INTEGRATED FISH/VEGETABLE PRODUCTION: A PRELIMINARY PROPOSAL

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INTRODUCTION

Aquaponics, the integration of fish and vegetable production in a recirculating system, represents a significant advance for raising large amounts of food while utilizing limited amounts of land and water. The effluent from intensive fish production systems contains high levels of nutrients that are normally discharged to the environment, contributing to pollution. In an aquaponic system, the waste nutrients are used to produce a valuable crop of vegetables. Removal of nutrients by vegetables purifies the culture water which is returned to the fish rearing tank. Water continuously cycles between the fish and vegetable components.

Plants grow rapidly with dissolved nutrients that are excreted directly by fish or generated from the microbial breakdown of fish wastes. Recirculating systems which have very little daily water exchange (< 5%) accumulate these nutrients in concentrations similar to hydroponic nutrient solutions. The benefits of aquaponic systems is that dissolved waste nutrient are recovered by the plants, reducing discharge to the environment, minimizing water exchange, and operational costs. The daily application of fish feed provides a regular supply of nutrients to the plants, providing a secondary crop to the fish a little cost. That being said, aquaponic systems do require a significant capital investment, moderate energy costs, and skilled management.

An aquaponic production system is well suited for work farms at penal institutions because in addition to producing large amounts of fish and vegetables, conserving and reusing water and recycling nutrients, the system will serve as an excellent model to teach fish culture, plant nutrition, water treatment, biological control of pests and diseases and the importance of a balanced ecological system. Inmates learn fundamental science skills, experience the satisfaction of agriculture – growing their own food -, literally can enjoy the fruits of their labor, and may generate income from sale of product.

SYSTEM DESIGN

The design of aquaponic systems is similar to many recirculating aquaculture systems with the addition of a hydroponic (plant growing) component and the elimination of some filtration devices. The essential elements of an aquaponic system are the fish-rearing tanks, a settleable and suspended solids removal component, a biofilter, a hydroponic component and a sumpt (Figure 1).

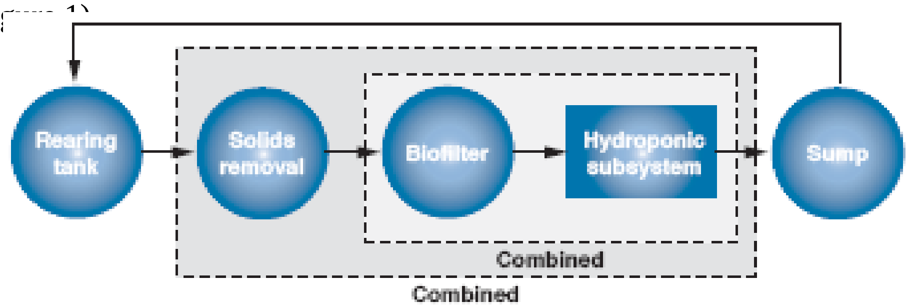

Figure 1. Optimum arrangement of aquaponic system components (not to scale). From Rakocy *et al.* 2006.

Effluent from the fish-rearing tanks is treated first to reduce organic matter (settleable and suspended solids), then biofiltration removes ammonia and nitrates; the hydroponic component utilizes dissolved nutrients and additional ammonia and nitrates by the plants, and finally, water collects in a reservoir sump for return to the fish-rearing tanks (Figure 2).

