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Photosynthesis and root characteristics of rice (*Oryza sativa* L.) in floating culture

H.-X. WU[*,+], Y.-Z. MA[**], J.-P. XIAO[***], Z.-H. ZHANG[*], and Z.-H. SHI[*]

Hunan Opulent Seed Industry Technology Co., Ltd., Huaihua Hunan 418000, China[*]
School of Life Science and Technology, Central South University of Forestry and Technology, Changsha Hunan 410004, China[**]
Huaihua Vocational Technology College; Huaihua Hunan 418000, China[***]

Abstract

To address the issue of water eutrophication and to use water more effectively, we conducted experiments on rice (*Oryza sativa* L.) grown in floating culture. From 2009 to 2011, we compared the photosynthesis and root characteristics of the rice, hybrid line Zhuliangyou 02, grown under a conventional tillage and in a floating culture in Huaihua, the home of hybrid rice. Rice in the floating culture showed a higher net photosynthetic rate and stomatal conductance than that under the conventional tillage. The activities of phospho*enol*pyruvate carboxylase and NADP-malic enzyme were 32 and 28% higher, respectively, in rice in the floating culture than under the conventional tillage. Rice in the floating culture also showed significantly greater number of roots, root activity, and antioxidant enzyme activity than that under the conventional tillage. Compared with rice under the conventional tillage, rice in the floating culture had 18 and 24% higher tiller number and effective panicle number, respectively. These results suggested that the floating culture system can promote rice production through enhancing root absorption, increasing effective panicle number, and improving the photosynthetic rate. In addition, rice cultivated in the floating culture could remove excess nutrients from water, which addresses the problems of a lack of arable land and water pollution.

Additional key words: eutrophic lake; photosynthetic characteristics; productivity; root characteristics; tillage.

Introduction

Rice, an amphibious crop, has two physiological mechanisms that allow an adaption to conditions of drought and flooding (Bo *et al*. 2007, Fan *et al*. 2002). Rice can be cultivated in paddy fields, which provide ample moisture during the whole growth period. This method of cultivation is known as a conventional tillage or water cultivation. Rice can be also cultivated on hillsides or in drought-affected regions; this is known as a rain-fed cultivation. Over the last few thousand years, the conventional tillage has been the main method of rice cultivation, because of its high productivity and its compatibility with the traditional farming culture. The traditions of rice breeding, the design of farm implements, and the strategies for farm management are all based on the water cultivation of rice, rather than the rain-fed cultivation. Therefore, the rain-fed cultivation has not developed to the same extent as the conventional tillage. Rice grown under the conventional tillage shows at least double productivity of that under the rain-fed cultivation, probably because of the high water consumption in the former system. As reported by Huang *et al*. (2003), approximately 1343 m^3 of water is used per 667 m^2 in the conventional tillage compared to 50–400 m^3 per 667 m^2 in the rain-fed cultivation, which is a 3–27-fold difference. The physiological water demand of rice is only 30–40% of the total water used for the conventional rice cultivation, while the ecological and farming water demands account for the remaining 60–70% (Tan 2008). If the water supply is lower than the physiological and ecological water demands, the reduction in productivity may occur. However, the huge water consumption of rice grown under the conventional tillage can waste both

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[+]Corresponding author; phone: 0086-745-8680880, fax: 0086-745-8680128, e-mail: wuhx73@126.com
Abbreviations: CAT – catalase; CE – carboxylation efficiency; CT – conventional tillage system; CT rice – rice grown under CT; DTT – dithiothreitol; *E* – transpiration rate; FC – floating culture system; FC rice – rice grown in the FC; g_s – stomatal conductance; MDA – malondialdehyde; NADP-ME – NADP-malic enzyme; PEPC – phospho*enol*pyruvate carboxylase; P_N – net photosynthetic rate; POD – peroxidase; ROS – reactive oxygen species; Rubisco – ribulose-1,5-bisphosphate carboxylase/oxygenase; SOD – superoxide dismutase; TTC – 2,3,5-triphenyltetrazolium chloride; WUE – water-use efficiency.

water and fertilizer (Zhu 2009).

