Dissolved Inorganic Carbon Loads from Rice and Lotus Fields to Lake Kasumigaura

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Abstract

Agricultural land plays an important role of atmospheric carbon dioxide sink into the soil sequestration. In paddy cropland dissolved carbonate species are leached out and exported to other water bodies by the fluvial carriers. The aim of this study is to investigate dissolved carbon dioxide (DIC) concentration and variation factors in drainage from paddy fields along the Nishiura lakeshore of Lake Kasumigaura, to estimate DIC loads from paddy fields to lake water. Field surveys and monthly water samplings were carried out. DIC concentration then was derived from the measurement data of sample waters. The data were analyzed and discussed with previous studies. The results of this study can be summarized as follows:

Dissolve inorganic carbon concentration in agricultural drainage was slightly higher than that in inflow river and lake water. There was no significant difference of mean DIC concentration among rice and lotus paddies drainage. The seasonal variation of DIC concentration was observed very small during the cultivation period. DIC loads from rice and lotus paddies during the cultivation period were strongly corresponding to the draining rate, which varied in the different cultivation stages and during the heavy rainfall event. DIC loads per watershed suggested that the paddy fields along the Nishiura lakeshore, particularly rice paddy directly exported more DIC to the lake, while inflow river brought very small DIC. The exported DIC from agricultural land in the upper catchment of inflow rivers, when loaded into river water, somehow, could be removed or diluted during the riverine transporting. Therefore, agricultural along the lakeshore should be accounted in the DIC carbon budget in the lake on the water drainage aspect.

Keywords: DIC loads, Lake Kasumigaura, agricultural drainage, paddy field

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Chapter 1 Introduction

1.1 Background

Carbon dioxide (CO_2) gained most of attention among greenhouse gases, because of its high radiative forcing (RF). Radiative forcing could be explained as the change in balance of radiations coming into and out going from the earth surface (Mandlebaum *et al.*, 2011). With the positive RF, earth surface is getting warm, while it is cooling down when RF is turning negatively. Therefore, the observed global climate change is attributed to the emission of carbon dioxide (Lal, 2004).

Carbon dioxide increased by 1.5 ppmv year^{-1} or 0.4 % year^{-1} from 1980 to 2004 (IPCC, 2007), with anthropologic effects accounting 50% to this increasing and 10% to 30% is due the effect of land cover change. Agricultural land plays significant role whether as sink and source of atmospheric carbon and annual exchange with atmosphere are large on the global scale (Smith et al., 2007). The terrestrial carbon stored in vegetation accounts 80%. Carbon dioxide is released to atmosphere through the plant respiration process. However, the same amount of carbon dioxide is returned to plant as the result of photosynthesis. Other pathway of atmospheric release of carbon dioxide is respiration of plant.

1.2 Previous studies

1.2.1 Dissolved inorganic carbon in agricultural land

In cultivated cropland compared to non-cropland carbon dioxide sequestration to the soil is potentially occurred through the weathering process. This in operate with dissolute minerals substance content in soil, resulting the production of bicarbonate acid (Mayorga, 2008), particularly in the flooding cropland. The released bicarbonate (HCO_3^-) is leached to the deeper soil layer then accumulated and be stored in the ground water system. In paddy field aqueous carbon dioxide is utilized by plankton and micro-organism in the photosynthesis, this process removes carbon dioxide from both soil and water containing.

Dissolved inorganic carbon, majority of bicarbonate flux increased due to the agricultural change that has led to increased weathering of silicate and carbonate rocks and the consequent sequestering of carbon dioxide (Sellers *et al.*, 1995), However, runoff from agricultural land dilute the dissolved organic carbon (DOC) in downstream water while dissolved inorganic carbon DIC is higher. (Huotari *et al.*, 2013).

Land use change, in particular to cropland could influence not only the ecosystem, but also, carbon budget in soil and the exchange with other storage. The study of DIC and DOC variation on land reclamation from natural wetland to rice paddy land in China (Wang *et al.*, 2010) indicated the significant ratio of the two carbonate systems. This explained the cultivation of rice converted organic carbon to inorganic spices by crop and be accumulated during the follow period. The soil characteristic is linked to the special variation of DIC export (Barnes and Raymond, 2009) the sedimentary condition of soil is the dominant of silicate weathering which directly enrich the DIC concentration.

1.2.2 Dissolved inorganic carbon in paddy field

Significant loss of DIC from soil carbon budget in rice paddy field suggested that under flooding cultivated land, DIC is exported through the drainage, especially the subsurface irrigation (Katoh *et al.*, 2004). Due to the rapid mineralization in the rice root zone, the large amount of carbon was observed in this zone. CO_2 produced during the mineralization of organic compounds, released from root and soil organic maters. Then export temporal and spatial into aquifers, drainage ditch and surface water (He *et al.*, 2012).

Water management with respect to soil redox potential and the application of rice straw in rice paddy decreased the CO_2 emission (Minamikawa and Sakai, 2007) and the decomposition of the remained wheat straw attributes the high accumulation of both inorganic and organic carbon in to the subsoil layer through the tillage and plowing (Katoh *et al.*, 2004)

In agricultural land, in general, acid produced during the nitrification of chemical fertilization or manure. The study of Barnes and Raymond (2009) indicate that the positive relationship between nitrate ion and DIC concentration in runoff from agricultural catchment explains the process of how carbonate acids is produced. When ammonium (NH_4^+) is spread and dissolute the NO_3^- and hydrate ion (H^+) are released equation (1). These substances are strongly associate with acid anions and replace carbonic acid in weathering process equation (2) (Brunet *et al.*, 2011), to this DIC is increased.

$$\mathrm{NH_4^+} + 2\mathrm{O_2} = \mathrm{NO_3^{2-}} + \mathrm{H_2O} + 2\mathrm{H^+} \tag{1}$$

$$\mathrm{C}_{a(1-x)}\mathrm{Mg}_x\mathrm{CO_3} + \mathrm{H^+} = (1-x)\mathrm{Ca^{2+}} + x\mathrm{Mg^{2+}} + \mathrm{HCO_3^-} \tag{2}$$

1.2.3 Dissolved inorganic carbon loads and carbon budget of lake system

The study of carbon budget in the eutrophic lakes located and distributing large proportion of runoff from the high intensive agricultural land (Pacheco *et at*., 2013) indicates the fertilization in agricultural land affects the DIC loads variation to the lake, corporate with land use change to the water flooding cropland enhance the aquatic DIC transport from the terrestrial carbon pool to the lake system. Furthermore, the study also suggests the important effect of high DIC exporting from these agricultural land to the eutrophication of the lake water. Barnes and Raymond (2009) suggest the significant loads rate of DIC from agricultural land compared with the forested watershed runoff is should be accounted in the regional carbon budget.

1.3 Objectives

In this study, we aim to investigate characteristics of dissolved inorganic carbon in agricultural drainage, particularly from rice and lotus fields surrounding Lake Kasumigaura. To estimate dissolved inorganic carbon dioxide loads from those paddy fields exporting to Lake Kasumigaura.

Chapter 2 Methodology

2.1 Study area

2.1.1 General description

Lake Kasumigaura (36.04° N, 140.40° E) is located in Ibaraki prefecture in Japan, with a surface area of 219 km^2 it is the second largest lake in Japan. The average depth of the lake is 4 m, very shallow with respect to its size. The Lake Kasumigaura consists of three water bodies which are Nishiura (surface area: 172 km^2), Kitaura (surface area: 36 km^2) and Sotonasakaura (surface area: 6 km^2), and connecting rivers (Figure 2-1). Lake kasumigaura has watershed area of 2156 km^2 (Ibaraki Kasumigaura Environmental Science Center, 2013). With the area of 849.83 km^2 it is an agricultural land for the national crop production, and 521.67 km^2 is paddy field with significant portion of the lotus cultivation is located along the shoreline of Lake Kasumigaura (National Institute for Environmental Studies, 2004). The paddy fields along Nishiura lakeshore was chosen for the study area of this study because the portion of its area is representative for the entire of the paddy field.

Average air temperature of the Tsuchiura station in 2016 was 15.3℃, minimum: -5.1℃, maximum 37℃ (Japan Meteorological Agency, 2016). Water temperature during the study period was 17.93℃ (minimum: 7.8℃, maximum 35.6℃). The annual rainfall in 2016 was averagely 3.4 mm, and high rainfall events were observed during the typhoon season (late August and September).

2.2 Field survey and water sampling

2.2.1 Field survey

Base maps used for field observation were created based on geographic information system (GIS) data. Figure 2-3 shows the date set elements on the map which includes: location of pumping, drainage facilities along Nishiura shoreline, at the beginning altitude and longitude of each point was obtained from Google Maps (2016) then after replaced by the actual information obtained from the following field surveys; map illustrating the divided areas of paddy fields identified with numbers obtained (Japanese Institute of Irrigation and Drainage, 2010); spatial data of Lake Kasumigaura water bodies, inflow and outflow rivers were obtained (Water Information System of Ministry of Land, Infrastructure, Transport and Tourism, 2006).

The first field observation was carried out in February 24^{th}, 25^{th} and 26^{th} in 2016 to verify irrigation system and distribution of the crops. The verification of irrigation system was based on operating objective written on information board, and structure of pumping and draining facilities. The distribution of lotus and rice paddies verification were made by sight inspection. During this observation, majority of the paddy were not being planted and therefor the remaining rice and lotus straws were used to determine the difference of the crops. After that, water sampling sites were designed and summarized in Table 2-2. During the cultivation period, monthly water samplings in lotus and rice paddies drainage, inflow and out flow rivers were carried out on February 24th, 25th, 26th; March 3rd, 16th, 17th, 29th; May 5th, 6th, 8th; June 19th; July 14th; and August 8t, 10th of 2016. The water sampling dates were chosen on the sunny weather to reflect the based flow condition. In addition, the measurement of flow rate (m^3 sec^{-1}) of paddy drainage was also carried out in August 8th.

The interviews were conducted with local farmers during the field surveys and water samplings. The interviews aimed to acquire information on field operation, cultivation method and schedule of both lotus and rice.

At (Koshin Observatory of the Kasumigaura River Office, Kanto Region Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism of Japan), monthly sampling was carried out on January 5, February 1st, March 3rd, May 18th, June 15th, July 14th, August 3rd, September 5th, October 3rd, November 4th and December of 2016.

At all sites in situ water sampling of drainage water was carried out in the depth of 0.1 m. Water temperature was measured by water temperature meter (Model D617, TECHNOL SEVEN). The pH value was measured by pH meter (Model S010, LAQUAtwin). Nitrate ion (NO_3^{2-}) concentration (mg L^{-1}) was measured by NO_3^{2-} meter (Model S040, LAQUAtwin), also electric conductivity (μS cm^{-1}) was measured by conductivity meter (Model B-173, Twin Cond). The 100 ml of water sample was immediately collected and stored in poly sealable bottle without air bubbles existing, then kept in cooling box to keep the constant temperature during the field trip.

2.3 Base map analysis

Based on the results of field observations, the location of lotus, rice paddies, different irrigation system paddies were analyzed using geographic information system analysis program (ESRI2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute). The verified paddy areas of were calculated based on the information exported from base map analysis.

2.4 Laboratory analysis

Water samples (100 ml) were brought back to laboratory and stored in refrigerator to keep at low temperature. Later, the concentration of bicarbonate ion (HCO_3^-) in (mmol L^{-1}) in each water sample was measured within two days. The measurement conducted using titration with sulfuric acid (0.005 mol L^{-1}) analysis consisted of Multi-dosimat (Model 645, Metrohm). Water temperature and pH value were also measured again during the laboratory analysis.

2.5 Data analysis

2.5.1 Dissolved inorganic carbon concentration

Dissolved inorganic carbon concentration (C_{it}) was derived from measured bicarbonate ion concentration and ionization fraction of carbonate substances by equations (3) (Suzuki *et al.*, 1995).

$$C_{it} = \frac{[HCO_3^-]}{\alpha_1} \tag{3}$$

Where α_0, α_1, α_2 are ionization fractions of carbonate substances and could be derived from equation (4) ~ (9) (Abe *et al.*, 1974).

$$\alpha_0 = \frac{[H_2CO_3^*]}{C_{it}} \tag{4}$$

$$\alpha_1 = \frac{[HCO_3^-]}{C_{it}} \tag{5}$$

$$\alpha_2 = \frac{[CO_3^{2-}]}{c_{it}} \tag{6}$$

$$\alpha_0 = \left(1 + \frac{k_1}{[H^+]} + \frac{k_1 k_2}{[H^+]^2}\right)^{-1} \tag{7}$$

$$\alpha_1 = \left(\frac{[H^+]}{k_1} + 1 + \frac{k_2}{[H^+]}\right)^{-1} \tag{8}$$

$$\alpha_1 = \left(\frac{[H^+]}{k_1} + 1 + \frac{k_2}{[H^+]}\right)^{-1} \tag{9}$$

$$pH = \log[H^+] \tag{10}$$

$$[H^+] = 10^{-pH} \tag{11}$$

$$[OH^-][H^+] = k_w = 1.01x10^{-14} \tag{12}$$

$$[OH^-] = \frac{1.01 \times 10^{-14}}{[H^+]} \tag{13}$$

Where $[H^+]$ is hydrogen ion concentration (mmol L^{-1}), $[OH^-]$ hydroxide ion concentration (mmol L^{-1}). k , k_1 , k_2 , k_w are equilibrium constants of carbonate substance and could be derived by equations (10) ~ (16) (Fukushima *et al.*, 1996), where T_w is water temperature (^{k}).

$$-\log k_1 = \frac{3404.71}{T_w} + 0.032786T_w - 14.712 \tag{14}$$

$$-\log k_2 = \frac{2902.39}{T_w} + 0.02379T_w - 6.471 \tag{15}$$

$$-\log k_w = \frac{4470.99}{T_w} + 0.01706T_w - 6.0875 \tag{16}$$

Once α_1, α_2 and C_{it} are determined, the total alkalinity A_k (mmol L^{-1}) and carbonic alkalinity A_c (mmol L^{-1}) were calculated using equations (17) ~ (18).

$$A_k = C_{it}(\alpha_1 + 2\alpha_2) + [OH^-] - [H^+] \tag{17}$$

$$A_C = C_{it}(\alpha_1 + 2\alpha_2) \tag{18}$$

The term C_w or $[H_2CO_3^*]$ is carbon dioxide (mmol L^{-1}) and expressed as function of A_c and $[H^+]$ in equation (19). C_{it} is total concentration of dissolved inorganic carbon or DIC (mmol L^{-1}) and defined in equation (20), while $[HCO_3^-]$ is bicarbonate ion (mmol L^{-1}), and $[CO_3^{2-}]$ is carbonate ion (mmol L^{-1}).

$$C_w = [H_2CO_3^*] = \frac{A_C[H^+]^2}{k_1([H^+] + 2k_2)} \tag{19}$$

$$C_{it} = [H_2CO_3^*] + [HCO_3^-] + [CO_3^{2-}] \tag{20}$$

2.5.2 Estimation of discharge

The discharge amount of drainage water from rice and lotus paddies was estimated in doctoral research (Baoyin chaogala, personal communication) on the title of "The estimation of withdrawals for irrigation and drainage amount from paddy fields and lake water balance in Lake Kasumigaura". The result was obtained and utilized to calculate loads of dissolved inorganic carbon. The depth of discharge water in a unit of area (δ) [m day^{-1}] of paddy fields with different irrigation systems were estimated as

$$\delta = Di + Dr \tag{21}$$

Where D_i is drainage from irrigation water [m day^{-1}] and was calculated using equation (22). D_r is drainage from rain water [m day^{-1}] and was calculated using equation (23).

$$D_i = (I + R_r)R_{wm} \tag{22}$$

$$D_r = P(1 - R_r) \tag{23}$$

Where R_r is effective rainfall rate which is the ratio of effective rainfall and total rainfall. R_{wm} is managed draining water rate which is a ratio of managed draining water and combination of irrigation with effective rainfall. P is rainfall amount and I is irrigation water.

Particularly in paddy field with the practice of irrigation type D there are both drainage from irrigation water and precipitation. However, in paddy field where circulating irrigation system is practice there is only discharge from precipitation or rain water.

2.5.3 Estimation of dissolved inorganic carbon loads

The daily mean DIC loads (Q_{it}) [mol day^{-1}] was calculated using equation (24), where C_{it} is monthly mean concentration [mol L^{-1}] and Q is the discharge [L day^{-1}].

$$Q_{it} = C_{it} \times Q \tag{24}$$

While monthly average discharge was calculated using equation (25), where A is area of paddy field [m^2] and δ is the depth of discharge water in a unit area [m day^{-1}].

$$Q = \mathrm{A} \times \delta \tag{25}$$

Area of paddy field was calculated in 2.3 using base map analysis. The depth of discharge water from paddy field was estimated and obtained from (Baoyin chaogala, personal communication), described in 2.5.2. The average discharge of main inflow river was obtained from Yabusaki et al. (2006). Where the average discharge of small inflow rivers was obtained from Yamamoto (2013). Comparison of the means of DIC concentration in drainage water from different discharges were performed using a *t*-test analysis.

Table 2-1 Field observation and sampling schedule

Date (YY/MM/DD)	Time (hh:mm)	Location	Weather, flow condition	T_a (℃) minimum ~ maximum [average]	Objectives
16/01/05	09:30	Koshin	Sunny	7.9	Water sampling
16/02/01	09:30	Koshin	Sunny	3.0	Water sampling
16/02/24	08:00 ~ 13:00	R_{in} & R_{out} & P &D & PD	Sunny, base flow	0.7 ~ 7.0 [4.2]	Field observation & water sampling
16/02/25	09:00 ~ 11:30	R_{in} & R_{out} & P &D & PD & paddy field	Sunny, base flow	-0.6 ~ 8.6 [3.0]	Field observation & water sampling
16/2/26	09:00 ~ 12:30	R_{in} & R_{out} & P &D & PD & paddy field	Sunny, base flow	-1.9 ~ 10.9 [4.6]	Field observation & water sampling
16/03/03	09:00 ~ 16:30	R_{in} & R_{out} & D & PD	Sunny, base flow	-0.9 ~ 17.6 [8.1]	water sampling
16/03/04	09:30	Koshin	Sunny	7.0	Water sampling
16/03/16	7:00 ~ 15:50	R_{in} & R_{out} & D & PD	Sunny, base flow	0.5 ~ 12.7 [7.2]	water sampling
16/03/17	7:55 ~ 14:35	R_{in} & R_{out} & D & PD	Sunny, base flow	2.3 ~ 19.5 [10.8]	water sampling
16/03/29	8:00 ~ 14:30	R_{in} & R_{out} & D & PD	Sunny, base flow	4.4 ~ 16.2 [11.0]	water sampling
16/05/05	7:55 ~ 14:35	R_{in} & R_{out} & D & PD	Sunny, base flow	12.0 ~ 28.0 [19.7]	water sampling
16/05/06	08:30 ~ 15:50	R_{in} & R_{out} & D & PD	Sunny, base flow	12.8 ~ 22.6 [17.6]	water sampling
16/05/08	08:10 ~ 16:20	R_{in} & R_{out} & D & PD	Sunny, base flow	14.0 ~ 25.7 [19.7]	water sampling
16/05/18	09:30	Koshin	Sunny	17.5	water sampling

Table 2-1 continued

Date (YY/MM/DD)	**Time (hh:mm)**	**Location**	**Weather, flow condition**	**T_a (℃) minimum ~ maximum [average]**	**Objectives**
16/06/15	09:30	Koshin	Sunny	18.6	Water sampling
16/06/19	08:15 ~ 15:45	R_{in} & R_{out} & D & PD	Sunny, base flow	20.3 ~ 29.5 [24.2]	water sampling
16/07/04	09:30	Koshin	Sunny	26.5	Water sampling
16/07/14	07:35 ~ 15:30	R_{in} & R_{out} & D & PD	Sunny, base flow	20.6 ~ 32.1 [25.1]	water sampling
16/08/03	09:30	Koshin	Sunny	26.8	Water sampling
16/08/08	08:25 ~ 17:00	R_{in} & R_{out} & D & PD	Sunny, base flow	25.0 ~ 32.0 [28.0]	water sampling & drainage rate measurement.
16/08/10	07:45 ~ 14:10	R_{in} & R_{out} & D & PD	Sunny, base flow	24.7 ~31.6 [27.4]	water sampling
16/09/05	09:30	Koshin	Sunny	26.8	Water sampling
16/10/03	09:30	Koshin	Sunny	21.6	Water sampling
16/11/04	09:30	Koshin	Sunny	12.3	Water sampling
16/12/05	09:30	Koshin	Sunny	11.3	Water sampling

Koshin: Koshin Observatory of the Kasumigaura River Office, Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism of Japan located at the center (36°02′35″N, 140°24′42″E) of Lake Kasumigaura. **P**: irrigation pumping facility, **D**: drainage facility of paddy field, **PD**: both pumping and drainage facility of paddy field. **R_{in}**: inflow rivers to Nishiura, R_{out} is referred as out-flow river from Nishiura. **T_a** is air temperature of observation day (Japan Meteorological Agency, 2016).

