is calculated by the following equation.

$$ro = \begin{cases} 0 & r \le p \\ r - p & r > p \end{cases} \quad (6)$$

Where, ro is run-off or surface drainage (m d^{-1}).

Boundary conditions are in the form of horizontal fluxes (Neumann type [e.g., 17]) specified by the following equations.

$$q_0 = -K_s \frac{\partial h}{\partial x}\Big|_0 \quad (7)$$

$$q_L = -K_s \frac{\partial h}{\partial x}\Big|_L \quad (8)$$

$$h(L,t) = h_L(t) \quad (9)$$

Where, L is length of the domain (m); and h_L is known as time function of pressure head (m) at x=L.

An initial condition is given by the following equation.

$$h(x,0) = h(x) \quad (10).$$

3.0 METHODS AND MATERIALS

3.1 Numerical Solution

By applying an explicit type of Finite Difference Method, Equation 2 was transformed into the following equations:

$$h_i^{t+1} = ah_{i-1}^t + bh_i^t + ch_{i+1}^t + ds^t \quad (11)$$

$$a = c = \frac{T_i \Delta t}{S \Delta x^2} \quad (12)$$

$$b = 1 - 2a \quad (13)$$

$$d = \frac{\Delta t}{S} \quad (14)$$

Where, i is index for spatial increment {i=1…n}, t is index for temporal increment, and n is the total number of spatial increments.

The boundary conditions of Equation 7 and Equation 8 were transformed into the following equations.

For i=1:

$$h_1^{t+1} = ah_0^t + bh_1^t + ch_2^t + ds^t \quad (15)$$

$$h_0^t = h_1^t - q_0 \frac{\Delta x}{K_s} \quad (16)$$

For i=n;

$$h_{n-1}^{t+1} = ah_{n-2}^t + bh_{n-1}^t + ch_n^t + ds^t \quad (17)$$

$$h_n^t = h_{n-1}^t - q_n \frac{\Delta x}{K_s} \quad (18)$$

Where, h_0 and h_n are the water level in each furrow, and q_0 and q_n are the associating fluxes from the furrow to the soil (positive sign), or vice versa (negative sign). Since the water flow domain was symmetrical then q_0 was equal to q_n.

The flux, q_0 was optimized using Solver in MS Excel with the following conditions:

$$\text{Minimize } SUMSQ(q_0^t) \text{ for } t = t_0 \text{ to } t_m \quad (19)$$

$$h_{min} \le h_0 \le h_{max} \quad (20)$$

Where, h_{min} and h_{max} are the lowest and the highest values of water level in furrows (cm).

The initial condition was given by equaling the water table with the soil surface.

$$h_i^0 = 0 \quad (21)$$

Since Equation 11 is conditionally stable, the maximum time step was determined by the following equation.

$$\Delta t \le \frac{S\Delta x^2}{2T} = \frac{S\Delta x^2}{2K_s h_{max}} \quad (22)$$

Table 1 shows values of numerical parameters used in the simulation. Length of the water flow domain (L) was 150 cm divided by 15 numbers of spatial increments (Δx). Based on the soil properties shown in Table 1 and Equation 22, the resulted Δt was 1.2 days. In this study however, Δt was set to 1 day in order to achieve the stability of calculation.

Table 1 Numerical parameters

Parameters	Symbol	Unit	Value
Length of Flow Domain	L	cm	150
Hydraulic Conductivity	Ks	cmd-1	0.5
Storativity	S		0.6
∑Spatial Increment	b		15
Spatial Increment	Δx	cm	10
Highest Water Level	hmax	cm	50
Time step	Δt	d	1.2
Maximum Transmissivity	Tmax	cm2d-1	25

3.1 Study Site

The paddy field selected for this study was at the Rice Research Center of the Ministry of Agriculture located in Sukamadi, West Java (Figure 1), Indonesia. It has about 300 ha of paddy field which is used mainly to test newly developed rice breeds and cultivation techniques.

