NITROGEN REMOVAL FUNCTION OF PADDY FIELD IN A CIRCULAR IRRIGATION SYSTEM

Yoshinaga Ikuo *, Y. W. Feng**, H. Hasebe*** and E. Shiratani****

* National Institute for Rural Engineering, Tsukuba Science City 305-8609 Japan
<E-mail: yoshi190@nkk.affrc.go.jp>
** JSPS Research fellow, National Institute for Rural Engineering, Tsukuba Science City 305-8609 Japan <E-mail: fengyw@nkk.affrc.go.jp>
*** National Institute for Rural Engineering, Tsukuba Science City 305-8609 Japan
<E-mail hhasebe@nkk.affrc.go.jp>
**** National Institute for Rural Engineering, Tsukuba Science City 305-8609 Japan
<E-mail ariake@nkk.affrc.go.jp>

ABSTRACT
The objective of this research work was to investigate the nitrogen removal function of a paddy field in a circular irrigation system. The paddy field was located in a lowland area by the side of a river and had an area of 4,800 m^2. The test samples and data collection was carried out once a week during the irrigation period from April to August 2002 and once a day during the paddling and transplanting period and the fertilization period. Water was sampled for measuring the concentrations of nutrients at three points (inlet point, center and outlet point of the paddy field). Except paddling and fertilization period, drainage water concentrations of total nitrogen were lower than irrigation water concentrations. The rate constants for nitrogen removal of the paddy field were evaluated during three periods. First period was just after irrigation water was applied to paddy field, second was paddling and transplanting and third was fertilizer application. The constant rate of nutrient removal has varied from 5.7 m/y to 7.7 m/y. Total nitrogen inflowed in the paddy field water was 27.9 $kg\cdot ha^{-1}$ and total outflow nitrogen discharged out of the paddy field water was 24.4 $kg\cdot ha^{-1}$. The paddy field had nitrogen removal capacity of 3.5 $kg\cdot ha^{-1}$ during observation period. This result indicates that the paddy field under investigation has good capacity of nitrogen removal.

KEYWORDS Paddy field; Nitrogen removal coefficient; Nitrogen balance; Circular irrigation system

INTRODUCTION
Nutrient load control is an important issue because eutrophication of surface water bodies in downstream side of paddy field will cause various problems due to deteoriation of water quality in these surface water bodies. Therefore, the load management is the most important for water quality environment conservation. In Japan, countermeasures against the point sources such as the factories and sewage plants have been carried out in recent years, so countermeasures against non-point sources including farmlands and livestock become more important because agricultural runoff I a major source of surface water pollution due to more use of fertilizers in current farming to end. The farmland area of Japan is about 4,800,000 ha, and the rice field accounts for 55% (MAFF, 2001). It is known that paddy fields have nitrogen purification function and this function will play an important role in executing nutrient load management of watershed. Tabuchi (1985) reported that nitrogen removal function differed greatly depending on water use and soil type. The recycling of irrigation water may reduce both irrigation water and nutrient use in agricultural catchment (Kudo et al., 1995). The objectives of this study are to investigate nitrogen removal function of a paddy field in circular irrigation system and to analyze nitrogen balance during the cultivation period.

DESCRIPTION OF STUDYFIELD
The study area is located in Yoshinuma area (36°8" north and 140°0" east), north east of Tsukuba city, ***Fig. 1***. Yoshinuma area is a typical agricultural area. Most of the land use of the area is paddy field and rest is upland field and house. The source of irrigation water is Kokai River located in the west of the area. The soil is alluvial soil, since this area is near the river. This area has 45 ha paddy field. There is circular irrigation system in 8 ha paddy field located in lower land. The circular irrigation system is pumping the irrigation water from the drainage canal. The water level of the drainage canal is kept high during irrigation period. The drainage canal gathers the surplus part of irrigation water and drainage from paddy field, upland field and household.

