Evaluating Geotextile Technology to Enhance Sustainability of Agricultural Production Systems in the U.S. Virgin Islands

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Introduction

Cultivating cash crops in a climate like the U.S. Virgin Islands can be challenging even with supplemental irrigation. Integrating recirculating aquaculture systems with the production of other valuable agronomic crops to reuse water and recycle nutrients can provide a viable solution to sustainable food production in semi-arid regions. Recirculating aquaculture systems discharge nutrient-rich effluent daily that is composed of feces, algae, and uneaten feed to ensure system sustainability. Experiments at the University of the Virgin Islands (UVI) have demonstrated discharged aquaculture effluent to be an excellent water and nutrient source for agronomic crops; thus, effluents should be treated as a resource and not as a disposal problem. One major constraint to the integration of aquaculture and field crops has been clogging of drip irrigation systems due to high levels of total suspended solids (TSS) in the aquaculture effluent. Technology capable of separating the solid fraction from the liquid fraction of aquaculture effluent would improve options for integrating aquaculture and field crop production.

Geotextile technology now exists that creates a more flexible approach to integrate aquaculture effluent with agronomic crops, therefore improving on-farm water and nutrient use. Geotextile technology has been used on dairy, swine, and aquaculture facilities to dewater animal wastes. A geotextile bag (GTB) is constructed from a high-strength, woven, polypropylene fabric. Small pores in the geotextile retain the majority of organic matter and allow water (i.e. filtrate) to drain out, resulting in effective dewatering and efficient volume reduction of the animal waste. Repeated fillings, resulting in additional filtrate, are possible until the bag reaches its volumetric capacity. Then, the retained waste matter can continue to consolidate by desiccation through the geotextile fabric. To utilize the solids, the farmer must cut the bag open to extract the solids for land application. A project at UVI evaluated the use of a GTB for the recovery and application of aquaculture effluent for agronomic crops cultivated in the U.S. Virgin Islands.

The objectives of this project were:

1) Evaluate a geotextile bag for dewatering aquaculture effluent and analyze the nutrient content of the filtrate exiting the bag and the manure captured in the bag. Also, determine if the filtrate could pass through a T-tape® irrigation system.
2) Evaluate the manure in the geotextile bag as a fertilizer for cucumber production.

Objective 1

Materials and Methods

Aquaculture effluent was stored in a 40,000 gallon lined pond under anaerobic conditions. Adjacent to the pond a 30 feet x 10 feet earthen pad was constructed with a 2% grade (Figure 1). In addition to the graded pad, a frame was constructed from 3-inch PVC pipe and installed on the peripheral edges of the pad to direct water exiting the bag toward a catchment area. Both the frame and the pad were covered with a 45-mil thick Ethylene Propylene Diene Monomer (EPDM) liner and approximately 1 inch of gravel was placed over the liner. Then, a GTB with a dimension of 25 feet x 7.5 feet was laid over the gravel (Figure 2).

A 3/4-horsepower (hp) vertical lift aerator and horizontal mixer were used to agitate the fish effluent prior to each pumping event (Figure 3). A 1/3-hp pump, pumped effluent at a rate of 10 gallons/minute to the GTB. Prior to entering the

Figure 1. Earthen pad with EPDM liner and gravel for the geotextile bag.

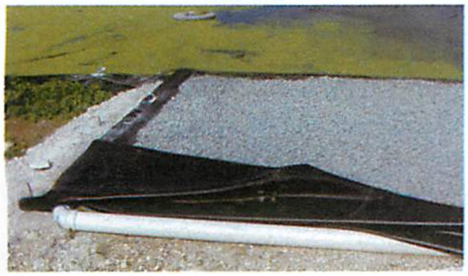


Figure 2. The geotextile bag resting on the earthen pad. The green, 3-inch PVC hose delivers effluent injected with polymer to the bag.

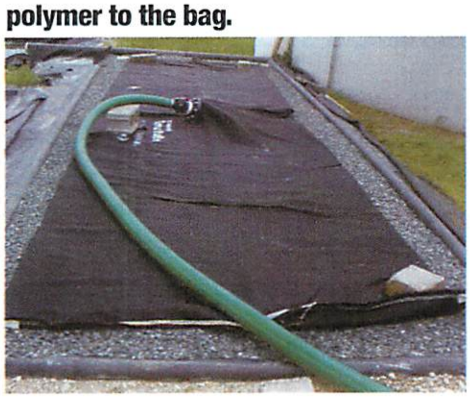


Figure 3. Untreated aquaculture effluent in the anaerobic pond being agitated prior to a pumping event.

