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Phuc, Nguyen
Laboratory of Irrigation Engineering, Faculty of Agriculture, Kyushu University

Tanabe, Kunimi
Laboratory of Irrigation Engineering, Faculty of Agriculture, Kyushu University

Kuroda, Masaharu
Laboratory of Irrigation Engineering, Faculty of Agriculture, Kyushu University

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Variation of Dissolved Oxygen in the Flooding Water of the Paddy Fields

Nguyen Phuc, Kunimi Tanabe and Masaharu Kuroda

Laboratory of Irrigation Engineering, Faculty of Agriculture, Kyushu University, Fukuoka

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The experimental measurements were carried out of DO (dissolved oxygen) in the flooding water of lysimeters, paddy fields and creeks during the rice planting seasons in 1973 and 1974. The DO diurnal curves were obtained under various conditions of the water bodies. Accordingly, the DO variation in the flooding water of the paddy fields is mostly attributable to the source and sink due to the metabolic activities of aquatic organisms in the water.

It is noted that in the day time, the DO increases with the intensity of diurnal solar radiation and the maximum values of DO can attain more than 200 percent to the saturation index. On the other hand, after sun set, the DO steeply falls toward the values about 50 percent or less to the saturation index.

The DO change rate $f(t)$ and its components $p(t)$, $h(t)$ and $e(t)$ can be evaluated, where $p(t)$ is the DO production rate, $h(t)$ is the DO consumption rate and $e(t)$ is the DO-O_2 exchange rate between atmosphere and water. As understanding these factors, it is possible to recognize that $p(t)$ is dependent on the photosynthetic activity of green algae and h(t) is ascribable to the chemical and biological absorptions.

It is clear to obtain that the daily DO production P and daily DO consumption H increase under the condition of large density of green algae at raised intensity of solar radiation, whereas both P and H decrease provided that small density of green algae in the flooding water of paddy fields.

INTRODUCTION

Among the natural substances existing under either gaseous or liquid phase, oxygen is a characteristic one that appears frequently as a solute and plays the physical, chemical and biological roles in the water.

Many previous authors have studied the roles of dissolved oxygen (DO) under the various points of view. Truesdale *et al.* (1955), Montgomery *et al.* (1964) and Carpenter (1966) measured the solubility of oxygen in the water. Downing and Truesdale (1955), Kanwisher (1963) and Liss (1973) speculated on the exchange of oxygen between atmosphere and water body. Ryther (1956) and Bartsch (1961) observed the species of algae as a source of oxygen in the water. Odum (1956) and Welch (1968) discussed the variations of dissolved oxygen in flowing water and standing water. In addition, Darby (1962) and Toyota (1972) attempted to mention the correlation among the factors such as DO, pH, alkalinity, EC, temperature and so on in the flooding water of paddy fields and in the water used to irrigate the paddy fields.

This study aims at performing the observations and experimental measurements of DO variations under various environmental conditions of the flooding water in the paddy fields by using the DO meters. These works were carried out in the lysimeters located inside the campus of Kyushu University and in the actual paddy fields situated in Saga plain in the rice planting seasons of **1973** and **1974.**

THEORETICAL CONSIDERATION ON DIURNAL VARIATION OF 'DO' IN WATER

The function F(t) is defined as the value of DO at time t. The DO change rate f(t) can be converted from the relation:

$$f(t) = \frac{dF(t)}{dt} \tag{1}$$

The function $f(t)$ can be assumed consisting of such components as production rate $p(t)$, consumption rate $h(t)$ and exchange rate e(t) :

$$f(t) = p(t) - h(t) + e(t) \tag{2}$$

(a) Evaluation of p(t), h(t) and e(t)

The method to evaluate $f(t)$ and its components $p(t), h(t)$ and $e(t)$ is indicated in Fig. 1. The uppermost part (A) shows the DO diurnal curve $F(t)$ and saturated DO curve G(t).

Curve $f(t)$ in part (B) is drawn by plotting the differences between the DO values measured every one hour and part (C) is related to the so called reaeration coefficient K that is proportional to the exchange rate $e(t)$ in the equation:

$$e(t) = KS \tag{3}$$

Where, S is the oxygen saturation deficit and equals $G(t) - F(t)$.

If presuming the consumption rate h(t) is invariable, plotting the change rate at night (no photosynthesis) against the saturation deficit S should give the line whose slope is equal to K. From the known value of K, $e(r)$ can be calculated from Eq. (3).

To obtain the consumption rate h(t), the known exchange rate $e(t)$ is subtracted from the curve $f(t)$ during the darkness. The DO production rate $p(t)$ is obtained finally by separating the DO exchange rate $e(t)$ and consumption rate $h(t)$ from the DO change rate $f(t)$ as indicated in part (D).

