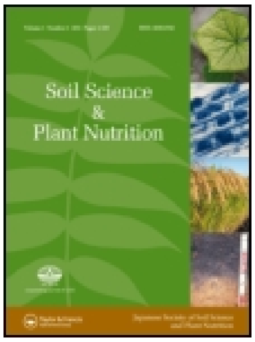

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Characteristics of Nutrient Absorption and Water Purification in Some Plant Species Grown by Floating Culture System

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Nutrient absorption and water purification by rice (*Oryza sativa* L.), canna (*Canna indica* L.), reed (*Phragmites communis* Trin.), and umbrella plant (*Cyperus alternifolius* L.), grown by the floating culture system, were compared under different pH conditions in natural water. The pH of the rooting zone in natural water changed due to the increase in the CO_2 concentration associated with root respiration, which was achieved by placing the roots in a plastic pot attached beneath the float to isolate the roots from the outside water. The absorption of nutrients (N and P) by umbrella plants was higher than that by the other plant species and was not inhibited by high pH values. In addition, the absorption of nutrients (N, P, K, and Fe) by umbrella plants increased with the application of a slow-release fertilizer to the basal part of the roots. As a result, umbrella plants grown with fertilizer displayed a strong water purification effect, regardless of the pH values. On the other hand, nutrient absorption by rice was severely inhibited by high pH values when fertilizer was applied. This was because the absorption of N and P increased with fertilizer application, while the absorption of Fe by rice was markedly reduced under high pH conditions, resulting in iron deficiency. Therefore, we suggest that species tolerant to high pH conditions, such as umbrella plants, should be selected and that fertilizer should be applied to those plants, although the levels of the nutrients contained in the fertilizer should not exceed those corresponding to the absorption capacity of the plant, for improving water quality in closed natural water bodies with high pH values.

Key Words: **fertilizer application, floating culture, nutrient absorption, pH, water purification.**

The floating culture system was originally developed to produce crop plants on the surface of lakes and rivers by using rafts (Song et al. 1991, 1995; Agata et al. 1998). This system can also be applied to water purification by allowing plants to absorb nutrients from natural water. In previous studies, we investigated the suitability of this system for various cereal and weed plants and found that umbrella plant (*Cyperus alternifolius* L.) and canna (*Canna indica* L.), perennial crops native to tropical and subtropical regions, displayed a strong capacity for water purification (Miyazaki et al. 1995, 1997; Agata et al. 2000). Water purification efficiency in those plants was enhanced by the application of a slow-release fertilizer to the basal part of roots, which was related to the root development (Miyazaki et al. 1999). However, the water purification efficiency of rice plants grown by the floating culture system was reduced by high pH values that are characteristic of closed natural water bodies (Miyazaki et al. 2000). Therefore, in the present study, we compared the effect of the pH in natural water on the water purification efficiency between rice and some water purification plants grown under different conditions of fertilizer application. We attempted to determine the conditions required for practical use of this system in a natural water area with high pH.

MATERIALS AND METHODS

Plant materials and culture conditions. Rice (*Oryza sativa* L., cv. Nipponbare), canna (*Canna indica* L.), reed (*Phragmites communis* Trin.), and umbrella plant (*Cyperus alternifolius* L.) were cultivated until

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transfer by the following methods: Rice plants were grown in a nursery box until the 3.5–3.9-leaf stage for 22 d after sowing by conventional methods. Seedlings of reed and umbrella plants were sampled from a riverbed and were adjusted to an even length by cutting the top and roots. Sprouted tubers weighing 50–60 g were collected in canna.

The floating culture experiment for these plants was conducted in a concrete water reservoir (7 × 7 × 0.9 m) placed outside from June 10 to September 18, 1999. The water in the reservoir consisted of natural water that had not been exchanged for more than decades. During the experimental period, the water was also not exchanged although rainwater came into the reservoir.