The investigated paddy field is in the circular irrigation system, having surface area of 4,800 m^2 (76 m x 64 m), two inlet points and one outlet point. The irrigation water is supplied from pump station. The north side and east side of the paddy field is farm road. Drainage canal is located in the south side. West side of the paddy field is also paddy field separated by concrete levee. Irrigation water volume was observed at two inlet points by cumulative flow meter.

The irrigated water volume from two inlet points is almost same. There is a little more amount of water from east inlet point than that from west inlet point, since east point was located on upper stream of irrigation pipeline. The total irrigated water was 853 mm during irrigation period. This value was less than the average of Japanese paddy field. This is because water level was kept low and because percolation potential of lower alluvial land was low. Although neighbouring farmland was covered for water on July 11 due to heavy rainfall, the study field was not covered.

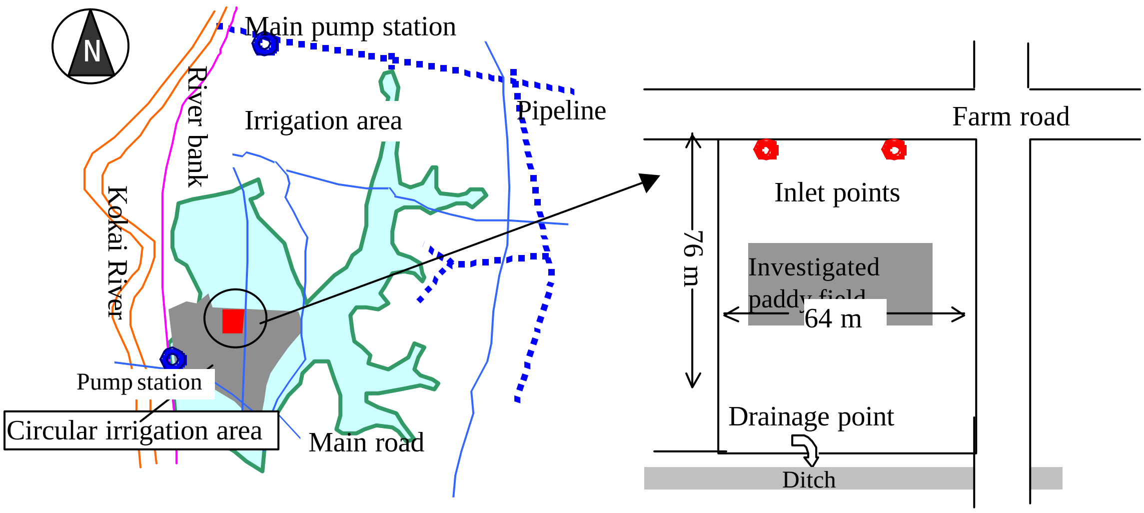

Fig. 1. Outline of investigated area and investigated paddy field (not on scale)

