The Effect of Solids Removal on Water Quality, Growth and Survival of *Litopenaeus vannamei* in a Biofloc Technology Culture System

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ABSTRACT

Biofloc technology culture systems can increase the productivity of shrimp culture. Through the use of minimal or zero exchange, biofloc technology culture systems can also reduce the use of water. Diet enhancement through the addition of feed increases the amount of excreta. Together with unconsumed feed, the additional excreta increases the amount of suspended solids and reduces the concentration of dissolved oxygen. In addition, the excess of suspended solids can harm the culture by reducing light penetration. In turn, the lower light levels reduce the abundance of photosynthetic organisms (microalgae) that are also important for water quality and shrimp nutrition. The objective of this study was to evaluate the removal of suspended solids from the water of the culture system by a clarification process (i.e. particle settling). Two treatments were applied: with clarification and no clarification. Six tanks, each 35 m³, were used in the study. In the clarification treatment, 35 m³ of water with bioflocs was pumped from the experimental unit for 6 hours. The water passed through a settling tank (1,000 L) and was returned to the culture unit through gravity. The clarification treatment reduced total suspended solids (24.5%), turbidity (27%) and chlorophyll

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a (27.8%). The availability of dissolved oxygen and pH values were also greater in the clarification treatment. Growth, feed conversion ratio, survival and productivity were significantly higher ($p<0.05$) with the removal of suspended solids. Control of the concentration of suspended solids contributed to the improvement of water quality and the growth performance of the shrimp *L. vannamei* in the superintensive biofloc technology culture.

INTRODUCTION

Recent culture systems that involve low rates of water renewal may be cited as examples of sustainability in cultured penaeid shrimp. These systems minimize the disposal of water and increase production through the cultivation of heterotrophic organisms and the discharge of nitrogen compounds (Wasielesky et al. 2006a). Addition of even small amounts of water contributes to an increase in the diet availability by the natural productivity in ponds (Burford et al. 2003). This approach results in high yields (Browdy et al. 2001; Hopkins et al. 1995) from this type of system. Currently these systems are named biofloc technology systems (BFT). The increased stocking density and the large amount of uneaten feed and fecal matter (Wasielesky et al. 2006a) in a BFT may affect the production system adversely (McMillan et al. 2003). These conditions also cause the precipitation of solids, and sludge formation is common (Hopkins et al. 1994). Studies of this problem should focus on the rapid removal of relatively large-sized particles. The smaller particles are difficult to remove (McMillan et al. 2003) owing to their slow sedimentation. This process may be important for enhancing solubility and nutrient release (Patterson et al. 1999).

According to Thakur and Lin (2003), one of the biggest problems affecting water quality in closed systems is the rapid eutrophication of tanks and ponds. This problem is the result of increased concentrations of nutrients and organic matter during culture. Ebeling et al. (2006) have outlined the main problems affecting water quality in heterotrophic systems. They have indicated that the elevated production of bacterial biomass, compared with the biomass of phytoplankton produced in autotrophic culture, leads to an increase in suspended solids. However, Brune et al. (2003) and Cohen et al. (2005) have emphasized the importance of phytoplankton and nitrifying bacteria in this context.

These organisms exhibit a high capacity to absorb inorganic nitrogen and are consequently able to control the level of ammonia in the culture systems The removal of suspended solids can improve light penetration, whereas the reduction of light may reduce primary production (Kirk, 1994). The photosynthetic microalgae added to maintain water quality are also a source of nutrition for shrimp (Burford et al. 2003). In closed culture systems for shrimp production at high stocking densities, the level of dissolved oxygen is reduced (Cohen et al. 2005) and nitrogen compounds, like ammonia and nitrite (Avnimelech 1999; Cohen et al. 2005), are produced from organic solids.