With global warming, the lack of water resources could reduce or even stop the rice production in some areas. Meanwhile, the food security becomes a serious problem because of the continuous decrease in the arable land area. In addition to the lack of water resources, water pollution becomes a more serious issue. For example, eutrophication of the lakes can result in a growth of harmful algae that produce toxins harming or killing fish. This does not affect only the fish production, the increased N/P content of the water can also cause serious water pollution (*e.g.* by nitrates and nitrites) (Chen *et al.* 1999). A number of studies have suggested that changing the cultivation pattern of rice could result in a better soil and water conservation, improve the diversity of soil bacterial communities, and increase soil fertility and crop productivity (Chèneby *et al.* 2009, Ceja-Navarro *et al.* 2010, Dai *et al.* 2011, Kulasekera *et al.* 2011, Liu *et al.* 2011, Zheng *et al.* 2011,). In China, the eutrophication is a serious problem in many lakes. Hence, the cultivation of rice in a floating system could be an effective way to alleviate the arable land shortage and to reduce water pollution (Ou *et al.* 2010, Zhao *et al.* 2011). In this paper, we compared photosynthesis and root characteristics of rice grown under the conventional tillage and in the floating culture. Our results could provide a theoretical and applied basis for improving crop culture systems to increase productivity, to use water more effectively, and to improve water quality.

Materials and methods

Plant material: The rice (*Oryza sativa* L.), hybrid line Zhulianghou 02, was used in our experiments. This line was derived from a cross between Zhu 1S (female) and ZR02 (male) parent lines.

Design of floating islands and field farming: The floating cultivation (FC) was ensured by floating islands (0.8 × 0.8 × 0.2 m) that were designed using bamboo and a foam box. On the island, 4/5 of the soil layer was above the water surface. The base of the foam box was 50 mm thick and had 5 mm holes at a density of 100 m^{-2}. The soil depth inside the floating island was 5 cm. After rice was sown on the island, it was placed in a pond and floated on the water. During the rice growth, the roots filled and clogged the holes at the bottom of the foam box, and further extended into the water to form two separate root environments, of which one was the rain-fed environment in the cropping through of the floating island and the other was the flooded environment underneath the island. Rice was also grown under the conventional tillage (CT) for comparison. The same planting density, fertilizer application regime, and pest control strategy as used in CT (Xie *et al.* 2006), was also applied in the FC.

Gas exchange: We conducted the gas-exchange measurements between 09:00 and 11:00 h (Beijing time) in mid-August using a portable photosynthesis system (*LI-6400, LI-COR, Inc.*, Lincoln, NE, USA). We conducted these measurements on rice at the tillering, heading, and maturity stages. The net photosynthetic rate (P_N), stomatal conductance (g_s), and transpiration rate (E) were measured under the following conditions: irradiance of 1,000 µmol m^{-2} s^{-1}, temperature of 32 ± 0.5°C, native CO_2 concentration of 349.50 ± 8.94 µmol(CO_2) mol^{-1}, and relative air humidity in the measuring cell of 60.40 ± 2.81%. The water use efficiency (WUE) was calculated as follows: WUE = P_N/E.

To determine the response to irradiance, P_N was measured at photosynthetic photon flux density (PPFD) of 2,000; 1,800; 1,600; 1,400; 1,200; 1,000; 800, 600, 400, 200, 100, 50, 25, and 0 µmol m^{-2} s^{-1} in turn from a *LI-COR* LED irradiation source. CO_2 concentration was kept at 400 µmol mol^{-1} with a *LI-COR* CO_2 injection system. The leaf temperature was 32 ± 0.5°C.

The carboxylation efficiency was calculated according to the method of Watling *et al.* (2000). After these measurements, flag leaf tissue was frozen rapidly between pieces of metal cooled to liquid N_2 temperature. The frozen leaf tissue was stored at –80°C until enzyme analyses were accomplished.

Enzyme assays: At the heading stage, approximately 0.5 g of flag leaf tissue was collected after gas-exchange measurements and quickly ground in 3 cm^3 extraction buffer containing 50 mM Tris-HCl (pH 7.5), 10 mM $MgCl_2$, 5 mM dithiothreitol (DTT), 2% (m/v) insoluble polyvinylpolypyrrolidone (PVP), 1 mM EDTA-Na_2, and 10% glycerol. After the tissue was completely macerated, the crude extract was centrifuged at 13,000 × *g* for 15 min at 4°C, and the supernatant was used immediately for enzyme assays.

Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco, EC 4.1.1.39) activity was assayed in a buffer containing 100 mM Tris-HCl (pH 7.8), 10 mM $NaHCO_3$, 20 mM $MgCl_2$, 10 mM DTT, 0.75 mM NADH, 5 mM ATP, 10 mM phosphocreatine, 60 units per cm^3 of 3-phosphoglycerate kinase, 300 units per cm^3 of triose-phosphate isomerase, 30 units per cm^3 of creatine phosphokinase, and 30 units per cm^3 of glyceraldehyde-3-phosphate dehydrogenase. Assays were initiated by adding 50 mm^3 40 mM RuBP. Absorbance of NADH at 340 nm was measured immediately.

Phospho*enol*pyruvate carboxylase (PEPC, EC 4.1.1.31) activity was assayed in a buffer containing 50 mM HEPES-NaOH (pH 8.0), 10 mM $NaHCO_3$, 5 mM $MgCl_2$, 1.5 unit malate dehydrogenase (MDH), 0.2 mM NADH, and 20−50 mm^3 of the enzyme extract. Assays were initiated by adding 2 mM PEP. The change in NADH was monitored by a spectrophotometer at 340 nm.

NADP-malic enzyme (NADP-ME, EC 1.1.1.3) activity was assayed in a buffer containing 150 mM Tris-HCl (pH 8.0), 12 mM $MgCl_2$, 1.5 mM EDTA, 150 mM DTT, 12 mM $NADP^+$, and 20−50 mm^3 of the enzyme extract. Assays were initiated by adding L-malic acid to a final concentration of 150 mM. The change in $NADP^+$ concentration was monitored spectrophotometrically at 340 nm.

Enzyme assays were conducted as described by Johnson and Hatch (1970) (NADP-ME), Gonzalez *et al.* (1984) (PEPC), Larson *et al.* (1997) (RuBPCO), Patrizia and Graziano (2000) (PEPC), and Ou *et al* (2008) (RuBPCO, PEPC and NADP-ME).

Number of roots and dry mass: 3 plants per plot were harvested at the tillering, heading, and maturity stages. The plants were washed carefully, and then the underground parts were placed on graph paper and the number of roots per plant at different soil depths (10, 20, 30, and 40 cm) was counted. The roots were washed again, impurities and dead roots were removed, and the remaining roots were dried and weighed. The average mass of the total of 27 plants (3 plots with 9 plants per plot) during the tillering, heading, and maturity stages was used for comparison.

Whole root activities and enzyme activities: The root activity was measured by the 2,3,5-triphenyltetrazolium chloride (TTC) method according to Ou *et al.* (2011). In detail, roots were collected and washed and their surfaces were dried carefully with absorbent paper. Then, 0.5 g of root tip tissue was cut into 1-cm pieces, placed in a small beaker, incubated with 10 cm^3 of the mixture (1:1, v/v) of 1% TTC solution and 0.1 M phosphate buffer (pH 7.0) at 37°C for 1 h in the dark, and then mixed with 2 cm^3 of 1 M sulfuric acid. As a control, the procedure was the same except that the sulfuric acid was added first, the root sample second, and the mixture last. To extract triphenylformazan, the roots were then collected, blotted dry, and ground with 3–5 cm^3 ethyl acetate and quartz sand using a mortar and pestle. The remaining roots were further extracted with ethyl acetate 3 times. All the red colored extracts were collected, transferred into a new tube and diluted with ethyl acetate to 10 cm^3. Absorption of the diluted extracts was measured at 485 nm. The blank solution was obtained similarly without adding the roots. Reduced TCC amount [mg] was obtained from the standard curve and its intensity in root tip was calculated as follows: TTC reduction intensity [mg $g^{-1}\cdot h^{-1}$] = reduced TTC amount FM^{-1} h^{-1}; where FM is a fresh root mass and h is an incubation time. Malondialdehyde (MDA) content and the activities of catalase (CAT, EC 1.11.1.6), superoxide dismutase (SOD, EC 1.15.1.1.), and peroxidase (POD, EC 1.11.1.7) were measured using commercial kits (A001-1 for SOD, A007-1 for CAT, A084-3 for POD, and A003-3 for MDA**,** *Nanjing Jiancheng Bioengineering Institute*, Nanjing China). SOD was measured by hydroxylamine method, CAT was measured by ammonium molybdate method, POD was measured by colorimetry method, and MDA was measured by microplate method.