Table 2-2 Information on runoff type, crop type, soil and irrigation system of sampling point in paddy drainage, inflow and out flow rivers.

Site ID	Latitude	Longitude	Altitude(m)	English name	Japanese name	Runoff type	Crop	Irrigation system	Soil
5D	36.05600	140.22233		-	-	Drainage	Rice paddy	D	Clay & gravel
11PD	36.03909	140.24703		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
15PD	36.03389	140.26610		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
21PD	36.02674	140.30009		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
24PD	36.03106	140.31358		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
26D	36.02610	140.32085		-	-	Drainage	Rice paddy	C1	Clay & gravel
27PD	36.02881	140.33153		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
28D	36.02863	140.33796		-	-	Drainage	Rice paddy	D	Clay & gravel
30PD	36.02888	140.35031		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
32D	36.01752	140.36001		-	-	Drainage	Rice paddy	D	Clay & gravel
33D	36.01511	140.36286		-	-	Drainage	Rice paddy	D	Clay & gravel
34D	36.00411	140.35614		-	-	Drainage	Rice paddy	C1	Loam
35PD	35.99519	140.35529		-	-	Pumping & Drainage	Rice paddy	C1	Clay & gravel
37PD	35.98955	140.34460		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
38PD	35.98071	140.34559		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
40PD	35.98262	140.35296		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
41D	35.98364	140.36539		-	-	Drainage	Rice paddy	D	Clay & gravel
42D	35.98319	140.36534		-	-	Drainage	Rice paddy	D	Clay & gravel
44D	35.98303	140.37347		-	-	Drainage	Rice paddy	D	Clay & gravel
45PD	35.98197	140.38952		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel

Table 2-1 continued

Site ID	Latitude	Longitude	Altitude(m)	English name	Japanese name	Runoff type	Crop	Irrigation system	Soil
50D	35.98646	140.41614		-	-	Drainage	Rice paddy	D	Clay & gravel
52D	35.98264	140.42842		-	-	Drainage	Rice paddy	D	Clay & gravel
53D	35.98117	140.43208		-	-	Drainage	Rice paddy	D	Clay & gravel
54D	35.98077	140.43389		-	-	Drainage	Rice paddy	D	Clay & gravel
59PD	35.96939	140.44653		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
60PD	35.96761	140.44853		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
63D	35.95180	140.45118		-	-	Drainage	Rice paddy	D	Clay & gravel
65D	35.94106	140.45131		-	-	Drainage	Rice paddy	D	Clay & gravel
71D	35.95202	140.48718		-	-	Drainage	Rice paddy	C1	Clay & gravel
72D	35.95664	140.49894		-	-	Drainage	Rice paddy	D	Clay & gravel
73PD	35.96120	140.50071		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
74D	35.96072	140.50469		-	-	Drainage	Rice paddy	D	Clay & gravel
85D	35.97159	140.50157		-	-	Drainage	Rice paddy	D	Clay & gravel
91D	35.98451	140.48540		-	-	Drainage	Rice paddy	D	Clay & gravel
95D	35.98909	140.47420		-	-	Drainage	Rice paddy	D	Clay & gravel
96D	35.99343	140.47276		-	-	Drainage	Rice paddy	D	Clay & gravel
99D	36.00089	140.47038		-	-	Drainage	Rice paddy	C1	Clay & gravel
100D	36.00464	140.46901		-	-	Drainage	Rice paddy	D	Clay & gravel
103D	36.00912	140.46738		-	-	Drainage	Rice paddy	D	Clay & gravel
104D	36.01232	140.46585		-	-	Drainage	Rice paddy	D	Clay & gravel

Table 2-1 continued

Site ID	Latitude	Longitude	Altitude(m)	English name	Japanese name	Runoff type	Crop	Irrigation system	Soil
105D	36.01315	140.46501		-	-	Drainage	Rice paddy	D	Clay & gravel
106PD	36.01696	140.46008		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
108D	36.03090	140.45323		-	-	Drainage	Rice paddy	D	Clay & gravel
109PD	36.03493	140.44916		-	-	Pumping & Drainage	Rice paddy	C1	Clay & gravel
111PD	36.04225	140.44337		-	-	Pumping & Drainage	Rice paddy	C1	Clay & gravel
113D	36.04937	140.43897		-	-	Drainage	Rice paddy	C1	Clay & gravel
116D	36.05622	140.43226		-	-	Drainage	Rice paddy	C1	Clay & gravel
117PD	36.05967	140.42774		-	-	Pumping & Drainage	Rice paddy	C1	Clay & gravel
119D	36.06244	140.42498		-	-	Drainage	Rice paddy	C1	Clay & gravel
120PD	36.06541	140.42258		-	-	Pumping & Drainage	Rice paddy	C1	Clay & gravel
124D	36.07757	140.41712		-	-	Drainage	Rice paddy	C1	Clay & gravel
125PD	36.08215	140.41744		-	-	Pumping & Drainage	Rice paddy	C1	Clay & gravel
127PD	36.09026	140.41239		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
134D	36.10658	140.39676		-	-	Drainage	Rice paddy	C1	Clay & gravel
135D	36.10989	140.39802		-	-	Drainage	Rice paddy	C1	Clay & gravel
139PD	36.12328	140.39508		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
141PD	36.12574	140.39371		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
144PD	36.13444	140.38391		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
148D	36.14227	140.37656		-	-	Drainage	Rice paddy		Clay & gravel
151D	36.14952	140.36653		-	-	Drainage	Rice paddy	C1	Clay & gravel

Table 2-1 continued

Site ID	Latitude	Longitude	Altitude(m)	English name	Japanese name	Runoff type	Crop	Irrigation system	Soil
154D	36.14960	140.36211		-	-	Drainage	Rice paddy	D	Clay & gravel
162PD	36.14776	140.33664		-	-	Pumping & Drainage	Rice paddy	C1	Clay & gravel
164PD	36.15186	140.33044		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
167D	36.16145	140.31550		-	-	Drainage	Rice paddy	D	Clay & gravel
168PD	36.16129	140.31278		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
169D	36.16135	140.30965		-	-	Drainage	Rice paddy	D	Clay & gravel
173D	36.15473	140.30813		-	-	Drainage	Rice paddy	C1	Clay & gravel
174D	36.15036	140.30661		-	-	Drainage	Rice paddy	D	Loam
177D	36.13511	140.33598		-	-	Drainage	Rice paddy	D	Clay & gravel
180PD	36.12378	140.33801		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
183PD	36.11848	140.35527		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
185PD	36.11115	140.36894		-	-	Pumping & Drainage	Rice paddy	D	Loam
187D	36.10054	140.37620		-	-	Drainage	Rice paddy	D	Clay & gravel
190PD	36.09187	140.38347		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
192D	36.08662	140.39353		-	-	Drainage	Rice paddy	D	Clay & gravel
195D	36.08228	140.38996		-	-	Drainage	Rice paddy	D	Clay & gravel
203PD	36.06172	140.36609		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
206D	36.06347	140.34674		-	-	Drainage	Rice paddy	D	Clay & gravel
207PD	36.06064	140.33409		-	-	Pumping & Drainage	Rice paddy	D	Clay & gravel
8PD	36.04594	140.22786		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel

Table 2-1 continued

Site ID	Latitude	Longitude	Altitude(m)	English name	Japanese name	Runoff type	Crop	Irrigation system	Soil
9D	36.04260	140.23336		-	-	Drainage	Lotus paddy	D	Clay & gravel
10PD	36.04137	140.23751		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
18D	36.03020	140.28465		-	-	Drainage	Lotus paddy	D	Clay & gravel
49D	35.98951	140.41073		-	-	Drainage	Lotus paddy	D	Clay & gravel
70D	35.95650	140.48269		-	-	Drainage	Lotus paddy	D	Clay & gravel
132D	36.10089	140.40164		-	-	Drainage	Lotus paddy	D	Clay & gravel
137PD	36.11834	140.39757		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
157D	36.14938	140.35581		-	-	Drainage	Lotus paddy	D	Loam
158PD	36.14453	140.35234		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
159D	36.14370	140.35232		-	-	Drainage	Lotus paddy	D	Clay & gravel
160PD	36.14084	140.35252		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
161D	36.14301	140.34042		-	-	Drainage	Lotus paddy	C1	Clay & gravel
176D	36.14397	140.32114		-	-	Drainage	Lotus paddy	D	Clay & gravel
202PD	36.06602	140.37175		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
205D	36.06300	140.35682		-	-	Drainage	Lotus paddy	D	Clay & gravel
208PD	36.06370	140.32327		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
210PD	36.06508	140.31988		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
211D	36.06624	140.31725		-	-	Drainage	Lotus paddy	D	Clay & gravel
212PD	36.06705	140.31468		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
213PD	36.06855	140.31025		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel

Table 2-1 continued

Site ID	Latitude	Longitude	Altitude(m)	English name	Japanese name	Runoff type	Crop	Irrigation system	Soil
215D	36.06707	140.30181		-	-	Drainage	Lotus paddy	D	Clay & gravel
216PD	36.06352	140.29743		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
217PD	36.06295	140.28888		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
218PD	36.06567	140.28220		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
220PD	36.06747	140.27285		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
221D	36.06840	140.26804		-	-	Drainage	Lotus paddy	D	Clay & gravel
222D	36.06908	140.26091		-	-	Drainage	Lotus paddy	D	Clay & gravel
224D	36.06851	140.24887		-	-	Drainage	Lotus paddy	C1	Clay & gravel
226PD	36.07232	140.24149		-	-	Pumping & Drainage	Lotus paddy	C1	Clay & gravel
227PD	36.08018	140.23915		-	-	Pumping & Drainage	Lotus paddy	D	Clay & gravel
229PD	36.08633	140.22596		-	-	Pumping & Drainage	Lotus paddy	C1	Clay & gravel
1R	36.07867	140.19014		Sakura R.	桜川	inflow river	-	-	-
3R	36.06936	140.20718		Bizen R.	備前川	inflow river	-	-	-
6R	36.05096	140.21215		Hanamuro R.	花室川	inflow river	-	-	-
16R	36.02775	140.27325		Seimei R.	清明川	inflow river	-	-	-
25R	36.02454	140.31794		Otsuka R.	大塚川	inflow river	-	-	-
36R	35.99692	140.34239		Takahashi R.	高橋川	inflow river	-	-	-
39R	35.97483	140.35081		Ono R.	大野川	inflow river	-	-	-
64R	35.94388	140.44590		Shintone R.	新利根川	inflow river	-	-	-

Table 2-1 continued

Site ID	Latitude	Longitude	Altitude(m)	English name	Japanese name	Runoff type	Crop	Irrigation system	Soil
87R	35.97789	140.49980		Asoumae R.	麻生前川	inflow river	-	-	-
92R	35.98648	140.48195		Shiroshita R.	城下川	inflow river	-	-	-
107R	36.02836	140.45646		Oo R.	大川	inflow river	-	-	-
110R	36.04231	140.44686		Funako R.	船子川	inflow river	-	-	-
121R	36.06911	140.42151		Shinta R.	新田川	inflow river	-	-	-
126R	36.08882	140.41850		Tega R.	手賀川	inflow river	-	-	-
128R	36.09518	140.41629		Hagine R.	萩根川	inflow river	-	-	-
131R	36.10033	140.40567		Kajinashi R.	梶無川	inflow river	-	-	-
153R	36.15542	140.36265		Kamata R.	鎌田川	inflow river	-	-	-
155R	36.16420	140.35411		Sonobe R.	園部川	inflow river	-	-	-
170R	36.16377	140.30770		Sano R.	山王川	inflow river	-	-	-
172R	36.16342	140.28381		Koise R.	恋瀬川	inflow river	-	-	-
188R	36.10319	140.36995		Hishiki R.	菱木川	inflow river	-	-	-
204R	36.06503	140.35813		Ichnose R.	一ノ瀬川	inflow river	-	-	-
219R	36.07056	140.27663		Kawashiri R.	川尻川	inflow river	-	-	-
228R	36.08641	140.23656		Tamura R.	田村川	inflow river	-	-	-
230R	36.09038	140.22079		Sakai R.	境川	inflow river	-	-	-
231R	36.08474	140.21159		Shin R.	新川	inflow river	-	-	-
79R	35.96021	140.50854		Hitachitone R.	常陸利根川	outflow river	-	-	-

Table 2-1 continued

Site ID	Latitude	Longitude	Altitude(m)	English name	Japanese name	Runoff type	Crop	Irrigation system	Soil
232L	36.03778	140.40389		Koshin	湖心	lake	-	-	-

Inflow: river flowing into Nishiura

outflow river: river outflowing from Nishiura.

C1: both irrigation and drainage system, **D:** circulation irrigation system.

Soil information: data obtained from the Geospatial Information Authority of Japan, Ministry of Land, Infrastructure, Transport and Tourism (2016)

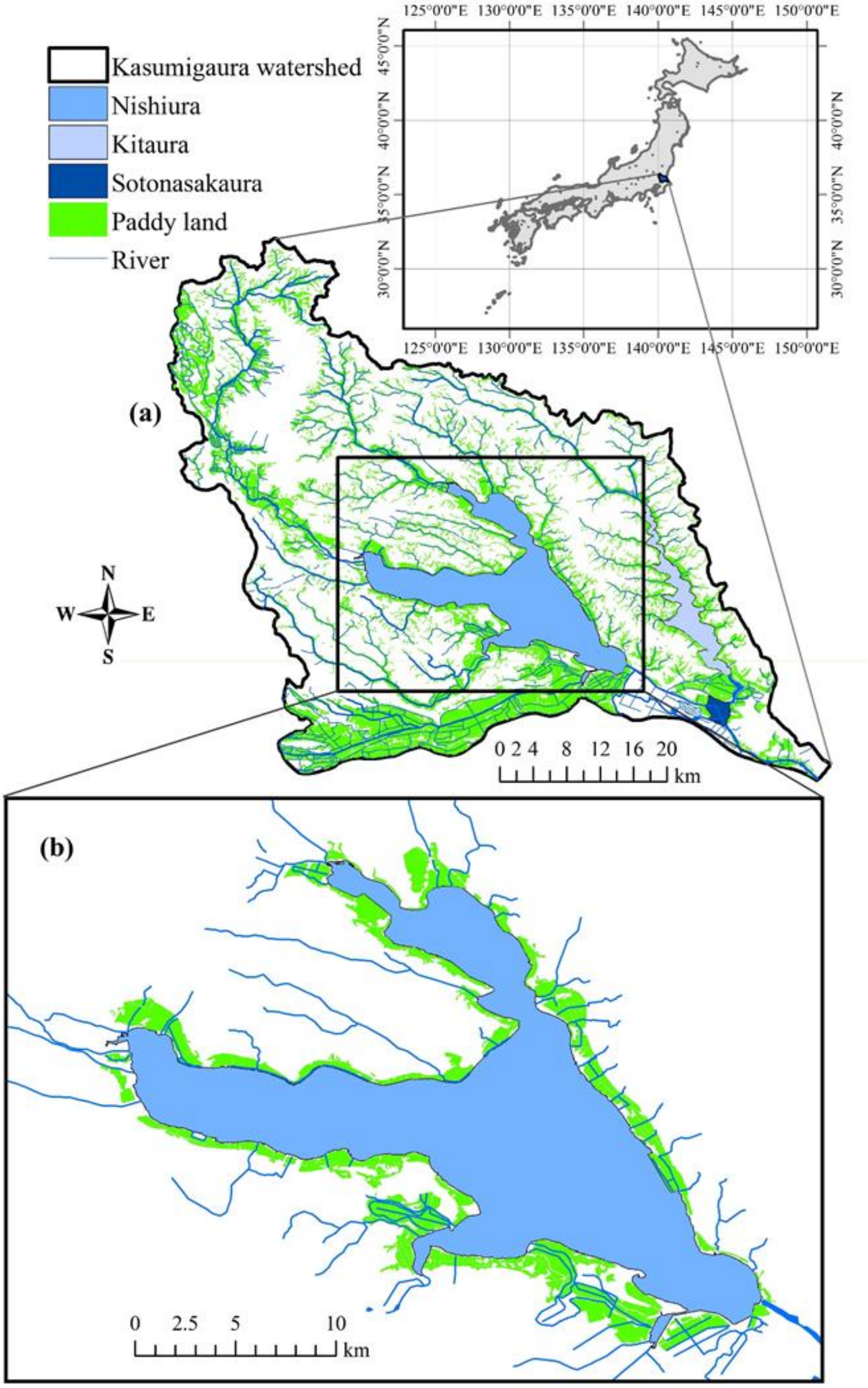

Figure 2-1 Map of Lake Kasumigaura.

