Operation Simplicity And Capital Prudency As Antidote For Failure Of Recirculating Aquaculture System: A Case Study Of Selected Facilities In Ibadan

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ABSTRACT

The operation of some troubled and unsuccessful recirculating aquaculture system (RAS) production facilities was evaluated to gain a better perceptive of the technical and economic aspects of operational problems that must be addressed for successful RAS business. Interview schedule was utilized to obtain data on the general operation and system characteristics for the facilities. Water flow rates in system components were estimated using a calibrated cylinder and a stopwatch. Fish culture tank, sedimentation tank and biological filter were monitored for water quality assessment. With the exception of one facility, all the farms were engaged in production of table size Clarias gariepinus. Water treatment component design in most of the farms did not match fish culture requirement. Wastes solids removal and dissolved oxygen delivery rate were not adequate and thus affect production capacity of the systems. Poor water quality led to elevated level of nitrite causing fish mortality. Flash rainfall on facilities located outdoors aggravates system operation and water quality problems. The improvisation of the water treatment components media coupled with outdoor operation culminated into a system that apparently could not accommodate the production demand of intensive culture in a recirculating fish production system. Systems with complex design run at low level of management, increased capital expenditure and eventual lower profit. Conscious effort to minimize system complexity and sufficient cash flow is recommended to ensure success of recirculating fish production ventures.

Keywords: Recirculation, Prudence, Design, Aquaculture, Venture

INTRODUCTION

The use of recirculating systems to hold or culture fish has been in operation since the 1970's (Masser e*t. al*. 1999). Though initially limited to researchers, over the last three decade years, the use was has been extended to commercial food fish production. Recirculating aquaculture system (RAS) has gained awareness within the food fish production sub sector in Nigeria due to its associated advantages over other conventional production technologies. RAS ensure high control of the land and water resources, reduced input requirements and overall production cost with expected high harvest. Despite these advantages, much is still unknown about the technology in terms of its adaptability to the Nigerian climate. An investment in commercial RAS has the same general risk and uncertainty as other livestock enterprises, uncertain market prices, uncertain and risky operational characteristics and uncertain input costs. Some of the techniques used in RAS setup are relatively new, and less is known about its technical performance. Investment in such ventures in Nigeria calls for a rigorous analysis and a logical framework within which to make investment decision. The pursuance of a twin track approach of government participation with private smallholder commercial aquaculture development must be encouraged. This could be enhanced through the collation and dissemination of already existing research results as well as initiating research into emerging technologies in the field of aquaculture. This would ensure that project failures are kept to a minimum thus encouraging new entrants (especially small-holder individual and corporate bodies) into aquaculture. This is because project design and conceptions would be based on solid economics and technical facts not wishful over-enthusiastic projections. Findings in a survey reported by Akinwole and Faturoti (2005) on the operation of some commercial RAS based fish production facilities in Oyo State, Nigeria shows that many (55% of the sampled facilities) farms experience a lot of problems within few months of operation. This paper report findings of a follow-up assessment carried out to appraise the operation of the reported problematic and failed RAS production facilities to gain a better understanding of the technical and economic aspects thereby accentuating problems that must be addressed or at least recognized for successful RAS operation. Possible antidotes to guide against, totally eliminate or at best ameliorate the identified failure factors are also discussed.

METHODOLOGY

Interview schedule was utilized to obtain data on the general operation and system characteristics for the facilities. Physical inspection, observation and measurement of system components and operations were done to validate information given in the collected interview schedule .All qualification measurements, both scalar and vector, were done in line with American Society of Civil Engineers, ASCE (1990) and Denn (1980). Water flow rates in system components were estimated using a calibrated cylinder and a stopwatch. Recorded flow rates were averages of at least three readings.

Water flow in fish culture tank, sedimentation tank and biological filter were monitored for water quality assessment. Water sampling quality records and analysis were done for pH,dissolved oxygen, ammonia-nitrogen (NH_3-N), nitrite-nitrogen, (NO_2) and suspended solids (SS). All analyses were done in line with standard methods (APHA 1995) pH was determined using Jenway® pH meter, dissolved oxygen (DO) using Winkler's method, NH_3^-N was determined using the Kjeldahl digestion method. Hach® water analysis kit was used to determine nitrite concentration. SS was determined gravimetrically by weight.

