# Water Quality and Nutrient Aspects in Recirculating Aquaponic Production of the Freshwater Prawn, *Macrobrachium rosenbergii* and the Lettuce, *Lactuca sativa*

H. Khoda Bakhsh[1], T. Chopin[2]

[1] Department of Biology, University of New Brunswick
P.O. Box 5050, Saint John, NB, E2L 4L5 Canada

[2] Canadian Integrated Multi-Trophic Aquaculture Network, University of New Brunswick
P.O. Box 5050, Saint John, NB, E2L 4L5, Canada

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## ABSTRACT

The purpose of this study was to investigate the effects of different nutrients and their ability to improve the production of *Macrobrachium rosenbergii* and Lactuca sativa in a prototype recirculating aquaponic (RA) system. Experimental units were set up with different amounts of supplemented organic and inorganic (complex minerals) nutrients to carry out the study. The results indicated that desirable growth of *M. rosenbergii* might be possible in RA systems when supplied sufficient levels of macro-micro nutrients. Analyses of nutrients in the prawn culture tanks demonstrated that ammonia and nitrate concentrations were critical in maintaining proper water quality during the culture period. Five-day biological oxygen demand (BOD5) increased significantly with the increased loading of organic supplement in the rearing tanks. A significant linear relationship of chlorophyll a and N:P ratio was observed among the treatments. The combination of complex minerals and organic chicken manure (CM15) displayed a higher N:P ratio, maximal total yield and did not show adverse effects of NH3 concentrations and other important water quality parameters.

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# INTRODUCTION

In the last decade, there has been increased interest in integrated aquaculture systems in line with increased activities for sustainable agriculture in developing and developed countries (Langdon et al. 2004). A wide variety of organic and inorganic materials (raw or pure by-product) can be used as supplements in fish and prawn aquaculture (Green et al. 1989). Meanwhile, large volumes of discharged aquaculture waste can become a serious source of pollution with environmental risk (Pillay 1992; Brown et al. 1999; Troell et al. 2009; Endut et al. 2010).

The giant freshwater prawn *(Macrobrachium rosenbergii*) has received the most attention from researches and farmers due to its nutritional value, taste and demand in the market (Schwantes et al. 2009). *Macrobrachium rosenbergii* production is economical and more environmentally sustainable compared to conventional intensive shrimp production. Information on stocking density and requirements of *M. rosenbergii* in monoculture systems is available (Marques et al. 2000). However, the development and production of freshwater prawn with high level efficiency in aqua/agriculture systems still requires the identification and evaluation of specific requirements (food and nutrient) of the different species cultivated in these systems.

Aquaculturists are continually looking for new ways to produce more aquatic animals with less water, land and pollution to minimize adverse environmental impacts. One source–waste reduction approach is the production of vegetables in the wastewater and effluents. Wastewater, effluents and sludge from semi-extensive or intensive aquaculture systems are potential sources of irrigation water, nutrients and media for vegetable crops (Adler et al. 2003). Accordingly, recirculating aquaponic technology acts as a small sewage treatment system to clean up the water and decrease nutrient concentrations. Aquaponic thin-film allows plants to selectively extract nutrients from water making dilute effluents a similar source of nutrients as more concentrated effluents.

Although integrated systems appear to show diversification and efficiency, they are not always successful and popular in some regions (tropical and subtropical for example). Undesirable results, lack of financial support and technical problems have led to a significant decrease in the importance of integrated culture farming. A basic problem in such a system may arise from the discrepancy between productive compartments and un-optimized intensity of the plant and aquatic species in the system (Rakocy et al.1993; Khoda Bakhsh 2008).

In fact, very little information is available on the concentration limits of nutrient elements (especially microelements) at which deficiency or toxicity may occur in the recirculating aquaponic systems (Khoda Bakhsh et al. 2007). Poor quality of water, mineral toxicity and nutrient deficiency are still problematic in integrated fish/prawn production, especially in the early stages of the life cycle (fry and fingerling). Indeed, for widespread utilization of recirculating aquaponic systems and exploitation of their maximal potential, there is a need for more information on the types of inorganic nutrients, volumes of organic substances, proper stocking densities, feed conversion ratios (FCR) and water quality.

The objective of this study was to evaluate the beneficial effects of supplemented inorganic and organic substances on the production of *M. rosenbergii* and *L. sativa* in a prototype recirculating aquaponic system. The outputs and relevant expected information including nutrient dynamics, biological oxygen demand (BOD), primary productivity (chlorophyll a), and growth performance will serve as a basis for future studies and provide some recommendations for aquaculturists and farmers that might improve their chances of succeeding with new production technology.

## MATERIALS AND METHODS

Twenty fiberglass tanks (1m3) were installed to evaluate different amounts of supplemental nutrients and new design in recirculated culture systems. Experimental units consisted of a rearing container (500 liters), aeration tank (300 liters) and hydroponic nutrient film technique (NFT) trays (110 L x 80 W x 5 cm H). Each NFT unit consisted of 45 lettuce seedlings (m2) and all plant troughs were located over the reservoir-aeration tanks. Rearing tanks were exposed to natural light conditions (12 hours/day) to mimic natural conditions for prawn growth (Figure 1).

