COMPUTERIZED VISUAL ASSESSMENT AND VALIDATION TECHNIQUE IN AN INTEGRATED AGRICULTURE-AQUACULTURE SYSTEM (IAAS)

*[1]KHODA BAKHSH, H., [2]WAN AZIZUN W. ADNAN, [3]CHRISTIANUS, A., [3]SAAD, C. R., [4]AIZAM, Z. A., [1]MOVASSAGH, S.

[1]Faculty of Agrotechnology and Food Science, Universiti Malaysia Terengganu (UMT), 21030 Kuala Terengganu, Malaysia. [2]Faculty of Engineering. [3]Faculty of Agriculture, University Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia. [4]Institute of Tropical Aquaculture, Universiti Malaysia Terengganu (UMT), Mengabang Telipot, 21030 Kuala Terengganu, Malaysia.

**Corresponding author: hamid110@hotmail.com*

Abstract: Laboratory and artificial models are the acceptable way to find and explore the relationship among various compartments in an integrated system which combine many variables and practical results in the same or different condition. The purpose of this study is to improve the available visual IAAS (Integrated Agriculture-Aquaculture System) program for evaluation of freshwater prawn (*Macrobrachium rosenbergii*) and plant (*Lactuca sativa*) yields. Available data on *Macrobrachium rosenbergii* yields, survival, nutrient concentration and plant production were compared to the predicted results by IAAS expert program. Results represent higher variation of survival, prawn and plant yields in abnormal culture system. Moreover the evaluation process demonstrated a good performance of IAAS expert program in predicting results for the optimized integrated culture system. In aquaculture, the success estimation of production depends largely on the state of physical and chemical parameters which define optimal culture conditions.

KEYWORDS: Validation, Computerized assessment, *Macrobrachium rosenbergii*, Integrated culture system, Recirculating system

Introduction

The efficient management and implementation of integrated culture systems requires monitoring of the different variables and environmental conditions, which are then followed by gathering, creating, formulating and maintaining information and knowledge. Development of new techniques and knowledge-base with regards to mitigation assessment through the incorporation of computer system provides the capability to manage and control a multi production system efficiently and easily. Expert systems represent a new opportunity in computing works. They open avenues of application that are so far closed and allow new problems to be tackled (Sell, 1986). The basic structure of expert systems can be divided into several categories such as knowledge-base, content, inference mechanism, descriptive facility, knowledge acquisition and user interface (Khoda Bakhsh and Rashid Shariff, 2007). Laboratory and artificial models are the acceptable way to find and explore the relationships among various compartments in a polyculture and integrated culture system which combine many variables and practical results in the same or different condition. Integration of output data and knowledge at all levels is necessary to enhance and understand results under certain condition. According to Stunder (1990), validation of an expert program can be done by using several methods; namely, conventional technique of requirement, fully automated testing tools and specific knowledge-based verification procedures or qualitative review (Jimenez-Montealegre *et al*., 2002). The specific knowledge-based verification procedures and appropriate regression analysis have been used in this study.

Methods and Design Rationale

The general objective of this study was to improve the available visual Integrated Agriculture-Aquaculture System (IAAS) program (Khoda Bakhsh and Rashid Shariff, 2007) for the evaluation of freshwater prawn and plant yields (quantity and quality) by using a standardized and recommended formula adopted from literature and current study. In this scope, the specific objectives are as follows:

- To consolidate the obtained knowledge from artificial integrated culture practices for *M. rosenbergii* and plant (*Lactuca sativa*) into a visual expert system.
- To design and formulate a prediction expert model of freshwater prawn (*M. rosenbergii*) and plant (*Lactuca sativa*) production in an integrated culture system.
- To validate the expert program (IAAS) with high efficient statistical techniques in a functional and predictive perspective.

The freshwater prawn (*M. rosenbergii*) is a famous and popular species for aquaculture in the Southeast Asia and developed countries (e.g. USA). This popularity stems from several positive characteristics which could be related to the cost and high-level tolerance of this species in the mono-and integrated-culture systems (FAO, 2002). Aquaculture activities and technology development may cause various effects on different compartments (aquatic animal, poultry and plant) in the sustainable integrated culture systems. Knowledge is an abstract term that attempts to capture an individual's understanding of a presented subject. In an expert system structure, knowledge acquisition is the most important and also most challenging in the development of the systems and it involves several main tasks including data collection, interpretation, analysis and designing the system. In this study, available results and information from the related experiments, the literature review was used to develop related expert program and for its validation purpose.