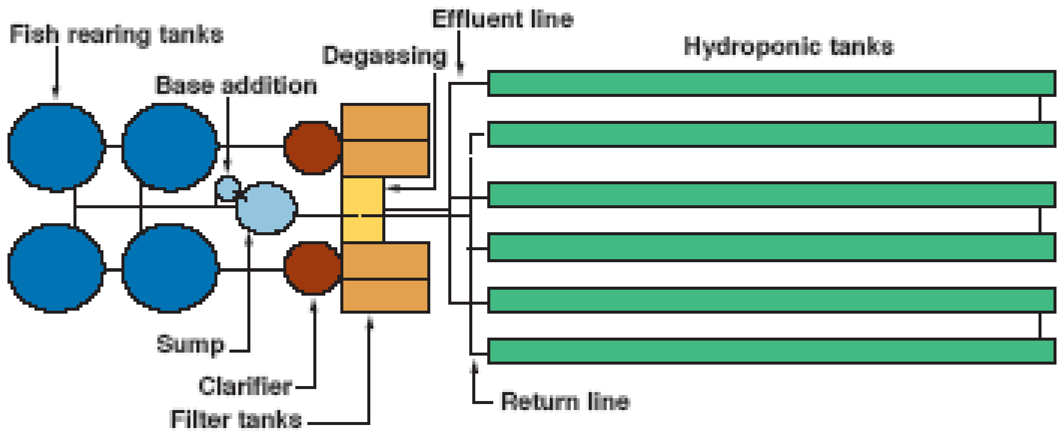

Figure 2. Layout of proposed aquaponic system, based on University of the Virgin Island prototype.

The biofilter and hydroponic components of the system are often combined by using plant support media, such as gravel or sand, which also serves as a biofiltration media. However, raft hydroponics, which consists of floating sheets of polystyrene and net pots for plant support, can be equally efficient if space is not limited. Figure 3 demonstrates the commercial-scale aquaponic system that has been developed at the University of the Virgin Islands which employs raft hydroponics for lettuce production. System component specifications are given in Table 1.

Table 1. Aquaponic system specifications based on UVI system (SRAC 2006).

Rearing Tanks	Diameter	Height	Volume	
Number = 4	10 feet	4 feet	2,060 gallon each	
Clarifiers Number = 2	6 feet	4 feet (cone 3.6 feet; slope 45º)	1,000 gallon	
Filter/degassing Number = 2	Length/width = 6 feet/2.5 feet	2 feet	185 gallon	
Hydroponic tanks Number = 6	Length/width = 100 feet/4 feet	16 inches	3,000 gallon (total)	Growing area = 2,304 feet
Sump	4 feet	3 feet	180 gallon	
Total system water volume				29,375 gallon
Flow rate				100 gpm
Water pump				½ hp
Air Blowers			1.5 hp fish	1 hp plants

Total land area			1/8 acre

FISH PRODUCTION

Tilapia is the fish species most commonly cultured in aquaponic systems because they grow rapidly, can be stocked at high densities, and they are extremely hardy with respect to water quality conditions (although several other species, including catfish, carp, crappies and even rainbow trout have been raised). In order to recover operating expenses of aquaponic systems, both the fish-rearing and hydroponic vegetable components mut be operated continuously near maximum production capacity.

Figure 3. An early model of the UVI aquaponic system showing staggered production of leaf lettuce in six raft hydroponic tanks.

Multiple tanks for fish-rearing allow for staggered production with each tank being harvested around every six weeks; it also eliminates the stress of grading fish and moving them from tank to tank during the production cycle. In general, the critical standing crop (maximum load) in aquaponic systems should not exceed 0.50 pounds/gallon. This density promotes fast growth, efficient feed conversion and reduces crowding stress (which can lead to disease outbreaks). The production cycle to produce a one pound tilapia is approximately 24 weeks. Therefore, with four production tanks, one tank would be stocked every six weeks and one would be harvested (perhaps longer in the winter if they are outdoors, due to lower temperatures) and yield 1,000 pounds of fish. Annual fish yield from this system would be approximately 10,000 pounds.

HYDROPONIC PLANT CROPS

Although the aquaponic system at UVI has grown a variety of plant crops, most of its analysis has been on lettuce varieties. Other aquaponic systems (e.g. Rutgers University, Cropt Diversification Center in Alberta, Canada) have cultivated a host of plant crops, including: tomatoes, eggplant, cucumbers, melons, okra, Swiss chard, bok choi, Chinese cabbage, collard, watercress, basil, cilantro, chives, parsley, and flowers (marigolds and zinnias). Some crops, such as lettuce may have a production cycle as short as 3 to 4 weeks, while seasonal crops or those that have long growing periods (> 3 months), such as tomatoes and cucumbers, may be intercropped with other vegetables. For example, if lettuce is intercropped with tomatoes and cucumbers, one crop of lettuce can be harvested before the tomato plant canopy begins to limit light. The choice of plants to raise will likely be determined by demand, environmental conditions, and space availability.

