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Effectiveness of *Eichhornia crassipes* in nutrient removal from domestic wastewater based on its optimal growth rate

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ABSTRACT

Water hyacinth (*Eichhornia crassipes*) was used to determine their efficiency in treating domestic wastewater. The wastewater sample was collected from the stabilization pond located at the University Technology Malaysia, and was determined for different parameters like pH, chemical oxygen demand (COD), phosphate (PO_4^{3-}), nitrate (NO_3^-), ammonical nitrogen (NH_3), total organic carbon (TOC), and biomass growth rate. A batch system fabrication was set up which contained 1 kg of fresh plant (*E. crassipes*) and the experiment was run for 21 d in order to correlate nutrient uptake and biomass growth rate. All the parameters were determined according to APHA standard and compared with Interim National Water Quality Standards, Malaysia (INWQS).The phytoremediation treatment of wastewater with water hyacinth showed pH ranging in between 5.3 and 6.3. Moreover, a considerable percentage of reduction was observed in most of the parameters used which included COD, TOC, and NH_3, when compared to the INWQS standard. The capability of these plants in removing nutrients present in the wastewater was successfully demonstrated during this study. The optimum growth period for water hyacinth was found to be 18 d and it is recommended that these aquatic macrophytes should be removed from the water bodies for providing efficient water purification.

Keywords: Biomass growth; Phytoremediation; Stabilization pond; Wastewater treatment; Water hyacinth; Nutrient removal

1. Introduction

In the past decade, application of waste stabilization pond has drawn attention towards treating swine effluent. Both laboratory and field studies have also been established to show the efficiency of water hyacinth plants in treating a wide range of pollutants present in the wastewater [1]. Numerous researchers [2,3] have tested *Eichhornia crassipes*, *Pistia stratiotes*, *Salvinia rotundifolia,and Lemna minor*, and it was found that water hyacinth (*E. crassipes*) showed greater efficiency in the removal of nitrogen and phosphorus. According to Rezania et al. [4], water hyacinth was found to be effective in treating wastewater located near a small stabilization pond with which it can grow efficiently. In aquatic environment, phosphorus

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pollution occurs from the following sources: industry, agriculture, and domestic sewage [5]. *E. crassipes* has been known to support its growth in contaminated or polluted water due to its settlement action and absorption capacity. The higher productivity and growth rate of water hyacinth is one of the most important reasons why it has been used in southern France for the treatment of industrial wastewater [6].

The rapid growth and quick spreading of water hyacinth cause serious problems for navigation, irrigation, and power generation. *E. crassipe*s has drawn worldwide attention so far as harmful weed, and it is also considered to be a non-native, invasive, and free-floating aquatic macrophyte [7]. This plant can double its growth within 5–15 d, and its growth has been already reported by Australia in 1895, India in 1902, Malaysia in 1910, Zimbabwe in 1937, and the Republic of Congo in 1952, with these unique reproduction potentials [8,9]. A population of 655,330 individuals can be produced by 10 plants within the period of eight months [9]. Its rapid reproductive rate and complex root structure enables this plant to form dense and interlocking mats [10].

Optimal plant growth is the best clue for the phytoremediation system to work efficiently. Many environmental factors can influence plant growth and its performance, which includes temperature, pH, solar radiation, and salinity of water. The weight and size of aquatic plants are as a function of these factors. Its growth can be demonstrated by two ways: first by calculating the percentage of water surface covered for a period of time, and second is by means of reporting the plant density in terms of wet plant mass per unit of surface area [9]. Nutrient availability also affects the growth and performance of aquatic plants. Based on Zhao et al. [11], it is found that the average height and total biomass of water hyacinth is found to be significantly increased along with the increasing nutrient level.

Three estimates were predicted for the extraction of nitrogen and phosphorus from nutrient-rich water using water hyacinth under good growth condition, (t/ha/year) [12]. The growth rate of water hyacinth is found to be dependent on the concentration of dissolved nitrogen (N) and phosphorus (P) present in the wastewater [13]. There are many reports for the laboratory and pilot scale study showing the effect of water hyacinth for the removal of organic matter occurring in wastewater [14]. This plant can be also used as a resource for agricultural production and waste management, although it is being considered to be an invasive plant in most of the countries [15]. In this study, the effectiveness of aquatic plant for the removal of nutrients present in domestic wastewater was carried out using locally available species of *E. crassipes* in a fabricated tank located near to the stabilization pond under stable mode of operation, without the interference of rain water.

