Economic Analysis Of A Commercial-Scale Aquaponic System For The Production Of Tilapia And Lettuce

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Introduction

A commercial-scale aquaponic unit has been developed at the University of the Virgin Islands. A demonstration trial has shown that the unit can produce red tilapia and leaf lettuce on a sustainable basis at commercial levels. The unit attains economic efficiency by making multiple use of resources, primarily water and nutrients, and sharing certain infrastructural, management and labor costs. A commercial aquaponic industry is now developing in the Virgin Islands to take advantage of this technology and provide consumers with fresh, high quality products.

To fully understand the commercial potential for these systems a financial analysis of existing production data was conducted. This analysis used pro forma enterprise budgets for each subsystem, fish and lettuce, and studied individual costs and their impact on the total production cost. A break-even analysis of price and quantity determined appropriate sales volume and price for each product to cover costs. The purchase price and installation costs for construction of the infrastructure and production units were estimated to understand the capital requirements of the farm. A cash flow budget was developed from this data and from production projections. The net present value and the internal rate of return for the investment were then calculated. These values can be used to compare this investment to other investment options.

An optimized model system, which incorporated the best design features for an aquaponic farm, was used in this financial analysis. An aquaponic unit similar to the one proposed is more fully described by Rakocy et al. (this publication). That unit produced red tilapia and three varieties of leaf lettuce continuously for 2.5 years. There were 19 fish harvests and 112 lettuce harvests.

Several design modifications were made to the system as a better understanding of the biology and nutrient dynamics was gained during the operational period. These changes were included in the design of the model system.

Three farm sizes consisting of 6, 12 or 24 production units were analyzed. As farm size increases, savings in the cost of infrastructure, goods and management can be obtained

System setup and operation

Each unit of the model system was composed of four fish rearing tanks, two cylindro-conical clarifiers, four filter tanks with orchard netting for trapping fine solids, a header tank, two hydroponic tanks, a sump and a ½hp in-line water pump. The hydroponic tanks were 29.7 m long x 3.7 m wide, and constructed of poured concrete walls and low-density polyethylene (LDPE) liners. Each hydroponic tank contained 36 polystyrene sheets (1.22 x 2.44 m). These components are listed in Table 1.

Water was pumped from the sump to the rearing tanks, from which it flowed by gravity into the clarifiers, filter tanks and hydroponic tanks. It then returned to the sump. No separate biofilter was required as the surface area in the hydroponic tanks and direct ammonia uptake by the plants provided sufficient biofiltration.

The four fish rearing tanks were stocked at six-week intervals with 800 tilapia fingerlings (30-50 g). Fish were harvested 24 weeks after stocking and the rearing tank was immediately restocked. Mean harvest weight was 357 kg (487 g/fish) and survival was 92%. During growout the fish were fed daily using a belt feeder from 6.0% body weight (initial) to 1.2% (final) using a floating pelleted ration (32% protein). An average of 558 kg of feed were required (feed conversion ratio = 1.76) for each production lot. There were 8.7 production cycles each year.

Three varieties (romaine, red leaf and green leaf) of lettuce seedlings were planted weekly into ¼ th of the hydroponic growing area (18 polystyrene sheets) at a density of either 48 or 60 plants per sheet, depending on the space requirements of the variety. Mature plants were harvested after 4 weeks of growth, packed at 24 heads per case and sold. New seedlings were immediately transplanted into the harvested area. There were 52 weekly lettuce harvests per year from each system.

In addition to the aquaponic production units each farm also consisted of the appropriate size of water, feed and cold storage facilities, office and work room areas, trucks, tractors and wagons, greenhouse nurseries, brood fish holding and breeding tanks and hatchery.

The weekly production of tilapia and lettuce for each farm size is listed in Table 2. Other operating assumptions (prices for operating costs, fixed costs, overhead and land charges) are listed in Table 3.

Marketing, sales and other post-harvest activities were not included in the analysis. Sales personnel can be hired on a commission basis to market and distribute farm production. They would not be needed by the 6-unit farm but would be required by the 12 and 24-unit farms.

