Aquacultural system management tool II: analytical and management capability

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Abstract: It is difficult to analyze the complex system by using conventional tools such as field experimentation and inventory monitoring. Thus, one of the major objectives is used to develop an ecosystem model as a tool for analysis for complex systems. In view of this, the Aquacultural System Management Tool (AQUASMAT) model, which was developed based on existing ecosystem model theories and coded using the C-sharp language, was used to conduct a modeling study on a static concrete fish tank, to demonstrate its managerial and analytical capabilities. The input variables for model execution were site specific parameters, fish/feed parameters, water quality parameters and management options from selected fish farm in Nigeria. The model simulation was for concrete tanks with surface area of 1 m^2 and 50 m^2, respectively, running for 151 periods by using various management techniques and varied feeding rates. Series of simulations were used to evaluate the ability of the model predicting the effects of different feed regimes, management intensities, budgetary requirements (solely based on the cost of fish and feed), and interaction of parameters over a range of fish production levels. The model was used to gain insight into the dynamics and interactions of major water quality parameters with respect to feed loading and fish growth in a 1 m^3 fish tank. The simulation result was compared to a farmer's production output, and then the best management practices will be provided to the user (farmer), such as the optimal feeding techniques and practices with lower feed conversation ratio (FCR) within recommended range. The relationships and interaction between water parameters with respect to feed loading and fish growth were used to gain insight in sizing the biofilter for aquaponics systems.

Keywords: AQUASMAT, simulation, analysis, management, capability, water quality, inter-relationships

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1 Introduction

The objective of intensive aquaculture practice is to increase profitability by maximizing harvest weight (biomass) per unit volume/area of production system. However, these practices always exceed the biological carrying capacity of the production unit. As for livestock production, overcrowding usually leads to problems of environmental degradation, disease, off-flavor (aquatic animals), and a reduction in individual performance of the cultured species (Wurts and Wynne, 1996; Tucker, 2000). Hence, the success and profitability of aquaculture production is highly dependent on the proper management employed during the culture period. Management in aquaculture is synonymous with water management as water of suitable quality and quantity is a pre-requisite for any successful aquaculture production. A good knowledge and understanding of the fish environment (water) is a prerequisite for increased production. Thus, the AQUASMAT model, which involved in the formulation of theoretical relationships for intensive tank-based fish culture from existing models, coded with Microsoft® Visual C# (C-sharp), was developed (Anyadike et al., 2015). The model was designed to predict the effect of different management operations on fish yield, to identify and quantify the cause, effect and relationships between water quality parameters,

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and to suggest remedial actions for impaired systems. It also predicts economic viability of the production system based on the cost input used in the system, and tracks the fate of many water quality parameters which are not readily measured. The primary objective of this paper is to demonstrate the managerial and analytical capability of the AQUASMAT. Another objective is to evaluate the managerial and analytical capabilities of the AQUASMAT, which include optimizing fish feed input in the production system and maximizing production, predicting the relationships and interactions between critical water quality parameters in order to improve fish health and growth rates, and modeling nitrogen requirement to aid sizing of biofilter (grow bed) in aquaponics system.

2 Methodology

The model development, general characteristics and implementation have been described as report by Anyadike et al. (2015). The design of the model involved synthesizing selected processes and interactions into a computational framework to simulate the conditions in a static concrete fish tank, and to reproduce the desired system response over a selected culture period. The system variables were grouped into components and organized for implementation as subroutines. The subroutines interacted with each other through the main program which calls them in appropriate sequence. These sub-routines are: initialization, site parameters, biota, feed, water quality, organic matter, economic, report generation and management. The main program flowchart for the simulation procedure was reported by Anyadike et al. (2015).

The model is applied in some fish farms in Enugu State, Nigeria (details of the input specification is presented in Table 1) at farmer's minimum and maximum daily feeding rations of 1000 g (equivalent to feeding rate of 3.33%) and 15000 g (equivalent to feeding rate of 1.25%) respectively. The result showed that the maximum biomass was not equal to the maximum profit as illustrated by Anyadike et al. (2015). The model suggested remedial action, especially variation of feed at overfeeding and underfeeding period of production (Table 2), which was disseminated through seminars, workshops, and interactions with the farmers. This aid the choice of a minimum and maximum varied feeding input (VFI) of 9% (2800 g daily) and 1% (10000 g), respectively. The VFI were compared to a real-life system, Aquaculture Holdings Ltd (AHL) feeding rates, which represent the typical farmer's management practices in South-Eastern Nigeria. This was done to ascertain the economic viability and optimum productivity and efficiency of the production system based on the cost of input (feed) at 30 fish m^{-2}.

