Effect of a Parabolic Screen Filter on Water Quality and Production of Nile Tilapia (*Oreochromis niloticus*) and Water Spinach (*Ipomoea aquatica*) in a Recirculating Raft Aquaponic System

Jason J. Danaher[1]

[1] Auburn University, Fisheries and Allied Aquaculture Program
203 Swingle Hall, Auburn, Alabama, 36849 USA

R. Charlie Shultz,[2] James E. Rakocy,[2] Donald S. Bailey,[2] Lasiba Knight[2]

[2] University of the Virgin Islands, Agricultural Experiment Station
RR 1, Box 10,000, Kingshill, United States Virgin Islands, 00850 USA

Keywords: Aquaponics, water quality, parabolic screen filter, Nile tilapia, water spinach

ABSTRACT

Aquaponics is an integrated fish and plant recirculating production system. Solid fish waste must be removed from the production system to maintain optimal **water quality** parameters for fish and plant health. The University of the Virgin Islands (UVI) raft aquaponic system's primary treatment device for solids removal is a cylindro-conical clarifier; however, alternative mechanical filtration devices such as a **parabolic screen filter** (PSF) may offer advantages. The objectives of the eleven-week experiment were to compare water quality parameters, **Nile tilapia** (*Oreochromis niloticus*) production and **water spinach** (*Ipomoea aquatica*) production in a raft aquaponic system using either a cylindro-conical clarifier or parabolic screen filter for primary treatment of solids in the waste stream.

International Journal of Recirculating Aquaculture 12 (2011) 35-53.

The water quality results showed no significant differences ($P > 0.05$) between treatments for temperature, oxygen, pH, alkalinity, EC, TAN, NO_2-N and NO_3-N, macronutrients and micronutrients concentrations, with the exception of copper and zinc. There was no significant difference ($P > 0.05$) between treatments for the total suspended solids (TSS) concentration entering either primary filtration device; however, there was a significant difference ($P \leq 0.05$) between treatments for TSS concentrations exiting the primary filtration device. The PSF treatment had a significantly higher ($P \leq 0.05$) TSS concentration exiting the unit and a significantly higher ($P \leq 0.05$) TSS concentration in the secondary treatment device (net tank) compared to the clarifier.

There were no significant differences ($P > 0.05$) between treatments for Nile tilapia production, average weight, survival, or feed conversion ratio. There were no significant differences ($P > 0.05$) in water spinach production or plant tissue analysis between treatments. In conclusion, the PSF used in this experiment performed less effectively in removing TSS compared to the clarifier, would require more labor to clean and would not be recommended for use in a larger raft aquaponic system. In addition, water spinach assimilated dissolved fish wastes well and grew vigorously in the raft aquaponic system.

INTRODUCTION

Aquaponics is the combined culture of fish and plants in a recirculating, aquaculture system and has received considerable attention as a result of the system's capability to raise fish at high density, sustain water quality, minimize water exchange, and produce a marketable vegetable crop (Rakocy 1997; Adler et al. 2000; Al-Hafedh et al. 2008; Graber and Junge 2009). The vegetable crop is responsible for the direct assimilation of dissolved fish wastes and products of microbial breakdown in the recirculating aquaponic system. However, methods to remove solids from the production system are still necessary to prevent sub-optimal water quality parameters, such as high un-ionized ammonia, nitrite and low dissolved oxygen, (Cripps and Bergheim 2000; Piedrahita 2003) in order to sustain fish and plant health.

Primary methods used to remove solids from aquaculture effluent are settling and sieving. The principal method for solids removal in the University of the Virgin Islands (UVI) raft aquaponic system uses settling via a cylindro-conical clarifier (Rakocy 1997). The clarifier uses the simple method of gravity separation to remove solids from the waste stream. Solids settle and concentrate to a cone bottom for daily discharge. The clarifier requires little energy input resulting in inexpensive operational costs; however, disadvantages of the clarifier are its large size and arduous labor required to excavate soil for installation. In addition, the water turnover rate for the fish production unit is limited by the 20 - 30 minute retention time (Rakocy 2003) required to settle solids in the clarifier that comes after the fish production unit. Alternative components for solids removal could replace the clarifier and still provide good water quality conditions for fish and vegetable production in a raft aquaponic system.

Screen filters are typically used as a primary treatment technology to remove solids from aquaculture effluent (Cripps and Bergheim 2000). Removal of solids occurs by straining the water with a specific mesh size and particles larger than the mesh size are removed from the waste stream (Mäkinen et al. 1988). Mesh screen pore sizes of 60–200 μm are commonly used for in-land, intensive fish farms (Mäkinen et al. 1988; Cripps and Bergheim 2000) and solids removal of 30 – 80% can be achieved with screen sizes of 40 -100 μm (Timmons et al. 2001). One type of screen filter is a parabolic screen filter (PSF). The PSF utilizes an angled, stationary screen to sieve solids from the waste stream using the Coanda effect. The advantage of a PSF compared to other variations of screen filters is its ease of operation, relatively low expense and it contains no mechanical parts which could breakdown (Timmons et al. 2001). Similarly to the clarifier, a PSF can operate with little energy input, but foreseen advantages of a PSF are its compact size, installation at ground level and increased flow rates leaving the fish production tanks. Nonetheless, a potential disadvantage of the PSF could be an increase in the number of cleaning intervals to remove solids trapped on the stationary screen. Rinsing the sieved wastes from the screen maintains the desired hydraulic capacity of the PSF. Our literature search found no research articles utilizing a PSF in a raft aquaponic system.