Design is the technical structure of the expert program related to organization and knowledge given by selected software. A prototype model and graphic user interface is an essential compartment of the expert system development process and it will be used for feasibility assessment by the user (Matthews *et al*., 1999). Each decision support system needs to be evaluated periodically to ensure accurate performance during operation by the user. The evaluation of models or programs with the field research data is an essential primary stage to develop a useful and practical model in establishing significant and reasonable effects on both agriculture-aquaculture community and professional users. Documentation and maintenance are the final steps of the program concerning appropriate modification and further development of the system. Schematic performance of the prediction models and visual user interface of the integrated culture system are shown in Figure 1.

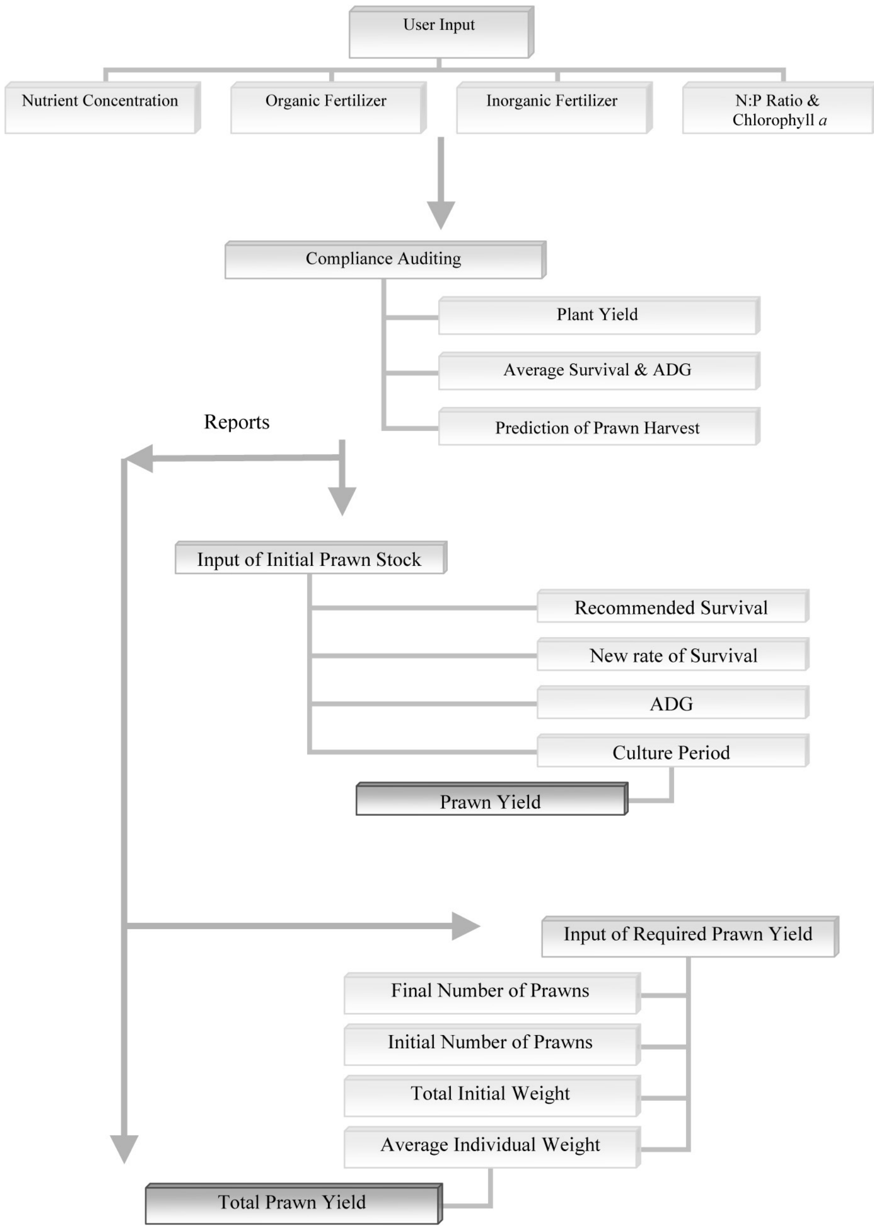

Figure 1: Diagram presenting parameters, components and processing of compliance auditing system (IAAS).

In order to improve and evaluate the quality of integrated aquaculture-agriculture expert system (IAAS), an experiment was adopted at the freshwater hatchery unit. Fourteen rectangular fiberglass tanks (1000 liter capacity) were used to culture freshwater prawn (*M. rosenbergii*) at different levels of nutrient in an artificial recirculated system (Table 1). *M. rosenbergii* was stocked at 250 post-larvae per 750 liters of filtered tap water. Water was finely aerated (48 hours) prior to stocking to deactivate adverse materials (e.g. chlorine). Animals were fed with an artificial prawn diet at the initial rate of 30 % biomass per day, which was then gradually reduced to 20%.