COMPONENT RATIOS: FISH SPACE TO PLANT GROWING AREA

Without delving into technical details of solids removal, biofiltration, and other water treatment components, the water surface area for hydroponic plant production (basing this on a floating raft design rather than gravel or sand media) is related to the amount of fish feed provided to the system daily (since that is the primary source of nutrients). As a general guide, a ratio in the range of 60 – 100 grams of fish feed/m^2 of plant growing area should be used. In raft hydroponics, approximately 75% of the system water volume is in the plant component. Estimated production for fish/lettuce in the system described herein is 11,000 pounds of tilapia and 1,400 cases of leaf lettuce per year.

COST ESTIMATES

A budget for materials for the system described herein was kindly provided by Dr. James Rakocy, the director of the Agriculture Research Station at the University of the Virgin Islands and director of the aquaponics program there for over 30 years. Although prices will vary, a general estimate of the materials for the aquaponic system is $ 48,000. Annual variable costs for fish fingerlings, fish feed, and plant seedlings is around $14,000, assuming that there are no labor costs and electricity is absorbed into the general operating expenses of the jail. Nonetheless, those costs are broken out in the tables provided by UVI.

Figure 4. Leaf lettuce being harvested from a raft hydroponic tank in the UVA aquaponic system in St. Croix.

CONCLUSION

Although the design of aquaponic systems and the combination of fish and plant production in a single system may seem complex, it is in fact quite simple to operate when the fish are stocked and fed at a rate that provides a good feeding rate ratio for plant production. Aquaponic systems are easier to operate than recirculating fish culture systems or hydroponic systems because they require less monitoring and have a wider margin of safety with regard to water quality. Aquaponic systems also provide excellent educational opportunities and are becoming increasingly popular in public schools. Finally, regardless of scale or purpose, the culture of fish and plants through aquaponics is a gratifying endeavor that is a sustainable approach to food production.

Tanks needed for UVI Aquaponic System									
Quantity	Size	Item	Purpose	Modification	Influent water	Efluent water	Price Each		
4	4' high x 10' diameter	circular tank	fish production tank	4" PVC female adapter coupling as drain in center bottom. Coupling is fiberglassed to outside tank bottom with threaded end flush to inside bottom of tank.	sump	center drain to clarifier - 4" pipe	$1,870	$7,480	
2	4' high x 6' diameter cylinder with 45º slope x 6' diameter bottom	cylinder tank top with cone bottom	clarifier solids removal	install PVC sheet as baffle in center and 2/3 point of the tank - 2" PVC coupling at apex for drain/connection of solid waste	fish production tanks (2 tanks supply water to 1 clarifier)	one pipe connecting to net tank - 4" pipe	$1,932	$3,864	
4	6' long x 2' wide x 2.5' high	rectangular tank	net tank for fine solids removal	cut 6" opening in sidewall of each tank to connect with PVC pipe.	clarifier	degassing tank - 4" diameter pipe	$500	$2,000	
1	6' long x 2.5' wide x 2.5' high	rectangualr tank	degassing tank	cut 6" holes in bottom and install stand pipe connecting to hydroponic tank.	net tank	hydroponic tanks 6" pipe	$500	$500	
6	4' wide x 100' long x 16" high	poured concrete wall	hydroponic tank	line with 9' x 106' P2000 LDPE 23 mil. Fit with 6" flange between tanks and to sump.	degassing tank	sump - 6" pipe	$1,000	$6,000	
1	4' high x 4' diameter	circular tank	sump	incoming pipe from hydroponic tank and outgoing pipe to pump/fish production tanks.	hydroponic tank	fish tank - 3" pipe	$370	$370	
1	2.7' high x 2' diameter	circular tank	base addition	incoming pipe from sump and outgoing pipe to sump.	sump	sump - 1.5" pipe	$155	$155	
									$20,369
Air Blower and Water Pump for UVI Aquaponic System									
Quantity	Size	Item	Item code	Supplier	Unit price	Total Cost			
1	1.5 HP	Air Blower Sweetwater 3 Phase	8453	Aquatic Ecosystms	739.00	$ 739.00			
1	2 HP	Air Blower Sweetwater 3 Phase	863	Aquatic Ecosystms	797.00	$ 797.00			
1		Circulating Pump Grundfos 3 Phase	UMC 80-80 or similar	Grundfos vendor	1268.10	$ 1,268.10			
									$ 2,804.10
Hydroponic tank liner and rafts									
1	12' x 750' LDPE liner	Hydroponic tank liner	P2000 WHT/WHT	Inland Plastics Ltd.	2187.50	$ 2,187.50			
63	1" x 4" x 10' lumber	Lumber (rip to 1" x 2" to attach liner to tank walls)		Local lumber yard	7.35	$ 463.05			
400	2.25" x 3/16"	Tapcon screw		Local hardware store	0.25	$ 100.00			
72	1.5" x 4' x 8'	Hydroponic rafts	Styrofoam square edge Extruded Polystyrene Insulation	Dow Chemical Co. vendor	35.00	$ 2,520.00			
1	3/8" x 4' x 8' plywood	template for rafts.		Local lumber yard	28.00	$ 28.00			
4	gallon	Cool-Cote Paint	Non-toxic Roof Paint	Paint Locker	22.00	$ 88.00			
2	case	2" x 2" net pots	SW559	Hydro-Gardens	142.95	$ 285.90			
									$ 5,672.45
									$ 11,158.45
								Total	$40,004.00

