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Removal of Turbidity, COD and Coliform Bacteria in Duck-Pond Water by Hydroponic Water Convolvulus Gardening

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Abstract

The objective of this research is to investigate the performance of hydroponic water convolvulus gardening in the removal of turbidity, COD, and coliform bacteria from duck-pond water. The experiment was done using 2 hydroponic gardening sets in the condition of 5-day HRT and 7-day HRT separately for a 42-day operation. The results showed that removal efficiencies were 89.39 ± 7.73% for turbidity and 77.48 ± 11.25% for COD at the 5-day HRT, and were 91.79 ± 6% for turbidity and 75.01 ± 18.41% for COD for the 7-day HRT. And removal efficiencies of total coliform bacteria and E. coli were 87.0 ± 15.3% and 94.5 ± 13.6% for 5-day HRT operation, and 81.5 ± 11.7% and 99.8 ± 0.5% for 7-day HRT operation. According to t-test results at the confidence level of 95%, the system showed no difference in removal efficiencies at both HRTs. The effluent from the systems had turbidity and COD in ranges of 5.52-40.10 NTU and 4.77-81.60 mg/L, respectively which passed the quality standard of effluent from the domestic wastewater treatment. Due to the surface water quality standard, total coliform bacteria and E. coli concentrations of the effluent were in the range of 0-31.8 CFU/100ml which could be used for full-body contact. However, the water convolvulus grown in the hydroponic systems should be well washed and inspected for residual bacteria before eating due to its high level of fecal coliforms (240 to 930 MPN/g).

Keywords : Hydroponic; Water convolvulus; Turbidity; COD; Coliform Bacteria; E. coli

Introduction

It has been the age-long tradition for Thailand to raise ducks in rice-developing regions [1]. As ducks prefer water [2], raising ducks require a pond, and this often conduces duck farmers to a water pollution problem. Due to natural inputs of duck manure, duck food waste, soil, plankton, microorganisms, etc. into the pond, the pond water can become turbid with high Chemical Oxygen Demand (COD) content or even become green in a eutrophication state with high concentrations of nitrogen and phosphorus compounds [3].

Phytoremediation is one of the economical wastewater treatment methods that can feasibly remove pollution from water and soil by cultivating plants [4]. The pollutants, such as organic matter, heavy metals, and certain toxic compounds were removed from wastewater and soil that present around the plant roots through several mechanisms, i.e., phytodegradation, rhizofiltration, phyto-stimulation, phytorestoration, and phytovolatilization, [4]. Lu et al. (2008) observed that water hyacinth planted in their constructed wetland system removed 64.44% of COD, 21.78% of Total Nitrogen (TN), and 23.02% of Total Phosphorus (TP) from duck-farm wastewater [5]. Pongthornpruek (2017) succeeded in removing 61.87-75.36% of COD, 66.11-75.74% of Total Kedah Nitrogen (TKN), 95.18-96.53% of TP from swine wastewater using constructed wetland planted with vetiver grass [6]. Interestingly, water convolvulus, a fast-growing vegetable that can be grown in all regions of Thailand in all seasons with a short harvest time [7] was proven possible to grow and treat sewage at the same time [8, 9]. Fahim et al. (2017) found that water convolvulus planted in floating-bed wetland achieved high performance in the removal of TN and TP with average removal efficiencies of 75.9, and 94.3%, respectively [8]. However, there is a possible disadvantage of applying plants directly in the polluted duck pond as an in situ constructed wetland since dead leaves and roots of the floating plants can fall and accumulate in the bottom of the pond. Recently, several researchers gave a trial to use the hydroponic system, another form of phytoremediation, in wastewater treatment. Nguyen et al. (2018) reported that water convolvulus planted in a pilot-plant hydroponic system can achieve the removal of 65% Suspended Solid (SS), 74% COD, 90% ammonium, 30% nitrate, and 86% phosphate from municipal wastewater [9]. This result suggested hydroponic water convolvulus gardening as a promising method to treat polluted duck ponds as well as to grow water convolvulus for sale. However, the ability of water convolvulus in coliform bacteria removal as well as the amount of residual coliform bacteria in hydroponic water convolvulus is still unclear. Additionally, design criteria, e.g., hydraulic retention time (HRT) for the hydroponic gardening system in wastewater treatment is unidentified. To provide more information for the construction and performance of the hydroponic water convolvulus gardening system, 2 sets of hydroponic water convolvulus gardening systems were constructed in this study. Polluted duck-pond water was applied to the hydroponic systems using 2 different HRTs. The removal of coliform bacteria, turbidity, and COD, as well as the growth of cultivated water convolvulus, were monitored throughout the experiment. The harvested water convolvulus was also analyzed for residual coliform bacteria.