Clarification is a practical method for removing solids. Gravity is allowed to bring particles to the bottom of the water column through sedimentation or settling. Johnson and Chen (2006) considered this method an efficient method of clarification for the removal of suspended solids in the culture of rainbow trout. For cultured tilapia, Azim and Little (2008) proposed an intermediate system based on the principles of sedimentation and separation of flocs. Ray et al. (2010) have evaluated the role of clarification in improving shrimp production. Their study used a mesocosm and two different diets where turbidity was used as an indicator to monitor the process. In a superintensive shrimp culture system, a clarification process can successfully reduce the depletion of oxygen and the accumulation of suspended solids, thereby improving the water quality for the crop.

The aim of this study was to evaluate the effect of clarification on water quality in the superintensive culture of the shrimp *L. vannamei* in a BFT system. In this study, the concentration of suspended solids was kept at a value of 500 mg/l, the maximum value specified by Samocha et al. (2007).

MATERIALS AND METHODS

Experimental design

The study was conducted over the winter from May 7 to August 28, 2010 in a greenhouse with six rectangular tanks (5.0 m X 7.0 m). Each lined tank had a usable volume of 35 cubic meters, 1.0 water column. The experiment was conducted using two treatments, namely clarification (C) and no clarification (NC), with three replicates per treatment in a fully randomized design. In both treatments, vertical structures were used

as substrates for the development of a natural biota. This natural biota represented an additional source of food for the shrimp (Ballester et al. 2007). Tanks were filled 90% with sea water initially treated with 10 ppm of chlorine. Prior to the beginning of the experiment, the shrimp were kept in a 70 m³ nursery tank. Bioflocs from that nursery were supplied by providing an inoculum at a ratio of 10% of the volume of the tanks with water for microbial aggregates. The organic fertilization method used was based on Avnimelech (1999) and Ebeling et al. (2006). This method allows the conversion of nitrogen into bacterial biomass. A total of 6 g of carbon was added for each g of total ammonia nitrogen. Dextrose was used as the carbon source. The carbon content of the compound was considered to achieve the correct concentration of carbon. Necessary corrections to the pH were made by adding 700 g of hydrated lime, $Ca(OH)_2$, to maintain pH values above seven. Corrections were made simultaneously in all tanks to not mask the effect of clarifying. A 7-hp blower was used to maintain aeration by allowing air to diffuse from air stones at the bottom of the tank. The density of the stones in the tanks was 1 stone per m². Shrimp with an average weight of 2.65 ± 0.69 g were stocked in the six experimental units at a density of 250 individuals/m². During the culture period, the shrimp were fed three times daily with a species-specific commercial feed containing 38% crude protein and 8% lipid (Guabi™). Feeding trays were used for the visual detection of possible unconsumed diet and for adjusting the amount of feed if necessary.

Clarifier

The clarifier was developed at the Aquaculture Marine Station (FURG) of the Institute of Oceanography, Federal University of Rio Grande, located at Cassino Beach in Rio Grande City, Rio Grande do Sul State, Brazil. The methodology for developing the clarifier was adapted from the study by Johnson and Chen (2006). When the concentration of the suspended solids reached 500 mg/l, the maximum value specified by Samocha et al. (2007) for superintensive systems, the clarification process was applied. Each application lasted for 6 continuous hours. The clarifier was housed in a plastic water box of 1,000 liters capacity. A cylindrical pipe, 300 mm in diameter and 700 mm high, was located at the center of the box. During treatment, a submerged pump was used to supply water at a flow rate of 4,500 l/h to the top of the cylindrical pipe through an intake tube connected with the culture tank. This design was