PVC Fittings, Parts and Other Supplies					
Quantity	Size	Item	Item code	Unit price	Total Cost
12	6"	pipe flange SCH 80 solid ty	851060 Total	$ 49.80	$ 597.60
18	6"	90º elbow	406060 Total	$ 37.30	$ 671.40
2	6"	T	401060 Total	$ 58.45	$ 116.90
3	6"	flexable coupling (fernco)	*1056-66 Total	$ 9.72	$ 29.16
2	4"	cap	447040 Total	$ 10.88	$ 21.76
4	4"	male coupling	436040 Total	$ 9.45	$ 37.80
4	4"	female coupling	435040 Total	$ 9.87	$ 39.48
4	4"	45º elbow coupling	417040 Total	$ 22.71	$ 90.84
16	4"	90º elbow coupling	406040 Total	$ 17.46	$ 279.36
1	3/4" MPT	float valve	*R7003 Total	$ 25.90	$ 25.90
3	3/4"	female adapter	435007 Total	$ 0.63	$ 1.89
1	3/4"	water meter	*FM2 Total	$ 69.93	$ 69.93
1	3" x 2"	reducer bushing	437338 Total	$ 4.75	$ 4.75
4	3"	cap	447030 Total	$ 4.78	$ 19.12
4	3"	coupling	429030 Total	$ 5.51	$ 22.04
1	3"	4 way cross	420030 Total	$ 20.24	$ 20.24
11	3"	90º elbow	406030 Total	$ 9.68	$ 106.48
7	3"	T	401030 Total	$ 14.27	$ 99.89
4	2" x 1"	slip x FNPT	438249 Total	$ 2.85	$ 11.40
6	2" x 1"	reducer bushing	437249 Total	$ 1.97	$ 11.82
1	2"	cap	447020 Total	$ 1.37	$ 1.37
2	2"	male adapter	436020 Total	$ 1.71	$ 3.42
2	2"	female adapter	435020 Total	$ 1.76	$ 3.52
4	2"	45º elbow	417020 Total	$ 3.13	$ 12.52
21	2"	90º elbow	406020 Total	$ 2.73	$ 57.33
7	2"	T	401020 Total	$ 3.30	$ 23.10
2	1"	male adapter	436010 Total	$ 0.81	$ 1.62
6	1"	female adapter	435010 Total	$ 0.74	$ 4.44
4	1"	poly plug	*114-C Total	$ 1.68	$ 6.72
4	1"	T poly hose nipple	*107-C Total	$ 2.06	$ 8.24
4	1"	90º elbow poly hose nipple	*105-C Total	$ 1.79	$ 7.16
8	1"	male threaded poly hose ad	*103-C Total	$ 0.89	$ 7.12
4	3"	ball valves	SBW18	$ 48.55	$ 194.20