2. Materials and methods

2.1. Study location and experimental set-up

A pilot pond experimental system was established near to the Desa Bakti River, University Technology Malaysia (UTM), whose location is found to be at the stabilization pond which is being used for the domestic wastewater treatment. The fabrication was made in order to test the efficiency of water hyacinth for the uptake of nutrients present in the domestic wastewater. The system comprised of two tanks with the dimension of (48 × 90 × 90 cm), interconnected through PVC pipes and equipped with electric pump that can pump wastewater directly from the stabilization pond. The holding capacity of the tank was 380 L capacity, to which 1 kg of freshly weighed water hyacinth was added to each of the tanks separately and operated under stable mode (without the flow of wastewater). A separate tank was maintained in presence of wastewater (without water hyacinth) to serve as a control and for identifying the pattern of pollution reduction. The experiments were carried out under a transparent shed made of polyethylene sheet, to prevent the effect on results caused by rainfall as shown in Fig. 1.

2.2. Water quality analysis

All the parameters were investigated and analyzed according to APHA standards, 1992. The sampling of wastewater was carried out once in every 3 d up to 21 d and the data were recorded until the completion of the experiment. The pH was measured using pH meter (Model-Orion 2 star) and TOC was measured with the help of TOC analyzer (Schimadzu comp.). The parameters included the determination of chemical oxygen demand (COD), phosphate (PO_4^{3-}), nitrate (NO_3^-), ammonical nitrogen (NH_3), and total organic carbon (TOC). All the samples were investigated before and after treatment in comparison to the control, and also the rate of biomass growth in terms of water purification was determined.

3. Results and discussion

The results obtained from the different parameters used in this experiment were compared to the Interim National Water Quality Standards for Malaysia

Fig. 1. Fabrication tank for the growth of water hyacinth.

Table 1
Comparison of obtained results with National Water Quality Standards for Malaysia (INWQS)

Parameters	Initial	Final	INWQS (Class IV)
COD	135	2	Less than 100
Nitrate	0.10 mg/L	0.68 mg/L	5
Ammonical nitrogen	6.1 mg/L	0.3 mg/L	0.3 Class IIA
pH	6–7	5–6	5–9
Phosphate	0.53 mg/L	0.16 mg/L	–
TOC	9.75	4.7	–
Biomass weight	1,000 g	1,460 g	–