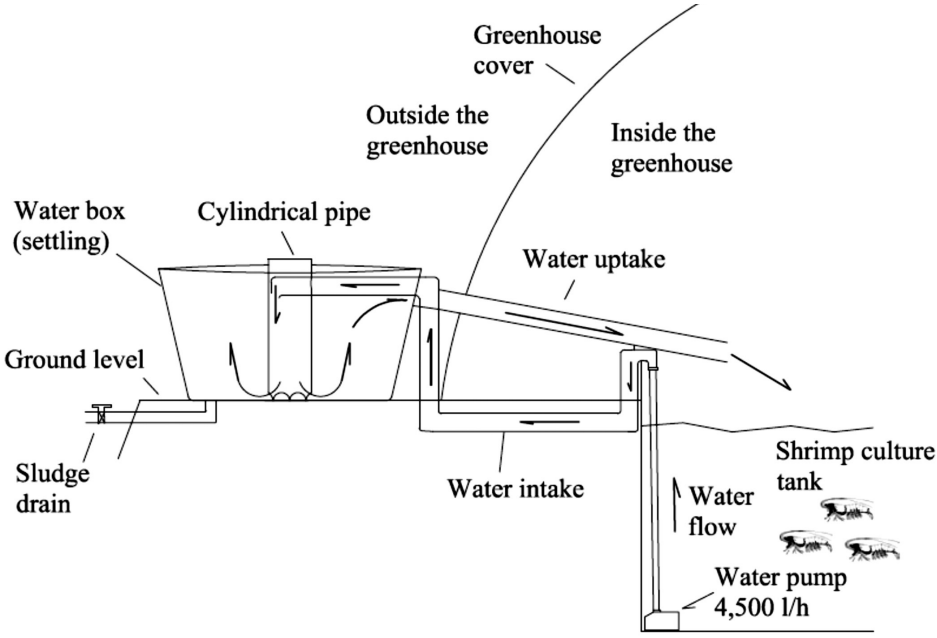

Figure 1. Schematic diagram of the clarifier used in this study. The clarifier was installed on the outside of the greenhouse. The arrows indicate the flow of water through the clarification system. The system was driven by a submerged pump at a flow rate of 4,500 l/h.

used to reduce turbulence. Water flowed out of the box and into the water uptake tube of the shrimp water tank (Figure 1). A column of water was formed in the box, and gravitational action produced sedimentation of particulate organic matter in the clarifier.

Water quality

Temperature, pH, salinity and dissolved oxygen were monitored daily using a multiparameter instrument (YSI® 556, YSI Inc., Yellow Springs, OH, USA). Water quality was monitored based on measurements of the levels of total ammonia nitrogen (TAN), nitrite-nitrogen (NO_2-N) and total suspended solids (TSS) taken every two days and on measurements of the levels of nitrate-nitrogen (NO_3-N), phosphate (PO_4-P) and alkalinity taken every seven days. Analyses of TAN followed the methodology described in UNESCO (1983). The methodology of Bendschneider and Robinson (1952) was used for the analyses of NO_2-N, and the methodology of Aminot and Chaussepied

(1983) was used for the analyses of NO_3-N and PO_4-P. Alkalinity was determined following the methodology described in APHA (1998). The water turbidity was determined by a turbidimeter (Hach® 2100P, Hach Company, Colo, USA). The volume of settleable flocs was quantified using an Imhoff cone according to the methodology of Eaton et al. (1995) adapted by Avnimelech (2007). The volume of flocs on the bottom of the cone was measured after 15 minutes of sedimentation. However, the Imhoff cone method could not be used to compare treatments because some samples lacked sedimentation tanks. Water was collected for the analysis of suspended matter (particles larger than 45 µm) according to the method of Strickland and Parsons (1972). The weight of suspended solids was determined gravimetrically from the filtration rates with up to 20 ml of culture water and glass fiber Whatman GF/F filters. The filters were dried for approximately 24 hours at 60ºC and then weighed on an analytical balance ± 0.0001 g (Sartorius MC1AC 210 S, Sartorius AG, Göttingen, Germany) to determine the final weight (AOAC, 2000). The analysis of chlorophyll *a* was carried out weekly on 20 ml of water. This volume was filtered in a dark room, and the material was stored in 90% acetone in dark bottles at -12°C. After 24 hours, the concentration of chlorophyll *a* was determined with a Turner TD700 (Turner Design, Inc., CA, USA) fluorometer (Welschmeyer 1994).