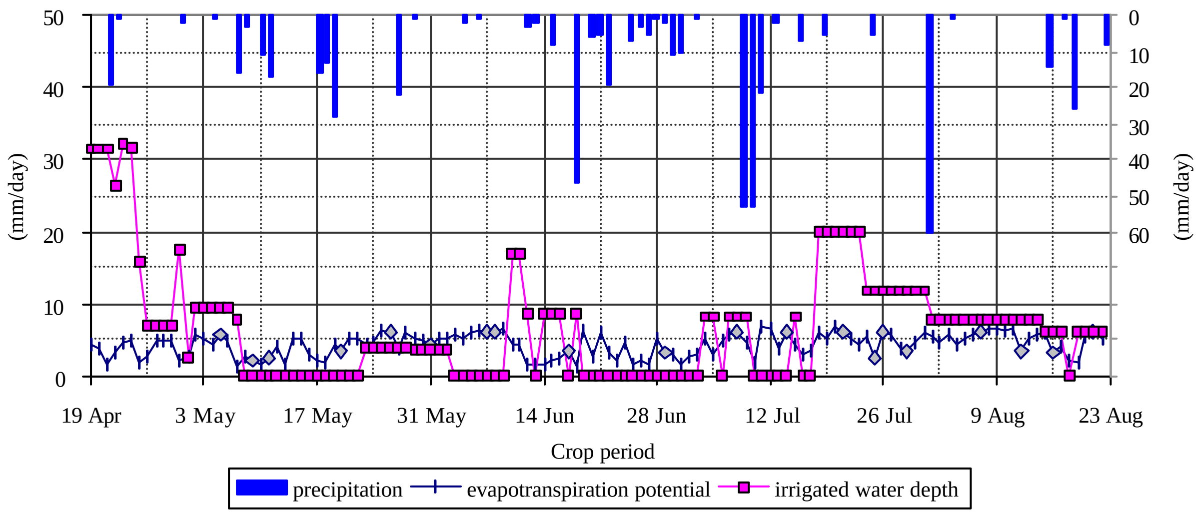

Fig. 2. Precipitation, irrigated water depth and evapo-tranpiration potential

Figure 2 shows the irrigated water level, precipitation and evapo-transpiration potential calculated by Makkink method (Nagai, 1993). Meteorological data were obtained from the Weather Data Acquisition System of the National Institute of Agro-Environmental Sciences, 10 km away from the study area. The water and fertilization application schedule of the investigated paddy field is shown in following **Table1**. In general, paddy is transplanted in the end of April and harvested in the beginning of September in all over Japan. The period when irrigation water is applied to the paddy field is from the middle of April to the end of August. The farming and water application schedule of investigated area was same as general schedule in Japan. Although three times fertilizer applications during irrigation period is more common in Japan but fertilizer was applied two times in the middle of April and in the middle of July in the investigated paddy field.

The irrigation water, runoff water of the paddy field and pump station water were sampled once a week from April to August. In addition, from April 25 to May 5, samples of irrigation and outflow water were collected at 4 hours interval using an auto sampler, and after the fertilizer had been applied, the investigation was carried out continuously for three days. EC, pH, DO and water temperature were measured at the time of sampling by the water quality meter. The concentrations of T-N were measured by T-N analyser. The concentration of NH_4-N, NO_2-N and NO_3-N were measured by ion chromatography.

RESULTS AND DISCUSSION

Observed nitrogen concentration

Figure 3 (a) shows the nitrogen concentration of KOKAI River, which was main water source of irrigation of investigated basin, and pump station, which was lowest point of irrigation area and water source of the circular irrigation system. The total nitrogen concentration ranged between 1.2 mg· L^{-1} and 3.7 mg· L^{-1}, and the average was 2.3 mg· L^{-1}. The paddling and planting period was from the end of April to the beginning of May. During this term nitrogen concentration of KOKAI River was about 3.5 mg· L^{-1}. It was thought that nitrogen concentration of Kokai River was influenced by drainage from paddy fields existed in upper region. From the middle of May to the end of August, the total nitrogen concentration did not change so much and it has decreased proportionally. On the other hand, the total nitrogen concentration at the pump station had ranged between 1.1 mg· L^{-1} and 4.9 mg· L^{-1}. There were two peaks. One was the paddling and planting period and another was fertilization period. Except the two peak periods, the concentration at the pump station was almost same or lower than the concentrations of KOKAI River. For example the difference of T-N concentrations between Kokai river and pump station were about 0.5 mg· L^{-1}, which was lower than KOKAI River concentrations from the middle of May to July. These results implied the paddy fields have nitrogen removal function, since upland fields and house are also located in the catchment area.

Table 1. Water application and farming schedule of investigated paddy field

No.	Schedule	Farm activity	Comments
1	Before April 19	First fertilize application	Before paddling
2	April 19	All pumps were turned on	Irrigation Water was diverted from KOKAI River to paddy fields
3	April 26	Paddling	Preparation for transplanting
4	April 28	Transplanting	
5	June 4	Irrigation was stopped	June 3 to June 10 (temporary drainage period)
6	June 19, June 26, July 3, July 10	The pump was temporary stopped.	
7	July 14	Second fertilize application	
8	August 22	All Pumps were stopped.	
9	August 30	Harvesting	