The objectives of this experiment were to compare water quality parameters, Nile tilapia (*Oreochromis niloticus*) production and water spinach (*Ipomoea aquatica*) production in a raft aquaponic system using either a cylindro-conical clarifier or PSF for primary treatment of solids in the waste stream.

MATERIALS AND METHODS

Experimental System

The experiment was carried out in six outdoor aquaponic systems located at the Agricultural Experiment Station, University of the Virgin Islands, St. Croix, United States Virgin Islands. The experiment consisted of two treatments with three replicates each. The Control used a 1.2 m diameter fiberglass, cylindro-conical clarifier (total volume = 1.7-m^3) containing a baffled wall perpendicular to the waste stream flow to dissipate the incoming current and facilitate solids settlement. The cone bottom had a 60^o slope. Treatment two used a stainless steel PSF (Aquasonic, LTD, Wauchope, Australia) equipped with a 200-micron, wedged-wire removable screen. The PSF had a volume of 0.13-m^3 and a screen surface area of 1,440-cm^2 for solids filtration. According to the manufacturer, the filter could accept a 265 L/min flow rate which equates to a hydraulic loading rate of 2,650 m^3/m^2/day of parabolic screen area.

To prevent sun exposure and algal growth the fish culture tank for each treatment replicate was constructed under a cold frame and shaded with a 100% high density polyethylene cloth. Each experimental system (Figure 1) consisted of a 3 m x 1.1 m fish culture tank (volume for fish production = 7.8 m^3), the primary solids filtration component tested, a net tank (0.7 m^3) with 15 m of orchard netting (1.2 cm square mesh) which acted as a secondary solids filtration component, two hydroponic raceways (area 6.1×1.2×0.3 m each; total volume 4.4 m^3) and a sump (0.6 m^3). Although water flowed from the fish tank to the sump via gravity, a 1/6 Hp Sweetwater® centrifugal pump (Aquatic Ecosystems, Apopka, FL, USA) was used to return water from the sump to the fish culture tank at a flow rate of 57 L/minute. Thus, the hydraulic loading rate on the PSF was 570 m^3/m^2/day of parabolic screen area and the surface loading rate on the clarifier was 73 m^3/m^2/day of plan area. Water loss due to daily waste removal, evaporation and plant transpiration was replaced with rainwater at the sump and controlled with a float valve. The quantity of rainwater was recorded with a water meter installed at each system. Hydroponic raceways were lined with a 20-mil white, food-grade liner (In-Line Plastics, Inc, Houston, TX, USA). The six experimental units were aerated by one, 1.5 Hp Sweetwater® regenerative blower (Aquatic Ecosystems, Apopka, FL, USA). Each fish tank had twelve, 8.0×4.0 cm silica airstones spaced 0.75 m apart around the tank perimeter and each hydroponic trough had four, 8.0×2.5 cm silica airstones placed in the middle of each trough and spaced every 1.2 meters.

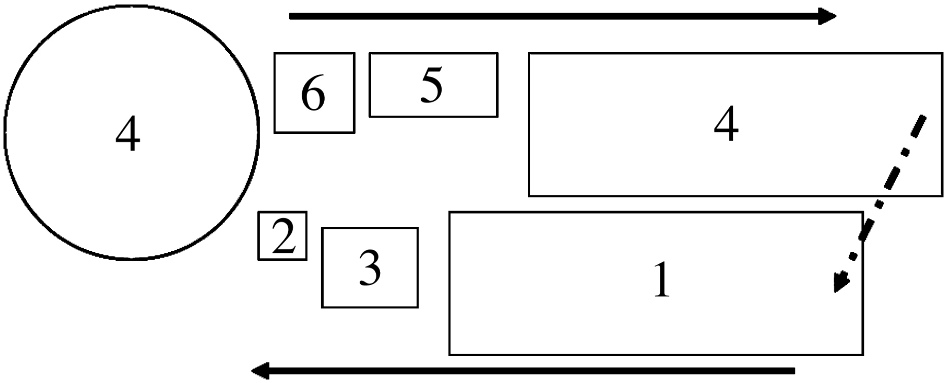

Figure 1. Layout of aquaponic system. System components were: fish tank (1), solids removal device being tested (2), net tank (3), hydroponic raceway (4), sump (5), pump (6). Water recirculates in the direction of the arrows by gravity until an electrical pump returns water from the sump to the fish tank. Rainwater used to make-up water lost to waste removal, evaporation and plant transpiration was added at the sump.