A hydroponics system based on the nutrient film technique (NFT) was installed over the water reservoir tanks. The water from freshwater prawn tanks was initially oxygenated, filtered (bio-physical) and passed frequently through the hydroponics troughs for plant (lettuce) irrigation during the culture period. The water quality variables, elements (N, P, K, Ca, Mg, Cu, Fe, Mn and Zn), and growth parameters of *M. rosenbergii* and plant were monitored weekly. Dissolved oxygen (DO) concentrations (mg L^{-1}), temperature (°C) and pH of the water were determined by using an YSI DO (550 DO) and pH meter (60-10 FT). The electrical conductivity (mS cm^{-1}) [EC], ammonia (NH_3 mg L^{-1}), turbidity (NTU) were all monitored by using HYDROLAB (DATASONDE^R 4a) and HACH spectrophotometer (DREL 12400). Available nitrogen, phosphorous and potassium were determined by the auto-analyzer (LACHAT instrument, 8000 Series), and Ca, Mg, K, Cu, Fe and Zn by atomic absorption spectrometry (Perkin Elmer 350). All determinations were made during 12.00-13.00 h.

Table 1: Different supplemented liquid fertilizer, chicken manure, density culture of *M. rosenbergii* and lettuce in integrated culture experiment.

Factors	Information
Nutrient	Formulated liquid fertilizer (LF), Chicken manure (CM)
Treatments	Levels of Liquid fertilizer (LF) + Chicken manure (CM)
HLFCM	HLF (145 $mLweek^{-1}$) + CM (15 g $week^{-1}$)
NLFCM	NLF (285 $mLweek^{-1}$) + CM (15 g $week^{-1}$)
MLFCM	MLF (430 $mLweek^{-1}$) + CM (15 g $week^{-1}$)
LF	LF (285 mL $week^{-1}$)
Freshwater prawn species	*Macrobrachium rosenbergii* (0.03-0.04 g) 3-4 cm
Vegetables N m^{-2}	(*Lactuca sativa*) 45 m^{-2}

HLFCM: Half Level of Liquid Fertilizer and Chicken Manure
NLFCM: Normal Level of Liquid Fertilizer and Chicken Manure
MLFCM: Maximum Level of Liquid Fertilizer and Chicken Manure

Water Quality and Bioassay Data

Changes of all monitored water quality variables and bio-assay parameters are presented in Table 2 and 3, respectively. The fluctuation of temperature (T°C), dissolved oxygen (DO), specific conductivity (SPC), salinity (Sal), turbidity (Tur), pH and total dissolved solid (TDS) were in acceptable range during the culture period (New, 1995). Fluctuations in pH were negligible, possibly due to the high buffering capacity of the water and supplemental liquid fertilizer (Table 2). The highest concentration of unionized ammonia (NH_3) was observed in the MLFCM and HLFCM rearing tanks (0.043-1.42 mg L^{-1}). The level of ammonia was considerably low and remained below 0.04 mg L^{-1} in the LF and NLFCM treatments. The concentration of nitrate (NO_3) fluctuated from 4.0 to 10.9 mg L^{-1} in the integrated rearing tanks and clinical signs of nitrate toxicity in the *M. rosenbergii* were not detected during the production cycle.

The yields of *M. rosenbergii* and plant were considerably varied in relation to the application of CM and formulated liquid fertilizer. The growth rate of freshwater prawn was higher in the NLFCM media, followed by MLFCM > LF > HLFCM rearing tanks (Table 3). Overall results of feed conversion ratio (FCR), survival (%) and average daily growth (ADG) indicated better performance in NLFCM culture media. Generally, the plants (lettuce) appeared healthy and grew rapidly during culture trials except in HLFCM treatment. At harvest, the total and marketable plant production varied in each trough of the culture tanks. The maximum and minimum yield ($P<0.05$) of lettuce were observed in MLFCM and HLFCM media, respectively. The medium nitrate and ammonia concentrations were below critical levels for the *M. rosenbergii* culture in all treatment, except in HLFCM (McMurtry *et al*., 1997). The nutrient toxicity and harmful condition reduced survival (36.3 %) and growth of *M. rosenbergii* (ADG, 0.044 g d^{-1}) during culture cycle in HLFCM rearing tank. This was possibly due to insufficient nutrient concentration, poor and retarded growth of plant, and increase in acute toxicity of unionized ammonia during the initial stage of culture period in the HLFCM culture tanks for *M. rosenbergii* growth. The recovery of nutrient (e.g. nitrate and phosphate) was introduced with the incorporation of hydroponic plant production in the culture of freshwater prawn. The profitable design, i. e., high rates of water exchange and minerals recovery in current recirculated culture system reduced the need for supplemental liquid fertilizer as well as produced a second marketable crop (*Lactuca sativa*) at harvest (Rakocy, 1999; Rakocy, 2004; Khoda Bakhsh, 2009).