Eight foam polystyrene boards (180 × 90 cm, and 5 cm in thickness each) as floats were put on the surface of water. Rice, reed, and umbrella plants with two seedlings, canna with one tuber were transferred to holes opened at a 23 cm × 23 cm spacing in the floats (8 × 4 holes in a board) and were fixed at their base with foam (Fig. 1A, floating culture; FC). Two foam polystyrene boards were used for each species. All the floats were connected to each other and the total area of the floats accounted for 26% of the area of the reservoir.

Treatments. Plants were grown with and without fertilizer application (hereafter referred to as "fertilized and non-fertilized conditions"). Under the fertilized conditions, slow-release fertilizer (N, 13%, including NO_3-N 6.5% and NH_4-N 6.5%; P, 11%; K, 13%; Longtotal 100, Chisso Asahi, Tokyo, Japan) was applied at a rate of 2 g $hill^{-1}$ in the foam at the time of plant transfer. The same fertilizer (2 g $hill^{-1}$) was also topdressed at 62 d after transfer of the plants.

Another treatment was applied to change the pH of the rooting zone. In this treatment, the roots were placed in a plastic pot attached beneath the float to isolate it from the outside water during the experiment (Fig. 1B, root pot culture; RPC). The pH of the water inside the pot was expected to be different from that of the water outside the pot due to the increase in the CO_2 concentration associated with root respiration, based on the fact that the pH in natural water generally changes with the CO_2 concentration (Matsuno 1982; Nakamura 1998) according to the following equation:

$$CO_2 + H_2O \leftrightarrows H_2CO_3 \leftrightarrows H^+ + HCO_3^- \leftrightarrows 2H^+ + CO_3^{2-}$$

The water was allowed to be exchanged between the inside and outside of the pot only through 2 holes (1.2 cm in diameter) located at the bottom (see Fig. 1B). For all the species and treatments, a split-split-plot design without replication was adopted.

Measurements. Plants and residual fertilizer in each treatment and species were sampled with three replications on 0, 22, 43, 75, and 100 d after transfer of the plants during the experiment. Dry matter weight was measured after the samples were dried at 80°C for 3 d. Dried samples from 0 and 100 d after transfer were milled for nutrient analyses. Samples from the plants and fertilizer were digested with sulfuric acid and salicylate sulfuric acid, respectively. These acid digestion solutions were used for analyses of the nitrogen (N), phosphorus (P), potassium (K), and iron (Fe) contents. The N content was determined according to the modified micro-Kjeldahl distillation method (Hidaka 1997). The P content was determined by the ascorbic acid method (Nanzyo 1997). The contents of K and Fe were determined by atomic absorption spectrophotometry (AA-610S, Shimadzu, Kyoto, Japan). The amount of nutrients absorbed by plants was estimated from the

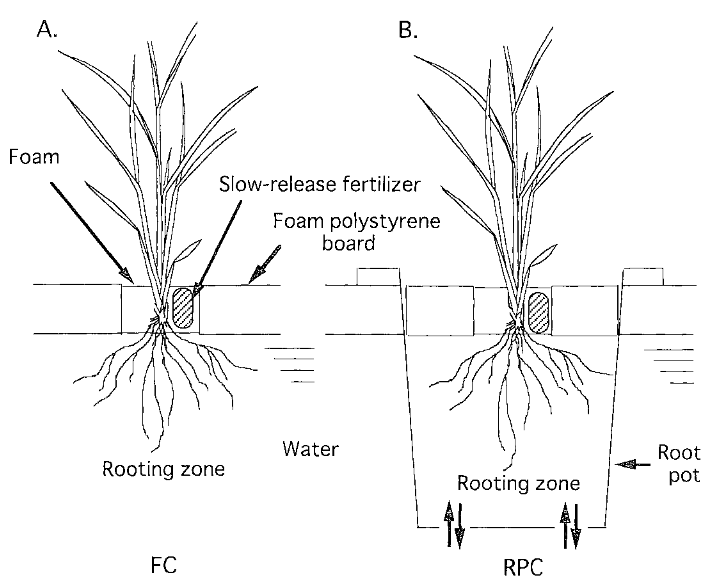

Fig. 1. Diagram of (A) floating culture (FC) and (B) root pot culture (RPC) systems. Exchange of water between the inside and outside of the root pot was restricted, and the pH of the water in the root pot decreased as the CO_2 concentration increased due to the respiration of roots.