Furthermore, the AQUASMAT model was used to predict culture conditions in an experimental tank of 1 m×1 m×1 m (water depth of 0.75 m) stocked with 5 g of *Clarias* at 14 fish m^{-2} (Simulation name: *clarias14*). The input specifications used to execute the model are presented in Table 3. This was done to give insight into the water quality variables and interactions, nitrogen dynamics and sizing of biofilter for aquaponics systems, thereby helping stakeholders in evaluating aquaponics (integrating aquaculture with agriculture) system adequacy and feasibility.

Table 1 The input specifications used to execute the model

Simulation specifications			
Simulation Name		Agricultural Holdings Nsukka	
Simulation Duration (days):		182	
Start Date:		7/3/2014	
End Date:		1/1/2015	
Site Parameters			
Concrete Tank Length (m):	10	Width (m):	5
Depth (m)	1	Altitude (m)	405
Wind speed (m s^{-1}):	1.66	Light Intensity (kW h^{-1}):	3.92
Fish/Feed Parameters			
Fish Specie:	*Clarias gariepinus*		
Fish Length (cm):	8	Fish Weight (g)	20
Fish Number:	1500		
Water Quality Parameters			
Feed Protein Content (%):	43	Max Feed Input (g):	15000
Min Feed Input (g):	1000	Max Temperature (°C):	29
Min Temperature (°C):	26	Dissolved Oxygen (g m^{-3}):	5
pH:	6.5	Detritus (g m^{-3}):	0.1
Carbon-dioxide (g m^{-3}):	0.1	Nitrate (g m^{-3}):	0.5
Ammonia (g m^{-3}):	0.5	Algae Biomass (g m^{-3}):	0.1
Management Operations			
Aeration:	Yes	Water Exchange:	No
Money			
Economic Settings:	Yes	Currency:	Naira
Feed Cost (kg):	300	Fingerling Cost:	60
Fish selling price (kg):	700		

Table 2 Management regimes suggested by AQUASMAT model for AHL fish farm

Days	Parameter	Effect	Suggested Management
Day 1 to Day 37	FCR	FCR from day 1 (0.03351) to day 37 (0.49034): Fish weight gain is poor.	Feed fish its percentage body weight
Day 15 to Day 182	Stocking Density	Stocking Density from day 15 (2087.46571 g m^{-2}) to day 182 (20155.64826 g m^{-2}). At carrying capacity growth is reduced, feeding is reduced	Reduce fish biomass, increase water exchange, reduce feeding
Day 116 to Day 182	FCR.	FCR from day 116 (2.01312) to day 182 (2.4897): High FCR, fish is overfed and at least 50% of feed is wasted, It can also lead to the introduction of waste in pond	Reduce feed to maintenance ration

Table 3 AQUASMAT model simulation input details for African catfish culture in experimental tanks at different stocking densities

Input information	Description
Duration	Simulation period of 5 months (151 days)
Site	Concrete tank of dimension 1 m×1 m×1 m (water depth = 0.75 m) Altitude was 405 m, wind speed was 1.66 m s^{-1}, light intensity was held constant at 3.91 Kwh m^{-2} day
Fish and feed data	Number of fish stocked was 14 fish in tank 2, measuring 5 g and 8 cm average weight and length, respectively. Feed was modeled as dynamic with minumum feeding rate of 5% of fish body weight (1.75 g) and maximum daily feed at 1.5% body weight (63 g). Percentage protein content of feed used was 40.4%
Water quality parameters	Temperature and pH were modeled as dynamic between 26℃-29℃ and 6.5 respectively. Initial concentration of DO was 4 mg L^{-1}, CO_2 = 0.9, TAN and NO_3 = 0.01 mg L^{-1}, Detritus = 0.01 g m^{-3}, and Algae at 0.1 g m^{-3}. Aeration was performed throughout simulation period.
Economic settings	The simulation was performed without the economic option (not available).

The coefficient of determination was used to statistically assess the goodness-of-fit between observed and predicted values, and to establish some regression relationships.

