Nutrient load characteristics of paddy fields along Lake Kasumigaura during the irrigation period

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Abstract: Lake Kasumigaura in Ibaraki Prefecture, Japan, has numerous paddy fields along its banks. Agricultural runoff enters the lake through an extensive network of irrigation channels with gates and drainage pump stations, which are used to pump water into and out of the fields. In this study, we investigated water balance and nutrient loads during an irrigation period to assess the movement of nutrients from paddy fields into a lake. During the operation of irrigation pumps, the irrigation system mixed and recirculated lake water and paddy field runoff; however, when the pumps were not in use, runoff flowed naturally into the lake through the pump station. Average total nitrogen (T-N) and average total phosphorus (T-P) loads in the lake inflow and outflow were estimated during the irrigation period; the estimated T-N and T-P loads entering Lake Kasumigaura were −4.4 $kg \cdot ha^{-1}$ and −0.28 $kg \cdot ha^{-1}$, respectively. In other words, nutrient loads in the inflow were greater than those in the outflow. Because 57% of the water in the irrigation system was recirculated paddy field runoff, this irrigation system contributed to a reduction in nutrient loading of the lake by the paddy fields.

Keywords: Lake Kasumigaura, Paddy field runoff, Irrigation system, Water balance, Nutrient loads

1. Introduction

There are 43,000 ha of paddy fields in the Lake Kasumigaura basin area. Agricultural runoffs from paddy fields are discharged to Lake Kasumigaura from rivers and irrigation channels. The paddy fields along Lake Kasumigaura are approximately 19,000 ha. These account for a large ratio compared to the number of paddy fields in the Kasumigaura basin. In the past, nutrient loads were investigated in rivers and channels [1, 2] but not irrigation pump stations. In this study, we report the characteristics of nutrient loads that are discharged into Lake Kasumigaura during the paddy field irrigation period through an irrigation pump station.

2. Methodology

2.1 Study area

The study was conducted in the Tega-Tamakawa area (50 ha) in the western part of Namegata City, along Lake Kasumigaura (Fig. 1). The sampling site was the area's second irrigation and drainage pump station. The area irrigated by this station is 118 ha, with paddy fields accounting for 38.1 ha of the total. The remaining 79.9 ha is outside the investigation area. There is no water inflow from this area. The paddy fields mainly grow rice; however, other crops are also grown. The study area includes a community of 77 houses.

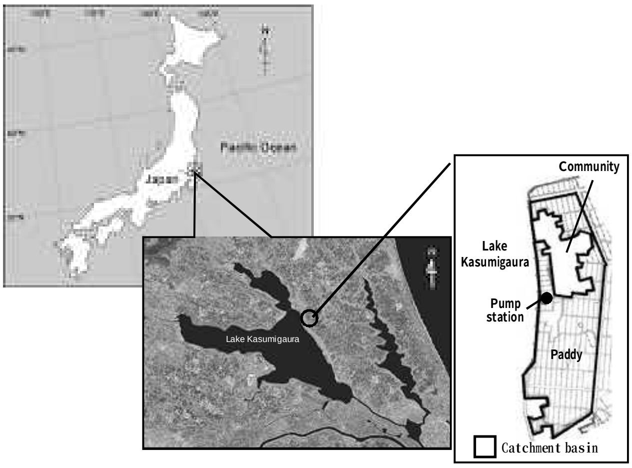

Fig. 1 Investigation area

2.2 Irrigation system

A schematic of the area's irrigation system is shown in Fig. 2. During operation of the irrigation pump, lake water and water from a bank-based channel (irrigation channel) is mixed with a portion of the irrigation channel water being recirculated; however, when the pump

