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Evaluation of Automatic Irrigation System in Paddy for Water and Energy Saving and Environmental Conservation

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ABSTRACT: In Japan, water delivery system for agriculture was highly-developed and managed by land improvement district. The 1st priority of irrigation is water supply to avoid the water stress, however, saving a labor input for agricultural land management such as weed control also the important factor. Therefore, farmers want to input much water for their paddy to save a labor cost. However, much irrigation water leads much energy consumption for pumping, as a result, water fee also increase. In addition, increase of drainage water cause a much nutrient load effluent to downstream water environment. In this study, the automatic irrigation system was evaluated to improve the water management system in paddy without the additional labor input. Kashima district, which was managed by Inbanuma land improvement district, Japan was selected for the test site. Water amount and nitrogen concentration was monitored at Iino pumping station and paddy drainage pipe. Meteorological data were also observed at Iino pumping station for calculation of evapotranspiration. From the monitoring data, water balance and nitrogen balance was estimated. Then, by using the water management model, the effect of automatic irrigation system was evaluated in the view point of water and energy saving and nitrogen load mitigation.

Keywords: Agricultural water use, Paddy, Nitrogen load, Inbanuma, Japan

1 INTRODUCTION

Irrigation is essential for food production especially in paddy rice, and much water has been withdrawn from water sources compare to other water use sector (Cantrell 2004). In Japan, water delivery system for agriculture was highly-developed and managed by LID (Land Improvement District) (Iida et al. 2013). Fig.1 shows the relation of provider and receiver of agricultural water delivery services. Provider is LID who is in charge of not only the water transfer but also the operation and maintenance of irrigation facilities. And service receivers are farmers who pay water fee to LID and can get water in any time they want.

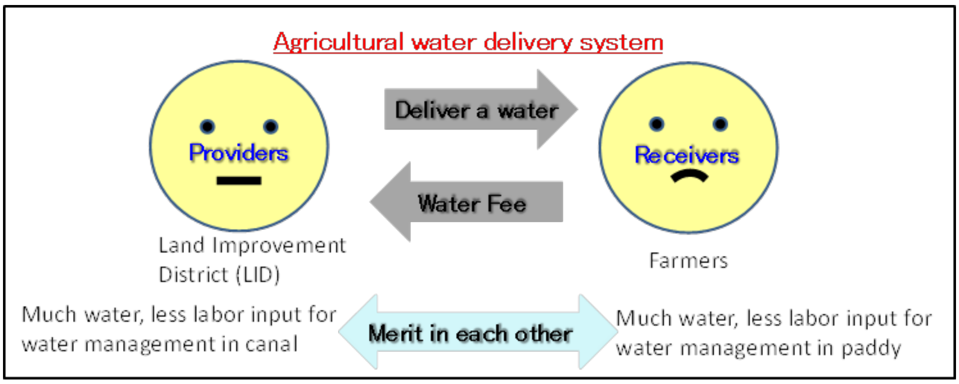

Figure 1. A relation of service provider and receiver in agricultural water delivery system