nutrient contents in plants sampled at 100 d after transfer by subtracting the nutrient contents in plants sampled. The amount of fertilizer nutrients dissolved was calculated from the amount of fertilizer nutrients applied by subtracting the amount of fertilizer nutrients that remained at 100 d after transfer. Based on these data, the water purification effect of the plants grown with fertilizer was calculated from the amount of nutrients absorbed by subtracting the amount of fertilizer nutrients dissolved.

Water quality in the rooting zone was analyzed 8 times, every 1 or 2 weeks, during the experimental period. The dissolved oxygen (DO) concentration, electrical conductivity (EC), water pH, and temperature were measured by inserting a water checker (U-10, Horiba, Kyoto, Japan) directly into the rooting zone. A minimum quantity of water was collected from a depth of 20 cm and was filtered with a filter paper (No. 6, Toyo Roshi, Tokyo, Japan) for the estimation of the concentrations of NO_3-N and NH_4-N. The concentrations of NO_3-N and NH_4-N were determined by the cadmium reduction method and Nessler's method, respectively (DR-2010, Hach, Loveland, USA). Kjeldahl N, the sum of the concentrations of organic N and NH_4-N, was determined by Nessler's method after sulfuric acid digestion (DR-2010, Hach). Total N content was calculated as the sum of the concentrations of Kjeldahl N and NO_3-N (Somiya and Tsuno 2000). Total P content was determined by the ascorbic acid method after persulfuric acid digestion (Saizyo and Mitamura 1999).

RESULTS AND DISCUSSION

Changes in the water quality of the reservoir during the experimental period are shown in Table 1. The value of the pH increased at 3 weeks after the beginning of the experiment, and ranged from 7.3 to 10.1 during the experiment. High concentrations of NO_3-N and NH_4-N which were observed at the beginning of the experiment, gradually decreased and the compounds were hardly detected after 1 month. Similar changes in the pH and nutrient concentrations are often observed in the surface layer in closed eutrophic water bodies, in which the increase in pH and the decrease in nutrient concentrations are caused by CO_2 assimilation and nutrient absorption of algae during the summer season, while high nutrient concentrations are detected in the aphotic layer because organic matter produced by algae undergoes precipitation and decomposition (Saizyo and Mitamura 1999; Miyazaki et al. 2000).

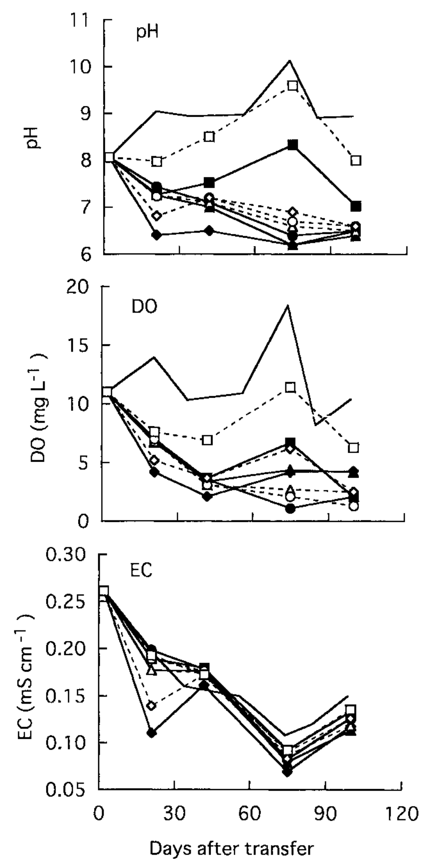

Fig. 2. Changes in pH, DO, and EC values of water in the experimental reservoir (FC) and in the root pot culture (RPC). Open: non-fertilized conditions; closed: fertilized conditions. □, ■, rice; ◇, ◆, canna; ○, ●, reed; △, ▲, umbrella plant.