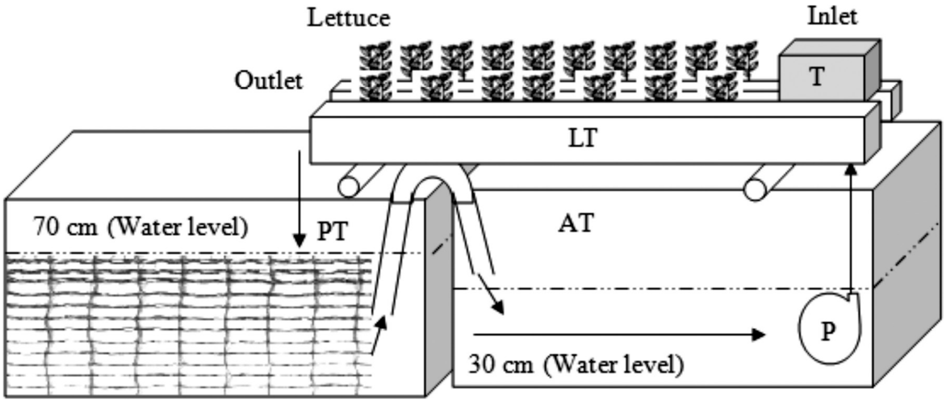


*Figure 1: Arrangement of the prawn culture, aeration tank and aquaponic troughs in the recirculating aquaponic system (PT-Prawn Tank, AT-Aeration Tank, AS-Artificial Substrate, P-Pump, T-Trickling system and LT-Lettuce Trough).*

The culture water effluent was transferred to the aeration tank continuously and passed through the vegetable troughs by using an electric pump (Aquanic Power Head 1500). *Macrobrachium rosenbergii* juveniles were stocked at 380/m3 and all tanks were provided with artificial substrate (polyethylene net) to increase available surface area (50%). To acclimate prawns to the prototype system, the partial stock of *M. rosenbergii* (55 juveniles /day) were adjusted together with seedlings of lettuce during the first week of the study. This system was not provided a specific fluidized-sand biofilter to remove solid-suspended waste. The simple trickling system and shallow streams in plant trays provided a suitable compartment for trap and mineralization of suspended solids in recirculating water before returning to the prawn tanks. Juveniles of *M. rosenbergii* were fed a commercial prawn diet two times daily (9:00 and 17.00). The feeding rate was adjusted according to the average body weight of the prawns every week, and gradually reduced from 30% (starter) to 10% (grower) during the study.

The physical and chemical parameters of the water in the prawn tanks were monitored weekly. Water quality factors were measured using standard apparatus and all determinations were recorded between 12:00 and 13:00. Dissolved oxygen (DO), temperature (°C) and pH of the rearing water were determined using an YSI DO (550 DO) and pH meter (60-10 FT). The specific conductivity (mS/cm), salinity (ppt), and turbidity (NTU) were measured in the field by in situ measurement with an HYDROLAB DATASONDE® 4a. The chemical parameters, including ammonia (NH3) and nitrate (NO3), were measured by the salicylate method (HACH kit DR

2010). Available nitrogen (N) and phosphorus (P) were determined with an auto-analyzer (LACHAT instrument, 8000 Series) and atomic absorption spectrometry (Perkin Elmer 350). Five-day biological oxygen demand (BOD5) and chlorophyll a contents of benthic algae were measured by standard methods (APHA 1995). The chlorophyll a content in benthic algae was initially determined by measuring the absorbance of acetone extract at 750, 664, 647, and 630 nm with a spectrophotometer (Thermo Spectronic 4001/4).

Lettuce growth analysis included total yield, and fresh and dry weight (oven dried at 105°C) which were carried out using a digital balance (Sartorius, BP 310S) at the end of the experiment. The survival and specific growth rate (SGR), average daily growth (ADG), net yield and feed conversion ratio (FCR) of freshwater prawn were calculated at the end of the experiment. The available information on water quality and *M. rosenbergii* growth (SGR and ADG) of nearby prawn ponds was recorded for overall comparison of the different culture system.

Complex mineral and organic supplements were used in order to meet nutrient requirements of *L. sativa* and *M. rosenbergii* together. Minerals were prepared to adjust specific conductivity from 0.2 to 0.4 mS/cm as followed: calcium nitrate (68.80 mg/l), EDTA iron (3.50 mg/l), potassium dihydrogen phosphate (18.10 mg/l), potassium nitrate (21.90 mg/l), magnesium sulphate (41.40 mg/l), manganous sulphate (0.4 mg/l), boric acid (0.10 mg/l), copper sulphate (0.02 mg/l), ammonium molybdate (0.023 mg/l) and zinc sulphate (0.03 mg/l). The complex minerals were applied to the first treatment group (CM15) together with 15 g/m2/week of oven dried chicken manure. By increasing the rate of chicken manure (30-50 g/m2), the level of supplemented minerals was reduced by 50% in CM50 and 30% in CM30 treatment, respectively. Unfertilized freshwater (UFW) and culture system enriched with 70 g chicken manure (CM70) were operated as controls in this study. The fixed-equivalent portion of the nutrients was added to the reservoir-aeration tanks every week.