The 1st priority of irrigation is water supply to avoid the water stress, however, saving a labor input for agricultural land management such as weed control or water temperature control also the important factor. Therefore, farmers want to input much water for their paddy to save a labor cost (Mizutani et al. 1999). The relation between water use amount and farmer labor input was shown in Fig.2. Normally, most of paddy farmers are part-time farmers in Japan who have another job in weekday, therefore they go to their paddy in the morning to open the water bulb and they go to paddy again to close it in evening after they finish the work. However, if paddy water can be controlled automatically, they don't need to go their paddy field in every day. For example, in case of water delivered by pipeline system, farmer just left the bulb open and water is charged when the pumping system is working and water stop when pump is stopped. On the other hand, in the provider side also, much water leads less labor input for water management for operation. When water shortage occurred in some area, farmers complain to LID stuffs, therefore it is convenient for LID to take some margin of water to control the system in safety. That is one reason why irrigation water use has not decreased so much compared to the reduction of paddy cultivation area. However, much irrigation water leads much energy consumption for pumping, as a result, water fee also increase. In addition, increase of drainage water cause a much nutrient load effluent to downstream water environment, because nitrogen load can be calculated multiplying drainage water amount (m^3) by nitrogen concentration (mg/l) (Sadler et al. 2005; Clemmens et al. 2008). Historically, water delivery system in paddy agriculture has been supply-oriented system. However recent innovation of pipeline, field monitoring or automatic regulation system will change it to demand-oriented system. In this study, the automatic irrigation system was evaluated to improve the water management system in paddy without the additional labor input. Kashima district, which was managed by Inbanuma land improvement district, was selected for the test site. Water amount and nitrogen concentration was monitored at Iino pumping station and paddy drainage pipe. Meteorological data were also observed at Iino pumping station for calculation of evapotranspiration. From the monitoring data, water balance and nitrogen balance was estimated. Then, by using the water management model, the effect of automatic irrigation system was evaluated in the view point of water and energy saving and nitrogen load mitigation.

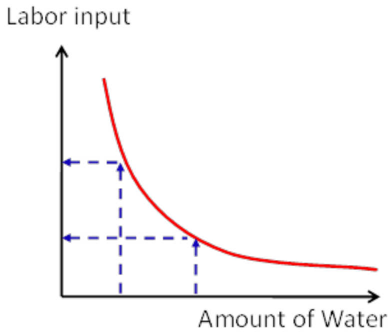

Figure 2. A relation of amount of water use and labor input in paddy

2 FIELD MONITORING

2.1 *Study Area*

For the test site, Kashima district was selected which was managed by Inbanuma land improvement district and having 46.1 ha benefit area (Fig.3). Fig.4 shows the monitoring paddy fields having 5.94 ha. All of these paddy fields were cultivated by same farmer group. Irrigation water was pumped up from Inbanuma lake, and water from paddy was drained to Inbanuma again flowing through Kashima river. In this paddy fields, open type drainage canal was not existed and subsurface drainage system was installed in all paddies so that all drained water, which was percolated through paddy soil layer and overflowed from paddy outlet, gathers to drain pipe. Inbanuma lake is closed water area and eutrophic lake (Nakamura et al. 2008; Hayashi et al. 2009). Therefore, drainage water from paddy fields was one of the diffuse pollution sources. Although drainage water from paddy have relatively low nutrient concentration compare to that from upland agriculture, drainage water amount from paddy is much more. In addition, there are 7,370 ha paddies within the catchment of Inbanuma lake which occupied 15.7% of land use. Therefore, nutrient load from paddy fields could not be negligible for the conservation of lake water environment.

