PRACTICAL EVALUATION OF ICT SMART AUTOMATED SLUICE GATE FOR PADDY FIELDS FROM THE ASPECT OF AN ADDITIONAL FUNCTION OF PONDING WATER TEMPERATURE CONTROL

Masaomi Kimura[1], Wenpeng Xie[1], Katsunori Shimomura[2], Takeshi Tsuji[3,4] and Kiichiro Katsumata[5]

ABSTRACT

Enhancing the productivity of paddy rice per labor cost of farmers is crucial for a future that is expected to encounter several problems, such as the aging of farmers and decreasing number of successors. As some statistical analyses have indicated, labor associated with daily water management, such as opening/shutting inlet/outlet gates of paddy fields for irrigation and drainage, accounts for the major proportion of the total labor time for cultivating paddy rice.

In recent years, technical innovation in the discipline of water management in paddy fields has shown steady progress, thereby enabling the reduction of labor associated with daily water management. ICT smart automated sluice gates for paddy fields is one of the solutions that enable remote control of inlet and/or outlet gates of paddy fields as well as automatic scheduling of irrigation and drainage. While it may be easy to understand the usefulness and effectiveness of such automated gates for reducing labor costs, these gates may bring in an additional advantage by enabling the control of ponding water temperature in paddy fields. The damage to rice grains due to high temperatures is one of the major concerns in Japan. Thus, being able to control the water temperature in paddy fields would be beneficial to several paddy rice farmers who want to avoid excessive increase in the water temperature, especially during extremely hot summers.

We performed field experiments in two paddy plots in different regions in Japan, where ICT automated gates were installed at each inlet. In one of the experimental plots, an ICT automated gate was also installed at an outlet of the paddy fields. We will present the experimental findings, focusing on the spatio-temporal variation of the ponding water temperature and the effect of scheduled water management by utilizing ICT automated gates on decreasing the water temperature.

Keywords: Paddy ponding water, Adaption strategy, Climate change, Paditch Gate, Labor saving for paddy water management, Japan

1. INTRODUCTION

Recently, high temperature damage to the ripening rice grains has been a big concern in Japan. It reduces yield, produces inadequately felled grains, and causes cracking of rice grains and milky white kernel. In addition to reduced rice yield, the quality of rice is also degraded. These adverse effects were conspicuous in the extremely hot summer of 2010 when the first-class rice rate came down to 62%, which is ordinarily about 80% (Nakagawa, 2013). High temperature damage is thought to be mainly caused by high temperature on days after rice heading (Morita, 2008). The quality of cultivated rice

[1] Graduate School of Agricultural and Life Sciences, The University of Tokyo. 1-1-1 Yayoi Bunkyo-ku Tokyo 113-8657 JAPAN; E-mail: akimur@mail.ecc.u-tokyo.ac.jp

[2] Enowa Co.,Ltd.

[3] Graduate School of Regional Innovation Studies, Mie University

[4] Tarafuku Rice Farm

[5] Drone Japan Co., Ltd.

grain is reduced due to high water temperature which may also lead to the value decrease of rice production. When the daily average temperature exceeds 28 degrees, the risk of high temperature damage increases extremely. From the analysis of variance and multiple regression analysis, 1 degree increase in daily minimum temperature during 10 to 30 days after heading reduced the ratio of first-class rice by 3.57%. Nowadays, some effective measures are proposed to prevent the damage, such as cultivar improvement, fertilizer management, delay of rice planting, paddy water management, and so on. Among them, the paddy water management is indeed one of the simplest ways for famers.

On the other hand, the future projections of Japanese rice farmers estimated by several institutes using various statistical data show that the Japanese rice farming faces complex and serious problems such as the aging of farmers and decreasing number of successors. Therefore, enhancing the productivity of paddy rice per labor cost of farmers is crucial for a future that is expected to encounter such kind of problems. As some statistical analyses have indicated, labor associated with daily water management, such as opening/shutting inlet/outlet gates of paddy fields for irrigation and drainage, accounts for the major proportion of the total labor time for cultivating paddy rice. In recent years, technical innovation in the discipline of water management in paddy fields has shown steady progress, thereby enabling the reduction of labor associated with daily water management. ICT smart automated sluice gates for paddy fields is one of the solutions that enable remote control of inlet and/or outlet gates of paddy fields as well as automatic scheduling of irrigation and drainage. While it may be easy to understand the usefulness and effectiveness of such automated gates for reducing labor costs, these gates may bring in an additional advantage by enabling the control of ponding water temperature in paddy fields. Considering the fact mentioned above that the damage to rice grains due to high temperatures is one of the major concerns in Japan, being able to control the water temperature in paddy fields would be beneficial to several paddy rice farmers who want to avoid excessive increase in the water temperature, especially during extremely hot summers.