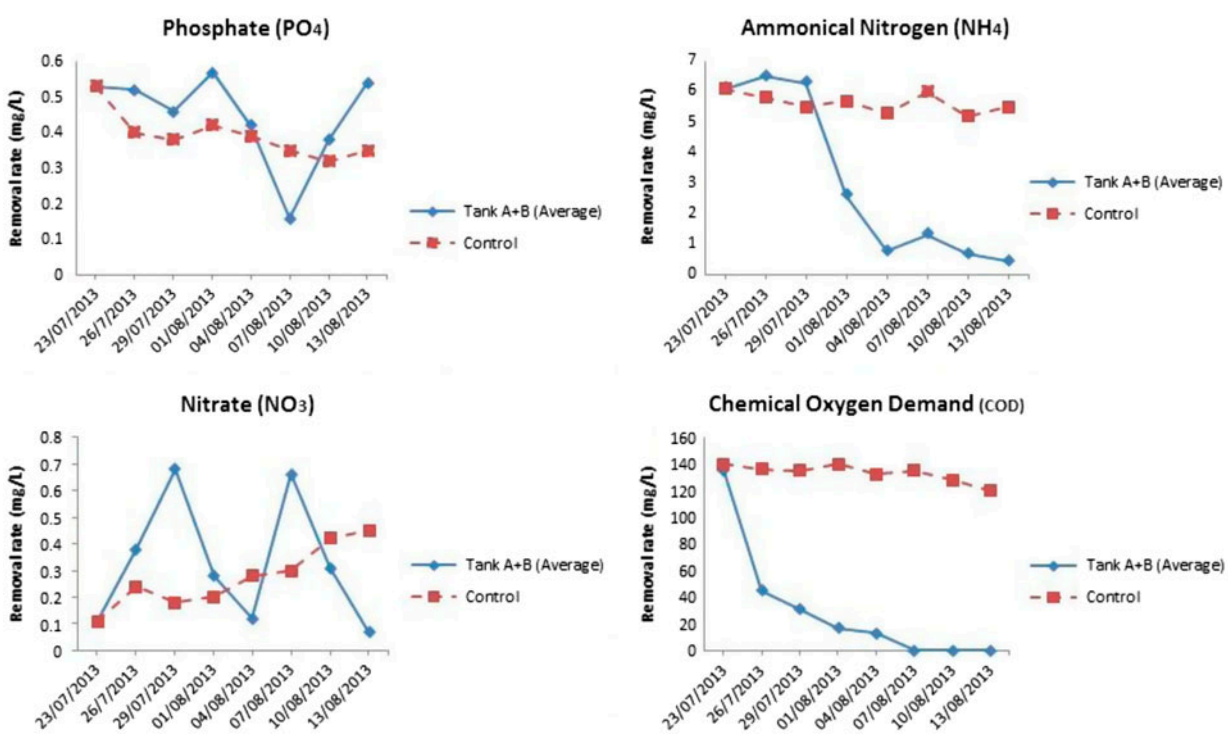

Fig. 2. Phosphate, ammonical nitrogen, nitrate, and COD.

(INWQS) in order to evaluate the water quality. The results obtained for COD, ammonical nitrogen, and pH after treatment were found to match with the standard water quality index, whereas TOC, nitrate, and phosphate did not match with the standards as shown in Table 1. The COD reduction occurred from 135 to 2 mg/L which is considered to be as 95% reduction. Similar type of reduction was observed for ammonical nitrogen (85%) from 6.1 to 0.3 mg/L, according to which the wastewater is classified to be as class IIA when compared to the standard (INWQS). The growth of water hyacinth is mostly dependent on the type of nutrient present in the waste water. In most of the conditions, growth and uptake of nutrient by water hyacinth are also controlled by the source of N (e.g. NH_4^+, NO_3^-, urea, or organic N) [16].

In this study, the presence of phosphate and nitrate did not show significant amount of variation (Fig. 2). The overall nitrate value ranged from 0.10 to 0.66 mg/L and the phosphate value was found to be

Table 2
Percentage reduction for different parameters using water hyacinth

Parameters	Optimum sampling period (d)	Uptake percentage (comparing to control)
Biomass weight	Day 18	46% increase
Phosphate	Day 12	45% reduction
Nitrate	Day 15	Almost four times increase
pH	Day 12	–
Ammonical nitrogen	Day 12	85% reduction
Volume of water reduction	Day 21	60% reduction
Total organic carbon	Day 12	45% reduction
COD	Day 15	95% reduction