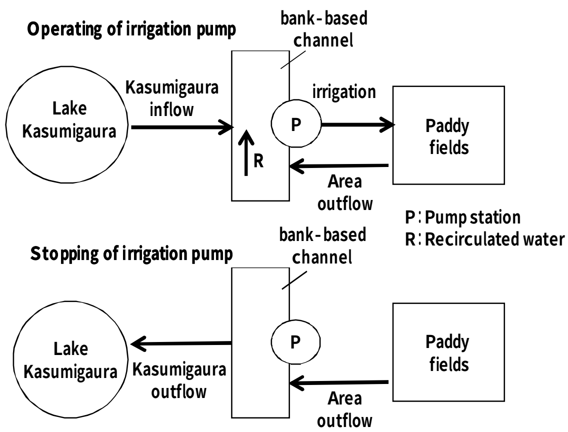

Fig. 2 Irrigation system

station is not in use, runoff from the paddy fields flows naturally into the lake from the pump station. The irrigation pump was generally operated from 06:00 to 18:00 h; however, it was not operated during rainy periods.

2.3 Investigative method

The study was conducted from April 23, 2008 to August 31, 2008. Water level and flow between the pump station and Lake Kasumigaura were measured using a water level meter (DL/N70, Sensor Technik Sirnach AG, Sirnach, Switzerland) and flow meter (SF-5511/SFT-200-12X, Tokyo Keisoku Co. Ltd., Tokyo, Japan) placed in a pipe entering the pump station's pressure-regulating tank (Fig. 3, St. 1). In addition, an automatic sampler (6712FR/NR, Teledyne-Isco Inc., Lincoln, NE, USA) was set in the pressure-regulating tank. The sampling interval was 3 h during the puddling and transplanting period. During other periods, samples were collected twice daily, once when the pump was operating and once when it was off. The total amount of irrigation water was calculated based on operation time and irrigation pump capacity. The amount of rainfall was used data of Automated Meteorological Data Acquisition System of the Meteorological Agency. Total nitrogen (T-N) and total phosphorus (T-P) were measured according to the Japanese Industrial Standard methods [3]. Suspended solids (SS) were obtained by weighing the filter sample after filtrating the water. A glass-fiber filter (GF/B, Whatman, Maidstone, England) that had been previously heated at 105℃ and weighed was used as the filter for SS. Filtrated water samples were measured for nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_4-N), and orthophosphate phosphorus (PO_4-P) by the autoanalyzer (AACS-Ⅱ, BRAN+LUEBBE, German).

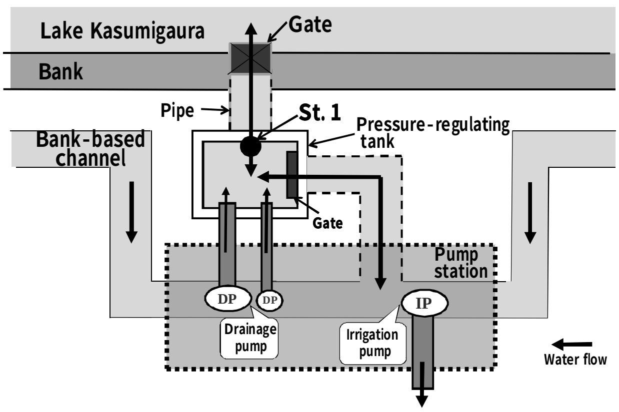

Fig. 3 Structure of pump station showing location of sampling station (St. 1)

3. Results and discussion

3.1 Current and water level changes during and after irrigation pump operation

Figure 4 shows the current and water level changes during and after operation of the irrigation pump in late April. During operation, a current of 0.05–0.1 m•s^{-1} flowed toward the paddy fields. On the other hand, while the pump was off, the current ranged from 0.005 to 0.01 m•s^{-1} and generally flowed toward Lake Kasumigaura. The water level at the pump station during the irrigation period ranged from 2.0 to 2.1 m and was always higher than that in the section of the pipe being sampled (1.5 m). Changes in water level related to operation of the irrigation pump were not detected (Fig. 4). This indicated that the water level in the pressure-regulating tank during pump operation was being maintained at the water level of Lake Kasumigaura because a gate connecting the irrigation channel and Lake Kasumigaura was open at all times.