Table 1. Averages of water quality parameters and nutrient concentrations measured during objective 1 for aquaculture effluent, geotextile bag (GTB) filtrate exiting the bag, and GTB manure inside the bag. The removal efficiency of different parameters as effluent passed through the geotextile bag is also reported (negative numbers represent an increase in nutrient concentration for the filtrate).

	Aquaculture Effluent (mg/L) Mean ± S.D.	**GTB Filtrate** (mg/L) Mean ± S.D.	**Percent Removal**	**GTB Manure** (lbs/t)
pH ($-\log_{10}[H^+]$)	7.6 ± 0.3	7.7 ± 0.4		8.1
Temperature (ºC)	24.5 ± 0.5	24.5 ± 0.5		
Alkalinity	860.0 ± 34.6	801.3 ± 90.5		
TSS	22,525.0 ± 3,892.2	115.0 ± 68.7	99	
Macronutrients				
NPK (%)	0.09 : 0.15 : 0.03	0.02 : 0.04 : 0.03		3.6 : 6.0 : 0.2
Total Nitrogen	898.7 ± 27.3	244.5 ± 59.7	73	8.6
Phosphorus	670.3 ± 550.1	155.7 ± 207.5	77	14.4
Potassium	248.4 ± 151.1	225.8 ± 151.3	9	0.4
Calcium	3,404.5 ± 2,878.4	417.3 ± 333.4	88	32.7
Magnesium	127.0 ± 62.1	66.3 ± 69.4	48	0.6
Micronutrients				
Iron	33.3 ± 14.1	14.5 ± 19.9	56	0.5
Copper	8.0 ± 7.0	8.3 ± 10.5	-4	0.1
Zinc	23.8 ± 22.0	22.3 ± 15.9	6	0.3
Boron	5.5 ± 3.7	13.5 ± 19.1	-73	0.1
Manganese	13.0 ± 9.0	5.8 ± 10.8	55	0.2
Molybdenum	7.3 ± 9.0	13.3 ± 20.0	-82	0.0

GTB, a peristaltic pump injected effluent with a polymer, HYPERFLOC® CE 854, at a concentration of 14 mg/L and effluent and polymer mixed by passing through a series of 90-degree PVC elbows (Figure 4). Jar tests were performed in the laboratory to determine 14 mg/L of polymer was necessary for TSS treatment. A polymer is a long-chain carbon molecule with high molecular weight. HYPERFLOC® CE 854 has a cationic charge attracting it to the surface of organic matter and results in coagulation of small particles. Thus, polymer addition helps the GTB to capture the majority of TSS present in the waste stream. There were three pumping events to fill the GTB: 29 November and 14 December 2007 and 17 January 2008 (Figure 5). On each pumping event a sample of aquaculture effluent was collected from the storage pond adjacent to the 1/3-hp pump and a sample of filtrate exiting the GTB was collected during filling (Figure 6). A sample of the solids retained inside the GTB was collected on 17 January prior to the final pumping event and analyzed, moist from the bag, for physical and chemical characteristics. Water quality parameters along with physical and chemical characteristics of aquaculture effluent, GTB filtrate, and GTB manure were analyzed at Micro Macro International (Athens, GA, USA) and results are shown in Table 1.

Results and Discussion

The GTB in combination with the polymer removed 99% of the TSS from the aquaculture effluent (Figure 7). When comparing nutrient concentrations of aquaculture effluent entering the GTB to filtrate exiting the GTB, the common trend was a decrease in nutrient concentration; however, some nutrient concentrations increased, suggesting the GTB was unable to capture them effectively. Comparison of aquaculture effluent to GTB manure showed macronutrient and micronutrient concentrations were concentrated by factors ranging from 7–40 times and 0–60 times, respectively. Analysis of the GTB manure showed it was composed of 87% moisture content after four weeks of dewatering

Figure 4. Effluent being pumped from the storage pond and injected with polymer prior to entering the geotextile bag. The white box houses the peristaltic pump which injects the polymer. The effluent coagulates as it mixes with the polymer in the series of 90-degree PVC elbows.

