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Study on Purification of Culturally-Eutrophicated Water Bodies by Terrestrial Higher Plants Planted on Floating Beds*

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Abstract: *Experiments on surface aquaponics were carried out in simulatedly-eutrophicated cement ponds with the concentrations of kjeldahl nitrogen (KN) 2.084 $mg \cdot l^{-1}$ and TP 0.248 $mg \cdot l^{-1}$ and without any interference from natural environment factors. On the surface of ponds rice was planted on floating-beds without soil for the purpose of collecting nutrients (N & P) from water by absorption and adsorption of rice roots. The results show that the design is not only feasible but also very effective. When the coverage of rice on floating-beds were 20 %, 40 % and 60 %, respectively with the water depth of about 1.4 m, the removal rates of KN in water reached 29.0 %, 49.8 % and 58.7 %, respectively and those of TP 32.1 %, 42.0 % and 49.1 %, respectively during the test period of 84 days from tillering to maturing of rice. Other main parameters of water quality were greatly improved. The results provided a scientific basis for surface aquaponics engineering to purify eutrophicated water bodies by planting terrestrial higher plants on floating-beds.*

Keywords: *Rice on floating-beds, Eutrophication, Coverage, Net removal rate of N and P*

1. Introduction

Attention has all along been put on how to control polluted, mainly eutrophicated water bodies in the world. Large amounts of manpower and material are being put into research and management. But it is very difficult to control eutrophication because the polluted area is so ample, the scale so broad and the concentrations of the pollutants in natural waters are relatively lower than those from point source.

In some developed countries, dredging and water change were conducted at all costs to solve the water pollution of small-sized lakes in certain area, which were heavily polluted and significant results have been achieved. However, the input is so tremendous that the third world can not afford. Moreover, these methods could only be adopted in small water bodies with new water source available nearby.

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In some countries or districts in temperate zone, aquatic macrophytes such as water hyacinth *Eichhornia crassipes* and alligator weeds *Alternanthera philoxeroides* are cultivated in polluted water bodies to purify water and some success has been achieved (Sun *et al.*, 1989; Chen *et al.*, 1995). But most of aquatic macrophytes can not lead to direct economic benefits. It is difficult to harvest and treat them. If not used, decayed aquatic macrophytes would cause subsequent pollution and harm the environment (Riemer, 1984). In south China, water hyacinth and alligator weeds flourishing in summer and autumn seriously affect the navigation in part of rivers and lakes. In winter and spring, the remnants of aquatic macrophytes, which float everywhere, seriously influence aesthetic appearance of water bodies. Year by year, the remnants sink to the bottom as accumulated sediment. River and lake beds would become high, causing malignant cycling of water bodies.

Chinese and Japanese scientists have tried to employ terrestrial higher plants to purify water and have achieved good results (Dai & Jiang, 1995; A, 1994) Lack of sophisticated method, their techniques have not been extended to natural waters so far.

In 1992, the authors proposed an idea that terrestrial higher plants (cereal crops, oil crops, vegetables and florist crops) be planted on floating-beds without soil on the surface of culturally-eutrophicated water bodies, not only to produce agricultural products and beautify the scene but also to collect main nutrients (N and P) and further to degrade organic pollutants, which are harmful but not toxic, by absorption and adsorption of roots. This method, in other words, surface aquaponics could be adopted so as to change waste material into things of value, to turn bane into boon, to purify water and to protect aquatic environment. The experiments of purification began to be conduct in an oxidation pond and some fish ponds, receiving excreta from a hog farm and succeeded in 1993 (Song *et al.*, 1993; Song *et al.*, 1995).

Based on above-mentioned experiments, in 1994 purification feasibility test by surface aquaponics was conducted in simulatedly-eutrophicated cement ponds, without any interference from natural environment factors. Comparative study on the purification effects between different plant coverage rate was also carried out in order to determine the removal rates of nitrogen and phosphorus and other main parameters of water quality and finally to provide a scientific basis for surface aquaponics engineering to purify eutrophicated water bodies.

2. Material and methods

Facilities: Experiments were conducted in cement ponds of 3 dimensions: 4 m×3 m×1.5 m each under the plastic greenhouse (Plate 1) with the cross section 12 m^2 and the volume 18 m^3 and the real water depth ±1.4 m. The water capacity is about 16 000 L.