3 Results and Discussion

3.1 Fish growth performance

As shown in Figure 1, the model simulation with farmer's feeding rate AHL and varied feeding input (VFI) on fish weight gain was at the same facility and stocking density. However, the cost of achieving the same average fish weight was observed to be cheaper than the VFI. The quantity of feed used by AHL was higher than that by VFI (Figure 2). It showed that a FCR was over than 2 (Figure 3), suggesting that more than half of the feed introduced to the concrete fish tank by the farmer was wasted (Isyagi et al., 2009; Timmons and Ebeling, 2010) daily. In addition, it has been reported that FCR <0.5 suggested underfeeding using the farmer's feeding rates (Isyagi et al., 2009). The feeding regime employed by the farmer (AHL) was therefore found to be flawed as underfeeding was observed in the first few weeks (5 weeks) of simulation and feed wastage from the 12th week. This is in contrast with the modified feeding regime (VFI), which was within acceptable range throughout the simulation. The effect of the farmer's high feeding rate was simulated as shown in Figure 4. The unionized ammonia rate was higher in greater parts of the simulation for AHL compared to the simulated VFI. Thus, the most suitable feeding rate as predicted under the two different scenarios could be used in maximizing production.

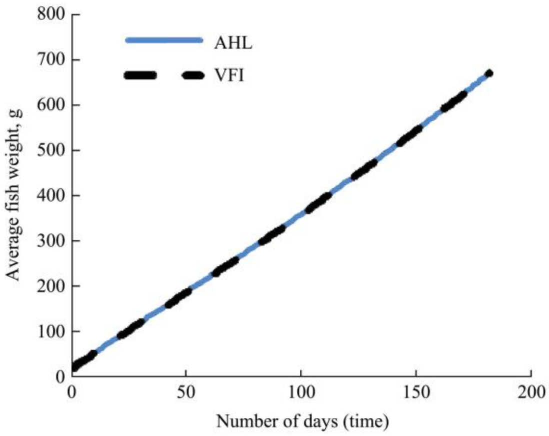

Figure 1 Comparison between the effect of AHL and VFI feeding regime on average weight of African catfish