Most of the operators were initially reluctant to give information or allow evaluation of their facilities. They thought the study was a clandestine government sponsored operation to assess their facilities for taxation. When finally convinced that the study is mainly an academic exercise, the farms consented to facilities' inspection and evaluation with a proviso that their identity be protected as much as possible. The actual names of the facilities under study are protected and thus represented by acronyms.

RESULTS AND DISCUSSION

The system characteristics and operation summary of all the facilities are as shown in Table 1. The facilities located indoors were 33.0% while 67.0% were outdoor. With the exception of MJF facility, all others were engaged in grow-out RAS facilities for production of table size *Clarias gariepinus*.

All the facilities, with the exception of MJF, were from the start, beset with a lot of technical problems, which ultimately had negative impact on their operation. Water treatment component design did not match fish culture requirement in respect of the holding capacity of the rearing tank. Treatment media for sedimentation and biofilter were composed of improvised materials (Table 1) whose suitability to support commercial RAS operation, in terms of successful and repeated profitable culture of fish, have not been proven. The exposure of culture components to the vagaries of weather elements, in outdoor facilities, places avoidable stress on the systems. Thus operators do not have enough control on the culture environment, as expected in RAS operation. This resulted in poor water quality as evident in the typical mean values of the water quality parameters (Table 1), which most times, are outside the acceptable range recommended by Masser *et. al.* (1999) for RAS operation as depicted in Table 2, and in some instance, outside acceptable range for *Clarias gariepinus* culture (Boyd, 1990). The water quality problems affect fish health, lead to slow growth rates and general reduction in the overall carrying capacity of the facilities thus negating the capacity to produce economic quantity of fish within the projected culture duration. These systems could not effectively remove solid wastes and maintain dissolved oxygen level at safe limit; the overall system production is thus negatively affected. Ridha and Cruz (2001), and Summerfelt *et.al.* (2004) noted that wastes solids removal and oxygen delivery rate are major factors that affect production capacity of RAS operations. The relatively low hydraulic exchanges through the rearing tanks, 1347 minutes in the best case, for grow-out system, does not represent a good oxygen delivery rate. The 1347 minutes, which translate to just one tank volume exchange per day, for the system concerned is not enough to ensure maintenance of safe dissolved oxygen level as against one rearing tank volume exchange per hour recommended for stable RAS by Malone (2002) and Summerfelt *et.al.* (2004). As culture duration progresses, the fish biomass to be supported by the system increases, poor water quality leads to elevated level of nitrite in culture water causing fish mortality. In some cases, flash rainfall which otherwise might be thought of as a relief to the water quality problem, aggravates system operations. Increased volume of water places extra duty demand on the water pumps and causes inundations of the facility location with water of doubtful quality and possible septic potential. This, apart from leading to problems in maintaining flow conditions in the system components, increases the health risk of cultured fish and staff, who have to spend a disproportionate amount of time and energy troubleshooting and managing the system.

A review of the evolution and establishment of these facilities show that they are, in virtually all the cases, modified copied version of system layout of older RAS-based fish farms, but which are usually operated indoors and with proven water treatment components' media in use. The improvisation of the water treatment components media coupled with outdoor operation culminate into a system that apparently could not accommodate the production demand of intensive culture in a recirculating fish production venture.

The inability of these facilities to produce table size fish economically does not necessarily imply that grow-out stage culturing of *Clarias gariepinus* in recirculating systems with these improvised sedimentation and biofilter media options (gravel, lava stones, baffle wall barriers) would lack merit. The fact that *Clarias gariepinus* were held for up to 5 months, in such poor water quality condition, is, on one hand, a testimony to the tenacity *Clarias gariepinus* for culture in RAS, and on the other hand , an indication of the potential of the use of these water treatment media in commercial RAS operation in a tropical climate. These media are in themselves not the problems, Malone (2002) and Timmons (2000) report the use of these media in successful RAS in the United States.