Figure 1 Location of the study site

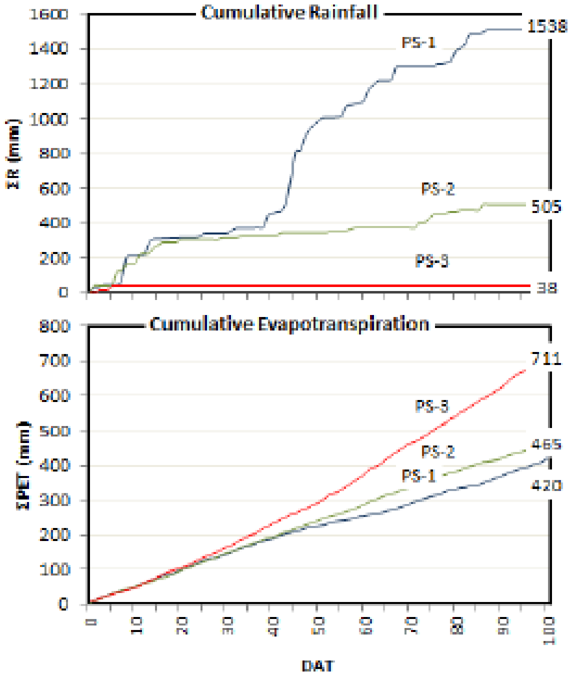


Figure 2 Rainfall and evapotranspiration at different planting season

Based on a decadal weather recorded in the location, there was a distinct transition of wet and dry seasons, and there was also temporal shifting on the beginning and length of dry season. The earliest and latest dry seasons were 50 days and 160 days of Julian date calendar, and the shortest and longest dry seasons were 170 days and 300 days [18]. This area is classified as dry land where the availability of rainwater is sufficient only for one planting season of paddy. However due to the irrigation, paddy can be planted up to 3 times a year. The first planting season is from December to the middle of March, the second season is from April to the middle of July, and the third season is from August to the middle of November.

In this study, we used whether data recorded from 2013 and 2014. As shown in Figure 2, the cumulative rainfall (ΣR) and potential evapotranspiration (ΣPET) in each planting season was significantly different. Total rainfall and evapotranspiration in the first planting season (PS-1) were 1538 mm and 711 mm, in the second planting season (PS-2) were 505 mm and 465 mm, and in the third planting season (PS-3) were 38 mm and 420 mm, respectively. It is clear that PS-2 and PS-3 are the seasons having deficit water while excessive water occurred in PS-1.

Based on Equation 4, Equation 5 and Equation 6, and by applying averaged percolation rate 5 mm per day, the rates of water sink and source for each season are shown in Figure 3. The rates clearly fluctuated with season and days of transplanting (DAT). The maximum range of sink and source was found in PS-2 which vary from -8.9 mm to 7.6 mm per day. The minimum range was found in PS-3 which vary from -5.4 to 5.6 mm per day.

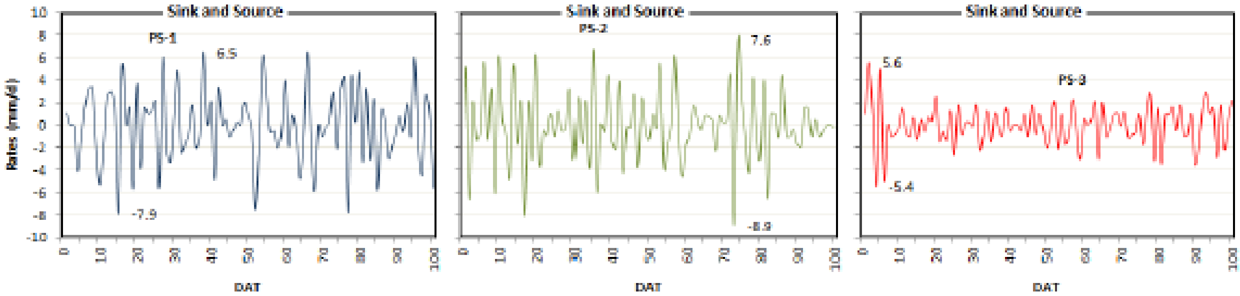


Figure 3 Rates of water sink and source at different planting season

4.0 RESULTS AND DISCUSSION

4.1 Water Level in the Furrow

Figure 4 shows water level in the furrow with and without optimization of irrigation and drainage during all planting seasons (PS-1, PS-2 and PS-3). As stated earlier that the target of optimization was to minimize irrigation and drainage rate which enable to maintain water level in the furrow in between 0 cm (high limit) to -5 cm (low limit). As clearly indicated in the left figure, without optimization, water level in many occasions for all planting seasons exceeded the soil surface (high limit). There was a general tendency that water level decreased gradually with time. Whereas, after applying optimization (right figure), water level in all occasions are between the expected high and low limits. In some cases, water level reached the low limit that shows responsiveness of the optimization process.