**Statistical Analysis**

Experimental units were arranged in a randomized design with two replicates. Significant difference in the mean number of water quality and growth rate variables between control (no supplements) and enriched media were determined by one-way analysis of variance (ANOVA) followed by Duncan's New Multiple Range Test ($P<0.05$).

# RESULTS

## Water Quality Variables

Most water quality parameters were significantly higher in the recirculating aquaponic systems than in natural ponds except for temperature, turbidity and ammonia concentration (Table 1). A quadratic response of ammonia over time was observed for CM15 (y = 0.0103x2 - 0.0548x + 0.2489, R2 = 0.60*, n = 8), CM30 (y = 0.017x2 - 0.1105x + 0.3631, R2 = 0.81**, n = 8) and CM70 (y = 0.0084x2 - 0.0335x + 0.271, R2= 0.64*, n = 8) treatments.  A sharp increase in ammonia was evident in weeks 4 and 7 of the UFW treatment (Figure 2).

*Table 1: Mean (±se) temperature (T), dissolved oxygen (DO), specific conductivity (SPC), salinity (Sal), turbidity (Tur), pH, total dissolved solid (TDS) and ammonia (NH3) concentration of different treatments in the recirculating aquaponic system.*

| Treatment | T (˚C) | DO (mg/l) | SPC (mS/cm) | Sal (ppt) | Tur (NTU) | pH | TDS (g/l) | NH3 (mg/l) |
|---|---|---|---|---|---|---|---|---|
| CM15 | 27.0± 0.3$^{a}$ | 7.09± 0.11$^{b}$ | 0.24± 0.04$^{b}$ | 0.12± 0.02$^{ab}$ | 1.53± 0.4$^{a}$ | 7.54± 0.17$^{b}$ | 0.16± 0.02$^{b}$ | 0.27± 0.04$^{a}$ |
| CM30 | 26.7± 0.2$^{a}$ | 7.09± 0.16$^{b}$ | 0.23± 0.04$^{b}$ | 0.11± 0.02$^{ab}$ | 1.96± 0.6$^{a}$ | 7.47± 0.12$^{b}$ | 0.15± 0.02$^{b}$ | 0.31± 0.05$^{a}$ |
| CM50 | 26.7± 0.3$^{a}$ | 7.06± 0.11$^{b}$ | 0.22± 0.03$^{b}$ | 0.19± 0.09$^{b}$ | 1.69± 0.6$^{a}$ | 7.41± 0.06$^{b}$ | 0.14± 0.02$^{b}$ | 0.30± 0.03$^{a}$ |
| UFW | 26.6± 0.3$^{a}$ | 7.01± 0.09$^{b}$ | 0.17± 0.02$^{b}$ | 0.08± 0.01$^{ab}$ | 0.95± 0.3$^{a}$ | 7.53± 0.04$^{b}$ | 0.11± 0.01$^{b}$ | 0.30± 0.04$^{a}$ |
| CM70 | 26.7± 0.2$^{a}$ | 7.20± 0.09$^{b}$ | 0.21± 0.03$^{b}$ | 0.10± 0.02$^{ab}$ | 2.03± 0.5$^{a}$ | 7.67± 0.06$^{b}$ | 0.13± 0.02$^{b}$ | 0.36± 0.05$^{a}$ |
| Pond | 29.7± 0.8$^{b}$ | 4.90± 0.30$^{a}$ | 0.06± 0.01$^{a}$ | 0.02± 0.01$^{a}$ | 22.53± 1.5$^{b}$ | 6.87± 0.11$^{a}$ | 0.04± 0.01$^{a}$ | 0.41± 0.21$^{a}$ |

Means within a column followed by the same letter are not significantly different by determination of the Duncan’s multiple-range test (P < 0.05).

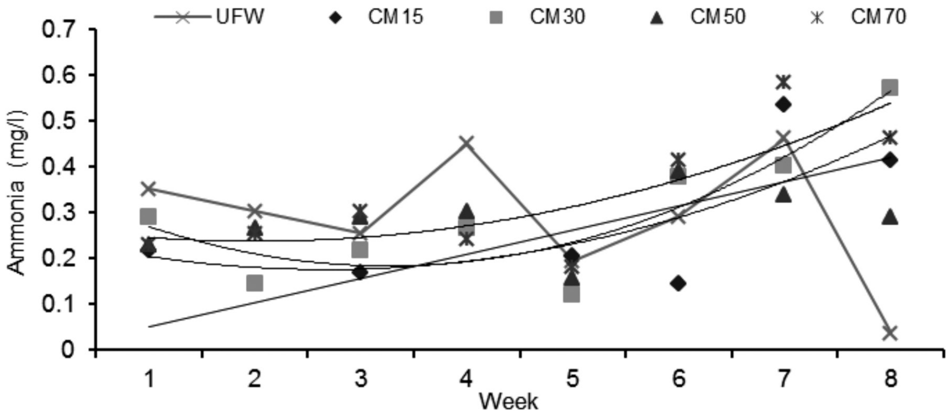


*Figure 2: Changes of ammonia concentration in the recirculating aquaponic system.*