Test materials: Water came from the small canal around the institute with the concentrations of KN and TP, 2.084 $mg \cdot l^{-1}$ and 0.248 $mg \cdot l^{-1}$, respectively. The trial materials were simulated to the trophic level according to some shallow eutrophicated lakes in China such as Lake West in Hangzhou and Lake Taihu. The plants material was hybrid rice Xieyou 46.

Test design: There were four treatments: 20 %, 40 %, 60 % plant coverage rate and control.

Test methods: Rice seed was broadcast in soil on the first June 1994 by the conventional method. PS foams were used as floating-beds (Song, *et al.*, 1991). The rice seedlings were transplanted onto floating-beds (plant space 20 cm×15 cm) with single plant each hill on the 4th July and floating-beds were let loose to fish ponds for pre-nurture. Test water was filled into cement ponds on the 20th July (the water volume, see Tab. 2). Rice seedlings along with floating-beds were moved into cement ponds on the 21st July.

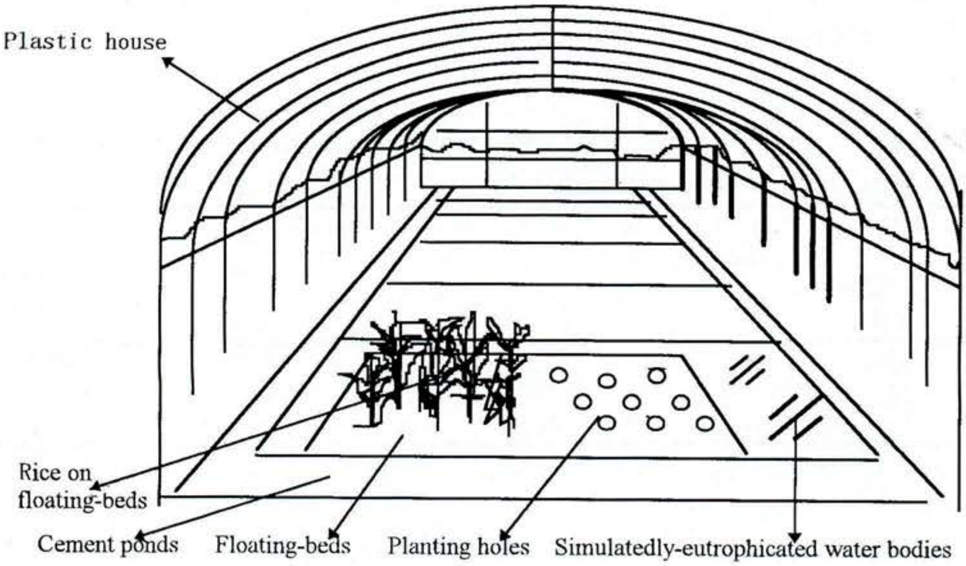

Fig. 1 Sketch map of the experimental facilities

Parameters monitoring and intervals: During the test period, the plant height, tillering and the dry matter of various plant organs were measured at a fixed date. Ten parameters including KN, TP, pH, conductivity, water temperature, turbidity, DO, CODcr, BOD_5, SS were monitored at a 14-day interval up to the maturity of rice plants. The real test period was 84 days.

Sampling and analytical method: The agronomic characteristics of rice were surveyed by conventional methods and the production was calculated in maturing stage of rice. Water samples were collected in static conditions at 40 cm below the surface from five points. After harvest, the pond water was stirred by diving pump. After mixture, it was a multi-point sample from the whole water body. The parameters (KN, TP, CODcr & BOD_5) were measured by semi-micro Kjeldahl method; stannous chloride reduction method; potassium bichromate method and dilution incubation method. Conductivity, pH, turbidity, water temperature and DO were measured by water quality apparatus (Horiba U-10). SS was measured by using water quality analytical apparatus of type of HACA co/2000.

3. Results and analysis

3.1 The effects of different rice coverage on floating-beds on the growth of rice

The results showed that rice planted on floating-beds could grow normally in various treatments. From the growth parameters of rice in various treatments, the less the coverage of rice on floating-beds; the better the individual plant grows; the more the unit area produce and the higher the biomass reaches (Tab. 1). This is because the total amounts of N & P possessed by unit-area rice plants in the pond with less coverage were higher than those in the pond with more coverage under the same water volume and the same concentrations of N & P. The less-coverage pond provided rice plants with better nutrient conditions for growth (Tab. 2).