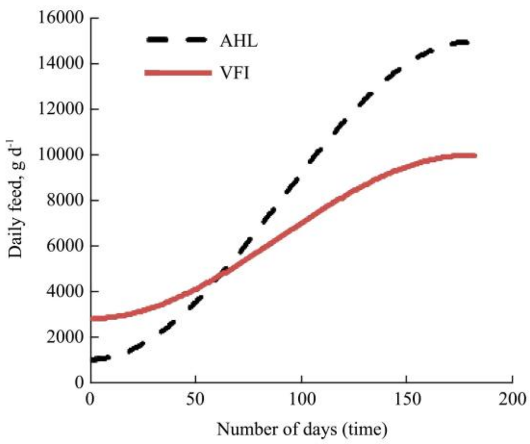

Figure 2 The quantity of feed utilized over a period of time

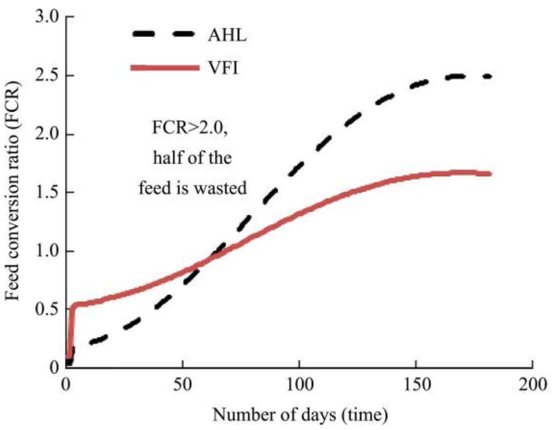

Figure 3 The comparison of FCR between AHL and VFI

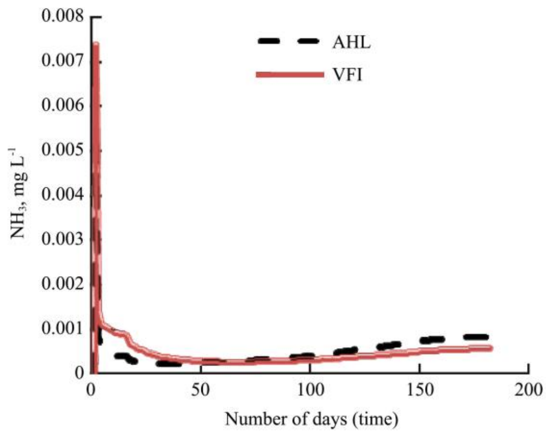

Figure 4 The unionized ammonia (NH_3) over a period of time for AHL and VFI

An abridged result generated by AQUASMAT for AHL and VFI was presented on Table 4. The simulations attained the carrying capacity that the average weight of fish was 70 g on day 16. The weight gain at carrying capacity was observed to be poor, which was in agreement with the report by Isyagi et al. (2009). The simulation result of VFI showed more feed input than that of AHL at the earlier stage (day 1 to day 30). In contrast, as shown in Figure 3, the FCR was observed to be within the recommended range of 2 (Isyagi et al., 2009). Furthermore, the result of AHL recorded more percentage profit early in the simulation but the margin was observed to be small as more than 50% of feed was wasted from the 12th week. This result contributed to the poor water quality output observed in simulation result of AHL. Meanwhile, there was a 20% difference in final feed cost between AHL and VFI as shown in Table 4. The simulation result also showed that there was 10% extra profit from VFI than that of AHL, and VFI was at better water quality. This result was expected since the AHL regime had incurred losses from wasted feed and poor fish growth induced by poor water quality. Hence, extra resources were required in managing the predicted poor water quality of AHL, despite poor production when compared with VFI.

Table 4 Cost of production at farmer's feeding rates (AHL) and simulated varied feeding rates (VFI)

Day	Avg. fish weight, g	Cost of feed (Naira)		Fish cost (Naira)		Profit (Naira)		% Profit		
		AHL*	VFI*	AHL	VFI	AHL	VFI	AHL	VFI	
16	70	4984	12849	73061	72169	68017	59260	87.2	69.7	◄Carrying capacity
30	116	11672	25889	122353	121461	110621	95512	82.5	64.8	
60	217	39712	60881	228203	227311	188431	166371	70.3	57.7	
90	320	95285	110032	336596	335703	241250	225611	55.9	50.6	
120	428	182675	175547	449704	448812	266969	273204	42.2	43.8	
150	540	297869	255361	568583	567691	270654	312269	31.2	37.9	
180	660	429600	343680	692796	691904	263136	348164	23.4	33.6	

Note: *AHL is feeding rate at 3.3% initial and 1.25% final; *VF is varied feeding input at 9.33% and 1%.

3.2 Model simulation of African catfish cultured in experimental tank

The success of a commercial aquaculture enterprise depends on providing the optimum environment for rapid growth at the minimum cost of resources and capital. One of the designed objectives of the AQUASMAT model is to predict the aquatic environment and critical water quality parameters so as to optimize fish health and growth rates. The aquatic environment is a complex eco-system consisting of multiple water quality variables, however few critical parameters such as temperature, suspended solids, and pH and concentrations of dissolved oxygen, ammonia, nitrite, CO_2, and alkalinity, play decisive roles. Each water quality parameter interacts with and affects other parameters, sometimes in complex ways, affects the healthy and growth rate of the fish (Ebeling, 2015).

In view of this, the model, which predicted the results of fish stocked at 14 fish m^{-2}, was used to establish and study the dynamics and interactions in an experimental static tank system with respect to feed loading and fish growth. The relationship and interaction of dissolved oxygen and carbon-dioxide with respect to fish weight is shown in Figure 5.

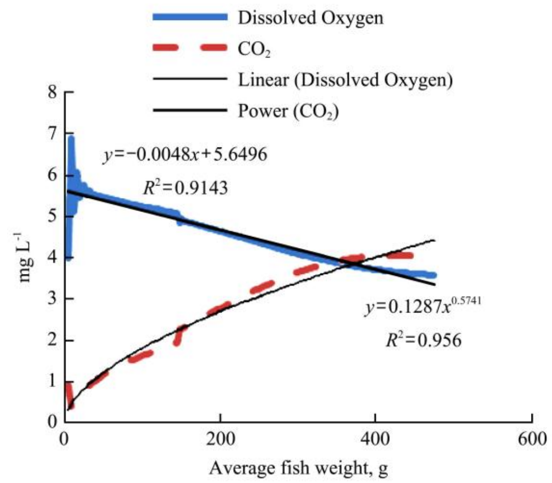

Figure 5 Dissolved oxygen and carbon_dioxide (CO_2) against weight of fish

The predicted result showed an increase in carbon-dioxide as dissolved oxygen decreases. The result of this particular situation showed that there was less oxygen available to the fish and the fishes were less able to use the available oxygen. The high carbon dioxide level of the water affected the fishes' blood capacity to transport oxygen, aggravating the stress imposed by low dissolved oxygen levels especially as the average fish weight increased (Ebeling, 2015). The model was able to demonstrate that oxygen consumption was a function of fish body weight, however, respiration per unit biomass was the greatest for small fish. This result was in agreement with the observation of Hargreaves and Tomasso (2004). From the regression analysis, the (R^2) value of body weight on dissolved oxygen consumption and body weight on carbon-dioxide released by respiration were 0.914 and 0.956, respectively. However, the relationship is linear for dissolved oxygen and average fish weight unlike the relationship between average fish weight and carbon dioxide released which is non-linear. Other examples (Figure 6) showed the relationship between un-ionized ammonia (NH_3) and detritus (organic matter). Despite high rate of organic matter addition to catfish tank, the accumulation of sediment organic matter is low and in agreement with Tucker (1985). However, the absence of dissolved oxygen to fully mineralize the organic matter caused temporary accumulation which increased the level of un-ionized ammonia in the system as suggested by Hargreaves and Tucker (2003).