4.2 Furrow Irrigation and Drainage Rates

Figure 5 shows irrigation and drainage rates, and theirs accumulations resulted from the optimization process in all planting seasons. Comparing to the drainage (negative value), irrigation rate (positive value) was more responsive even in the wet season (PS-1) indicating that the optimization process preferred to maintain the water level closed to the high limit (soil surface). This preference might be due to the given initial condition that was at the soil surface. Therefore, when the water level has dropped below the soil surface, irrigation rate amplified immediately to put back the water level position to the initial value. This trend resulted in higher cumulative irrigation (middle curves) in PS-1 (56 mm) rather than in PS-2 (43 mm) and in PS-3 (17 mm). Similarly, a higher cumulative drainage (bottom curves) occurred in PS-1 (1.5 mm) rather than in PS-2 (0.4 mm) and in PS-3 (0.04 mm).

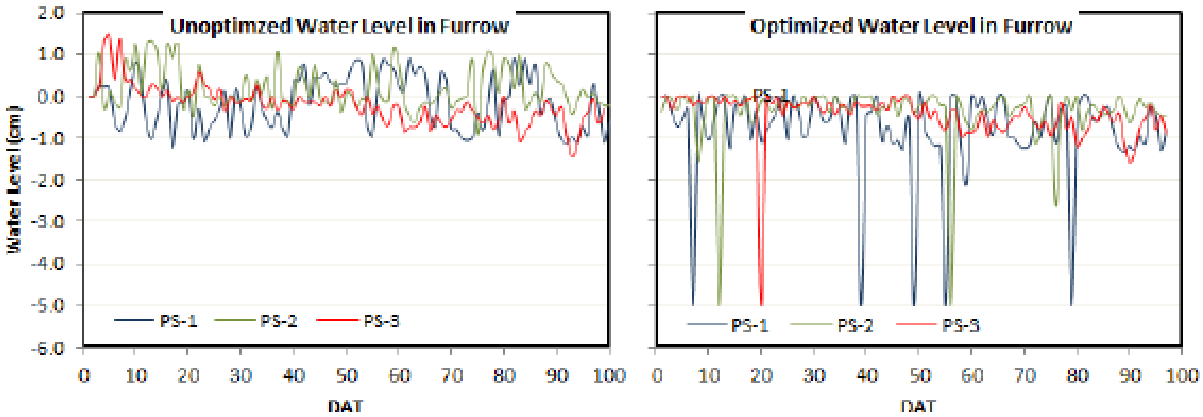


Figure 4 Water level in the furrow with and without optimization for all planting seasons

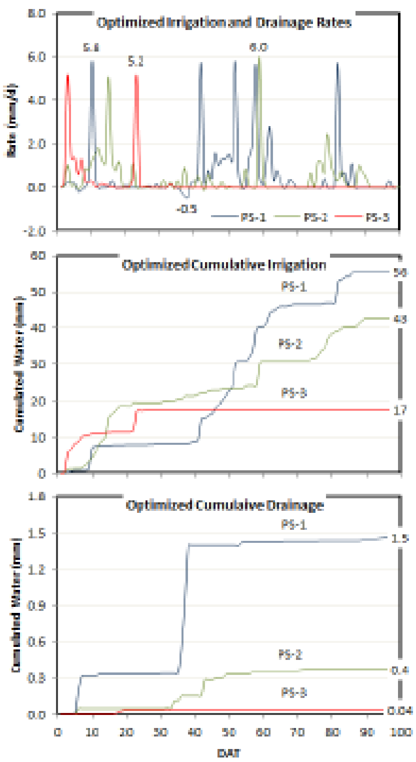


Figure 5 Optimized irrigation and drainage for all planting seasons

As shown in the Figure 5, the highest value of irrigation rate in the furrow was 6 mm per day, and that of drainage was 0.5 mm per day. These values are very important to determine the capacities of irrigation and drainage infrastructures in the field scale that may consists of many furrows with different width and length. These values would change depending upon soil properties and interval between two adjacent furrows. Prior to the optimization process, it is important to find the optimum spacing between two furrows. For this purpose, Hooghoudt equation [19] might be applicable.