Tab. 1 Comparative study on the yields and main economic characteristics of rice on floating-beds with different coverage rate

Coverage rate* (%)	Tillers (plant/ hill)	Plant Height (cm)	Grain yield ($g\cdot m^{-2}$)	Biomass ($g\cdot m^{-2}$)			
				Plant(1)	Roots(2)	Total Weight (1+2)	Net weight**
20	23.0	94.0	486.2	1070.0	235.9	1305.9	980.7
40	22.2	93.0	430.7	991.1	205.0	1196.1	870.9
60	21.0	91.0	386.3	919.1	149.1	1069.0	743.8

* The rate of between the floating-beds area of planting rice and the area of whole Water

** The dry matter of the whole plant at harvest subtracting the one at transplanting

Tab. 2 The concentrations of N & P in different coverage rate

Coverage	KN/m^2	TP/m^2
60 %	04.71g	0.57 g
20 %	14.03 g	1.70 g

As far as production and biomass are concerned, the rice production and biomass in this trial obviously were lower than those planting on floating-beds in natural waters (Song *et al*, 1996). This is because the relative concentrations of essential nutrients (N, P & K) were lower and the absolute concentrations were less as well. It is due to relative smallness and stillness of trial ponds. Thus, the growth potential of rice was hampered.

3.2.The removal rates of KN & TP by rice plants from trial ponds & their dynamic changes

Tab. 3 shows that rice in surface aquaponics could absorb the nutrients (N & P), the concentrations of which were much lower compared with in hydroponics or land cultivation. The results were conspicuous e.g. in 60% coverage of floating-beds, the removal rates of KN and TP reached 58.7 % and 49.1 %, respectively; in 20 % coverage, 32.1% and 29.0 %, respectively. There was a reat difference among the removal rates of KN and TP from water in different coverage rate of rice on floating-beds. The more the coverage was, the more KN and TP were removed from the whole water body, the higher the removal rates were. As far as the actual removal of KN and TP by unit-area rice on floating-beds is concerned, the less the coverage of rice on floating-beds; the higher removal of KN and TP. For example, in 60% coverage in pond, the removal rates of KN and TP by one square meter of rice on floating-beds were 2.93 g and 0.32 g, respectively while in 20 % coverage pond, they reached 4.488 g and 0.552 g, respectively. Therefore, from the point of view of effectiveness, it is more economical for 20-40 % coverage. But from the time frame of purification, it is more effective to raise the coverage rate.

Tab. 3 Comparative study on the removal rate of KN and TP by rice on floating-beds with different coverage rate

Coverage rate (%)	Amount of water (L/pool)		Initial amount (g/pool)		Final amount (g/pool)*		Removal amount (g/pool)		Net removal rate (g/pool)**	
	Initial	Final	KN	TP	KN	TP	KN	TP	KN	TP
0	16260	14100	33.886	4.033	33.050	4.019	0.835	0.014	0	0
20	16440	13500	34.261	4.077	23.490	2.754	10.771	1.323	29.0	32.1
40	15960	12880	33.261	3.958	15.855	2.280	17.405	1.678	49.8	42.0
60	16560	13140	34.511	4.107	13.416	2.076	21.095	2.031	58.7	49.1

* Measurements after stirring water

** The removal rate of from a test pond subtracting self-purified in control pond

Fig. 2 and Fig. 3 indicated that the concentrations of KN and TP in all treatment ponds including control pond were decreasing from the beginning of treatment with a tendency of fast in early stage, slow in middle stage, but increasing a little in late stage, esp. TP. From the dynamic changes of KN and TP among all treatments, the concentrations of KN and TP in treatment ponds were lower than those in control. The more the coverage was; the lower the concentrations of KN and TP were. This trend was in conformity with the concentrations of KN and TP in the final stage.

