論文の内容の要旨

農　学　国　際　専　攻
平成２２年度博士課程入学
氏　名 クスヌル　アリフ
指導教員名　溝口　勝

論文題目　Optimizing Water Management in System of Rice Intensification Paddy Fields by Field Monitoring Technology

(フィールドモニタリング技術による SRI 水田の最適水管理に関する研究)

Chapter 1: Introduction

Water consumption and greenhouse gas emissions have emerged as major issues in rice production. Conventional rice farming with application of continuous flooding is not essential to achieve good yields and is known as a major source of greenhouse gas emissions from paddy fields. Hence, 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. The main challenge in the application of SRI is finding the optimal water management to raise yield and water productivity and to reduce greenhouse gas emissions simultaneously. To achieve this goal, improving the technology for collecting precise field data is important through continuous measurements of related variables by a field monitoring system (FMS). Therefore, the main objectives of this study were to develop and evaluate the FMS for SRI paddy fields with different irrigation regimes, to identify effects of irrigation regimes on yield and water productivity and greenhouse gas emissions, and then to find the optimal irrigation regime for maximizing yield and water productivity and reducing greenhouse gas emissions.

Chapter 2: Data Acquisition by Field Monitoring System for SRI Paddy Fields in Indonesia

In this chapter, a method of data acquisition was presented. Here, we used the FMS consisting of a FieldRouter equipped with a surveillance camera and connected to meteorological and soil data loggers. The meteorological data consisted of solar radiation, air temperature, relative humidity, wind speed, wind direction, and precipitation, while soil data consisted of soil moisture and soil temperature. The FieldRouter was set to automatically work from 12:00 to 12:30 PM (local time) regulated by a timer to collect the data, and then to send the data as well as a plant image to the data server through the GSM connection. The FMS was installed in Nusantara Organic SRI Center (NOSC), Nagrak, Sukabumi, West Java, Indonesia. Four SRI paddy plots under different irrigation regimes were monitored by the FMS. The FMS was demonstrated to be effective, efficient and reliable in monitoring the plots during 2010-2012. The actual field conditions were monitored well in terms of image, numeric, and graphic data. The data were then used for further analyses to find the optimal water management in SRI.

Chapter 3: Soil Moisture Estimation in SRI Paddy Fields using Neural Network

In this chapter, neural network (NN) models were proposed to estimate soil moisture based on meteorological data. Sometimes during the above monitoring period, some soil moisture data were lost by unexpected problems in the field, where the sensor was broken, the cable was unplugged or the data logger battery was depleted. Therefore, the motivation of this chapter was to solve the problems. We developed two NN models; the first model was developed to estimate reference evapotranspiration (ETo) according to maximum, average, and minimum values of air temperature and solar radiation; the second model was to estimate soil moisture according to the estimated ETo and precipitation. As the results of NN performance, ETo was accurately estimated by the first NN model with R^2 values of 0.95 and 0.92 ($p<0.01$) for training and validation processes, respectively. Then, the second model estimated soil moisture with R^2 values of greater than 0.70 ($p<0.01$) for the processes. Thus, the tight correlations between observed and estimated values of soil moisture were generated by the models.

Chapter 4: Field Monitoring Data for Estimating Non-Measurable Water Balance Variables

Water balance variables such as irrigation water, runoff, percolation, and crop evapotranspiration (ETc) are required to evaluate effects of irrigation regimes on yield and water productivity. However, the variables were not easily measured in the fields. Therefore, an Excel Solver method was proposed to estimate the variables based on the monitored and estimated data in chapters 2 and 3. The method was reliable as indicated by R^2 values of greater than 0.90 ($p<0.01$) between observed and calculated values of soil moisture. As supporting evidences of the model reliability, a significant linear correlation of $R^2 > 0.90$ ($p<0.01$) was recognized between precipitation and estimated runoff. Also, a well-matching relationship between the total inflow and outflow was observed for all irrigation regimes.