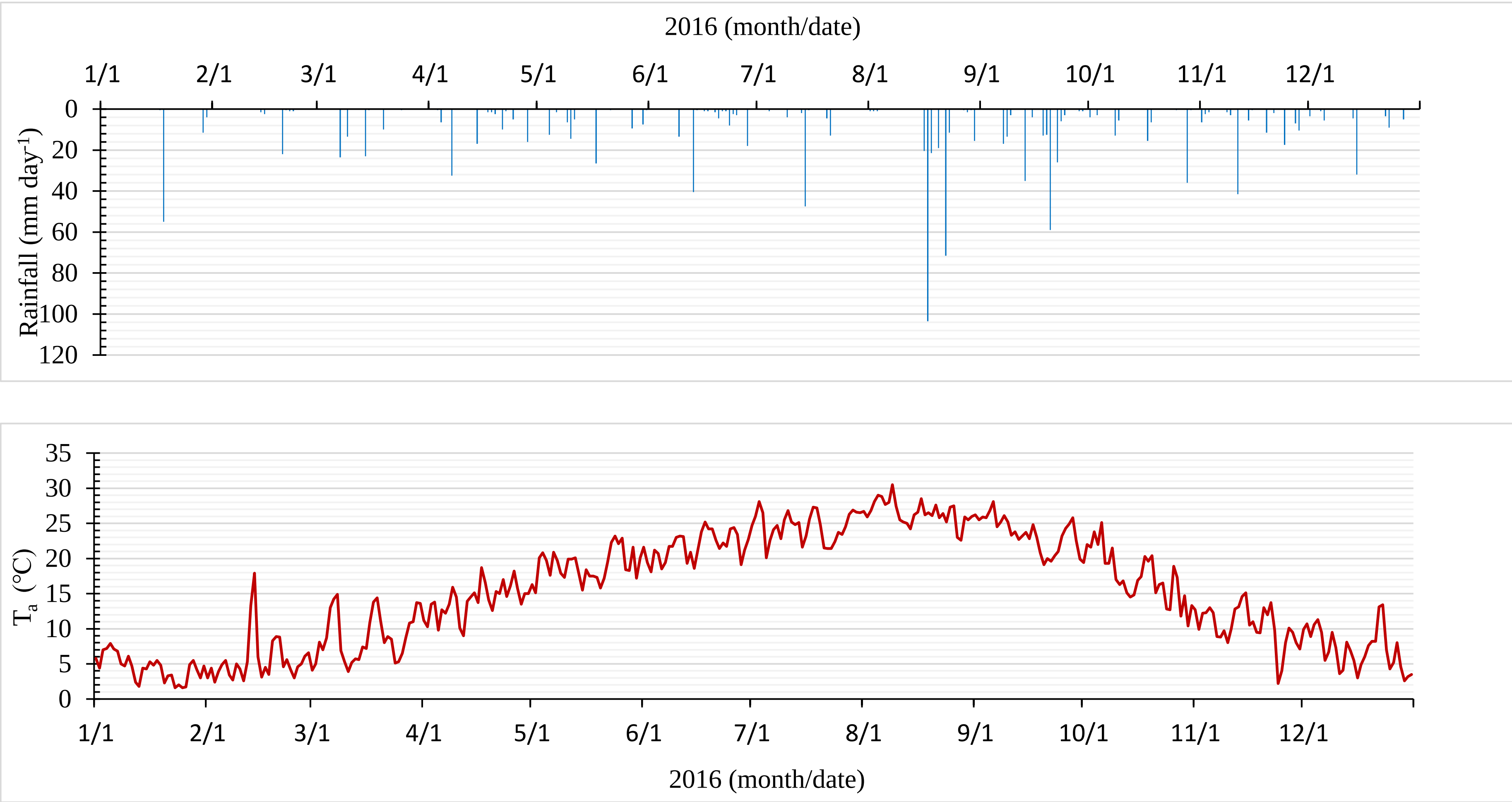

Figure 2-2 Annual rainfall (mm day^{-1}) and air temperature in 2016, data obtained from Tsuchiura station, Japan Meteorological Agency (2016)

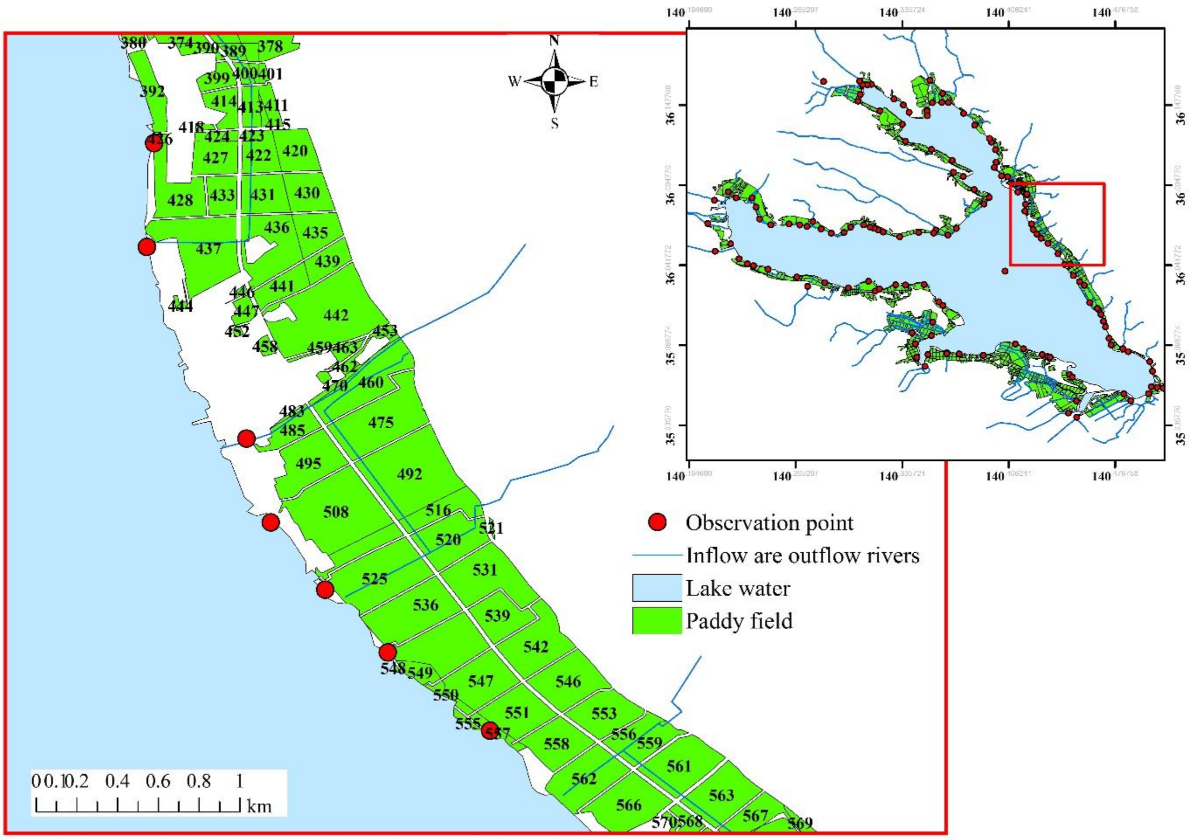

Figure 2-3 Sample of base map for field observation. The green sub-areas are un-verified paddy fields with number identified. Red circles represent observation points where the irrigation and drainage stations located.

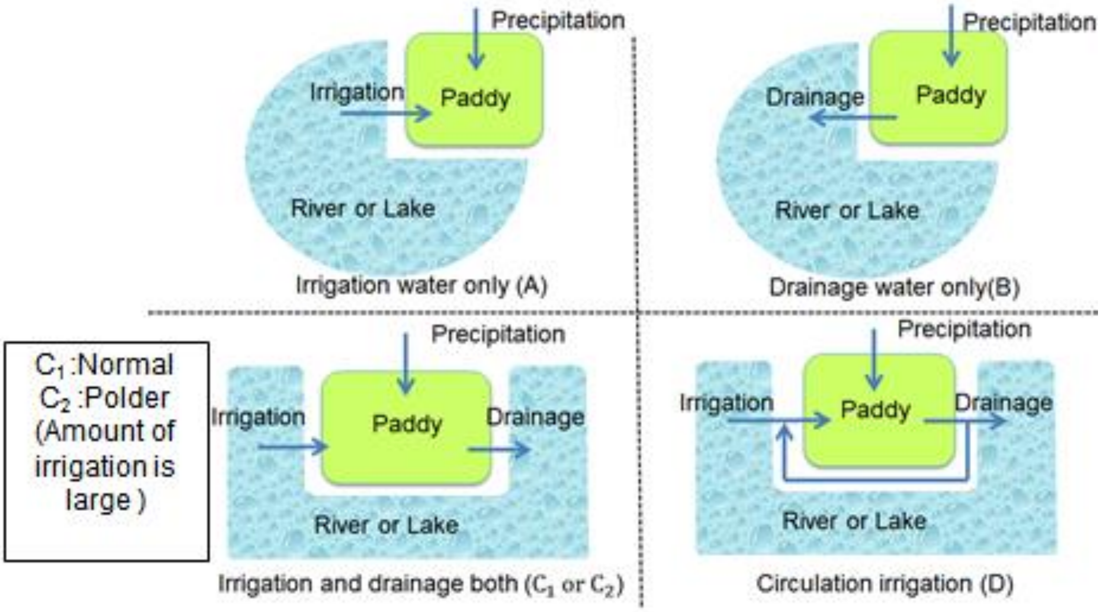

Figure 2-4 Schematic diagram of irrigation system classification of paddy field in lake Kasumigaura watershed (Baoyin Chaogela 2016, personal communication)

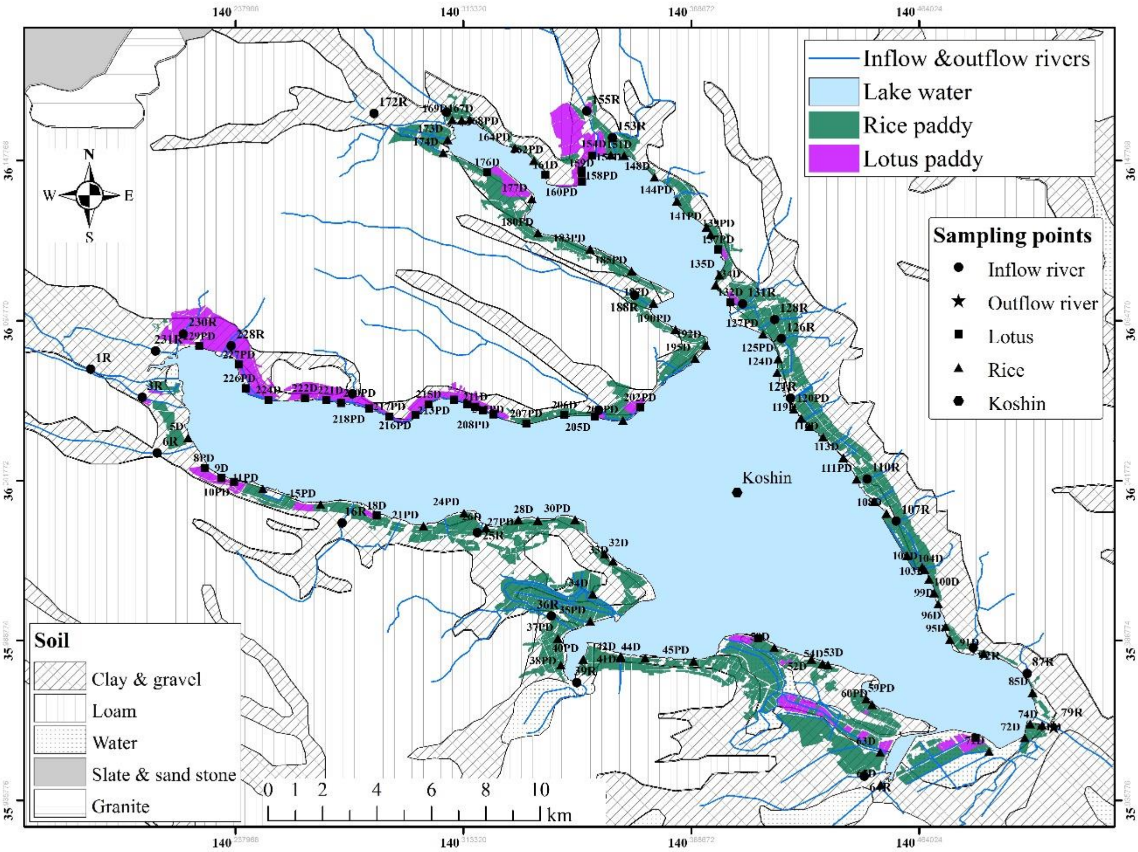

Figure 2-5 Map illustrating location of water sampling site. The lotus paddy drainage points are labeled with squares, the rice paddy drainage points are indicated with triangle, inflow rivers are labeled with circles and star for out flow river. The hexagons represent Koshin observatory station located in center of Nishiura.

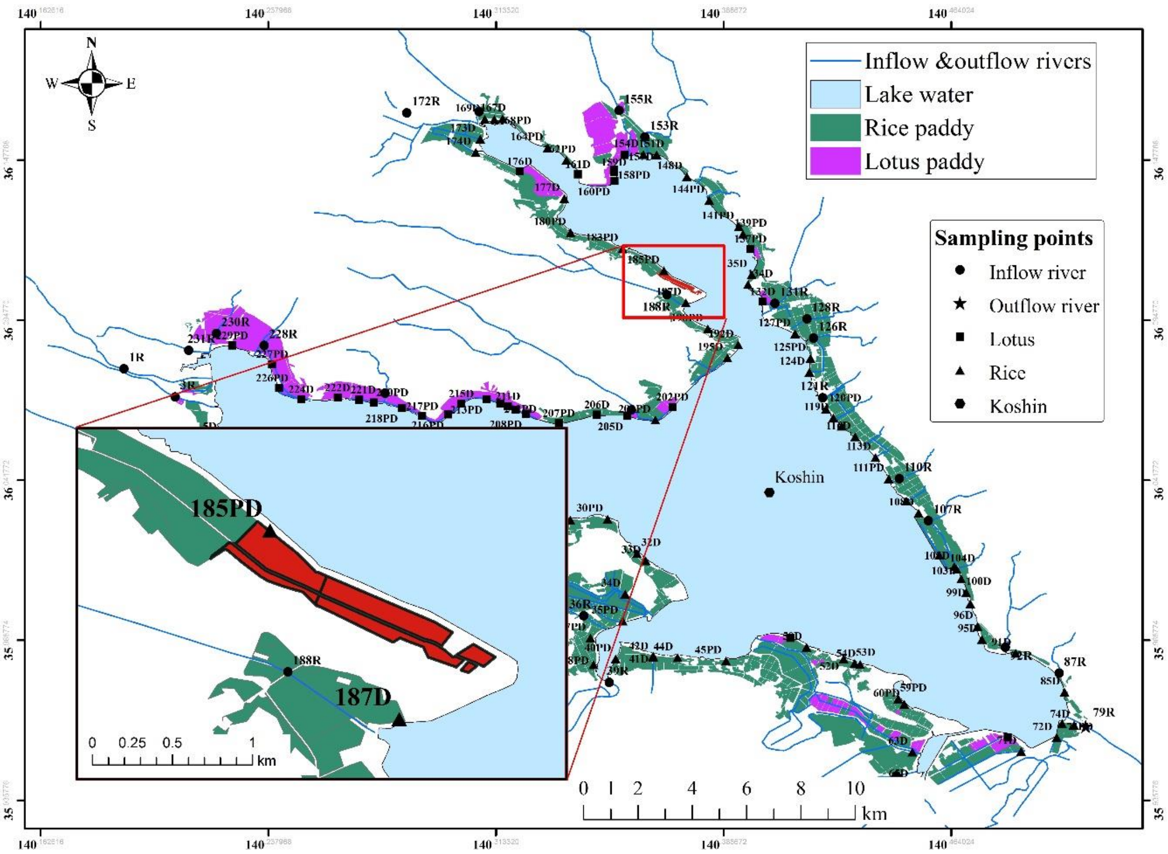

Figure 2-6 Map illustrating water sample point in paddy field drainage. The sampling points are identified with number following with letter in capital (D: draining station, PD: pumping and draining station), red area indicate draining area to 185PD pumping and draining station.

Chapter 3 Results

3.1 Soil characteristic and spatial distribution of dissolved in organic carbon.

Soils around the Nishiura lakeshore are shown in Figure 3-1. Clay, gravel and loam are majority of soil textures observed in the targeted area. Clay and gravel underlay the paddy field covered 50.69 km^2 (93 % of Nishiura paddy field) and the rest (3.81 km^2) is loam (Table 3-1). Clays are mostly observed in may flooding cultivated land. Due to their muddy characteristic compared to loam, therefore, clays are having high probability of releasing soil mineral contents to water solution. This process supports the carbonate rock weathering (Barnes & Raymond, 2009). Somehow, the mentioned processes could enhance the DIC contain in water drainage from this area.

The DIC concentration in mmol L^{-1} of the sampling sites illustrated on the maps (Figure 3-14 to Figure 3-19), with soil types distribution layer and area of rice and lotus paddies. Figure 3-14 shows the DIC concentration of sampling sites in February, Figure 3-15 in March, Figure 3-16 in May, Figure 3-17 in June, Figure 3-18 in July and Figure 3-19 in August in 2016. In three sampling points of 159D, 185PD and 174D that are the drainages from paddy field underlay with loam which is different with the nearby paddy. However, the DIC concentration in those sample points showed no significant difference with the nearby paddy with different soil characteristic. Also the number of samples across the two different soil type are different. Furthermore, weathering itself, without the cooperation of acidification that produce hydrate ion would not lead the effect on the change of carbonate contains. The two processes could occur in the intensive agricultural practiced with the application of chemical manure (Brunet *et al.*, 2011).

3.2 Distribution of rice and lotus paddies

The area of rice and lotus paddies are shown in Figure 3-2. Rice is major crop that being cultivated in Kasumigura and distributing along the lakeshore of the Nishiura. Lotus paddy is distributing in small portion in the Northern part and some in Southern part in Inashiki city. The high density of lotus field was observed in the North-West side of the shoreline to the Tsuchiura city direction. The area of lotus paddy field is only two percent of the entire paddy area in the watershed (Table 3-1). However, this area is still large comparing to proportion of lotus field in Kitaura and other location. Lotus roots production of this region accounts half of total production in Japan (National Institute for Environmental Studies 2004). Furthermore, cultivation of lotus is practice in all year round and requires water to be accumulating during both planting and harvesting period. that lead to also saturation and accumulating nutrients. In contrast, rice cultivation time is shorter and use less irrigated water. Therefore, with small portion however may effective the DIC concentration in the drainage water.

3.3 Cultivation schedule

Based on the interview results and information from Kitamura (2015), the cultivation schedule and time scale of lotus and rice in 2016 were summarized and show in Table 3-3 and Figure 3-20.

In lotus paddy, the harvesting of lotus root was being carried on almost throughout the year excluding additional fertilization period from late June to mid-August. During this time manure was applied continuously to the paddy to accelerate the growth of lotus after being planted. Before lotus is planted, the paddy was prepared by flooding and tilling in April. During this time, the fertilizer was also applied. The large amount of irrigation water is required during this time and along the harvesting time.

In rice paddy, the cultivation starts from mid-April. At the beginning, land preparation is carried out through the tilling and fertilization procedures. The planting is from May 16th to 28th. Additional fertilization applied from June to July. After that the rice paddy was drained out water to increase stress tolerance of the rice until late September. The harvesting period was approximately 9 to 10 days in September.

3.4 Irrigation, drainage facilities and irrigation system

Figure 3-3 illustrating locations of water pumping and draining stations for irrigation purpose. The stations are located along the shoreline of the lake, and connected to lake water through the pipe lining across and under the lakeshore road. There is water gate between the edge of the pipe and lake water for water management. The pumping devises are installed inside the building of each facility. The facilities could be classified into three types: pumping station, drainage station, and pumping and draining station. Pumping station is only utilized to intake irrigation water from the lake, and to distribute water to paddy area by underground pipe line. The drainage station is only utilized for water drainage from the paddy field. However, the drainage is mostly managed by opening and closing the water gate. The pumping devises is only operated to drain high flooding event during the typhoon season. The pumping and draining stations are major facilities have been installed, they are operated both to pump the irrigation water distributing to the field and to pump the drainage water out of paddy field.

The irrigation water utilized in the paddy fields in the Lake Kasumigaura watershed are mainly from river, lake and rainfall. The irrigation systems practiced in paddy fields are different due to the water allocation and location of the paddy. There are mainly four types of irrigation system (Ministry of Environment of Ibaraki Prefectural Government, 1978, Figure 2-4). Type A (irrigation water only) which only intakes irrigation from lake water and rainfall, type B (drainage water only) which only drains cultivated water to the lake and only intakes water from rainfall, type C1 (both irrigation and drainage) which intakes water from lake or river and rainfall for irrigation, and export the drainage to the lake, type D (circulating irrigation) which is similar to type C1. Though, the drainage water will be circulated and used again as irrigation water in type D.

The results are from the field observation and GIS data analysis shows the area of the different irrigation system across lotus and rice paddies, illustrated in Figure 3-3. Along the Nishiura lakeshore, only paddy field with irrigation type C1 and D are observed in this region. Irrigation type C1 (both irrigation and drainage) takes large percentage (64%) and mostly are rice paddy field (Table 3-1).

3.5 Dissolved inorganic carbon concentration

3.5.1 Average dissolved inorganic carbon in drainage from lotus and rice paddies, inflow river and lake water

Figure 3-4 shows the average DIC concentration in drainage waters from rice and lotus paddies, inflow rivers and the lake water. From March to mid-August, the average of DIC concentration in lotus paddy drainage was 2.44 (± 0.74) mmol L^{-1}, that in rice paddy was 2.06 (± 0.73) mmol L^{-1} and 1.54 (± 0.44) mmol L^{-1} in inflow rivers. Monthly average DIC concentration in the lake water was 1.25 mmol L^{-1}. The statistical analysis result suggests the difference of DIC of among the study subjects (Table 3-2). The rice paddy drainage was the highest DIC which is 1.11 and 1.39 times higher than that in the drainage from rice paddy and in inflow rivers to the lake. The lake water has lower concentration of DIC than the surrounding water bodies.