1	2"	ball valve	SBW17	$ 12.92	$ 12.92
1	2"	4 way cross	420020	$ 6.58	$ 6.58
4	2"	ball valve	SBW17	$ 12.92	$ 51.68
725	ft.1"	poly tube	P300	$ 0.45	$ 326.25
2	3"	toilet flange		$ 5.00	$ 10.00
2	6"	cap	448060	$ 10.95	$ 21.90
2	5 gallon	bucket		$ 5.00	$ 10.00
2	2"	ball valve	SBW17	$ 12.92	$ 25.84
4	14' x 100'	orchard netting		$ 62.10	$ 248.40
8	1" x 2" x 7'	ceder wood slats		$ 5.00	$ 40.00
16	4" x 4"	flat angle braces		$ 1.00	$ 16.00
8	yards 1000 micron	nylon net material	M1000	$ 18.47	$ 147.76
10	ft. 3/4"	plastic mesh screen (vexar)	TN524	$ 4.75	$ 47.50
3	sheets 3/8" x 4' x 8'	4'x8' PVC sheet		$ 40.00	$ 120.00
72	2" x #8	stainless steel screws		$ 0.50	$ 36.00
176	6" x 1.5"	airstones	AS15L	$ 7.84	$ 1,379.84
88	1/4" NPT x 3/8" Barb	nipples	62008	$ 0.30	$ 26.40
4	3/8" i.d.	vinyl hose	TV60	$ 25.32	$ 101.28
150	3" x 1"	airstones	AS5L	$ 2.97	$ 445.50
150	1/4" NPT x 1/4" barb	nipples	62006	$ 0.30	$ 45.00
6	1/4" i.d.	vinyl hose	TV40	$ 20.63	$ 123.78
6	tube	silicone		$ 5.00	$ 30.00
8	gallon	fiberglass resin and hardner		$ 20.00	$ 160.00
10		fiberglass mat		$ 10.00	$ 100.00
10		paper buckets -disposable		$ 1.00	$ 10.00
10		paint brushes - disposable		$ 1.00	$ 10.00
50		latex gloves - disposable		$ 0.50	$ 25.00
10		dust mask - disposable		$ 2.00	$ 20.00
1	organic vapor	vapor mask		$ 25.00	$ 25.00
3	1"	ball valve (slip x slip)		$ 4.50	$ 13.50
1	48'x30'	Quonsset greenhouse		$ 2,693.80	$ 2,693.80
1	48'x47'	100% shade cloth		$ 500.00	$ 500.00
PIPE					
120	6"	PVC pipe		$ 4.00	$ 480.00
80	4"	PVC pipe		$ 4.00	$ 320.00
100	3"	PVC pipe		$ 4.00	$ 400.00
120	2"	PVC pipe		$ 4.00	$ 480.00
10	1"	PVC pipe		$ 4.00	$ 40.00
					$ 11,158.45