Table 1. Changes in water quality in the experimental reservoir during the growth period.

Water parameters	Days after transfer								Average
	2	15	21	34	56	74	85	99	
pH	8.06	7.34	9.05	8.94	8.98	10.13	8.91	8.95	8.80
EC (mS cm^{-1})	0.26	0.21	0.20	0.16	0.15	0.11	0.12	0.15	0.17
DO (mg L^{-1})	11.0	6.2	13.9	10.3	10.9	18.4	8.2	10.4	11.2
Temperature (°C)	24.5	25.0	25.1	27.5	29.8	28.7	29.1	27.0	27.1
Total N (mg L^{-1})	—	3.14	—	0.60	0.00	—	0.45	0.42	0.92
NH_4-N (mg L^{-1})	1.29	0.44	—	0.29	0.11	—	0.37	0.25	0.46
NO_3-N (mg L^{-1})	0.30	0.07	—	0.00	0.00	—	0.00	0.00	0.06
Total P (mg L^{-1})	—	0.24	—	0.06	0.07	0.00	0.06	0.09	0.09

Comparison of the pH, DO, and EC values in the rooting zone between the RPC and FC is shown in Fig. 2. The pH value in RPC was lower than that in FC at 21 d after the transfer of the plants until the end of the experimental period. The pH value in the rooting zone of canna, reed, and umbrella plants in RPC ranged between 6.2 and 7.4 after 21 d, and it was lower than that in rice plants in RPC. The pH value in the rooting zone of rice in RPC with fertilizer application was lower than that in RPC without fertilizer application. These changes in the pH value were similar to those in the DO concentration, and there was a significant relationship between the changes in the two parameters (r = 0.880, significant at 0.1% level). Therefore, the decrease in the pH values in RPC was attributed to the increase in the CO_2 concentration associated with the decrease in the DO concentration due to root respiration, suggesting that the pH values inside the pot decreased with the enlargement of the roots. The values of EC in the rooting zone for all the plants in RPC were slightly lower than those of the plants in FC after 75 d.

The effect of RPC on dry matter production is shown in Fig. 3. Numbers in parentheses in Fig. 3 indicate the ratio of dry weight in RPC to dry weight in FC, for the plants sampled at 100 d after transfer. Under non-fertilized conditions, RPC exerted a significant effect on the dry weight of canna, reed, and umbrella plants, although the dry weight of rice was low in both RPC and FC. On the other hand, under fertilized conditions, RPC exerted a negligible effect on the dry weight of canna, reed, and umbrella plants, although it markedly affected the dry weight of rice. The difference in the reactivity of rice between the two fertilizer conditions was partly due to the lower pH values in the rooting zone of rice grown with fertilizer compared with rice grown without fertilizer application (Fig. 2). However, this did not explain the reason for the difference in the reactivity of canna, reed, and umbrella plants between the two fertilizer conditions, in which the pH values were not different, while the effect of RPC on the dry weight was clearly different. These results indicated that the effect of RPC on the root function varied considerably with the plant species and nutrient conditions associated with the fertilizer. In this experiment, RPC decreased the DO and EC values (Fig. 2), but did not decrease the dry matter weight of all the plant species (Fig. 3). Therefore, we consider that RPC did not cause the shortage of oxygen and nutrients for the growth and nutrient absorption.