Table 1. Items required, quantity, new cost, years of life and annual depreciation for the fish and lettuce production components of an aquaponic unit.

Item	Quantity	New Cost Each ($)	New Cost Total ($)	Years of Life	Annual Depreciation ($)
Fish Production Component					
Rearing tanks	4	1,200.00	4,800	20	240
Clarifiers	2	700.00	1,400	20	70
Net tanks	4	420.00	1,680	20	84
Cylindrical tank	1	112.00	112	20	6
Sump	1	280.00	280	20	14
Piping- water (ft.)	40	1.50	60	20	3
Piping- air (ft.)	40	1.50	60	20	3
Shade structure	1	600.00	600	20	30
Valves	4	11.00	44	10	4
Polyethylene pipe	100	0.20	19	10	2
Blower	1	665.00	665	10	67
Filter netting	400	17.00	7,000	10	700
Circulating pump	1	820.00	820	5	164
Shade roof	1	800.00	800	5	160
Anti-bird netting	4	20.00	80	5	16
Vertical-lift pump	4	280.00	1,120	3	373
Belt feeder	4	185.00	740	3	247
Airstones	40	9.40	376	1	376
Vinyl tubing (ft.)	160	0.18	28	1	29
Total			13,780		1,896
Lettuce Production Component					
Hydroponic tank	2	2,500.00	5,000	20	250
Piping- air (ft.)	40	1.50	60	20	3
LDPE liner	2	200.00	400	10	40
Polyethylene pipe (ft.)	200	0.20	39	10	4
Blower	1	665.00	665	10	67
Polystyrene sheets	72	15.00	1,080	5	216
Paint	5	20.00	100	5	20
Airstones	300	3.50	1,050	1	1,050
Vinyl tubing (ft.)	600	0.18	108	1	108
Total			8,863		1,829
Aquaponic Unit - Total			22,642		3,726

Table 2. Weekly production of tilapia and lettuce from aquaponic farms with 6, 12 or 24 production units.

Farm size (production units)	6	12	24
Tilapia (kg.)	357	714	1428
Lettuce (cases)	210	420	840

System Capital Costs

An initial capital outlay was required to finance the development and construction of the farm. The total value per production unit was approximately $22,642 (Table 1). The table was subdivided into fish and lettuce components for analysis of the costs associated with each component including a calculation of the break-even price and quantity for the product. The fish and lettuce production components cost $13,780 and $8,863 respectively. Individual items were listed with their unit price, number required per production unit, total cost for the item, years of expected useful life and annual depreciation expense. Each item in the table had an estimated useful life and was depreciated over that time period by straight line depreciation with no salvage value. The depreciation expense was used as a portion of the fixed costs reported in the enterprise budget. Depreciation expense for the fish and lettuce production components was $1,896 and $1,829 respectively. Farms with 6, 12 or 24 production units will have $135,852, $271,704 or $543,408 in capital costs, respectively.

Additional capital expense ($149,282 for 6 units, $268,564 for 12 units or $487,128 for 24 units) for infrastructure was required. This infrastructure provided support services to the production units. The farm produced its own tilapia fingerlings in a breeding and hatchery facility ($37,293, $74,586 or $149,172). It also produced lettuce seedlings in greenhouses ($2,900 $5,800 or $11,600) and rainwater collection and storage facilities were needed ($59,089, $118,178 or $236,356). Farm offices, workrooms, cold feed storage, and farm vehicles were also included as capital expenses ($50,000, $70,000 or $90,000).

Operating costs

Variable costs were those costs that change with different production output levels. They were identified with the production component to which they were most closely associated and were included only in that component's enterprise budget. Fingerlings, feed, pH balancing chemicals, electricity and labor were costs associated with fish production. Seedlings, packing boxes, chemical fertilizer, and labor were the costs associated with lettuce production. As the size of the farm increased these items were used in greater quantity. Increased quantities were reflected in the enterprise budgets for each farm (Tables 4 and 5).