3.5.2 Hourly variation

In this study, the water samples were token and in situ measured in the different time ranging from 07:30 to 17:00 JTS (Japanese Standard Time). The variation of DIC observed in a small range of 0.2 to 0.4 mmol L^{-1} in that time period. This variation may have influenced by the respiration of micro-organism in soil and water, by adding carbon dioxide (Schlesinger & Andrews, 2000) and reduce carbon dioxide through the photosynthesis (Mandlebaum *et al.*, 2011). These process could be observed by the different times in day.

Bicarbonate ion (HCO_3^-) was dominant constituent of DIC in both drainages from rice and lotus paddies. HCO_3^- was making up 89.5%, carbonate ion (CO_3^{2-}) dominated 10.5%, and 0.4% dominated by and carbonic acid or aqueous carbon dioxide ($H_2CO_3^*$). In theory, the equilibrium of carbon dioxide with atmospheric CO_2 could be describe by Henry's law on gas solubility and degassing. The CO_2 gas exchange between liquid surface with air is governed by water temperature, while the equilibrium of the carbonic acid substances dissolved in water are governed by pH and water temperature. Furthermore, pH value of samples was from 7.4 to 7.9 with water temperature average from 16℃ to 22℃. This supports the percentage of carbonate species in this study with those reported in Saruhashi (1955).

In conclusion, hourly variation was small in the water during sampling day. The variation was likely to be the consequences of respiration and photosynthesis processes of micro-organisms in soil and water during the day.

3.5.3 Seasonal variation

The seasonal variation DIC concentration in lotus paddy was 0.19 mmol L^{-1} and rice paddy was 0.21 mmol L^{-1} both were significantly very small. However, these result were analyzed by mean of large number of samples in different location, different crop types practiced different planting, irrigation systems and cultivation stages. To find the variation in each sample, more detailed analysis was done in lotus and rice paddy drainages.

The seasonal variations of DIC concentration in lotus paddy drainages in all samples are shown in Figure 3-5. Those of rice paddy drainages are shown in Figure 3-9. In order to understand the changing tendencies in those samples, samples of lotus paddy drainage were classified into three patterns. Similarly, rice paddy drainage samples were classified into 4 patterns.

Pattern I of both rice and lotus paddies drainages showed a very small change. This change could be considered as hourly variation described in 3.5.2. Pattern II of rice paddy drainage showed slightly increasing tendency from March to August. Pattern II of lotus paddy drainage showed decreasing tendency from March to May, while Pattern III and Pattern IV of rice paddy showed the same tendency of decreasing from March to May. Some samples showed increasing trends to August. Pattern III of lotus paddy drainages showed the increasing trend from March to June, and decrease from July to August.

In conclusion, seasonal variation of DIC concentration in both lotus and rice paddy drainage around the mean values were significantly small. However, the analysis of all samples of DIC concentration variations could be summarized as: 1. DIC concentration in rice paddy drainage decreased from March to May, then increased until August, 2. DIC concentration in lotus paddy drainage increased from March to June, then decreased until August. These changing tendencies could be corresponding to cultivation schedule and drainage rate.

3.6 Discharge amount

Figure 29 shows the average discharge per day from lotus and rice paddies. From April to August of 2016, rice paddy drained water in very large amount compared with lotus paddy. The highest discharge was 176×10^6 L day $^{-1}$ in September. From May to July the discharge kept its constant tendency (Table 3-3). Discharge amount per day from lotus paddy was likely to have the same tendency with that of rice paddy. The high discharge observed in April and September. Figure 30 shows the average discharge per day from paddy fields with different irrigation systems. overall, paddy field with irrigation type C1 drained very large water compared to those with type D. The high discharges were in April, August and September. The difference between drainage rate from the two different paddy fields may corresponds with drainage area, irrigation system and cultivation schedule. The average discharge per day of small inflow rivers was 11.32×10^6 L day $^-1$, calculated by using the estimation from 2008 to 2010 (Yamamoto, 2013). The average discharge of main inflow rivers was 604.8×10^6 L day $^{-1}$.

3.7 Dissolved inorganic carbon loads

Figure 31 shows the monthly average of DIC loads from rice and lotus paddies to Nishiura. Figure 32 shows the monthly average of DIC loads from paddy fields with irrigation type C1 and D. The overall DIC loads fluctuated corresponding to the change of discharge amount. The high loads were observed in April, August and September.

The loads drained from rice paddy on average from May to August was 171.57×10^3 mol L^{-1} day $^{-1}$, from lotus paddy was 61×10^3 mol L^{-1} day $^{-1}$, from small inflow rivers was 18.14×10^3 mol L^{-1} day $^{-1}$, and from main inflow rivers was 1573.96×10^3 mol L^{-1} day $^{-1}$ (Table 3-4).

The loads across paddy drainages were significantly different. This was because the different areas and secondly rice paddy drained larger amount of water compared to lotus paddy. The inflow rivers contain less DIC concentration than paddy drainages. However, with very large discharge they transport DIC loads in to the lake in the very high rate (Table 3-5).

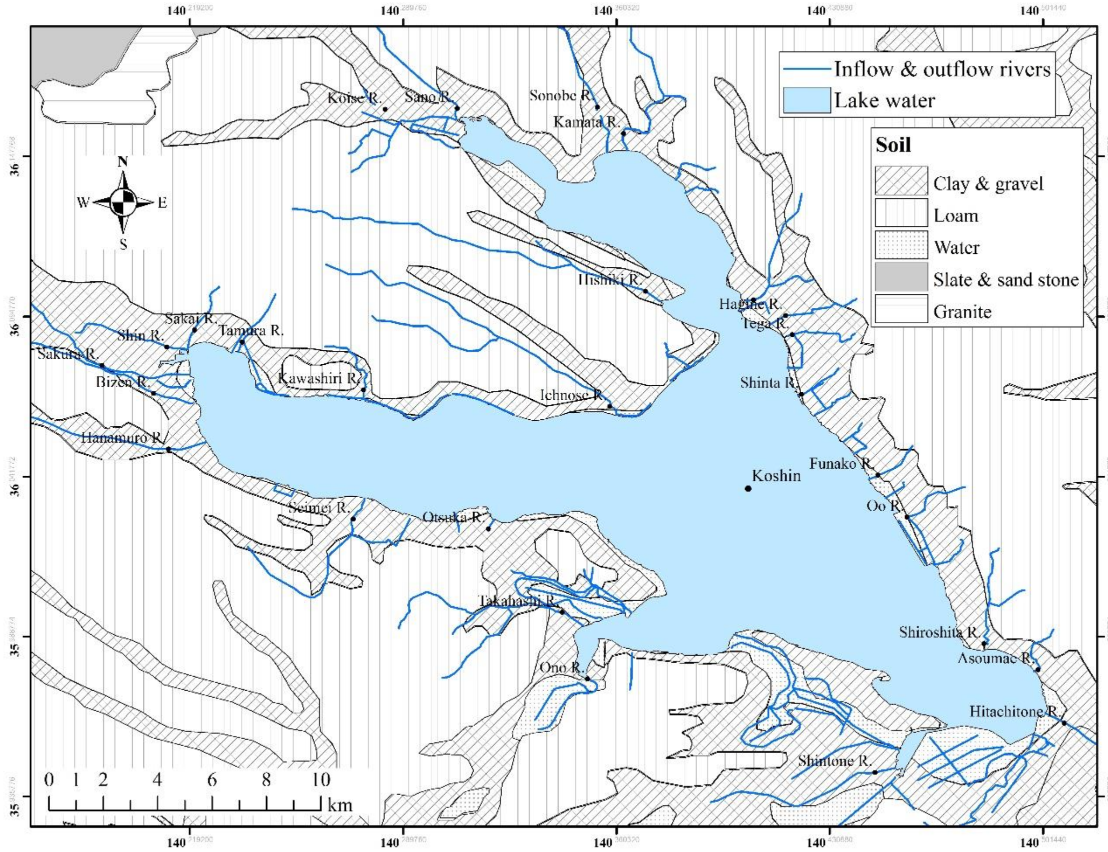

Figure 3-1 Soil characteristic under paddy field alone Nishiura shoreline.

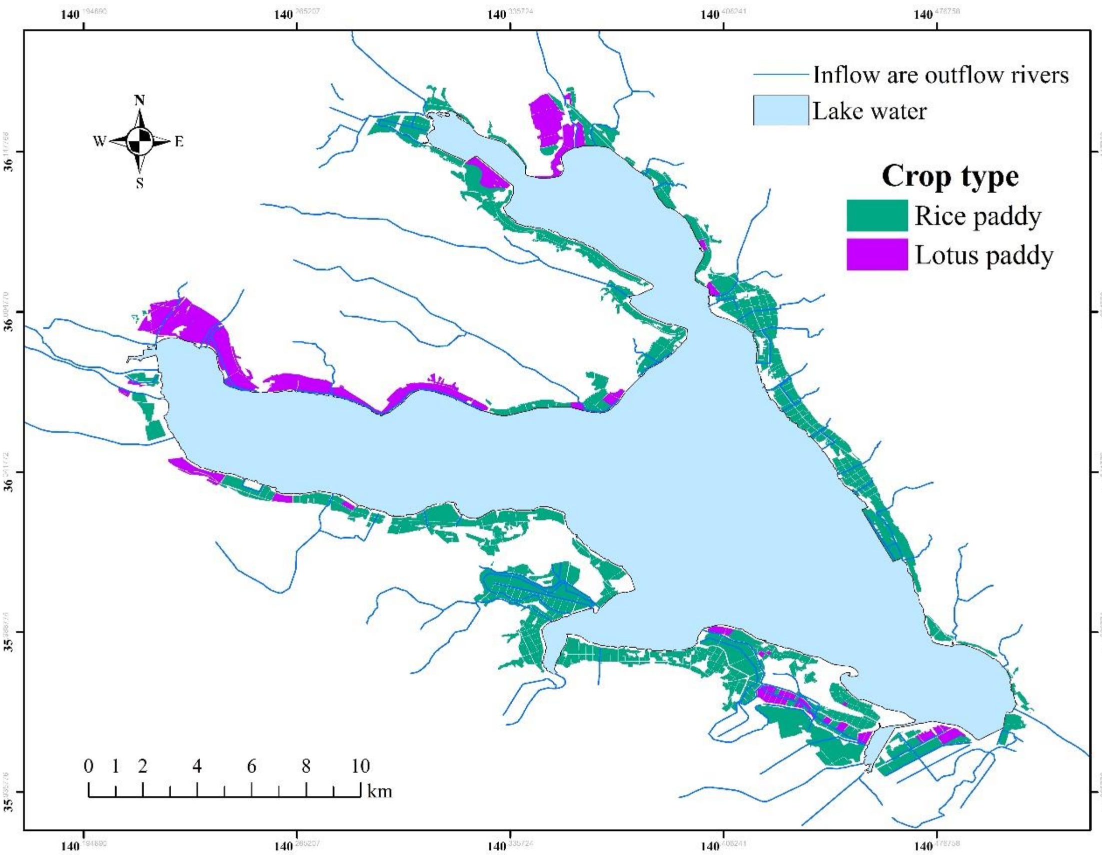

Figure 3-2 Map illustrating rice and lotus paddies along Nishiura shoreline.

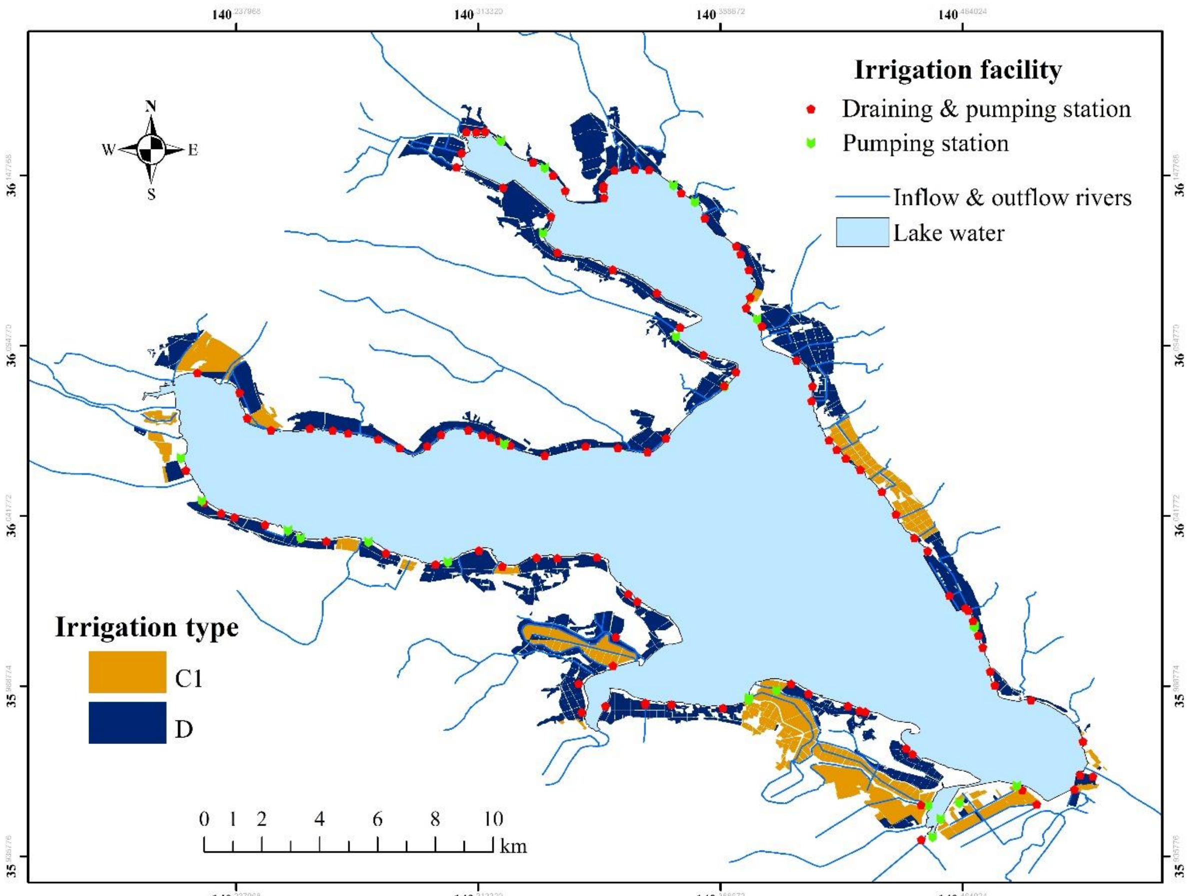

Figure 3-3 Map illustrating area of irrigation systems, location of pumping and draining facilities. **C1**: both irrigation and drainage type, **D**: circulating irrigation type.

Table 3-1 Area of lotus and rice paddies with irrigation type C1 and D

	Area (km^2)					
	Kasumigaura watershed	**Nishiura shoreline**	**Irrigation system**		**Soil**	
			C1	**D**	**Clay & gravel**	**Loam**
All	2156.00	-	-	-		
Agricultural land	849.83	-	-	-		
Paddy field	521.67	54.51 (10%)	35.15 (64%)	19.36 (36%)	50.69 (93%)	3.81 (7%)
Rice paddy	-	42.48 (8%)	27.30 (50%)	15.17 (28%)	41.21 (76%)	1.27 (2%)
Lotus paddy	16.19	12.04 (2%)	7.85 (14%)	4.19 (8%)	11.55 (21%)	0.48 (1%)

% of paddy land area in Kasumigaura watershed is in blue color,

% of different soil area in paddy fields along Nishiura lakeshore is in red color,

% of different irrigation system area in paddy fields along Nishiura lakeshore are in green color.

C1: both irrigation and drainage system

D: circulating irrigation system

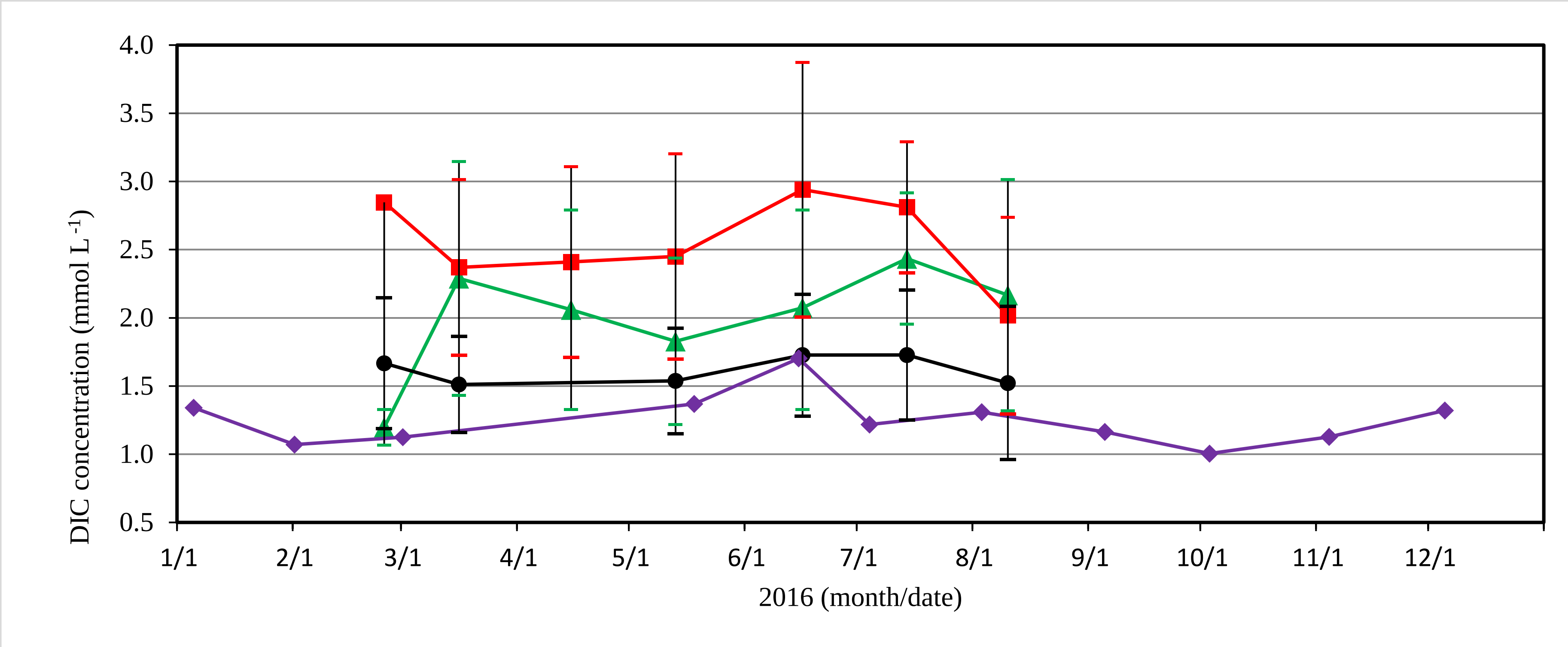

Figure 3-4 Seasonal variation of DIC concentration in drainage from rice and lotus paddies, inflow river and lake water. Red square symbol represents mean from lotus paddy with standard variation. Green triangle symbols representing mean from lotus paddy, black circles representing mean in inflow rivers, and purple diamonds representing values in the lake water.