Note: Activity done by farmer association

Figure 3 (b) shows the observed T-N concentration at the investigated paddy field. The concentrations of T-N of drainage water and paddy field water were almost same. Except paddling and fertilization period, irrigation water concentrations were higher than drainage water concentration. These results implied that paddy fields have nitrogen removal function.
One of the characteristics of the paddy field was water depth. Water depth of the paddy field was kept less than 50 mm. Water percolation potential of the paddy field was low, since soil type was an alluvial soil. Water was hardly drained from the surface drainage point. Inlet water volume during irrigation period was 853 mm, much less than average water volume, 1,800 mm. The residence time in the paddy fields was long, and biological and chemical reactions might progress further. As a result, nitrogen was removed on a paddy field. The nitrogen concentrations of drainage water were close to that of irrigation water when lots of water was supplied.

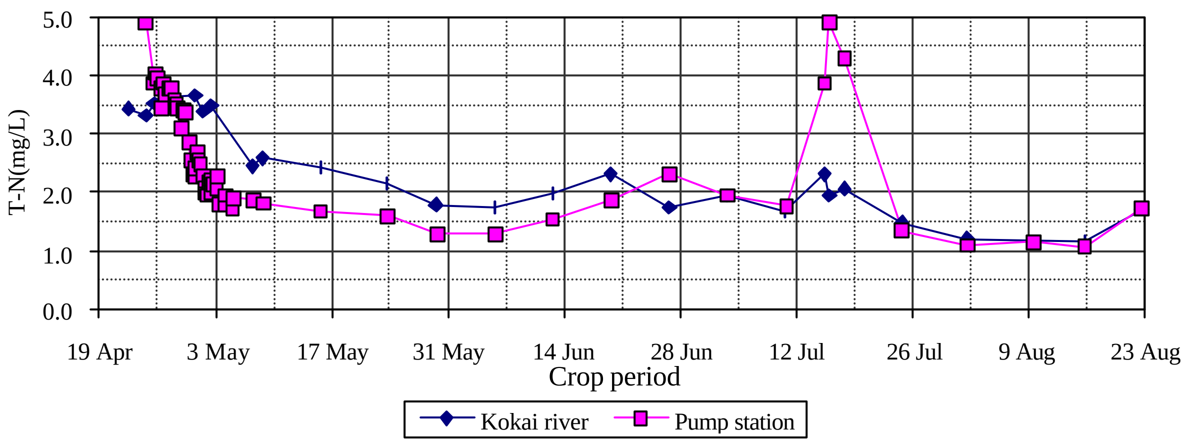

Fig. 3(a). *Crop period versus T-N concentration of Kokai river and the pump station*

Nitrogen removal coefficients

Concentration change of the nitrogen in a paddy field can be represented by the following first-order- kinetic, reaction formula.

$$C = C_0 \cdot \exp^{-at} \quad (1)$$

Number of papers have reported nutrient removal rate with first-order-reaction formula in various field. Nitrogen removal coefficients in this formula were examined focusing on the three periods, when nitrogen concentrations were high and changed rapidly. First period was from April 22 to April 26. That was before paddy field paddling, just after irrigation water began to be supplied. Nitrogen concentration increased when water was firstly applied into paddy field. This is because not only the irrigation water containing high concentration nitrogen but the dissolution of the fertilizer scattered before. Second period was from April 26 to May 2. That was paddling and transplanting period. Third period was from July 15 to July 24, just after the application of fertilizer.

