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＜原著論文＞

Recycling Type of Water Purification System with Hydroponic Culture to Apply the Floating Type of Aquatic Plants of Water Spinach Under the Influence of Global Warming in Kochi, Japan

M. Fujimaki*, A. Chikami, T. Mouri***, S. Nishimura* and M. Murakami***

*School of Environmental Science and Engineering; Kochi University of Technology Tosayamada-cho, Kami-city, Kochi 782-8502 Japan

**Sanyu Consultants Inc., Daiichi Fuji Bldg. Daikan-cho Higashi-ku Nagoya 461-0002 Japan

***Japan Agricultural Cooperatives, Ohte-cho Chiyoda-ku Tokyo 100-6837 Japan

Abstract

The purpose of this study is to evaluate the effect of artificial wetland water purification system with specific aquatic plant of vegetable such as water spinach (*Convolvulus*) treating the wastewater from hydroponic culture which uses liquid chemical fertilizer. It is a serious problem for hydroponic culture at warm temperate region in the south western part of Japan to discharge the deteriorated liquid chemical fertilizer with very high concentration of nutrients (N, P) from the farm into the river system without any treatment. A new treatment system is applied at Tai farm to reduce the concentration of the nutrients in the deteriorated liquid fertilizer. Water purification system using aquatic plant of water spinach has been examined to reduce the treatment cost of the wastewater. A series of field observation and water quality measurement were carried out to evaluate the capability of water purification by aquatic plant. The water spinach has a high capability of reducing 85% of T-N and 83% of PO_4-P. Cost and benefit analysis suggests the advantage of hydroponic culture with water spinach to cover the installation and operation and maintenance cost (C) with substantial benefit (B) with B/C ratio of 2.6.

Keywords: water purification; nutrients removal; hydroponic culture; water spinach

1. Introduction

Kochi is located in the southern part of Shikoku, south-western Japan. It is surrounded by the Shikoku Mountains in the north, and faces the vast Pacific Ocean in the south with wide arcuate coast line along the Tosa Bay. "Tosa" is the old name of Kochi. (**Fig**. 1)

Kochi has a mild climate throughout the year. The annual sunlight amount to 2,373 hours and daily maximum solar radiation of 15.0 MJ/m^2 and rainfall with annual average of 2,700 mm in 2013 are among the top ranks in Japan. Thus, Kochi is a most suitable place in Japan to apply the subtropical agriculture study and research.

While, Kochi is located at the best hot spot of global warming study in the south western part of Japan, where the world largest black warm current of Kuroshio directly flows into the off-shore of Kochi (**Fig**. 1). Sea surface temperature (SST) at the off-shore of Kochi has been increasing by 2 °C in the recent 35 years from 1974 to 2009, which is one of the largest increasing trend in Japan as well as in template climatic zone of the world (Hosokawa, 2013). On 12th August, 2013, the highest air temperature of 41.0 °C in Japan was recorded at Ekawasaki AMEDAS station by Meteorological Agency of Japan (Edahiro, 2013 and Kondo, 2015).

*高知工科大学環境理工学群（〒782-8502 高知県香美市土佐山田町宮ノ口 185）
**三祐コンサルタンツ（〒461-0002 名古屋市東区代官町 35 番 16 号第一富士ビル）
***JA 全国農業協同組合（〒100-6837 東京都千代田区大手町 1-3-1JA ビル）

Tai farm is located in the Kubokawa town at most upper part of Shimanto River which has been listed as the last cleanest river in Japan. There is a typical problem of up-stream and down-stream dimensions in the sustainable water environment conservation of the watershed (**Fig**. 1).

It is a serious creping environment problem for hydroponic culture at warm temperate region in the western Japan, which discharges the deteriorated liquid chemical fertilizer with very high concentration of nutrients (N, P) from the farm into the river system without any treatment (Yamaguchi, 2007).

Fig.1 Location map of Kochi

A new wastewater treatment system with simple technology application is being applied to reduce the concentration of nutrients in the deteriorated liquid fertilizer through the hydroponic culture in the greenhouse. Ecological purification system using aquatic plant of water spinach has been studied to reduce the treatment cost of the deteriorated liquid fertilizer (Dillaha, et al., 1989; Guadagnina, et al., 2005; Stewart, et al., 2008).

Efficient reuse of the deteriorated liquid chemical fertilizer from the greenhouse requires to select the specific vegetable with features of i) high absorbing capacity of nitrogen and phosphorous (Furukawa, et al., 1993), ii) heat-tolerant and iii) salt-tolerant (Nakaso, 2013). This study focuses on the water spinach (*Convolvulus*), which is an herbaceous aquatic or semi-aquatic plant of East Indian origin and a member of the *Convolvulaceae* (morning glory) family to take into account of the economic viability of the hydroponic culture in the region (Chikami 2006).

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The purpose of this study is to evaluate the effectiveness of artificial wetland water purification system with specific aquatic plant of vegetable such as water spinach (*Convolvulus*) by applying the artificial wetland system with hydroponic culture and deteriorated liquid chemical fertilizer.