In this study, field experiments were performed in two paddy plots in different regions in Japan, where ICT automated gates were installed at each inlet. In one of the experimental plots, an ICT automated gate was also installed at an outlet of the paddy fields. We will present the experimental findings, focusing on the spatio-temporal variation of the ponding water temperature and the effect of scheduled water management by utilizing ICT automated gates on decreasing the water temperature. In this paper, we will also focus on the description of the numerical models that can represent the mechanisms of water temperature variation in paddy ponding water by combining a heat balance model among air-rice plants-water-soil with 2-dimensional flow analysis models.

2. METHODS

2.1 Field experiments

Two observation paddy plots were selected from Toyama prefecture and Mie prefecture in Japan. Plot A is located at 36°39'16" N, 137°17'51" E in Toyama prefecture, and plot B is located at 34°46'20" N, 136°29'28.95" E in Mie prefecture. In plot A, an ICT automated gate (Paditch Gate, Enowa Co.,Ltd.) is installed at its inlet (**Figure 1**) so that the paddy farmer can control the gate and manage the irrigation to the paddy plot remotely at arbitrary timing. Plot A can access relatively cool and large amount of

Figure 1. Paditch Gate (ICT smart automated sluice gate) installed at plot A.

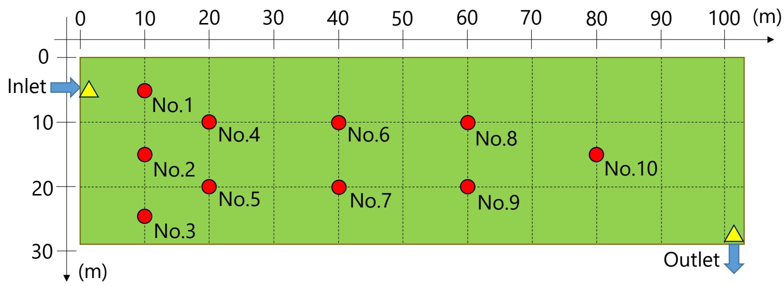

Figure 2. Observation points of water temperature and depth of ponding water in plot A.

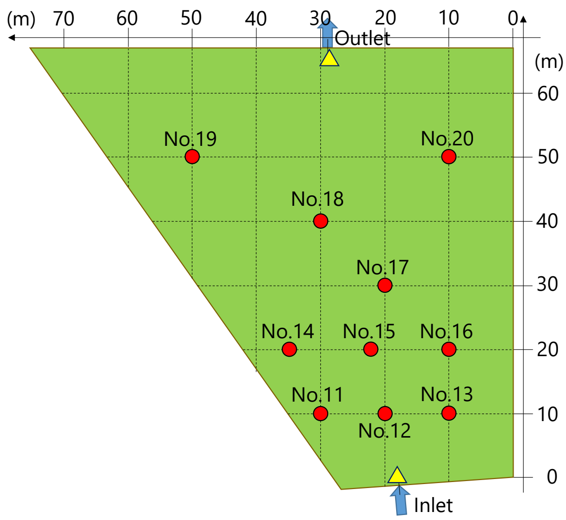

Figure 3. Observation points of water temperature and depth of ponding water in plot B.

irrigation water from its mountainous basin. Plot B has an ICT automated gate installed at its outlet as well its inlet so that both of irrigation and drainage management can be controlled remotely. In addition, the Paditch Gate also has the scheduled operation function which can be set thorough a web site. Since plot B is located downstream of branch irrigation channel and it is hard to access relatively cooler and larger amount of irrigation water, the daily operation schedule of ICT automated gates installed at plot B was set as follows; the Paditch Gate at inlet opens at 10:00 and closes at 18:00 and the gate at outlet opens at 15:00 and closes at 5:00. The above schedule was considered to be effective to suppress the water temperature increase since it is figured out by previous studies that the shallower the ponding water depth is at nighttime, lower the peak of water temperature becomes because of the lowered heat capacity of the ponding water.

