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Effects of Aeration and Chemical Treatments on Nutrient Release from the Bottom Sediment of Tropical Marine Shrimp Ponds

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Abstract

The effects of aeration, and addition of aluminum sulfate (alum) and calcium carbonate on the release of nutrients from shrimp pond bottom sediments to the overlying water were studied in laboratory using sediment-water systems. Soluble reactive phosphorus (SRP) concentrations in the water column showed a decreasing trend culminating with the lowest values after 21 days of experiment, indicating strong adsorption of SRP by the sediment. Aeration significantly ($p<0.05$) decreased SRP concentrations compared to tanks without aeration in 14 days. During the first seven days, the addition of alum and calcium carbonate significantly ($p<0.05$) enhanced the decrease of SRP in the water column both in the aerated and unaerated tanks. The addition of alum did not affect the water pH, probably due to high buffering capacity of the marine pond water. From day 14 onwards, SRP concentrations in the aerated alum and calcium carbonate treatments had significantly higher SRP than the unaerated systems, probably due to the positive correlation between P-release and mixing energy, and higher pH and nitrate values in the aerated systems. Total ammonia nitrogen significantly decreased with aeration and the addition of lime. Total ammonia was not detected after day 14 as it was probably oxidized to nitrite and nitrate, adsorbed to the sediment or lost to the atmosphere at high pH. Nitrite concentrations were high in unaerated tanks only during the first 14 days and remained low thereafter. Nitrate remained high throughout the experiment, as there was absence of phytoplankton uptake in the system. This study illustrated that aeration together with the addition of alum and calcium carbonate may help control the release of excessive SRP and ammonia from the pond bottom sediments and minimize the occurrence of eutrophication and water quality deterioration in shrimp ponds.

Introduction

One of the major problems in intensive shrimp ponds is the presence of high concentrations of nutrients, especially soluble reactive phosphorus (SRP), ammonia and nitrate, causing excessive phytoplankton blooms and deterioration of pond water quality. Poor water quality affects the health of the cultured organisms, which often results in low production. Major sources of these nutrients are from the uneaten feed and metabolic wastes of the cultured organisms. The decomposition of unconsumed feed and the use of manure and chemical fertilizers add further nutrients to ponds. Shishehchian et al. (1999) demonstrated that shrimp fed with artificial feed excreted significantly high ammonia and nitrites compared to those fed on live diets.

Since the studies of Mortimer (1941; 1942), it has been well established that under oxidized condition, phosphate is adsorbed and coprecipitated with amorphous ferric oxyhydroxides, while reduced conditions cause dissolution of the ferric-oxyhydroxide-phosphate complexes, resulting in the release of ferrous iron and phosphate. Möller-Andersen (1974) reported that increased temperature, increase in pH and change of redox conditions are factors that could cause phosphorus liberation from the sediments. Increase in temperature increases the biological activity, which lowers the oxygen concentrations. If the oxidized microzone at the sediment surface becomes reduced, iron (II) and phosphate can be liberated to aerobic water.

According toBöstrom and Pettersson (1982), the prerequisites for a high phosphorus release from sediment due to mineralization are likely to be found in sediment where organic phosphorus content is high and the sorption sites are occupied, resulting in a low sorption capacity. Thus, mineralization of organic matter at the sediment surface, followed by continuous transport to the water column by turbulent mixing, can be important in nutrient release in ponds. Adsorption and sorption are often synonymous with uptake, which may include biological processes as well as precipitation of the solid phase. The sorption capacity of a sediment is strongly influenced by its mineral composition. Inorganic solids, such as ferric oxyhydroxides, aluminium oxyhydroxides, calcium compounds and clay minerals have high affinity for phosphate (Edzwald et al. 1976; Lijklema 1980; deKanel and Morse 1978). In addition, bioturbation can increase the release of phosphorus from the sediment under aerobic condition. Graneli (1979), van der Loeff et al. (1984) and Matisoff et al. (1985) reported that the phosphorus flux increased 2 to 4 times in the presence of chironomid larvae (1000 $\mathrm{ind \cdot m^{-2}}$) under oxidized condition. Bioturbation effect on nutrient flux is negligible under anaerobic condition. The effects of benthic organisms on phosphorus flux to the water column are mainly due to active transport of sediment particles and water across the sediment water interface and by alteration of the physical environment such as pH and redox properties.

Since shrimp aquaculture ponds are shallow, ranging between 1.2 to 1.8 m deep, and often well mixed through aeration, the release of nutrients from sediments would be readily available for phytoplankton growth. Yusoff et al. (2002) reported that there was a shift of algal dominance from diatoms to blue-green algae after approximately one month into the 110-day culture period. Matias et al (2002) also noted that total ammonia N, nitrite-N, nitrate-N, total nitrogen, and hydrogen sulphide increased steadily with the culture period due to accumulation of excess feed materials and metabolites. Thus, adsorption of some nutrients to the sediment, especially in the second half of the culture period, may help reduce the phytoplankton blooms in shrimp ponds and improve the water and bottom sediment quality. To maintain healthy condition of the pond environment, management strategies should include maintenance of aerobic condition in all layers of water column and on sediment surface, as well as reduction of nutrients, both from external and internal sources. In view of the general concern about increased eutrophication of aquaculture pond water, presumably resulting in increased algal blooms and oxygen deficiency, the present study was carried out to investigate the effectiveness of aeration, alum and calcium carbonate in reducing available nutrients in water columns in shrimp ponds.