Shrimp monitoring

Every 14 days, 50 shrimp were arbitrarily sampled from each tank. Wet weight was individually measured using a digital scale accurate to 0.01 g. The weekly growth rate (WGR) was determined by the following calculation: WGR = (final weight / number of weeks of culture). The feed conversion ratio (FCR) was calculated as FCR = offered feed / biomass increment. Survival was calculated as S% = [(final biomass / average individual weight) / number of individuals stocked)] x 100. The survival data were transformed (arcsine $x^{0.5}$) before analysis. Productivity was calculated as Prod = (final biomass / tank volume).

Statistical analysis

The homoscedasticity of variances and normality of the data obtained were verified by Levene's test. The Student *t*-test was used to detect possible differences ($p<0.05$) between treatments (Sokal and Rohlf, 1969).

RESULTS

The variation in the water and shrimp parameters measured during the 16 week experiment in the treatments with NC and with C are shown in Figures 2 and 3. From the eighth week onward, no significant differences ($p>0.05$) in the concentration of total suspended solids were observed. The concentration of total suspended solids was lower in the C treatment (Figure 2). The turbidity values measured during the clarification period were significantly ($p<0.05$) lower in the C treatment than in the NC treatment (Figure 2). The average concentration of chlorophyll *a* was not significantly lower ($p>0.05$) in the C treatment. Variations of dissolved oxygen (Figure 2) demonstrated no significant differences ($p>0.05$) from the tenth week onward. The oxygen levels observed in the C treatment were better than those observed in the NC treatment (Figure 2). The pH in both treatments was maintained above 7. However, the value of pH was not significantly different ($p>0.05$) among the treatments (Figure 2).

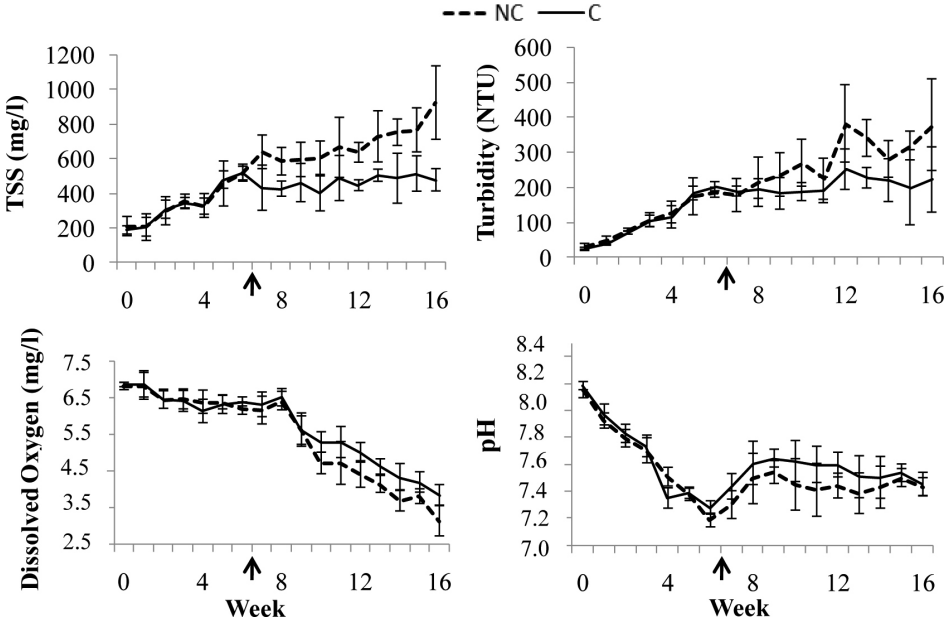

Figure 2. The variations in concentrations of total suspended solids (TSS), turbidity, concentrations of dissolved oxygen and pH values observed during the 16 week experiment in the treatments with no clarification (NC) and with clarification (C). The vertical bars indicate the standard deviation. The time at which the clarification process began is indicated by the arrow on the time axis.

The growth and survival of the shrimp differed quite significantly between treatments ($p<0.05$) during the clarification period (Figure 3, Table 2). No significant differences ($p>0.05$) between treatments were observed during the experiment for the water parameters measured (Table 1).