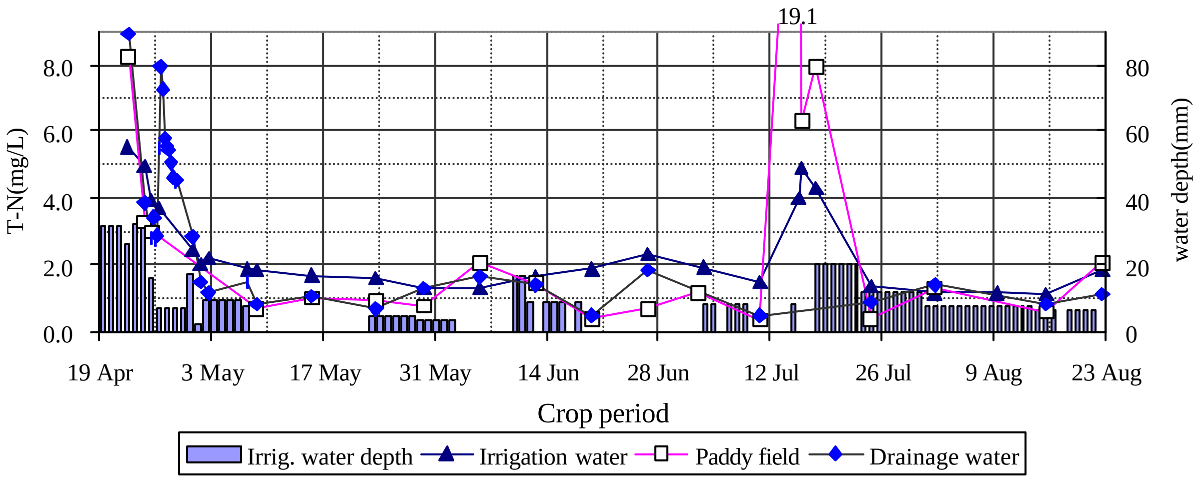

Fig. 3(b). *Crop period versus T-N concentration of irrigation water and irrigated water depth of investigated paddy field*

Figure 4 shows the change of observed nitrogen concentration and approximate curve. Total nitrogen concentrations at start time of each period were assumed as 1, subsequent values were expressed as the ratio with each initial value.

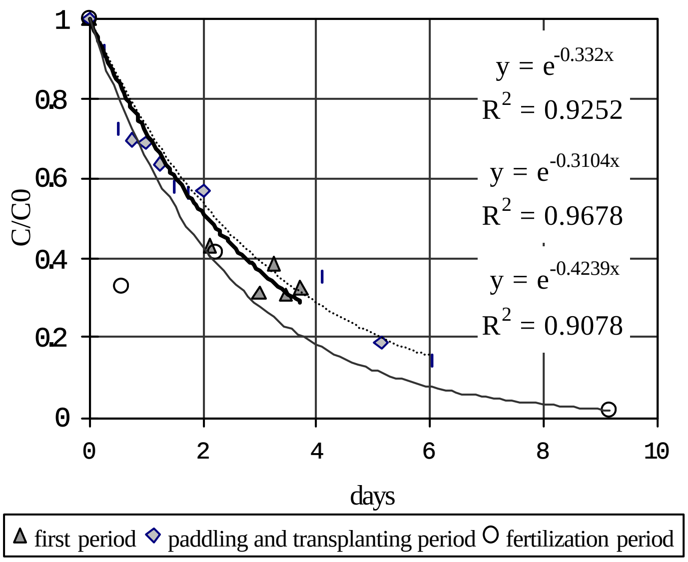

Fig. 4. *Time series analysis of nitrogen concentration in three periods*

Nitrogen removal coefficients in three periods were 0.332 day^{-1}, 0.310 day^{-1} and 0.424 day^{-1}. These coefficients per year were 6.1 m/y, 5.7 m/y and 7.7 m/y, if water depth was assumed to be 50 mm.

Tabuchi et al. (1993) reported that the nitrogen removal coefficient of paddy field was 4.1 m year^{-1} when water temperature was 25 centigrade. Shiratani (1995) clarified the coefficient of bottom sediment of creek was 4.4 m year^{-1}. The coefficient of the artificial swamp aiming at water quality purification was 9.0 m year^{-1} (Hosomi et al., 1994). It was elucidated that the paddy field had high function of nitrogen removal compared with these values. This is because inlet water volume was low and residential time was longer than usual paddy fields and because nitrogen concentrations of inlet water were high.

Water balance during cultivation period

The water balance equation in a paddy field can be represented by the following form.

$$W_d^i = W_d^{i-1} + I + Pr - E - Pe, \qquad (2)$$

where W_d^i is water depth at ith day in the paddy field (mm), I is daily irrigated water depth, Pr is daily precipitation amount, E is daily evapo-transpiration depth and Pe is daily percolation depth. It had failed to measure water depth.