Fish budget (lbs)

		Units	Price or Cost/Unit	Quantity	Value or Cost per system	Value or Cost per lb. produced	Value or Cost per 6 systems	Standard Budget
Receipts								
	Tilapia	lbs	$ 2.50	11,000	$ 27,500.00	$ 2.50	$ 165,000.00	
Variable Costs								
	Fingerlings	ea	$ 0.30	5,220	$ 1,566.00	$ 0.14	$ 9,396.00	6.1%
	Feed	lb	$ 0.53	18,700	$ 9,945.00	$ 0.90	$ 59,670.00	39.0%
	Chemicals							
	KOH	lb	$ 0.58	400	$ 232.23	$ 0.02	$ 1,393.39	0.9%
	Ca(OH)2	lb	$ 0.26	400	$ 104.10	$ 0.01	$ 624.62	0.4%
	Electrical	kwh	$ 0.40	14,235	$ 5,694.00	$ 0.52	$ 34,164.00	22.3%
	Manager Labor	system	$ 30,000.00	0.083	$ 2,500.00	$ 0.23	$ 15,000.00	9.8%
	Hired Labor	system	$ 15,000.00	0.167	$ 2,500.00	$ 0.23	$ 15,000.00	9.8%
	Equipment	system	$ 496.00	1	$ 496.00	$ 0.05	$ 2,976.00	1.9%
Total VC	Total VC				$ 23,037.34	$ 2.09	$ 138,224.02	90.4%
Income above VC	Income above VC				$ 4,462.66	$ 0.41	$ 26,775.98	17.5%
Fixed Costs								
	Tanks and equipment		$ 1,807.11	1	$ 1,807.11	$ 0.16	$ 10,842.68	
Total FC					$ 1,807.11	$ 0.16	$ 10,842.68	7.1%
Total of above costs	Total Costs				$ 24,844.45	$ 2.26	$ 149,066.70	97.5%
Net returns	Net return				$ 2,655.55	$ 0.24	$ 15,933.30	
Other costs								
	Land Charge	System	$ 225.00	0.015	$ 3.37	$ 0.00	$ 20.24	0.01%
	General overhead	% VAR	2.8%	$ 23,037.34	$ 645.05	$ 0.06	$ 3,870.27	2.5%
Total Costs	All costs				$ 25,492.87	$ 2.32	$ 152,957.21	100.0%
Returns to Risk &Mgt.	Return to risk and management				$ 2,007.13	$ 0.18	$ 12,042.79	

Lettuce Budget

		Units	Price or Cost/Unit	Quantity	Value or Cost per system	Value or Cost per case	Value or Cost per 6 systems	Standard Budget
Receipts								
	Lettuce	case	$ 20.00	1,404	$ 28,080.00	$ 20.00	$ 168,480.00	
Variable Costs								
	Seedlings	ea	$ 0.0130	44,928	$ 584.38	$ 0.42	$ 3,506.30	5%
	Chemicals					$ -		
	Fe	lb	$ 13.18	37	$ 493.00	$ 0.35	$ 2,958.00	4%
	Insecticide	bags	$ 16.00	12	$ 192.00	$ 0.14	$ 1,152.00	2%
	Electrical	kwh	$ 0.40	9,125	$ 3,650.00	$ 2.60	$ 21,900.00	30%
	Manager Labor	system	$ 30,000.00	0.083	$ 2,500.00	$ 1.78	$ 15,000.00	21%
	Hired Labor	system	$ 15,000.00	0.167	$ 2,500.00	$ 1.78	$ 15,000.00	21%
	Equipment	system	$ 50.00	1	$ 50.00	$ 0.04	$ 300.00	0%
Total VC	Total VC				$ 9,969.38	$ 7.10	$ 59,816.30	
Income above VC	Income above VC				$ 18,110.62	$ 12.90	$ 108,663.70	
Fixed Costs								
	Tanks and equipment		$ 1,911.60	1	$ 1,911.60	$ 1.36	$ 11,469.59	16%
Total FC					$ 1,911.60	$ 1.36	$ 11,469.59	
Total of above costs	Total Costs				$ 11,880.98	$ 8.46	$ 71,285.88	
Net returns	Net return				$ 16,199.02	$ 11.54	$ 97,194.12	
Other costs								
	Land Charge	System	$ 225.00	0.048	$ 10.80	$ 0.01	$ 64.81	0%
	General overhead	% VAR	2.8%	$ 9,969.38	$ 279.14	$ 0.20	$ 1,674.86	2%
Total Costs	All costs				$ 12,170.92	$ 8.67	$ 73,025.55	100%
Returns to Risk &Mgt.	Return to risk and management				$ 15,909.08	$ 11.33	$ 95,454.45	