Water Quality

Dissolved oxygen (DO), temperature and electrical conductivity (EC) were monitored directly from each aquaponic system every two weeks. The DO and temperature were monitored in the fish culture tank using an YSI Model 550A meter (Yellow Springs Instruments, Yellow Springs, Ohio, USA) and a Commercial Truncheon pen (NZ Hydroponics International Ltd, Tauranga, New Zealand) was used to record EC at the end of the second hydroponic raceway. The pH was monitored at the end of the second hydroponic raceway three times per week using a pH Testr 10 (Oakton Instruments, Vernon Hills, IL, USA) to maintain a desired pH of 7.0. The raft aquaponic system maintains a pH of 7.0 to accommodate the needs of fish, plants and nitrifying bacteria. The addition of 300 – 500 grams of calcium-hydroxide [$Ca(OH)_2$] or potassium-hydroxide (KOH) was added on an alternate basis when pH fell below 7.0 to neutralize pH and supplement calcium and potassium concentrations. An 11% DTPA iron chelate (Akzo Nobel, Lima, Ohio, USA) was added initially and periodically thereafter to maintain an iron concentration of 2 mg/L to prevent plant nutrient deficiency. One, 250-mL grab sample was taken every two weeks from the end of the second hydroponic raceway in each system to measure water quality parameters in a laboratory at the Agricultural Experiment Station.

A HACH DR/2000 spectrophotometer (Hach Company, Loveland, Colorado, USA) was used to measure total ammonia-nitrogen (TAN), nitrite-nitrogen (NO_2-N), and nitrate-nitrogen (NO_3-N). Alkalinity was measured using the method described in Boyd and Tucker (1992). An additional 250-mL grab sample was taken every two weeks from the end of the second hydroponic raceway and sent to a lab (MicroMacro International, Inc., Athens, GA, USA) for macronutrient and micronutrient analysis. Samples were prepared at MicroMacro International (MMI) using US EPA method 6010a (USEPA 1986) and measured via inductively coupled plasma spectroscopy.

Total-suspended solids (TSS) entering and exiting the clarifier and PSF along with TSS exiting the net tank were sampled every two weeks one-hour after the morning feeding. A 2.5-cm PVC sampling port was installed just before and after each filter for sampling purposes. At each sampling event the sample port was flushed and a 4-L sample was taken from which one, 250-mL aliquot was collected. The TSS concentration was quantified according to the method described in Boyd and Tucker (1992).

Wastes were discharged twice daily (0900 and 1600 h) from the clarifier and PSF. Effluent was discharged from the clarifier based on the concept of hydrostatic pressure. A 5 cm ball-valve was opened to allow settled solids in the cone bottom to discharge and closed immediately when the effluent went from a dark brown appearance to clear in color. For the PSF, solids that did not move into the waste trough as a result of the Coanda effect were carefully washed down into the trough with influent water entering the PSF. This method was slow, but resulted in little water unintentionally entering the waste trough. If the PSF screen clogged, its design allowed water to bypass the screen and flow into the net tank. In this circumstance aquaculture staff carefully scrubbed the screen to allow water to pass through the wedge-wire screen again. Then remaining solids were hand washed into the trough as described previously. After every discharge event, the PSF screen was removed and sprayed with a garden hose to clear the screen openings. Screen removal and replacement during the rinsing process took approximately 60 – 90 seconds. The minute amount of particulate matter that was rinsed from the screen during this rinsing process was not quantified as part of the effluent discharged.

The volume of effluent discharged was quantified at least twice weekly. Additionally, the TSS concentration of discharged effluent was measured every two weeks from one, 250-mL aliquot taken from the combined morning and afternoon discharged effluent. An additional 250-mL sample was collected and sent to MMI for macronutrient and micronutrient concentration. Samples were prepared at MMI using US EPA method 3050b (USEPA 1986) and measured via inductively coupled plasma spectroscopy. At the end of the experiment the orchard netting in each experimental unit's net tank was cleaned of solids via gentle shaking. The slurry in the net tank was manually stirred to suspend solids and two, 250-mL aliquots were taken to quantify TSS concentration.

Tilapia

On 4 November 2009, sex-reversed male Nile tilapia (231.8 ± 21.7 g) were counted into groups of 40 fish then weighed and stocked in rotation until each experimental unit was stocked with 360 fish (46 fish/m^3). Nile tilapia were fed an extruded diet (6.3 mm pellet) containing 32% protein (PMI Nutrition International, Mulberry, FL, USA) twice daily (0900 and 1600 h) based on the recommended feeding rate of 60 – 100 grams of tilapia diet/m^2 of hydroponic plant growing area/day (Rakocy 2003). The culture period for tilapia was 79 days and Nile tilapia were harvested on 22 January 2010. A final count was conducted to determine survival and bulk weight was recorded for each tank to determine final production, average weight, and feed conversion ratio (FCR). Feed conversion ratio (FCR) was calculated as: FCR = feed fed/weight gain (Tidwell et al. 1999).