Chapter 5: Crop Coefficient for SRI Paddy

In this chapter, we used the estimated ETc in chapter 4 to determine crop coefficient (Kc) values for the SRI paddy. Usually, Kc value is estimated by using the lysimeter method. But the method is time consuming and expensive for equipment preparation. Therefore, we proposed a simple method using Excel Solver to estimate ETc, and then the estimated ETc was used to determine Kc value. Here, we evaluated the method by comparing the estimated ETc and the ETc derived from the FAO procedure. The result showed that the estimated ETc had a highly significant correlation to the ETc derived from the FAO procedure. Then, the Kc value was well determined using the estimated ETc. The Kc value gradually increased in the initial and crop development stages, and it reached a peak in the mid-season stage. Then, the Kc value declined rapidly in the late season stage. The Kc trend agreed with the typical Kc trend described by the FAO procedure for most crops.

Chapter 6: Optimizing SRI Water Management using Genetic Algorithm

In this chapter, water management in SRI was optimized by a genetic algorithm (GA) model to maximize yield and water productivity based on the monitored and estimated data in chapters 2, 3, and 4. Before performing optimization, a formula to describe yield by plant growth parameters was identified using multiple linear regression analysis. Then, the plant growth parameters were estimated by the NN model using the soil moisture data set. The results showed that plant growth and yield were clearly affected by irrigation regime. Then, according to the identification results, the optimal irrigation regime was represented by the optimal combination of soil moisture levels for the growth stages. The GA model recommended the optimal combination of soil moisture levels of 0.622, 0.563, 0.522, and 0.350 cm^3/cm^3 for the initial, crop development, mid-season, and late season growth stages, respectively. By this scenario, it was estimated that the yield can be increased up to 6.33% and water productivity up to 25.09% with water saving up to 12.71%.

Chapter 7: Effects of Water Management on Greenhouse Gas Emissions from SRI Paddy Fields

Since the FMS was not yet equipped with greenhouse gas sensors and their data loggers, experiments to investigate effects of irrigation regimes on greenhouse gas emissions were carried out separately in the greenhouse of Meiji University in Kanagawa Prefecture, Japan. There were two experiments, i.e., using lysimeters and pots with three different regimes and two replications in each experiment. We called the regimes as continuous flooding, combination, and intermittent drainage regimes for the lysimeter experiment, while wet, medium, and dry regimes for the pot experiment. As the results of both experiments, greenhouse gas emissions were clearly affected by water management. The combination regime was found to be the best strategy for mitigation of greenhouse gas emissions achieving a greater rice yield than the others, with water saving up to 16.92%. Meanwhile, in the pot experiment, the dry regime was the best for the mitigation, but this regime resulted in a lower yield than the wet regime.

Chapter 8: General Discussion

All of the findings of this study were discussed in this chapter. By adopting quasi-real time monitoring, the developed FMS was more power saving and Internet cost effective than real time monitoring. The field data were collected properly and could be used to find the optimal SRI water management. The proposed methods were reliable as indicated by their acceptable performances. The optimal SRI water management was the combination of soil moisture levels of wet, wet, medium, and dry for the initial, crop development, mid-season and late season stages, respectively. In the initial and crop development stages, the field should be kept at the wet level because the plants need enough water to meet their requirements for optimally developing root, stem, leaf and tiller. Meanwhile, in the mid-season stage the field should be drained to make the field in the medium level when plants are focusing on their reproductive period to avoid spikelet sterility. Finally, in the last season stage, the field should be drained to make the soil in the dry level to save water because all plant organs have perfectly developed. Following the one season experiment for examining effect of water management on greenhouse gas emissions in the lysimeter experiment, the combination regime with the application of mid-season drainage was found as the best mitigation strategy against greenhouse gas emissions from SRI paddy fields. The lowest gas emission was mainly caused by significantly reduced methane emission when the water was drained in the mid-season stage in this regime. This result agreed with the previous study that suggested mid-season drainage irrigation as an effective option to reduce greenhouse gas emissions.

Chapter 9: Conclusions

Finally, in chapter 9, we drew conclusions from the results described in the previous chapters. Based on the FMS data, the optimal SRI water management to maximize yield and water productivity could be well determined by the proposed methods, i.e., the NN models, the Excel Solver method, multiple linear regression analysis and the GA model. For further studies, the utilization of FMS for SRI paddy fields may be enforced with greenhouse gas sensors and their data loggers. Then, the optimal water management can be determined not only for maximizing yield and water productivity but also for reducing greenhouse gas emissions.