In order to grasp the spatio-temporal variation of ponding water temperature in each plot, ten temperature loggers (HOBO MX2201, Onset) were deployed, respectively, the place where they were set is illustrated in **Figure 2** and **3**. An auto-capturing camera (TLC 200, Brinno) was also installed at inlets scoping the ICT automated gate to capture the situation around the gate every 30 min. as well as the temperature and depth loggers (HOBO U20, Onset) were installed at inlet and outlet as illustrated in **Figure 2** and **3**. Meteorological data (air temperature, relative humidity, atmospheric pressure, wind speed, solar radiation) during the observation term was also obtained by the weather station (ATMOS 41, Meter) installed adjacent to each plot.

2.2 Numerical models

In this section, the numerical algorithms will be described which were developed by the authors in order to simulate temperature distributions of paddy ponding water and evaluate the efficiency of decreasing ponding water temperature by utilizing the automated sluice gates. **Figure 4** shows the schematic diagram of the numerical models (layer model) which consist of three parts (rice leaves, water body, and underground soil) described below. This layer model referred to several previous related studies (e.g. Yoshida et al., 2013).

The basic equation for the heat balance of leaf surface is given as;

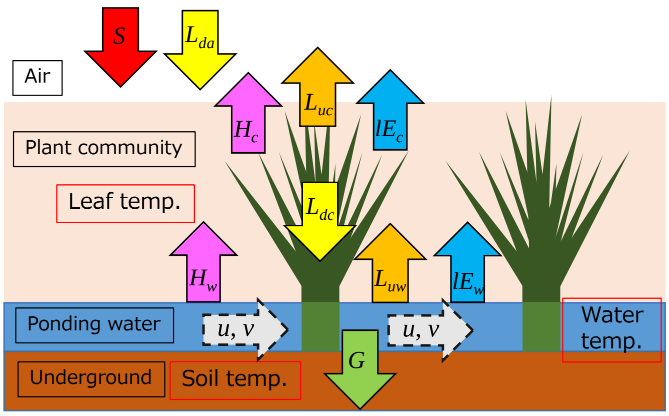

Figure 4. Schematic diagram of the numerical models for thermal energy exchange considering the flow velocity of ponding water in a paddy plot.

$$\frac{\partial T_c}{\partial t} = \frac{R_{nc} - H_c - lE_c}{c_c \rho_c l_c LAI} \qquad (1)$$

where, T_c is plants community temperature, R_{nc} is net radiation to the vegetation layer, H and lE are sensible heat flux and latent heat flux, respectively. c_c is specific heat of leaves, ρ_c is leaf density, l_c is leaf thickness and LAI is leaf area index.

The net radiation R_{nc} can be expressed by following equation;

$$R_{nc} = (1 - f_v)\{(1-\alpha_c)S + L_{da} + L_{uw} - L_{uc} - L_{dc}\} \tag{2}$$

where S is solar radiation, α_c is albedo of vegetation, L_{dc} and L_{da} are downward long wave radiation of plants and atmosphere, respectively. L_{uc} and L_{uw} are upward long wave radiation of plants and water, respectively. f_v is radiation transmittance of vegetation which is expressed by the following equation;

$$f_v = \exp(-k \cdot LAI) \tag{3}$$

where k corresponds to the degree of extinction. Subscription a, w, c means atmosphere, paddy water and vegetation, respectively.

The basic equation for the heat balance of water body is given as;

$$\frac{\partial T_w}{\partial t} + u\frac{\partial T_w}{\partial x} + v\frac{\partial T_w}{\partial y} = D_w\left(\frac{\partial^2 T_w}{\partial x^2} + \frac{\partial^2 T_w}{\partial y^2}\right) + \frac{R_{nw} - H_w - lE_w - G}{\rho_w c_w h} \tag{4}$$

where u and v are the components of x and y axis of flow velocity of ponding water, respectively, which are given by solving the shallow water equations considering the resistance of rice bunches represented by drag coefficients (Kimura et al., 2015). D_w is diffusion coefficient of water temperature, G is heat flux to the ground and h is water depth. The net radiation R_{nw} can be expressed by following equation;

$$R_{nw} = f_v\{(1-\alpha_w)(1-\alpha_c)S + L_{da}\} + (1 - f_v)L_{dc} - L_{uw} \tag{5}$$

In order to calculate the soil heat flux G, the vertical soil temperature distribution is estimated by following equation.

$$\frac{\partial T_g}{\partial t} = D_g\frac{\partial^2 T_g}{\partial z^2} \tag{6}$$

where T_g is soil temperature, D_g is thermal conductivity of paddy soil and z is depth from the soil surface. In this study the upper boundary condition was set as water temperature and the lower boundary condition was set as the annual average air temperature of the observation field.