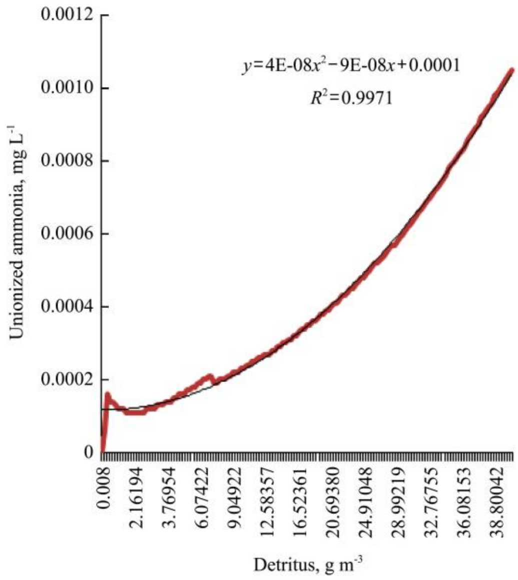

Figure 6 Relationship between unionized ammonia and detritus

The relationship between pH and carbon-dioxide (CO_2) is as presented in Figure 7. The pH of water decreased with the increased CO_2, which was in agreement with Boyd and Tucker (1998). The regression analysis of the relationship between pH and CO_2 indicated an R^2 value of 0.9. This showed strong predictability of the model to forecast accurately. The relationship is logarithmic and can be expressed as:

$$pH = -0.44\ln CO_2 + 6.3268 \tag{1}$$

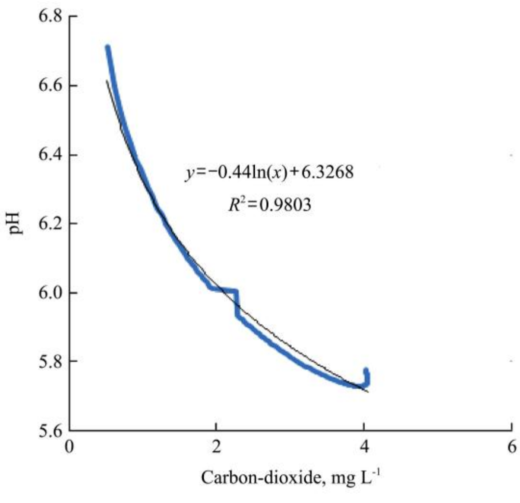

Figure 7 Relationship between pH and CO_2

The relationship between rates of oxygen consumption by bacteria in oxidizing waste generated in the system (i.e., biochemical oxygen demand) was presented in

Figure 8. The increase of metabolic waste increased biochemical oxygen demand (Timmons and Ebeling, 2010; Pillay, 2004; Tucker et al., 2008). The regression analysis established a linear relationship between metabolic waste generated by fish and oxygen required to decompose this waste. This was directly proportional to rate of metabolic waste generated by fish and was presented in Equation (2).

