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# Nutrient removal from aquaculture wastewater by vegetable production in aquaponics recirculation system

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**ABSTRACT**

Nutrient removal is essential for aquaculture wastewater treatment to protect receiving water from eutrophication and for potential reuse of the treated water. The integration of aquaculture with agriculture appears to be an excellent way of saving water, disposing aquaculture wastewater and providing fertilizer to the agricultural crop. The study was conducted to evaluate aquaponics recirculation system (ARS) performance in removing inorganic nitrogen and phosphate from aquaculture wastewater using water spinach (*Ipomoea aquatica*) and mustard green (*Brassica juncea*). The results showed that water spinach was able to significantly reduce the total ammonia nitrogen, nitrite-N, nitrate-N and orthophosphate with efficiencies of 78.32–85.48%, 82.93–92.22%, 79.17–87.10%, and 75.36–84.94%, respectively, compared to mustard green that removed the nutrients in the range of 69.0–75.85% for total ammonia nitrogen, 72.49–79.34% for nitrite-N, 66.67–80.65% for nitrate-N, and 66.79–77.87% for orthophosphate. Overall results suggest that water spinach is better than mustard green in nutrient removal in the aquaponics system used due to its root structures provided more microbial attachment sites, sufficient wastewater residence time, trapping and settlement of suspended particles, surface area for pollutant adsorption, uptake, and assimilation in plant tissues.

*Keywords*: Aquaponics recirculation system; Aquaculture wastewater; Nutrient removal; Mustard green; Water spinach

## 1. Introduction

The intensive development of the aquaculture industry has been accompanied by an increase in environmental impact. The production process generates substantial amounts of polluted effluent, containing uneaten feed and feces [1]. Discharges from aquaculture into the aquatic environment contain nutrients, various organic and inorganic compounds such as ammonium, phosphorus, dissolved organic carbon and organic matter [2,3]. The high levels of nutrients cause environmental deterioration of the receiving water bodies. In order to produce 1 kg live weight fish one needs 1–3 kg dry weight feed (assuming a feed conversion ratio about 1–3) [4]. About 36% of the feed is excreted as a form of organic waste [5]. Around 75% of the feed nitrogen and phosphorus is unutilized and remain as waste in water [2,6]. Depending on the species and culture technique, up to 85% of phosphorus, 80–88% of carbon and 52–95% of nitrogen input into a fish culture system may be lost to the environment through feed wastage, fish excretion, fecal production and respiration [7].

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Remediation of aquaculture effluents is important because, in many areas, water is a limited resource and depending on the receiving water body, the total mass loading of nutrients from effluents can contribute to significant environmental degradation [8]. Aquaponics, also known as the integration of aquaculture with hydroponics is gaining increased attention as a bio-integrated food production systems. The primary goal of aquaponics is to reuse the nutrients released by fish to grow crop plants [9]. Integrated culture systems promote nutrient recycling and aquaculture-agriculture yields so they are more environmentally sustainable than most traditional farming practices, which have resulted in widespread soil erosion, desertification and pollution in Asia [10]. The success of such systems must however depend ultimately on their profitibility. Most systems separate fish faeces as quickly as possible to reduce the nutrient load in the recirculation aquaculture system to enhance nitrification performance and to reduce clogging of plant roots, which could lead to loss of crop productivity [11].

Aquaponics system has been examined over the past three decades with a wide variety of system designs, plant and aquatic animal species, and experimental protocols efficiencies [12–19]. Most results showed efficient use of resources, reduction in the risk of total crop failure, additional sources of food, extra income and reduction of operation costs for farmers than fish culture alone. Although it appeared that ARS really show an ingenious diversity and respectable efficiency especially in ability to control water quality parameters and environmental conservation, however, they are not always successful and popular in expected regions. The undesirable results and low public acceptance of products has led to a significant decrease in the efficiency and importance of integrated culture farming. Basic problem in such system may arise from the discrepancy between productive compartments and unoptimized intensity of the plant and fish species in the system. Poor quality of water and mineral toxicity are two problems in fish production, especially in early stage of life cycle. In fact, very little information is available on the concentration limits of nutrient elements at which deficiency or toxicity occurs in the integrated culture systems. As a result of extensive research work on this systems in the past decade, the technical knowldge on practiced systems has considerably improved and socio economical studies also implemented in these areas. Recent advances by researchers [18–20] alike have turned aquaponics into a working model of sustainable food has the potential to fill an entire world's requirements for premium quality food stuffs, it can produce staples for a small community or village in a developing country.