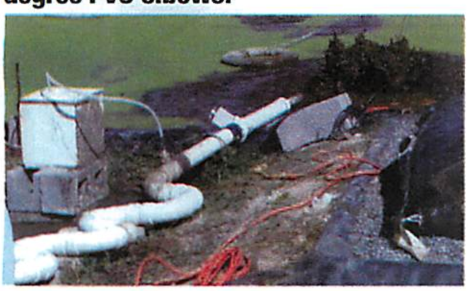
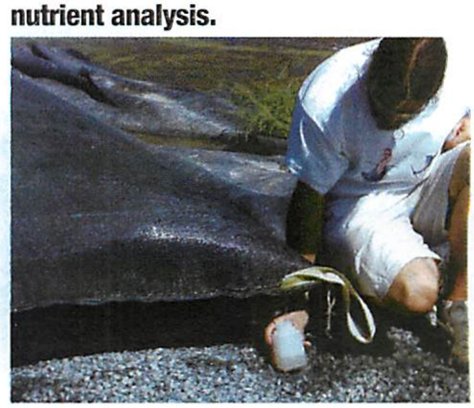


Figure 5. Filling the geotextile bag with aquaculture effluent injected with polymer. The slurry entering the bag will dewater as filtrate escapes and evaporation takes place. The bag can be filled multiple times.

Figure 6. Collecting filtrate as it slowly exits the bag for water quality and nutrient analysis.



(Figure 8). The dry weight of the manure was 59% organic solids. The GTB manure may provide a farmer with an alternative nutrient source for field production of vegetable crops while improving the physical characteristics of soil with the addition of organic matter. The GTB filtrate was also found to pass through a T-tape® irrigation system without clogging emitters over a four-week period. This would allow a farmer to integrate an aquaculture operation with agronomic field crops without the clogging problems previously experienced with untreated aquaculture effluent at UVI. The GTB filtrate was low in nutrient concentration and we hypothesize this was a result of storage in an anaerobic environment. Under anaerobic conditions nutrient concentrations can decrease over time.

Objective 2

Materials and Methods

An experiment was conducted to compare GTB manure to a commercial, inorganic fertilizer as a nutrient source for field production of cucumber (*Cucumis sativus* 'Calypso'). A total of six treatments were used. The four GTB manure treatments were 90, 120, 150, or 180 lbs nitrogen/acre. The inorganic fertilizer used was 13-13-13 Osmocote®. The two inorganic fertilizer treatments used were 90 and 180 lbs nitrogen/acre. A GTB was filled with aquaculture effluent which was analyzed for nutrient content. After several weeks of dewatering, the manure was sampled moist as it was obtained from the bag (Table 2). Analysis of soil samples was performed on field plots prior to fertilizer application and appropriate amounts of fertilizer, based on nitrogen concentration, were applied to field plots.

The experiment was conducted from 14 January to 10 April 2009 at the UVI Agricultural Experiment Station on St. Croix. A Randomized Block Design was used with three replicates per treatment. All treatments were irrigated with rainwater. Plots were established measuring 20 feet long × 8 feet wide. On 14 January Osmocote® and GTB manure were applied to their respective plots (Figure 9). Fertilizers were rototilled about 6 inches deep into the soil and allowed to rest for 2 weeks. One-week-old cucumber seedlings were transplanted on 29 January to the three-row plots with a row spacing of 4 feet and plant spacing within rows of 2 feet. On 2 February straw mulch, composed of dry guinea grass (*Panicum maximum* L.) was applied at a depth of 2-3 inches over the entire area of the plot. Dipel® DF biological insecticide and M-Pede® insecticidal soap were applied twice weekly to kill insect pests, and weeds were controlled by hand-weeding when necessary. Cucumbers were harvested starting on 6 March until 10 April for a total of 16 harvests (Figure 10, next page). Plant tissue analysis was performed on the middle row of each plot by sampling two or three recently mature leaves per plant at the appearance of first flower. A & L Laboratories (Memphis, TN, USA) performed the soil and plant tissue analysis. After initial fertilizer application soil samples were collected at planting, first flower, and at the end of the experiment. One-way analysis of variance (ANOVA) was used to compare total yield, total marketable yield, total number of fruit and marketable fruit, average fruit weight, plant tissue samples, and soil samples between treatments. A marketable fruit was categorized as ≥ 5-inches in length with no insect damage, no canker present, and no excessive yellowing of the fruit.

Results and Discussion

Nitrogen and phosphorus concentrations in the GTB manure used in objective 2 were similar to concentrations measured in objective 1. However, in objective 2 one composite sample was prepared from multiple samples after the GTB was cut open and more accurately represented manure nutrient concentrations throughout the GTB. No significant differences were found between any treatments regarding the total yield and marketable yield (Figure 11, next page) of cucumber. Over 97% of the cucumbers were marketable based on our categorization. There was no significant difference between treatments for total number of fruits and marketable fruits harvested. There was no significant difference in the average fruit weight between treatments with an overall average weight of 7.5 ounces/fruit. There was no significant difference in plant tissue analysis, and tissue nutrient levels were in optimal ranges for all treatments. There were no significant

Table 2. Nutrient analysis of manure removed from the geotextile bag and used as a fertilizer in the cucumber experiment.