Water Spinach

Cuttings of water spinach were allowed to root for a two-week period in a commercial-scale aquaponic system. On 31 October 2009 a total fresh weight of 3.3 ± 0.1 kg of water spinach was transplanted into the hydroponic raceways of each experimental system. Spinach was placed on-top of 2.5 cm thick polystyrene floating boards and the roots were able to contact the water through a series of 4.8-cm diameter circular cutouts. For the duration of the experiment, spinach stems and leaves were harvested from these initial transplants every 3 weeks. Spinach was sprayed twice weekly with DiPel® PRO DF (Valent USA Corporation, Walnut Creek, CA, USA) biological insecticide to control caterpillar pests. The spinach was grown for 81 days and on 20 January 2010 all spinach was removed from each experimental unit and total wet weight of spinach production was calculated. Total spinach production did not include roots, only the marketable leaf and stem biomass harvested from the top of the polystyrene sheets.

On 20 January, cuttings of water spinach were taken, immediately weighed, and put into paper bags. The bags were placed into a forced air oven and dried at 80^{o}C for 72 hours to determine percent moisture content. In addition, samples of leaf and stem were sent to MMI for plant tissue analysis. At MMI, plant tissue samples were oven dried and ashed according to AOAC test method 922.02 and 900.02b, respectively (AOAC International 2007). Then, samples were analyzed for nutrient content using US EPA method 6010a (USEPA 1986) and measured via inductively coupled plasma spectroscopy.

A two-sample t-test was used to compare water quality parameters, tilapia production and spinach production between treatments for significant ($P \leq 0.05$) differences. Data was analyzed in Microsoft© Excel 2007 (Microsoft© Corporation, Redmond, Washington, USA). If required, percent data was transformed to arc sin values prior to analysis (Bhujel 2008); however, data are presented in the untransformed form to facilitate interpretation.

RESULTS AND DISCUSSION

The water quality results showed no significant differences ($P > 0.05$) between treatments for temperature, oxygen, pH, alkalinity, EC, TAN, NO_2-N and NO_3-N (Table 1). All aforementioned parameters were within optimal ranges for a raft aquaponic system producing tilapia (Rakocy 2003; Al-Hafedh et al. 2008). There was no significant difference ($P > 0.05$) between treatments for TSS concentration entering either primary filtration device; however, there was a significant difference ($P \leq 0.05$) between treatments for TSS concentrations exiting the primary filtration device (Table 1). The TSS concentration was significantly higher ($P \leq 0.05$) exiting the PSF (11.3 mg/L) compared to the clarifier (7.4 mg/L). The PSF was only able to remove 5.8% of the solids entering it compared to a 30.8% removal efficiency for the clarifier. Chen et al. (1993) and Kelly et al. (1997) found 80 - 95% of the solids in their recirculating systems were less than 30 µm in size. Although particle size distribution was not calculated in the present experiment it is suspected solids passed through the 200-µm screen in the PSF because there was a significant difference ($P \leq 0.05$) between treatments for TSS retained in the net tank. The purpose of the net tank is to retain small particulate matter that escapes the clarifier (Rakocy 1997; Rakocy et al. 2003).

The TSS concentration in the net tank was significantly higher ($P \leq 0.05$) in the PSF treatment (4,300 mg/L) than the clarifier treatment (3,560 mg/L) (Table 1). The net tank component in the PSF treatment acted as a storage reservoir for solids over the 11-week experiment and was able to handle an increased solids loading rate as a result of solids passing through the PSF wedged-wire screen. Furthermore, the wedge-wire

Table 1. Treatment mean (± standard deviation) of water quality parameters sampled during the eleven-week aquaponic experiment. Treatment means within a row and followed by a different letter are significantly different ($P \leq 0.05$) using a two-sample t-test.

	Treatment	
Parameter	**Clarifier**	**Parabolic Screen Filter**
Temperature (°C)	26.3 ± 0.1[a]	26.1 ± 0.1[a]
Oxygen (mg/L)	6.1 ± 0.1[a]	6.1 ± 0.2[a]
pH	7.1 ± 0.1[a]	7.1 ± 0.1[a]
Alkalinity (mg/L)	54.8 ± 9.9[a]	62.4 ± 4.6[a]
Electrical Conductivity (µS/cm)	0.3 ± 0.0[a]	0.3 ± 0.0[a]
Total Ammonia-Nitrogen (mg/L)	0.5 ± 0.0[a]	0.5 ± 0.0[a]
Nitrite-Nitrogen (mg/L)	0.6 ± 0.3[a]	0.6 ± 0.3[a]
Nitrate-Nitrogen (mg/L)	6.9 ± 0.5[a]	6.4 ± 1.3[a]
Total Suspended Solids (mg/L)		
Entering filter	10.7 ± 2.3[a]	12.0 ± 1.5[a]
Exiting filter	7.4 ± 1.2[b]	11.3 ± 1.8[a]
Retained in net tank	3,560 ± 483[b]	4,300 ± 592[a]
Exiting net tank	6.8 ± 0.7[a]	5.7 ± 0.6[a]
In discharged effluent	8,100 ± 2,208[a]	5,364 ± 3,011[a]
Daily effluent discharged (L)	7.6 ± 0.3[a]	7.3 ± 0.4[a]

screen frequently clogged allowing solids to bypass the PSF and enter the net tank. Most of the time the PSF clogged between the previous afternoon cleaning at 1600 hr and the subsequent morning cleaning at 0900 hr. Occasionally, the PSF would clog with solids between the morning and afternoon cleaning on the same day resulting in the waste stream bypassing the screen and entering directly into the net tank. In addition, the hand cleaning of solids to allow water to flow through the PSF when it was found clogged may have resulted in some solids getting squeezed through the wire screen. However, the authors feel the time elapsed between the afternoon and subsequent morning cleaning resulted in the majority of solids entering the net tank.