The reason for above-mentioned dynamic change of KN and TP was supposed to be:one,This experiment was conducted in static conditions. The concentrations of KN and TP in trial water body decreased abruptly at early stage partly by virtue of sedimentation. This supposition could be verified by the dynamic change in control pond and the concentrations of KN and TP when mixing the pond water after harvest of rice; the other, the main reason is that the absorption and adsorption of N and P by rice plants during the growth period. At early vegetative phase, rice plants on floating-beds absorbed more N and P. This made the concentrations of KN and TP decrease abruptly. In the middle and late phases, rice plants required less nutrients. The transpiration of rice plants and evaporation of water surface reduced the water volume of the ponds and this increased the concentrations of KN and TP in trial ponds. The decreasing speed of the concentrations of the nutrients seemed to be lessened up to stoppage and the concentrations of the nutrients went up so far to increase. These analysis and judgment were verified by the comparative study between the water volumes in ponds at the early phase and at the final phase as well as dry matter accumulation process of rice plants (See Fig. 4 and Tab. 3). In control pond, algae collected the nutrients by absorption and adsorption during proliferation. The algae reproduction rate appeared rapidly at early phase and slowly at the late phase so that the dynamics of the concentrations of KN and TP were basically the same as those in treatment ponds.

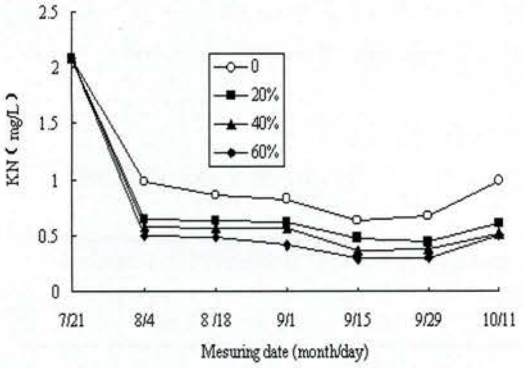

Fig. 2 Comparison dynamics of KN concentration in water with different coverage rates of floating-beds; Under the static conditions

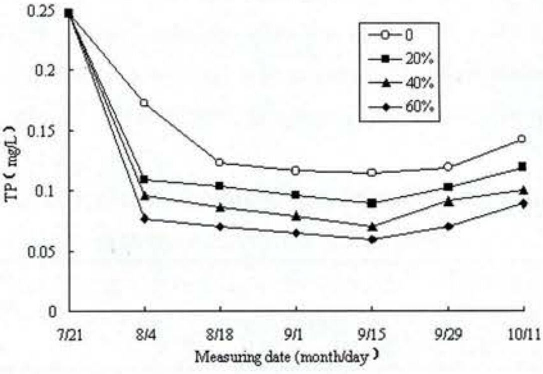

Fig. 3 Comparison dynamics of TP concentration in water with different coverage rates of floating-beds; Measuring and calculating methods are the same as in Fig. 2

3.3. The improvement of other water quality parameters by rice plants on floating-beds

The results in Tab. 4 indicated that the net removal rates of COD_{Cr}, BOD_5 and SS by rice plants on floating-beds were much higher, among which the removal rate of SS was the highest. The net removal rate of SS reached 88.4 % in the treatment pond with 60% coverage and 77.8% in the treatment pond with 20 % coverage. It has a tendency that the more the coverage was, the better the removal rates of the above parameters were and the improvement of water quality. After rice planting on floating-beds the pH value obviously dropped. The pH value tended to be neutral when the coverage became higher. Tab. 3 and 4 indicated that among the measured parameters, DO was the only parameter with negative effect. The more the coverage of floating-beds was; the less the DO appeared to be. The main reasons might be: (1) The growth of rice plants consumes oxygen; (2) Rice plants inhibit the proliferation of algae by collecting the nutrients and the function of shading so that the photosynthesis of algae releases less oxygen; (3) The coverage of floating-beds reduces the water surface so that air can not convey oxygen to the water body. The 24 hours monitoring and surface aquaponics in hyper-eutrophicated water body with almost zero DO indicated that rice plants could secrete certain oxygen per se. That's why the difference between treatments became smaller around 5 AM when DO is always at the lowest and DO would not drop further after down to 1 $mg \cdot l^{-1}$. Moreover, DO appeared in hyper-eutrophicated water body after rice planting on floating-beds and would go up as treatment time extended.