Commercial aquaponics is the youngest sector of agriculture to date, though it is far from being unproven, and the development of newer technology in this field is progressing by leaps and bounds around the world. Nutrients can be maintained at concentrations sufficient for hydroponic plant culture [21]. Theoretically, the nutrient content of a diet can be manipulated to make the relative proportions of nutrients excreted by fish more similar to the relative proportions of nutrients assimilated by plants. With such a diet, there would exist an optimal ratio of fish to plants and optimal nutrient concentrations could be maintained over prolonged periods without nutrient supplementation. This study was conducted to evaluate (a) the efficiency of two food crops in purifying the wastewater from aquaculture operation, and (b) the effect of seed quantity on fish and plant production performances. The need for the study arises due to the growing demand for food and environmentally safe removal of wastewater. From the presented data, this paper will extrapolate and speculate on viability of two food crops species in biological nutrient removal processes and their potential application for wastewater treatment onsite and for small sized communities.

## 2. Materials and methods

### *2.1. Experimental procedure*

The water spinach seedlings were directly sown of two seeds per hole with evenly spaced at 5–8 cm apart. Seeds of mustard green were sown in plastic basin that were 5–6 cm deep containing silica sand. The plants were watered manually two times daily. Mustard green plants were transferred to the aquaponics system when the plant height is about 4–6 cm. The amount required to cover the surface of hydroponic trough was approximately 20 g for each plants. Therefore three different quantities of seeds (15 g, 20 g and 25 g) were tested to determine the effect of seed quantity on plant and fish growth as well as nutrient percentage removal. The experiment was conducted in triplicate and one trough was utilized as control and contained gravel only. The study was carried out in a newly built insulated greenhouse, in which environmental conditions were recorded but not controlled and only natural light was used during the period of study. Technical details of design, operational characteristics and sample analyses of ARS were described in Endut et al. [20].

African catfish (*Clarias gariepinus*), initial mean individual weight 30 g, was used to generate the wastes for this study. Final density was set at about 42 $kgm^{-3}$, with estimated an initial total fish biomass about 6 kg. Two types of catfish food pellets, manufactured by Cargill Company, of known nutrient content were used. The main differences between the two types of pellets were in terms of crude protein contents and pellet sizes. However, other components such as lipid, fibre, ash and carbohydrate were at about similar levels. The fish were hand fed initially with 3.2 mm commercial diet floating pellet (32% protein) at 3% of body weight. The food size was adjusted to compensate for changes in fish size.

Larger pellet size and a lower crude protein level (28% by weight) was appropriate for the larger fish. During the experiment, all leftover feed, wastes and dead fish in each tank were removed and recorded.

### *2.2. Monitoring and data collection*

The key variables of interest in this study are plant growth and yield, fish growth and yield as well as water quality parameters in recirculation system. A monitoring program of the aquaponics recirculation system began one week after planting in order to allow the vegetation and biofilm to be established. The monitoring was carried out for a period of three months for each plant. The water flow rate was set at a rate of 2.84 L $min^{-1}$ (HLR = 1.28 m/d). Wastewater flow rates were adjusted manually at the inlet of culture tank using 24 mm gate valves and measured using a measuring cylinder and stopwatch. Sprinklers technique was used to irrigate the plants in the troughs.

During the germination period, seed germination and seedling height were observed and recorded daily. Effluent samples were collected from each trough once a week and stored in a fridge (at 4°C) in a labeled bottle for chemical analyses. During the growth period, the height, leaf length and leaf width of 20% of plant sample in each troughs were measured and recorded daily. The plants were harvested at height ranging from 45 to 50 cm. Each growing troughs was cleaned and the biomass of plants was measured and recorded.