Table 2: Water quality in the *M. rosenbergii* rearing tanks of the integrated culture system (mean ± SE).

Media	T (°C)	DO (mg L^{-1})	SPC (mS cm^{-1})	Sal (ppt)	Tur (NTU)	pH	TDS (g L^{-1})	NH_3 (mg L^{-1})	NO_3 (mg L^{-1})
LF	27.5± 0.3^a	5.92± 0.10^a	0.25± 0.02^a	0.12± 0.01^a	0.46± 0.18^a	7.52± 0.04^a	0.16± 0.01^a	0.04± 0.02^a	9.4± 1.0
NLFCM	27.4± 0.2^a	6.03± 0.10^a	0.25± 0.02^a	0.12± 0.01^a	2.75± 1.08^a	7.62± 0.04^a	0.16± 0.01^a	0.03± 0.01^a	9.0± 1.4
MLFCM	27.5± 0.2^a	5.97± 0.12^a	0.27± 0.02^a	0.13± 0.01^a	1.39± 0.68^a	7.63± 0.05^a	0.18± 0.01^a	0.45± 0.16^a	10.9± 1.9
HLFCM	27.7± 0.2^a	5.75± 0.12^a	0.25± 0.01^a	0.11± 0.01^a	2.00± 0.85^a	7.62± 0.01^a	0.16± 0.01^a	1.42± 0.61^b	4.0± 0.6

Means within a column followed by the same letter are not significantly different ($P<0.05$) as determined using DMRT (Duncan Multiple Range Test). T=temperature, DO=dissolved oxygen, SPC=specific conductivity, Sal=salinity, Tur=turbidity, TDS= total dissolved solid.

Table 3: Plant and prawn yield, survivals (%), average daily growth (ADG) and feed conversion ratio (FCR) of *M. rosenbergii* at harvest in the integrated culture system (mean ± SE).

Treatment	Plant yield (g $tank^{-1}$)	Prawn net yield (g $tank^{-1}$)	Prawn ADG (g d^{-1})	Prawn survival (%)	FCR
LF	1080.4±14^{ab}	261.3±3.8^b	0.053±0.001^b	66.7±1.8^b	2.6±0.04^a
NLFCM	1192.5±48.2^b	319.1±2.7^b	0.055±0.001^b	78.3±1.5^b	2.1±0.02^a
MLFCM	1869.3±201.2^c	291.0±23.9^b	0.062±0.001^c	63.6±4.5^b	2.3±0.19^a
HLFCM	689.9±71.6^a	113.8±18.8^a	0.044±0.001^a	36.3±6.2^a	6.1±1.01^b

Means within a column followed by the same letter are not significantly different ($P<0.05$) as determined using DMRT.

Validation Process

In the IAAS program, compliance auditing of different components and parameters were conducted for operation aspects, management, and knowledge base on the intended integrated culture system. The major module and available visual interface used for displaying the overall yield and survival monitoring status in IAAS program are shown in Figures 2 and 3, respectively. Direct monitoring and estimation of aquaculture yields are often impossible and inaccurate processes. Scientific estimation of growth rate, survival, and water quality variables in an aquaculture system could be the best approach to ensure environmentally-and economically-sustainable aquaculture production. Polynomial and linear regression models have been used for prediction and evaluation aquaculture activities, yield and crop outputs (Rijn and Nussinovitch, 1997; Chou *et al*., 2004).

Accuracy analysis of the prediction and decision models (IAAS) were tested with a serial data collected from the artificial integrated culture trial. Supplemental liquid fertilizer varied from 145 to 430 mg L^{-1} in *M. rosenbergii* rearing tanks. The levels of chicken manure (CM) ranged from 0 to 15g $tank^{-1}$ with 0.03-0.04 g initial prawn weight. The relationships between IAAS program output versus growth rate and water quality factors were determined by polynomial and linear regression techniques (Primavera *et al*., 1998; Lee, 2000; Jamu and Piedrahita, 2001). The results of selected parameters are presented in Table 4, and Figures 4 and 5, respectively.