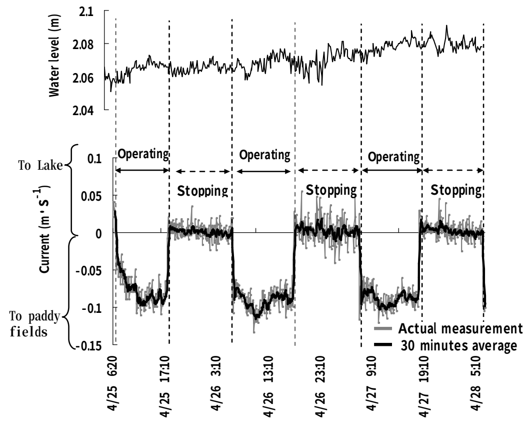

Fig. 4 Changes in water level and current when the irrigation pump was in operation and when stopped

3.2 Water balance

The water balance in the study area during the irrigation period is shown in Fig. 5. The amount of inflow from Lake Kasumigaura and irrigation water in the study area was calculated by deducting the amount flowing to the area outside the study area from the total amount. Recirculated water was 5.9 mm•d^{-1}, which was calculated by subtracting Lake Kasumigaura inflow from the amount of irrigation water being pumped. Paddy field area outflow was 7.7 mm•d^{-1}, which was calculated by adding the amount of recirculated water to the amount of outflow to Lake Kasumigaura. Evapotranspiration was determined from a previous report [4]. The remaining amount of outflow and inflow was 1.9 mm•d^{-1}. We

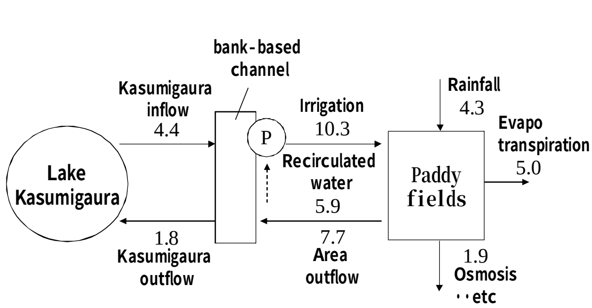

Fig. 5 Water balance diagram of average flow during the

irrigation period (mm•d^{-1})

believe that this remaining water flowed out of the system by penetration into the study area's substrates or drainage to ground water areas. The recirculated channel water represented 57% of the total irrigation water being supplied to paddy fields.

3.3 Water quality of Kasumigaura outflow and inflow

Changes in the water quality of the outflow to Lake Kasumigaura during the irrigation period are shown in Fig. 6. NO_3-N tended to increase with rainfall. During the puddling and transplanting period from late April to early May, T-P increased to 0.45 mg•l^{-1}, but SS did not increase. NH_4-N increased to 0.96 mg•l^{-1} and PO_4-P increased to 0.18 mg•l^{-1}. During topdressing in mid-July, T-N increased to 3.5 mg•l^{-1} and NH_4-N increased to 1.4 mg•l^{-1}, which were the greatest values detected during the study period. Moreover, T-P increased to 0.33 mg•l^{-1} and PO_4-P increased to 0.10 mg•l^{-1}.

In other investigations of the water quality in rivers flowing into Lake Kasumigaura, SS increased three-fold

