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The Economics of Recirculating Tank Systems:

A Spreadsheet for Individual Analysis

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A well-designed recirculating aquaculture system offers a number of advantages over pond systems. Designed to conserve both land and water resources, recirculating systems can be located in areas not conducive to open pond culture. Operators have a greater degree of control of the fish culture environment and can grow fish year-round under optimal conditions. The crop can be harvested at any time, and inventory can be much more accurately determined than in ponds. This latter characteristic is particularly beneficial when trying to gain financing or insurance for the crop.

Because of these advantages, interest in water recirculating systems for fish production continues to grow, despite the lack of economic information available on their use. This publication and accompanying spreadsheet are designed to help prospective recirculating system operators examine the economics of proposed systems. With modifications to the example spreadsheet, the same format can be used to monitor costs and returns once systems are operating. The Excel spreadsheet can be downloaded from the following Internet address: http://www.agr.state.nc.us/aquacult/rass.html.

The spreadsheet in this publication uses tilapia for the example species. However, the resulting figures on costs and returns are not meant to be used as an economic analysis of tilapia production. Each individual using the spreadsheet should input equipment and supply costs and the appropriate market price for the specific system being analyzed.

System design

There is no single recommended design for growing fish in a recirculating aquaculture system (RAS). In general, a system includes tanks to culture fish, pumps to maintain water flow, and some form of water treatment to maintain water quality. Following are a few general considerations on system design and how design can affect profitability. For a more complete explanation of component options and management issues see SRAC publications 450, 451 and 452.

Proper sizing of all system components is very important. If equipment is oversized for the application, the system will function but will be very costly. If equipment is undersized, the system will not be able to maintain the proper environment to sustain fish production.

Operators should size equipment according to the maximum daily amount of feed placed into the system. The estimated daily feed rate is based on the system carrying capacity, which does not usually exceed 1 pound of fish per gallon of water for even the most efficient system. Once carrying capacity and feed rate are defined, the operator estimates the size of equipment components by calculating the required flow rate. The flow rate of each component must be sufficient to flush out and treat any wasted feed and by-products of fish metabolism, while supplying a uniform concentration of oxygen.

Because equipment is sized to maximum feeding rates, the most inefficient stock management method is to stock fingerlings at low densities in a tank and grow them to market size within the same tank. Most RAS operators try to make maximum use of each

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tank's carrying capacity by stocking fish at increasingly lower numbers as the fish grow in size. The more efficient the use of system carrying capacity, the more fish can be moved through the system annually, which generally lowers the cost per pound harvested. The trade-off is that the more often fish are restocked, the higher the labor cost and greater the chance of mortality if fish become stressed from the move.

Operators also face a trade-off when determining both the size of tanks and the configuration of equipment for filtering and oxygenating water. The use of fewer, larger tanks, or several tanks sharing water treatment equipment, is usually much less expensive than having a number of smaller tanks that do not share water or components. Managing quality and disease prevention, however, is typically more effective where water is not shared between tanks. There is less risk of losing large portions of the fish crop when each tank has its own set of treatment equipment.

There are economies of scale for individual tank size and for the size of the entire system. Up to a point, the increase in system size generally results in a lower cost per pound produced, because the fixed costs associated with the building and equipment can be spread over more pounds harvested.

The example system

The data used for this publication are taken from experiences in a small unit at the North Carolina State University Fish Barn Project (NC Fish Barn).

The NC Fish Barn system grows fish in nursery tanks, then grades and splits the population into larger growout tanks as the fish gain weight. The system consists of six tanks: one 1,500-gallon (5.68-cubic meter) quarantine tank (Q); a 4,000-gallon (15.14-cubic meter) nursery tank (N), and four 15,000-gallon (56.78-cubic meter) growout tanks (G1, G2, G3 and G4). The quarantine and nursery tanks have their own water filtration systems, while each pair of growout tanks shares a water treatment system. A more detailed description of the system and equipment can be found in Hobbs et al., 1997.

Fish are initially stocked in the Q tank, screened for diseases for 35 days, then harvested and restocked into the N tank. After 35 days, the fish are transferred to one of the four G tanks where they remain an additional 140 days until harvest. This 140-day period is broken down into four distinct production units of 35 days each (defined as g1, g2, g3 and g4 in the spreadsheet). Each of these units has a different feed rate, oxygen demand, and pumping need. (An alternative to this configuration would be to move the fish into a different tank for each of the 35-day periods).