Table 3. Assumptions used for an economic analysis of a commercial aquaponic unit for the production of red tilapia and hydroponic lettuce.

1.	Each system produced 357 kg of red tilapia every 6 weeks. Harvested fish were sold for $ 5.51 per kg.
2.	Each system produced 35 cases (24 heads/case) of lettuce every week. Cases of lettuce were sold for $20 each.
3.	Eight hundred, 30-50 gram fingerlings were stocked in each tank for grow-out. Fingerlings were produced on the farm for $1.23 each.
4.	Feed was an extruded, floating complete tilapia diet (32% protein) and was delivered using a belt feeder. Fish were fed 6% initial BW daily for the first week and to satiation with weekly feed increments for the remaining 23 weeks of growout. Feed cost $0.66 per kg.
5.	Aeration was supplied to all rearing tanks and to the hydroponic tanks with diffused air from 2 regenerative blowers, 1 hp and ½hp. Supplemental aeration was provided by a vertical-lift pump for the final 12 weeks of growout. Water was pumped through the system with a ½hp circulating pump. Electricity cost $0.10 per kWh.
6.	The system consisted of four circular fiberglass rearing tanks, two conical bottom clarifiers, four rectangular filter net tanks, one cylindrical header tank, two hydroponic tanks, and one fiberglass reservoir. (See Rakocy et al., this publication.) The system components cost $31,232 to purchase and construct.
7.	The number of managerial and hired employees varied with the size of the farm. The farm manager's salary is $40,000 for the 6 and 12-unit farms and increased to $50,000 per year for the 24-unit farm. Hired farm laborer salary was $15,000 per year.
8.	A brood fish holding tank, spawning tanks and fry rearing system were included in the ancillary support infrastructure of the farm. Capital cost of the unit was $37,293 with an annual operating budget of $8,428.
9.	Greenhouses were constructed for the production of lettuce seedlings. Capital cost of the unit was $2,900 with an annual operating budget of $18,875.
10.	Support services for administrative tasks were included in a general overhead budget category at 2.8% of the operating budget applied to each component.
11.	Land is rented from the government for $247 per hectare per year.
12.	Budgets and cash flow projections were presented on a pre-tax basis.

Table 4. Yearly enterprise budgets for the tilapia production component of three model aquaponic farms having 6, 12 or 24 units.

		Units	Price or Cost/Unit ($)	Quantity per unit	Value or Cost per 6 units ($)	Value or Cost per 12 units ($)	Value or Cost per 24 units ($)
Receipts							
	Tilapia	kg	5.51	3,094	102,334	204,668	409,336
Variable Costs							
	Fingerlings	ea.	1.23	7,200	53,136	106,272	212,544
	Feed	kg	0.66	5,260	20,829	41,658	83,315
	Chemicals						
	KOH	kg	1.30	100	780	1,560	3,120
	$Ca(OH)_2$	kg	0.12	100	72	144	288
	Electrical	kWh	0.10	10,400	6,240	12,480	24,960
	Supplies	unit	2,423.20	1	14,539	29,078	58,157
	Manager	unit	variable[a]	0.083	20,000	20,000	25,000
	Hired Labor	unit	15,000.00	0.083	15,000	15,000	30,000
	Maintenance	unit	15,000.00	0.083	7,500	7,500	15,000
Total VC					138,096	233,692	452,384
Income above VC					(35,762)	(29,024)	(43,048)
Fixed Costs							
	Depreciation expense		1,896.68	1	11,380	22,760	45,520
Total FC					11,380	22,760	45,520
Total of above costs					149,476	256,452	497,904
Net returns					(47,142)	(51,784)	(88,568)
Other costs							
	Land Charge	ha/yr.	247.00	0.025	43	86	173
	General overhead	% VC	2.8%	30,176.13	5,070	0,139	20,278
Total Costs					154,589	266,678	518,355
Returns to Risk &Mgt.					(52,255)	(62,010)	(109,019)

[a] Manager salary was $40,000 for 6 and 12-unit farms and $50,000 for 24-unit farms

Table 5. Yearly enterprise budgets for the lettuce production component of three model aquaponic farms having 6, 12 or 24 units.