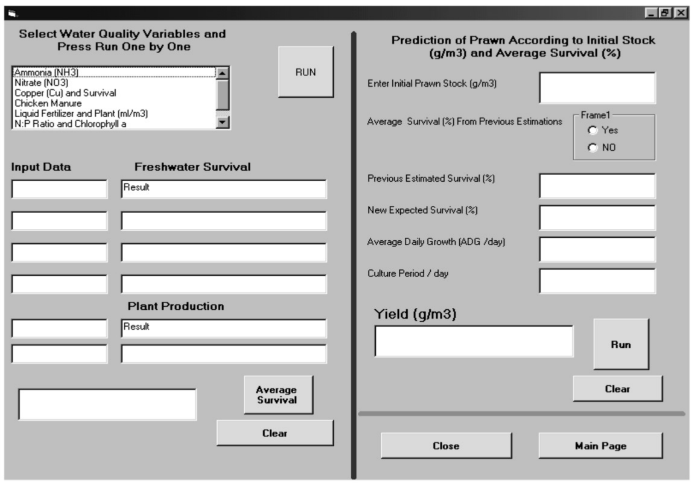

Figure 2: Graphical visual interface showing the compliance audit for the evaluation of *M. rosenbergii* survival and yield (first and second step).

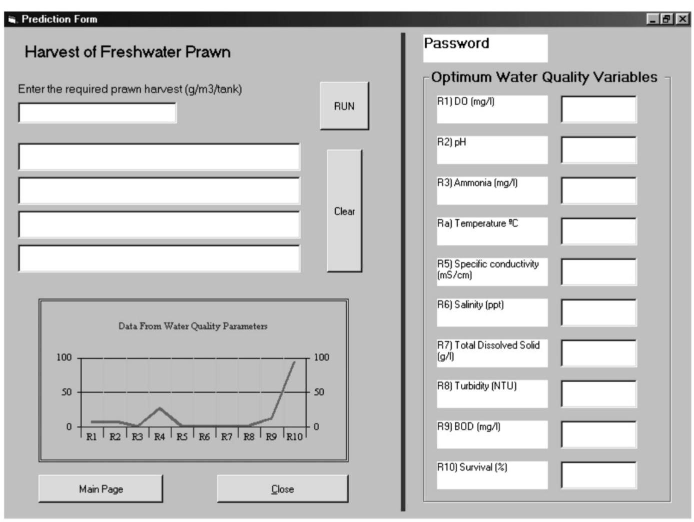

Figure 3: Graphical visual interface showing the compliance audit for prediction of *M. rosenbergii* yield with optimum levels of individual component.

Table 4: Comparison of the selected variables in the real experiment and IAAS expert program.

			Treatments		
Parameters	LF	NLFCM	MLFCM	*HLFCM	Average
Conducted experiment					
Survival %	66.7	78.3	63.6	36.3	61.2
Predicted value					
IAAS output	67.5	69.2	68.2	44.9	62.5
Difference	0.8	-9.1	4.6	8.6	1.2
Percentage Error %	1.2	11.6	7.2	23.7	5.1
Conducted experiment					
*Prawn yield (g m^{-3})	261.3	319.1	291.0	113.8	246.3
Predicted value					
IAAS output	313.8	321.5	316.9	208.8	290.3
Difference	52.5	2.4	25.9	95	44.0
Percentage Error %	20.1	0.8	8.9	83.5	28.3
Conducted experiment					
Plant yield (g m^{-3})	1080.4	1192.5	1869.3	689.9	1208.0
Predicted value					
IAAS output	1403.8	1449.8	1981.7	898.6	1433.5
Difference	323.4	257.3	112.4	208.7	225.5
Percentage Error %	29.9	21.6	6.0	30.3	21.9