TABLE 1: System Characteristics of the RAS production facilities assessed

	Facilities					
	EPF	**FTD**	**MJF**	**MOA**	**MOH**	**OPF**
Type of System	Grow-out	Grow-out	Fingerlings	Grow-out	Grow-out	Grow-out
Location	Outdoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
No. of RAS modules	1	2	1	1	1	3
Water source(s)	Stream	Borehole	Deep well	Deep Well	Deep Well	Borehole
No. of Rearing tanks per module	2	3	4	2	2	2
Volume of each Rearing tank, m^3	13.2	12.0	1.8	11.9	17.3	12.0
Rearing tank volume exchange (minutes)	1347	1579	720	1988	2408	1714
Rearing tanks material	Solid blockwall, Rectangular	Concrete, Rectangular	Solid blockwall, Rectangular	Concrete, Rectangular	Solid blockwall, Rectangular	Concrete Rectangular
Sedimentation tank details, volume, media (all Rectangular Shape)	3.17 m^3, Solid blockwall, plastic crates with gravel stones	9.36 m^3, Concrete, Plastic crates with gravel stone	2.19 m^3, Solid blockwall, polypropylene media	5.48 m^3, Concrete, Plastic crates with macadam	1.76 m^3, Blockwall, Baffle walls with plastic netting frame barriers	3.6 m^3, Concrete, with baffle walls barriers
Biofilter details (volume, media,types	3.44 m^3, plastic crates with larva stones media, Trickling	4.50 m^3, Plastic crates with larva stone media, Trickling	1.93 m^3, Polypropylene media, Trickling	1.44 m^3; Polypropylene media, Trickling	0.89 m^3, Plastic crates with larva stone media, Trickling	13.84 m^3, Coarse sand filter media, submerged bed
Average stocking						

density, fish/ m^3	210	175	6660	180	160	195
No. of feeding per day	4	5	11	5	5	4
Duration of effective system operation (Months)	9	8	8	5	6	5
Typical mean SS (mg/l)	≥35.1	≥38.6	≤6.3	N.A.	≥29.4	≥46.3
NO_2-N(mg/l)	≥1.5	≥1.4	≤0.3	N.A.	≥1.63	≥1.4
$NH_{3\text{-N}}$(mg/l)	≥12.4	≥45.8	≤1.8	N.A.	≥73.4	≥67.5
DO (mg/l)	≤3.6	≤2.3	≥4.5	N.A.	≤1.9	≤1.6

N.A. not available for verification, facility has been abandoned totally

TABLE 2: General optimal water quality requirements for Recirculating Aquaculture System and Ranges recorded in this study

Parameter	Recommended range *	Ranges recorded in the facilities studied
Suspended solids	Less than 25 mg/l	6.2 - 46.4 mg/l
Dissolved oxygen	5mg/l or more for warm water fish and greater than 2 mg/l in biofilter effluent	1.5 – 4.6 mg/l
pH	7.0 to 8.0	6.0 – 9.0
Un –ionized NH_3-N	Less than 3 mg/l	1.7 – 73.5 mg/l
Nitrite-Nitrogen	Less than 0.5mg/	0.2 – 1.65 mg/l

*adapted from Masser et.al. (1999); Eding and Kamstra (2001)

EPF facilities, with stream water as source of freshwater exhibits a comparatively better water quality than others . This lends credence to the advantage of surface water over groundwater sources for fish culture, if its associated problems of upstream pollution, conjunctive use law, can be controlled. The operation experience at MJF brings to the fore, the problems of fish pathogens and disease outbreak on one hand and under capitalization and expertise in intensive aquaculture on the other. The farm closed down operation when problems of disease outbreak that brings catastrophic fish mortality, owing to the sensitive nature of Clarias *gariepinus* at the fingerling stage. The high fish kill experienced as a result of diseases lead to low yield and consequently low returns. The owner could not raise enough funds to expand facility to other stage of culture, the operation thus collapsed as fund to keep it going were not available. Repeated production of fish at an economically viable level would be difficult if disease problems persist, and sufficient cash flow is not ensured to carry the operation through trouble period like components breakdown and disease outbreak. These problems do occur more often than not in recirculating fish production ventures.