Materials and Methods

Construction of the hydroponic systems

The authors constructed 2 sets of hydroponic water convolvulus gardening systems. Each one system composed of 4 cultivation vessels made from a 5.08-cm diameter pipes with total length of 504 cm. Each cultivation vessel contained 6 holes with 5.5-cm diameter. Therefore, totally 24 holes per 1 set were available for the plant cultivation as shown in Figure 1.

Figure 1 Experimental apparatus

Preparation of water convolvulus

Approximately 300 water convolvulus seeds were wrapped with cloth and put in water for one night. Bad seeds which were floating in the water were then removed. Selected good seeds (1-2 seeds per sheet) were planted in small foam sheets soaked in water and put in the shade at room temperature. After 5 days the seedlings were ready to plant in the hydroponic system.

Experimental setup

Each hydroponic gardening set contained 12-L duck-pond water which was loaded into 50-L tank and circularly pumped up to the 4 cultivation pipes (100% recirculation all days and nights) before being collected and released at the end of each HRT cycle. This setting provided HRT of 5 days for the 5-d HRT hydroponic set, and 7 days for the 7-d HRT hydroponic set.

Five water convolvulus seeds were put inside sponges (2×2 cm) before placing them inside each hole of the gardening systems.

System operation

On the 1st day of each operation cycle, raw duck-pond water samples were collected and analyzed for turbidity, COD, and coliform bacteria. At the end of each operation cycle, i.e., day 5th for the 5-d HRT hydroponic set, day 7th for the 7-d HRT hydroponic set, treated duck-pond water samples were collected at the 50L-tank using grab sampling method and analyzed for turbidity, COD, and coliform bacteria. Stem length, root length, and weight of water convolvulus inside each hole were also measured on every sampling day to confirm the viability of the plants. Water convolvulus plants were harvested at the end of the experiment which was day 42nd when the 5-d HRT hydroponic set completed 8 operation cycles and the 7-d HRT hydroponic set completed 6 operation cycles. The whole surviving plants including roots, stems and leaves were collected for the residual bacteria analysis.

Analytical methods

Water samples were analyzed according to verified methods, i.e. Nephelometry [10] for turbidity analysis, Closed reflux, titrimetric method [11] for COD analysis, Compact dry EC method [12] for total coliform bacteria, and Escherichia coli (E. coli) analysis in the unit of CFU/100ml. Additionally, the Presumptive test stated in Bacteriological Analytical Manual (BAM) [13] was used for fecal coliform analysis in the unit of MPN/100ml. Wastewater treatment capability of the hydroponic gardening sets was considered from removal efficiencies calculated by equation (1) where C_0 is pollutant concentration (turbidity, COD, total coliform bacteria, E. coli) in raw duck-pond water and C is pollutant concentration in treated duck-pond water. Paired two-sample Student's t-Test with one-side 95% confidence interval was used for removal- capability comparison between the 7-d- HRT hydroponic set and the 5-d HRT hydroponic set.

$$\% \text{ removal} = (C_0 - C) \times 100 / C_0 \qquad (1)$$

Results and Discussions

Turbidity removal efficiencies

The result revealed that both hydroponic gardening sets can treat raw duck-pond water. For a 5-d HRT hydroponic set, turbidity values of 121.30-395.00 NTU in raw duck-pond water reduced to 10.28-40.10 NTU at the end of the operation cycles as shown in Figure 2. Turbidity removal efficiencies ranged from 70.94 to 94.94% with the mean ± standard deviation of 89.39 ± 7.73%.