(b) Accumulation of p(t), h(t) and e(t)

The accumulation of the components p(t), $h(t)$ and e(t) can be calculated in ppm/day by reckoning the area under each individual involved curve:

$$\begin{aligned} P &= \int_0^{24} p(t)\ dt \\ H &= \int_0^{24} h(t)\ dt \\ E &= \int_0^{24} e(t)\ dt \end{aligned} \tag{4}$$

Multiplying Eq. (4) with the water depth z (meter), the expressions are converted in $g/m^2/day$.

In many natural water bodies, a maximum in the afternoon and a minimum just before dawn of DO are observed and indicated as in part (A) of Fig. 1. The saturated DO tends to fall slightly in the afternoon due to the raise of temperature.

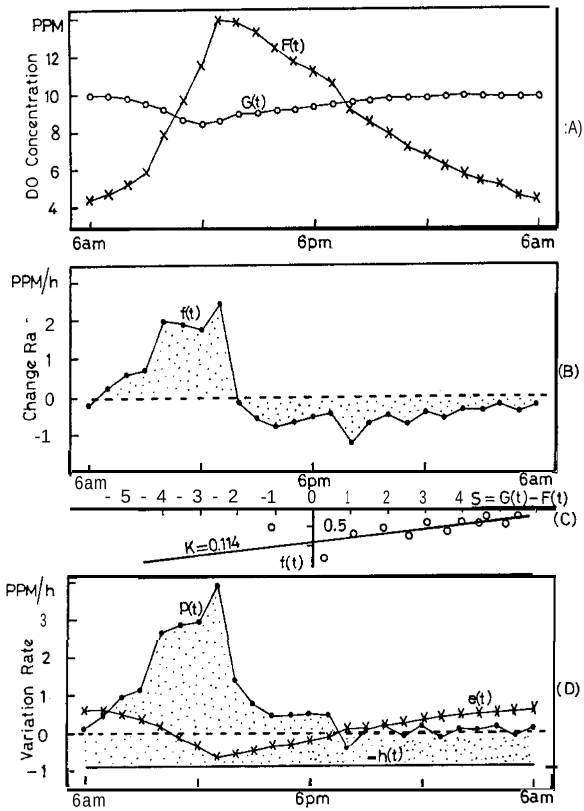

Fig. 1. Evaluation of values $p(t)$, $h(t)$ and e(f).

MATERIALS AND METHODS

In the rice planting season of 1973, the experimental works were performed in the lysimeter and pots while in the season of 1974, they were done in the lysimeters and actual paddy fields.

(a) The case of rice planting season in 1973

As illustrated in Fig. 2, the concentrations of dissolved oxygen in water were measured in the lysimeter and in pots transplanted with rice plants on July 1 and in the 3 tanks contained water with separated living aquatic organism, for example, T_1 with water only, T_2 with water and duck-weeds and T_3 with water and green algae.

The flooding water in the transplanted parts of the lysimeter was allowed to percolate into each separate part Cr,, Cr, and Cr, of the creek which was attached with the concrete block of the lysimeter. The depth of water was kept 10 cm, 90 cm, 5 cm and 17 cm in the transplanted parts of lysimeter, creek, pots and tanks, respectively.

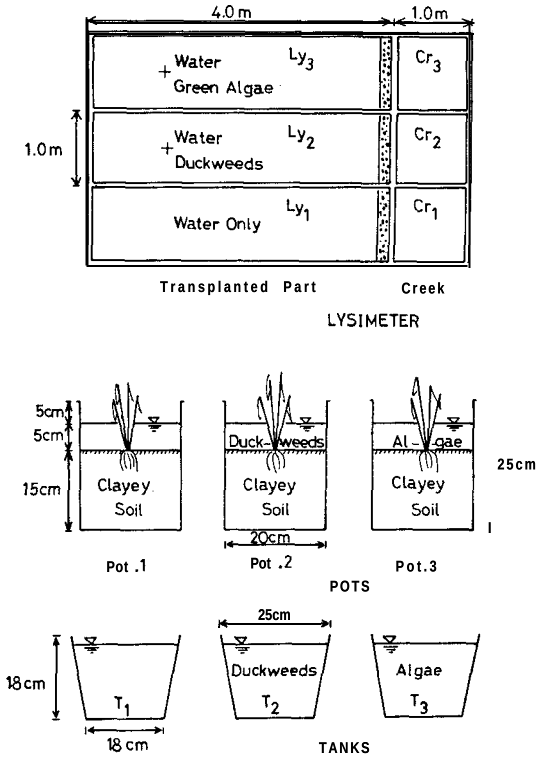

Fig. 2. Schematic diagram of experimental measurements in the season of 1973.