Fish food input and mortality data were recorded daily. Satiation feeding was employed in the first day of each sampling period for adjusting the amount of food offered to percent of body weight per day. 20% of fish randomly selected per tank were weight every fortnight in order to estimate mean fish weight, fish production, and to adjust feeding levels accordingly. The following production parameters were determined according to the procedure of Ridha and Cruz [22] as follows:

Specific growth rate (SRG)

$$= \frac{(\ln \text{mean final weight} - \ln \text{mean initial weight})}{\text{Culture period (d)}} \times 100 \quad (1)$$

Daily growth rate (DGR)

$$= \frac{\text{Final weight (g)} - \text{Initial weight (g)}}{\text{Culture period (d)}} \quad (2)$$

Feed conversion ratio (FCR)

$$= \frac{\text{Total weight of dry feed given (g)}}{\text{Total wet weight gain (g)}} \quad (3)$$

Thereafter, weekly water quality analysis was performed on both the influent and effluent water from each treatment system. Water samples were tested for total ammonia-nitrogen (TAN), nitrite-nitrogen ($NO_2$-N), nitrate-nitrogen ($NO_3$-N), and orthophosphate (OP) concentration by the Nessler Reagent, diazotization, cadmium reduction and asid ascorbic methods, respectively. All samples were first filtered with a fibre glass filter (Whatman paper) with a pore size of 0.45 μm before analysis. The resulting solutions were analysed using a Hach DR/4000 spectrophotometer. Removal efficiency was calculated for the above variables using the following equation:

$$\text{Removal efficiency (\%)} = \frac{\text{Influent} - \text{Effluent}}{\text{Influent}} \times 100 \quad (4)$$

The DO and pH of the samples were measured using DO meter YSI 550A and pH Cyber Scan Waterproof, respectively.

### *2.3. Statistical analysis*

Fish production performances, plant growth and nutrients removal were determined and expressed as mean ± standard deviation. Data analyses were performed using statistical package for the social sciences (SPSS), Version 16 with an alpha set at 0.05 (significance at $P < 0.05$). Mean values of fish production performances, plant growth rate, plant yield, and nutrient removal between treatments were tested with two-way ANOVA. If there were significant differences at significant level 0.05, then Duncan multiple comparison test was used to compare means in order to identify significant difference between treatments.

## 3. Results and discussion

### *3.1. Plant growth and yield*

#### *3.1.1. Plant growth*

After 3 and 6 days, the radicles of water spinach (*Ipomoea aquatica*) and mustard green (*Brassica juncea*), respectively had broken through the seed coat and were visible on 70–80 % of the seeds. During the germination period, the plant seedlings in all growing troughs grew rapidly and fairly uniform and appeared healthy with green in color. At the end of the germination period, the water spinach plants were approximately 4.0 cm height. The plants continued to grow rapidly and showed the same positive response to wastewater applications. Both of the plants in all replicates grew quickly and seemed healthy, with no signs of any nutrient deficiency syndromes or toxic effect during the growth period. At the end of the growth period, the water spinach and mustard green plants reached the market size of 45–50 cm and 30–35 cm, respectively. Results of plant growth in terms of plant height for both crops are shown in Fig. 1.

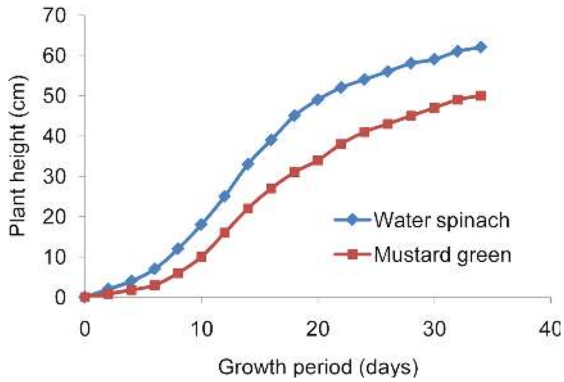


Fig. 1. Average plant growth.

### 3.1.2. Crop yield

Plant growth is another criterion on which to correlate the suitability or efficiency of aquaponics recirculation system. Fig. 2 shows the above ground biomass of water spinach and mustard green during the growth period. The average crop yields at harvest ranged from 1.45 to 1.85 kg/trough and 1.71 to 2.50 kg/trough for mustard green and water spinach, respectively depending on the seed quantity.