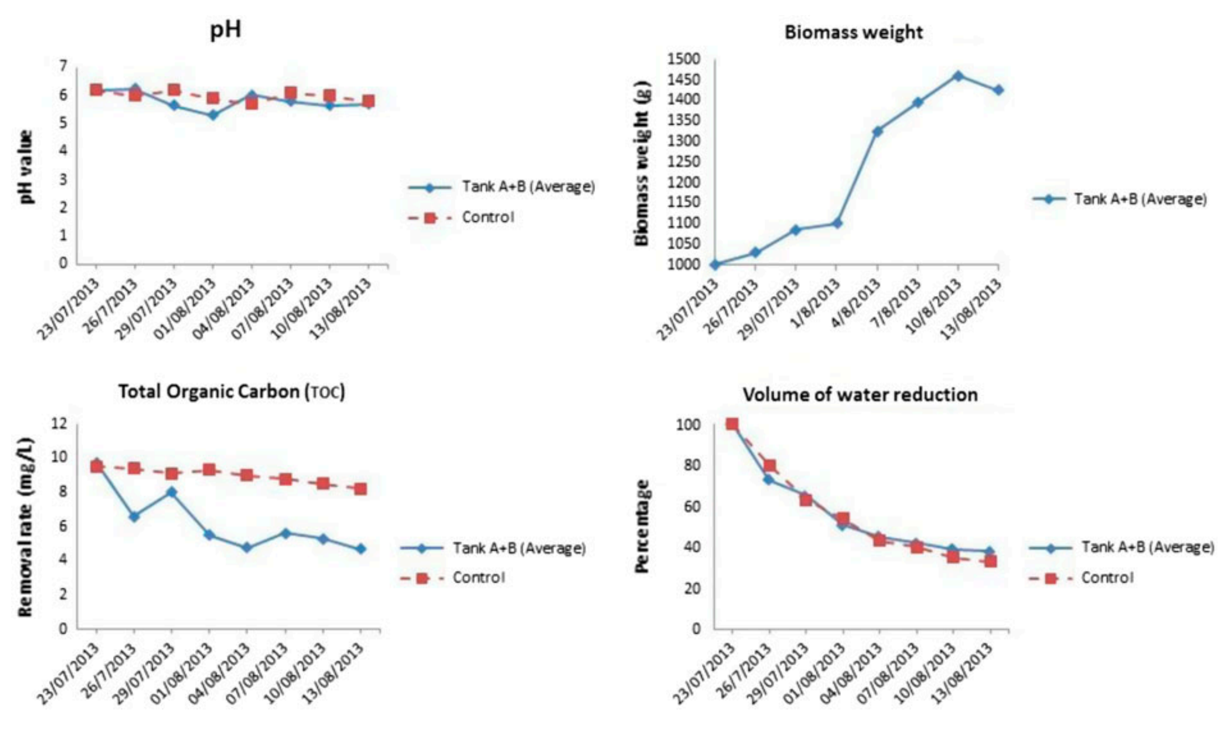

Fig. 3. pH, water reduction, biomass weight, TOC, and volume of water reduction.

in the range of 0.1–0.6 mg/L. The amount of available nitrogen and phosphorus has been considered as one of the most important factors in limiting the growth of water hyacinth [17]. The result of Reddy et al. [18] has shown that survival of water hyacinth requires 5.5 mg of N/L and 1.06 mg of P/L, where maximum growth can be achieved by the addition of N, P, and K (potassium) at the rate of 20 mg N/L, 3 mg P/L, and 52 mg K/L, respectively. In a research carried out by Dixit et al. [19], water hyacinth was grown in a concrete tank at outdoor condition containing sewage effluent. The uptake of P was observed to be as 5.5 mg/g of the plant dry weight for a period of 5 weeks.

TOC results showed significance reduction from 9 to 4.7 mg/L which occurred on day 12 (Table 2), which means that the activities of living organisms or chemicals are becoming less due to the utilization of all the nutrients present in wastewater. It is seen from Fig. 3 that approximately 60% of wastewater evaporation occurred, which is responsible for causing a substantial decline in the volume of wastewater from 380 to 152 L after three weeks of the experimental period when compared to the beginning of the experiment, and the pH was found to be ranging in between 5.3 and 6.3

Table 2 shows that the reduction rate for most of the parameters (TOC, phosphate, pH, and ammonical nitrogen) was on day 12, and for nitrate and COD it is on day 15, during the sampling period. The biomass growth efficiency during the stable mode of treatment consisting of wastewater treatment is based on the increasing weight of biomass form day 1 until the end of experiment, d 21. It was found that the optimal biomass growth obtained was 1,460 g/L at day 18, which is considered to be as 46% increase in the biomass of water hyacinth when compared to the beginning of experiment. Based on the findings of Dixit et al. [19], increase in the weight of water hyacinth was found to be maximum with its total amount of 97 g/m^2 water surface during the first week, which means 45% increase in the weight of the plant was observed.

4. Conclusion

The aquatic plants play a very crucial role in the purification of wastewater. The results of the current study show that water hyacinth (*E. crassipes*) can be employed to remove nutrients present in the wastewater. The phytoremediation treatment with water hyacinth showed reduction in pH, COD, and ammonical nitrogen. It was observed that most of the reduction occurred at day 12 and was found to be associated with the water hyacinth optimal growth rate, which was day 15 as compared to the literature. It was found that the stable mode of operation delayed the water hyacinth optimum growth; however, it did not affect the nutrient removal rate and efficiency from wastewater. Also, based on the results obtained, it can be concluded that correlation occurred between the nutrient uptake (removal rate) and biomass growth rate.

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