Procedures to calculate the water budget and water depth of the investigated paddy field were as follows.

1. Potential of evaporation were calculated with Makkink Method and percolation potential was decided by farmer hearing
2. Daily water balance and water level was calculated using the volume of rain, irrigation, percolation and evaporation.
3. When water level exceeded the height of drainage gate, water level was assumed equal to the height of drainage gate, and exceeded water volume was taken as surface drainage.

When water level became less than zero, this had been corrected as follows.

4. The amount of percolation was revised downward to correct the depth of water to zero, since it was considered that percolation volume was over estimated.
5. The amount of evaporation was revised to smaller value so that water depth might not be less than 0.

It was assumed that the maximum water depth was 50 mm and percolation potential was 10 mm per day. Total supplied water volume was 1,383 mm, and in the breakdown, the irrigated water was 853 mm, and precipitation was 530 mm. On the other hand, the calculated consumptive water use was that of evapo-transpiration was 447 mm, percolation was 789 mm, and surface discharged was 146 mm. Calculated daily water depth is shown in following Fig. 5. Figure 6 shows the water budget during investigation period.

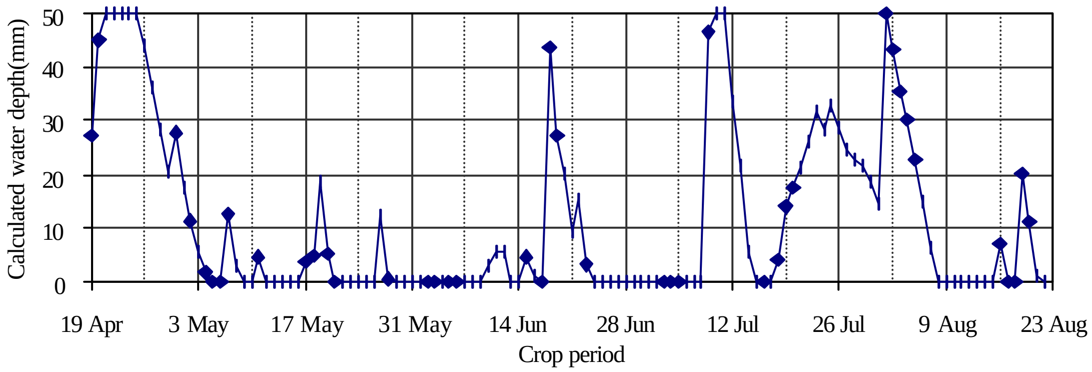

Fig. 5. Calculated water depth of the investigated paddy field during cultivation period

Nitrogen balance during cultivation period

Nitrogen balance was calculated using water budget mentioned above and nitrogen concentrations of inlet, paddy field and outlet water.

$$\text{Nitrogen balance} = F + IL_i + IL_p - OL_s - OL_p \quad (3)$$

where F is load by fertilizer, IL_i is inflow loads by irrigation, IL_p is inflow loads by rain, OL_s is outflow loads by surface discharged water, OL_p is outflow loads by percolation. The daily nitrogen concentrations were linearly interpolated with observed data. Irrigation loads were estimated with daily inlet water volume and interpolated nitrogen concentration. Input loads by precipitation were calculated by the multiplication of daily amount of precipitation and 1.0, which was assumed the nitrogen concentration of rainfall. Outlet loads from paddy field were calculated by the multiplication of the nitrogen concentration of the paddy field and discharged water amount.

Inflow loads by irrigation was 22.6 kg· ha^{-1}, by rain was 5.3 kg· ha^{-1} and fertilizer loads was 62.0 kg· ha^{-1}. Output loads by surface drainage was 6.1 kg· ha^{-1} and by percolation was 18.3 kg· ha^{-1}. It is investigated that paddy field under investigation had nitrogen removal capacity of 3.5 kg· ha^{-1} during observation period. Moreover, percolation loads were not discharged load to lower watershed but the amount of disappeared loads from the paddy field surface. It is thought that discharged loads by percolation were much less, since nitrogen will be absorbed by soil in the process of percolation. Refer following Fig. 6 for total water and nitrogen balance of the paddy field during cultivation period.