From the field experiments, water spinach can reduce the significant amount of T-N by 85 % and PO_4-P of 83 %., respectively. Cost and benefit analysis suggests the advantage of hydroponic culture with water spinach to cover the installation and operation and maintenance cost with substantial benefit at B/C ratio of 2.6.

2. Method of field experiments in Kochi Prefecture

2.1 Crop selection and water spinach (*Convolvulus*)

The water spinach was selected to reuse the deteriorated liquid chemical fertilizer.

Water spinach grows anywhere at anytime in the tropics. Optimal temperatures for growth are between 23.9 °C (75 °F) and 29.4 °C (85 °F) and chilling injury can occur below 10 °C (50 °F). It grows all year with regular watering without requiring any maintenance (Frank, 2004).

The plant stems are not strong, but plants grown in beds support each other and produce longer stems with less branching. Leaves are flat, and vary in shape depending on variety, from heart-shaped to long, narrow and arrow-shaped. Narrow leaves are 1-2.5 cm wide and 20-30 cm long. Broad leaves are up to 5 cm wide and 15-25 cm long (**Fig**. 2). Harvest of the entire plant can be made 50 to 60 days after planting (Peter, 2014).

It contains rich vitamins such as five times of vitamin A, twice of vitamin B and C and four times of calcium than the spinach.

Fig. 2 Water spinach (*Convolvulus*),

Water spinach will certainly benefit from the addition of manure and compost. Increasing irrigation can leach out readily available nutrients.

The field experiments of hydroponic culture with water spinach and deteriorated liquid fertilizer have been carried out at Tai farm in Kubokawa town. The farm, which produces eggplant and other vegetables by hydroponic culture in greenhouse, is located at the upper most part of Shimanto River to conserve the clean water quality environment of the river system.

2.2 Method of field experiments of the artificial wetland

A series of water quality monitoring has been carried out from summer to autumn to evaluate the relation between growth character of floating water spinach and change in water quality in the eco-ponds.

The field experiments were performed to apply the artificial and/or constructed wetland method with eco-pond of 0.4 m depth and 1,200 mm x 1,200 mm area. The three eco-ponds were connected by gravity flow to fill up with the deteriorated liquid fertilizer from the greenhouse (**Fig**. 3).

The water quality monitor were carried out to measure the flow discharge, air and water temperature, pH, EC, COD, DO, T-N, PO_4-P, turbidity and Chlorophyll-a at the outlet of deteriorated liquid fertilizer, outlet of pond 3 and river.

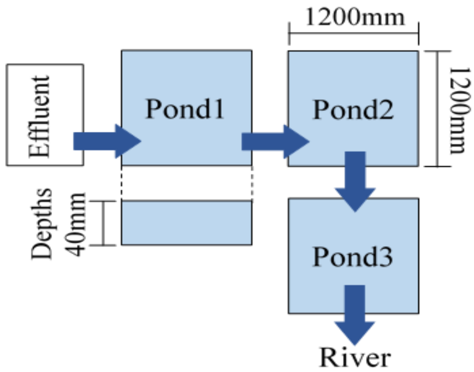

Fig.3 Schematic diagram of eco-pond

Seeds of water spinach which had been germinated in advance were planted in the rock wool box pot in the floating island. The monitoring was carried out from 2nd and 17th September, 1st and 16th October.

3. Results of Field Experiments and Major Findings

3.1 Growth monitoring of water spinach in the eco-pond system

Growth monitoring of water spinach has been performed in the end of summer season from 2nd September to 16th October to measure the growth rate in the different nutrient (T-N and PO_4-P) levels in each eco-pond. The water spinach grows more significant in the upstream ponds 1 & 2 than the downstream pond 3 (**Fig**. 4), depending on the cascading concentration of the nutrients (T-N, PO_4-P) level of the deteriorated liquid fertilizer in each pond.

Fig.4 Growth monitoring of water spinach in the eco-pond system

Monthly average air temperature at AMeDAS Kubokawa station in September, October and November are 23.8 °C, 18.3 °C and 10.6 °C, respectively. The growth rate has a close relation with temperature to die less than 10 °C of daily mean temperature in November.

3.2 Capability of water purification to apply the water spinach

Water quality monitoring of the three eco-ponds water has been carried out in accordance with the growth monitoring, to measure the plant absorption capacity of nutrients in the pond. The influence of precipitation and evapotranspiration in the field is examined to apply the hydro-chemical analysis method (Bowden, 1987) using the metrological station data in Kubokawa town. The more absorption capacity suggests the higher purification capacity of the plant. The water spinach absorbs 68% of nutrient of T-N in the first pond 1 except the beginning two weeks of the 1st period from 3～17 September. Temperature has a direct influence on the absorption capacity and on the productivity (Petrucio, et al., 2000). The reduction rate of T-N decreases significantly after the pond-2 to suggest the minimum requirement of the T-N concentration for the growth is more than 30 mg/L (**Tab.** 1 and **Fig**. 5) (Throop, et al., 1997). Nearly same correlation among the nutrient of PO_4-P and the plant growth is confirmed as shown in **Tab**. 2 and **Fig**. 6.