Table 1 displays the relationship of seed quantity for the crops, their rates of growth and plant production. Water spinach (*Ipomoea aquatica*) was more productive with an average in wet weight of 2.14, kg per harvest, compared to 1.64 kg per harvest for the mustard green (*Brassica juncea*).

The average growth rate was 1.91 and 1.32 cm/d for water spinach and mustard green, respectively. Two-way ANOVA did not detect significant differences in plant height or the plant growth rate between the seed quantity (15, 20 and 25 g/trough) for both crops ($P = 0.072$ and $P = 0.125$ for mustard green and water spinach, respectively). This study corroborates the finding of Snow and Ghaly [19], which found that seed quantity did not has any effect on average crop height. However, both crops yield were significantly influenced ($P = 0.000$) by the seed quantity. The 25 g of seeds per trough produced the highest crops yield. The higher the seed quantity the higher the crop yields.

(a) Mustard green

(b) Water spinach

Fig. 2. The biomass of crops during growth period: a) mustard green; b) water spinach.

## 3.2. Fish growth and yield

### 3.2.1. Fish feeding and growth

Results of fish growth in terms of fish average weight for both crops are shown in Fig. 3. Daily feeding rate increased with culture time and accounted for 3–4% of fish body weight.

The trend of fish weight increment showed a similar

Table 1
Average crops yield at harvest by seed quantity

| Seed quantity (g) | Water spinach | | Mustard green | |
|---|---|---|---|---|
| | Average growth rate (cm/d) | Crop yield (kg/m$^2$/month) | Average growth rate (cm/d) | Crop yield (kg/m$^2$/month) |
| 15 | 1.92[1] | 1.71[1] | 1.33[1] | 1.45[1] |
| 20 | 1.92[1] | 2.20[2] | 1.32[1] | 1.63[2] |
| 25 | 1.90[1] | 2.50[3] | 1.31[1] | 1.85[3] |
| Average | 1.91 | 2.14 | 1.32 | 1.64 |

Treatments with different numbers in the same column are significantly different at $P < 0.05$ level.

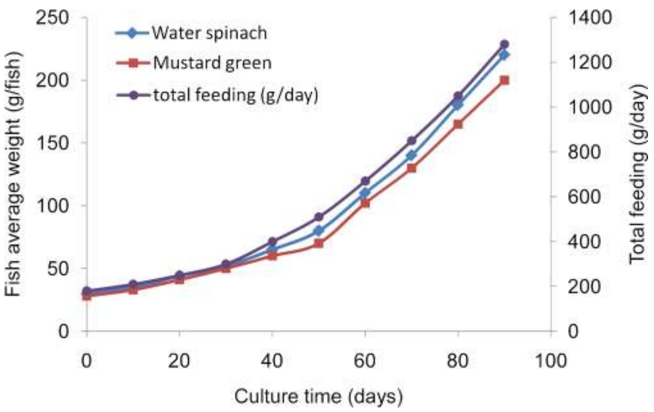


Fig. 3. Time courses of fish average weight and total feeding.

pattern for both crops. Fish successfully grew in the culture tank with a maximum growth rate of 3.57 g/d, which were occurred between days 70 and 80. Slight decrease in average weight was observed between days 40 and 50 probably due to the change of feeding pellet. Water spinach exhibited a significantly lower value in FCR as compared to mustard green.

### 3.2.2. Fish production performance

The fish production performance was evaluated in terms of SGR, DGR, FCR and survival rate. The values of SGR, DGR, FCR, survival rate and fish biomass for three treatments (15 g, 20 g, and 25 g) for both crops are tabulated in Table 2.

During the initial stages of the study, a few mortalities occurred. These were then replaced by similar sized of fish. The overall survival rate was about 94% and mortality would be due to the natural death and to the manipulations during the weekly samplings. In all treatments, fingerlings did not exhibit cannibalism during this experiment. No significant differences ($P > 0.05$) were observed when comparing fish production performances with various seed quantities for SGR, DGR, FCR, survival rate and fish biomass for both crops. This suggests that none of the amount of seed quantity tested in this study had a deleterious effect on fish growth or survival.