Once the system is fully stocked, one of the four G tanks is harvested for sale every 35 days. The system has a maximum culture density of 0.8 pounds of fish per gallon of water (103 kgs of fish per cubic meter of water) in each growout tank, and each harvest yields approximately 12,400 pounds (5,636 kgs) of fish. With 10.43 harvests annually (one every 35 days once the facility is fully stocked), total production for the facility is approximately 130,000 pounds (59,091 kgs) per year.

Using the spreadsheet

The Recirculating Aquaculture System Spreadsheet (RASS) must be supplied with accurate and realistic input data based on a properly designed system. Proper design means that the equipment components work together to produce the amount of fish in the time period stated.

The spreadsheet is divided into five sections. The user supplies information for the first three sections. Data in the final two sections are calculated from this information. Shaded areas in the tables indicate needed information and are represented as bold type in the spreadsheet. "Spreadsheet Cell Range" and cell numbers refer to the location of information within the Excel spreadsheet.

Section 1: Specify the Initial Investment Spreadsheet Cell Range B13:E25

The initial investment cost is supplied by the user in cells E16:E20. The total is calculated in cell E21. The investment includes the total value of purchased land, a settling pond, building, equipment, and construction labor, as well as the current value of any owned assets used in the business.

Annual depreciation on building and equipment (E22) is the amount of money that must be earned each year by the business to eventually replace equipment when it wears out.

Interest rate on operating capital (E24) is used to calculate a cost of interest on variable inputs (oxygen, energy, bicarbonate, fingerlings, chemicals, maintenance and labor). The interest charge could be interest owed to a bank for the financing of the purchase of these inputs, or the charge could be for the cost of using the owner's own funds to purchase variable inputs. A cost of using owner's funds is used because the investment of funds in the recirculating system means that the owner foregoes potential earnings from an alternative investment.

Interest rate on building and equipment (E25) is used to calculate an annual interest charge based on the average investment. Again, this could be interest owed on a bank loan used to finance the initial investment, or it can represent earnings that could have been made on an alternative investment.

Section 1.
Specify the Initial Investment
Spreadsheet Cell Range = B13:E25

Initial investment	
land	$8,000
settling pond	$5,000
equipment	$172,500
building	$60,000
construction labor & overhead	$30,000
Total initial investment	$275,000
Annual depreciation on building and equipment	$19,100
Interest rate on operating capital	9%
Interest rate on building and equipment	11%

System parameters

The remainder of this section (E48..E54) contains system parameters that will be needed for calculations related to costs and returns. *Annual production* (E48), *Average size at harvest* (E49), and the *Survival rate* (specified in the next section) are used to calculate the initial stocking density.

There are six production units in this example (*Number of production units* [E50] = 6). As discussed above, a production unit refers to a specific tank or life stage of the fish. Here, three tanks are used: a Q tank, an N tank and a G tank. Fish remain in the Q tank and N tank for 35 days each. Within the

Section 2: Specify the Cost of Inputs, Sale Price, and System Parameters
Spreadsheet Cell Range = B27:E54

Variable costs

Variable costs are those directly related to production. In the cell range E31:E38 the user specifies the cost per unit of oxygen, energy, bicarbonate, fingerlings, chemicals, maintenance and labor. The quantity used of each of these inputs is defined in Section 3.

Fixed costs

Fixed costs are incurred regardless of whether or not production occurs. They are *Liquid oxygen tank rental* (E41), *Electrical demand charge* (E42), and *Building overhead* (E43). Each of these is specified as a cost per month.

Sale price

Average overall sale price (E45) is the weighted average sale price per pound, taking into account the size distribution at harvest and differing prices for various sizes of fish. The example uses $1.25 so that the system will break even (with $0 profit and $0 losses).

Section 2.
Specify the Cost of Inputs, Sale Price, and System Parameters
Spreadsheet Cell Range = B27:E54

	unit or description	cost or amount
Variable Costs:		
Liquid oxygen	$/100 cu. ft.	$0.30
Energy	$/kwh	$0.065
Bicarbonate	$/lb.	$0.190
Fingerlings	$/fingerling	$0.090
Chemicals	$/cycle	$100.00
Maintenance	$/month	$637.00
Labor: management	$/month	$2,000.00
Labor: transfer & harvest	$/hour	$6.50
Fixed Costs:		
Liquid oxygen tank rental	$/month	$250.00
Electrical demand charge	$/month	$100.00
Building Overhead	$/month	$100.00
Average overall sale price	$/lb.	$1.25
System Parameters		
Annual production	lb.	129,107
Average size at harvest	lb.	1.25
Number of production units	number	6
Days per production unit	days	35
Kwh per lb. of production	kwh/lb. of prod.	2.30
System volts	volts	230
Transfer/harvest labor	hrs. per cycle	64

G tank, the fish go through four 35-day stages. Note that the *Days per production unit* (E51) must be the same for each unit in order for the spreadsheet to accurately calculate costs and returns in Section 5.