Biomass measurement: Samples were collected at the tillering, heading, and maturity stages. Three plants were randomly sampled to measure the number of tillers, plant height, and biomass (dry mass after drying at 80°C). The average mass of the total of 27 plants (3 plots with 9 plants per plot) at the tillering, heading, and maturity stages was used for comparison.

Statistical analysis: Parametric data were analyzed using analysis of variance (*ANOVA*) in *Microsoft Excel*. Other data were analyzed using *t*-test. *P* values less than 0.05 and 0.01 were considered as statistically significant and highly significant, respectively.

Results

Photosynthetic characteristics: At the tillering stage, P_N increased or decreased with the irradiance under the two tillage conditions and showed a "midday depression". P_N was significantly higher in rice in the FC (FC rice) than under the CT conditions (CT rice) (Fig. 1*A*). Under natural CO_2 concentration at the tillering stage, P_N increased with the increase of the irradiance and it was significantly higher in plants in the FC than under the CT (Fig. 1*B*).

The values for P_N, g_s, and E in all tested stages were significantly higher in rice in the FC than under the CT (Table 1). These data indicated that rice could maintain high P_N by increasing g_s in the FC.

At the tillering stage, the carboxylation efficiency (CE) was higher in FC rice (0.172 mol m^{-2} s^{-1}) than in CT rice (0.164 mol m^{-2} s^{-1}). At this stage, FC rice also showed slightly higher Rubisco activity than CT rice. The activities of PEPC and NADP-ME were 32.1% and 28.2% higher, respectively, in the FC than under the CT at the tillering stage (Table 2).

Root numbers and mass: A strong root system is essential for high yields in rice. The number of roots and root lengths differed significantly between the two tillage systems. In FC rice, the total root number was 17.7, 28.3, and 38.3% higher than in CT rice at the tillering, heading, and maturity stages, respectively. In addition, the number of roots at different soil depths was higher in FC rice than in CT rice. The difference increased with the increasing soil depth (Table 3). The results showed that

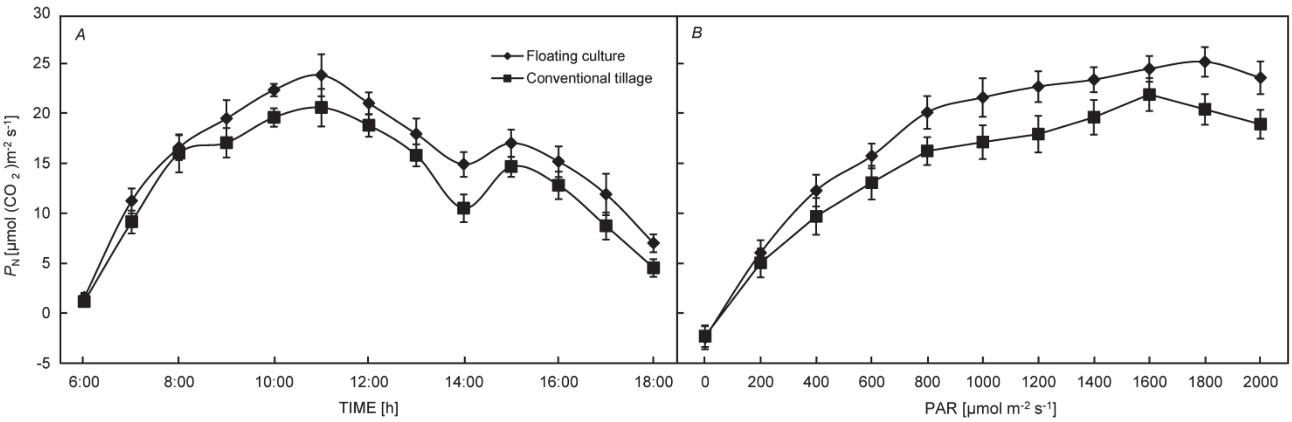

Fig. 1. Net photosynthetic rate (P_N) during the day (*A*) and under different irradiances (*B*) of a hybrid rice cultivar Zhuliangyou 02 under two different tillage conditions. Values are means ± SE (n = 9).