### 3.3. Water quality parameters

Table 3 shows the average percent removal by seed quantity. The values are the average of three measurements.

The greatest mean reductions of 85.84%, 92.22%, 87.10% and 84.94% for TAN, nitrite-N, nitrate-N and orthophosphate, respectively were found in troughs planted with 25 g seed of water spinach. Statistically, there were significant differences in percent removal between seed quantity of the water spinach and mustard green for TAN ($P < 0.05$), nitrite-N ($P < 0.05$), nitrate-N ($P < 0.05$) and orthophosphate ($P < 0.05$).

ARS essentially comprises self-contained artificially engineered wetland ecosystems. It utilizes particular combinations of plants, gravels, bacteria, substrates, and hydraulic flow systems to optimize the physical, chemical, and microbiological processes naturally present in the root zone. Biological nutrient removal is possible due to the special characteristics of hydroponic plants, such as water spinach, which transfer substantial amounts of atmospheric oxygen through their root systems. Additionally, roots, through their growth provide an attachment surface for microbial communities, which is the main function of plants in hydroponics system. These are needed for the effective breakdown of many types of compounds, such as the oxidation of ammonia to nitrate - the first step in the biological breakdown of this compound.

Table 2
Fish production performance by seed quantity

| Fish production performance | Water spinach | | | | Mustard green | | | |
|---|---|---|---|---|---|---|---|---|
| | Seed quantity (g) | | | *P* value ($\alpha$ = 0.05) | Seed quantity (g) | | | *P* value ($\alpha$ = 0.05) |
| | 15 | 20 | 25 | | 15 | 20 | 25 | |
| SGR[a] (%/d) | 2.25 | 2.27 | 2.28 | 0.242 | 2.15 | 2.17 | 2.18 | 0.226 |
| DGR[b] (g/fish/d) | 2.12 | 2.13 | 2.14 | 0.296 | 1.89 | 1.89 | 1.91 | 0.113 |
| FCR[c] | 1.16 | 1.14 | 1.13 | 0.182 | 1.32 | 1.30 | 1.29 | 0.113 |
| Survival rated (%) | 94.00 | 94.33 | 95.33 | 0.154 | 93.67 | 94.00 | 95.00 | 0.236 |
| Fish biomass (kg/m$^3$) | 42.0 | 42.3 | 42.5 | 0.155 | 37.5 | 37.8 | 37.8 | 0.206 |

Values given are mean from triplicate data ($n$ = 3)
[a]Specific growth rate (SGR) = ln final weight (g) – In initial weight (g) ×100 d$^{-1}$
[b]Daily growth rate (DGR) = [Final weight (g) – initial weight (g)]/Culture period (d)
[c]Feed conversion ratio (FCR) = Total weight of dry feed give/Total wet weight gain
[d]Survival rate (SR) = (Total fish number harvested/Total fish number stocked) × 100.

Table 3
Average percent removal by seed quantity

| Crop | Seed quantity (g) | TAN | Nitrite-N | Nitrate-N | OP |
|---|---|---|---|---|---|
| Water spinach | 15 | 78.32 | 82.93 | 79.17 | 75.36 |
| | 20 | 81.85 | 89.46 | 82.14 | 78.98 |
| | 25 | 85.84 | 92.22 | 87.10 | 84.94 |
| | *P* value ($\alpha$ = 0.05) | 0.000 | 0.000 | 0.000 | 0.000 |
| Mustard green | 15 | 69.09 | 72.49 | 66.67 | 66.79 |
| | 20 | 70.93 | 76.85 | 75.00 | 71.02 |
| | 25 | 75.85 | 79.34 | 80.65 | 77.87 |
| | *P* value ($\alpha$ = 0.05) | 0.000 | 0.000 | 0.000 | 0.000 |