Table 3-2 Statistical analysis results comparing DIC concentration in lotus and rice paddies, inflow river and lake water

	Lotus			**Rice**			**River**			**Lake**		
		σ	Z		σ	Z		σ	Z		σ	Z
Lotus	1.00			1.11	0.119386	1.857048	1.39	0.113215	5.573227	1.80	0.10326	9.62848
Rice	0.90	0.119386	-1.85705	1.00			1.25	0.075799	8.324277	1.62	0.05992	12.89262
River	0.72	0.113215	-5.57323	0.80	0.075799	-5.39937	1.00			1.29	0.046423	7.825037
Lake	0.56	0.10326	-9.62848	0.62	0.05992	-12.8926	0.77	0.046423	-7.82504	1.00		

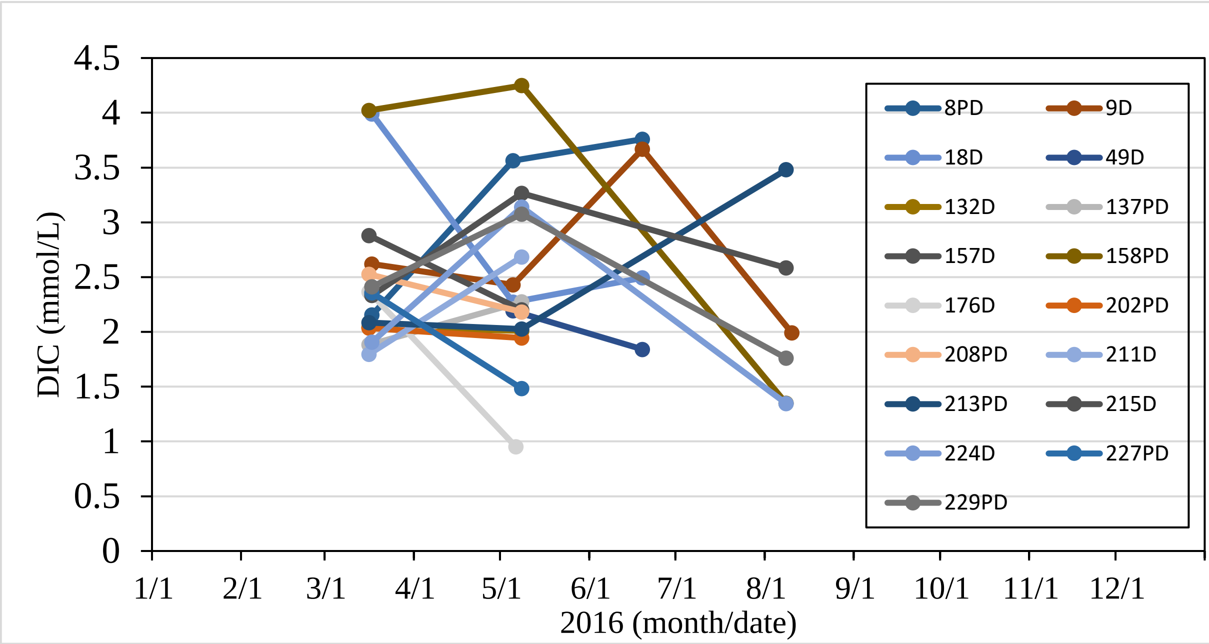

Figure 3-5 Seasonal variation of DIC concentration in sampling points in lotus paddy drainage. Each symbol represents measured value in particularly plot (n= 17).

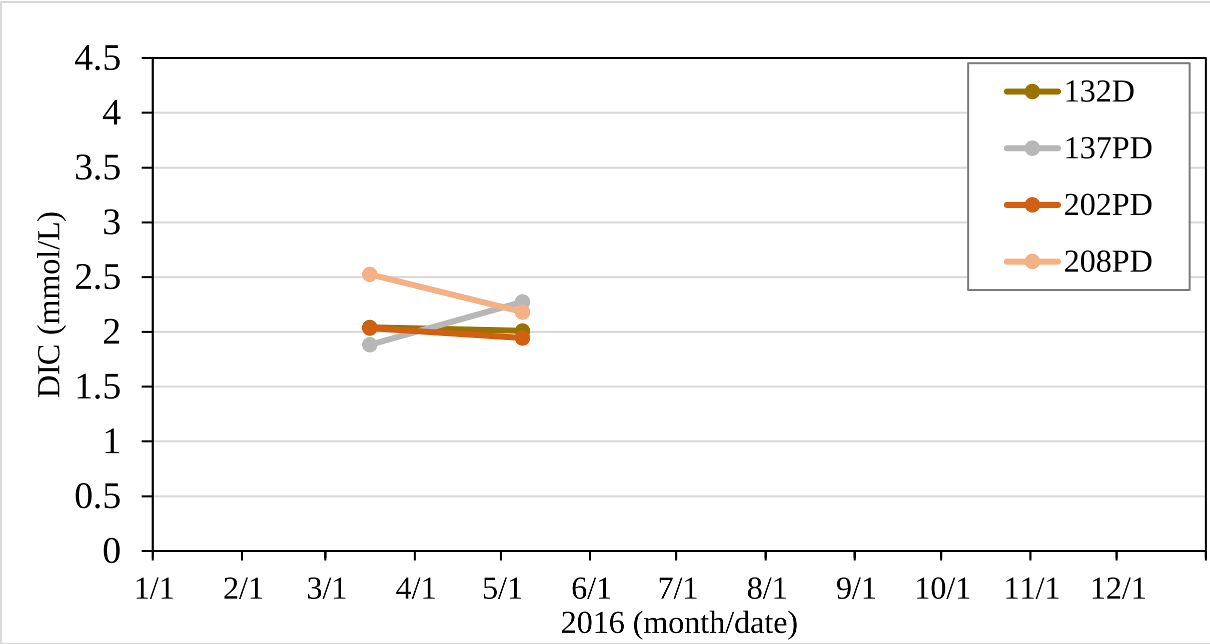

Figure 3-6 Seasonal variation of DIC concentration in sampling points in lotus paddy drainage in pattern I. Legends indicate sampling site ID (n=4).

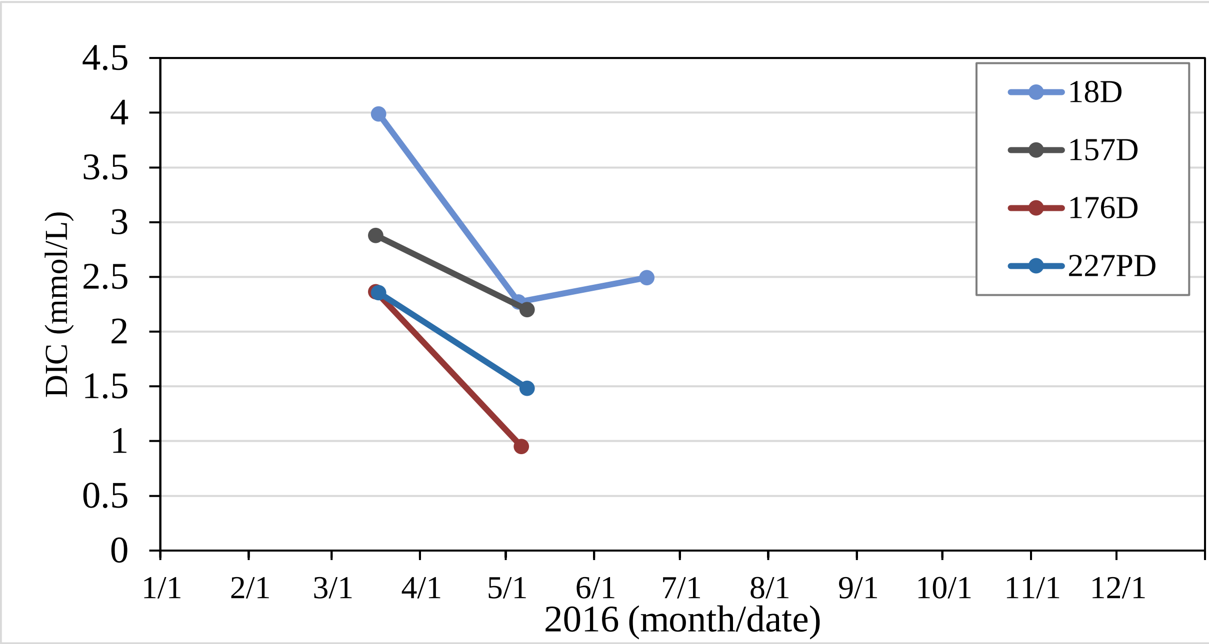

Figure 3-7 Seasonal variation of DIC concentration in sampling points in lotus paddy drainage in pattern II. Legends indicate sampling site ID (n=4).

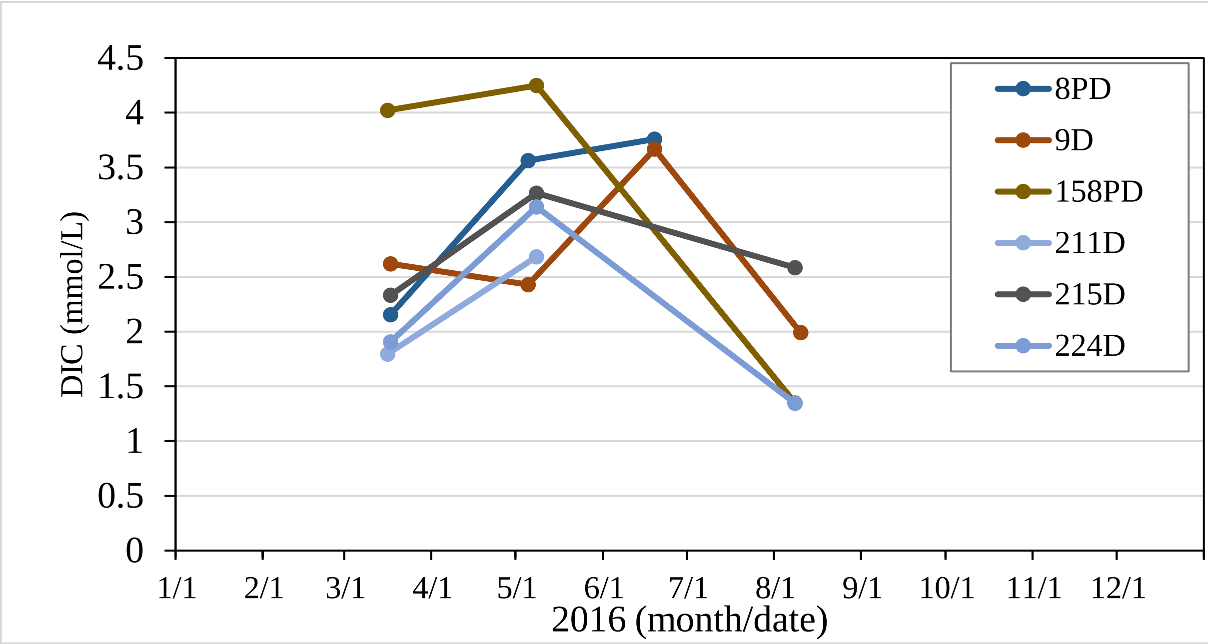

Figure 3-8 Seasonal variation of DIC concentration in sampling points in lotus paddy drainage in pattern III. Legends indicate sampling site ID (n=5).

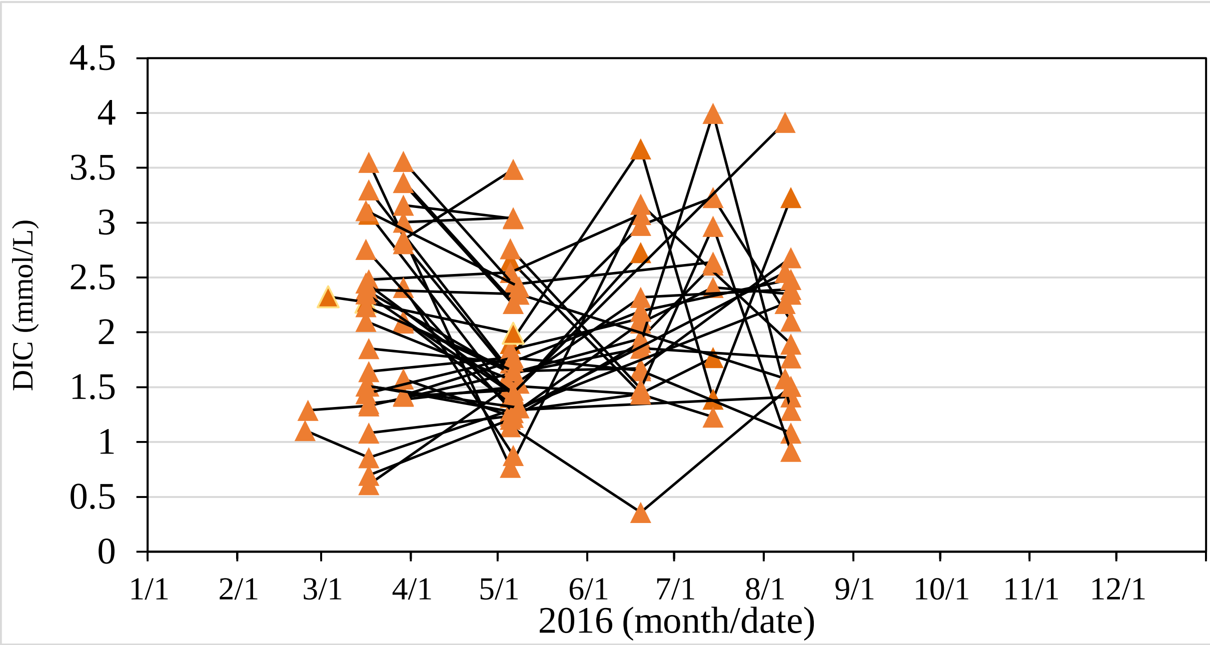

Figure 3-9 Seasonal variation of DIC concentration in sampling points in rice paddy drainage. Each symbol represents measured value in particularly plot (n = 42).

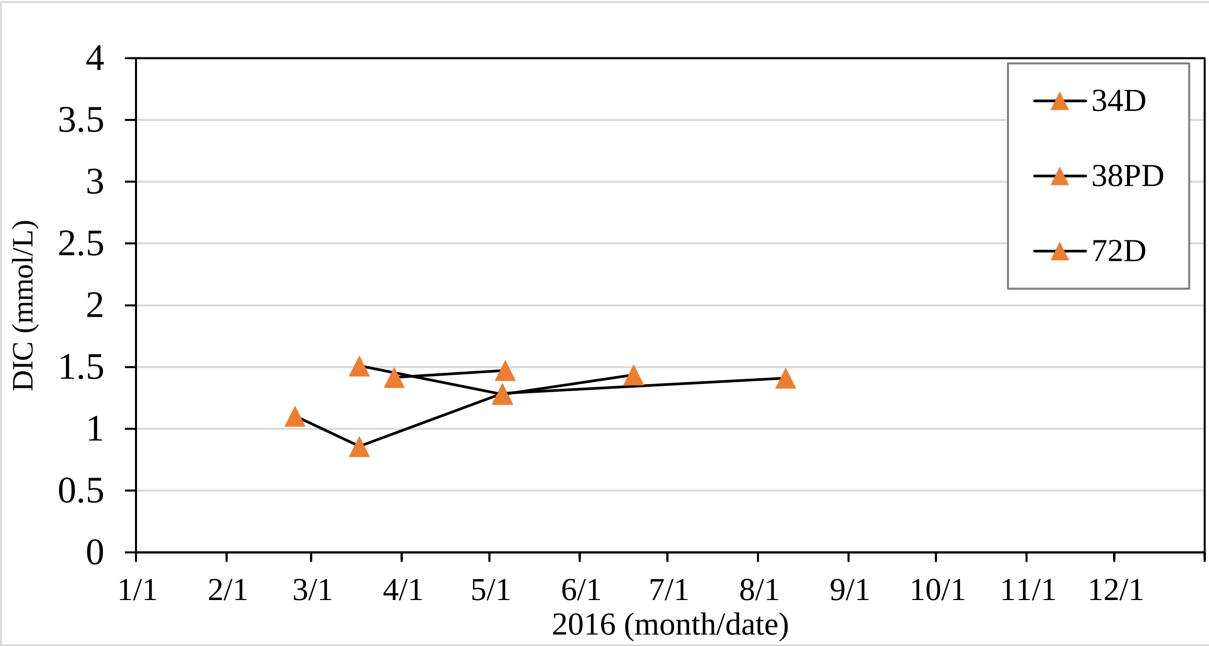

Figure 3-10 Seasonal variation of DIC concentration in sampling points in rice paddy drainage in pattern I. Legends indicate sampling site ID (n=3).

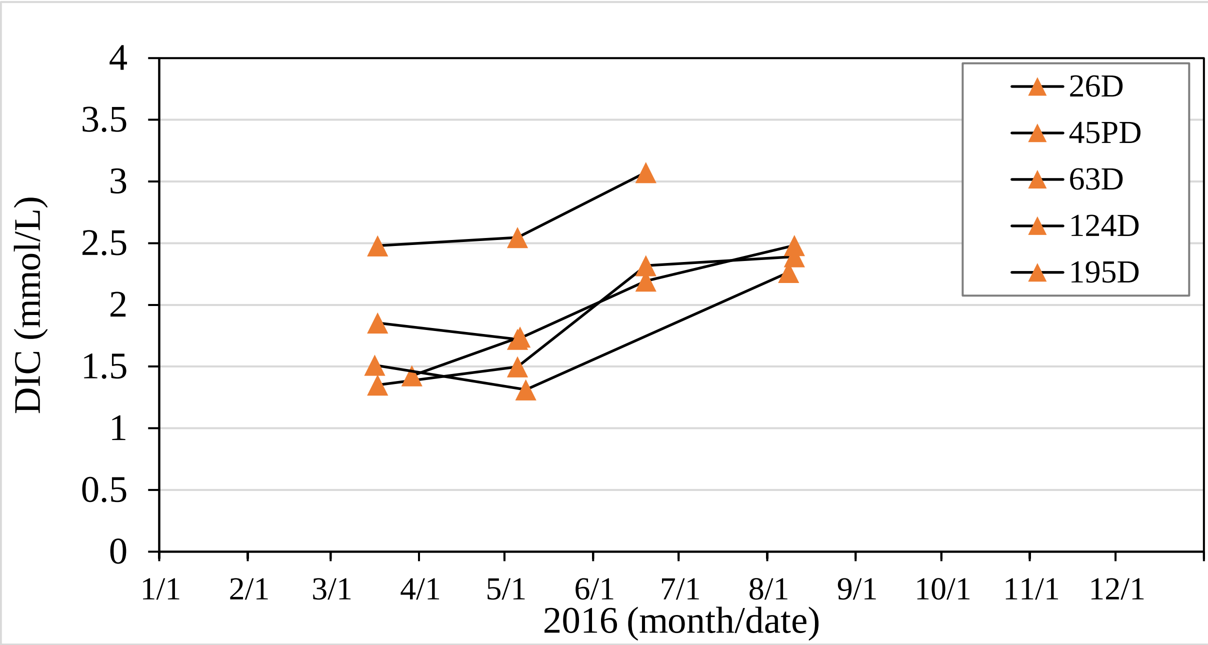

Figure 3-11 Seasonal variation of DIC concentration in sampling points in rice paddy drainage in pattern II. Legends indicate sampling site ID (n=4).

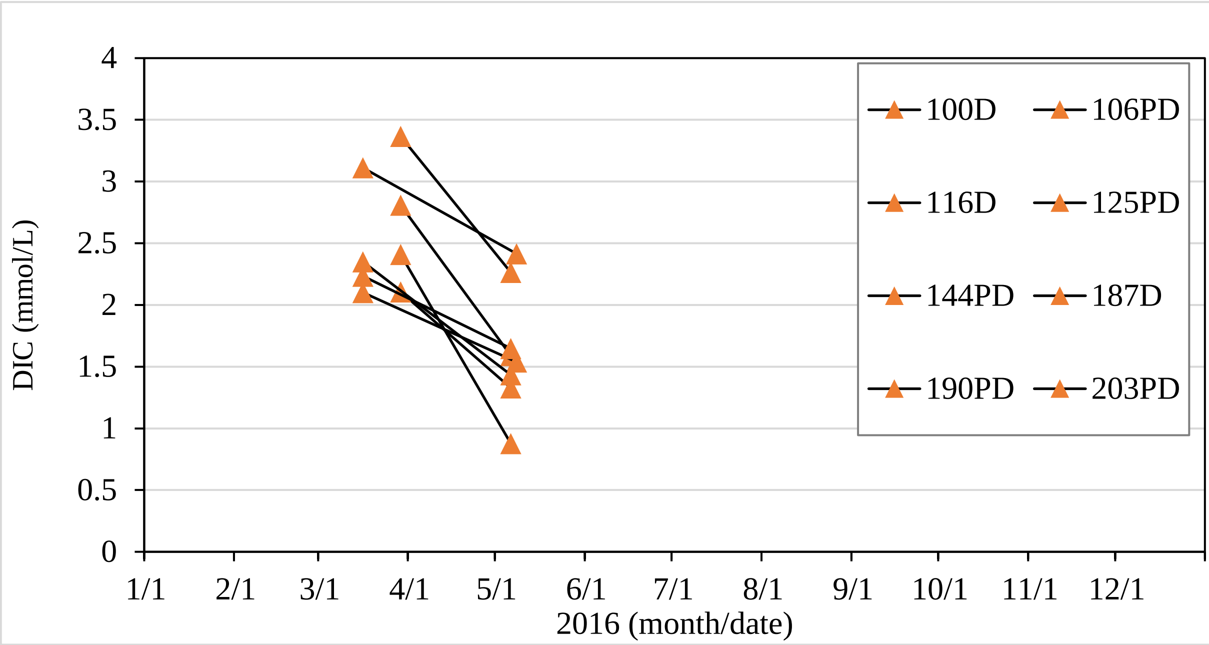

Figure 3-12 Seasonal variation of DIC concentration in sampling points in rice paddy drainage in pattern III. Legends indicate sampling site ID (n=8).