Clogging of stationary screen filters is problematic in aquaculture (Mäkinen et al. 1988) and more frequent cleaning would be required to ensure the PSF functioned properly. The authors recommend the PSF used in this experiment be cleaned in six hour intervals if used in a similar sized raft aquaponic system with a flow rate of 57 L/min and maximum daily feeding of 80 grams/m^2 of hydroponic growing area/day. However, additional cleaning would result in increased daily management of the raft aquaponic system compared to a system utilizing a clarifier. Alternatively, installing a PSF with an increased screen surface area may result in less frequent clogging by supplying a larger area to filter solids. The PSF used in this experiment was rated for a maximum flow rate of 270 L/min; yet, the PSF could not handle the aquaculture waste at a maximum feeding rate of 80 grams/m^2 of hydroponic growing area/day (1,120 g feed/system/day) and one-fifth its maximum flow rate. The soft organic matter and fecal waste clogged the screen without difficulty. As a result, the feeding rate never exceeded 80 grams/m^2 of hydroponic growing area/day.

Although the PSF treatment was shown to have an increased TSS concentration (11.3 vs 7.4 mg/L) exiting the filter, there was no significant difference ($P > 0.05$) between treatments in TSS concentration exiting the net tank (Table 1). Overall the TSS concentration exiting the net tank was 6.3 mg/L. The 1.2 cm, square mesh orchard netting placed in the net tank was able to capture the additional solids in the PSF treatment and prevent their escape. The net tank for the PSF and clarifier treatments were able to retain approximately 50 and 8 %, respectively, of the solids that entered. These solids remained in the aquaponic system, specifically the net tank, but no adverse effects on water quality were observed, except for the increased copper and zinc concentrations. This finding demonstrates the importance of the net tank for capturing remaining solids that may escape when the primary solids removal device does not perform optimally.

There was no significant difference ($P > 0.05$) in the TSS concentration of effluent discharged daily (Table 1). The authors acknowledge the reported concentration of solids discharged from the PSF treatment is not as precise as the clarifier treatment due to the cleaning process. Nonetheless, each treatment discharged an average daily TSS concentration of 6,732 mg/L and 7.4 L of effluent, overall. This resulted in an overall average daily discharge of 50.3 g of solids/day and represented approximately 4.5% of the daily feed fed on dry matter basis. It was initially thought the PSF would have created a more concentrated effluent compared to the clarifier because it would strain the solids; however, over time water from the waste stream naturally settled in the PSF waste trough. This water that entered the trough was also discharged and resulted in dilution of the screened solids. Water loss due to daily waste removal, evaporation, plant transpiration and fish splashing during feeding was equivalent to 1.6% of the system volume. This demonstrates the recirculating aquaponic system conserves freshwater resources in the production of fish and water spinach.

There was no significant difference ($P > 0.05$) between treatments for macronutrient concentration in the culture water (Table 2). However, there was a significant difference ($P \leq 0.05$) between treatments for two micronutrients in the culture water (Table 2). The PSF had a significantly higher ($P \leq 0.05$) copper (0.06 mg/L) and zinc (0.38 mg/L) concentration compared to the copper (0.03 mg/L) and zinc (0.29 mg/L) concentration in the clarifier treatment. This may have resulted from the increased solids concentration within the net tank of the PSF treatment and the opportunity for micronutrient leaching; however, this did not have a negative impact on Nile tilapia or water spinach production. Macronutrient and micronutrient concentrations were similar to previous studies examining floating raft aquaponics (Rakocy 1997; Rakocy et al. 2003) and was lower than concentrations reported in low exchange recirculating systems used for rainbow trout (*Oncorhyncus mykiss*) culture (Davidson et al. 2011).

Table 2. Treatment mean (± standard deviation) of macronutrient and micronutrient concentration in culture water during the eleven- week aquaponic experiment. Treatment means within a row and followed by a different letter are significantly different ($P \leq 0.05$) using a two-sample t-test.