**Five-day Biological Oxygen Demand (BOD5)**

Five-day biological oxygen demand was significantly higher in all enriched treatments compared to the UFW media (Table 2). The BOD5 increased significantly with increasing chicken manure loading rates in the rearing tank (Figure 3). The value of BOD5 can be predicted from the amount of chicken manure used (x, g CM week-1) with the following equation: $y = 0.0018x + 0.0813$, $R2= 0.9096^{**}$, $n = 10$.

*Table 2: Five-day biological oxygen demand (BOD5) in the recirculating aquaponic system (mean ± se).*

| Treatment | $BOD_5$ mg/l |
|---|---|
| CM15 | 0.12±0.01[b] |
| CM30 | 0.15±0.00[bc] |
| CM50 | 0.17±0.01[cd] |
| UFW | 0.07±0.01[a] |
| CM70 | 0.20±0.02[d] |

Means within a column followed by the same letter are not significantly different by determination of the Duncan's multiple-range test ($P < 0.05$).

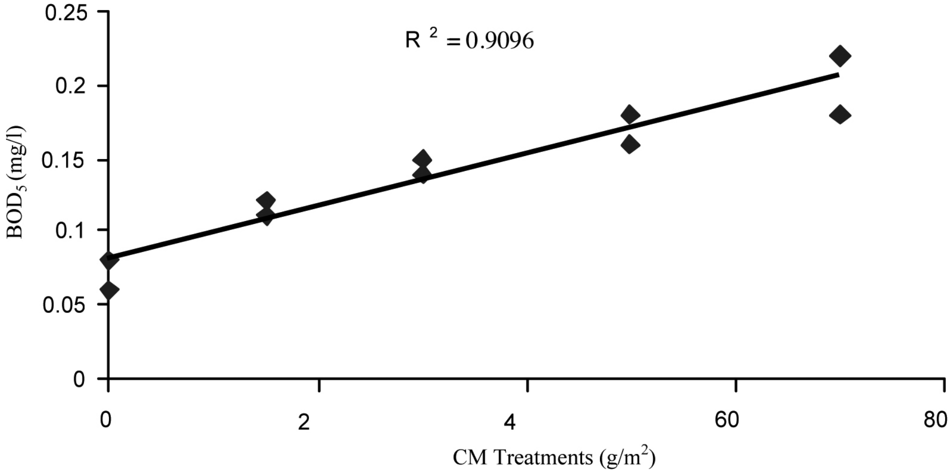


*Figure 3: Linear relationship between five-day biological oxygen demand (BOD5) and treatments fertilized with chicken manure (CM).*

## Chlorophyll a content and N:P Ratios

A significant linear relationship between the chlorophyll a content (periphyton and benthic algae) and N:P ratios was observed among the treatments (Figure 4). The lowest chlorophyll a content ($P<0.05$) was recorded in CM15, followed by the CM30 and CM50 treatments ($y = 254.43x + 76.255$; $R2 = 0.8651^{**}$, $n = 10$). The combination of complex minerals and chicken manure showed increasingly higher N:P ratios in CM15, CM30 and CM50, respectively ($y = -1.698x + 14.94$; $R2 = 0.7803^{**}$, $n = 10$). The UFW and CM70 media represented the lower range of nitrogen versus phosphorus during the culture period.

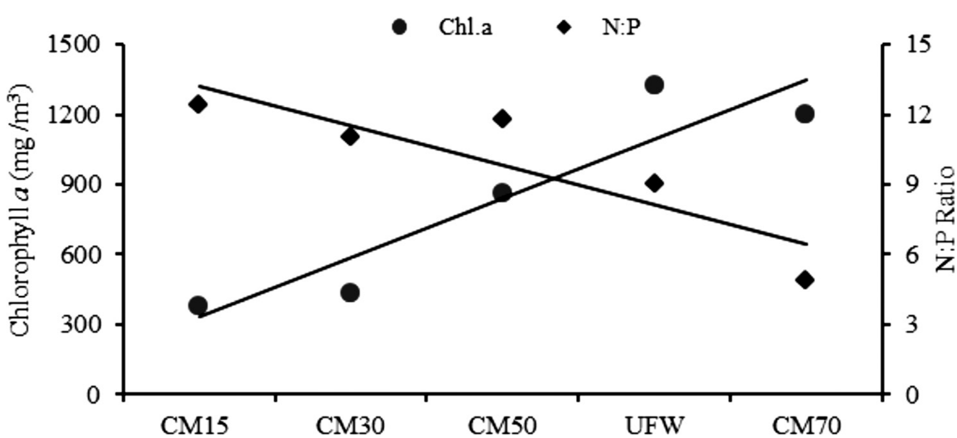


*Figure 4: Concentration of chlorophyll a (benthic algae) and N: P ratio in M. rosenbergii culture tanks.*