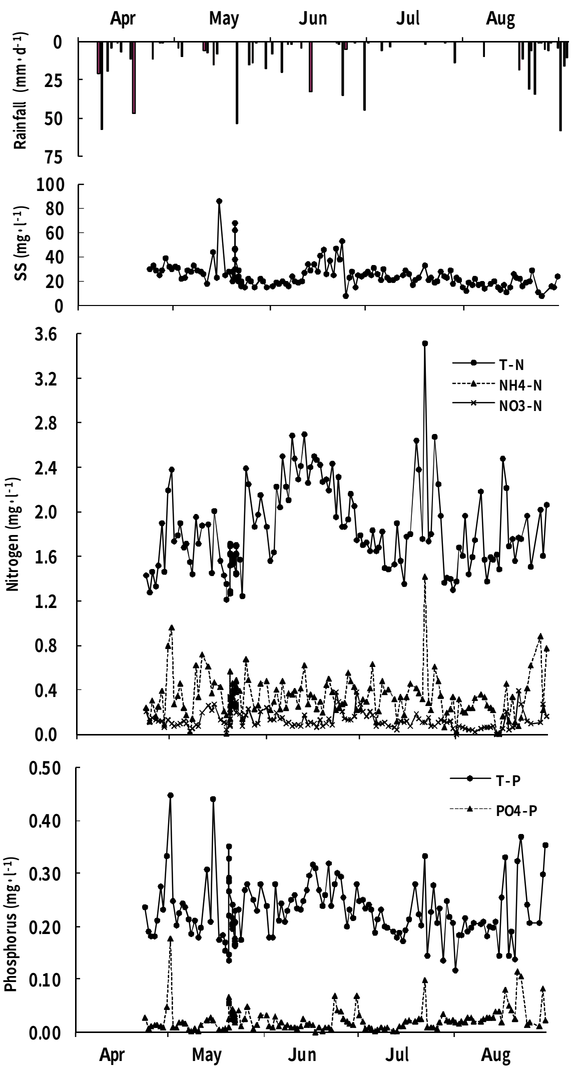

Fig. 6 Changes in water quality parameters in the Kasumigaura outflow water

and T-P increased two-fold during the studied irrigation periods [5]. In this study, T-P increased but SS did not. These results suggest that sediment particles may have settled down in the irrigation channel before the irrigation water flowed out to Lake Kasumigaura. We suggest that this is because the current in the outflow to Lake Kasumigaura was too slow to carry the suspended sediments. This slow current is related to the equal water levels between Lake Kasumigaura and the irrigation channel.

The average, maximum, and minimum values for SS, T-N, NO_3-N, NH_4-N, T-P, and PO_4-P in the outflow to and inflow from Lake Kasumigaura during the irrigation period are shown in Table 1. The T-N and T-P averages were higher in the Kasumigaura outflow than in the Kasumigaura inflow. In particular, NO_3-N was five times and NH_4-N was eight times higher in the outflow water.

Tab. 1 Water quality of Lake Kasumigaura outflow and inflow

(mg·l^{-1})

		Kasumigaura outflow	Kasumigaura inflow
SS	mean	25	27
	(min - max)	(8 - 86)	(12 - 46)
T-N	mean	1.8	1.5
	(min - max)	(1.2 - 3.5)	(0.9 - 2.1)
NO3-N	mean	0.14	0.03
	(min - max)	(0.00 - 0.39)	(0.29 - 0.95)
NH4-N	mean	0.34	0.04
	(min - max)	(0.01 - 1.42)	(0.00 - 0.28)
T-P	mean	0.23	0.15
	(min - max)	(0.12 - 0.45)	(0.09 - 0.33)
PO4-P	mean	0.025	0.013
	(min - max)	(0.001 - 0.178)	(0.000 - 0.061)
		n=143	n=93

3.4 Characteristic of nutrient loads in Lake Kasumigaura outflow

Changes in the load of T-N and T-P discharged to Lake Kasumigaura during the irrigation period are shown in Fig. 7. The discharged load tended to increase with rainfall. The concentration of T-N and T-P increased during paddy field topdressing in July, but the load in the outflow to Lake Kasumigaura did not increase. Correlations of specific outflow, specific load, rainfall, and water quality were considered. The results indicate that the correlation coefficient between specific outflow and specific load was $r^2 = 0.97$ in both T-N and T-P. The correlation coefficients between specific load and rainfall were $r^2 = 0.49$ and $r^2 = 0.53$ in T-N and T-P, respecitively, while the correlation coefficients between specific load and water quality were $r^2 < 0.01$ and $r^2 = 0.13$ in T-N and T-P, respectively. Because relatively high correlations with the amount of rainfall were detected, it was suggested that the influence of rainfall on load amounts was greater than that of agricultural loading. The average load during the irrigation period in both Lake Kasumigaura outflow and inflow waters is shown in Fig. 8. The Kasumigaura outflow nutrient load was 4.3