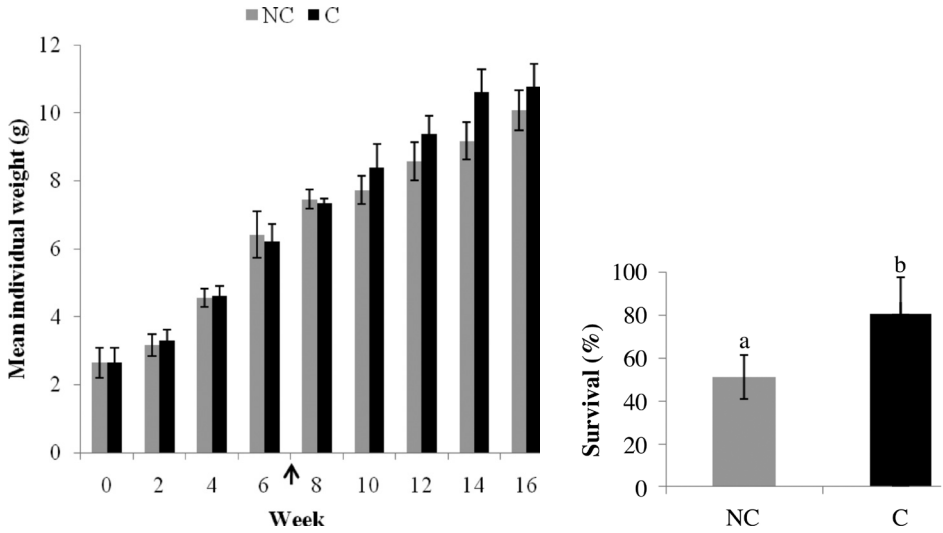

Figure 3. The growth (individual weight) and survival of L. vannamei in treatments with no clarification (NC) and with clarification (C) over the 16 week experimental period. The vertical bars indicate the standard deviation. The beginning of the clarification period is indicated by the arrow on the time axis.

Table 1. The values of water parameters monitored for the period during which clarification was applied. The table shows the mean ± standard deviation of the parameters in the treatments with no clarification (NC) and with clarification (C). The minimum and maximum values observed appear in parentheses.

	Treatments	
Parameter	**NC**	**C**
Temperature (°C)	22.03 ± 1,62 (19.20-25.50)	22.02 ± 1.61 (19.10-25.60)
Salinity	34.45 ± 0.59 (33.83-35.40)	34.46 ± 0.58 (33.83-35.40)
Alkalinity (mg/l)	114.06 ± 26.65 (73.75-146.25)	127.34 ± 21.26 (80.00-151.25)
Ammonia (mg/l)	0.12 ± 0.11 (0.04-0.56)	0.12 ± 0.14 (0.03-0.73)
Nitrite (mg/l)	0.12 ± 0.04 (0.03-0.20)	0.16 ± 0.11 (0.04-0.48)
Nitrate (mg/l)	39.35 ± 8.88 (3.58-55.25)	34.81 ± 8.04 (3.01-48.77)
Phosphate (mg/l)	5.34 ± 1.86 (2.40-7.60)	4.83 ± 176 (2.20-7.84)
TSS (mg/l)	649.53 ± 112.82 (518-923)	453.91 ± 95.07 (425-515)
Turbidity (NTU)	270.01 ± 96.15 (177-381)	197.01 ± 49.64 (187-251)
Chlorophyll *a* (µg/l)	378.42 ± 131.67 (240-485)	282.38 ± 97.45 (179-363)
Dissolved Oxygen (mg/l)	4.66 ± 1.18 (3.48-6.73)	5.07 ± 0.06 (3.32-6.83)
pH	7.45 ± 0.16 (7.33-7.76)	7.56 ± 0.15 (7.30-7.84)

Table 2. Comparison of the growth of L. vannamei in treatments with no clarification (NC) and with clarification (C). Different letters appearing on the same line indicate significant differences ($p<0.05$).