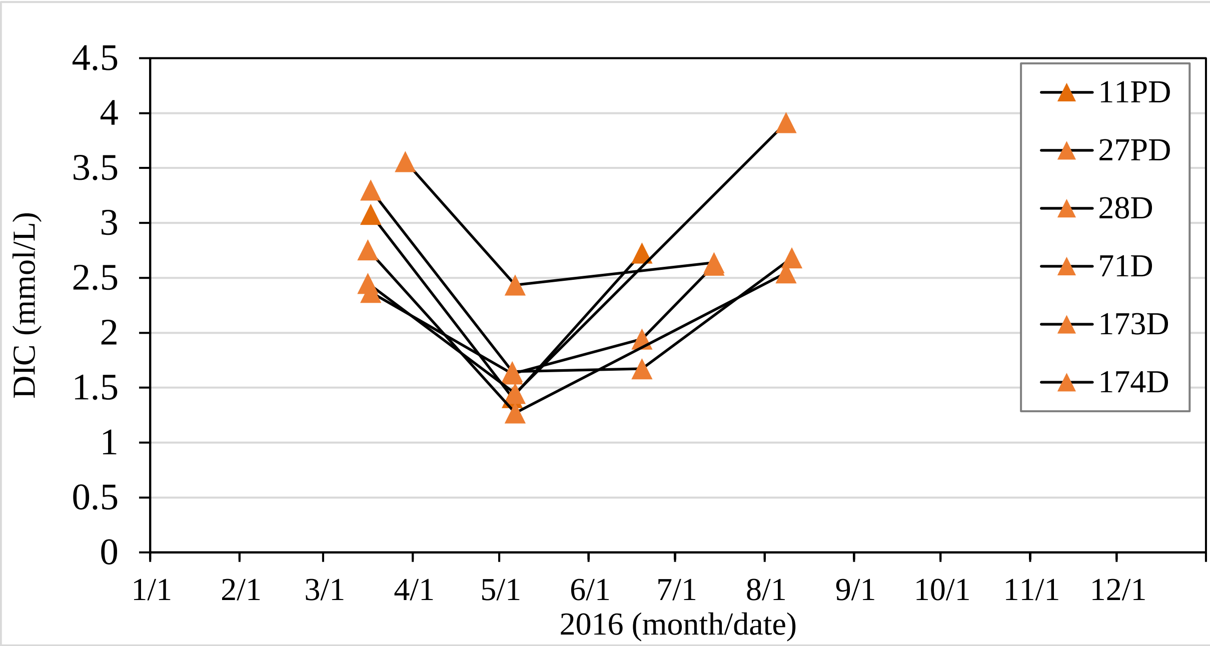

Figure 3-13 Seasonal variation of DIC concentration in sampling points in rice paddy drainage in pattern IV. Legends indicate sampling site ID (n=7).

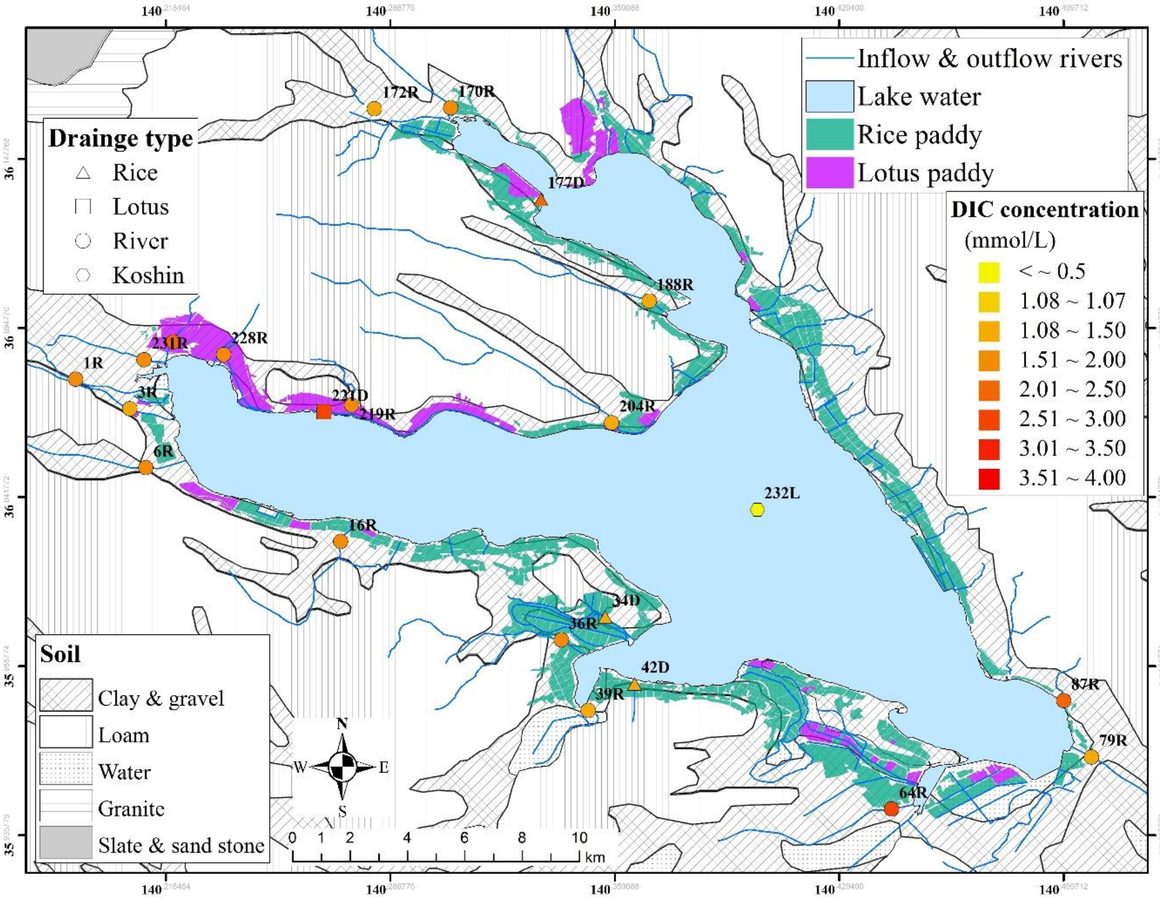

Figure 3-14 Spatial distribution of DIC concentration in drainage from rice and lotus paddies, inflow river and lake water in February of 2016.

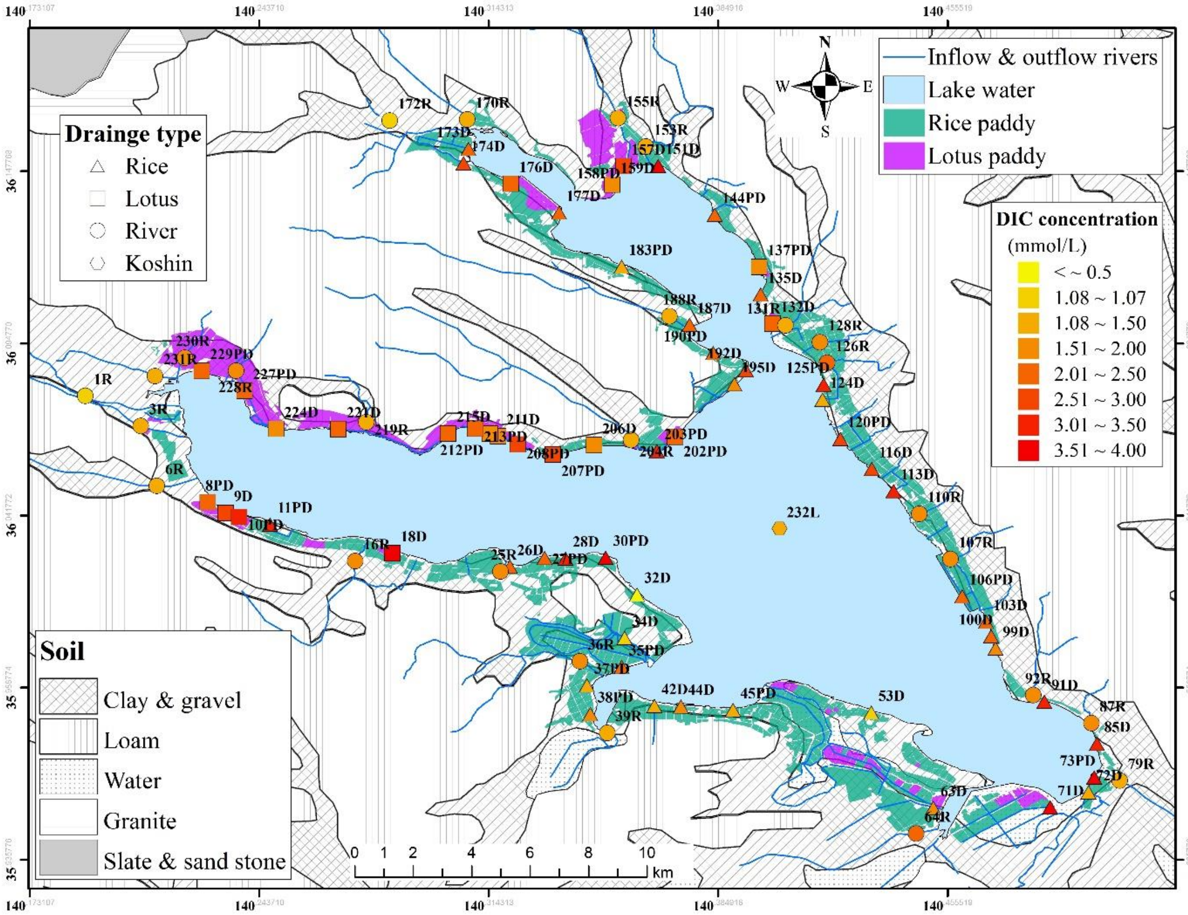

Figure 3-15 Spatial distribution of DIC concentration in drainage from rice and lotus paddies, inflow river and lake water in March of 2016.

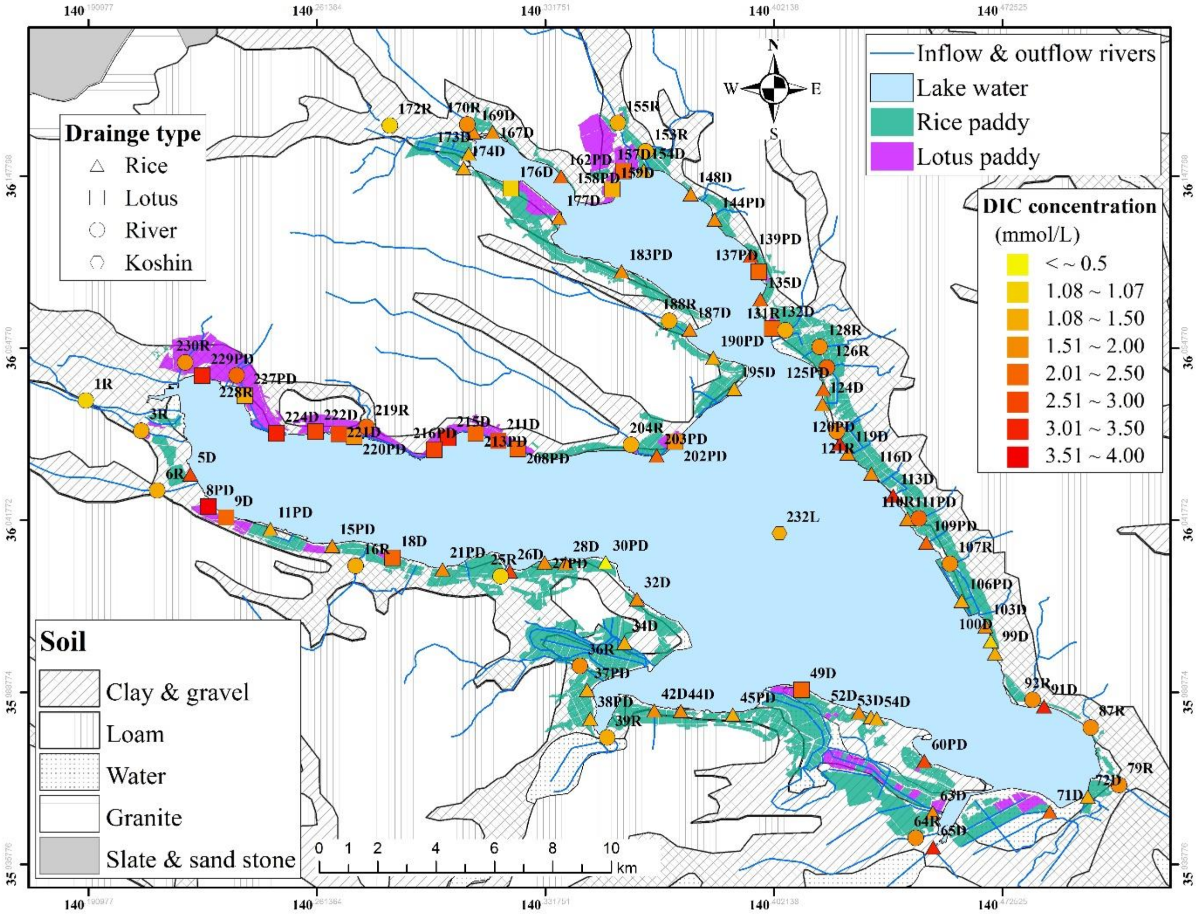

Figure 3-16 Spatial distribution of DIC concentration in drainage from rice and lotus paddies, inflow river and lake water in May of 2016.

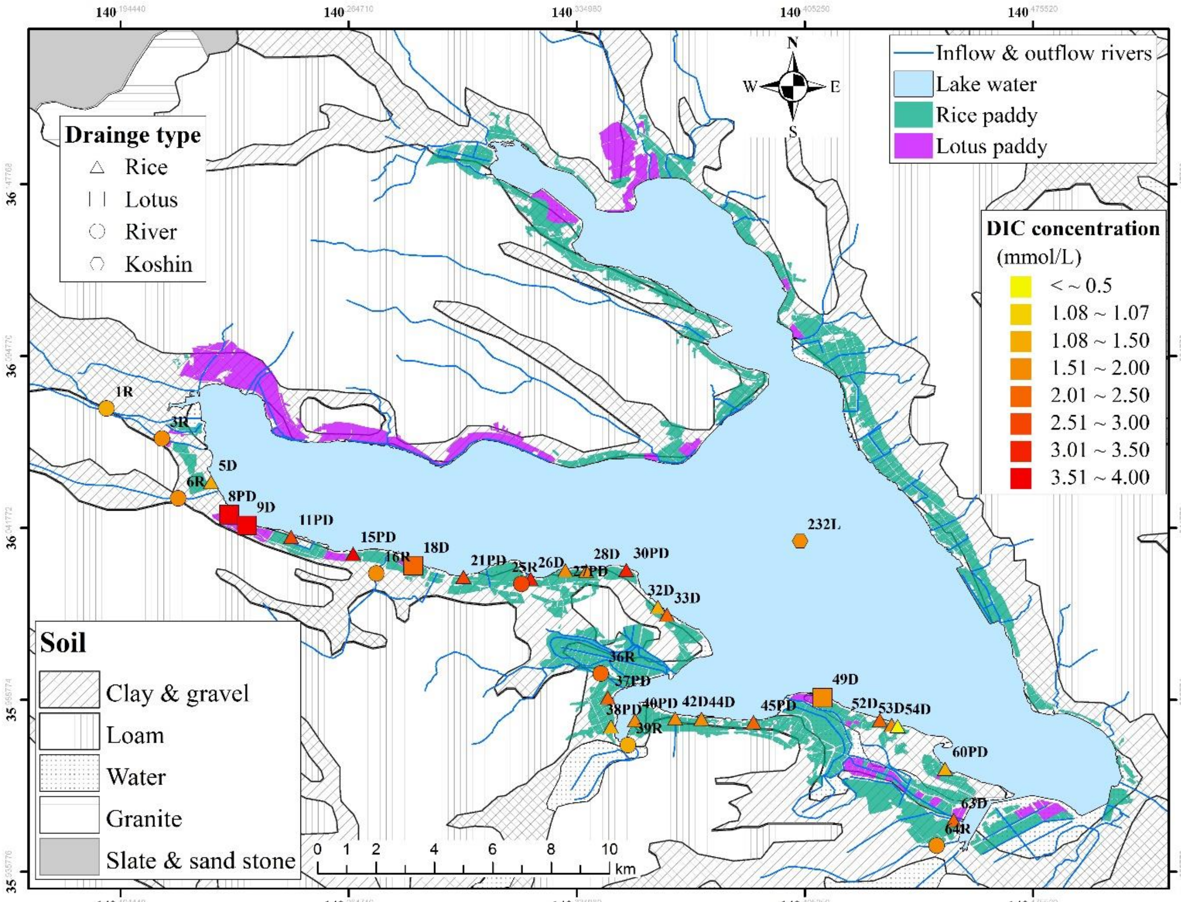

Figure 3-17 Spatial distribution of DIC concentration in drainage from rice and lotus paddies, inflow river and lake water in June of 2016.