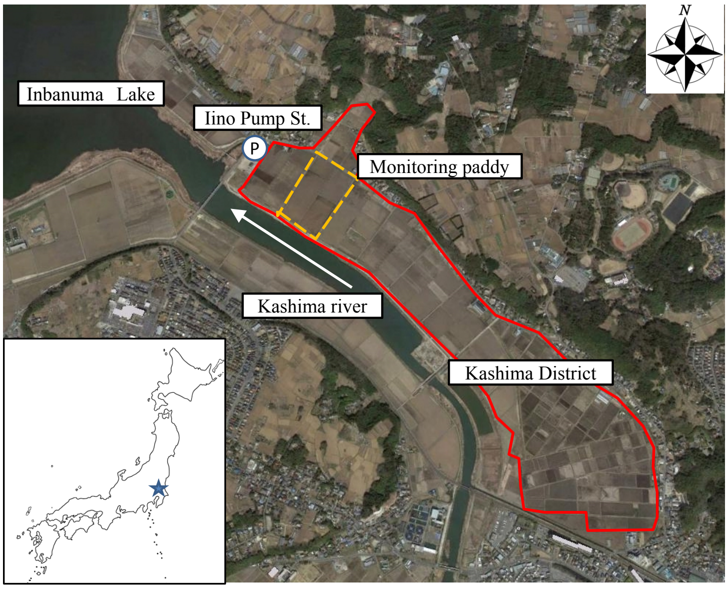

Figure 3. Outline of Kashima irrigation district

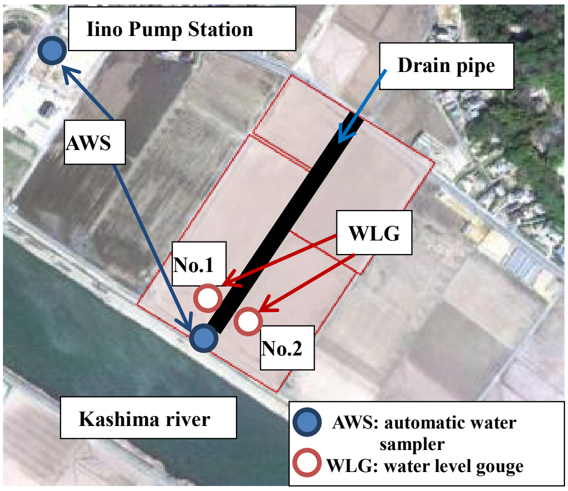

Figure 4. Monitoring paddy fields

2.2 *Monitoring Items*

To evaluate the water balance such as how much water was irrigated, evaporated and drained, paddy water level was monitored in hourly basis at 2 paddies by using HOBO U20 water level loggers (Onset Co. Ltd.). In addition, to evaluate the nitrogen balance, water quality at Iino pumping station and paddy drainage pipe was measured in daily basis (at noon) such as soil sediment (SS), total nitrogen (TN), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), chemical oxygen demand (COD), dissolved oxygen (DO) and PH. Meteorological data also measured by using Field Router system at Iino pumping station for calculating evapotranspiration. The Field Router is Quasi real-time monitoring system that consists of a CPU (Web server), AD converter, DA converter, Ethernet controller, high-intensity LED lighting, and sensors such as air temperature, relative humidity, solar radiation, soil moisture, soil temperature, wind direction, wind speed and precipitation. The Field Routers are interconnected by a mobile internet (GSM/3G). Web cameras can be connected to the Field Routers, and high-resolution pictures of fields are transferred through mobile internet networks and stored on Web servers. Rice variety was Momiroman which was not a variety for human food but for livestock feeding. Observation period was from 2013/5/16 to 11/20. A questionnaire to the farmer also conducted to grasp the fertilizer input or land management practices.

3 RESULT AND DISCUSSION

3.1 *Water Balance*

From the monitored water level, irrigated water and drained water amount was calculated by using paddy water balance equation as follows.

$$h^{t+\Delta t} = h^t + (I^t + R^t - Q^t - P^t - ET^t)\Delta t \tag{1}$$

where h : paddy water level(m), I :irrigation rate(m/h), R :rainfall intensity(m/h), Q :surface drainage (m/h), P : percolation rate(m/h), ET : evapotranspiration rate(m/h), t : time, Δt : time step(=3600s). Surface drainage and percolation rate were calculated as a function of paddy water level as following equation.

$$Q = C \times B_w \times (\mathrm{h}^t - H_w)^{3/2} \times \Delta t / A \tag{2}$$

$$P = T \times h^t \tag{3}$$

where C: parameter, B_w: a width of drainage weir(m), H_w: a height of drainage weir(m), A: area of paddy field(m^2), T: percolation parameter(=0.005).