	Treatments	
Growth Performance	**NC**	**C**
Survival (%)	51.22 ± 10.32^{a}	80.70 ± 16.97^{b}
Initial weight (g)	2.65 ± 0.69	2.65 ± 0.69
Final weight (g)	10.07 ± 1.20^{a}	10.76 ± 0.67^{b}
WGR* (g/s)	0.46 ± 0.07^{a}	0.51 ± 0.05^{a}
Productivity (kg/m³)	1.34 ± 0.23^{a}	2.15 ± 0.24^{b}
FCR**	2.39 ± 0.43^{a}	1.47 ± 0.08^{b}

*Weekly Growth Rate
**Apparent Feed Conversion Rate

DISCUSSION

The shrimp *L. vannamei* can tolerate a temperature range between 15 and 35°C. The ideal temperature range for this species of shrimp is 28 to 32°C (Van Wyk and Scarpa, 1999). These temperatures determine the most favorable conditions for metabolism, oxygen consumption, growth and survival. Wyban et al. (1995) and Peixoto et al. (2003) have found that temperatures below 23°C represent suboptimal conditions for the growth of *L. vannamei.* Temperatures in this range affect growth negatively because the shrimp consume less food. The average temperature in the culture during the study was 22°C. Even though this experiment occurred during the winter, the greenhouse had the capacity to maintain the water temperature higher than the temperature outside the greenhouse (Krummenauer et al. 2011). This value falls within the tolerance range, but it also falls within the temperature range within which food intake is reduced. In this study, temperatures below the ideal value affected the observed weekly weight gains. These weight gains were less than the values reported by Wasielesky et al. (2006a) and Vinatea et al. (2010). These previously reported values reflect

temperatures within the optimal range for this species. The salinity in both treatments was within the tolerance range of the species (Van Wyk and Scarpa, 1999).

Nitrogenous compounds in the experiment followed a route determined by the nitrification system used in BFT (Azim and Little, 2008; Schryver et al. 2008). In heterotrophic systems, ammonia can be immobilized by heterotrophic bacteria. It is successively converted to nitrite and nitrate. The nitrogen assimilated by the bacteria during this process is converted into bacterial biomass (Ebeling et al. 2006; Hargreaves, 2006). The nitrification method used in this study was identical to that previously cited. According to Preston et al. (2000), the particulate fraction of nitrogen is reduced by the continuous flow of water and sediment, but the dissolved fraction may be higher and may remain in the water of the culture. Ray et al. (2010) suggest that sedimentation can remove feces and uneaten feed that would otherwise be available for the formation of total ammonia. Sedimentation can thereby reduce the concentration of nitrate to be converted by nitrification. In this experiment, particulate organic matter retained by decanting may have concentrated the degradation activity within the sedimentation box. Ammonia subsequently released into the water would then have maintained the nitrification process. This process was accentuated owing to the use of an inoculum of 10% of the volume of the tanks when the experiment with bioflocs was initiated.The amounts of nitrogenous compounds found in this study remained within the tolerance values for the species (Van Wyk and Scarpa, 1999).

The decomposition of unconsumed food and the excretion products of the organisms cultured are the main source of phosphorus in the culture system (Barak et al. 2003). Teichert-Coddington et al. (1999) have analyzed the sedimentation of particles through the hydraulic retention of the effluent from the intensive shrimp culture. These authors have found that phosphorus was associated with soil minerals, probably by adsorption on soil particles or as a precipitate because the concentration decreased concomitantly with the decrease of suspended solids, promoting a 14% reduction in the concentration of phosphorus. Jackson et al. (2003) achieved a 35% removal of phosphorus by using sedimentation. Ray et al. (2010) used a settling chamber for the sedimentation of particles and found that the removal of solids produced a 61% reduction of phosphate. In the present experiment,

the buildup of phosphate that occurred was typical of that occurring in superintensive systems with the reduction of phosphate occurring during the clarification. The concentrations of phosphate were lower than those found in the treatment with no clarification, but this difference was not statistically significant.