In the case of the 7-d HRT hydroponic set, turbidity values of 94.70-424.00 NTU in raw duck-pond water were reduced to 5.52-24.8 NTU at the end of the operation cycles as shown in Figure 3. Turbidity removal efficiencies ranged from 80.64 to 96.86% with the mean ± standard deviation of 91.79 ± 6.00%. According to the t-test result, turbidity removal efficiencies of the 2 hydroponic sets were not significantly different (P-value = 0.109).

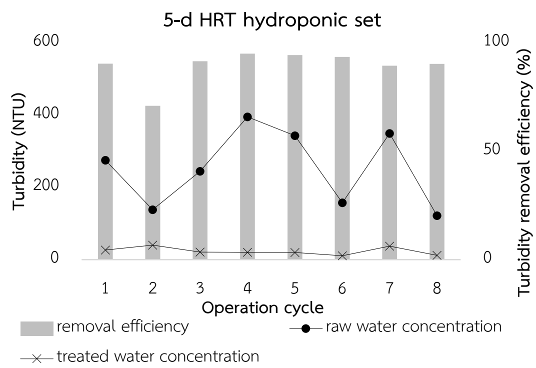

Figure 2 Turbidity concentrations and removal efficiencies of 5-d HRT hydroponic set

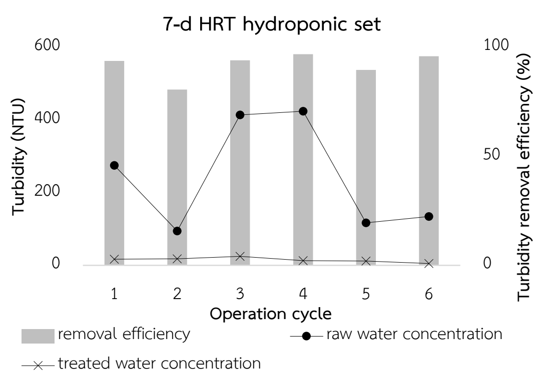

Figure 3 Turbidity concentrations and removal efficiencies of 7-d HRT hydroponic set

Turbidity removal in this study probably occurred due to the clinging of colloidal and suspended solids onto the water convolvulus root. Sedimentation [9] at the bottom of the hydroponic pipes, and biodegradation [9] of the bacteria living on the surface of water convolvulus root were also possible.

COD removal efficiencies

For COD treatment, the 5-d HRT hydroponic set was able to reduce COD concentrations from 85.88-159.12 mg/L to 4.77-50.22 mg/L as shown in Figure 4 with COD removal efficiencies ranging from 64.51 to 97.00% while the 7-d HRT hydroponic set was able to reduce COD concentrations from 112.00-190.08 mg/L to 9.08-81.60 mg/L with COD removal efficiencies ranged from 40.51 to 95.22% (77.48 ± 11.25%) as shown in Figure 5.