Nutrient absorption was compared among the plant species grown by the RPC and FC systems for the estimation of the water purification efficiency (Fig. 4). Numbers in parentheses in Fig. 4 indicate the ratio of nutrient absorption in RPC to nutrient absorption in FC, although some ratios were not indicated because nutrient absorption by plants in FC was negligible. The absorption of N, P, K, and Fe by the umbrella plants was higher than that by the other species (except for K in canna) and was hardly inhibited by high pH values under the FC conditions. Moreover, the absorption of Fe by the umbrella plants in FC was higher than that by the umbrella plants in RPC when fertilizer was applied. In the canna and reed plants, the absorption of N and K was not inhibited by high pH, while the absorption of P and Fe was inhibited under the fertilized conditions. In

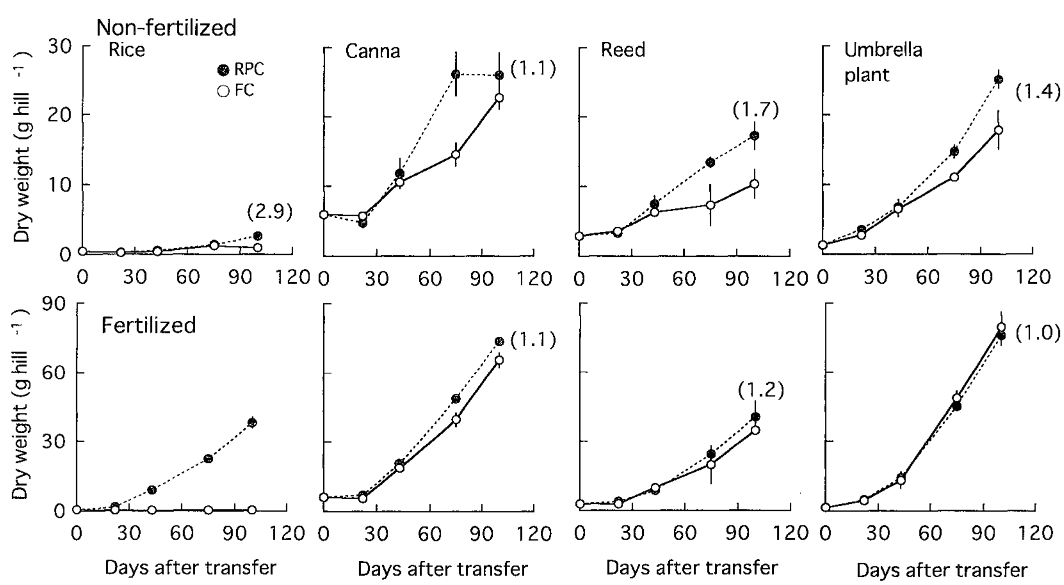

Fig. 3. Total dry weight of plants grown by RPC and FC systems with and without fertilizer application. Numbers in parentheses indicate the ratio of dry weight in RPC to that in FC for the plants sampled at 100 d after transfer, although the ratio was not always indicated because the dry weight of the plants in FC was negligible. Bars indicate standard errors.

this experiment, there was no difference in the absorption of N and P by the umbrella plants between RPC and FC, suggesting that there was no difference in the diffusion of fertilizer nutrients between the RPC and FC systems.

Compared with the canna, reed, umbrella plants, the absorption of N, P, K, and Fe in rice was strongly influenced by RPC, especially when fertilizer was applied. This is because the absorption of N, P, and K increased with fertilizer application, while the absorption of Fe in the rice plants in FC was strongly inhibited by high pH values. These differences in the amount of nutrients absorbed appear to have led to severe iron deficiency. As a result, the rice plants in FC under fertilized conditions died at the early vegetative stage due to severe chlorosis, while the rice plants in RPC under fertilized conditions reached the maturity stage and produced grains.