$$y = 0.0036x - 0.003 \tag{2}$$

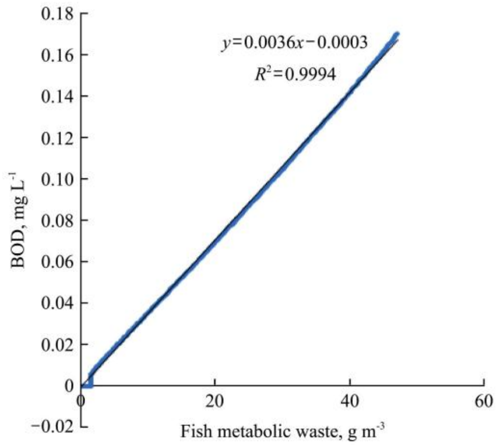

Figure 8 Relationship between fish metabolic waste and BOD

The relationships between temperature, dissolved oxygen and fish respiration were also predicted that temperature affected virtually all processes in the system (Park et al., 2009). Figure 9 was a predicted model result relating to temperature and dissolved oxygen (DO). DO levels were observed to reduce with increased temperature (Park and Clough, 2012). Fish metabolic rate was also observed to be highly influenced by temperature as presented in Figure 10. The AQUASMAT model predicted an increase in metabolic rate with a peak activity at temperature of 27℃ before a slow decline which continued to increases with temperature and becomes limiting, which was in agreement with the previous report (Hargreaves and Tomasso, 2004). This temperature at peak activity was within the range of optimal temperature required for production of catfish as suggested by Hecht et al. (1988) and Isyagi et al. (2009). The predicted model result was in agreement with Ebeling (2015) that the environmental temperature changes affected the fishes' rate of biochemical reactions, leading to different metabolic and oxygen consumption rates. At the lower ranges of the species tolerable temperature range, these rates decreased. As water temperatures increased, fish became more active and consumed more dissolved oxygen, while simultaneously produced more carbon dioxide and other excretory products, such as ammonia. These increasing rates of consumption of necessary elements and production of detrimental elements had a direct effect on overall fish healthy and survival rate if these parameters were allowed to exceed nominal values. If it was not corrected, the fish will become stressed to some degree. Even low levels of stress can have adverse long-term consequences in the form of reducing growth rates or mortality due to opportunistic organisms that take advantage of the stressed fish.

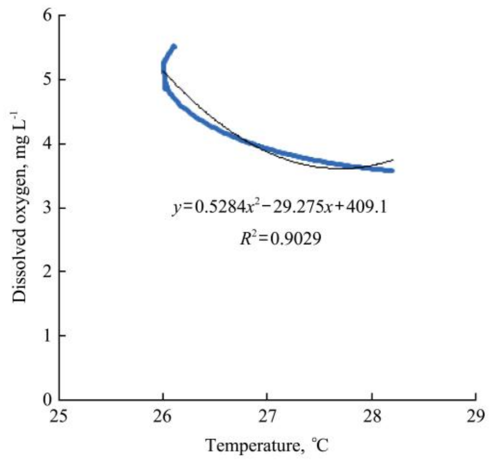

Figure 9 Relationship between temperature and DO

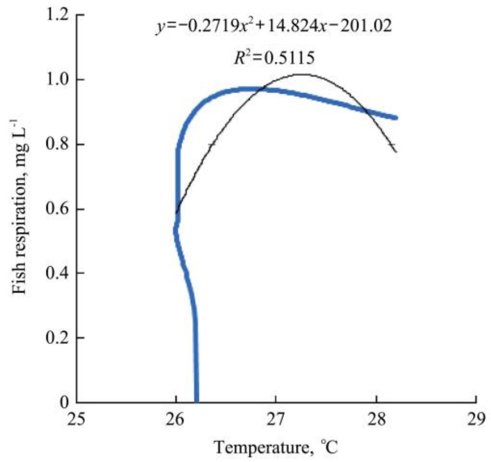

Figure 10 Relationship between temperature and fish metabolic rate

3.3 Modeling nitrogen requirement for sizing biofilter (grow bed) in aquaponics system

The biofilter, a major component of the aquaculture treatment unit, was used to remove the total ammonia nitrogen to a recommended level of 1 ppm through nitrification (Al-Hafedh et al., 2003). The efficiency of the biofilter depended on its size. The amount of feed fed to the cultured fish at any time was used to determine the maximum load that the biofilter can handle. The AQUASMAT model was used to predict the nitrogen load at a specified feeding rate. The result of the model prediction showed that metabolic waste accumulated in an intensive culture system as feed input increased. The waste was differentiated into sediment and dissolved detritus (Figure 11). Total ammonia nitrogen, a major contributor to this waste, was the most critical water quality parameter in intensive recirculating system like the aquaponics (Figure 12). The R^2 value of 0.9995 was presented in Figure 13, it showed the relationship between dissolved nitrogen and fish biomass, suggesting that AQUASMAT could be used to relate and quantify nitrogen dynamics in a culture system.