**Plant and Prawn Growth**

The plant bioassay did not show any significant differences among enriched treatments. Plant growth was low in UFW media and displayed a significant difference in the yield, leaf and root weight (dry) when compared to the CM15 treatment at the end of the experiment (Table 3). No significant difference in root weight (wet) was observed among the treatments. The best performance of plant growth was recorded in the CM15 medium supplemented with minerals plus chicken manure (15 g/week).

*Table 3: Weight (g/plant) and total yield of Lactuca sativa at harvest in the recirculating aquaponic system (mean ± se).*

| Treatment | Leaf wet weight (g) | Leaf wet weight (g) | Root wet weight (g) | Root wet weight (g) | Yield (g/tank) |
|---|---|---|---|---|---|
| CM15 | 39.6±7.22$^{b}$ | 1.7±0.43$^{b}$ | 4.2±1.11$^{a}$ | 0.22±0.03$^{b}$ | 1783.4±325$^{b}$ |
| CM30 | 24.1±9.12$^{ab}$ | 1.1±0.23$^{ab}$ | 4.1±2.72$^{a}$ | 0.12±0.08$^{ab}$ | 1086.3±410$^{ab}$ |
| CM50 | 17.6±2.01$^{ab}$ | 0.9±0.01$^{ab}$ | 2.1±0.28$^{a}$ | 0.10±0.01$^{ab}$ | 791.6±90$^{ab}$ |
| UFW | 1.9±0.62$^{a}$ | 0.3±0.05$^{a}$ | 0.3±0.04$^{a}$ | 0.03±0.01$^{a}$ | 84.2±28$^{a}$ |
| CM70 | 16.7±10.33$^{ab}$ | 0.7±0.33$^{ab}$ | 1.4±0.87$^{a}$ | 0.06±0.04$^{ab}$ | 753.1±465$^{ab}$ |

Means within a column followed by the same letter are not significantly different by determination of the Duncan's multiple-range test ($P < 0.05$).

For prawn, the CM15, UFW and CM70 treatments resulted in better SGR (%) than in natural ponds and the ADG was significantly higher in the CM15 treatment followed by the UFW and CM70 culture tanks. The highest prawn yield was observed in CM15, followed by CM50, CM30, CM70 and UFW. The minimum and maximum levels of FCR (0.42-1.18) were observed in the CM15 and UFW rearing tanks, respectively (Table 4).

*Table 4: Survival rate (%), specific growth rate (SGR), average daily growth (ADG), net yield and feed conversion ratio (FCR) of Macrobrachium rosenbergii in the recirculating aquaponic system and prawn pond (mean ± se).*

| Treatment | Survival (%) | SGR (%/d) | ADG (per day) | Yield g/tank | FCR |
|---|---|---|---|---|---|
| CM15 | 87.9±0.8$^{c}$ | 6.02±0.003$^{e}$ | 0.07±0.001$^{e}$ | 1343.0±11$^{d}$ | 0.42±0.004$^{a}$ |
| CM30 | 90.0±0.7$^{c}$ | 5.17±0.011$^{b}$ | 0.04±0.001$^{b}$ | 840.1±13b$^{c}$ | 0.67±0.010$^{b}$ |
| CM50 | 93.8±1.4$^{c}$ | 5.16±0.002$^{b}$ | 0.04±0.001$^{ab}$ | 869.5±14$^{c}$ | 0.65±0.010$^{b}$ |
| UFW | 41.0±1.7$^{a}$ | 5.68±0.027$^{d}$ | 0.05±0.001$^{d}$ | 481.1±15$^{a}$ | 1.18±0.035$^{c}$ |
| CM70 | 75.0±3.5$^{b}$ | 5.47±0.059$^{c}$ | 0.05±0.002$^{c}$ | 820.5±14$^{b}$ | 0.69±0.012$^{b}$ |
| Pond | - | 5.03±0.015$^{a}$ | 0.04±0.001$^{a}$ | - | - |

Means within a column followed by the same letter are not significantly different by determination of the Duncan's multiple-range test ($P < 0.05$).