The differences in the nutrient absorption capacity exerted a remarkable effect on the water purification efficiency (Fig. 4). The absorption of N, P, and K by the umbrella plants exceeded the amount dissolved from the fertilizer (indicated by a dotted line in Fig. 4), indicating that water purification was effective. In addition, the purification effects associated with the absorption of P and K were more pronounced in the umbrella plants grown with fertilizer than in those grown without fertilizer. On the other hand, in the case of rice, the water purification effect of N, P, and K was less conspicuous. Above all, in rice, the water purification effect of N under both pH conditions could not be observed, presumably because the amount of N in the water was much lower than that required for the growth of rice. Actually, the amount of N absorbed by rice in this experiment was lower than that previously recorded in eutrophic water (Song et al. 1994; Miyazaki et al. 2000).

Based on the results shown in Figs. 2–4, it appears that the rice plants were highly sensitive to the pH within the range of the values recorded in this experiment. Therefore, the nutrient absorption of the rice plants was remarkably improved in RPC, although the RPC system was not suitable for extensive cultivation. On the other hand, umbrella plants and the other species were much more tolerant to high pH values than rice plants, even within the range of pH from 6 to 9, when fertilizer was applied. Therefore, we suggest that species with a high tolerance to pH should be selected and that fertilizer should be applied to those species, although the levels of nutrients in the fertilizer should not exceed those corresponding to the nutrient absorption capacity of the plant species, in order to achieve water purification by the FC system in natural water with high pH values.

The results described above and in other previous reports are summarized in a flow chart shown in Fig. 5. The water purification effect in the FC increased with the application of slow-release fertilizer to the base of roots (Miyazaki et al. 1994, 1999). This is because the fertilizer nutrients were used for dry matter production, resulting in the enhancement of the nutrient demand and increase in the nutrient absorption through the expanded root system, although the fertilizer nutrients that were not absorbed leached into the water. The water purification efficiency of the umbrella plants varied with the amount of nutrients contained in natural water, but was not appreciably affected by the pH values (Fig. 4; Miyazaki et al. 2000). On the other hand, the water purification efficiency of rice was often severely inhibited by high pH values under the fertilized conditions, presumably because the high pH values exerted an adverse effect on the absorption of Fe compared with that of N and P, causing a large difference in the amount of absorption between nutrients and resulting in severe iron deficiency. Therefore, the growth of rice in the FC sys-

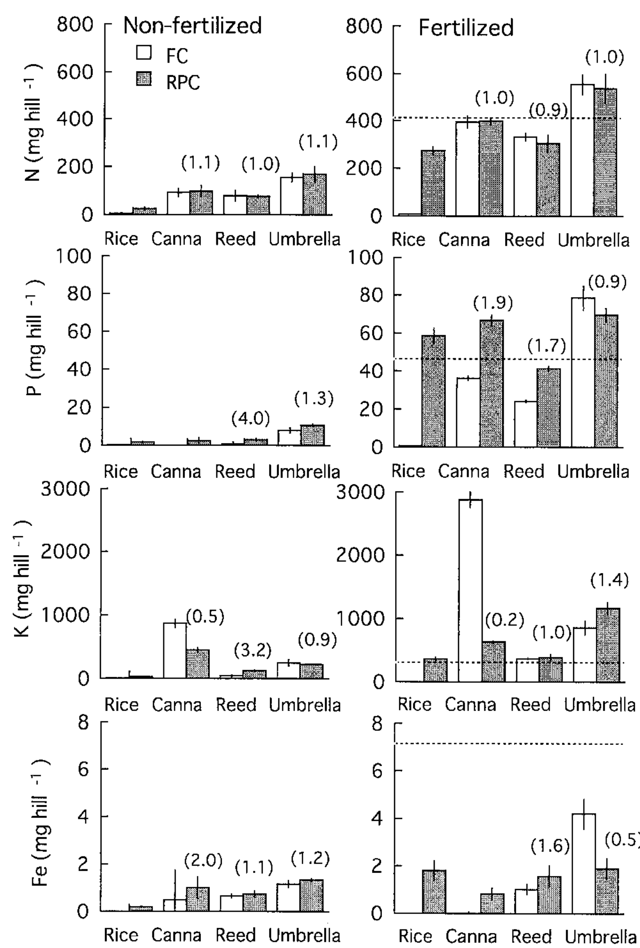

Fig. 4. Absorption of N, P, K, and Fe during the cultivation of plants grown by RPC and FC systems with and without fertilizer application. Dotted lines in the figures indicate the dissolution of fertilizer nutrients. Numbers in parentheses indicate the ratio of absorption in RPC to absorption in FC, although some ratios were not indicated because the nutrient absorption by plants in FC was negligible. Bars indicate standard errors.