4.3 Water Table in the Soil Profile

Figure 6 shows water table profiles in the soil layer between two adjacent furrows in all planting seasons. With and without the optimization process, the water table profiles in the same planting season were lookalike except those at the distance closer to the furrows in which the effects of the water level became significant. Farther than the furrow, fluctuations of water table occurred as direct responses to the sink and source rates.

For comparison purpose, the curve lines were selected on DATs that could represent the minimum and maximum values of the water table occurring in the PS-1. We found that the minimum water table of -1.0 mm occurred on 12 DAT and the maximum of 1.0 mm on 81 DAT in PS-1. This range of water table is sufficient for cultivating SRI paddy fields. All curve lines in PS-1 laid between these two lines but not the case for those curve lines in PS-2 and PS-3. Higher and more intense rainfall affected the water table profiles fluctuated more than the others. In PS-2 and PS-3, water table profiles were more concentrated and stable around the soil surface. It turns out that maintaining water table in the soil layers with lesser rainfall is easier because ones might deal only with irrigation though a sufficient irrigation which must be readily available.

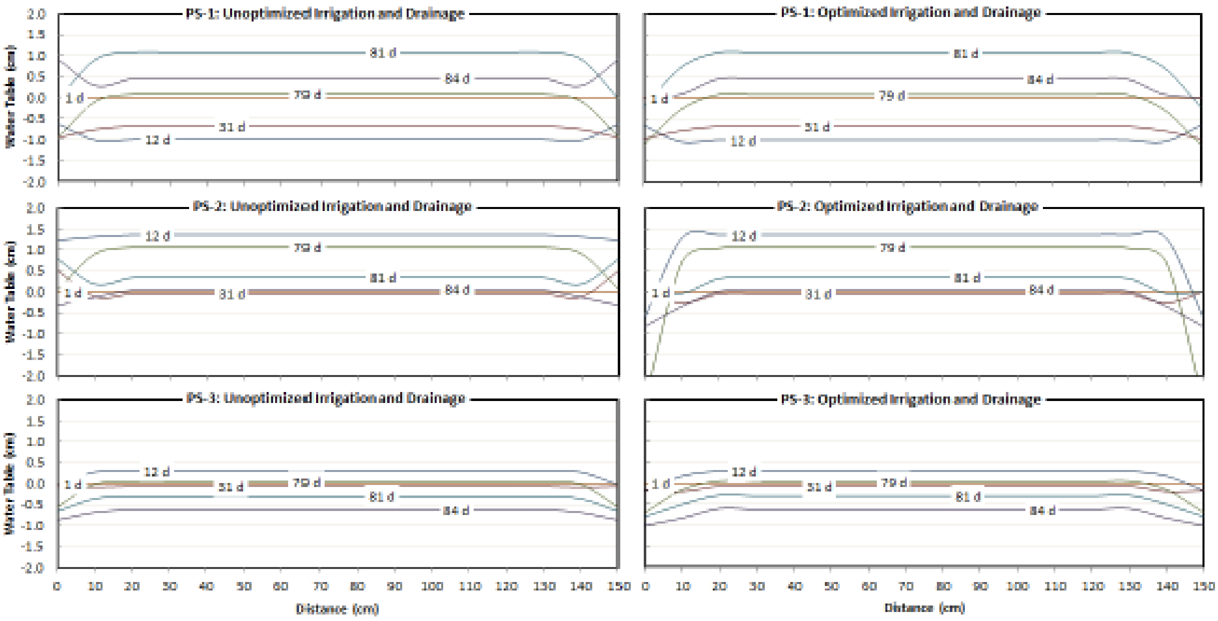


Figure 6 Profile of water table in the soil layers with (right) and without (left) the optimization process for all planting seasons