Table 1. Net photosynthetic rate (P_N), transpiration rate (E), and stomatal conductance (g_s) of Zhuliangyou 02 at different developmental stages under different tillage conditions. Values followed by a different *uppercase* or *lowercase letter* are significantly different at the 0.01 or 0.05 probability levels, respectively. Values are means ± SE (n = 9).

Stage	Treatment	P_N [µmol(CO_2) m^{-2} s^{-1}]	g_s [mol (H_2O) m^{-2} s^{-1}]	E [mmol m^{-2} s^{-1}]
Tillering	Conventional tillage	21.09 ± 1.23^{Bb}	0.460 ± 0.06^{Bb}	0.826 ± 0.075^{Bb}
	Floating culture	23.76 ± 0.97^{Aa}	0.574 ± 0.07^{Aa}	0.108 ± 0.080^{Aa}
Heading	Conventional tillage	21.11 ± 1.32^{Bb}	0.442 ± 0.04^{Bb}	0.854 ± 0.062^{Bb}
	Floating culture	24.65 ± 1.83^{Aa}	0.575 ± 0.08^{Aa}	0.112 ± 0.098^{Aa}
Maturity	Conventional tillage	17.12 ± 2.01^{Bb}	0.403 ± 0.05^{Bb}	0.732 ± 0.089^{Bb}
	Floating culture	19.88 ± 1.98^{Aa}	0.465 ± 0.09^{Aa}	0.856 ± 0.109^{Aa}

Table 2. Carboxylation efficiency (CE) and activities of key photosynthetic enzymes in Zhuliangyou 02 under different tillage conditions. Values followed by a different *uppercase* or *lowercase letter* are significantly different at the 0.01 or 0.05 probability levels, respectively. Values are means ± SE (n = 9).

Treatment	CE [mol m^{-2} s^{-1}]	Enzyme activities [µmol(CO_2) mg^{-1}(protein) min^{-1}]		
		Rubisco	PEPC	NADP-ME
Conventional tillage	0.164 ± 0.003^{b}	1.37 ± 0.04^{a}	0.165 ± 0.002^{Bb}	0.174 ± 0.018^{Bb}
Floating culture	0.172 ± 0.006^{a}	1.42 ± 0.07^{a}	0.218 ± 0.002^{Aa}	0.223 ± 0.007^{Aa}

Table 3. Number and dry mass of roots of Zhuliangyou 02 at different developmental stages under different tillage conditions. Values followed by a different *uppercase* or *lowercase letter* are significantly different at the 0.01 or 0.05 probability levels, respectively. Values are means ± SE (n = 27).

Stage	Treatment	Number of roots at different depths			Root dry mass [g]
		0–10 [cm]	10–20 [cm]	20–40 [cm]	
Tillering	Conventional tillage	321.2 ± 15.8^{B}	47.2 ± 7.1^{B}	13.5 ± 3.6^{B}	5.03 ± 0.98^{B}
	Floating culture	366.4 ± 20.1^{A}	56.3 ± 6.2^{A}	26.7 ± 5.2^{A}	7.11 ± 0.57^{A}
Heading	Conventional tillage	348.2 ± 16.4^{B}	54.3 ± 9.5^{B}	20.4 ± 4.1^{B}	13.08 ± 1.14^{B}
	Floating culture	424.1 ± 18.1^{A}	77.2 ± 10.4^{A}	41.2 ± 7.0^{A}	20.47 ± 1.31^{A}
Maturity	Conventional tillage	371.2 ± 17.1^{B}	64.2 ± 5.9^{B}	25.8 ± 3.4^{B}	19.14 ± 1.87^{B}
	Floating culture	500.7 ± 17.1^{A}	94.1 ± 8.8^{A}	43.1 ± 6.7^{A}	30.12 ± 2.39^{A}

Table 4. Root activity, root enzyme activities and malondialdehyde (MDA) content in Zhuliangyou 02 at different developmental stages under different tillage conditions. Values followed by a different *uppercase* or *lowercase letter* are significantly different at the 0.01 or 0.05 probability levels, respectively. Values are means ± SE (n = 9).