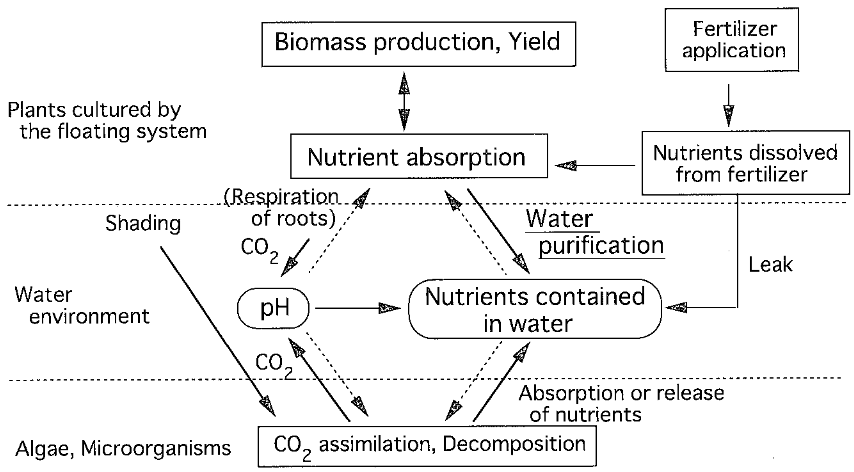

Fig. 5. Flow chart of water purification in the floating culture system.

tem was improved by the application of iron element in fertilizer (Miyazaki et al. 2000). In addition, it was reported that when rice plants were grown on the surface of eutrophic water containing adequate amounts of Fe (0.7 mg L^{-1}) and other nutrients (NO_3-N, 1.7 mg L^{-1}; NH_4-N, 1.6 mg L^{-1}; total P, 0.38 mg L^{-1}) under the same conditions of plant density, fertilizer, and variety, even at a higher pH (7.2) than the optimum pH level for rice cultivation (pH 5.5–6.0), the yield was comparable to that of rice plants grown in paddy fields (Miyazaki et al. 2000). Since these conditions are observed in open natural water bodies with continuous inflow and outflow of nutrients, in which adequate amounts of nutrients are supplied for crop production and since the rise in pH with the growth of algae is not appreciable, the rice plants may be used not only as water purification crops, but also as food crops.

The pH value in closed natural water bodies changes with the CO_2 assimilation of algae, the respiration of microorganisms and plant roots in the FC system (Fig. 2; Matsuno 1982; Nakamura 1998). Therefore, we consider that in this system, there is a strong interaction among the plants subjected to FC, algae, and microorganisms through the water environment, such as nutrients and pH. This suggests that the removal of nutrients in the FC system may inhibit the growth of algae.

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REFERENCES

Agata W, Miyazaki A, Aoki N, Song X, Kojima Y, and Hikuma Y 1998: Studies on floating culture for surface greening, water improvement and plant production in pond of golf course. 1. An actual scale experiment in the Koga Golf Club. *Bull. Nishinihon Green Res. Inst.*, **1**, 23–30 (in Japanese)

Agata W, Takeuchi Y, Aoki N, Yamaji H, Kawanabe Y, and Miyazaki A 2000: Botanical character and cultural method of umbrella plant (*Cyperus alternifolius* L.). *Bull. Nishinihon Green Res. Inst.*, **2**, 27–36 (in Japanese with English summary)