### *3.4. Comparative study of water spinach and mustard green in nutrients removal effciency*

Changes in individual nutrient concentrations during the experiment in the three treatment systems (control, water spinach and mustard green planted) are shown in Fig. 4. Although nutrient concentrations in the influent increased with culture time, the highest levels accumulated in the water spinach system (0.857 mg/L, 0.156 mg/L, 3.2 mg/L for TAN, nitrite and nitrate respectively) were well below the levels (3.0–6.7 mg/L, 0.4–1.5 mg/L, and 50 mg/L, for TAN, nitrite and nitrate respectively), considered toxic to african catfish [23]. Significant decreased in TAN, nitrite, nitrate and orthophosphate was consistently observed and the pattern of changes in inorganic nitrogen (TAN, nitrite and nitrate) and orthophosphate was similar for all treatment systems. The effluent concentrations (TAN, Nitrite-N, and nitrate-N) were generally increased with time (Fig. 4a, 4b and 4c) during the seed germination period (days 3–9) due to the release of dissolved and suspended organic matter from the developing seeds and was dependent on the quantity and the type of seeds [24].

However, towards the end of growth period, the nutrient effluent concentrations gradually reduced. Reduction in these quantified water quality parameters was well demonstrated in planted troughs and was generally higher in water spinach than mustard green troughs. Significant decreased in TAN, nitrite-N, nitrate-N and orthophosphate in effluent water was consistently observed and the pattern of changes in TAN, nitrite-N, nitrate-N

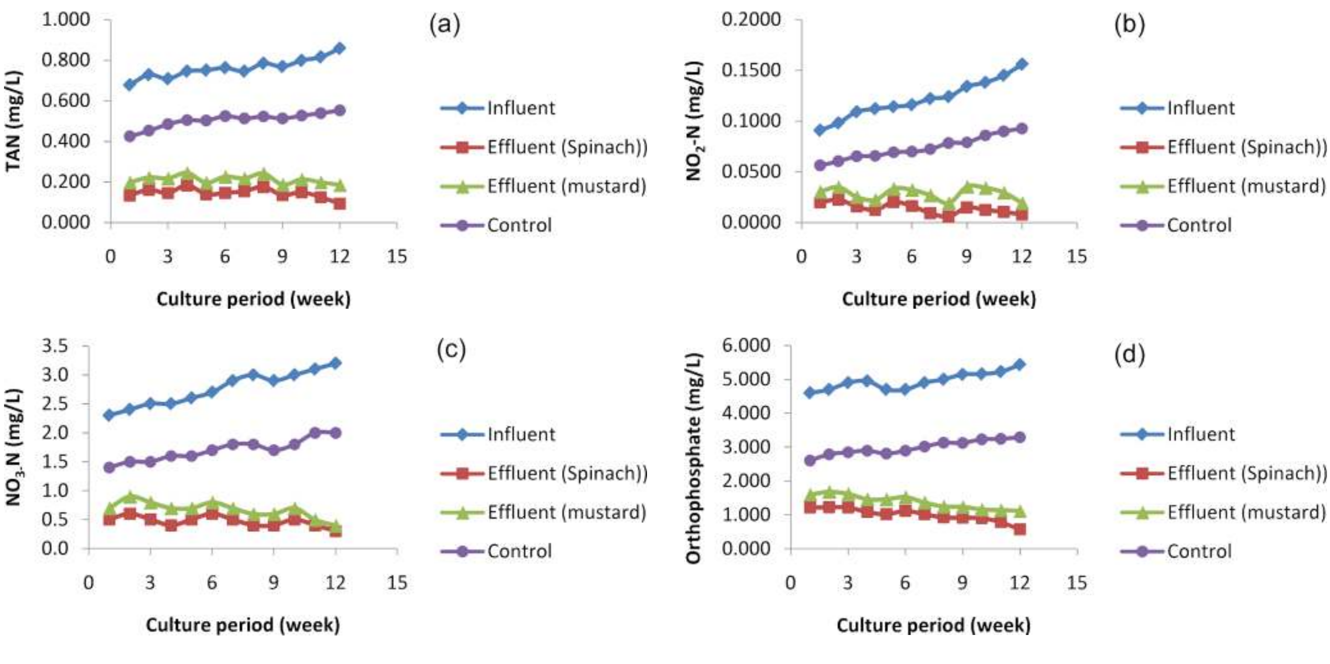


Fig. 4. Time courses of (a) TAN, (b) $NO_2$-N, (c) $NO_3$-N and (d) Orthophosphate in the influent and effluent water of all treatment systems.