		Units	Price or Cost/Unit ($)	Quantity per unit	Value or Cost per 6 units ($)	Value or Cost per 12 units ($)	Value or Cost per 24 units ($)
Receipts							
	Lettuce	cases	20.00	1,820	218,400	436,800	873,600
Variable Costs							
	Seedling transplants	ea.	0.05	67,600	20,280	40,560	81,120
	Boxes	ea.	2.00	1,820	21,840	43,680	87,360
	Chemicals						
	Chelated Iron	kg	5.70	17	581	1,163	2,326
	Electrical	kWh	0.10	5,200	3,120	6,240	12,480
	Manager	unit	variable[a]	0.083	20,000	20,000	25,000
	Hired Labor	unit	15,000.00	0.083	45,000	90,000	180,000
	Maintenance	unit	15,000.00	0.083	7,500	7,500	30,000
Total VC	Total VC				118,321	209,143	418,286
Income above VC					100,079	227,657	455,314
Fixed Costs							
	Depreciation		1,829.45	1	10,977	21,953	43,907
Total FC					10,977	21,953	42,907
Total of Above Costs					129,298	231,096	462,192
Net Returns	Net return				89,102	205,704	411,408
Other Costs							
	Land Charge	ha/yr.	247.00	0.034	148	299	598
	General overhead	%VC	2.8%	35,345.23	5,938	11,876	23,752
Total Costs					135,385	243,271	486,543
Returns to Risk &Mgt.					83,015	193,529	387,057

[a] Manager salary was $40,000 for 6 and 12-unit farms and $50,000 for 24-unit farms

Management and maintenance labor were shared between enterprises and were divided equally between the two components. Only one manager was required for all farm sizes. The manager's salary increased from $40,000 per year for 6 and 12-unit farms to $50,000 for a 24-unit farm. One maintenance employee was needed for farms with 6 and 12 units and two were needed for a 24-unit farm. The maintenance employee's wage was equally divided between the enterprises. Hired labor wages were allocated for each component. One hired laborer was needed for the operation of the fish component and four were needed for the lettuce component of the 6-unit farm. Hired labor wages were $15,000 per employee per year. In a 12-unit farm, one employee was required for the fish component and eight employees were required for the lettuce component. In a 24-unit farm, two and 16 employees were required for the fish and lettuce components, respectively. Other employees were needed to operate the hatchery and greenhouse facilities. Total employee needs are listed in Table 6.

Table 6. Employee number by type for aquaponic farms with 6, 12, or 24 production units.

Farm size	6	12	24
Management	1	1	1
Hired labor	5	9	18
Maintenance	1	1	2
Total	7	11	21

Budget Analysis

Total fixed and variable costs exceeded receipts from tilapia sales (Table 4). The tilapia production enterprise produced negative returns of $-52,255, $-62,010 and $-109,019 for the three farms. Fingerlings purchased at cost from the hatchery contributed 38, 45 and 47% of the variable costs for the three farms. Fish feed, variable costs of 15, 18 and 18% respectively, were the second largest contributor to total variable cost,

The high fingerling cost was attributed to the labor required for fingerling production and the extensive brood fish holding and fingerling rearing facilities required. Reducing the price of fingerlings by 50% to $0.62 would bring positive returns to risk for the largest farm (24 units). There may be an opportunity to reduce costs for fingerling production with more efficient use of brood fish and labor and a reduction in holding facilities.

The break-even price for variable costs decreased from $7.44 per kg for a 6-unit farm to $6.29 and $6.09 per kg for a 12 and 24-unit farm, respectively. The sale price of tilapia was $5.51/ kg, lower than the cost of production. Break-even price for all variable, fixed, land and overhead costs was $8.33, $7.18 and $6.98.