## DISCUSSION

### Water Quality

In an aquatic ecosystem, fish and prawn are directly affected by several chemical and physical factors. The major water quality factors important in freshwater aquaculture were evaluated in this study. All pH, DO and measured water quality parameters were within acceptable limits for freshwater prawn culture, however, disparity and abnormal concentration of ammonia influenced the productivity of *M. rosenbergii* and *L. sativa* in the recirculating aquaponic systems. The DO concentration was higher in prawn culture tanks when compared to that in natural ponds (Table 1). Adequate DO is necessary for good water quality in intensive aquaculture systems (Stickney 1994; Alon et al. 2008). The DO results in the prawn-plant system illustrated the effectiveness of the second aeration tank to re-oxygenate water from *M. rosenbergii* rearing tanks. Temperature ranged from 26.6 to 27.0°C, typical of operating during the rainy season (November to January). Most of the available studies on temperature tolerances were conducted on *M. rosenbergii* production in earthen ponds or larval stages in tanks (FAO 2002). Data on the quantitative relationship between water temperature and juvenile or adult production of prawns in indoor recirculating aquaponic systems are still rare. Generally, temperatures of 26-31°C are considered satisfactory for prawn growth (New 1995). There is an advantage of a lower range of temperatures (at the lower end of 25-32˚C) for freshwater prawn growth because lower temperatures delay sexual maturity so more energy is used for muscle growth rather than sexual development. According to Tidwell et al. (1994), prawn cultured in ponds with average water temperatures of 25° showed higher production rates (11.5 kg/ha/day). These lower culture temperatures appeared to increase both total production and the percentage of market-size prawns.

The CM15 treatment with the higher level of total dissolved solids (TDS) showed lower turbidity than the other enriched treatments. In fact, high turbidity in CM30, CM50 and CM70 culture tanks was related to different application rates of chicken manure (brown color) rather than suspended solids. In water or wastewater, total solid (TS) includes both total suspended solids (TSS) and TDS and is related to both specific conductance and turbidity (APHA 1995). Changes in TDS concentrations (either too high or too low) can be harmful and may even cause death because their relative densities determine the flow of water into and out of an organism's cells (Murphy 2002). The increase in conductivity, TDS and TSS, based on accumulation of nutrients and solid waste, are important factors for design, waste and operating performance. In aquaponic systems, the conductivity may reach critical levels (2000 mg/l as TDS) by additions of approximately 10 kg feed/m3 system volume (Rakocy et al. 1993). High concentrations of suspended solids should be avoided as they form an additional source of ammonia, which in its unionized form is highly toxic to fish and crustaceans. Furthermore, suspended solids may cause gill damage by fouling, resulting in stress and increased susceptibility to diseases (hyperplasia in gill tissue). Removal of small suspended solids can be accomplished by either chemical or biological oxidation. Rakocy (1999) stated that large amounts of TSS may accumulate on plant roots and produce a deleterious affect by creating anaerobic zones and blocking the flow of water and nutrients into the plant. The mineralization of organic matter (suspended solids) by microorganisms and aerobic bacteria may produce adequate nutrients for plant growth. In aquaponics, solids mineralization may occur in deeper parts of media beds. With high fish density and more solid fish waste, the deeper tank. The water level beneath the rafts is anywhere from 250 to 500 mm deep and as a result the volume of water is approximately four times greater than in other systems. This higher volume of water results in lower nutrient concentrations hence, higher feeding ratios are recommended for the release of soluble nutrients and improved plant growth (Rakocy et al. 2006). By increasing feed, the total solids and suspended waste will be increased to accelerate mineralization. This trend seems unsustainable and costly, because feeds are the only available source to produce minerals through long physical-biological pathways. Thus, a separate biofilter is needed to remove excess solid wastes and provide suitable surface-medium for bacterial activities. parts of the bed can actually turn into an anaerobic zone (lack of oxygen) where anaerobic mineralization can occur. This anaerobic zone can release gases and chemicals which may be toxic to the organisms living in the system, whether fish, plants or aerobic bacteria. Therefore, commercial models of aquaponic systems are calibrated to provide required bed surface area to aerobically mineralize the solid fish wastes using a separate biofilter or 30 cm gravel-sand deep media in floating raft system and flood–drain system (Rakocy et al. 2006).

These aquaponic models do not require the addition of synthetic, chemical fertilizer as the fish waste from the rearing tank and mineralization of bacteria provides sufficient amounts of ammonia, nitrate, nitrite, phosphorus, potassium and micronutrients (Diver 2006; Spade 2009; Connolly and Trebic 2010). Complex macro-micronutrients would be required in shallow media beds to recover low mineralization and sequence nutrient deficiency in hydroponic plants.

The major difference between the commercial raft systems and our recirculating aquaponic system is the amount of water used (depth of media) and reservoir-aeration

## Five-day Biological Oxygen Demand (BOD5)

The density of organic matter in aquaculture ponds is related to feed losses, aquatic animal feces and other organic wastes produced by culture activities. A 5-day biological oxygen demand is the measure of organic matter in the waste over a five day time period. This study indicated a significant relationship of BOD5 and loading of CM ($R2=$ $0.91^{**}$) in rearing tanks (Figure 3). Maclean et al. (1994) reported that mean concentration of BOD0.5 increased from 1.8 to 2.0 mg O2/l/12h by decreasing the frequency of CM application in prawn ponds. They concluded that higher oxygen requirement, due to algal and bacterial respiration (through organic decomposition), influenced the trend of BOD0.5 in the treatments.