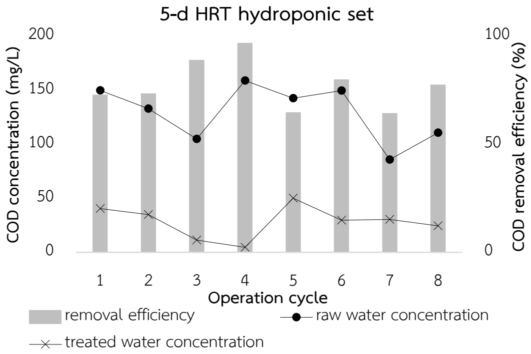

Figure 4 COD concentrations and removal efficiencies of 5-d HRT hydroponic set

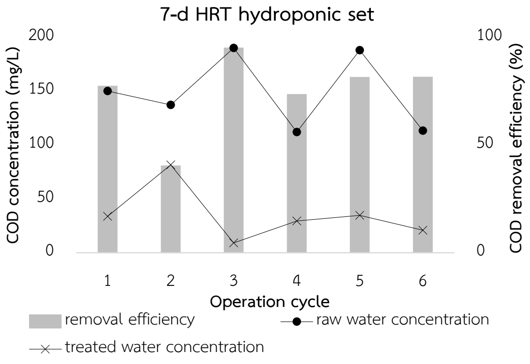

Figure 5 COD concentrations and removal efficiencies of 7-d HRT hydroponic set

The main COD removal mechanism in this study should be the organic-matter degradation caused by microbes living on the surface of water convolvulus root as suggested by Nguyen et al. (2018) [9]. Comparing mean COD removal efficiencies of the 5-d HRT hydroponic set (77.48 ± 11.25%) with the 7-d HRT hydroponic set (75.01 ± 18.41%) based on the t-test result (P-value = 0.342), there was no significant difference between both sets.

Bacteria removal efficiencies

As shown in Figure 6-9, both hydroponic gardening sets were able to reduce total coliforms bacteria and E. coli.

For total coliforms bacteria (Figure 6-7), the concentrations of 127-709 CFU/100ml were reduced to 0-75.23 CFU/100ml with removal efficiencies between 55.49 and 100% (87.0 ± 15.3%) for the 5-d HRT hydroponic set.

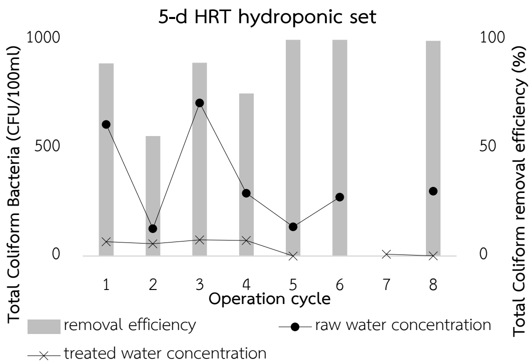

Figure 6 Total coliforms bacteria concentrations and removal efficiencies of 5-d HRT hydroponic set

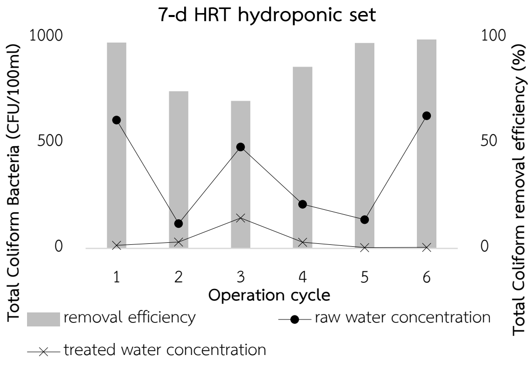

Figure 7 Total coliforms bacteria concentrations and removal efficiencies of 7-d HRT hydroponic set

In the 7-d HRT hydroponic set, total coliforms bacteria of 118-630 CFU/100ml were reduced to 3.33-144.71 CFU/100ml with removal efficiencies ranging from 69.98 to 99.21% (81.5 ± 11.7%). The t-test results showed no significant difference in total coliform removal efficiencies between both hydroponic sets (P-value = 0.321).

For E. coli reduction, concentration values of E. coli in untreated water were in ranges of 64-713 CFU/100ml (Figure 8) and 73-499 CFU/100ml (Figure 9) which were reduced to 0-31.8 CFU/100ml and 0-5.11 CFU/100ml by 5-d HRT hydroponic set and 7-d HRT hydroponic set, respectively. E. coli removal efficiencies, in this case, ranged from 61.22-100% (94.5 ± 13.6%) for the 5-d HRT hydroponic set and 98.66-100% (99.8 ± 0.5%) for the 7-d HRT hydroponic set. However, the t-test results (P-value = 0.196) indicated no significant difference between both sets.

The decline of bacteria after being treated by the hydroponic systems could occur due to natural UV radiation during the experiment, attachment or adherence of bacteria such as E. coli on roots of the plants or biofilms formed on the plant material [14], antimicrobial compounds produced by roots of aquatic plants which reduce the survival of pathogens [14], oxygen supplied through roots of aquatic plants which is crucial for the activity and metabolism of microorganisms such as bacteria, and viruses [14].