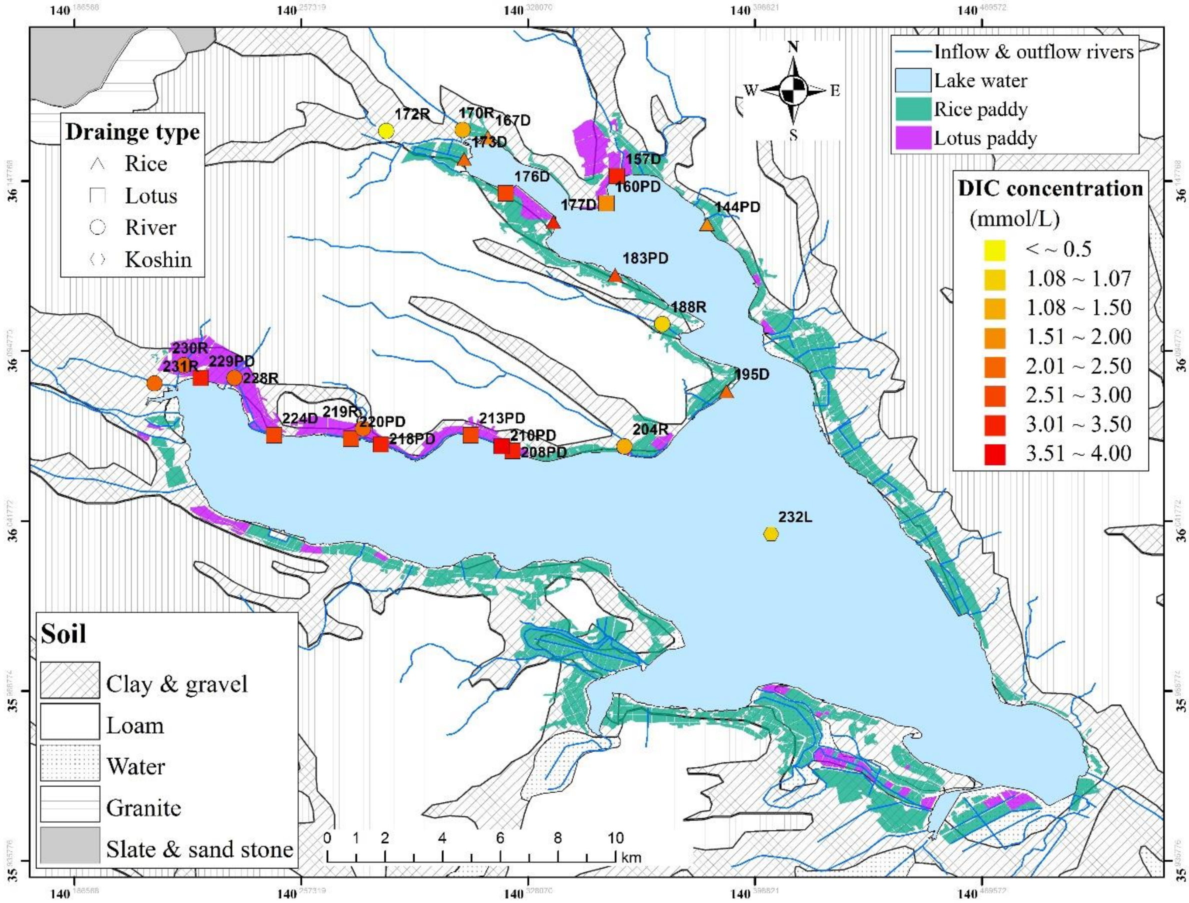

Figure 3-18 Spatial distribution of DIC concentration in drainage from rice and lotus paddies, inflow river and lake water in July of 2016.

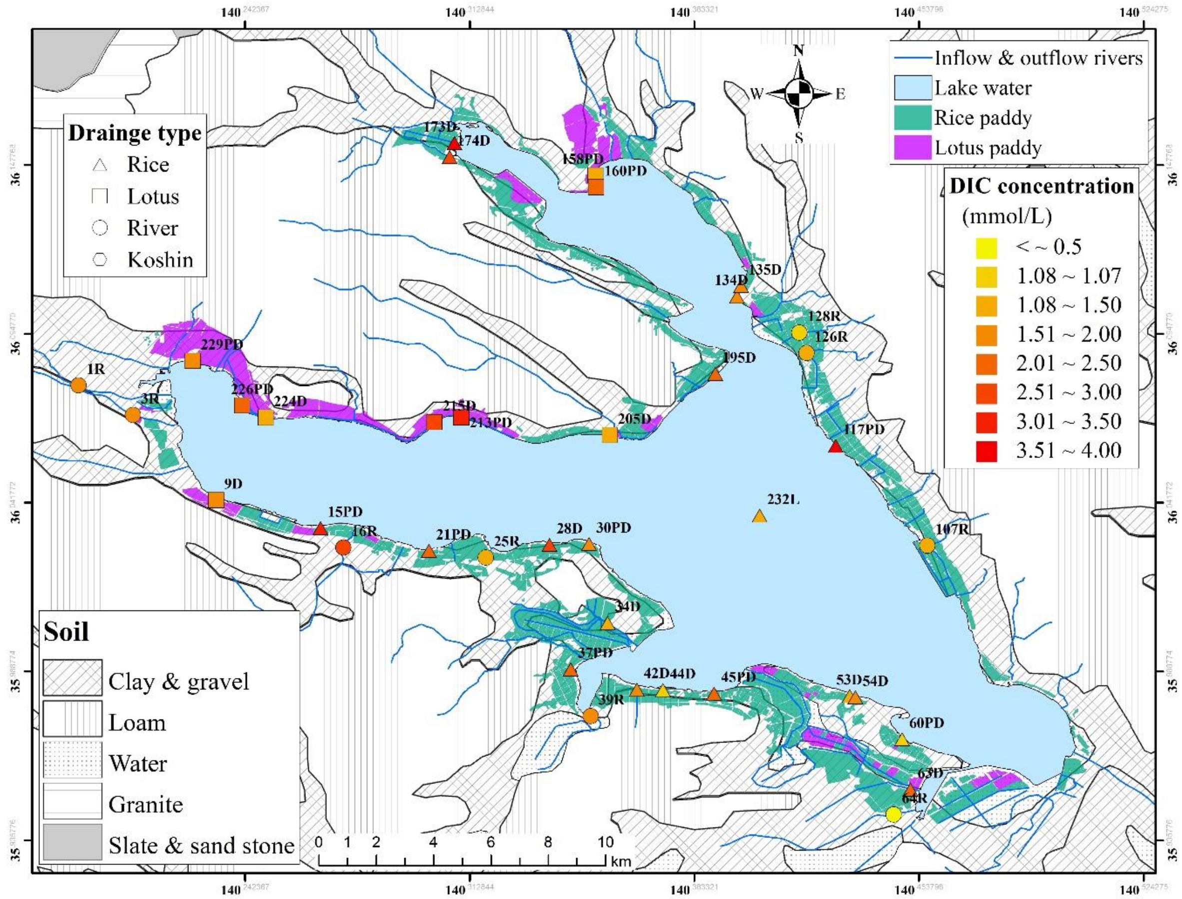

Figure 3-19 Spatial distribution of DIC concentration in drainage from rice and lotus paddies, inflow river and lake water in August of 2016.

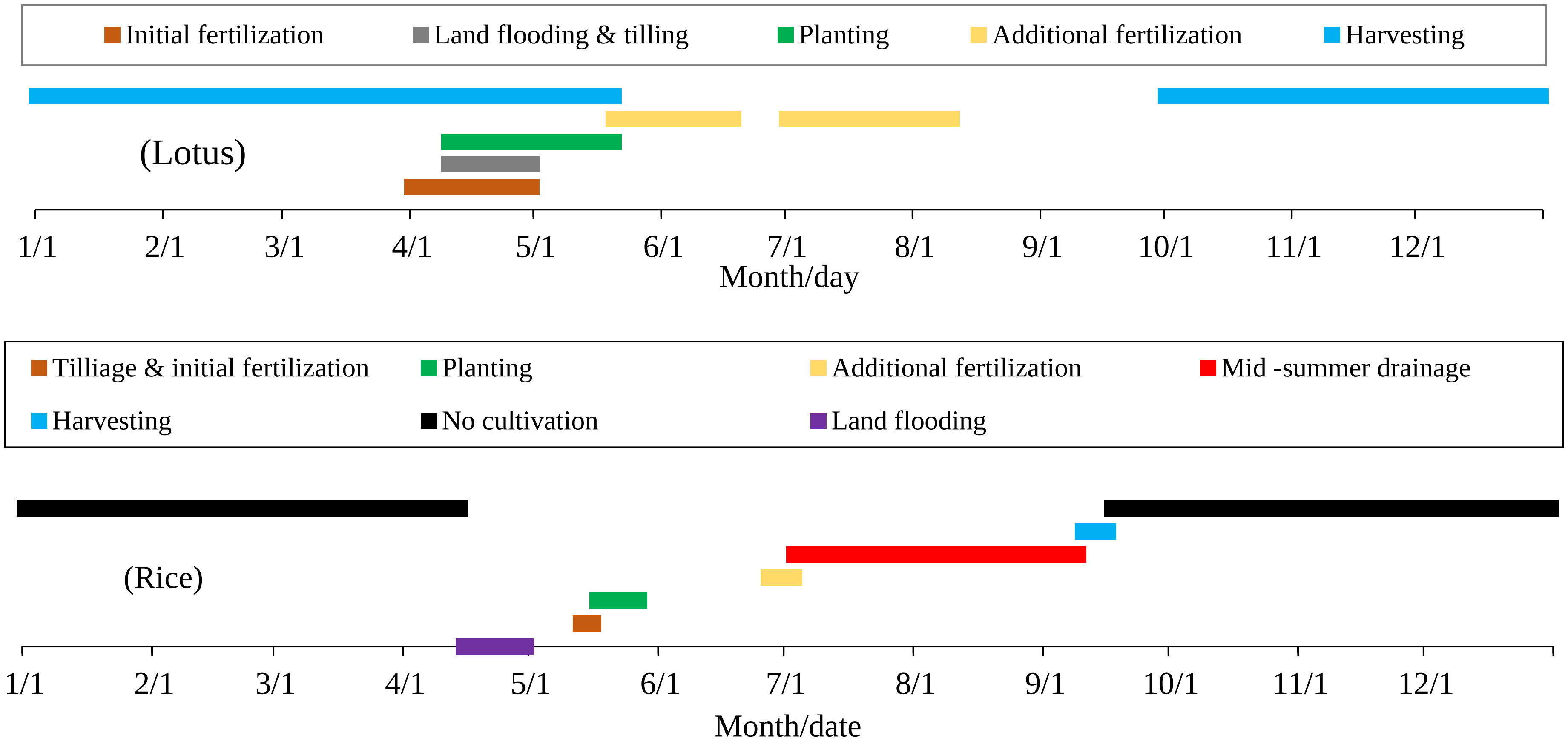

Figure 3-20 Cultivation schedule of lotus and rice, based on field survey result of this study and Kitamura (2015).

Table 3-3 Cultivation stages and time periods of rice and lotus in 2016.

Crop	**Cultivation stage**	**Period (month, date)**
Lotus	Initial fertilization	April 1 ~ April 30
	Land flooding & tilling	April 10 ~ April 30
	Planting	April 10 ~ May 20
	Additional fertilization	May 20 ~ June 15 July 1 ~ July 30 August 1 ~ August 10
	Harvesting	October 1 ~ May 20
Rice	Land flooding	April 13 ~ May 3
	Tillage & initial fertilization	May 13~ May 16
	Planting	May 16 ~ May 28
	Additional fertilization	June 2 ~ July 3
	Mid -summer drainage	July 3 ~ September 9
	Harvesting	September 9 ~ September 19
	No cultivation	January 1 ~ April 13 & September 19 ~ December 31

Based on field survey result of this study and Kitamura (2015).

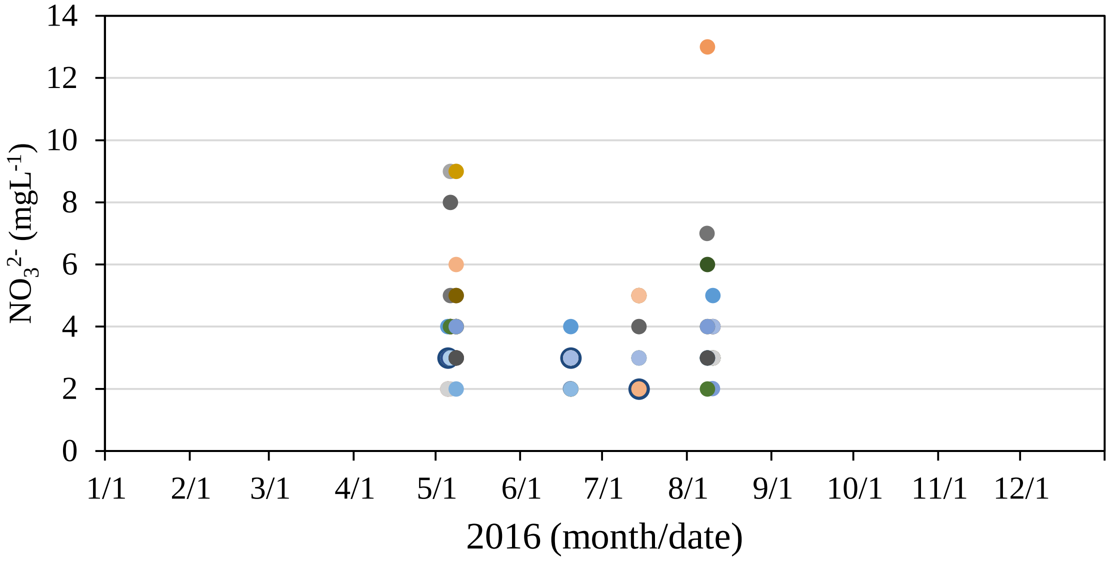

Figure 3-21 Nitrate ion concentration variation in drainage from rice and lotus paddies.

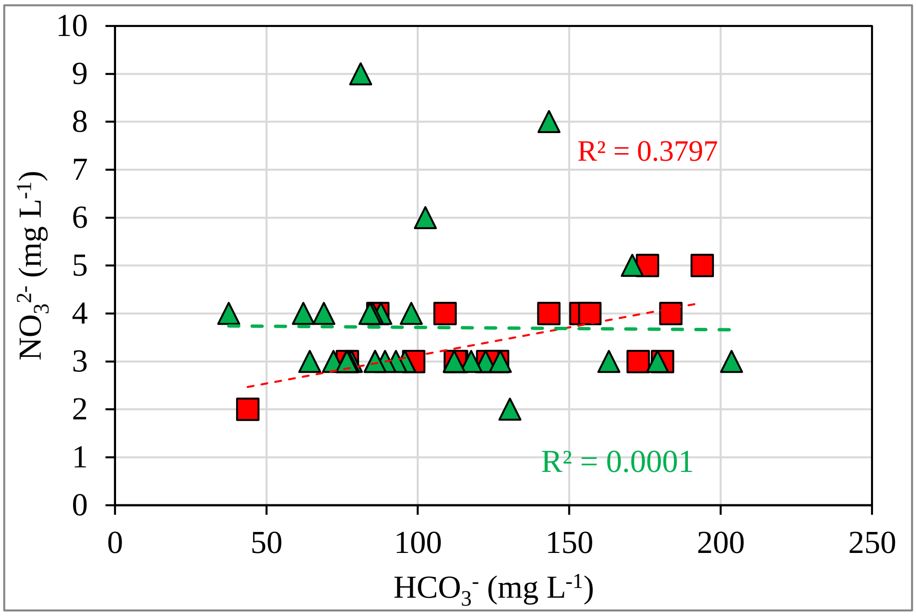

Figure 3-22 The relationship between bicarbonate ion and nitrite ion with in lotus paddy drainage (red squares) and rice paddy (green triangles) in June 2016.

Table 3**Error! No text of specified style in document.**-4 DIC concentration, drainage amount and DIC loads per day from rice, lotus paddies and inflow rivers to Nishiura.

Site	Month	Discharge amount	DIC concentration		DIC loads	
		(10^6 L day^{-1})	(mmol L^{-1})	(mg L^{-1})	(10^3 mol day^{-1})	(kg day^{-1})
Rice paddy	January	44.22	-		-	0.11
	February	1.10	1.20	97.07	1.31	3.20
	March	28.46	2.29	112.36	65.16	14.39
	April	128.29	2.06	112.19	264.11	8.59
	May	76.68	1.83	112.01	140.16	8.80
	June	69.52	2.07	126.52	144.19	11.35
	July	75.84	2.43	149.65	184.64	18.85
	August	134.18	2.17	140.46	290.60	-
	September	176.00	2.14	-	376.95	-
	October	83.98	-	-	-	-
	November	166.08	-	-	-	-
	December	136.40	-	-	-	9.52
	Average (March ~ August)	85.50	2.01	111.36	171.57	0.11

Table 3-4 continued

Site	Month	Discharge amount (10^6 L day^{-1})	DIC concentration (mmol L^{-1})	DIC concentration (mg L^{-1})	DIC loads (10^3 mol day^{-1})	DIC loads (kg day^{-1})
Lotus paddy	January	12.71	2.50	141.38	31.78	1.80
	February	0.32	-	-	-	-
	March	8.18	2.37	149.62	19.39	1.22
	April	36.53	2.41	141.40	88.04	5.17
	May	21.87	2.45	133.18	53.57	2.91
	June	19.81	2.94	179.36	58.24	3.55
	July	21.67	2.81	-	60.92	-
	August	38.36	2.02	122.32	77.36	4.69
	September	49.87	2.50	141.38	124.67	7.05
	October	24.14	2.50	141.38	60.36	3.41
	November	47.06	2.50	141.38	117.64	6.65
	December	38.65	2.50	141.38	96.62	5.46
	Average (March ~ August)	24.40	2.50	141.38	61.00	3.45
Inflow river	(small)	11.32	0.02	118.03	18.15	1.34
	(main)	604.80	1.57	118.03	1573.96	71.39

Table 3-5 Average DIC loads per day and per watershed area from rice, lotus paddy and inflow rivers to Nishiura.

Site	**DIC loads**		**DIC loads per watershed area**	
	(10^6 mol day^{-1})	(10^6 g day^{-1})	(10^3 mol Km^{-2} day^{-1})	(10^6 g km^{-2} day^{-1})
Rice paddy	171.57	9.52	4.04	0.2241
Lotus paddy	61.00	3.45	5.07	0.286
Inflow river (small)	18.15	1.34	0.06	0.0045
Inflow river (main)	1573.96	71.39	1.89	0.0858

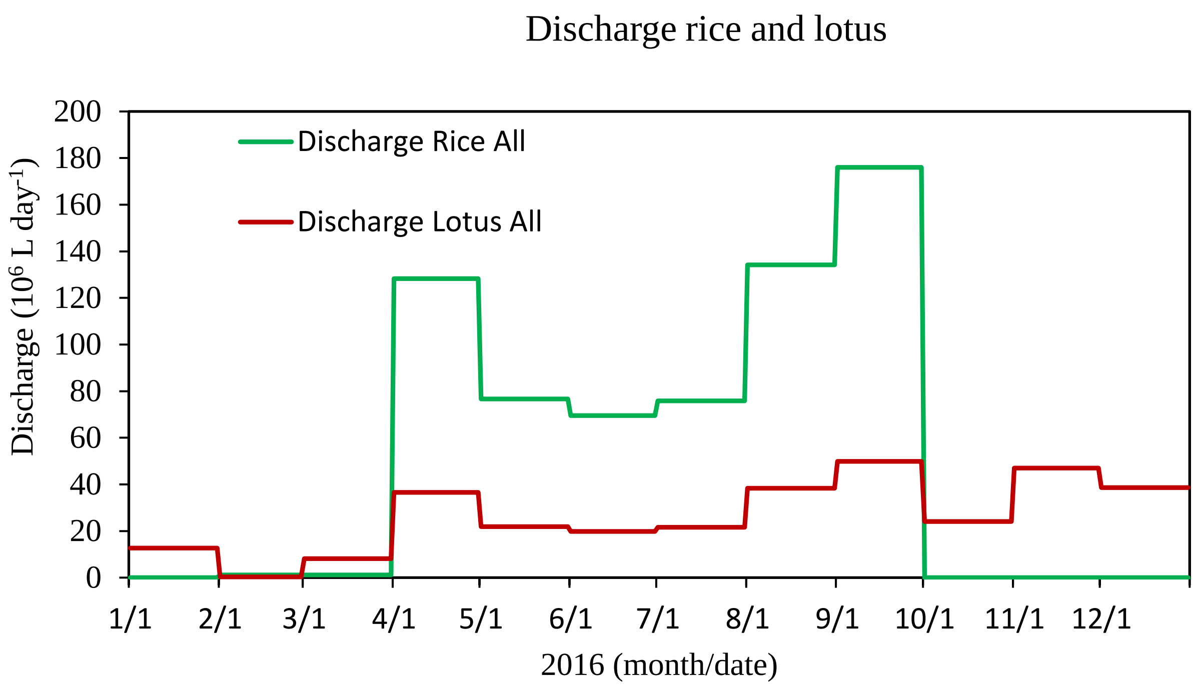

Figure 3-23 Average discharge amount from rice paddy (green line) and lotus paddy (red line).