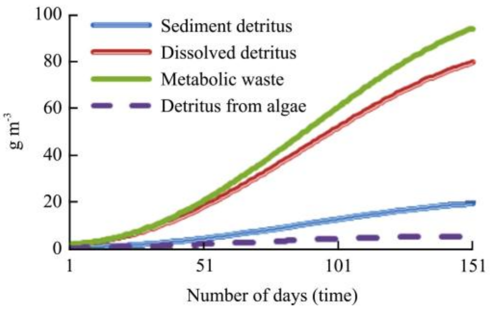

Figure 11 Organic matter accumulation

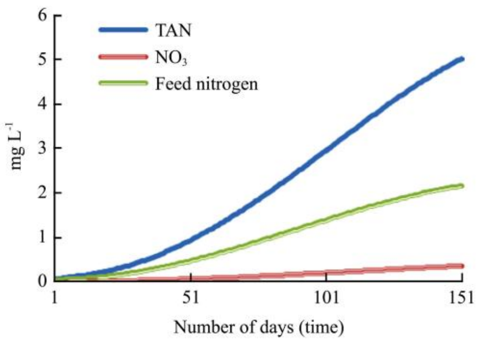

Figure 12 TAN, NO_3 and nitrogen input from feed in the system

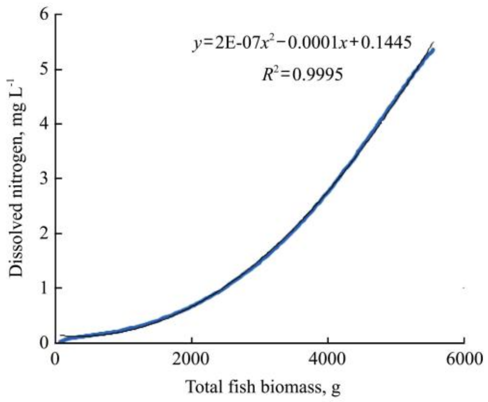

Figure 13 Relationship between fish biomass and dissolved nitrogen in the system

In aquaponics, plants are grown in a hydroponic system which enables them to use the nutrient-rich water from the culture system. Nitrogen availability in fish production systems is an important factor in determining the success of an aquaponics system. The plants take up the nutrients, and then reduce or eliminate the water's toxicity for the aquatic animal (Parker R., 2012). According to Tyson (2012), 100 pounds of fish (45.5 kg) will supply enough nitrogen for 4,050 lettuce plants or 540 tomato plants. Optimum feeding rate is 60-100 g of fish feed m^{-2} of plant growing area/day (Shultz et al., 2012) Simulation result from the farmer was used to evaluate the possibility of integrating agriculture with aquaculture (aquaponics). As shown in Figure 14-16, a predicted fish biomass of 1 tonne (1000 kg), feeding rate peak of about 300 g m^{-3} and accumulated ammonia was observed. These results were in agreement with the reports by Tucker and Ploeg (1993), and Hansen (1996). They indicated that tomato, melon, pepper, lettuce and cucumber nutrient requirement is approximately 0.08 mg L^{-1} d^{-1} to 0.16 mg L^{-1} d^{-1} nitrogen for growth, flowering, fruiting. This result could be useful in gaining insight into the nutrient generation needed for designing the biofilter (grow bed) of an aquaponics system.