(b) The case of rice planting season in 1974

The diagrams of experimental measurements in the season of 1974 are demonstrated in Fig. 3 for the lysimeters and Fig. 4 for the actual paddy fields.

In the rice planting season in 1974, the lysimeters were transplanted with rice plants: BLOC(l) and BLOC(3) were located in the campus of Faculty of Agriculture, Kyushu University, and while the actual paddy fields were situated at Mikazuki and Saga Agricultural Experimental Station (E. Station) in Saga Plain : BLOC(4) and BLOC(5).

(c) Method of measurement

The DO meters used for the measurements were Model 715 Process Oxygen Monitor in the season of 1973 and Fieldlab Oxygen Analyser in the season of 1974. Moreover, the other factors such as temperature, solar radiation, rate of rice growth and the general circumstances of the experimental places were also observed and measured.

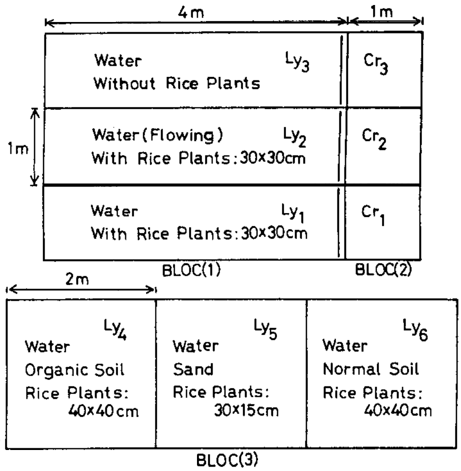

Fig. 3. Experimental conditions in lysimeters.

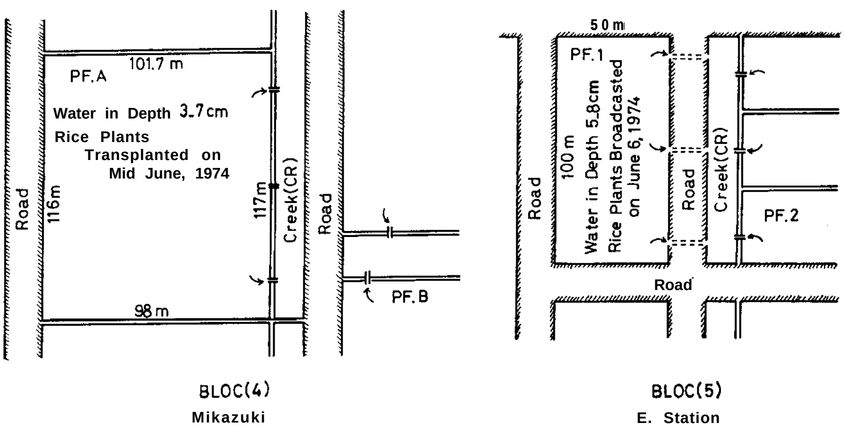

Fig. 4. Experimental conditions in paddy fields.

RESULTS AND DISCUSSION

(a) Results of rice planting season in 1973

In Fig. 5, part (A) indicates the daily variation of DO in the lysimeter consisting of the transplanted parts Ly_1, Ly_2, Ly_3, part (B), those of the creek Cr_1, Cr_2, Cr_3 and part(C), those of the tanks T_1, T_2, T_3.

The DO variation was largest in Ly_1 and T_3 availing green alga ***Pithophora*** as a result of photosynthesis in the day time and respiration at night. In Ly_2 and T_2 with duckweed ***Spirodela,*** there was nearly no variation, because the photosynthetic effect was limited at the water surface where the leaves of ***Spirodela*** were floating.

Ly_3 with unknown green algae other than ***Pithophora*** indicated such DO to be greater in day-time and smaller at night while T_1 with only tap water did not show any change in DO.

A little raise of DO in T_2 with duckweed ***Spirodela*** might be due to the photosynthetic activity of unknown green algae coexisting with ***Spirodela.***

In the water of creek, the DO values were usually in the undersaturated condition. It was likely that the DO in creek water depended on the percolation rate of water leaking from the transplanted parts of the lysimeter, but the percolating water was frequently influenced by the communities of green algae growing in water or attaching on the creek walls..