Evapotranspiration ET can be calculated from Penman-Monteith equation by using observed meteorological data, and rainfall, paddy water depth also measured so that only irrigation rate was unknown. Therefore, by the model fitting of observed water level and calculated one, irrigation rate can be estimated. Fig.5 shows fitting results of observed and calculated water level. The calculated result shows good agreement with observed data except extremely high water depth on 10/16. Huge typhoon was attacked this area on 10/16 and flood water from other land use in upstream area flowed into these paddy fields. Fig.6 shows estimated irrigation rate and other parameters related to water balance in paddy field from 5/16 to 11/20. Iino pumping station was operated until 9/1 so irrigation rate also zero after 9/1. Table1 shows water balance during observation period. At the monitoring paddy fields, rainfall was 931 mm/season (=5.0 mm/day), 2,045mm/season (=10.9 mm/day) of irrigation water was pumped up for paddy cultivation and 50.9% of supplied irrigation water was released by surface drainage from paddy outlet in current situation. Therefore there was still large possibility to save water by introducing elaborated water management system to reduce surface drainage water (Hanson and Ayars 2002).

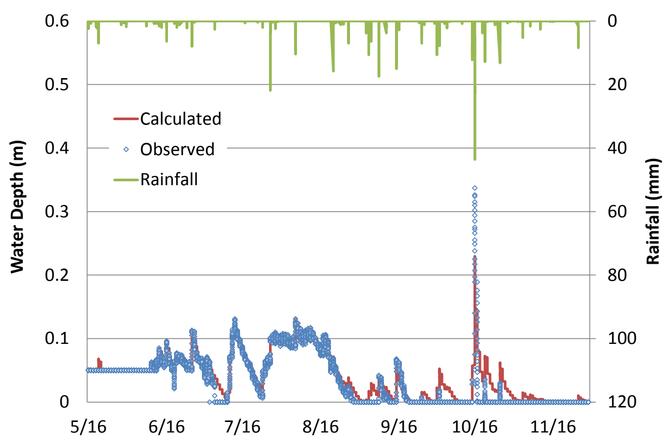

Figure 5. Comparison of observed and calculated paddy depth

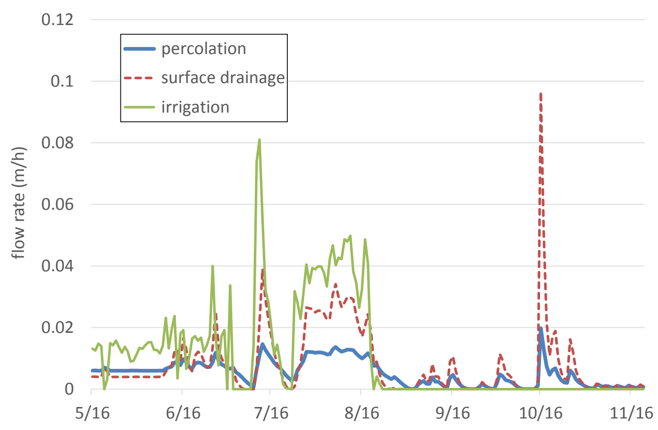

Figure 6. Estimated percolation, surface drainage and irrigation rate during observation period

Table 1. Water balance at observed paddy fields (5/16 - 11/20)

	parameters	amount(mm/period)	rate(%)
input	rainfall	931	31.3
	irrigation	2045	68.7
	(sum)	(2976)	(100)
output	surface drainage	1569	50.9
	percolation	987	32.0
	evapotranspiration	528	17.1
	(sum)	(3084)	(100)