The amount of total suspended solids is an effective parameter for evaluating the efficiency of methods used for settling particles. Ray et al. (2010) achieved a 45% reduction of total suspended solids with a clarification system representing 3.2% of the volume of the culture tank of *L. vannamei* and settling chambers were operated when the turbidity found to be above 30 NTU. Johnson and Chen (2006) used a clarifier for the removal of particles greater than 104 μm. Their system represented 3.10% of the volume of the culture of rainbow trout and achieved a TSS reduction of 82%. The clarifier used in this study represented 2.28% of the tank volume of the culture and removed 24.5% of TSS, conditional on the maintenance of suspended solids at 500 mg/l. These studies on the use of different clarifier systems involved different criteria for evaluation. Different parameters were compared with each other to evaluate the objectives proposed for each study. These parameters included turbidity, particle size and the concentration of suspended solids. Our system demonstrated a good capacity to retain suspended solids by sedimentation while maintaining the level of total suspended solids at 500 mg/l.

Turbidity has a direct relationship with suspended solids and regulates light penetration (Vinatea et al. 2010). These authors have confirmed that high levels of particulate matter reduce light penetration and therefore generate negative net photosynthetic rates, i.e., an oxygen deficit. Ramos et al. (2009) have used hydraulic retention for sedimentation and have found that turbidity decreased 18%. Ray et al. (2010) have achieved a 57% reduction in turbidity, which is the parameter they used to evaluate the performance of the clarification method in their study. They also reported an apparent increase in photosynthesis. In the present study, clarification resulted in a 27% reduction in turbidity relative to the value for the NC treatment, and the concentration of suspended solids was successfully maintained at 500 mg/l.

Microalgae play an important role in recycling nutrients from shrimp feed and feces and thereby help maintain the water quality of shrimp

culture. Control of phytoplankton biomass becomes important if respiration by microalgae in the absence of light can reduce the concentration of dissolved oxygen. A related problem is that the respiration of microorganisms resulting from the decomposition of the dead cells of microalgae can cause risks to the culture. In this study, the clarification achieved a reduction of 27.8% in chlorophyll *a*. A similar result was obtained by Jones et al. (2001), who used a static process for settling particles and achieved a chlorophyll *a* reduction of 27.7%, whereas Ramos et al. (2009) found a decrease of 45.4%.

In the bioflocs system, the concentration of dissolved oxygen in the culture water is directly related to the consumption of oxygen by shrimp, by aerobic microbes and by the decomposition of organic matter (Avnimelech, 2009). The aerobic metabolism of microbes in cultures with bioflocs can decrease the levels of dissolved oxygen (Schryver et al. 2008). In this study, the amount of oxygen consumed by the decomposition of particulate organic matter by aerobic microbes may have decreased as a result of the removal of suspended solids by sedimentation. Effects of this sort have been observed by Teichert-Coddington et al. (1999), Ramos et al. (2009) and Ray et al. (2010). Oxygen is directly associated with the conditions required for the growth and survival of shrimp. The recommended level of dissolved oxygen for shrimp is 5 mg/l (Cheng et al. 2003), and concentrations below 2.8 mg/l are considered hypoxic conditions (Mugnier and Soyez, 2005). In the present study, both treatments showed a constant decrease in the mean concentration of dissolved oxygen. The level of dissolved oxygen was below the recommended level during the last 28 days in the clarification condition and during the last 49 days in the no-clarification condition. The removal of suspended solids in the C treatment was reflected in the improved growth performance of the shrimp.