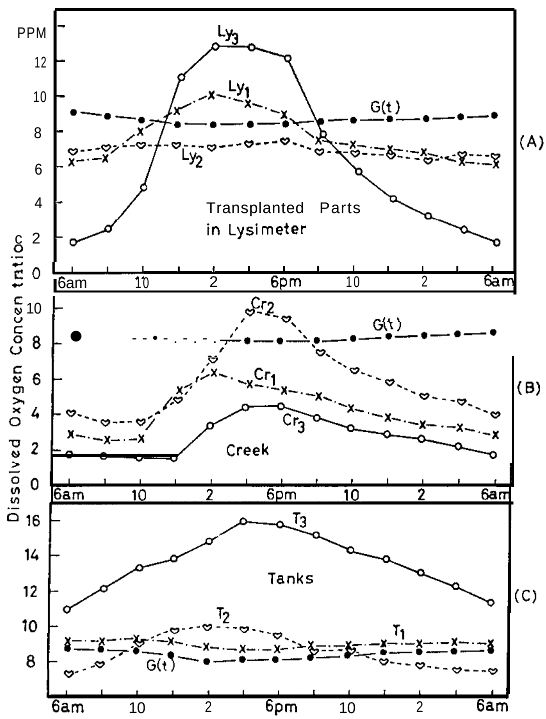

Fig. 5. DO diurnal curves measured in the parts of lysimeter, creek and tanks on Sept. 5-6, 1973.

Fig. *6* shows the development of rice plants in length (plant height) and width (tiller number) in the lysimeter under different stages of the growth. After the tillering stage, the tiller number did not change so much while the plant height continued to elongate until the flowering stage.

In Fig. 7, the DO diurnal curves in flooding water of pots transplanted with rice plants are demonstrated, The DO deviation was shown to be highest in Pot. 3 with water containing green algae and lowest in Pot. 2 with water containing duckweeds. In Pot. 1, the DO curve rose a little in the day time as a result of photosynthesis of unknown green algae.

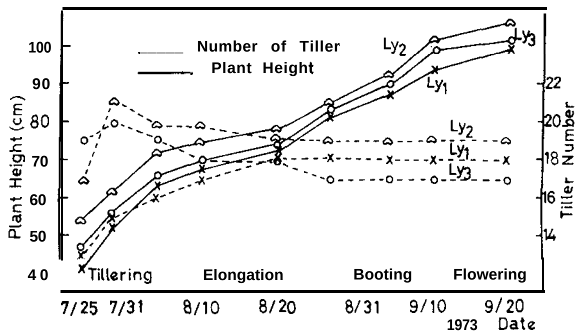

Fig. 6. Growth in height and tiller number of rice plants in the lysimeter

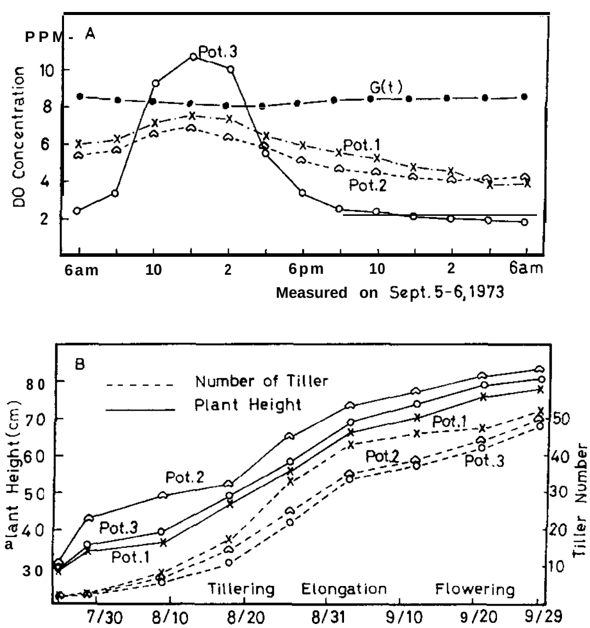

Fig. 7. **A:** DO diurnal curves of flooding water in pots. B: Growth in height and tiller number of rice plants in pots.

(b) Results of rice planting season in 1974

Results of measurements on many days in the lysimeters are demonstrated in Fig. 8.

BLOC(Z): Ly_1 had the largest deviation of DO on August 13, when both temperature and intensity of solar radiation were notified in the largest values. The DO deviation in Ly, was the lowest as a direct result of flowing action of water in this place. On July 19, the water in Ly, was muddy condition, thus very small values of DO were resulted. When the water in Ly, became much clearer (Aug. 13 and Sept. 5), green algae and higher plants developed more actively and very great DO values were obtained.