Materials and Methods

Laboratory sediment-water systems were established using pond bottom sediment and filtered (glass fiber GS 25) pond water in 12 l (30 cm height x 20 cm length x 20 cm width) glass aquaria. Intact bottom sediment (5 cm thick) was collected from marine shrimp ponds at the beginning of the culture period. The sediment used in the experiment was analyzed for pH using pH meter Model Orion SA 520, and total carbon, total nitrogen and total sulfur using CHNS/O Analyzer Model Perkin Elmer Series II 2400. Total phosphorus was determined using the Auto-Analyzer II Model Technicon Second Generation. Aluminum and iron were analyzed using the Atomic Absorption Spectrophotometer Shimadzu AA670.

The experiment was accomplished according to factorial design and each treatment was done in triplicates. Two types of sediment-water systems were set up; aerated and unaerated. Six tanks (three aerated and three unaerated) were treated with 20 $mg{\cdot}l^{-1}$ aluminum sulfate ($Al_2(SO_4)_3.16H_2O$ - alum) and another six tanks were treated with calcium carbonate at the rate of 0.20 $kg{\cdot}m^{-2}$. Another six tanks served as control.

Water temperature, dissolved oxygen, pH, alkalinity, salinity, soluble reactive phosphorus (SRP), total ammonia N, nitrate-N and nitrate-N in all the tanks were determined at the interval of seven days for 28 days. Temperature, dissolved oxygen, pH, and salinity were analyzed using dissolved oxygen meter Model YSI 57, pH meter Model Orion SA 520 and S-C-T meter Model YSI 33, respectively. Total alkalinity, SRP, total ammonia-N, nitrate-N and nitrite-N were analyzed according to Parsons et al. (1984). Data were analyzed according to two-way ANOVA using SAS statistical package with Duncan's Multiple Range Test.

Results and Discussion

The mean carbon, nitrogen and phosphorus contents of the sediment were 2.92%, 0.49% and 155 $\mu g{\cdot}g^{-1}$, respectively (Table 1). The carbon and nitrogen values of this sediment were higher while the phosphorus was lower than those reported by Shariff et al. (2001) for shrimp pond sediments in the same area. The variation was probably due to the quantity and quality of feed and fertilizers used in the farm. The water temperature, total alkalinity and salinity were not significantly different ($p>0.05$) in different treatments (Table 2). However, dissolved oxygen and pH values were significantly higher ($p<0.05$) in aerated tanks compared to the unaerated tanks in all treatments. The addition of alum and carbonate did not significantly change the alkalinity and pH compared to the control indicating that the pond water was adequately buffered. Boyd and Scarsbrook (1974) demonstrated that addition of lime to fish ponds with low alkalinity resulted to an increase of total alkalinity. Apparently, the pond water in this study had high alkalinity, which neutralized the H^+ formed during Al^{3+} hydrolysis (Masuda and Boyd 1994). Helfrich and Newcomb (2000) and Wilkinson (2002) suggested that since alum may lower pH and increase acidity in soft water (< 20 mg $CaCO_3 \cdot l$), it should be used in combination with limestone to correct total alkalinity and pH. In addition, residual aluminum concentration that was shown to be toxic, begins to accumulate at the level at which alkalinity is completely consumed. However, complications arising from acidity and toxicity due to alum are rather unlikely in marine shrimp ponds due to high alkalinity and stable circumneutral pH values (Table 2).

Table 1. Soil characteristics for the shrimp pond sediment used in the experiments

Parameter	Mean ± standard error	Range
pH		7.94-7.97
Total Carbon (%)	2.92 ± 0.08	2.80-3.04
Total Nitrogen (%)	0.49 ± 0.01	0.47-0.51
Total Sulfur (%)	0.09 ± 0.03	0.06-0.14
Iron ($\mu g \cdot g^{-1}$)	130 ± 2	127-133
Exchangeable Aluminum ($\mu g \cdot g^{-1}$)	170 ± 2	168-174
Total Phosphorus ($\mu g \cdot g^{-1}$)	155 ± 23	115-155

Table 2. Ranges of water quality parameters in the experimental tanks during the 28-day period