and orthophosphate was almost similar for all treatment systems as shown in Figs. 4a–d. The differences in concentrations of TAN, $NO_2$-N, $NO_3$-N, and orthophosphate between the three treatments were highly significant ($P < 0.05$). Although nutrient concentrations in the influent increased with culture time, the highest levels accumulated in the water spinach system (0.857 mg/L, 0.156 mg/L, 3.20 mg/L for TAN, nitrite and nitrate, respectively) were well below the levels (3.00–6.70 mg/L, 0.40–1.50 mg/L, and 50.00 mg/L, for TAN, nitrite and nitrate, respectively), considered toxic to African catfish [23].

For the water spinach system, influent concentration of TAN was 0.6780 mg/L at week 1 and then dropped to 0.0920 mg/L at week 12 (Fig. 4a). The removal percentage was 78.38% after week 4, and 85.84% for the rest of the trial period. The trend was similar in the system planted with mustard green with appreciable removal percentage of 69.09% after week 4, and 75.85% for the rest of the trial period. The reduction of ammonia-N concentration in this system was significantly greater than in the water spinach and mustard green and the control trough. The reductions were significantly influenced by the seed quantity ($P = 0.000$). A greater root shoot ratio might actually be advantageous for the treatment capacity of the system since the roots will greatly increase the surface area available for attachment of biofilms.

Several mechanisms exist for the removal of TAN from the aquaculture wastewater. Forms of inorganic nitrogen that are associated with particulate matter may be removed from waste streams by sedimentation and filtration by the root mats of plants. Ammonium ($NH_4^+$) is one of the major sources of inorganic nitrogen taken up by the roots of higher plants [16]. It may be assimilated by microorganisms and converted back into organic matter or may be removed from waste streams through the process of nitrification. It is interesting to note that results obtained from this study indicate that using crop vegetables can be one of the ways to mitigate the toxicity effect of ammonia to plants and other living organisms.

The mean weekly changes in $NO_2$-N concentration in influent and effluent water measured throughout the 12 weeks experiment is depicted in Fig. 4b. The influent concentration of $NO_2$-N gradually decreased from 0.1120 mg/L to 0.0122 mg/L for week 4 and from 0.1560 mg/L to 0.0076 for week 12 in water spinach troughs. The same decrease was observed in mustard green trough system where the concentration was reduced from 0.1120 mg/L to 0.0224 mg/L and from 0.1560 mg/L to 0.0192 mg/L, for week 4 and week 12, respectively. The levels of $NO_2$-N concentration were lower in the effluent water of all planted systems. The reduction of the nitrite might have resulted from the nitrification process. The greatest mean reduction of 92.22% was found in troughs planted with 25 g of the water spinach. Significant differences of $NO_2$-N percent removal were found between the three treatments. The concentration of $NO_2$-N in the final effluent was very low, as most of the nitrite was already converted to nitrate. At the end of the growth period, $NO_2$-N reductions of 82.93%, 89.46%, 92.22% and 72.49%, 76.85%, 79.34% were achieved in the troughs containing water spinach (15, 20 and 25 g/trough) and mustard green (15, 20 and 25 g/trough), respectively. The NO2-N reductions were significantly influenced by seed quantity as shown in Table 3.

In natural waters, ammonium is converted rather rapidly to nitrite and further to nitrate by aerobic bacteria from the genera *Nitrosomonas* and *Nitrobacter*, through a process called nitrification. Nitrification was facilitated by the continuous aeration of the system during this experiment. Princic et al. [25] reported that the optimum pH range for conversion of $NH_4^+$ to nitrite ($NO_2^-$) is between 5.8 and 8.5. The pH of the water in all experiments was within this range. Although $NO_2$-N is considerably less toxic than $NH_3$-N, it may be more important than ammonia toxicity in intensive recirculation aquaculture systems because it tends to accumulate in the recirculated water as a result of incomplete bacterial oxidation [26]. The average $NO_2$-N concentrations in the final effluent from the planted troughs were in the range of 0.01–0.03 mg/L (Table 3). Eding and Kamstra [23] recommends a $NO_2$-N concentration less than 0.15 mg/L in water used for the culture of African catfish. Therefore, the effluents from troughs containing water spinach and mustard green at a seed quantity of 15, 20 and 25 g were suitable for reuse in an aquaculture system.