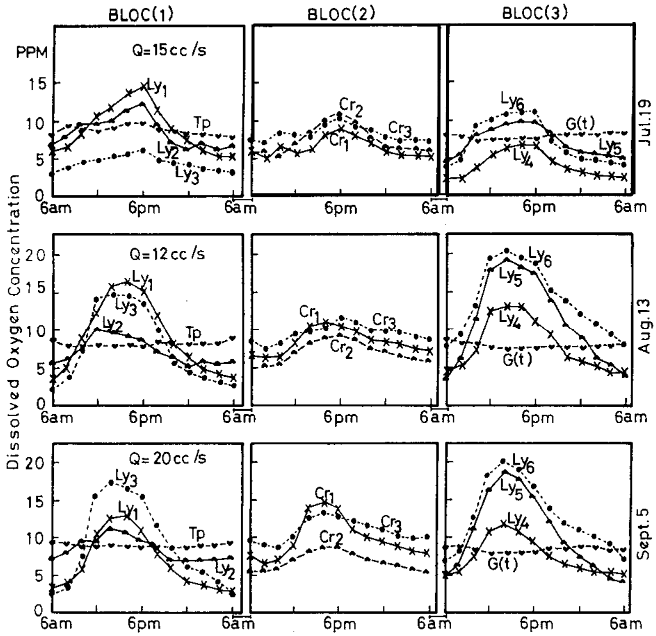

Fig. 8. DO diurnal curves measured on different days in the rice planting season of 1974.

The smaller DO values in Ly, than in Ly, on Aug. 13 and the greater DO values in Ly, than in Ly, on Sept. 5 could be explained by the fact that the rice plants in Ly, had grown up in this period and their shadows might interrupt the solar radiation to reach onto the water. This reduced the photosynthetic activities of green algae in water and resulted in lower DO values. On the contrary, Ly, was not planted with rice plants but the green algae thrived well in water during the same period, so the sun-light should accelerate the assimilation of carbon dioxide due to green algae and result in the larger DO production. The curves T_p indicate the DO variation of tap water supplied to Ly,, and the letter Q presents the overflow rate from Ly, into Cr,.

BLOC(2): This consists of 3 parts: Cr,, Cr, and Cr,. The DO values were nearly the same in Cr, and Cr, due to the similar stagnant condition of water in these 2 places. The variation of DO in water of Cr, seemed to depend on the overflow rate Q. As time elapsed, the dense community of green algae affected increasingly the DO in this place.

BLOC(3) : In Ly,, the lowest values of DO were obtained in the condition of absence of ***Pithophora*** during the first half of the rice planting season. This might be due to the organic materials in the soil. It is well known that the organic matters in soil have the ability to absorb oxygen in water. As in Ly, ***Pithophora*** thrived and spread fully in the water body, the values of DO were slightly greater than those in Ly_5 wherever the less community of ***Pithophora*** was observed.

Results of measurement in the paddy fields are indicated in Fig. 9 with

BLOC(4) for those in Mikazuki and BLOC(5) for those in E. Station.

BLOC(I) : In the paddy fields at Mikazuki, *Pithophora* did not thrive so well and the paddy soil was common to those in many other paddy fields. These brought about less variations of DO as seen in PF. A and PF. B. A large deviation of DO in the creek water of Mikazuki revealed the abundance of various species of green algae. On Sept. 2425, the DO depleted less than those on Jul. 22-23 and Aug. 21-22, because of the inevitable decrease of solar radiation intensity and the consequent temperature decrease.

BLOC(S) : In the paddy fields at E. Station, *Pithophora* developed abundantly in the flooding water. Particularly in PF. 1, the organic matter decomposed from the barley stubbles of the previous planting season was observed in large amount. These resulted in very large value of DO in the day time due to the intensive photosynthesis and small value of DO at night due to both decomposition of organic detritus and the biological respiration.

Except the data on Sept. 25 26, the DO values of day time in the water bodies of PF. 1, PF. 2 and CR were oversaturated due to high degrees of temperature and intensity of solar radiation. The variation of DO in the creek water (CR) was observed to be in similar way of that in the creek water at Mikazuki.

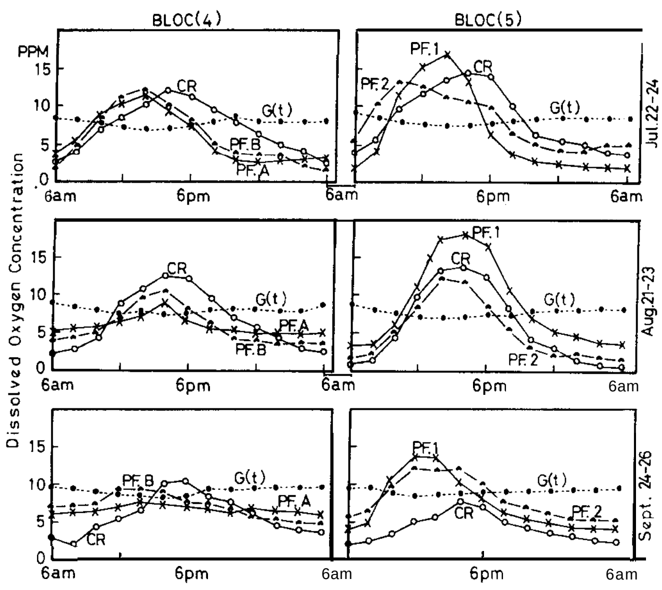

Fig. 9. DO diurnal curves measured on different days in the rice planting season of 1974.