*HLFCM= represent maximum error (%)
*Prawn yield= prawn net yield

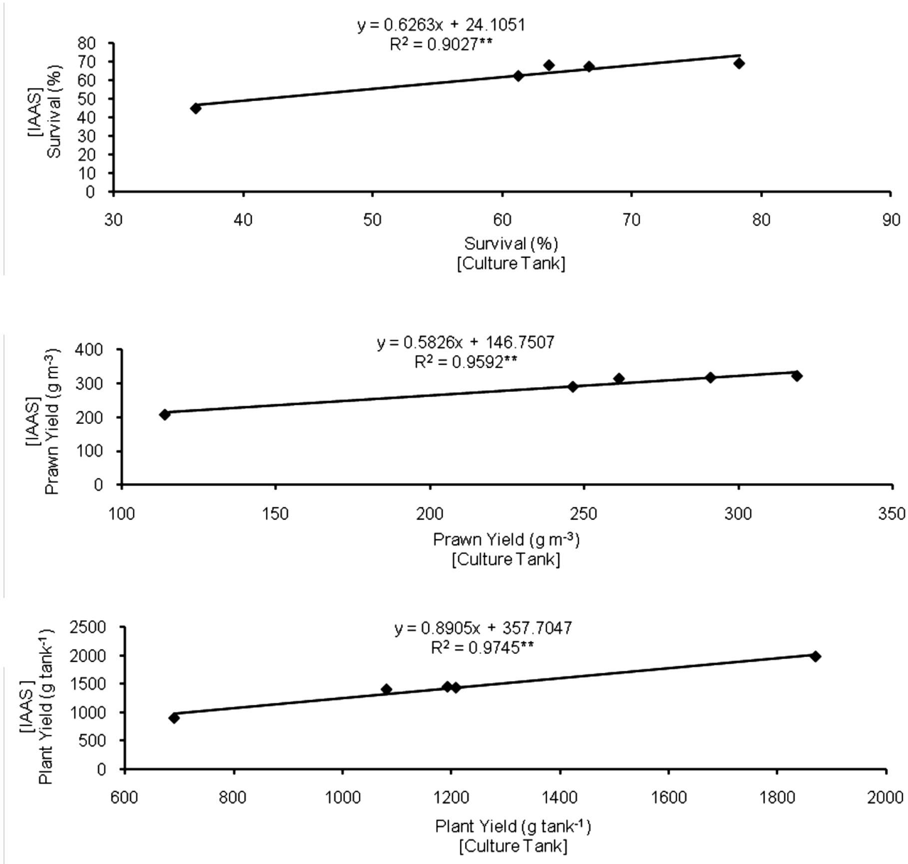

Figure 4: Linear relationships of IAAS outputs vs. integrated culture trial data in survival, prawn and plant yields.
** (P<0.01)

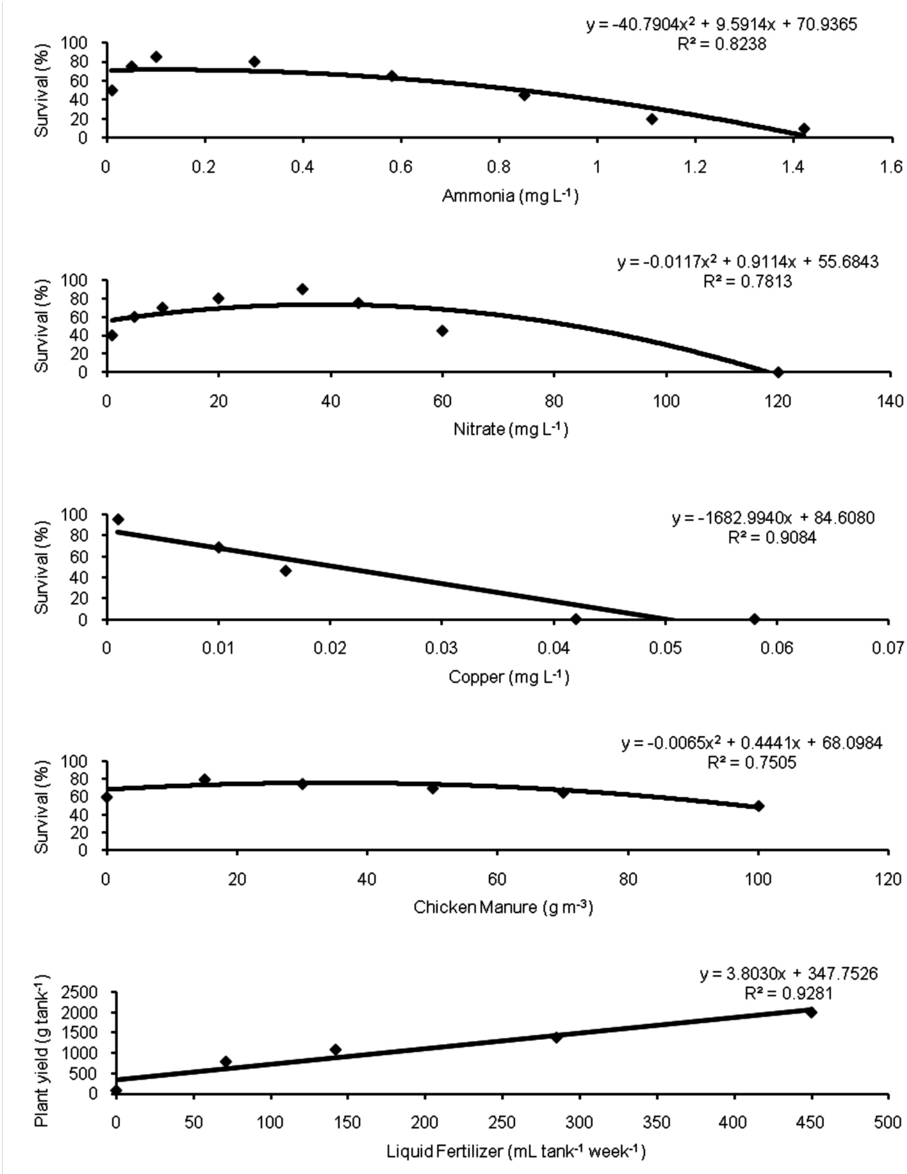

Figure 5: Quadratic and linear regression trends of Survival (%) and plant yield (IAAS program) versus selected variables in integrated culture trial (ammonia, nitrate, copper, chicken manure, liquid fertilizer).