According to Ebeling et al. (2006), the alkalinity in the bioflocs system should be maintained between 100-150 mg $CaCO_3$/l. Otherwise, a drop in pH may occur and thereby compromise the growth of the cultured organisms. These authors have also emphasized the consumption of alkalinity during the oxidation of ammonia to nitrate. Another important process is the release of CO_2 by respiration in the water column. The carbon dioxide dissociates to form carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions. This process causes the release of H^+ and produces a lower pH and alkalinity. Ray et al. (2010) have suggested that the removal

of suspended solids results in increased photosynthesis by the algal community during the day and causes increases in pH and in alkalinity. In this study, clarification did not affect the alkalinity in the treatment with solid removal, with the only increase in alkalinity being associated with the removal of particulate organic matter. During the experiment, the correction of pH using lime was the only application used to affect alkalinity. This method was probably sufficient to maintain the required level of alkalinity. In both treatments, the values of average alkalinity were within the acceptable range for *L. vannamei*.

During the period in which clarification was applied, the pH was significantly higher. Vinatea et al. (2010) have found that high levels of particulate matter provided a substrate for bacteria and other microorganisms. This finding was confirmed by the direct relationship between respiration in the water column and turbidity. Wasielesky et al. (2006a) have found that a lower pH resulted from the respiration of heterotrophic microorganisms. In their study, this process was found to produce increased CO_2 in the water of the culture. The removal of suspended solids may have reduced the oxygen consumption associated with the process of decomposition of organic matter by microorganisms in the tanks. This change would have reduced the rate of CO_2 production by respiration in the water column. The pH range for the optimal growth of marine shrimp is between 7 and 9 (Van Wyk & Scarpa, 1999). In BFT systems, Wasielesky et al. (2006b) have found a reduction in growth rates and feed conversion at pH values below 7. In this study, the average pH was maintained above 7 and within the recommended range for the species.

Among the physical and chemical parameters discussed, temperature, oxygen and total suspended solids were the main factors that reached values that may have affected the growth performance of *L. vannamei*. In this study, the growth found in both treatments may have been affected by the average temperature of 22°C. This species is ectothermic, and its metabolic rate is a function of the ambient temperature (Zhang et al. 2006). The highest concentrations of dissolved oxygen and the lowest amount of total suspended solids coincided with the best growth of shrimp in association with the removal of suspended solids. Similarly, the weekly growth rate was significantly higher in the C treatment in association with the reduction of suspended solids. This finding agrees with the results of Ray et al. (2010). These authors found an average survival of 71% in all their experimental tanks, but they reported no

differences between treatments. In contrast, the present study found significant differences between treatments. The highest survival rate, 81%, occurred in the C treatment. In the NC treatment, suspended solids were not removed, and the survival rate was 51%. Furthermore, the concentrations of total suspended solids in the NC treatment exceeded 500 mg/l. This excess represents a stressful condition for the culture of organisms. These high levels of total suspended solids can increase the biochemical oxygen demand (BOD) and cause occlusion of the gills of cultivated species (Hargreaves, 2006; McMillan et al. 2003). In the BFT system, the removal of suspended solids is very important because survival depends on the availability of dissolved oxygen and on the amount of suspended solids in the water column (Hopkins et al. 1995, 1996). According to Ray et al. (2010), the removal of solids can decrease BOD by reducing the stress levels of the shrimp. This process leads to an increase in production. These authors achieved a feed conversion ratio of 2.15 for a treatment that involved the removal of suspended solids. The present study found an even better rate of 1.47. This superior performance probably resulted from the fact that the clarification improved the water quality. This suggestion can be confirmed by the results of the study conducted by Vinatea et al. (2010) on the interactions of water quality variables with the growth of *L. vannamei*. These authors have found that the feed conversion rate decreased with increasing concentrations of volatile suspended solids.

CONCLUSION

The biofloc technology culture system used for clarification was effective for the maintenance of total suspended solids at 500 mg/l. The removal of suspended particulate organic matter increased the availability of oxygen. The removal of particulate organic matter improved water quality, and resulted in the better growth performance of *L. vannamei*. Thus, the water clarification system used in this study seems to be feasible and applicable. It successfully removed excess organic matter from the water used in the superintensive culture of shrimp and thereby maintained water quality. However, further studies of the use of clarification should be made to investigate the optimal concentration of total suspended solids and to understand the dynamics of suspended particles during the removal process.

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