(c) Accumulation values of h(t), e(t) and p(t)

The daily DO consumption *H,* exchange *E* and production *P* are defined as the integrated forms of the DO consumption rate *h(t),* exchange rate *e(t)* and production rate *p(t),* respectively.

The following results were obtained from the measurements of DO in the flooding water bodies at the lysimeters and paddy fields. The hourly maximum (Max.), average (Ave.) and minimum (Min.) DO values in the days of experiment were also given.

Table 1. Daily DO consumption (H), daily DO-O_2 exchange (E) and daily DO production (P) with their hourly maximum, average and minimum values obtained from BLOC (1).

Date	Ly₁			Ly₂			Ly₃		
	H	*E*	*P*	*H*	*E*	*P*	*H*	*E*	*P*
7/19	21.3	-3.6	23.4	12.2	-9.5	21.6	18.5	+10.8	[illegible] 8.1
8/02	19.0	-0.4	19.2	22.8	-8.0	30.6	35: 24.0 0	-0.6 4.9	35.229.0
8/13				18.2	+3.3	14.7			
9/05	26.4 28.7	+4.6 -3.9	30.2 24.4	10.8	−3.1	14.3	31.3	− 6.2	37.3
9/19	20.5	+3.2	17.6	18.3	+3.7	15.4	18.0	− 8.6	28.6
10/05	21.0	+2.7	19.3	15.3	+4.2	11.5	15.4	− 7.4	22.6
Average	22.8	+0.6	22.3	16.2	-1.6	18.0	23.7	-- 2.8	26.8

Date	Ly₁			Ly₂			Ly₃		
	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.
7/19	14.5	9.3	5.2	12.5	9.6	6.5	[illegible] 6.4	4.2	3.2
8/02	13.0	8.2	4.2	15.0	9.5	5.4	15.616.3	8.9	4.2
8/13		9.8	3.0		7.5	5.7		7.7	2.5
9/05	16.0	8.8	3.9	10.3	8.9	6.3	17.7	9.4	3.0
9/19	12.3	9.0	5.0	11.3	9.1	6.5	[illegible]	5.0
10/05	14.0	8.8	4.5	11.0	8.9	6.3	19.4	11.8	6.3
Average	14.0	9.0	4.3	12.1	8.9	6.1	15.8	8.9	4.0

A review of Table 1, 2, 3 and 4 brings the next interpretations:

(1) The greater the DO Max. in water with abundant green algae, the smaller the DO Min. is accompanied. This can be interpreted with both large values of daily DO consumption ***H*** and production ***P*** such as the cases of Ly, in BLOC(l), Ly, and Ly, in BLOC(S), CR in BLOC(4), PF. 1 and PF. 2 in BLOC (5).

(2) When the daily DO consumption ***H*** and production ***P*** are nearly equal, the DO-O_2 exchange ***E*** is very small, as exemplified with those in Ly, of BLOC (1), PF. 2 of BLOC(5). The positive or negative values of the daily DO-O, exchange ***E*** depends on the relation of either ***P***>***H*** or ***P***<***H***.

(3) In the paddy field with high content of organic materials in soil and low density of algal community in flooding water, DO was low due to the large value of daily consumption ***H*** and small value of daily production ***P*** as in the case of Ly, in BLOC(3).

(4) In the paddy field with high content of organic material in soil and dense algal community in water, both daily consumption ***H*** and production ***P*** were found to be very large: PF. 1 and PF. 2 of BLOC(5).

(5) In the paddy field with low content of organic matter in soil and thin algal community in water, both values of ***H*** and ***P*** were found to be small as in PF. A and PF. B of BLOC(4).

Table 2. Daily DO consumption (H), daily DO-O_2 exchange (E) and daily DO production (P) with their hourly maximum, average and minimum values obtained from BLOC (3).

Date	Ly4 H	Ly4 E	Ly4 P	Ly5 H	Ly5 E	Ly5 P	Ly6 H	Ly6 E	Ly6 P
7/19	21.4	+10.8	10.4	13.5	+1.20	13.6	19.1	+ 2.0	17.0
8/02	15.8	+ 2.4	12.9	23.8	−9.40	33.1	23.6	−14.2	37.5
8/13	13.8	− 2.4	20.2	25.0	−6.30	31.8	10.8	−12.8	24.2
9/05	17.6	+ 2.3	15.3	24.8	−7.20	31.6	10.3	−10.5	21.2
9/19	13.0	+ 0.1	14.2	17.2	−5.90	24.3	14.6	− 6.1	23.0
10/05	15.1	+ 3.6	11.5	14.0	−2.10	16.6	16.4	− 2.3	18.3
Average	16.9	+ 2.8	14.1	19.7	--4.90	25.2	15.8	- 7 . 3	23.5