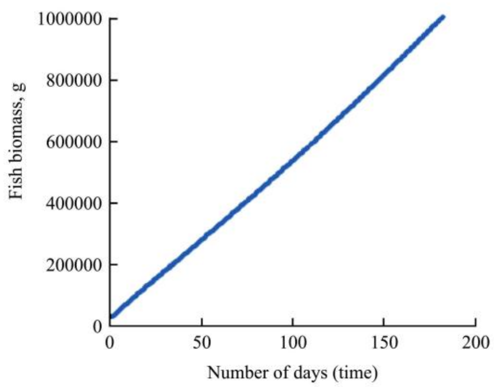

Figure 14 Predicted fish biomass

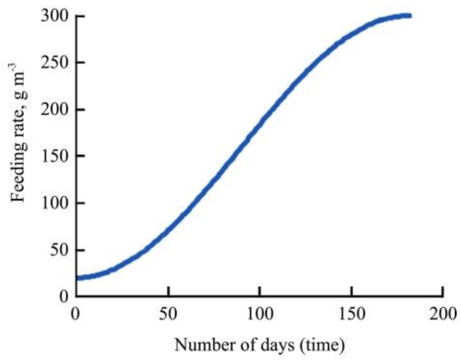

Figure 15 Predicted feeding rate

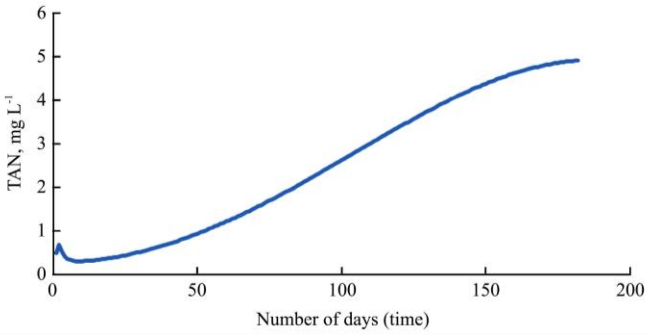

Figure 16 Predicted total ammonia nitrogen

4 Conclusion

In this study, the managerial and analytical capability of the AQUASMAT was developed. The results predicted the environmental quality, production and economic outcomes of African catfish cultured in tanks in order to aid stakeholders (farmers, managers, and researchers) in carrying out production process (day-to-day management operations such as determining stocking and feeding rates, predicting dissolved oxygen levels and examining the effects of different management strategies) and analyzing economical ways of improving the productivity of their farms. The result and process interrelationships predicated in this model were in agreement with existing literatures of water quality relationships. This result indicated that the AQUASMAT model could be useful in studying processes and interactions of water quality parameters with respect to fish performance, and sizing of biofilters for aquaponics systems.

References

Al-Hafedh, Y. S., A. Alam, and M. A. Alam. 2003. Performance of plastic biofilter media with different configuration in a water recirculation system for the culture of Nile tilapia (Oreochromis niloticus). *Aquacultural Engineering*, 29(3): 139–154.

Anyadike, C. C., C. C. Mbajiorgu, and G. N. Ajah. 2015. Aquacultural System Management Tool (AQUASMAT) I: Model development. *Aquacultural Engineering*, 69: 60–77.

Boyd, C. E., and C. S. Tucker. 1998. *Pond Aquaculture Water Quality Management*. Berlin, Germany: Springer Science and Business Media.

Ebeling, J. M. 2015. Water quality. Recirculting workshop on aquaculture systems technologies LLC Orleans L.A. Available at: www.ag.arizona.edu. Accessed 29 January 2016.

Hargreaves, J. A., and C. S. Tucker. 2003. Defining loading limits of static ponds for catfish aquaculture. *Aquacultural Engineering*, 28(1): 47–63.

Hargreaves, J. A., and J. R. Tomasso. 2004. Environmental biology. In: *Developments in Aquaculture and Fisheries Science, Biology and Culture of Channel Catfish*. C. Tucker and J. Hargreaves, eds., 36-68. Netherlands: Elsevier B.V.

Hecht, T., W. Uys, and P. J. Britz. 1988. The culture of sharp tooth catfish, Clarias gariepinus in Southern Africa, In *National Programs for Aquaculture Research, South African National Scientific Report*, vol. 153: 47–61.

Isyagi, N. A., K. L. Veverica, R. Asiimwe, and W. H. Daniels. 2009. *Manual for the Commercial Pond Production of the African Catfish in Uganda*. 109–112. Kampala: Department of Fisheries and Allied Aquacultures; Alabama, USA: Auburn University.

Park, R., J. Carleton, J. Clough, and M. Wellman. 2009. *AQUATOX Technical Note 1: A Calibrated Parameter Set for Simulation of Algae in Shallow Rivers*. Washington, DC: U.S. Environmental Protection Agency.

Park, R., and J. Clough. 2012. *AQUATOX (Release 3.1) Technical Documentation vol.2*. Washington, DC: U.S. Environmental Protection Agency.

Parker, R. 2012. *Aquaculture Science*. USA: Cengage Learning.

Pillay, T. 2004. *Aquaculture and the Environment*. Oxford: Blackwell Publishing.

Timmons, M. B., and J. M. Ebeling. 2010. *Recirculating Aquaculture*. Ithaca, NY: Cayuga Aqua Ventures.

Tucker, C. S. 1985. Organic matter, nitrogen, and phosphorus content of sediments from channel catfish ponds. Mississippi Agricultural and Forestry Experiment Station Research Report 10-7, Mississippi State University, Mississippi, USA.

Tucker, C. S. 2000. Off-flavor problems in aquaculture. *Critical Reviews in Fisheries Science*, 8(1): 45–88.

Tucker, C. S., J. Hargreaves, and C. Boyd. 2008. Aquaculture and the environment in the United States. In *Environmental Best Management Practices for Aquaculture*, 3-54. C. Tucker and J. Hargreaves, eds. Iowa: Blackwell Publishing.

Tucker, C. S., and M. Ploeg. 1993. Seasonal changes in water quality in commercial channel catfish ponds in Mississippi. *Journal of the World Aquaculture Society*, 24(4): 473–481.

Tyson, R. 2012. Aquaponics. University of Florida, Orange County Extension Service. Available at: http://orange.ifas.ufl.edu/uf_workshop/pdffiles/Aquaponics%202012.pdf. Accessed 17 August 2012.

Wurts, W. A., and F. Wynne. 1996. Sustainable channel catfish farming: low management production through modified stocking and feeding practices. *World Aquaculture*, 26(3): 54–60.