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Treating eutrophic water for nutrient reduction using an aquatic macrophyte (*Ipomoea aquatica* Forsskal) in a deep flow technique system

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ABSTRACT

Wetlands can be used in a cost-effective manner to treat nutrient-rich water for release to freshwater ecosystems. Eutrophic water was treated with the freshwater macrophyte, *Ipomoea aquatica* Forsskal (swamp cabbage), in a horizontal-flow, Deep Flow Technique (DFT) system. Plants were also exposed to a Hoagland and Arnon [Hoagland, D.R., Arnon, D., 1938. The water culture method for growing plants without soil. Calif. Agr. Expt. Sta. Circ., 347] solution using the same exposure system. After a 48-h exposure to the plant, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total suspended solids (TSS) and chlorophyll *a* (Chla) in the effluent were reduced by 84.5, 88.5, 91.1, and 68.8%, respectively, and the removal of nutrients (total nitrogen and total phosphorus) varied between 41.5 and 75.5%. Vitamin C and NO_3-N concentrations in plants grown in the eutrophic water were significantly different from those grown in a standard nutrient solution. Chlorophyll *a*, chlorophyll *a/b* and shoot to root dry weight ratio were not significantly different between the different waters. The concentrations of cadmium, copper, lead and zinc were lower than the permissible levels set by the FAO and WHO for human consumption. The results of this study indicate that cultivating edible, aquatic macrophytes with nutrient-rich, eutrophic water in a DFT system can be an effective, low-cost phytoremediation technology to treat water with undesirable levels of nitrogen and/or phosphorus.

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1. Introduction

The negative impact of excessive nutrients on riverine and palustrine systems, estuaries and coastal waters is recognized as a serious global problem. Nutrients, primarily nitrogen and phosphorus, arise from rapidly expanding urban areas, agricultural and industrial activities. These nutrient inputs can trigger undesirable eutrophication, resulting in unhealthy algal blooms, spreading of certain aquatic macrophytes, oxygen depletion and loss of key species, resulting in widespread degradation of many freshwater ecosystems (Smith et al., 1999). In fact, eutrophication is the most widespread water quality problem in the world (Carpenter et al., 1998). While it is clear that some steps must be taken to significantly reduce the negative impacts of high nutrient inputs to water bodies, the need to maintain required rates of agricultural productivity precludes the possibility of stopping the use of fertilizers altogether. Alternatively, an ecologically-friendly system of reducing inputs and/or treating point and nonpoint source runoff is desirable.

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Aquatic macrophytes can utilize large amounts of nitrogen and phosphorus and thus remove them from the water. Many researchers have investigated the nitrogen and phosphorus removal capacities of different aquatic plants (Hill et al., 1997; Coleman et al., 2001; Lauchlan et al., 2004). Hunter et al. (2001) reported that uptake by *Scirpus validus* removed over 90% of nitrogen and over 74% of phosphorus in a microcosm. Similar experiments have also indicated that aquatic macrophytes were responsible for approximately 90% of nitrogen removal (Rogers et al., 1991). Mavrogianopoulos et al. (2002) found that stem biomass production of the giant reed varied from 12 to 23 kg dm^{-2} yr^{-1} using wastewater from a swine production operation. In the first 2 years of that study, the average uptake rates were 31 and 7.5 g m^{-2} yr^{-1} for total N and total P, respectively, based on stem analyses. Using non-food crops as part of a wastewater treatment system can also have the added benefit of generating materials for the production of biofuels. Jewell (1994) produced substantial biomass by connecting anaerobic treatment of primary sewage with a specialized hydroponic (water as a growth medium) system. The nutrient film technique (NFT) has also been applied to wastewater treatment (Vaillant et al., 2003, 2004).