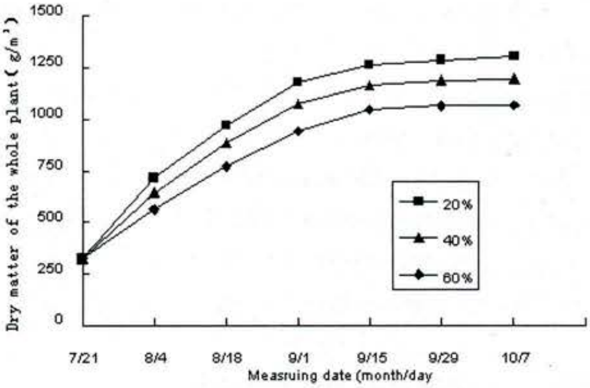

Fig. 4 Cumulative dynamics of dry matter of rice on floating-beds with different coverage rate

The monitoring data at intervals indicated that the dynamic changes of COD_{Cr}, BOD_5, SS and turbidity were basically the same as those of N and P. But their scope of decrease was different: The decrease of those parameters in treatment ponds was larger than that in control pond. The removal rates of those parameters were greater in the pond with more coverage than with less coverage. The dynamics of pH and DO in treatment ponds were the same as above, but DO increased greater than others at the late phase. In control pond, on the contrary, pH and DO increased obviously from the beginning of experiments and reached to the maximum at the middle phase and then, decreased.

Tab. 4 Comparative of effects on the purification of other main parameters of water quality beside N and P with different coverage rate by the beds

Coverage rate	Net removal rate （%） **			TURB	pH	DO	COND
（%）	COD_{Cr}	BOD_5	SS	（FTU）		（mg·l^{-1}）	(s·cm^{-1})
0	0	0	0	158	9.29	7.35	0.235
20	37.6	18.6	77.8	38	8.04	5.91	0.306
40	49.5	31.1	83.4	28	7.93	4.42	0.349
60	57.8	50.8	88.4	21	7.74	2.58	0.352

* Measuring and calculating methods are the same as in Tab. 3

**The removal rate of from a test pond subtracting self-purified in control pond

When the air temperature reached 32℃, the water temperature in treatment ponds was lower than that in control. If the air temperature was higher, the difference between the water temperatures would be larger. When the air temperature was below 25℃, the water temperature in treatment ponds was higher than that in control. The lower the air temperature, the greater the difference between water temperatures in treatment ponds and the control pond. The water temperature dynamics indicated the rice plants on floating-beds could regulate the water temperature. It can not underestimated that this regulation function would play an important role on raising fish yields in ponds. This judgment was verified by the results of the experiment integrating surface aquaponics with aquaculture in this institute.

From Fig. 2 and 3 since the 14th day after the treatment began, the concentrations of TP in the water of treated ponds had been below 70 marks standard, which is the eutrophication standard for

Lake Taihu (Jing & Wu, 1990). The concentration of TP in treated pond with 60 % coverage was close to 60 marks (meso-eutrophication level) at its minimum whereas that in control pond always was above 70 marks.

In this experiment, KN occupied 80 % above in TN. Thus, we can conclude that the concentrations of TN in treated ponds were below 70 marks, among which all the measurements in the pond with 60 % coverage, the last three measurements in the pond with 40 % coverage and the last two measurements in the pond with 20 % coverage were below 60 marks. This analysis indicated that one crop of rice planting on floating-beds could reduce the concentrations of N & P from eutrophicated level to meso-eutrophicated level in a water body, not including that in sedimentation.

4. Discussion and conclusion

The results show that surface aquaponics in eutrophicated waters not only produce direct economic benefits and social benefits. It may not only produce agricultural products and beautify the aquatic ambiance; but also collect the main nutrients (N and P) by absorption and adsorption of terrestrial higher plants, which have potential to produce greater dry matter than aquatic macrophytes. So it is feasible to utilize this technique to turn the waste materials into things of value, to purify water, to protect environment and finally to make water bodies cycle benignly.

Compared with the similar past designs (Riemer, 1984; Song, *et al.*, 1991) this study has many merits: water body larger, test duration longer and the concentrations of N & P more close to the real conditions so this study is of practical value.

It has broadened the scope of plants for purification of water from aquatic vascular macrophytes to terrestrial higher plants esp. cereal crops. This opens a new approach to screen and develop varieties of plants with higher purifying efficiency and better economic benefits.

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