Table 2 Water balance components

Water Balance Components	Unit	Planting Season-1	Planting Season-1	Planting Season-1
Rainfall	mm	1538	505	38
Percolation	mm	505	505	505
Effective Rainfall	mm	264	133	16
Evapotranspiration	mm	420	465	711
Surface Irrigation	mm	156	332	695
Surface Drainage	mm	1274	372	22
Furrow Irrigation	mm	28	21	9
Furrow Drainage	mm	0.73	0.19	0.02

4.4 Water Balance in the Field

Table 1 shows a resume of water balance components comprising rainfall, percolation, effective rainfall, evapotranspiration, surface irrigation and drainage, and furrow irrigation and drainage for all planting seasons. Notice that even total rainfall was very large (1538 mm) in PS-1, however, most of them (1274 mm or 83%) was drained. Conserving drained water is more than enough to supply irrigation for the following two seasons (PS-2 and PS-3). The required water for furrow irrigation could also utilize the drained water. The values of furrow irrigation and drainage in Table represent one unit of furrow. Thus, for a given width (w), length (l) and number (n) of furrow in a specified SRI paddy field, the total required water can be estimated. According to the information (Table), ones can make throughout design and planning of irrigation and drainage schemes.

5.0 CONCLUSION

The present numerical study provides better understanding on conditioning the optimum water level for one unit of furrow of SRI paddy field.

Our study shows that optimizing irrigation and drainage rates has effectively set the water level of SRI Paddy fields into a range of -5 to 0 cm for all planting seasons. The highest value of irrigation rate in the furrow was about 6 mm per day, meanwhile that of drainage rate was about 0.5 mm per day. The different water table profile is significantly affected by planting season. Our study also confirmed that conserving drained water from a planting season is required to provide sufficient irrigation water for the next planting seasons.

Acknowledgement

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Full Paper

NITROGEN UPTAKE OF SRI PADDY FIELD COMPARE TO COMMON FIELD

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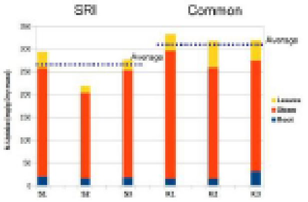
Graphical abstract



Abstract

The aim of this research is to compare nitrogen uptake in SRI field and common paddy field. Three SRI plots and three common plots were given same amount of organic fertilizer and three different biochar amount. In SRI field, S1 were plot with 5 ton/ha biochar application, S2 were plot with 10 ton/ha biochar application, and S3 were plot with 20 ton/ha biochar application. Similarly, in common paddy field, K1, K2, and K3 were plots with 5 ton/ha, 10 ton/ha, and 20 ton/ha biochar application. Mineral fertilizer were not used in this research. Result shows that, Nitrogen uptake in SRI paddy field (average of 262.9 mg/g Dry mass) were less than Common paddy field (average of 323.8 mg/g Dry mass). However, average of the grain weight of 1000 paddy grain shows that grain from SRI field is heavier (average of 20.7 g) than common paddy field (average of 19.0 g). Biochar application of 5 ton/ha, for both SRI and common fields shows higher result in most of plant parameters (plant height, amount of grain, total weight). SRI method usually shows the high production compare to common method. However, in this experiment there is almost no difference in SRI field (3.6 ton/ha) and common field (3.7 ton/ha). Plant observation shows that SRI paddy develop good rooting system than common paddy field that implies on more nutrient uptake. Soil were suspected to be the cause of low nitrogen uptake in SRI field.

Keywords : System of Rice Intensification (SRI); nitrogen uptake; biochar application

1.0 INTRODUCTION

Many questioning, why SRI field generally has higher biomass (number of tillers, deep rooting system, crop yields, etc) than common field [1]. Where it does get the nitrogen and whether the mechanism is general rule for all type of soils. Nitrogen uptake related to crop biomass production. However it doesn't always connected to higher crop yield. Critics on SRI practice usually lies on the claims that the crop yield should be high, without explaining how, for example, deep rooting system resulting from the practice could increase yield [2].

Biomass and crop yield model has been an interesting subject for researchers for many years. In order to explain how biomass formed and what the involving factors are, model were made. The model describe biomass or crop yield as function of one or more factors. Some biomass model describing biomass growth simply as a function of meteorological factors [3], another model also involves cultivar and crop management as additional factors influencing biomass [4]. Another model explains that radiation and nitrogen uptake (hence biomass) strongly related. Radiation were observed to be most influencing nitrogen uptake [5]. More specific model from the past considers evapo-transpiration (ET) as main factors that deterimines crop yield [6].