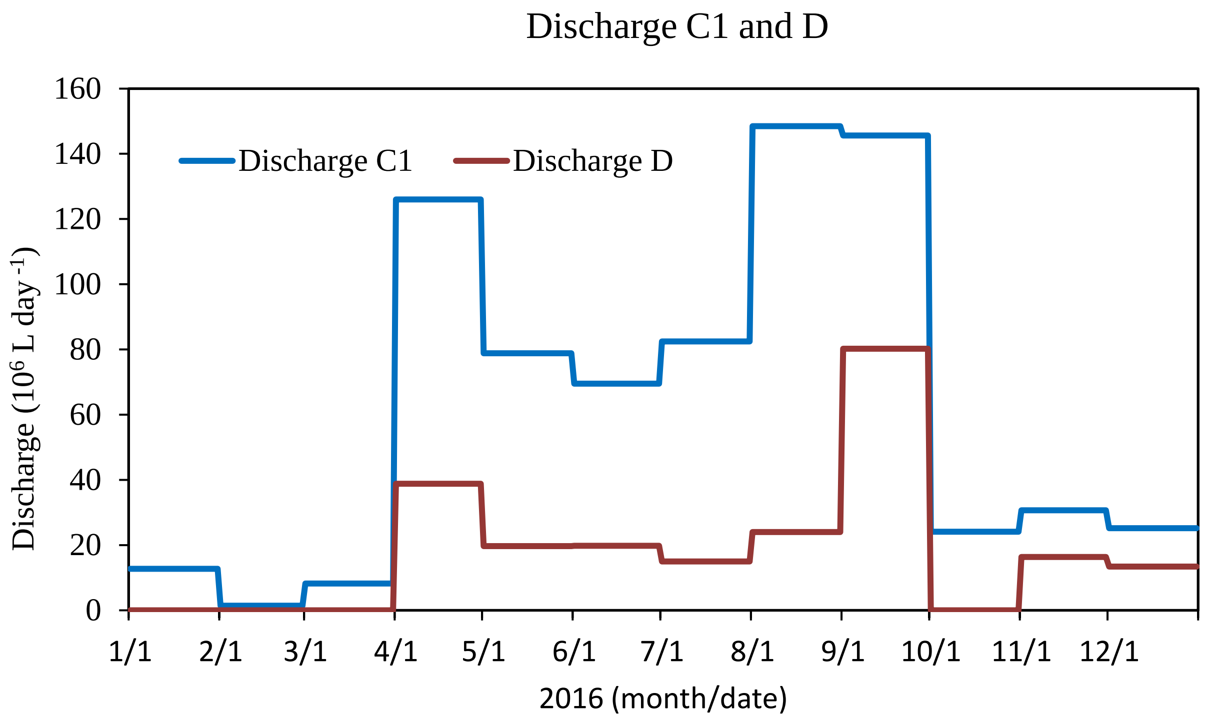

Figure 3-24 Average discharge amount from paddy field with irrigation type C1 (blue line) and irrigation type D (red line).

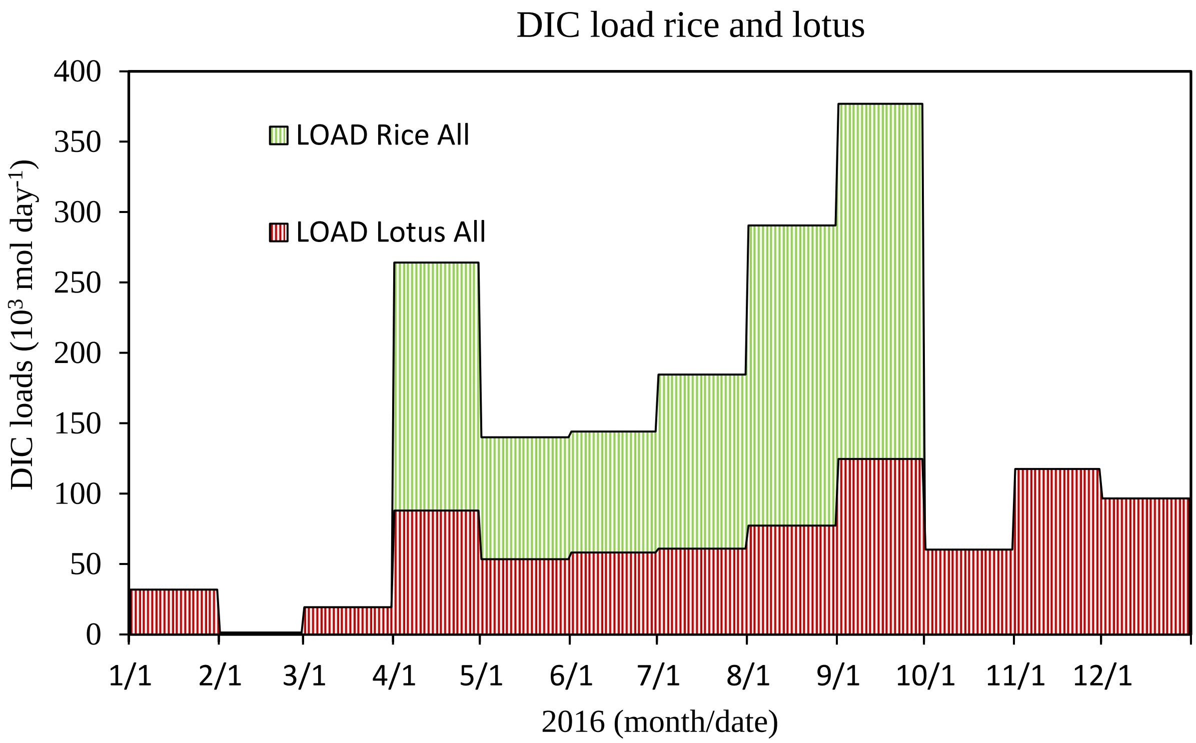

Figure 3-25 The average DIC loads from rice paddy drainage (green bar) and lotus paddy drainage (red bar).

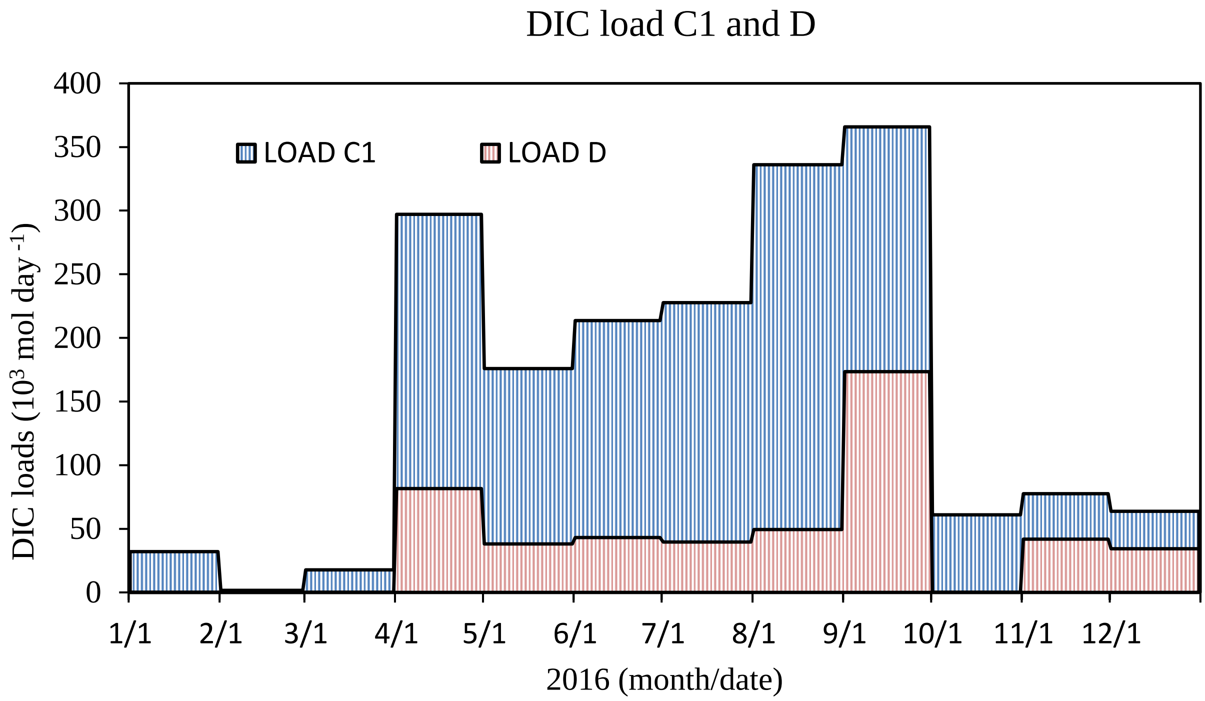

Figure 3-26 The average DIC loads from paddy drainage with irrigation type C1 (blue bar) and paddy drainage with irrigation type D (pink bar).

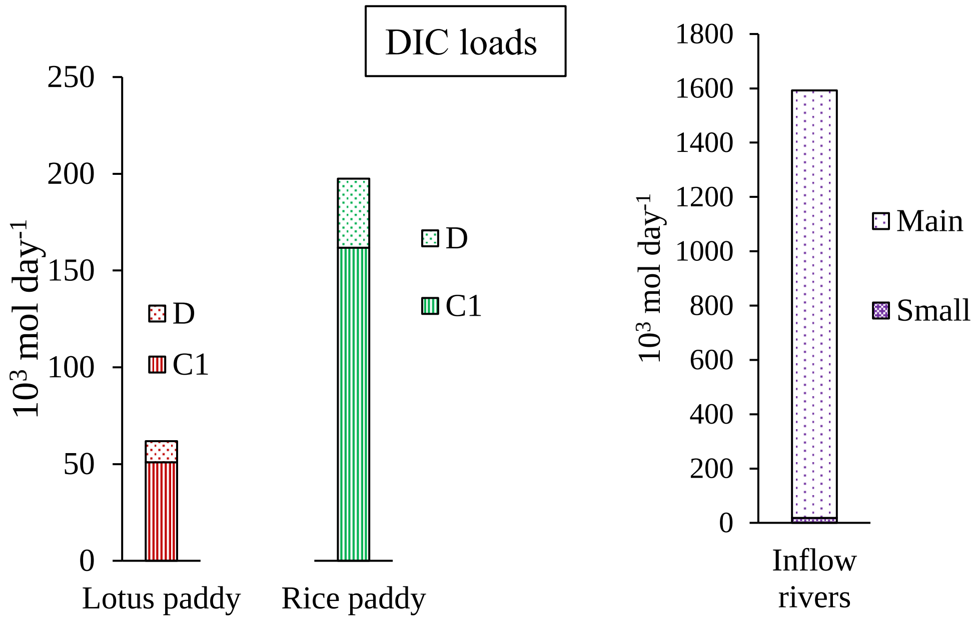

Figure 3-27 The total average DIC loads from lotus paddy (red bar), rice paddy (green bar) and inflow rivers (purple bar). D representing irrigation type D and C1 for type C1.

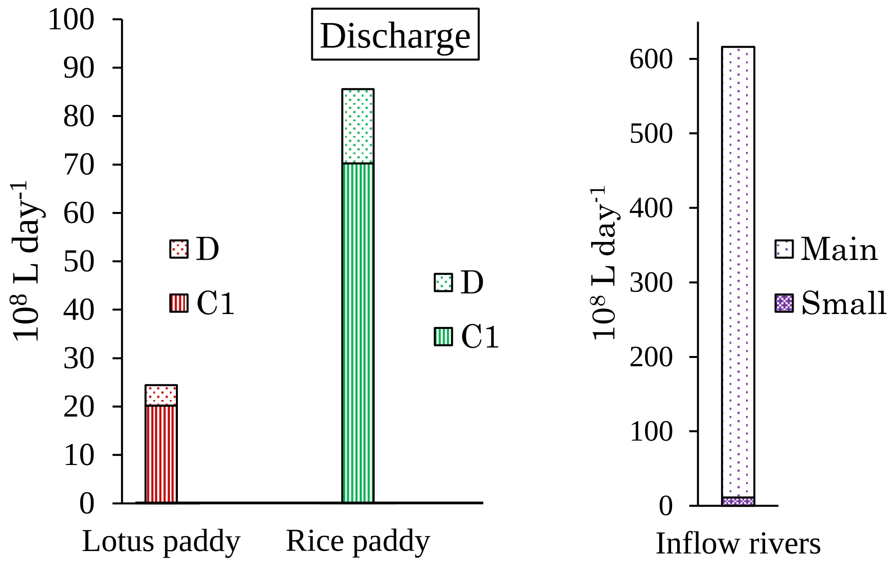

Figure 3-28 The total average discharge amount from lotus paddy (red bar), rice paddy (green bar) and inflow rivers (purple bar). D representing irrigation type D and C1 for type C1.

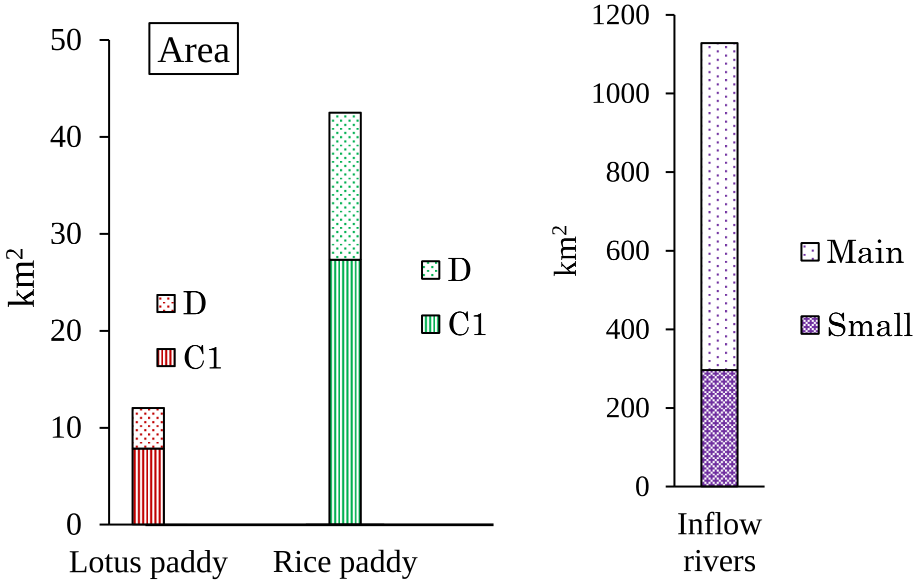

Figure 3-29 The area of lotus paddy (red bar), rice paddy (green bar), and watershed area of inflow rivers (purple bar). D representing irrigation type D and C1 for type C1.

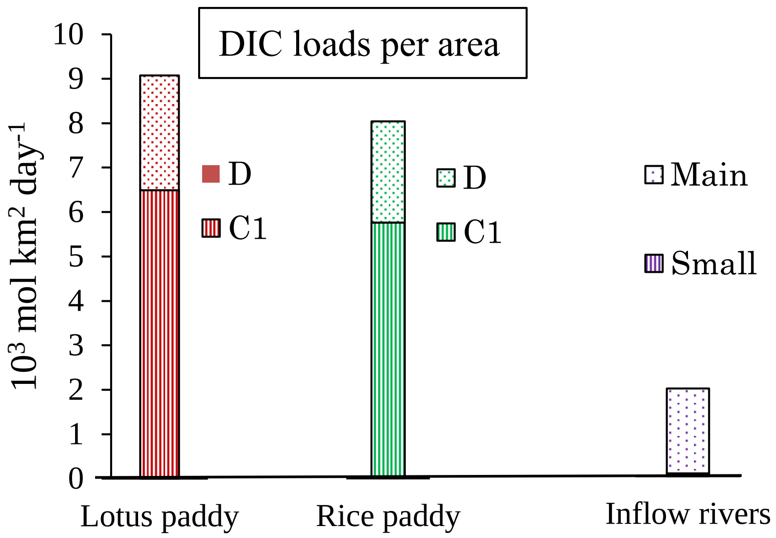

Figure 3-30 The total average DIC loads per area of lotus paddy (red bar), rice paddy (green bar) and inflow rivers (purple bar). D representing irrigation type D and C1 for type C1.

Chapter 4 Discussion

4.1 DIC concentration

4.1.1 DIC concentration vitiation and nitrate ion concentration.

In agricultural land, the utilized N-fertilizer once be spread and dissolved in water, the nitrification releases nitrate and hydrogen ion, these ions associated with strong acid anions and replace the carbonic acid in the carbonic acid in carbonate weathering. This process add bicarbonate ion (HCO_3^-) to DIC (Oh and Raymond, 2006).

Barnes and Raymond (2009) suggests the positive relationship between NO_3^- and HCO_3^- concentration indicate that chemical manure apply could enhance the DIC in cultivated water. This may be the cause of high DIC concentration in lotus paddy drainage in June. However, there was no significant correlation between NO_3^- and HCO_3^- in lotus paddy drainage (Figure 3-22). Furthermore, there was no significant change of NO_3^- observed (Figure 3-21). Because the use of fertilizers can only temporally increase concentration of nitrate ion (Manaka *et al.*, 2013). Therefore, the increasing DIC concentration should correspond to other factors.

4.1.2 DIC concentration and drainage rate

Figure 3-23 illustrates amount and DIC concentration of lotus paddy drainage. The inverse correspondence was observed with drainage rate. This suggests the accumulation of DIC in drainage water. However, less correspondence was observed in rice paddy (Figure 3-24).

4.2 Drainage rate

Lotus cultivation requires flooding water in the field throughout the year. Only few irrigation intakes occur to maintain flooding level. Therefore, compared with drainage amount from rice paddy, lotus field discharge water was very small. During the land preparation procedure and harvesting, large amount of water is used. In the result (Figure 3-24), in April high amount of water was drained, because during this time large amount of water was used for land preparation and harvesting. The same drainage amount was also observed in August, though there was no harvesting or land preparation during this time. In this case, this may correspond to influence of heavy rainfall event occurred in August (Figure 2-2).

In rice paddy, drainage rate was observed in April, August and September. To this water was used in April to flood the field to submerge soil before planting. The high drainage amount may also correspond to the influence of heavy rainfall event mentioned above.

Figure 3-25 illustrates the drainage amount per day from rice and lotus paddy across the different irrigation systems. The drainage from paddies which practice circulating irrigation system was small compared to other irrigation type. This is because the water once drained from the paddy was reused to the field. This also suggests the accumulating of nutrients contain in the water.

4.3 Dissolved inorganic carbon loads

Dissolved inorganic carbon loads increased and strongly corresponds with discharge rate both from lotus and rice paddies. The average DIC loading from rice paddy during the cultivation period was 13.8 times higher than from lotus paddy (Table 3-4). This was because, rice paddy covered larger area and has grater drainage rate.

In conclusion, the inflow rivers dominate as the main carrier of DIC to Nishiura lake water, greater than the surrounding paddy field runoff. However, the DIC loads per watershed area (Table 3-5) suggested that the paddy fields along the Nishiura lakeshore, particularly rice paddy exported more DIC to the lake, while inflow river brought very small DIC. To this, the DIC exported from watershed of inflow river, when loaded into river water DIC could be removed or diluted during the riverine transporting. Therefore, agricultural along the lakeshore should be accounted for the DIC carbon budget in the lake.

Chapter 5 Conclusions

The study was conducted to investigate the dissolved inorganic carbon concentration and loads in drainage water from the agricultural land, in particular, rice and lotus paddies along the lakeshore of Nishiura to lake water.

The results of the study could be summarized as follows:

1. Rice is the main crop being cultivated along Nishiura lakeshore. Lotus field was observed with high density in the North-West of the lakeshore.
2. The irrigation type C1 (both irrigation and drainage) is widely operated in paddy fields compared to type D (circulating irrigation). Both irrigation and drainage system drainage large amount of water and mostly operated in rice paddy.
3. The average dissolve inorganic carbon concentration in agricultural drainage was 1.4 times higher than that in inflow rivers and 1.7 times higher than that in the lake water. The DIC concentration in drainage from both rice and lotus paddies appeared to have small seasonal fluctuations during the cultivation period.
4. During the cultivation periods, the DIC loads from rice and lotus paddies were strongly correlated with the draining rate, which varied largely in the different cultivation stages and during the heavy rainfall event.
5. DIC loads per watershed suggested that the paddy fields along the Nishiura lakeshore, particularly lotus paddy exported large DIC loads to the lake. while the inflow rivers brought very small amount of DIC.

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