Lettuce production contributed significant returns to risk for the lettuce component and the whole farm (Table 5). Returns of $83,015, $193,529 and $387,057 were realized for the 6, 12, and 24-

unit farms. Hired labor was the largest variable cost for this component, contributing 38-45% of the costs. Seedling transplants (17-20%) and packing boxes (18-22%) were the next highest contributors to variable cost.

Harvesting and packing lettuce was very labor intensive. The polystyrene sheets were lifted out of the system and placed on a support stand to facilitate harvesting. The lettuce plants were removed from the sheets and their roots were cut off. The lower leaves were trimmed and the plants were inspected for quality before packing. After the harvest the polystyrene sheets and the net pots which held the plant were cleaned. The sheets were returned to the system and the net pots were inserted individually into their spaces. New seedlings were then transplanted individually into the pots. All these tasks were time consuming and could not be easily automated. Labor expenses could be reduced by using part time labor without benefits and paying the minimum wage to harvest employees.

The break-even prices for variable costs were $10.84, $9.58 and $9.58/case for 6, 12 and 24-unit farms, respectively. The break-even prices for total costs were $12.40, $11.14 and $11.14. These prices were below the sale price of $20 per case that the farm was able to receive in the market.

Table 7. Enterprise budgets for three model aquaponic farms with 6, 12 or 24 tilapia and lettuce production units, and necessary infrastructure to support fingerling production, lettuce seedling production, water storage, land costs and general overhead.

		Value or Cost per 6 units ($)	Value or Cost per 12 units ($)	Value or Cost per 24 units ($)
Revenue				
	Fish	102,334	204,668	409,336
	Lettuce	218,400	436,800	873,600
Total Revenue		320,734	641,468	1,282,936
Variable Cost				
	Fish	138,096	233,692	452,384
	Lettuce	118,321	209,143	418,286
Total VC		256,417	442,835	870,670
Income Above VC		64,317	198,633	412,267
Fixed Cost				
	Fish	11,380	22,760	45,520
	Lettuce	10,977	21,953	43,907
Total FC		22,357	44,714	89,427
Total VC and FC Costs		278,774	487,548	960,097
Net Returns		41,960	153,920	322,840
Other Costs		11,199	22,400	44,801
Total of All Costs		289,973	509,949	1,004,898
Returns to Risk		30,761	131,519	278,038

The individual component enterprise budgets for each farm are combined in Table 7. Due to the high revenues gained by lettuce sales, all variable and fixed costs were covered. All three farm sizes had positive returns to risk and were viable investments.

Cash flow projections were made over a 20-year period for each of the three farms. There was an initial cash outlay to purchase capital items for the construction of the facility. In the following years there were operating expenses and revenues generated from sales. Capital items with useful lives of less than 20 years were replaced at the end of their depreciation period and those costs were subtracted from revenues for that year. The net present value (NPV) and internal rate of return (IRR) were calculated for each of the model farms. A discount rate of 20% was used to calculate the NPV. At that level only the 24-unit farm is profitable. The internal rate of return, which gives the actual rate of return for the investment was 11.1% for a 6-unit farm, 17.9% for a 12-unit farm and 21.7% for the 24-unit farm. Investors must determine their requirements for acceptable returns when choosing their farm size. If the IRR is too low, than other investment opportunities must be found.

Table 8. Net present value (NPV) and internal rate of return (IRR) for 3 model aquaponic farms having 6, 12, or 24 units.

Farm size	6	12	24
NPV (20%)	$(127,655)	$(60,208)	$116,508
IRR	11.1%	17.9%	21.7%

Conclusion

Aquaponic farms can be profitable in the U.S. Virgin Islands. The lettuce component of the model farms contributed revenues that exceeded their cost of production and the tilapia production costs not covered by sales. Each farm size had positive returns but at different rate of return for the investment. The smallest farm has the lowest return and may not be an acceptable investment given the risks associated with aquaponic farming. Higher, and more acceptable returns were achieved with larger farms of 12 or 24 production units.

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References

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