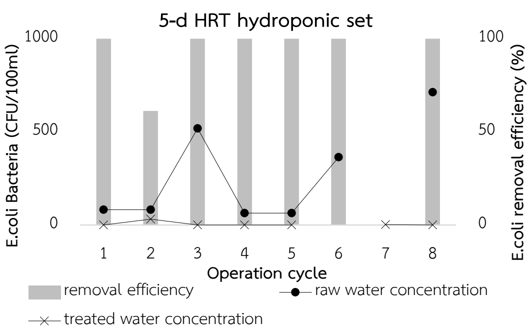

Figure 8 E. coli concentrations and removal efficiencies of 5-d HRT hydroponic set

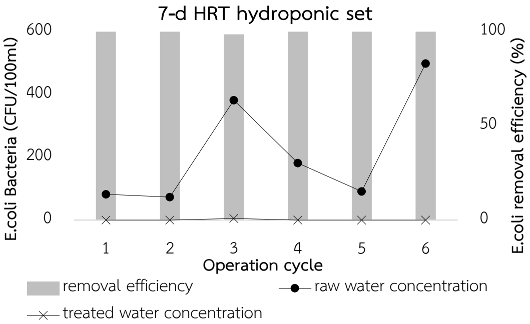

Figure 9 E. coli concentrations and removal efficiencies of 7-d HRT hydroponic set

Since mean concentrations of E. coli in treated water of both hydroponic sets were 4.8 ± 11.0 CFU/100ml and 0.85 ± 1.9 CFU/100ml which were less than 126 CFU/100ml, the suitable level for full-body contact defined in Bacterial Water Quality Standards for Recreational Waters of USEPA (EPA-823-R-03-008) stated in the work of Sanders et al. (2013) [15], the hydroponic systems could be one of the possible methods for water reclamation.

On the last day of the operation, fecal coliforms were detected in the treated water samples, i.e., 13 MPN/100ml for the 5-d HRT hydroponic set and 17 MPN/100ml for the 7-d HRT hydroponic set. Based on these fecal coliform concentrations and Thailand surface water quality standards [16], the treated water can be classified as a category 2 water resource that was allowed to be used for fisheries and water sports.

It was noted that the standard deviations of removal efficiencies derived in this study varied between 0.5% and 15% in spite of the large fluctuation of raw water quality. This result implied stability of the hydroponic sets for wastewater treatment.

Plant growth

Plant growth (Figure 10-12) was monitored through three parameters including plant height, root length, and plant weight. As shown in Figure 10-11, the growth of water convolvulus mostly increased due to the operation time in both hydroponic sets.

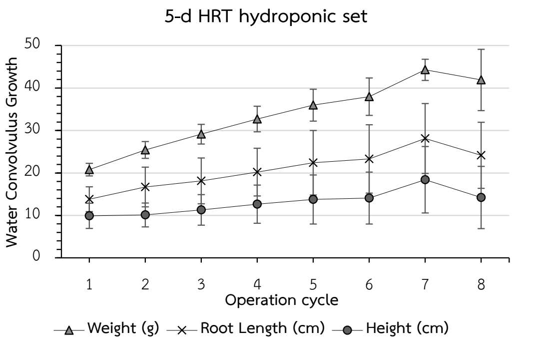

Figure 10 Water convolvulus growth at 5-d HRT hydroponic set

In the case of a 5-d HRT hydroponic set, average plant heights ranged from 3.92 to 9.95 cm; mean values of plant roots length ranged from 9.91 to 18.40 cm, and plant weights ranged between 6.95 and 17.94 g. The decrease of plant growth from the 7th to 8th operation cycle occurred due to the rot on plants. For the 7-d HRT hydroponic set, the mean values of plant heights were 10.75-19.95 cm, average root lengths were 9.88-17.93 cm and plant weights were 6.95-17.74 g.