3.2 *Nitrogen Balance*

Fig.7 shows TN concentration of Iino pumping station for irrigation intake and that of paddy drainage pipe during observation period. TN concentration of Iino station was more than 2 mg/L, because Inbanuma lake was eutrophic water source. 6/24 and 7/8,7/9 was windy day so that relatively high TN concentration might be observed because of bed load transport. However after the beginning of July, TN concentration at Iino station was reduced until less than 2 mg/L because photosynthetic of algae was activated during summer and nitrogen was absorbed by algae biomass. On the other hand, TN concentration of drainage water was relatively high at the beginning stage. Rice plant was still small at the beginning stage, therefore some of the fertilizer component was effluent from paddy outlet. Nitrogen load from paddy fields can be estimated multiplying nitrogen concentration by drainage water amount. Table2 shows nitrogen balance. In the conventional paddy field, 90-120 kg/ha nitrogen was recommended in food rice cultivation. However 154 kg/ha nitrogen was fertilized in this monitoring paddy. Because, in feed rice cultivation, farmers do not need to pay attention to a taste of rice, therefore much amount of fertilizer was input to increase the rice biomass. In addition, farmer can get manure in free from livestock sector by exchanging the rice straw and manure. Estimated nitrogen load from paddy was 36 kg/ha, it was summation of surface drainage 26 kg/ha and percolation 10 kg/ha. In Inbanuma watershed, there are 7,370 ha paddy field so that about 265 ton/season was flow into the Inbanuma lake from all paddy fields. The pollution load through surface runoff can be reduced by controlling the surface drainage water volume (Rice et al. 2001). Such water management leads water and irrigation cost saving, and pollution load to downstream water environment also can be reduced.

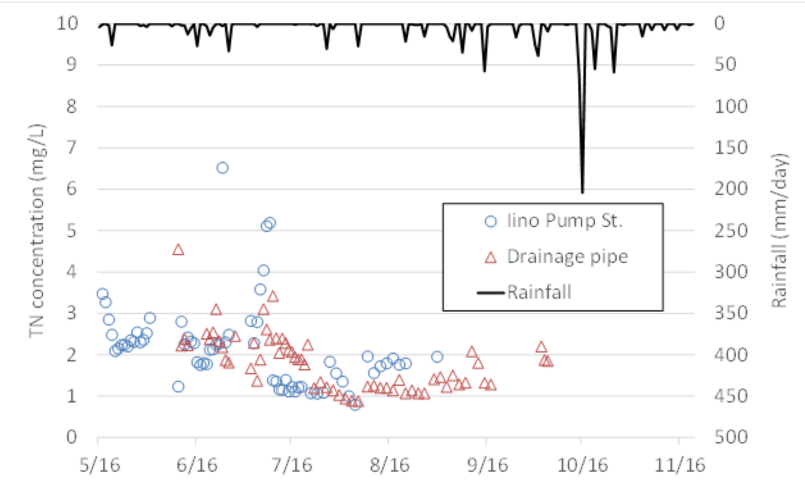

Figure 7. Observed TN concentration at Iino pump station and paddy drainage pipe

Table 2. Nitrogen Balance at observed paddy fields (5/16 – 11-20)

	parameters	amount(kg/ha)	rate(%)
input	manure	25	12.5
	chemical	129	64.5
	irrigation	39	19.5
	rainfall	7	3.5
	(sum)	(200)	(100)
output	harvest	101	50.5
	surface drainage	26	13.0
	percolation	10	5.0
	denitrification and storage in soil	63	31.5
	(sum)	(200)	(100)

3.3 *Effect of Automatic Irrigation System*

For saving water without additional farmer's labor input, automatic irrigation system was developed and introduced in some irrigation district in Japan. Fig. 8 shows schematized description of float auto irrigator. Farmers just set the target water level and auto irrigator supply water until float level become target depth.