Form the soil temperature distribution, G was calculated by following equation.

$$G = c_g \rho_g \int_0^D \frac{\partial T_g}{\partial t} dz \tag{7}$$

3. RESULTS AND DISCUSSION

The discharge of water taken through the Paditch Gate at inlet of each plot was calculated by utilizing the equation of overflow discharge of weirs and the observed water level at upstream of the gate. The time series of calculated discharge and the observed water depth near the inlet and outlet at each plot are shown in **Figure 5** and **6**. The functions of the ICT automated gates in terms of the remote scheduled paddy water management were easily confirmed by the results. However, while the value of discharge was relatively high always when the gate was opening at plot A, the discharge of plot B showed almost none at several timings even when the inlet gate was opening. These phenomena were considered to be caused by the lack of irrigation water in the connected channel. Hence, it should be noted that the efficiency of deployment of the ICT automated gates strongly depends on the availability of irrigation water at the installed point, such as water pressure in pipelines or water level in open channels.

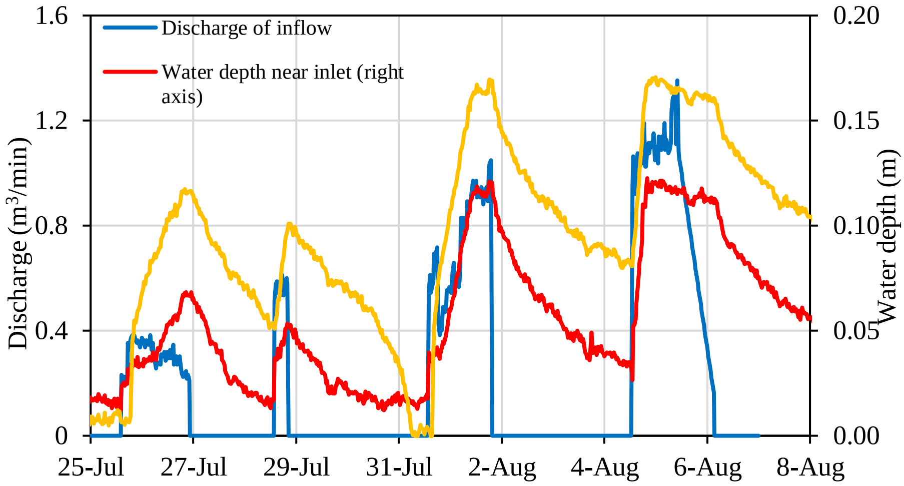

Figure 5. Discharge of inflow from the ICT automated gate and water depth near the inlet and outlet at plot A

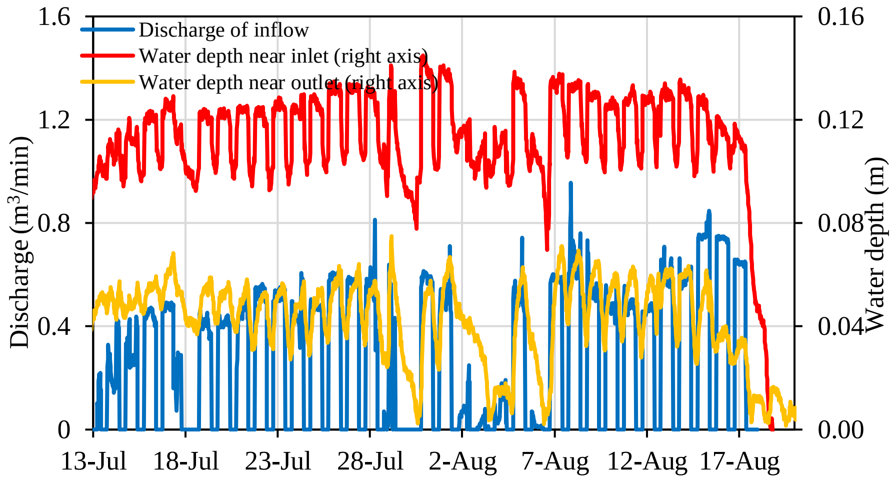

Figure 6. Discharge of inflow from the ICT automated gate and water depth near the inlet and outlet at plot B

The time series of water temperature obtained at ten points inside the paddy plot are illustrated in **Figure 7** and **8**. The water temperature variation showed a tendency that the closer it is to the inlet point of paddy fields, the cooler the ponding water was. Therefore, it is revealed that the water temperature near the inlet was easily lowered during the gate opening period compared to the other position. The magnitude of efficiency to suppress the water temperature rising seemed relatively higher in plot A compared to that in plot B, as the temperature of the available irrigation water to plot A was lower than plot B.