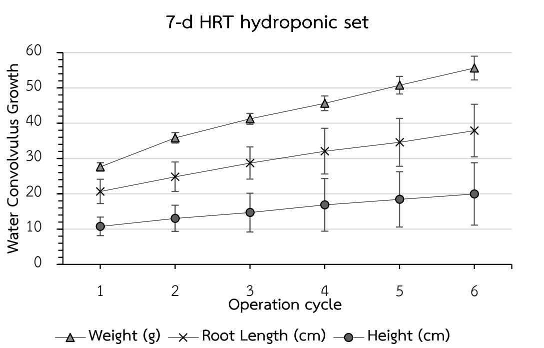

Figure 11 Water convolvulus growth at 7-d HRT hydroponic set

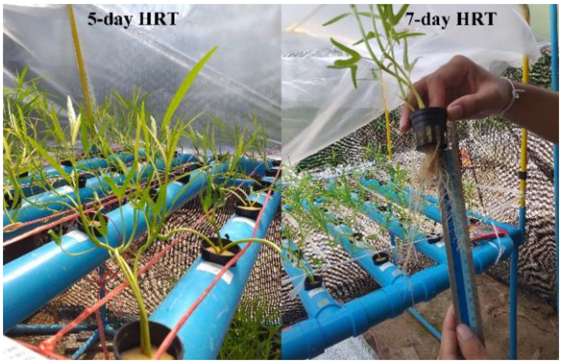

Figure 12 water convolvulus plants during the operation

According to the t-test result, the mass of water convolvulus grown in the 7-d HRT hydroponic set was significantly greater than that of the 5-d hydroponic set (P-value = 0.0224).

Residual coliform bacteria in water convolvulus

Total coliform bacteria, which all were fecal coliforms, were detected in water convolvulus plants grown in the hydroponic sets. With the fecal coliforms of 240 MPN/g for the 5-day HRT set, and 930 MPN/g for the 7-day HRT set exceeded the recommended levels by WHO and International Commission on Microbiological Specifications for Food (ICMSF) standards (10-100 coliforms/g, 10 fecal coliforms/g) [17], the harvested water convolvulus plants were considered not ready to eat. Well-washing followed by the inspection of residual bacteria is required for good hygiene before cooking or sending the vegetable for sale.

Conclusion

By circulating duck-pond water in hydroponic water convolvulus gardening sets at hydraulic retention time (HRT) of 5 and 7 days, turbidity, COD, and coliform bacteria in the water were removed. The removal efficiencies were 89.39 ± 7.73% for turbidity, 77.48 ± 11.25% for COD, 87.0 ± 15.3% for total coliform bacteria, and 94.5 ± 13.6% for E. coli at the 5-day HRT operation. In terms of 7-day HRT operation, the efficiencies were relatively high, i.e. 91.79 ± 6% for turbidity, 75.01 ± 18.41% for COD, 81.5 ± 11.7% for total coliform bacteria 69.98-99.21%, and 99.8 ± 0.5% for E. coli. However, no significant difference between removal efficiencies of 7-day HRT operation and 5-day HRT operation was approved by statistical analysis. The effluent quality of both hydroponic systems showed 5.52-40.10 NTU turbidity and 4.77-81.60 mg/L COD which passed the quality standard of effluent from the domestic wastewater treatment. In the viewpoint of bacterial contamination, the effluent from the 2 systems with E. coli of 0-31.8 CFU/100ml satisfied the water quality standard for full-body contact. However, the water convolvulus plant grown in the hydroponic systems were not ready to eat due to their high level of fecal coliforms (240 to 930 MPN/g) which exceeded the acceptable level (10 MPN/g). Based on these findings, hydroponic gardening at a 5-day or 7-day hydraulic retention time is not only the method for growing vegetables, such as water convolvulus plants but also the cost-effective method for wastewater treatment which duck farmers can easily install and operate in their farms. For pilot-scale operation, the farmers can install a long-pipe hydroponic system near or surrounding their duck ponds. The duck-pond water should be directly pumped up and continuously feed to the hydroponic system using a low flow-rate water pump to arrange the sufficient HRT. The effluent of the system can be directly discharged to the duck pond. Better water quality of the duck pond could be expected during a long operation period. However, the aspect of bacterial contamination in harvested vegetables is still left for further improvement.

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