	Treatment	
Parameter	**Clarifier**	**Parabolic Screen Filter**
Macronutrients (mg/L)		
Phosphorus	1.7 ± 0.1[a]	1.9 ± 0.2[a]
Potassium	24.3 ± 3.9[a]	27.1 ± 5.1[a]
Calcium	34.7 ± 0.7[a]	35.6 ± 4.5[a]
Magnesium	3.9 ± 0.3[a]	4.4 ± 0.7[a]
Micronutrients (mg/L)		
Iron	1.86 ± 0.08[a]	2.00 ± 0.29[a]
Manganese	0.01 ± 0.00[a]	0.00 ± 0.00[a]
Boron	0.05 ± 0.01[a]	0.05 ± 0.00[a]
Copper	0.03 ± 0.01[b]	0.06 ± 0.01[a]
Zinc	0.29 ± 0.03[b]	0.38 ± 0.02[a]
Molybdenum	0.01 ± 0.01[a]	0.01 ± 0.01[a]
Sodium	7.62 ± 0.75[a]	8.46 ± 0.36[a]

There was no significant difference ($P > 0.05$) in water spinach production between the clarifier (212.4 kg) and the PSF (192.6 kg) treatment (Table 3). Overall, total water spinach production in the aquaponic system was 202.5 kg, which equates to 14.5 kg/m^2 of hydroponic growing area or 1.3 kg/m^2/week. The water spinach grew vigorously in the aquaponic system and produced dense masses of foliage within a few weeks of transplanting and between successive harvests. Water spinach has no relation to ordinary spinach (*Spinacia oleracea*), but is closely related to sweet potato (*Ipomoea batatas*) and is in the family Convolvulaceae.

We found few papers regarding the production of this Asian vegetable. Eddie and Ho (1969) and Snyder et al. (1981) suggest 70-100 mt/ha or 7-10 kg/m^2 annually is possible in traditional field production of water

Table 3. Total fresh weight of water spinach harvested, total spinach production per unit surface area and weekly spinach production per unit surface area grown in the raft aquaponic systems during the eleven-week experiment. Treatment means within a row and followed by a different letter are significantly different ($P \leq 0.05$) using a two-sample t-test.

	Treatment	
Parameter	**Clarifier**	**Parabolic Screen Filter**
Total fresh weight harvested (kg)	212.4 ± 15.1[a]	192.6 ± 6.2[a]
Total production per unit area (kg/m^2)	15.2 ± 1.1[a]	13.8 ± 0.4[a]
Weekly production per unit area ($kg/m^2/wk$)	1.4 ± 0.1[a]	1.3 ± 0.0[a]

spinach. Savidov (2005) evaluated water spinach production in a large raft aquaponic system modeled after UVI and reported the water spinach had the highest annual yield (58.3 $kg/m^2/year$) compared to other vegetable crops cultured. In the present aquaponic experiment both treatments could produce 7 times the biomass per unit area annually reported by Eddie and Ho (1969) and Snyder et al. (1981). Also, this experiment yielded an additional 17% water spinach biomass per unit area compared to Savidov (2005). The system Savidov (2005) used was enclosed in a climate controlled greenhouse in a northern Canada. It was not stated what time of year production occurred but day length may have become limiting for water spinach production.

This experiment's findings coincide with Endut et al. (2009) that water spinach produced in an aquaponic system showed a positive response to tilapia effluent in terms of growth and production. This leafy green has potential as a marketable crop in the mainland United States and United States Virgin Islands with an increasing ethnic population and a broader proportion of the residents starting to consume it (Palada and Crossman 1999); in addition, Prasad (2008) found water spinach had medicinal value which could help in marketing to consumers. Unfortunately, water spinach remains on the United States federal invasive plant species list and production may be prohibited in the mainland United States, especially southern states like Florida (Gordon 1998) where frost exposure is negligible.

Effect of Screen Filter on Production of Tilapia and Spinach

The solids removal device did not significantly affect ($P > 0.05$) the percent moisture content (90.5% overall) of the water spinach. This species of water spinach prefers a wet environment to flourish (Eddie and Ho 1969) and water was not limiting in the raft aquaponic system. There was no significant difference ($P > 0.05$) in plant tissue analysis between treatments (Table 4). Nitrogen concentration (6.7% overall) in plant tissue was well above recommended levels (Mills and Jones 1996) for both the clarifier and PSF treatment, which may reveal water spinach quickly uptakes forms of inorganic nitrogen present in the treated fish effluent. No signs of nutrient deficiency were observed although plant tissue analysis revealed calcium and magnesium were below recommended ranges. Nitrogen concentrations can affect the level of calcium and magnesium uptake in plants (Mills and Jones 1996), but it depends on the form the plant is uptaking. Future studies may need to address this concern for raft aquaponic systems producing water spinach if signs of plant nutrient deficiencies occur. Results of this experiment demonstrate an average daily feeding rate of 70 grams of tilapia diet/m^2 of hydroponic growing area/day was sufficient for water spinach growth.