The *Kwh per lb. of production* (E52) is used to calculate energy costs for the total system and each production unit. This variable is calculated by adding up the total KW usage of the system—including energy usage for pumps, blowers and other equipment as well as heating, ventilation and air-conditioning—converting this to kwh used per year, and then dividing by the number of pounds produced. (For the example, the total energy demand is 34 KW. Multiply by 24 hours per day and 365 days per year, then divide by annual production of 129,107 pounds to arrive at 2.30 kwh per pound of production).

System volts (E53) is used to calculate required amperage in Section 5. This is a useful number for planning energy requirements for the facility.

Transfer/harvest labor (E54) is the number of hours of labor required per cycle in addition to *Labor: management* (defined in E37).

Section 3: Specify Operating Parameters per Production Unit
Spreadsheet Cell Range B56:J64

Each column in this section represents a production unit, which could be a tank or group of tanks managed in the same manner, or it could refer to a particular life stage. For example, two tanks stocked at the same time with the intent to transfer and harvest fish at the same time, and in which fish are fed and managed in the same manner, could be treated as one production unit. Or, as in the table below and spreadsheet example, two of the six columns (Q & N) refer to particular tanks, while the remaining four (g1, g2, g3, g4) refer to a production stage for fish that remain within the same tank.

Section 3.
Specify Operating Parameters per Production Unit
Spreadsheet Cell Range = B56..J64

			Growout tank			
	Q tank	N tank	g1	g2	g3	g4
Water volume, gallons	1,500	4,000	15,000	15,000	15,000	15,000
Size stocked (grams)	1	15	60	135	250	385
Size harvested (grams)	15	60	135	250	385	567
Survival rate	85%	99%	99%	99%	99%	99%
Feed cost, per pound	$0.52	$0.38	$0.21	$0.21	$0.21	$0.21
Feed conversion	1	1.1	1.3	1.6	1.6	1.6

Water volume, gallons (E59:J69) is used to calculate the *Maximum standing biomass, lbs. per gal. of water* (E73:I73) for any one tank, discussed in Section 4.

Size stocked (E60:J60) is the average size of fish stocked into that production unit. *Size harvested* (E61:J61) is their average size when transferred or harvested from the system. In the example, fish are initially stocked at 1 gram into the Q tank, and transferred into the N tank when they reach 15 grams.

Survival rate (E62:J62) is the percentage of survival for that production unit. In the example, the lower survival rate for the Q tank includes the discarding of runts when the fish are graded before restocking into the N tank.

Feed cost, per lb. (E63:J63) is the average cost per pound for feed fed to that production unit. *Feed cost, per lb.* and *Feed conversion* (E64:E64) are used to calculate the cost of feed for each production unit, for each cycle, and annually. Feed usage is also used to calculate the amount of energy used, as discussed in the following section.

Spreadsheet calculation of costs and returns

Section 4: Use of Primary Inputs and Costs per Production Unit
Spreadsheet Cell Range B66:J87

This section summarizes the quantity and cost of primary operating inputs—fingerlings, feed, energy, oxygen, and bicarbonate—used over one cycle, and extrapolates this information to an annual basis. No user input is required in this section.

In the example, once the fish culture system is fully stocked after 210 days, the system will have 10.43 harvests per year (365 days/35 days). Thus, each number in the *Cycle Total* (column L) is multiplied by 10.43 to calculate the *Annual Total* (column M).

Beginning number of fish (E69:J69) begins with the original stocking density and adjusts that number according to the *Survival rate* (E62:J62).

Ending number of fish (E70:J70) is based on density and survival for each production unit.

Beginning biomass, lbs. of fish (E71:J71) is based on the number of fish and average weight stocked into that production unit.

Ending biomass, lbs. of fish (E72:J72) is based on the number of fish and weight transferred or harvested from that unit.