Results and Discussion

The corresponding regression coefficient of determination of survival (R^2=0.9027**), prawn (R^2=0.9592**) and plant yields (R^2=0.9745**) was significantly high and represent the close relationships between predicted results by IAAS expert program and artificial integrated culture system (Figure 4). The mean percentage error (| actual -predicted | x l00/actual yield) varied extremely in different culture systems. In overall, the survival (%) and prawn net yields were higher at NLFCM culture tank, while the predicted and measured plant yields agreed well at high supplementary liquid fertilizer (MLFCM), followed by the normal integrated culture system (NLFCM). Treatment inoculated with minimum level of liquid fertilizer (HLFCM) indicated higher variations of estimated values than others (Table 4). This phenomenon was related to culture condition and abnormal concentration of nutrients.

The above illustrates that the application rate of formulated liquid fertilizer (LF) is important in modeling prospect and prediction status of integrated culture system. Moreover, environmental and biological parameters have major effects on the nutrient variations in prawn rearing tanks. Over-fertilization may encourage plant growth, but results in an increase of nutrients (nitrogenous compound) and decreases quality of water in the integrated culture system. A high level of toxicity in a very low culture condition drastically reduced the prawn survival rate. Ammonia and nitrite poisoning are common in a recirculated culture system, especially when prawns were immediately stocked to maximum capacity. These toxins weaken and stress crustaceans to the point where they become vulnerable to many sub-clinical diseases. Understanding the nitrogen cycle is essential in the culturing of aquatic life. Depending on the life stage of *M. rosenbergii* (post-larvae, juveniles or adult), suboptimal water quality associated with stressful condition allow potential pathogens to cause disease outbreaks and mortality (Floyd, 2003).

The corresponding value of regression trends (Figure 5) between *M. rosenbergii* survival evaluated by IAAS versus ammonia concentration was highly significant ($R^2 = 0.8238^{**}$, $P<0.01$). The predicted quadratic trend by IAAS between prawn survival and nitrate concentration (NO_3) indicated significant relationships ($R^2 = 0.7813^{**}$, $P<0.01$). Copper is an essential minor element which can be toxic to aquatic crustaceans at certain levels (New, 1995). The linear regression trend of freshwater prawn survival and copper (Cu) indicated significant relationship in computerized (IAAS) and integrated culture trials ($R^2 = 0.9084^{**}$, $P<0.01$). Polynomial regression of freshwater prawn survival (IAAS) and value of CM application have shown significant relationships ($R^2 = 0.7505^{**}$, $P<0.05$) during production period. The strong linear relationships between plant yield and levels of liquid fertilizer represent a significant harmony of both variables ($R^2 = 0.9281^{**}$, $P<0.01$).

The present experiment illustrated strong relationships between selected variables in natural integrated culture and IAAS expert program. Prediction is the most unrealistic feature of the logical model or decision support systems. Thus, the evaluation methods should be always identical under any given combination of related water quality and growth rate variables. The study was conducted in order to clarify the difference between the IAAS program and artificial integrated culture systems. Simple and multi-assumptions were made in all mathematical models and simulation processes. In a natural integrated culture system, the quality of water, nutrient inputs, and the whole environmental condition have complex effects on the culture of fish and crustaceans. It was concluded that the survival rate of *M. rosenbergii* could be estimated by using the polynomial and linear regression equations, but the average daily growth rate (ADG) should be optimized through the normal and abnormal quality conditions in improving the efficient monitoring prospects. It is suggested that the variations in yield estimation were probably due to natural errors (variance) in polynomial trend rather than linear models and management practice (fertilization and operation).

Summary and Conclusion

Aquaculture activities and technology development may cause various effects on different compartments in sustainable integrated culture systems. By taking the conduction of the effectiveness of management and monitoring of available sources of water and land, and thereby quality, the potential impact of integrated culture on aquatic and terrestrial ecosystem is possible through a quantitative technique development and the application of computer systems as an expert compliance auditing tool. Most evaluation studies involve collection of data and reports, which are then followed by the use of established methods and models in predicting and validating some of the significant physico-chemical, biological and environmental factors. Yield and prediction of nutrient impact made by the IAAS program would be tested with the real data collected in the natural integrated system. However due to the facility and unavailability of similar integrated production system in conducts the study, the IAAS program was then evaluated by employing artificial experiment. Other than the nutrient concentration, the available data of *M. rosenbergii* yields, survival and plant production were compared to the predicted result generated by the IAAS expert program. Validation of the IAAS program determined the performance of the system with a reasonable level of accuracy in the prediction of survival, prawn yield and plant yield in the optimized artificial integrated culture system with the error of 7.2, 8.9, and 6.0%, respectively (Table 4). The flexibility of the IAAS system has been validated separately by using selected variables (survival and yield) in different culture media. Domain flexibility of prawn yields was higher than those of yield of plant and prawn survival rate.