Stage	Treatment	Root activity [mg g^{-1} h^{-1}]	Enzyme activity [U mg^{-1}(protein)] CAT	SOD	POD	MDA [nmol mg^{-1}(protein)]
Tillering	Conventional tillage	142.20 ± 10.21^{B}	11.45 ± 1.87^{B}	78.71 ± 9.77^{B}	88.01 ± 17.41^{B}	3.58 ± 0.50^{A}
	Floating culture	168.31 ± 7.05^{A}	26.44 ± 2.35^{A}	91.77 ± 12.04^{A}	147.45 ± 20.14^{A}	2.37 ± 0.58^{B}
Heading	Conventional tillage	160.88 ± 13.36^{B}	19.47 ± 1.37^{B}	83.37 ± 8.12^{B}	97.25 ± 13.08^{B}	3.74 ± 0.38^{A}
	Floating culture	197.01 ± 18.79^{A}	38.49 ± 4.08^{A}	98.41 ± 13.01^{A}	147.25 ± 20.44^{A}	2.35 ± 0.43^{B}
Maturity	Conventional tillage	158.78 ± 10.01^{B}	18.45 ± 2.33^{B}	84.36 ± 7.04^{B}	97.24 ± 14.28^{B}	4.01 ± 0.68^{A}
	Floating culture	188.64 ± 11.25^{A}	37.37 ± 3.87^{A}	103.45 ± 12.03^{A}	156.24 ± 23.01^{A}	3.26 ± 0.47^{B}

Table 5. Height and shoot dry mass of Zhuliangyou 02 at different developmental stages under different tillage conditions. Values followed by a different *uppercase* or *lowercase letter* are significantly different at the 0.01 or 0.05 probability levels, respectively. Values are means ± SE (n = 27).

Stage	Treatment	Height [cm]	Shoot dry mass [g]
Tillering	Conventional tillage	68.0 ± 4.50^{a}	21.01 ± 2.24^{B}
	Floating culture	68.4 ± 3.20^{a}	28.14 ± 4.08^{A}
Heading	Conventional tillage	87.6 ± 4.20^{a}	34.05 ± 4.47^{B}
	Floating culture	88.4 ± 3.80^{a}	43.81 ± 5.34^{A}
Maturity	Conventional tillage	92.4 ± 5.20^{a}	60.38 ± 4.20^{B}
	Floating culture	91.9 ± 4.80^{a}	78.57 ± 8.50^{A}

Table 6. Major agronomic characters of mature Zhuliangyou 02 under two different tillage conditions. Values followed by a different *uppercase* or *lowercase letter* are significantly different at the 0.01 or 0.05 probability levels, respectively. Values are means ± SE (n = 27).

Treatment	Tiller number	Effective panicle number	Ear length [cm]	Filled grain	Seed setting rate [%]	1,000-grain mass [g]
Conventional tillage	13.4 ± 1.7^{B}	10.8 ± 1.4^{B}	23.68 ± 2.14^{a}	113.9 ± 14.3^{a}	86.2 ± 3.5^{a}	26.83 ± 0.50^{a}
Floating culture	15.8 ± 2.1^{A}	13.4 ± 1.8^{A}	23.80 ± 2.50^{a}	118.2 ± 12.6^{a}	88.3 ± 4.4^{a}	26.51 ± 0.44^{a}

FC rice developed better root system, promoting absorption of nutrients.

Root mass could reflect the root growth status to a certain degree, and the dry mass of rice roots increases with the rice growth. FC rice showed significantly higher root dry mass than CT rice.