Maximum standing biomass, lb. per gal. of water (E73:J73) gives the pounds of fish per gallon of tank water at the end of that production period.

Feed used (E74:J74) is calculated from the specified *Feed conversion ratio* (E63:J63) and the difference between the *Beginning biomass* (E71:J71) and *Ending biomass* (E72:J72).

The *Kwh used* is calculated for each production unit as a weighted percentage of the feed usage for that unit multiplied by the total amount of kwh used for the cycle. The total kwh for the cycle is based on estimated energy usage of 2.30 kwh per pound of production. For example, one cycle yielding 12,354 pounds (5,615 kg) of fish requires an estimated 28,414 kwh of energy. The g1 production unit consumes 11.72% of feed used during the cycle (2,172 pounds feed/18,524 pounds feed), so the estimated energy use during that 35-day unit is 3,330 kwh (11.72% x 28,414), given in cell G75. The cost of energy for that period, given in G82 as $217, is calculated using the user-specified cost of $0.065 per kwh (E45).

Oxygen used, cubic feet (E76:J76) is calculated as follows: pounds of feed (E74:J74) x 30% (the amount of oxygen used per pound of feed, this is system specific) x 12.05 (a conversion factor).

Bicarbonate used (E77:J77) allows for 0.175 pound of sodium bicarbonate used per pound of feed fed.

Costs by production unit (E80:J87) are calculated using the cost per input specified in Section 2.

Section 5: Summary of Annual Costs and Returns to System in Full Production

Spreadsheet Cell Range = B89:J122

This section summarizes the costs and returns per cycle and annually for this system once it is in full production (after 210 days). Net returns are calculated before tax.

Days per production unit (D91) repeats information given in cell E51.

The Number of cycles per year (D92) is simply 365 days divided by *Days per production unit*.

Required system amps (D93) is calculated from *System volts* (E53) and kwh usage assuming a power factor of one.

Overall survival (F91) is calculated using survival given in E62:J62, and *Cycle FCR* (F92) from feed conversion ratios in E64:J64.

The cell range C96:J122 calculates system costs per cycle, annually, and per pound based on information specified previously in the spreadsheet.

Section 4.
Use of Primary Inputs and Costs per Production Unit
Spreadsheet Cell Range = B66:J87

			Growout tank				Cycle	Yearly
Inventory & Input Use:	Q tank	N tank	g1	g2	g3	g4	total	total
Beginning number of fish	12,252	10,415	10,310	10,207	10,105	10,004	12,252	127,775
Ending number of fish	10,415	10,310	10,207	10,105	10,004	9,904	9,904	103,286
Beginning biomass (lbs. of fish)	27	344	1,361	3,032	5,558	8,474	27	281
Ending biomass (lbs. of fish)	344	1,361	3,032	5,558	8,474	12,354	12,354	128,838
Max. standing biomass (lbs./gal.)	0.23	0.34	0.20	0.37	0.56	0.82	--	--
Feed used, lbs.	317	1,119	2,172	4,042	4,665	6,209	18,524	193,179
Kwh used	486	1,717	3,331	6,200	7,156	9,525	28,415	296,328
Oxygen used, cubic ft.	1,145	4,045	7,851	14,612	18,864	22,447	66,964	698,342
Bicarbonate used, lbs.	55	196	380	707	816	1,087	3,242	33,806
Costs:								
Fingerlings	$1,103						$1,103	$11,500
Feed	$165	$425	$456	$849	$980	$1,304	$4,178	$43,575
Energy	$32	$112	$217	$403	$465	$619	$1,847	$19,261
Oxygen	$3	$12	$24	$44	$51	$67	$201	$2,095
Bicarbonate	$11	$37	$72	$134	$155	$206	$616	$6,423
Total of above costs for this unit	$1,313	$586	$768	$1,430	$1,651	$2,197	$7,945	$82,855
Cumulative cost for cycle	$1,313	$1,899	$2,667	$4,098	$5,748	$7,945	$7,945	$82,855
Cumulative cost per lb.	$3.82	$1.40	$0.88	$0.74	$0.68	$0.64	$0.64	$0.64

Section 5.
Summary of Annual Costs and Returns to System in Full Production
Spreadsheet Cell Range = B89:J122