The mechanism of nitrogen uptake has also been evaluated from the point of view of biochemical [7], [8]. While it provide more detail information on the biochemical aspect, it still difficult to transform the mechanism into simple and easily understandable model equations. Thus, there is a need to recognize both SRI and non-SRI practice to understand simple mechanism for subsequent modeling purpose

The aim of this study are to observe nitrogen uptake in SRI and Common field and the differences in relating factors during crop growth. The factors is focused on soil nitrogen content and evapo-transpiration.

2.0 EXPERIMENTAL

Plot experiment were conducted to observe nitrogen uptake in SRI field and Common field. Soil nitrogen dynamic during crop growth were also observed. Three SRI plots (S1, S2, S3) and three common plots (K1, K2, K3) were given the same amount of organic fertilizer and three different biochar amount. In SRI field, S1 were plot with 5 ton/ha biochar application, S2 were plot with 10 ton/ha biochar application, and S3 were plot with 20 ton/ha biochar application. Similarly, in common paddy field, K1, K2, and K3 were plots with 5 ton/ha, 10 ton/ha, and 20 ton/ha biochar application. Mineral fertilizer were not used in this research.

Weather parameters consist of; radiation, air temperature, air humidity, wind speed, and rainfall were taken from weather station (Davis Vantage Vue-Davis Instrumen Corp.) installed in research location. Soil moisture sensors installed in SRI field in S1 plot. Soil nutrient were analyzed from soil samples taken in the field during crop growth. Total nitrogen (Total-N) and available nitrogen (available-N) were determined in the laboratory. Plant parameters observed were nitrogen content in biomass, crop yield, and grain weight.

3.0 RESULTS AND DISCUSSION

3.1 Nitrogen Uptake

Figure 1 shows nitrogen uptake per gram of dry mass for three treatments of both SRI field and Common field. Visually, it appears that plant biomass in Common field has more nitrogen content than SRI field. Nitrogen content in straw seems to be a "difference maker", that influence total nitrogen uptake for both field type. Average of total N-uptake from Common field (323 mg/g_dry mass) is larger than SRI field (262 mg/g_dry mass). Straw, root and leaves are biomass formed in vegetative stage, thus it shows that in Common field, vegetative growth is higher than SRI field.

Weight of 1000 paddy grain shows that grain from SRI field is more weight (average of 20.7 g) than Common field (average of 19.0 g), as in Figure 2.

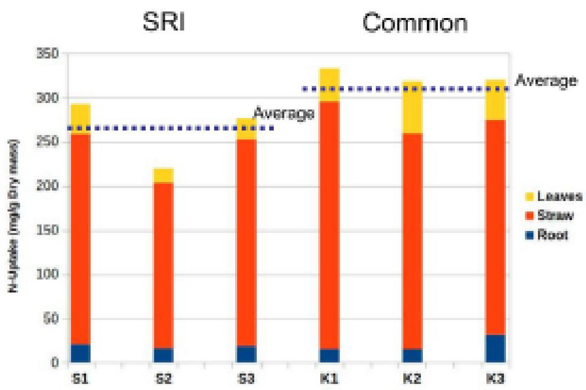


Figure 1. Nitrogen uptake in SRI field and Common field

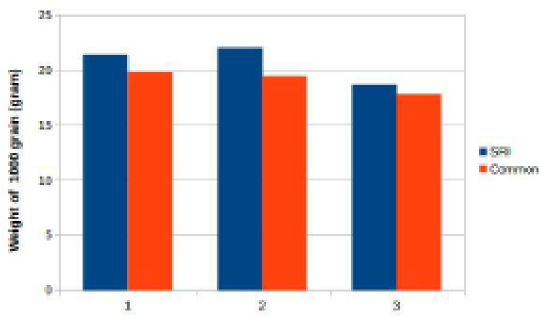
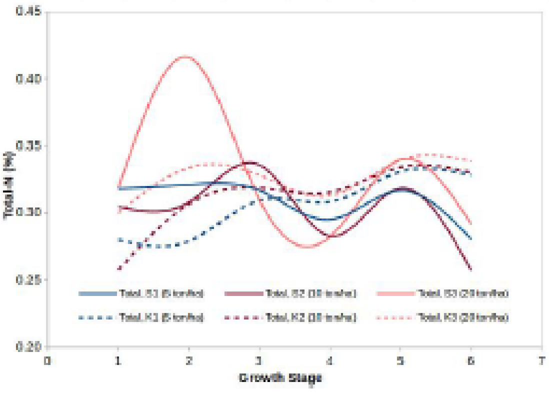