There were no significant differences ($P > 0.05$) between treatments for Nile tilapia production. Overall, the Nile tilapia production, average weight, survival, and FCR were 16.7 kg/m^3, 372.3 g, 97.5 %, and 1.6, respectively (Table 5). Both treatments resulted in Nile tilapia survival and FCR typical for raft aquaponics (Rakocy et al. 2003, 2006). The fish to plant production ratio is an important concept for aquaponics and a proper ratio creates a balanced production system through nutrient uptake and assimilation into plant biomass. Wilson (2005) discovered 1 kg of fish production resulted in 7 kg of vegetable biomass. Graber and Junge (2009) found 1 kg of fish production resulted in 4 kg of tomato production. In the present experiment the nutrients in the wastewater from the net production of 1 kg of Nile tilapia resulted in the net production of 4 kg of water spinach. In essence, aquaponic systems emphasize plant culture and nutrients in the fish waste are a valuable resource for vegetable crop production. When the total harvestable biomass (Nile tilapia + water spinach) was calculated the FCR fell to 0.32 and reveals the importance of integrated systems in maximizing nutrient utilization. This is especially important with the increasing cost of commercial fish diets.

Table 4. Percent moisture, macronutrient levels, micronutrient levels and recommended nutrient levels for water spinach plant tissue at final harvest of aquaponic experiment. Treatment means within a row and followed by a different letter are significantly different ($P \leq 0.05$) using a two-sample t-test.

	Treatment		
Parameter	**Clarifier**	**Parabolic Screen Filter**	**Recommended[1]**
Percent Moisture (%)	90.4 ± 0.4[a]	90.5 ± 0.5[a]	
Macronutrients (%)			
Nitrogen	6.8 ± 0.0[a]	6.7 ± 0.0[a]	3.3 – 4.5
Phosphorus	0.5 ± 0.0[a]	0.5 ± 0.0[a]	0.2 – 0.5
Potassium	3.6 ± 0.0[a]	3.3 ± 0.0[a]	3.1 – 4.5
Calcium	0.5 ± 0.0[a]	0.5 ± 0.0[a]	0.7 – 1.2
Magnesium	0.1 ± 0.0[a]	0.1 ± 0.0[a]	0.4 – 1.0
Sulfur	0.3 ± 0.0[a]	0.3 ± 0.0[a]	0.3 – 0.5
Micronutrients (mg/L)			
Iron	61.5 ± 12.1[a]	64.1 ± 23.7[a]	40 – 100
Manganese	117.1 ± 50.5[a]	76.3 ± 19.5[a]	40 – 250
Boron	25.8 ± 3.9[a]	24.2 ± 1.1[a]	25 – 75
Copper	6.2 ± 0.7[a]	6.4 ± 1.5[a]	4 – 10
Zinc	60.2 ± 22.3[a]	44.8 ± 9.9[a]	20 – 50
Molybdenum	1.1 ± 0.1[a]	1.1 ± 0.2[a]	0.1 – 0.4

[1] Based on recommended levels for sweet potato (*Ipomoea batatas*) by Mills and Jones (1996).

Table 5. Final production, individual harvest weight, survival and food conversion ratio (FCR) of tilapia grown in the aquaponic system. Treatment means within a row and followed by a different letter are significantly different ($P \leq 0.05$) using a two-sample t-test.

	Treatment	
Parameter	**Clarifier**	**Parabolic Screen Filter**
Final Production (kg/m^3)	16.4 ± 2.7[a]	16.9 ± 2.0[a]
Individual harvest weight (g)	373.7 ± 18.0[a]	370.8 ± 10.9[a]
Survival (%)	95.7 ± 5.2[a]	99.2 ± 0.5[a]
FCR	1.7 ± 0.0[a]	1.6 ± 0.1[a]

In conclusion, using a PSF in the UVI raft aquaponic system did not negatively affect water quality, Nile tilapia production or water spinach production compared to the traditional cylindro-conical clarifier. However, the stationary screen of the PSF frequently clogged while straining solids from the waste stream and the required cleaning events were often times unpredictable. The PSF would require increased cleaning intervals compared to the clarifier. The authors would not recommend the PSF used in this experiment as the primary solids treatment method in a commercial-scale raft aquaponic system having a higher waste load and flow rate. Future studies could address the use of a PSF with similar mesh size, but with more frequent cleaning intervals or a PSF with a larger surface area for straining solids could be evaluated. In addition, an alternative solids removal device like a swirl separator should be evaluated as the primary solids removal device in the raft aquaponic system.

ACKNOWLEDGEMENTS

We would like to thank Louis Cariño, Jr. for his help with the daily management of the Nile tilapia and water spinach in the aquaponic systems. The research was financed in part by the United States Geological Survey through the Virgin Islands Water Resources Research Institute grant #2009VI150B. The contents of this publication do not necessarily reflect the views and policies of the U. S. Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the United States Government.

REFERENCES

Adler, P.R., J.K. Harper, E.W. Wade, F. Takeda and S.T. Summerfelt. **2000**. Economic analysis of an aquaponic system for the integrated production of rainbow trout and plants. *International Journal of Recirculating Aquaculture* 1: 15-34.

Al-Hafedh, Y.S., A. Alam and M.S. Beltagi. **2008**. Food production and water conservation in a recirculating aquaponic system in Saudi Arabia at different ratios of fish feed to plants. *Journal of the World Aquaculture Society* 39(4): 510-520.

AOAC International. **2007**. Official Methods of Analysis of the Association of Official Analytical Chemists - 18th edition, Rev. 2. AOAC International, Gaithersburg, Maryland, USA.