Date	Ly4 Max.	Ly4 Ave.	Ly4 Min.	Ly5 Max.	Ly5 Ave.	Ly5 Min.	Ly6 Max.	Ly6 Ave.	Ly6 Min.
7/19	7.2	4.7	2.6	10.5	7.2	4.9	10.5	7.6	4.0
8/02	11.0	7.4	4.8	19.6	11.0	4.7	21.0	13.0	5.5
8/13	13.9	8.7	4.5			4.1	20.5	14.4	7.7
9/05	11.0	7.2	4.2	19.8	10.6	4.4	19.7	12.2	6.4
9/19	13.8	9.9	6.4	18.3	11.3	5.9	17.2	12.1	6.1
10/05	11.5	8.4	5.9	14.9	9.8	6.4	16.3	10.8	5.4
Average	11.4	7.7	4.7	17.1	10.1	5.1	17.5	11.7	5.8

Table 3. Daily DO consumption *(H)*, daily DO-O_2 exchange (E) and daily DO production *(P)* with their hourly maximum, average and minimum values obtained from BLOC (4).

Date	PF. A H	PF. A E	PF. A P	PF. B H	PF. B E	PF. B P	CR H	CR E	CR P
7/22	23.1	+7.20	17.0	20.2	+5.00	16.0	24.0	+2.90	21.0
8/21	15.4	+7.10	8.3	14.5	+2.10	11.0	23.9	$0.60	24.6
9/24	11.9	+8.70	3.7	9.5	+0.40	8.6	22.5	$4.90	18.6
Average	16.8	+7.70	9.7	14.7	+2.50	11.9	23.5	f2.80	21.4

Date	PF. A Max.	PF. A Ave.	PF. A Min.	PF. B Max.	PF. B Ave.	PF. B Min.	CR Max.	CR Ave.	CR Min.
7/22	18.6	6.20	2.90	12.2	6.50	2.70	11.7	7.50	3.60
8/21	7.9	6.20	4.80	11.8	7.50	4.90	13.9	8.40	3.30
9/24	.	6.90	6.00	8.8	7.20	5. 60	30.3	6.10	2.30
Average	9.3	6.40	4.60	10.9	7.10	4.40	32.0	7.30	3.10

(d) Relationships between DO and other factors

In Fig. 10, the relationships of DO to intensity of solar radiation and water temperature are illustrated using the data from the lysimeter and paddy fields.

Table 4. Daily DO consumption (H), daily DO-O_2 exchange (E) and daily DO production *(P)* with their hourly maximum, average and minimum values obtained from BLOC (5).

Date	PF. 1			PF. 2			CR		
	H	***E***	***P***	***H***	***E***	***P***	***H***	***E***	***P***
7/23	24.3	+3.00	25.7	22.0	-1.30	23.3	26.0	− 2.5	28.6
8/22	28.9	-1.80	31.0	30.2	+2.70	27.6	36.5	+ 5.6	32.9
9/24	24.4			18.7			37.7	+22.4	
Average	25.9	+7.00 +2.70	24.7 17.4	23.6	+2.60 +1.30	16.3 22.4	33.4	+ 8.5	15.5 25.7

Date	PF. 1			PF. 2			CR		
	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.
7/23	16.2	7.10	1.7	16.2	8.70	4.7	15.5	9.0	3.6
8/22	17.3	8.70	3.2	16.1	6.90	1.4	14.9	6.5	0.8
9/24	13.7	7.40	4.0	13.2	8.50	5.1	8.2	4.3	2.1
Average	15.7	7.70	3.0	15.2	8.0	3.7	12.9	6.6	2.2

There were observed certain time lags between the increases in DO in water and in the intensity of solar radiation. However, the raise of water temperature happened concurrently with DO increase. The direct effect of raising temperature was to reduce the DO in water as shown in the curve of saturated DO in which the high temperature in day-time resulted in small oxygen concentration. But high water temperature, accompanied with solar radiation, affected directly the growth and metabolic processes of the aquatic organisms. As a matter of fact, the DO values changed in a proportional trend with temperature and intensity of solar radiation.

Table 5 shows the variation of average DO and the factors such as average air temperature, intensity of solar radiation, average height and tiller number of rice plants on each in 6 days of measurement in Ly, of BLOC(3).

Table 5. Relationships between DO and other in *situ* factors: data in Ly_6 of rice season in 1974.