Test	Pounds Per Ton
Nitrogen, N	10.6
Phosphorus, P	17.0 P_2O_5
Potassium, K	0.96 K_2O
Sulfur, S	2.40
Magnesium, Mg	0.80
Calcium, Ca	37.0
Sodium, Na	<0.50
Iron, Fe	0.54
Aluminum, Al	0.32
Manganese, Mn	0.18
Copper, Cu	0.05
Zinc, Zn	0.29
	Result
Moisture, %	88.8
Solid, %	11.2

Figure 7. Comparison of untreated effluent (left), effluent treated with the polymer prior to entering the geotextile bag (middle), and filtrate exiting the bag virtually free of total suspended solids (right).

Figure 8. Cutting open the geotextile bag and removing manure for use as a fertilizer in the cucumber experiment.

Figure 9. Fish manure being broadcasted over research plot prior to being rototilled into the soil.

differences in soil analysis at any sampling period. Cucumber growth response, based on number of internodes at first flower, was not significantly affected by either source of fertilizer or different application levels of either fertilizer. Therefore, GTB manure applied at a rate of 90 lbs nitrogen/acre resulted in similar cucumber production as 90 lbs nitrogen/acre of Osmocote® and application rates of > 90 lbs nitrogen/acre did not improve cucumber yield. Physical characteristics of the soil, specifically organic matter, was not improved by the addition of GTB manure.

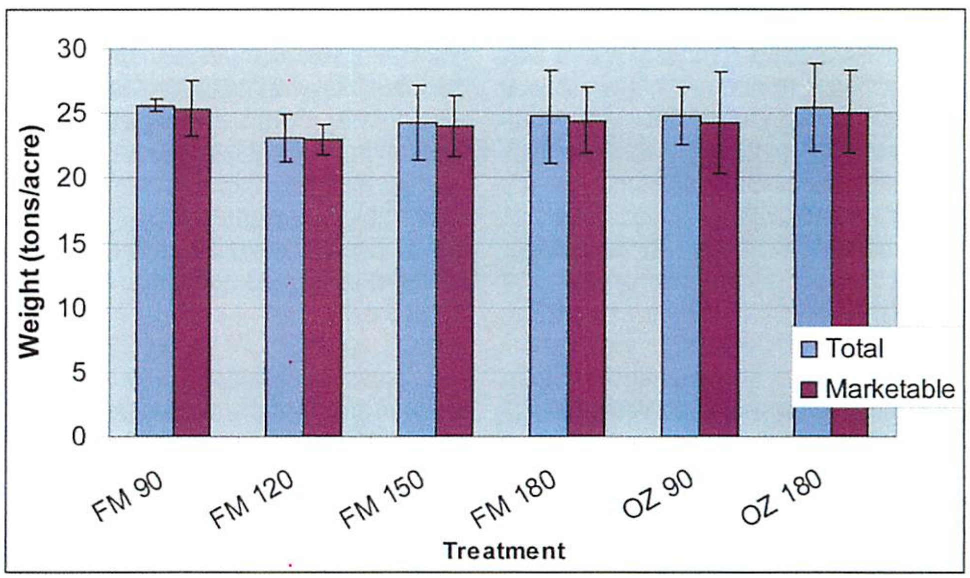
Conclusions

- The GTB was highly effective in reducing the concentration of TSS in fish effluent while providing a filtrate with some dissolved nutrients.
- The GTB filtrate was able to pass through standard, commercial irrigation lines without clogging emitters.
- The GTB would allow an integrated farming system to utilize aquaculture effluent on agronomic crops during seasonal water shortages or persistent droughts.
- There was no difference in cucumber production when comparing the GTB manure to a commercially available inorganic fertilizer.

Future research should address the economics of integrating fresh aquaculture effluent from the UVI biofloc system with agronomic crop production. Although this project demonstrated the geotextile technology is capable of improving on-farm water and nutrient use, a study is needed to determine if there is a cost savings for the farmer through recycling the nutrients with geotextile technology. The UVI Aquaculture Program has a commercial-size biofloc system with an adjacent agronomic field to perform the experiments. Research should also address the effect of crop production to maximize residual nutrient levels in the soil from initial GTB manure application and determine if GTB manure improves physical characteristics of the soil after repeated applications.

Figure 10. The cucumber research plot was harvested three times each week from 6 March to 10 April.

Figure 11. Mean total harvest weight and marketable harvest weight (± standard deviations) of Calypso cucumber as affected by fish manure (FM) or Osmocote® (OZ) treatments.



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