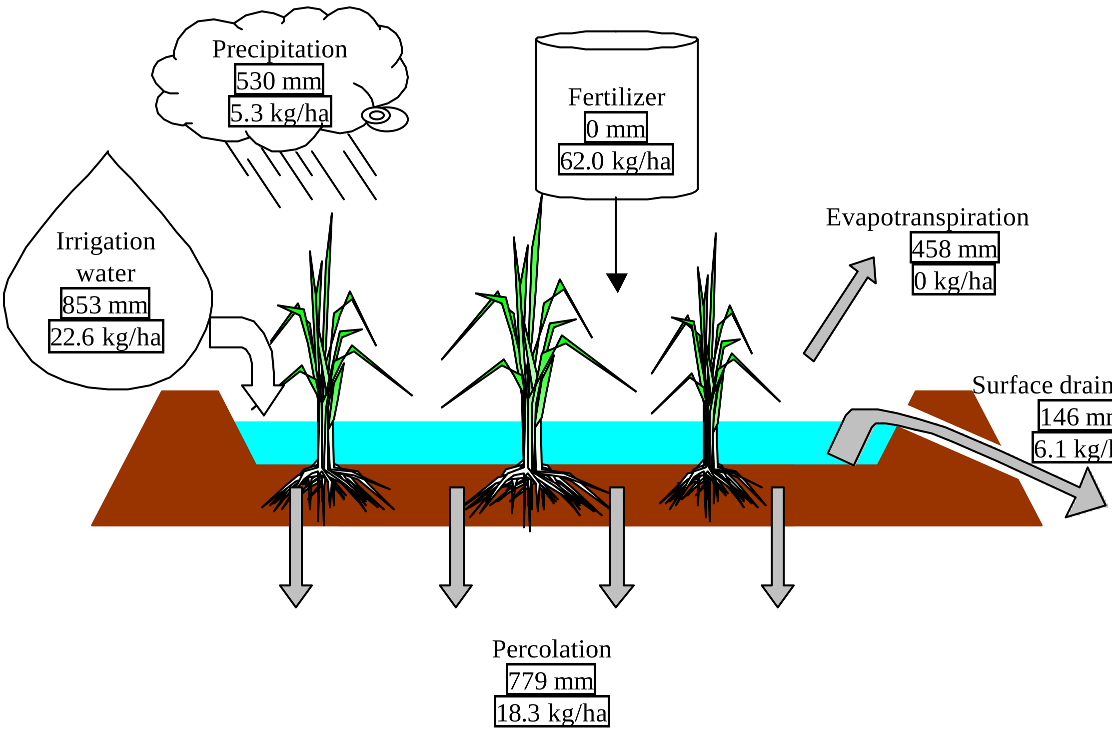

Fig. 6. *Water and nitrogen balance of paddy field during crop period Top number: water (mm), bottom number: nitrogen (kg ha^{-1})*

CONCLUSION

We carried out field observation focusing on the nitrogen removal function of a paddy field located in a circular irrigation system. The main concluding results of the investigation are as follows.

1. Except paddling and fertilization period, drainage water concentrations of total nitrogen were lower than irrigation water concentrations. These results implied that paddy fields have nitrogen removal function.

2. It was found that the nitrogen removal coefficient of the paddy field ranged from 5.7 m/y to 7.7 m/y. These values were higher than earlier reported values. This is because inlet water volume was low and because nitrogen concentrations of inlet water were high.

3. Total nitrogen inflowed in the paddy field water was 27.9 kg· ha^{-1} and total outflow nitrogen discharged out of the paddy field water was 24.4 kg· ha^{-1}. The paddy field had nitrogen removal capacity of 3.5 kg· ha^{-1} during observation period.

Further research should be carried out to evaluate nitrogen removal function of paddy field considering denitrification, mineralization and plant uptake, in mind.

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