kg·ha^{-1} of T-N and 0.60 kg·ha^{-1} of T-P. On the other hand, the inflow from Lake Kasumigaura was 8.7 kg·ha^{-1} of T-N and 0.88 kg·ha^{-1} of T-P. As a result, the estimated net T-N and T-P loads entering Lake Kasumigaura were −4.4 kg·ha^{-1} and −0.28 kg·ha^{-1}, respectively. In other words, nutrient loads in the inflow from the lake were greater than those in the outflow from the irrigation channel. Because 57% of the water in the irrigation system was recirculated paddy field runoff, this irrigation system is considered to reduce nutrient loads entering Lake Kasumigaura.

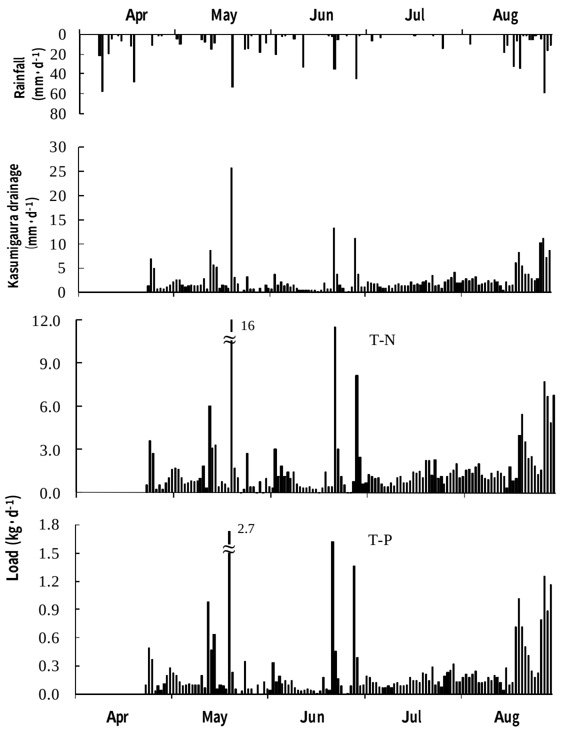

Fig. 7 Changes in nutrient loads of Lake Kasumigaura outflow

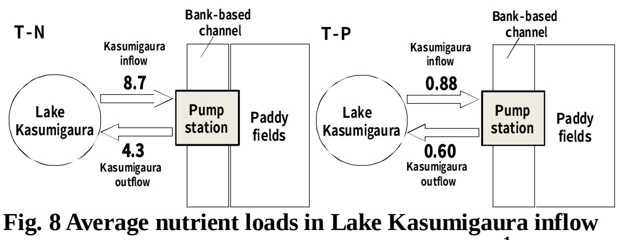

Fig. 8 Average nutrient loads in Lake Kasumigaura inflow and outflow during the irrigation period (kg·ha^{-1})

4. Conclusion

Nutrient loads discharged into Lake Kasumigaura from a pumping station during a paddy field irrigation period were investigated. The results suggested the following:

・Because an increase in SS was not detected at the pumping station during the puddling and transplanting period, suspended sediment particles settled down in the irrigation channels before flowing out to Lake Kasumigaura.

・Because 57% of the irrigation water was recirculated paddy field runoff, net T-N and T-P loads entering Lake Kasumigaura were −4.4 kg·ha^{-1} and −0.28 kg·ha^{-1}, respectively.

Thus, this type of irrigation system can reduce suspended sediment and nutrient loads moving from paddy fields to Lake Kasumigaura.

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