Hidaka S 1997: Kjeldahl method. *In* Dojo-Kankyo-Bunseki-Ho (Analytical Methods for Soil Environment), Ed. Editing Committee of Analytical Methods for Soil Environment, p. 233–241, Hakuyusha, Tokyo (in Japanese)

Matsuno T 1982: pH and carbon dioxide. *In* Suishitsuodaku-Dojoosen (Pollution of Water and Soil), Ed. Safety Technology Association, p. 104–105, Kaibundo Publishing, Tokyo (in Japanese)

Miyazaki A, Agata W, Kubota F, Matsuda Y, and Song X 1995: Bio-production and water cleaning by plant grown with floating culture system. 2. Water cleaning effects by the growth of several plant species. Proceeding of the 6th International Conference on the Conservation and Management of Lakes-Kasumigaura, Vol. 1, p.560–563

Miyazaki A, Agata W, Kubota F, and Song X 1994: Bio-production and water cleaning by plants grown with floating culture system. 3. Effects of application amount of fertilizer on the growth and yield of wheat, and water cleaning. *Jpn. J. Crop Sci.*, **63** (Extra Issue 2), 5–6 (in Japanese)

Miyazaki A, Kubota F, Agata W, and Song X 1999: Comparative analysis of water purification efficiency of *Oryza sativa* L. and *Cyperus alternifolius* L. grown in the floating culture system. *Jpn. J. Crop Sci.*, **68**, 570–575 (in Japanese with English abstract)

Miyazaki A, Kubota F, Agata W, Yamamoto Y, and Song X 2000: Plant production and water purification efficiency by rice and umbrella plants grown in a floating culture system under various water environmental conditions. *J. Fac. Agric., Kyushu Univ.*, **45**, 29–38

Miyazaki A, Tokuda S, Agata W, Kubota F, and Song X 1997: On the photosynthetic production and water cleaning ability of *Cyperus alternifolius* L. grown by the floating culture system. *Jpn. J. Crop Sci.*, **66**, 325–326 (in Japanese)

Nakamura Y 1998: Dissociation equilibrium of water and pH. *In* Suiken-no-Kankyo (Environment of the Hydrosphere), Ed.

M Arita, p. 25–26, Tokyo Denki University Publishing, Tokyo (in Japanese)

Nanzyo M 1997: Available phosphorus. *In* Dojo-Kankyo-Bunseki-Ho (Analytical Methods for Soil Environment), Ed. Editing Committee of Analytical Methods for Soil Environment, p. 267–269, Hakuyusha, Tokyo (in Japanese)

Saizyo Y and Mitamura O 1999: Kosho-Chosa-Ho (Methods for Investigation of Lakes and Ponds), Ed. Kodansha-Scientific, p. 1–230, Kodansha, Tokyo (in Japanese)

Somiya I and Tsuno H 2000: Nitrogen. *In* Kankyo-Suisitsugaku (Water Quality and Environment), p. 145–151, Corona Publishing Co., Tokyo (in Japanese)

Song X, Ying H, Zhu M, and Wu W 1991: A study on growing rice with floating method on the waters. *Sci. Agric. Sin*, **24**, 8–14 (in Chinese with English abstract)

Song X, Agata W, Jim Q, Wu W, Ying H, Zhu M, Lu Y, and Kubota F 1994: Bio-production and water cleaning by plants grown with floating culture system. 2. Water cleaning by rice plants. *Jpn. J. Crop Sci.*, **63** (Extra Issue 2), 3–4 (in Japanese)

Song X, Agata W, Zou G, Wu W, Ying H, Yu Q, Huang Y, Kubota F, and Muramoto S 1995: Bio-production and water cleaning by plant grown with floating culture system. 1. Effect of floating culture area of rice plants on water quality criteria and bio-production. Proceedings of the 6th International Conference on the Conservation and Management of Lakes-Kasumigaura, Vol. 1, p.426–429