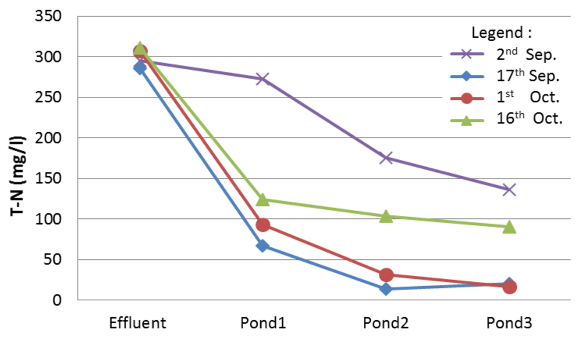

Fig.5 Reduction of T-N in the eco-pond 1~3

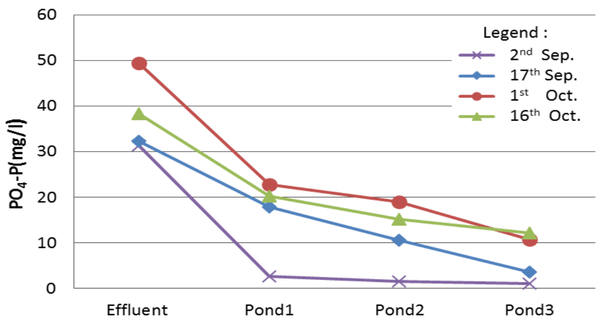

Fig. 6 Reduction of PO_4-P in the eco-pond 1~3

Tab. 1 Mean reduction rate of T-N in each observation period

Observation period		3 ~ 17 Sept. (16days)	18 Sept. ~ 1 Oct. (14days)	2 ~ 16 Oct. (15days)
Daily mean T-N (mg/day)	Wastewater	290	296	309
	Pond 3	62	19	52
Reduction rate (%)		79	94	83

Tab. 2 Mean reduction rate of PO_4-P in each observation period

Observation period		3 ~ 17 Sept. (16days)	18 Sept. ~ 1 Oct. (14days)	2 ~ 16 Oct. (15days)
Daily mean PO_4-P (mg/day)	Wastewater	32	41	44
	Pond 3	2	8	11
Reduction rate (%)		94	80	75

Tab. 3 Mean reduction rate of T-N and PO_4-P in the eco-pond system throughout the period

Reduction rate of T-N (%)	Reduction rate of PO_4-P (%)
85	83

3.3 Major findings

Major findings of the water spinach are i) significant capacity of absorbing the nutrients from the deteriorated liquid fertilizer with T-N of more than 30 mg/L, ii) high purification capacity of reducing 83~85 % of PO_4-P and T-N in the deteriorated liquid fertilizer **(Tab.3)**, iii) close relation with temperature to die less than 10°C of daily mean. It takes one to two months to harvest the water spinach in the summer season, of which the short growing period within two months suggest the economic incentive to the farmers.

4. Concluding remarks

The water spinach, which is a popular nutritious leafy vegetable in south-east Asia, has not been farmed in Japan except Okinawa island with temperate to sub-tropical climate. Pioneering pilot field model study on the purification capacity of water spinach has been initiated at Tai farm and Kochi University of Technology in 2005 to take into account of the significant influence of global warming in the hot spot of Kochi in Japan. The unique application of growing the water spinach in Kochi has soon incorporated in the international technical group training/research programs in JICA(Japan International Cooperation Agency) since 2006 and Science and Technology Research Partnership for Sustainable Development" (SATREPS/JST-JICA) in 2000 .

The nutritious water spinach with good taste grows rapidly under the warm climate in the western Japan and can survive to absorb substantial nutrients (N, P) in the thick deteriorated liquid fertilizer. The application of artificial wetland of eco-pond with floating water spinach is very effective measure to remove the excessive amount of nitrogen and phosphorus in the deteriorated liquid fertilizer by 85% of T-N and 83% of PO_4-P, respectively.

The proposed eco-pond system with floating type of aquatic plant of *Convolvulus* requires low investment and operation and maintenance costs with substantial benefit suggesting B/C ratio of 2.6 at discount rate of 4%. However, the culturing water spinach is confined in summer season in Japan. The watercress, which can grow even in winter season, is being incorporated to sustain the year-round culture in the farm.

The Tai farm has succeeded in commercial farming of the water spinach in 2011 to adapt the influence of global warming in Kochi. It is suggested to develop the sustainable agriculture under the influence of global warming in the western Japan, not only conserving the regional environment but also enhancing the agro-economy in the vulnerable rural community by initiating the adaptation policy of sustainable development with environment-food security perspective.

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