The evaluative study provides analytical evidence for the feasibility of combining intensive prawn and plant production in a formulated recirculating integrated culture system. Although statistical tests (regression technique) confirmed the significant relationships of natural and predicted data in an optimized (normal) culture system, the IAAS expert program however gave higher variation in survival rate (%), prawn and plant yields in the abnormal culture system. Knowledge and additional data obtained in respective experiments were used to develop domain efficiency and multi reaction quality of IAAS expert system.

Acknowledgements

The authors would like to acknowledge the assistance of the Hatchery Units, Faculty of Agrotechnology and Food Science (FASM) and the Research Management Center (RMC) at Universiti Malaysia Terengganu (UMT) and Universiti Putra Malaysia (UPM) for laboratory analyses, technical support and system construction.

References

Chou, C. L., Haya, K., Paon, L.A. and Moffatt, J. D. (2004). A regression model using sediment chemistry for the evaluation of marine environmental impacts associated with salmon aquaculture cage wastes. *Marine Pollution Bulletin* 49: 465–472.

FAO (Food and Agriculture Organization of the United Nation). (2002). Farming Freshwater Prawns. A manual for the culture of the giant river prawn (*Macrobrachium rosenbergii*). FAO Fisheries Technical Paper 428. http://www.fao.prg/documents. Accessed on 27 December 2002.

Floyd, R. F. (2003). Introduction to Fish Health Management. Agricultural Science, University of Florida. Original Publication, Document No. CIR921. 4pp.

Jamu, D. M. and Piedrahita, R. H. (2001). Ten-year simulations of organic matter concentrations in tropical aquaculture ponds using the multiple pool modeling approach. *Aquacultural Engineering* 25: 187–201.

Jimenez-Montealegre, R., Verdegem, M. C. J., Van Dam, A. and Verreth, J. A. J. (2002). Conceptualization and validation of a dynamic model for the simulation of nitrogen transformations and fluxes in fish ponds. *Ecological Modelling* 147: 123–152.

Khoda Bakhsh and Rashid Shariff. (2007). Nutrient Optimization and Computerized Decision Support Program in Recirculating Integrated Aquaculture System. *The International Journal of Environmental, Cultural, Economic and Social Sustainability* 3(5): 25-34.

Khoda Bakhsh, H. (2009). *Production of Freshwater Prawn through Integrated Culture System (Hydroponics & Aquaponics)*. Malaysia: UMT Publisher. 30pp

Lee, P. G. (2000). Process control and artificial intelligence software for aquaculture. *Aquaculture Engineering* 23(1-3): 13-39.

Matthews, K. B., Sibbald, A. R. and Craw, S. (1999). Implementation of a spatial decision support system for rural land use planning: integrating geographic information system and environmental models with search and optimization algorithms. *Computers and Electronics in Agriculture*, 23: 9–26.

McMurtry, M. R., Sanders, D. C., Cure, J. D., Hodson, R. G., Haning, B. C. and Amand, P. C. S. (1997). Efficiency of water use of an integrated fish/vegetable co-culture system. *Journal of the World Aquaculture Society* 28: 420-428.

New, M. B. (1995). Status of freshwater prawn farming: A review. *Aquaculture Research* 26(1): 1-54.

Primavera, J. H., Parado-Estepa, F. D. and Lebata, J. L. (1998). Morphometric relationship of length and weight of giant tiger prawn *Penaeus monodon* according to life stage, sex and source. *Aquaculture* 164: 67-75.

Rakocy, J. E. (1999). The Status of Aquaculture, Part 2. Aquaculture Magazine September/ October, P: 64-70.

Rakocy, J. (2004). Aquaponics Journal Question and Answer. http://www.aquaponics.com. Accessed on 12 July 2004.

Rijn, J. V. and Nussinovitch, A. (1997). An empirical model for prediction degradation of organic solids in fish culture systems based on short-term observation. *Aquaculture* 154: 173-179.

Sell, P. S. (1986). *Expert Systems- A Practical Introduction*. London:MACMILLAN PUBLISHERS LTD. 99 pp.

Stunder, M. (1990). Verification and validation of environmental expert systems. Pages 39-51 in J. M. Hushon ed. Expert Systems for Environmental Applications, ACS symposium Series. Washington: American Chemical Society.