Organic fertilizer has been used to stimulate the development of heterotrophs (bacteria), autotrophs (alga) and other food organisms in the aquatic ecosystem. When biodegradable organic matter is released into the water, microorganisms, especially bacteria, feed on the waste and break it down into simpler organic and inorganic substances. This decomposition takes place in aerobic conditions (Polprasert 1996). The total amount of oxygen required for biodegradation is an important measure of organic loading and bacteria activity, while stabilizing decomposable organic matter under aerobic condition (Boyd 1990). In our recirculating aquaponic system, the installation of a second aeration tank assisted all biodegradation phenomena with exposure to adequate dissolved oxygen. Dissolved oxygen affects water chemically by the oxidation of minerals and physically through the stripping of organic volatiles that are generated in prawn rearing tanks.

**Organic Fertilizer, Primary Productivity and N:P Ratio**

From our study, the application of 70g/m3 CM (alone) promoted the growth of benthic and filamentous algae. The relative advantages of organic and inorganic fertilizers and their effectiveness in fish and prawn production have been previously demonstrated (Obasa et al. 2009). Chicken manure is valuable in aquaculture systems because of its effectiveness in promoting natural food, growth of second level food chain organisms, and ease in handling and application (Qin et al. 1995; Yi et al. 2003; Anakalo et al. 2009).

A suitable N:P ratio of nutrient or fertilizer will enhance consumable phytoplankton and zooplankton growth while at the same time controlling the blue-green algal blooms (Reyssac and Pletikosic 1990). Phytoplankton communities are an essential component of most pond systems. Primary production by phytoplankton is the base of the food chain in a pond ecosystem that depends on natural or artificial feed to support fish or prawn production.

Table 5 shows estimated nitrogen and phosphorus contents of organic fertilizers commonly used in agriculture and aquaculture. Manure from chickens displayed the lowest N:P ratio (0.6:1) compared to other fertilizers. Accordingly, the N:P ratio was low in the CM70 and UFW treatments (Figure 4). One of the limits of N is that it encourages blooms of blue-green and periphyton algae or drives the total productivity down to the bottom where N is more available (Levings and Schindler 1999). These algae are also well adapted to high and low light conditions. The CM settled at the bottom of the culture tanks and slowly released nutrients near the bottom and, therefore, may have established good conditions for the growth of benthic algae. The results of this experiment strengthen the notion that nutrient ratio is an important determinant of species composition in natural phytoplankton communities (Tilman et al. 1986; Qin et al. 1995; Khoda Bakhsh et al. 2010). Different algal species have different specific requirements for N:P ratio inputs.

*Table 5: Concentration of nitrogen (N) and phosphorus (P) in different sources used for pond fertilization regime (% dry weight).*

| Manure | N (%) | P (%) | N:P ratio | Reference |
|---|---|---|---|---|
| Chicken | 1.4 | 2.2 | 0.6: 1 | Knud-Hansen et al. (1991) |
| Cow | 1.5 | 0.6 | 2.5: 1 | Green et al. (1989) |
| Duck | 4.4 | 1.1 | 4.0: 1 | Asian Institute of Technology (1986) |
| Buffalo | 1.4 | 0.2 | 7.0: 1 | Asian Institute of Technology (1986) |

**Growth Rate Parameters**

The best yields of *L. sativa* and *M. rosenbergii* were obtained in the CM15 treatment. Moreover, survival (87.9%), SGR (6.02%/d), ADG (0.07/d), yield (1343 g/tank) and FCR; (0.42) obtained with this treatment confirmed the potential of prepared formulation and complex nutrients for high density production of *M. rosenbergii* in recirculating aquaponic systems. Organic and mineral elements are important in many aspects of fish and prawn metabolism. These elements are chemically combined in the organism's body to form complex molecules and allow the conversion of food to energy or to build organic molecules and provide strength and rigidity to bones in fish and exoskeleton in crustaceans.

The CM15 media was enriched with complex mineral and organic supplements. The recommended value of dry CM at 15 g/week was equal to 1000-1200 birds/hectare (Little and Muir 1987) in a natural integrated poultry-fish production system. In a rural integrated fish farming system, CM has been claimed to be better and more popular than other manures such as cattle and pig manure. Some fish farmers build chicken coops over fish ponds; manure and uneaten chicken feed can then be washed into the pond. Pens may also be built with flooring that allows waste to fall or be swept directly into the pond. In recirculating systems, to maintain water quality, CM should be applied at regular intervals. Maclean and Ang (1994) showed that the highest ($P<0.05$) prawn mean weight (2.0 g) and growth rate (0.06 g day-1) was achieved when organic CM partially replaced pelleted feed. The maximal survival of prawn was 66% in their report which is lower than in our study (93%).