Date	Ave. Air Temperature (°C)	Solar Radiation (cal/cm²/day)	Average 'DO' (ppm)	Plant Height (cm)	Tiller Number (number)
7/19	27.9	—		37.5	12
			7.6		19
8/13	28.0 27.9	445.0	13.0 14.0	57.0 71.0	20
9/05					
9/19	19.0 24.7	450.0 314.0	12.2 12.1	101.5 89.0	20 20
10/05	18.8	251.0	10.8	103.0	20

In Ly,, after rice plants were transplanted, ***Pithophora*** was still present in small density and this related to small DO in July. In the middle of August,

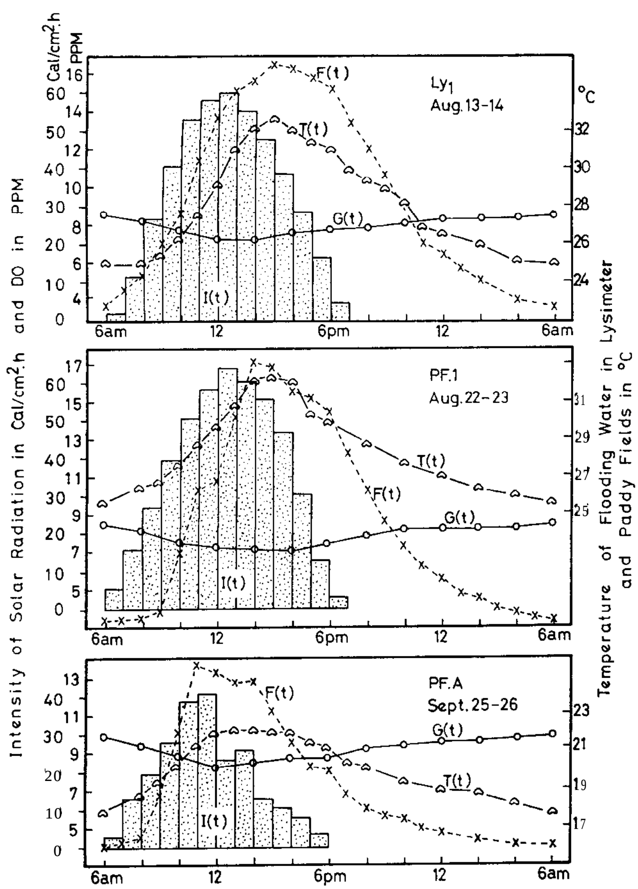

Fig. 10. Some examples about the relationships among the DO diurnal curve $F(t)$, saturated DO $G(t)$, water temperature $T(t)$ and intensity of solar radiation $I(t)$.

when both temperature and sun-light intensity attained the maximum levels, DO in water was also the largest. On the subsequent stages of the rice planting season, all the 3 values decreased gradually while *Pithophora* and other aquatic plants became prostrate and degenerated.

Furthermore, the shading effect of rice plants also took part in changing DO value in water. From the tillering and elongation stages, both width and height of rice plants increased progressively, these obstructed the sun-light and temperature to reach upon the water body, diminished the metabolic activities directly, and reduced the DO in water indirectly,

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REFERENCES

Bartsch, A. F. 1961 Algae as a source of oxygen in waste treatment. J. ***WPCF., 33:*** 239-249

Carpenter, J.H. 1966 New measurements of oxygen solubility in pure and natural waler. ***Limnol. Oceanogr.,*** 11: 264-277

Darbg, R. E. 1962 Midges associated with California rice fields, with special reference to their ecology (Diptera : Chironomidae) ***Hilgardia, 32: l-206***

Downing, A. L. and G. A. Truesdale 1955 Some factors affecting the rate of solution of oxygen in water. ***J. Appl. Chem., 5: 570-581***

Kanwisher, J. 1963 On the exchanges of gases between the atmosphere and the sea. ***Deep Sea Res.,*** 10: 195-207

Liss, P. S. 1973 Processes of gas exchange across an air-water interface. ***Deep Sea Res.,*** 20 : 221-238

Montgomery, H. A. C., N. S. Thorn and A. Cockburn 1964 Determination of dissolved oxygen by the Winkler method and the solubility of oxygen in pure water and sea water. ***J. Appl, Chem., 14:*** 280-296

Odum, H. T. 1956 Primary production in flowing waters. ***Limnol. Oceanogr.,*** 1: 102-117

Ryther, J. H. 1956 Photosynthesis in the ocean as a function of light intensity. ***Limnol. Oceanogr.,*** 1: 61-70

Toyota, M. 1972 Study on the effect of low content oxygen water on the rice growth and the simple method for DO measurement (in Japanese). ***Wat. Purif. Liq. Wast. Treatm., 13: 25-32***

Truesdale, G. A., A. L. Downing and G. F. Lowden 3955 The solubility of oxygen in pure water and sea-water. ***J. Appl. Chem., 5:*** 53-62

Welch, H.E. 1968 Use of modified diurnal curves for the measurement of metabolism in standing water, ***Limnol. Oceanogr., 19:*** 65-73