Figure 2. Comparison of 1000-grains-weight for SRI and Common field

3.2 Soil Nitrogen Content

Total-N and available-N measured from soil samples were observed on each of growth stage. Total-N is the amount of nitrogen that need to decompose to make it available for plant. It range from 0.26 to 0.42 %. Available-N is amount of nitrogen that is ready for plant uptake. It range from 73.46 to 135.2 ppm in this research. Comparison of nitrogen dynamics of common field and SRI field is given in Figure 3. The dynamics of nitrogen in soil is a result of decomposition of organic-N, plant nitrogen uptake and nitrogen loss through volatilization and leaching [9]. Either in Figure 3a.(total-N) or Figure 3b.(available-N), amount of nitrogen in common field were slightly higher than SRI field. Total-N is increasing in S3 field after fertilizer application, however it decreases below common field in the next stage.

(a)



(b)

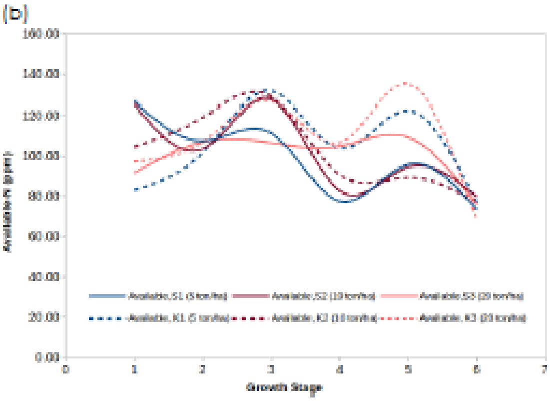


Figure 3. (a) Soil Total Nitrogen (Total-N) and (b) Available Nitrogen (Available-N) on: 1.Before fertilizer application; 2.After fertilizer application; 3.Day 14; 4.Day 57; 5.Day 85; 6.Day 96(Before harvesting)

Total-N and available-N measured from soil samples were observed on each of growth stage. Total-N is the amount of nitrogen that needs to decompose to make it available for plant. It ranges from 0.26 to 0.42 %. Available-N is amount of nitrogen that is ready for plant uptake. It ranges from 73.46 to 135.2 ppm in this research. Comparison of nitrogen dynamics of Common and SRI field is given in Figure 3. The dynamics of nitrogen in soil is a result of decomposition of organic-N, plant nitrogen uptake and nitrogen loss through volatilization and leaching [9]. Either in Figure 3a.(total-N) or Figure 3b.(available-N), amount of nitrogen in common field were slightly higher than SRI field. Total-N is increasing in S3 field after fertilizer application, however it decreases below common field in the next stage.

3.3 Evapo-Transpiration (ET)

There is difference between evapo-transpiration (ET) in SRI field and Common field. Figure 4 Shows that during vegetative growth, ET in Common field is larger than SRI field, meanwhile the value is almost similar in generative stage, especially in stage of grain maturity.

The difference among treatments for both SRI field and Common field is not shown here. ET in SRI field were calculated using water balance method, considering changes in soil moisture content throughout the day. ET in Common field were calculated from Penman-Monteith equation and using FAO crop coefficient [10], assuming in wet condition, ET value is mostly potential.