Bhujel, R.C. **2008**. Statistics for Aquaculture. Wiley-Blackwell, Ames, Iowa, USA.

Boyd, C.E. and C.S. Tucker. **1992**. Water Quality and Pond Soil Analysis for Aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.

Chen, S., M.B. Timmons, D. J. Aneshansley, J.J. Bisogni, Jr. **1993**. Suspended solids characteristics from recirculating aquacultural systems and design implications. *Aquaculture* 112(2-3): 143-155.

Cripps, S.J. and A. Bergheim. **2000**. Solids management and removal for intensive land-based aquaculture production systems. *Aquacultural Engineering* 122(1-2): 33-56.

Edie, H.H. and B.W.C. Ho. **1969**. *Ipomoea aquatica* as a vegetable crop in Hong Kong. *Economic Botany* 23: 32-36.

Endut, A., A. Jusoh, N. Ali, W.B. Wan Nik and A. Hassan. **2009**. Effect of flow rate on water quality parameters and plant growth of water spinach (*Ipomoea aquatica*) in an aquaponic recirculating system. *Desalination and Water Treatment* 5: 19-28.

Good,C., J. Davidson, C. Welsh, K. Snekvik and S. Summerfelt. **2011**. The effects of ozonation on performance, health and welfare of rainbow trout *Oncorhynchus mykiss* in low exchange water recirculation aquaculture systems. *Aquacultural Engineering* 44 (3): 97 – 102.

Gordon, D.R. **1998**. Effects of invasive, non-indigenous plant species on ecosystem processes: Lessons from Florida. *Ecological Applications* 8(4): 975-989.

Graber, A. and R. Junge. **2009**. Aquaponic systems: Nutrient recycling from fish wastewater by vegetable production. *Desalination* 246(1-3): 147-156.

Kelly, L.A., A. Bergheim and J. Stellwagen. **1997**. Particle size distribution of wastes from freshwater fish farms. *Aquacultural International* 5: 65-87.

Mäkinen, T., S. Lindgren and P. Eskelinen. **1988**. Sieving as an effluent treatment method for aquaculture. *Aquacultural Engineering* 7: 367-377.

Mills, H.A. and J.B. Jones, Jr. **1996**. Plant Analysis Handbook II. MicroMacro Publishing, Inc., Athens, Georgia, USA.

Palada, M.C. and S.M.A. Crossman. **1999**. Evaluation of tropical leaf vegetables in the Virgin Islands. p. 388–393. In: J. Janick (ed.), Perspectives on new crops and new uses. ASHS Press, Alexandria, Virginia, USA.

Piedrahita, R.H. **2003**. Reducing the potential environmental impact of tank aquaculture effluents through intensification and recirculation. *Aquacultural Engineering* 226: 35-44.

Prasad, K.N., G.R. Shivamurthy and S.M. Aradhya. **2008**. *Ipomoea aquatica*, an underutilized green leafy vegetable: A review. *International Journal of Botany* 4(1): 123-128.

Rakocy, J.E. **1997**. Integrating tilapia culture with vegetable hydroponics in recirculating systems. In: Tilapia Aquaculture in the Americas. Vol. 1. pp. 163-184 (Costa Pierce, B.A. and J.E. Rakocy, Eds.). The World Aquaculture Society Baton Rouge, Louisianna.

Rakocy, J.E., R.C. Shultz, D.S. Bailey and E.S. Thoman. **2003**. Aquaponic production of tilapia and basil: Comparing a batch and staggered cropping system. Acta Hortaculturae (ISHS) 648: 63-69.

Rakocy, J.E., M. Masser and T. Losordo. **2006**. Recirculating aquaculture tank production systems: Aquaponics – integrating fish and plant culture. Southern Regional Aquaculture Center Publication 454. Retrieved online at: https://srac.tamu.edu/index.cfm/event/getFactSheet/whichfactsheet/105/

Savidov, N. **2005**. Evaluation of aquaponic technology in Alberta, Canada. Aquaponics Journal 37: 20-25.

Snyder, G.H., J.F. Morton, W.G. Genung. **1981**. Trials of *Ipomoea aquatica*, nutritious vegetable with high protein and nitrate-extraction potential. Proceedings of the Florida State Horticultural Society 94: 230-235.

Tidwell, J. H., S. Coyle, C. Weibel, and J. Evans. **1999**. Effects and interactions of stocking density and added substrate on production and population structure of freshwater prawn, *Macrobrachium rosenbergii*. *Journal of the World Aquaculture Society* 30(2):174-179.

Timmons, M.B., Ebeling, J.M., Wheaton, F.W., Summerfelt, S.T., Vinci, B.J. **2001**. Recirculating Aquaculture Systems. Cayuga Aqua Ventures, Ithaca, New York, USA.

United States Environmental Protection Agency (USEPA). **1986**. Test Methods for Evaluating Solid Wastes. SW-846, 3rd ed., Washington, D.C., USA.

Wilson, G. **2005**. Australian barramundi farm goes aquaponic. *Aquaponics Journal* 37: 12-16.