Days per production unit	35	Overall survival	81%
Average number of cycles/yr.	10.43	Cycle FCR	1.5
Req. system amps	147		

	unit	cost/unit	quantity/ cycle	$/cycle	$/year	$/per lb. of fish	% of total
Gross Receipts	lb.	$1.25	12,354	$15,443	$161,048	$1.25	
Variable Cost							
fingerlings	unit	$0.09	12,252	$1,103	$11,500	$0.09	7%
feed	lb.	$0.23	18,524	$4,178	$43,575	$0.34	27%
energy	kwh	$0.07	28,415	$1,847	$19,261	$0.15	12%
oxygen	100 cubic feet	$0.30	670	$201	$2,095	$0.02	1%
bicarbonate	lb.	$0.19	3,242	$616	$6,423	$0.05	4%
chemicals	$ per cycle	$115.07	1	$115	$1,200	$0.01	1%
maintenance	$ per cycle	$732.99	1	$733	$7,644	$0.06	5%
labor: management	$ per cycle	$2,301.37	1	$2,301	$24,000	$0.19	15%
labor: transfer & harvest	hour	$6.50	64	$416	$4,338	$0.03	3%
interest on variable costs	dol.	9%	6,307	$327	$3,406	$0.03	2%
Subtotal, Variable Cost				$11,837	$123,442	$0.96	77%
Fixed Cost							
Oxygen tank rental	dol.			$288	$3,000	$0.02	2%
Electrical demand charge	dol.			$115	$1,200	$0.01	1%
Building overhead	dol.			$173	$1,800	$0.01	1%
Interest on initial investment	dol.			$1,226	$12,788	$0.10	8%
Depr. on bldg. & equip.	dol.			$1,832	$19,100	$0.15	12%
Subtotal, Fixed Cost				$3,633	$37,888	$0.29	23%
Total Cost				$15,470	$161,330	$1.25	100%
Net Returns above Var. Cost				$3,606	$37,606	$0.29	
Net Returns above Total Cost				-$27	-$282	$0.00	

Interpreting the spreadsheet results

This publication is not an evaluation of the economics of tilapia production. A sale price of $1.25 was chosen so that the example system would have annual costs nearly equal to annual returns.

It is important to keep in mind that before the end of the first cycle on day 210, costs are incurred while no fish are harvested and sold. Until that time, the cost of operations must either be paid by additional owner funds or bank financing. To approximately calculate the point at which the system becomes self-supporting (can pay all fixed and variable costs), divide the total costs per cycle by the net returns per cycle. For example, if the sale price were $1.65 per pound, Total Costs per Cycle would be $15,470 and Returns above Total Costs would be $4,957. This is equal to 3.1 cycles ($15,470/$4,957) or 651 days (3.1 cycles x 210 days per cycle). The system would not become self-supporting until approximately 2 years from startup.

This spreadsheet can be used to test the effect on costs and returns of changes in sale price, feed conversion, survival, or the cost of energy and other inputs. Users can also examine the change in profitability based on a change in the stocking and transfer of fish or overall size of the system. For example, more frequent moves of fish between tanks could make better use of tank carrying capacity, increasing the amount of fish that could be harvested annually. Or, a more energy intensive system might support a higher carrying capacity per tank. Either of these may result in increased profit if the costs associated with each (higher labor cost, stress that may result in lower survival in the case of more frequent moves, and a higher energy cost if the system were reconfigured) do not outweigh the increase in production. Larger systems—more tanks and larger tanks—also often increase the profitability of recirculating systems.

Caveats (a warning)

There is no single recommended design for recirculating aquaculture systems. Therefore, it is impossible to supply a ready-made cost/returns spreadsheet that will be suitable for every system. Operators with existing or proposed systems similar to the example presented here can use this spreadsheet. Radically different systems may require extensive modifications of the spreadsheet structure by the user. The example spreadsheet is simple in design and does not contain any macro-programming. It can be modified once cells are unprotected. When working with the original spreadsheet or a modified version, keep in mind that it can only evaluate the economics of a properly designed system, and can not correct for flaws in design.

References

Hobbs, A., T. Losordo, D. DeLong, J. Regan, S. Bennett, R. Gron and B. Foster. 1997. "A commercial, public demonstration of recirculating aquaculture technology: The CP&L /EPRI Fish Barn at North Carolina State University." Pages 151-158 *In*: M.B. Timmons and T.M. Losordo, editors. Advances in aquacultural engineering. Proceedings from the aquacultural engineering society technical sessions at the fourth international symposium on tilapia in aquaculture. NRAES-105. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

For additional suggested reading, see the Internet site.

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