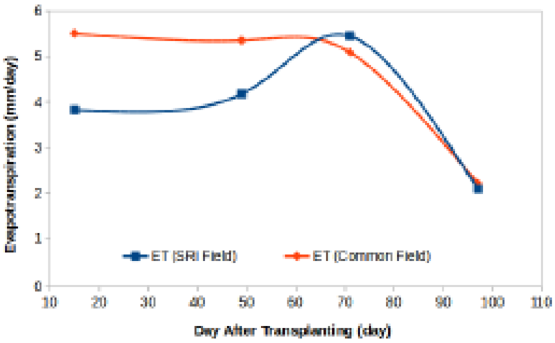


Figure 4. Evapo-Transpiration for SRI field and Common field

3.4 Discussion

Crop yield in this experiment shows almost no difference for both SRI field (3.6 ton/ha) and Common field (3.7 ton/ha), but still, Common field shows higher result. Visual observation in root shows that SRI paddy develops good rooting system than common paddy. It implies that SRI paddy was supposed to have more space for higher nutrient uptake. However, the opposite were happened. The yield itself were unlike many other research that showed dramatic increase in biomass and crop yield for SRI field [9], [11]–[13] Comparison for some items observed in both SRI and Common field showed in Table 1. The only item that SRI field is higher than Common field is Weight of 1000 grains.

Observing Available-N and ET in above data, it can be concluded that both parameters interact simultaneously to create uptake process for paddy. Available-N act as stock factor which determine how much maximum nitrogen can be absorbed by plant root, while ET act as pulling factor which the uptake energy is provided from. Simple if-then conclusion could be made such as ; if available-N is enough, and ET is high, than Nitrogen uptake is also high. Conversely, lower available-N and lower ET resulting low nitrogen uptake. Hence, filling the gap between low-high ET and low-high Available-N, the possibilities of nitrogen uptake are presented in Table 2.

Table 1. Comparison of Items, Observed for SRI field and Common field

Items Observed	SRI field	Common field
Nitrogen content per gram of dry mass		v
Weight of 1000 grains	v	
Soil Available-N		v
Vegetative stage of Evapo-Transpiration		v
Crop Yield		v

Table 2. Possibility of Nitrogen Uptake considering Available-N and Evapo-Transpiration

	Available-N Low	Available-N medium	Available-N high
Evapo-traspiration low	low	low	low
Evapo-traspiration medium	low	medium	medium
Evapo-traspiration potential	low	medium	high

Available-N is suspected to be the result of aerobic microbial activity. It provides more available-N to soil by decomposing organic-N. The only factor that suspiciously limiting available-N in soil is decomposition rate or mineralization, as the amount of total-N is abundant in soil.

Generally, N mineralization decreases in lower soil moisture especially in dry-air soil[14]. It restrains microbial activities for decomposing organic matter. However, alternate wetting-drying irrigation in SRI field don't create dry-air soil. Soil were drying to certain level of moisture content that still tolerable for plant to grow well. The possibility is now lies on biochar application. Biochar application to soil were reported to reduce N_2O emissions. In addition to biochar application, soil aeration may also contribute to the suppression of N_2O release [15]. In the nitrogen cycle, N_2O emission comes from mineralized Organic-N that finally released into air. Reducing N_2O emissions means decreasing in nitrogen mineralization.

Soil in SRI field develop cracks when drying, which means it shrinking. The shrinking causes void ratio reduces and makes the air difficult to enter (low aeration) [16]. Different from soil without shrinking-swelling properties, reducing moisture content still maintain it void ratio and spare some pore spaces for aeration. Thus, the soil condition in SRI field is soil with biochar application and low aeration. There is challenging question to understand aerob-anaerob or shrinking-swelling condition in SRI field related to available-N.

Evapo-Transpiration is always in potential value during vegetative stage, because soil is sufficiently wet for paddy to grow. However, there is a difference in ponding and non-ponding evaporation for Common and SRI field. There is also possibility of difference in fraction of Evaporation and Transpiration for both SRI and Common field that make most SRI practice resulting higher biomass and yield. Although evapo-transpiration in Common field higher during vegetative stage, this research shows only slight difference in crop yield.

4.0 CONCLUSIONS

It is shown that nitrogen uptake is a product of soil nitrogen availability and evapo-transpiration. High nitrogen uptake is usually a result of high evapo-transpiration that brings soil nutrition to leaves. However the available-N in soil act as limiting factors for nitrogen uptake. Slight difference in available-N for SRI and Common field and its respective crop yields confirms the hypothesis. It is still unkown the effect of shifting from anaerob-aerob or shrinking-swelling combine with biochar applicaition to nitrogen availability.

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