Root- and enzyme activities: The root activity reflects the status of a root growth, and it is an essential indicator of the dynamic relationships among the root growth, soil moisture, and the surrounding environment. In FC rice, root activities were significantly higher at all developmental stages than those in CT rice. This indicated that FC resulted in a better root growth and nutrient use. In addition, CAT, SOD, and POD activities at all studied developmental stages were significantly higher in FC rice than in CT rice. This suggested that roots of FC rice had stronger anti-aging ability and that the FC system was conducive to high yields. The content of MDA, a lipid peroxidation product, is an important index of lipid oxidation, and it is often used as an indicator of the degree of organ aging. In FC rice, the MDA content was lower than in CT rice at all developmental stages. This result suggested that there was lesser membrane lipid oxidation and slower aging in the FC, which could help to extend the fertile period (Table 4).

Agronomic traits: There was no difference in the plant height under the two tillage conditions at any of the growth stages. However, the shoot dry mass was greater in FC rice than in CT rice (Table 5). There were no differences in the ear length, filled grain, seed setting rate, and a 1,000-grain mass under the two tillage conditions. However, FC rice showed significantly higher effective panicle number than CT rice (24.1 and 18.4%, respectively) (Table 6). The results suggested that different tillage conditions could result in significant increases in parameters that affect yield, such as the number of panicles.

Discussion

The root is an important organ for absorption and metabolism, and its morphology, activity, and enzyme activity can vary with different cultivation conditions (Cui *et al*. 2003, Yang *et al*. 2009, Pan *et al*. 2011, Zhang *et al*. 2010, 2011a). In the present study, we found that the total root number was higher in FC rice compared with the plants under the CT, especially at greater depths. These results indicated that FC promoted the root growth. When plants accumulate reactive oxygen species (ROS), the activities of their endogenous ROS-scavenging enzymes, such as SOD, POD, and CAT also increase (Reddy *et al*. 2004). In this study, the root activity and enzyme activities were higher in FC rice than in CT rice, indicating that the FC system helped to maintain vitality and reduced amounts of free radicals and membrane lipid peroxidation products in the root. Rice productivity is largely determined by the panicle number, grain number per panicle, seed setting rate, and the mass of 1,000 grains (Pan *et al*. 2011). It is widely accepted that increasing the panicle number at the tillering stage can increase the productivity. The cultivation method can affect the panicle number; *e.g.*, the increase in the effect-tive panicle number was the major reason for increased productivity of straw-fertilized rice (Peng *et al*. 2007, Li *et al*. 2011, Zhang *et al*. 2011b). Here, we found that the two distinct environments of floating culture enabled the roots to absorb more oxygen from the rain-fed layer, so that the roots immersed in the water were supplied with sufficient oxygen for the root growth and absorption. This promoted tillering and increased productivity.

Rice is a C_3 plant; therefore, the C_3 pathway is considered as the main photosynthetic pathway, still the C_4 pathway also operates to varying extents under certain conditions (Ou *et al*. 2008). Rubisco activity is positively correlated with carboxylation efficiency (Farquhar and Sharkey 1982, Collatz 1977). In this study, the FC rice showed higher carboxylation efficiency and greater activities of PEPC and NADP-ME, implying that these photosynthetic enzymes might play an important role in plant metabolism in the FC.

Rice requires a large amount of fertilizer. Although fertilizer is applied regularly under the CT, much of it is lost *via* the flowing water in the paddy, which also results in secondary water pollution (Wen *et al*. 2011, Xia *et al*. 2011). Studies on changes in water and fertilizer use under different cultivation patterns can provide scientific evidence for appropriate fertilization and prevention of nonpoint source pollution (Cui *et al*. 2011, Zhang *et al*. 2011c). The small holes at the bottom of the floating island, used for the FC, were rapidly filled by soil particles and rice roots. Fertilizer applied to the FC should be adsorbed by the soil and thus retained in the soil layer. Furthermore, the well-developed roots in the water beneath the floating island should be able to absorb nutrients, thus reducing the requirement for fertilizer and improving water quality.

In summary, FC rice did not only absorb nutrients from nutrient-rich waters, but also resulted in reduced production costs. Therefore, the FC was an effective cultivation method that can be used for treatment of eutrophic lake waters, while increasing the income of farmers. However, FC, in which plants are grown on the water, is inconvenient for day-to-day management practices, *e.g.*, weeding, fertilizing, pesticide application, and mechanized production. Therefore, this method is not feasible for a large-scale production.

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