The cultivation of aquatic, edible vegetables in eutrophic water using existing infrastructures, with only minor modifications, could have substantial economic benefits. In the present study, an edible aquatic plant was used to treat eutrophic water with the deep flow technique (DFT). The DFT is a modified hydroponic culture method, developed and used in Japan since 1973, which requires large quantities of water and nutrients (Ikeda, 1984, 1985). The test plant was *Ipomoea aquatica* Forsskal (known by various common names, including swamp cabbage, water spinach and swamp morning glory). *I. aquatica* Forsskal (Family Convolvulaceae) has a world-wide distribution in tropical and warm regions, including southeastern North America where it is considered an exotic, invasive plant (Hauer and Lamberti, 2006). It is a fast-growing herbaceous vine commonly found creeping along muddy stream banks or floating in freshwater marshes and ponds. The leaves of swamp cabbage are highly nutritious and can be eaten by humans as well as fish and other grazing animals. It is one of the most common vegetables consumed in China. It has been reported that swamp cabbage can be effective in purifying wastewater (Rai and Sinha, 2001; Lin et al., 2004; Cao et al., 2006). In previously conducted studies, the ability of swamp cabbage to remove water-borne nutrients was studied (Hu et al., 2007). Using the information obtained in the earlier research, the current study was designed to (1) examine changes in the nutrient characteristics of eutrophic water with no additional culture substrate using the DFT system and (2) compare the efficiency of removal to a parallel system using *I. aquatica* Forsskal cultivated with an additional nutritive solution.

2. Materials and methods

2.1. Characteristics of the DFT system

The DFT system included PVC (polyvinyl chloride) trays which were 4 m long, 0.15 m wide and 0.20 m deep (Fig. 1). It was modified by Vaillant et al. (2003), and regulated by a flow meter and an electric pump set at a rate of 60 L min^{-1}. The eutrophic water was obtained from the Huajia pool on the campus of the Zhejiang University, China. The physico-chemical characteristics of the water, which receives no industrial influent, are shown in Table 1. Water in the DFT system was renewed every 72 h, and water quality was monitored after 0, 24, 48 and 72 h of treatment. Each treatment was analyzed in triplicate.

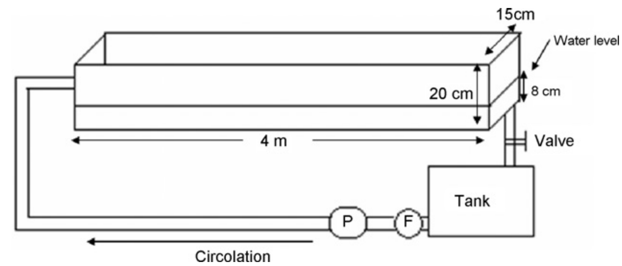

Fig. 1 – DFT system; *I. aquatica* plants were exposed in a 20 cm × 15 cm × 400 cm tray (F is the flowmeter; P is the pump).

2.2. Plant culture

Seeds of swamp cabbage were disinfected with warm water (75–80 °C) for 10 min. The seeds were then soaked for 5–6 h at 30 °C. During this time, viable seeds germinated and the seedlings were transferred to nursery trays containing vermiculite. The seedlings were held at 25–28 °C during the day under ambient sunlight and at 15–18 °C during night. When the seedlings were 5 cm in length, they were transferred to the hydroponic system.

The seedlings, which had a mean shoot length of 12 ± 2 cm and a mean fresh mass of 12 ± 5 g, were placed every 0.15 m in 3.2 cm-diameter holes in a PVC panel. Each DFT cell (4 m long) contained 24 hills of plants, each hill having 12 seedlings. The study included three treatments, with three replicates each: (1) water without plants, (2) water with plants, (3) Hoagland and Arnon (1938) solutions (but no pond water) with plants.

Table 1 – Physio-chemical characteristic of the Huajia pool (eutrophic) water and the Hoagland and Arnon solution

	Huajia pool[a] (mg L^{-1})	Hoagland nutrient solution (mg L^{-1})
TN (mg L^{-1})	2.70	210.15
TP (mg L^{-1})	0.57	30.97
NO_3-N (mg L^{-1})	0.32	196.14
NO_2–N (mg L^{-1})	0.024	/
NH_4–N (mg L^{-1})	2.18	14.01
DP (mg L^{-1})	0.08	30.97
BOD (mg L^{-1})	29.37	/
COD (mg L^{-1})	45.84	/
SS (mg L^{-1})	100.01	/
Chla (μg L^{-1})	49.76	/
pH	8.13	6.5

[a] Mean values (n = 6); (/) not detected.

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