The lowest yields of *L. sativa* and *M. rosenbergii* were observed in the UFW culture tank ($P<0.05$). However, this treatment led to significantly higher SGR and ADG than with fertilized treatments, except in the case of CM15. Increased individual weight of *M. rosenbergii* was related to a lower survival rate and decreased prawn population (41.0%) in UFW culture tanks during the 45 day culture period. Previous research on prawn-fish integrated culture with poultry manure indicated that the growth and survival of fish and prawns are independent, and that prawns were influenced only by their stocking density, which correlates positively with yield but negatively with survival and individual growth. Wohlfarth et al. (1985) showed that the mean weight of prawns decreased (from 40 g to 24 g) as stocking density increased and the proportion of prawns with marketable weight decreased. Similar results have been observed in monocultures of *M. rosenbergii* (Willis and Berrigan 1977; Brody et al. 1980).

The concentration of ammonia varied among the treatments during the production cycle (0.27 to 0.36 mg/l). The poor results of *M. rosenbergii* survival and growth rate in the UFW treatment could be related to toxicity of ammonia and nitrate concentrations. In contrast to the low survival rate of freshwater prawn, New (1995) stated that the survival rate was more closely related to DO levels than to any other water quality parameter. The recirculating aquaponic tanks showed a acceptable range of DO from 6.4 to 7.8 mg/l during the production cycle. It seems that the factors leading to poor survival in this study are more related to toxic and lethal chemical parameters. Unlike physical parameters (i.e. turbidity), the chemical changes in the rearing water of *M. rosenbergii* can occur with no visible signs. These changes would be due to the metabolic waste produced by the organisms or by the degradation of excess feed. Some of these sudden changes can be extremely harmful to aquatic organisms. For instance in tropical systems, one of the most serious phenomenon is the increasing non-ionized form of ammonia, as this can be associated with high water pH. Details of ammonia concentrations in the UFW treatment showed a sudden peak in weeks 4 and 7 (Figure 2). *Macrobrachium rosenbergii* is highly sensitive to abnormal environmental conditions and stress, and sudden changes of water quality parameters may have adverse, even lethal effects on prawn survival and growth (FAO, 2002).

In the natural environment, turbidity is composed of organic, inorganic and bio constituents; however, in prawn rearing tanks, turbidity is influenced by algae and phytoplankton population (free of clay and suspended sediments). Phytoplankton production is enhanced when nutrient concentrations increase in the system. The concentration of NO3 showed a significant increased during weeks 3 to 6 in the UFW culture tanks (Figure 5). However, turbidity originating from phytoplankton growth did not show any significant response and was relatively constant during these weeks of the experiment. It seems that the phytoplankton community and plants with insufficient population and poor growth were not effective enough to absorb soluble nitrogenous compounds (NO3 and NH3) from metabolism activity and decomposition of waste in the system. These phenomena caused harmful conditions in the UFW rearing tanks, as well as a detrimental influence on prawn survival and growth rate.

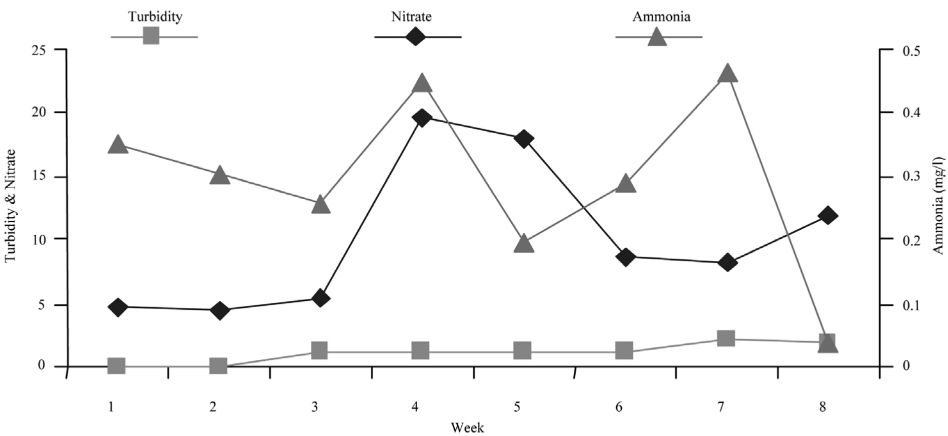


*Figure 5: Fluctuation of turbidity (NTU), nitrate and ammonia (mg/l) concentrations in freshwater (FW) culture tanks.*

This study illustrated that an optimal dosage of minerals and CM is essential to obtain the best results in recirculating aquaponic systems. The results also showed obvious reduction in plant and prawn yields with CM70, which was only enriched with high density CM. In natural earthen ponds the appropriate fertilization regime (organic by- product) can promote the growth of both autotrophic and heterotrophic organisms which will be directly consumed by aquatic animals along the ecological pathway. The choice of the appropriate nutrient model should consider mineral stimulation and tolerance of aquatic organisms, feeding habit of the cultured species, effect on the desired natural food organisms, cost and abundance and proximity of the source to the vertebrate and invertebrate production farms. In recirculating aquaponic systems, application of organic-inorganic complexes would be an ideal approach to improve production techniques during short periods. Organic-inorganic complexes not only provide minerals for aquaponic plants, but also organic substrates vital for enhancing primary productivity within aquatic environments.

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