Changes in $NO_3$-N concentrations over the three months period in the three treatment systems are shown in Fig. 4c. The concentration of $NO_3$-N in wastewater decreased in both the vegetables but the decrease was more rapid for water spinach than for the mustard green. The removal percentage was 79.17% after week 4 and then 87.10% after week 12 for the water spinach system. It was about 66.67% after week 4 and then 80.65% after week 12 for the mustard green. The nitrate-N reductions were significantly influenced by seed quantity ($P = 0.000$).

Under natural conditions major sources of nitrogen for plants, are ammonium and nitrate-N [27]. Nitrate-N is the preferred form of inorganic nitrogen taken up by the roots of higher plants [16]. It may also be assimilated by microorganisms in the water column or by biofilms associated with the root mats of plants [28]. In agreement of the previous findings, therefore it can be assumed that the decreases in nitrate concentration in this study are due to plant absorption, assimilation of water microorganisms and association of biofilms with root mats of vegetables. The average $NO_3$-N concentrations in the final effluents from the planted system were in the range of 0.3–0.9 mg/L. Poxton [29] recommended that $NO_3$-N concentrations do not exceed 50 mg/ L in waters used for the culture of fish and shellfish, since high nitrates concentrations typically result in algae blooms, which over time can result in lowering of pH [30].

The measured concentration of orthophosphate in the ARS over the twelve weeks experimental period is depicted in Fig. 4d. The pattern of changes in orthophosphate concentration was similar with nitrate concentrations for all three treatment systems. The orthophosphate concentration in effluent decreased with time during the growth period and was dependent on type of plants. The concentration of the orthophosphate in the final effluent was low due to the crop root mates were fully developed and the amount of orthophosphate absorbed by the roots increased. The orthophosphate concentrations in the effluent decreased with the increased of the seed quantity. At the end of the growth period, orthophosphate reductions of 75.36%, 78.98%, 84.94% and 66.79%, 71.02%, 77.87% were achieved in the troughs containing water spinach (15, 20 and 25 g/trough) and mustard green (15, 20 and 25 g/trough), respectively. The orthophosphate reductions were significantly influenced by seed quantity ($P = 0.000$) as shown in Table 3. During a twelve weeks period, the orthophosphate concentration in the effluent was reduced from 5.432 to 0.568 mg/L and 5.432 to 1.136 mg/L using water spinach and mustard green, respectively.

Several mechanisms are responsible for the removal of OP from wastewater. Forms of phosphorus that are associated with particulate matter may be removed from wastewater by sedimentation or by filtration by the root mats of plants. Soluble and insoluble forms of organic phosphorus are not biologically available until they have been converted into soluble, inorganic forms. Organically bound phosphorus is converted into inorganic phosphates by microbial oxidation. In aquatic, plant based treatment systems, microbial communities responsible for this oxidation process are associated with litter, sediments and the root mats of plants. Ebeling et al. [31] showed that the majority of the phosphorus discharged from intensive aquaculture systems (50–85%) is contained in the filterable or settleable solids fraction. Phosphorus is often the limiting nutrient in natural ecosystems, and excessive algae blooms can occur if discharge concentrations exceed the absorption capacity of the receiving water body.

## 4. Conclusion

Water spinach and mustard green have the ability to reduce the pollution potential of aquaculture wastewater. The differences in the structure and recruitment of roots by the two plants depicted important consequences for the deprivation of wastewater components and uptake of nutrients. This study indicates that seed quantity of both crops does not affect fish growth performances in terms of SGR, DGR, FCR, fish biomass and survival rate. High growth rates in fish adult seem to be associated with high productions and feed conversion efficiencies. Fish effluent can compliment or even substitute for organic fertilizers of vegetables production. The aquaponics recirculation system showed that it is not only a successful method for biomass production as food crops, but also a useful system to recycle aquaculture wastewater.

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