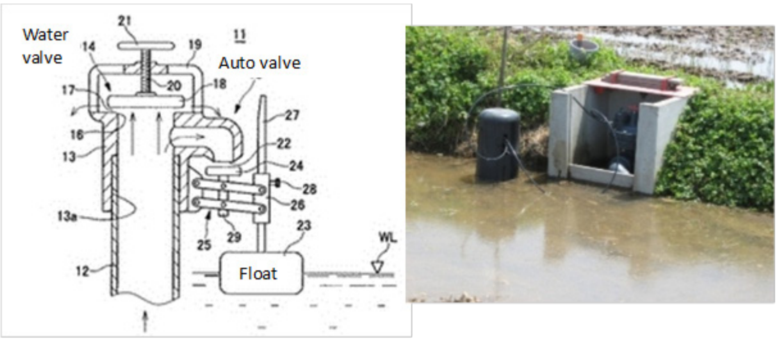

Figure 8. Schematized description of float auto irrigator

In this study, numerical simulation was conducted to evaluate the effect of this auto irrigation system on water saving and nitrogen load reduction. For the calculation, following assumptions were employed.
(1) target water level is 5cm and it is constant during irrigation period (5/16 - 9/1).
(2) auto irrigator performs perfectly. Just consumed water by percolation and evapotranspiration was supplied so that surface drainage does not occur.
(3) TN concentration of drainage water is not changed and same as current situation case.
Fig.9 shows nitrogen load change from paddy before and after installing auto irrigator. The water saving effect was about 1,335mm (65.3%) and energy consumption for pumping also can be saved. As a result, farmer can save water fee which farmer pay to land improvement district for the maintenance and operation of water delivery facilities. Nitrogen load reduction was 24 kg/ha (66.7%), which was about 177 ton nitrogen reduction in Inbanuma watershed. Especially, nitrogen load reduction of first growing stage (June, july) was 17kg/ha (47%), therefore application of auto irrigation system was relatively effective at that period.

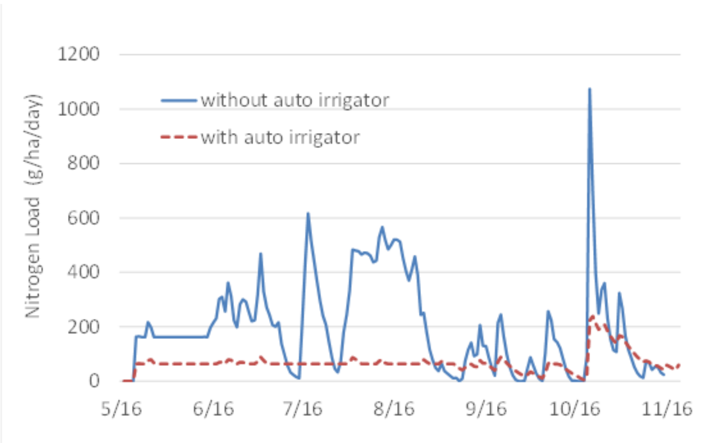

Figure 9. Nitrogen load change from paddy with and without auto irrigator

4 CONCLUSION

In this study, field monitoring was conducted to grasp the current condition of water and nitrogen balance in the paddy field. Large amount of irrigation water and nitrogen fertilizer were inputted in monitoring paddy of Kashima district, because feed rice was cultivated in this paddy. And high input of water and nitrogen leads much nitrogen load to downstream water environment. Recently, feed rice paddy area is increasing under the governmental regulation policy. Therefore, water pollution in closed type lake may become worse if feed rice paddy spread widely. Auto irrigation system is effective to save irrigation water input and pumping energy consumption and to conserve the water environment without more farmer's labor input for water management (Kim 2000; Schaible 2000).

However even after farmers install auto irrigator to their paddies, they will go to see and check paddies almost in every day. Because they afraid of their paddies without to check by their eyes. In such case, auto irrigator is not useful and not effective for them. Therefore, auto irrigator should be combined with web-camera system. Important point is that if farmer don't need to go to paddy and they can monitor their paddy in their house, for example by internet or using smart phone, auto irrigator is very useful and effective. In current situation, the distance between famer and their paddy is still close. The meaning of "distance" here is not only physical distance but also mental distance. In the near future, paddy farming structure will be changed and 1 farmer have to cultivate more than 10 ha. In such case, more new service are needed in the agricultural field also. Recently, ICT technology in agricultural filed is developed and spread rapidly so that farmer will be able to manage their paddy at their house in near future. In addition, to motivate the farmer to save water, this kind of data should be informed to them and their merit of saving water fee and effect of water saving on environmental conservation also should be explained.

ACKNOWLEDGEMENT

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