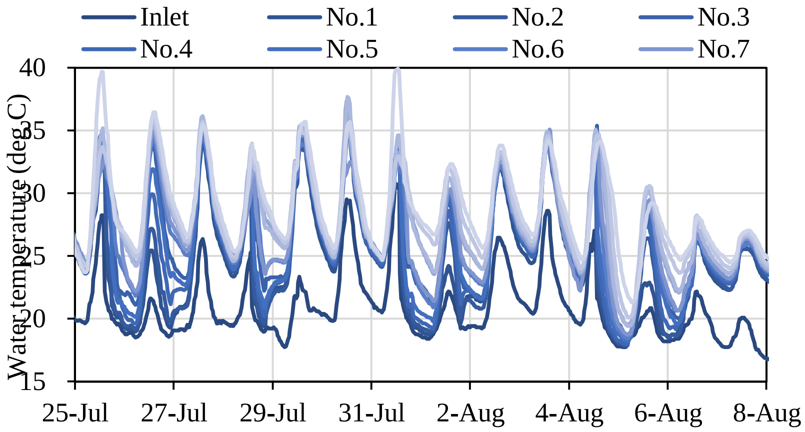

Figure 7. Time series of ponding water temperature distribution in paddy plot A

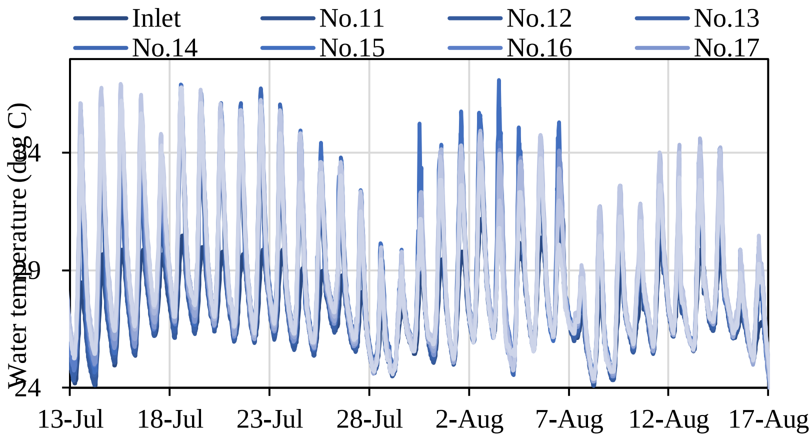

Figure 8. Time series of ponding water temperature distribution in paddy plot B

4. CONCLUSIONS

In this study, field experiments were performed in two paddy plots in different regions in Japan, where ICT automated gates were installed at each inlet in order to clarify the additional function of the gates in terms of ponding water temperature control. The observed results showed the firm reliability of remote scheduled ICT automated gate management. However, the efficiency of deployment of the ICT automated gates strongly depends on the availability of irrigation water at the installed point, such as water pressure in pipelines or water level in open channels. The observed variation of ponding water temperature suggested a possibility of temperature management in thermal environment in paddy plots which may contribute to deciding the adaption strategy against high temperature damage to rice grains by paddy water management controlled by the ICT automated sluice gates in future. Further quantitative analysis regarding the effect of scheduled paddy water management on decrease of the ponding water temperature rise is undergoing and the results and findings will be performed.

REFERENCES

Morita, S., 2008. Prospect for developing measures to prevent high-temperature damage to rice grain ripening, Japanese Journal of Crop Science, 77(1), 1-12 (in Japanese with English abstract).

Nakagawa, H., 2013. High-temperature damage to grain ripening in rice, Water, Land and Environmental Engineering, JSIDRE, 81(4), 52 (in Japanese).

Yoshida, K., Azechi, I., Kuroda, H., 2013. Application of two-layer heat balance model for calculation of paddy thermal condition, Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering), 69(4), I_139-I_144.

Kimura, M., Kouketsu, H., Iida, T., Kubo, N., 2015. A calculation method for two-dimensional ponding water flow on a paddy field plot with rice plants, Irrigation, Drainage and Rural Engineering Journal, 83(1), 47-58 (in Japanese with English abstract).