Lessons and possible solutions

The antecedent of over 90 percent of the farms shows that their RAS components are either entirely packaged from Europe or are typical version of system layout of "older" RAS- based farms who themselves have major components imported from Europe. This gives room for a lot of unknown about the technology. There is much to learn about nutrition, water quality, species genetics, aeration and their concomitant interaction with disease outbreak in RAS production facilities. Many of these facilities that have failed have not done so, solely because of the unknowns about the technology but majorly due to failure to adhere to basic concepts of operation simplicity and capital prudency as expected for a venture into an emerging in new field.

System Simplicity

When the level of production intensity is considered, commercial RAS would ordinarily defy the term simplicity. Though RAS is an inherently complex system, a deliberate effort should be made to minimize the complexity right from inception. As with any technology, for a well designed system, the relationship between simplicity, operating cost and management is mutually dependent. System simplicity in fact represents the point on which production cost and operations management is balanced. Increases in design simplicity will translate to a concomitant increase in system management for the same level of capital input. Systems with complex design run at low level of management, increased capital expenditure and eventual lower profit.

Conscious effort to minimize system complexity for recirculating fish production facilities can be made by adhering to the following ;

Make realistic critical assessment of target and resources.

The rule, though simple, is the most crucial step in developing a successful aquaculture venture. Most RAS facilities have failed because a realistic assessment of expectation (goals) and resources were not made. It is important that absolute honesty is ensured in doing this, else, the investment is doomed from the onset. A would-be investors in RAS may have a goal of producing 30 metric tonnes catfish per year with facilities at his backyard. Thus would be unrealistic if his resources, (say water and capital) are at most 120 litres per minute and a total investment of 4 million naira (by 2011 economic standard in Nigeria). The resources are okay, but they cannot realistically match the 30 tonnes per year expected harvest in a recirculating system.

Once investor's goals and resources are known, system design to match them can then be done. Higher goals may imply large complex system for a relatively inexperienced aquaculturist, this would in turn means increase in room for errors in system operations and management.

Identify and quantify system production parameters.

Using chosen goals and available resources, a quantification of the important system operating/ production parameters should be done to span the proposed complete culture cycle. Table 3 gives essential parameters that should be defined before RAS design is embarked upon. The parameters in the Table 3 do not represent an all inclusive list but are provided to serve as a general guideline.

Table 3: Common operating parameters for recirculating aquaculture system.

o Stocking density	o Culture tank size
o Total daily feed required	o Total water volume
o Number of feeding per day	o Water flow rates
o Feed amount per tank per day	o Tank volume exchanges
o Waste loading per day	o Percentage makeup water
o Waste load variation per day	o Monthly feed requirement
o Water quality limits/range for chosen fish species	

Choose the simplest design layout and components.

There is always more than one way to achieve any process objective in RAS. Available technologies or components options for essential RAS processes are given in Table 4 as adapted from Malone (2002) and Timmons(2000).. Choose the simplest available options in terms of operation and management. The underlying reason here is that every location, owners goals and available resources introduce peculiarity that make the system concerned different in itself compared to the other systems even of the same yield/ capacity.

Table 4: Essential operation in recirculating aquaculture system and available option/technologies.

Essential Process	Goal	Available options
Species containment	To hold the cultured organisms	Tanks of various size, shapes and materials(PVC,Concrete,Sandcrete blocks, fibreglass)
Solids removal	To remove uneaten food,faeces, settleable solids	Sedimentation tanks of various barriers(lamella,walls,granular media); Microscreening; Granular filtration
Biofiltration	To remove toxic nitrogenous compounds	Granular biofilters; Submerged filters(upflow or downflow); Trickling filters; Rotating bio-contactors
Aeration	To replenish dissolved oxygen used by fish and nitrifying bacteria	Air stone; Cascade columns,Surface agitators;U-Tubes.

System simplicity and operation management could be further improved by avoiding machines where manual labour would suffice. Equipments and machines are reportedly designed to save labour and time. Caution is needed in choice of machines over manual labour as the machine might turn out not to be as beneficial as it first appears. Incorporating a machine one can do without only lead to problems like increased cost, mechanical breakdown, operators error, non flexibility in operations. Cases where this can occur includes; the use of automatic feeders as opposed to manual feed administration, use of vacuum pump to dislodge sludge in a settling tank compared to intermittent use of two tanks to give room for manual cleaning of one; the use of probes, sensors linked to computer screen to monitor water quality or possible problem situations in some components. Apart from increased investment cost, computer monitoring system are not infallible. They can only react when a problem exist and can, most times, not warn that a problem is developing, a situation which can easily be detected by an experienced fish culturist on routine manual system monitoring check.

Opt for small size modules

Though system size will depend on owners goals and resources, the size should be large and enough to conserve the economy of scale but not to the detriment of efficient operation. Large rearing tank may increase tank production but should not be too large and too deep to hinder feeding, cleaning, grading and harvesting operations. System should be designed such that when operational, perturbations should be at the barest minimum while resources are maximized.

Though the buffering capacity of systems are increased as system becomes large, it also makes it difficult to effect changes when alleviating a problem. Size should relate more to available managerial resources. Management needs for reviving three separate RAS modules with 1hp capacity pump for water circulation is quite different from that required to run a single RAS module with one 3hp pump. For small holder individuals fresh in aquaculture, low head designs are appropriate.

Compartmentalize system layout.

Design configuration should have a built-in ability to isolate components of the system at any time. This need becomes evident when failure of a component (especially the water treatment components) occurs and it becomes necessary to carry out maintenance. Effecting biofilter cleaning can pose difficult problems if no provision for shutting down the component for maintenance exists in the initial design and layout. Additionally, provision of make-up fresh water to keep system running in flow- through configuration is a crucial fall back arrangement for water treatment component maintenance and disease outbreak.

Capital prudency

As with any commercial venture, a strong financial base is a key to success. Though it is not a guarantee of success, the wise utilization of available funds could make or mar the success of RAS. A starting point for prudency is to resist the tendency to over capitalize the system with too many machines or equipments which may not be necessary. Capital prudency as a precaution against failure in RAS could be implemented by adhering to the following;

Ensure sufficient cash flow

Over enthusiastic projection in terms of culture duration can lead to cash problem. Contrary to what most 'RAS sales men' claim while product- marketing, culture cycles in intensive systems like RAS do extends beyond predicted harvest date. Rarely do fish perform at idealistic projection. An investor who expect to have the first sale of produced fish after four months of culture would run into cash problem if at the end of four months, average fish size is not marketable. Maintaining cash flow to allow for possibility of extended culture duration is a good antidote to being cash- stranded mid- way. Sufficient cash flow provision from onset is also needed to carry the venture through period of system or components failure. Like pumps or electricity generator breakdown, disease outbreak and total stock loss in some tanks. These problems do occur more often than not. Some investors (like MJF and MOA farms in this study) have had to pack up operation entirely due to insufficient cash to push through period like those mentioned . Opportunity of learning from such incidence and starting over again is obviously out of suggestion for such cash strapped investors.

Start small, expand slowly.

RAS as a fish production technology in Nigeria is still at its infancy and its operation is faced with a lot of unknowr but can be phased not in implementation. A 10-tonnes facility could be phased out into five and developed by starting and running a 2-tonnes module for some time before expanding further. This would allow investors the time to get used to operation and financial intricacies involved. Expanding too quickly after just one successful production cycle may lead to management and cash flow crisis when erstwhile hidden system problems arises. Viewed another way, it would be relatively easier to source for funds to expand a small successful RAS than to raise money to keep a large troubled facility from going under.

CONCLUSION

With increasing fish demand and available market for aquaculture products in Nigeria, the attention given to RAS adoption will not fade away. While some farms report success some RAS based facilities have failed. Complex system layout and design of water quality conditioning components not matching fish culture requirement in respect of the holding capacity of the rearing tank is responsible for collapse of some facilities while others failed due to insufficient funds to run system through the duration of culture. The unknowns about technology notwithstanding, success could be improved if facilities are designed to operate as simple and as manageable as possible without bearing unnecessarily over capitalized.

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