Parameters	Control		Alum		$CaCO_3$	
	Aerated	Unaerated	Aerated	Unaerated	Aerated	Unaerated
Temperature (°C)	28.5-29.3	28.4-29.7	28.4-29.6	28.6-29.7	28.2-29.7	28.6-29.8
Diss. Oxygen ($mg \cdot l^{-1}$)	7.23-7.83	4.41-5.93	7.30-7.75	4.04-5.97	7.25-7.80	4.12-5.83
pH	7.85-8.17	7.30-7.76	7.84-8.18	7.22-7.65	7.88-8.30	7.47-7.60
Total alkalinity (mg $CaCO_3 \cdot l^{-1}$)	103.7-136.1	99.7-126.4	na	na	98.4-128.0	100.1-129.9
Salinity (ppt)	18.0-19.5	18.0-19.5	18.0-19.5	18.0-19.5	18.0-19.5	18.0-19.5

na = not analyzed

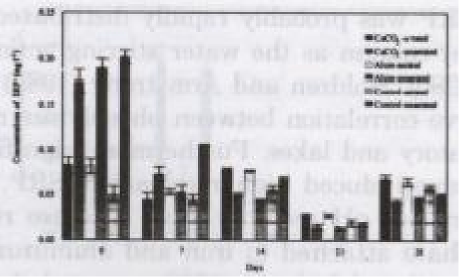

Fig. 1. Concentrations of soluble reactive phosphorus (SRP) in the overlying water of different treatments. Vertical bars are standard errors of the means, n = 3.

George et al. (1991) reported that hardness and alkalinity decreased alum toxicity. They further noted that due to the amphoteric nature of aluminum, its toxicity occurred in acidic and basic waters, but not in circumneutral condition. Previous studies have indicated that alum can adversely affect algal production in acidic waters (George et al. 1991) and fish in waters with low alkalinity (Wilkinson 2002). More studies are required to determine if alum is detrimental to organisms in highly alkaline marine waters.

Before the addition of the chemicals (day 0), the concentrations of SRP in aerated tanks were significantly lower ($p<0.05$) than those without aeration (Fig.1), indicating that aeration is effective in decreasing SRP in the water column. Seven days after the addition of the chemicals, SRP concentrations in carbonate and alum aerated tanks were not significantly different ($p>0.05$) from the aerated control tanks. However, SRP values in carbonate and lime unaerated tanks were significantly lower ($p<0.05$) than the unaerated-control tanks, demonstrating that alum and carbonate treatments were effective in decreasing SRP in tanks without aeration. Masuda and Boyd (1994) showed that alum caused marked reduction of SRP in freshwater fish ponds.

From day 14 onwards, SRP in carbonate and alum aerated tanks had significantly higher ($p<0.05$) SRP than other tanks, indicating that there is a release in SRP from the sediment in these tanks. The aerated control tanks followed the same trend although the reaction was slower (Fig.1). In general, SRP concentrations in the water column of all tanks showed a decreasing trend culminating with the lowest values after 21 days of experiment, indicating adsorption of SRP by the sediment. Since the iron concentrations in the soil was relatively high (Table 1) under oxidized conditions, phosphorus could be adsorbed onto ferric hydroxide compounds (De Vitre et al. 1988; Sarazin et al. 1995). Adsorption was accelerated with aeration and addition of carbonate and alum. On day 28, there was an increase of SRP in all the tanks with significantly higher values in aerated tanks. This study showed that under stabilized condition, SRP released from the sediment was higher under aerated condition. Enell and Löfgren (1988) reported that compaction of sediment may cause an advective flux of pore water upwards, thus the increase of nutrients in the water later in the experiment. In addition, they reported that turbulence, bioturbation and gas ebullition always increase P release from the sediment compared with values from molecular diffusion. Holdren and Armstrong (1980) showed that high bacterial activity at high temperatures caused microanaerobic conditions at the sediment surface and phosphorus release to the oxygenated overlying water. Mass balance studies have shown that the release of phosphorus can be substantial from sediments to well aerated water (Ryding and Forsberg 1977; Stevens and Gibson 1977). In this study, SRP was probably rapidly distributed from the sediment surface to the water column as the water stirring action increased the diffusive flux (Hesslein 1980). Holdren and Armstrong (1980) and Ahlgren (1980) demonstrated positive correlation between phosphorus release and mixing energy both in laboratory and lakes. Furthermore, significantly higher pH in aerated tanks may have induced higher release of SRP. Böstrom et al. (1982) showed that increased pH resulted to an increase release of P, due to the release of phosphate attached to iron and aluminum compounds at the sediment surface. Enell and Löfgren (1988) reported that a decrease in pH would increase the binding of P to iron and aluminum. In the presence of nitrate, a pH increase favored phosphorus release as pH increase decreases the ability of nitrate to keep phosphorus in the sediment (Böstrom and Pettersson 1982). According to Graneli (1979), van der Loeff et al. (1984) and Matisoff et al. (1985), bioturbation can also increase the release of phosphorus from the sediment under aerobic condition. Aerated tanks could have higher benthic animals, but no attempt was made to assess the benthic populations in the sediment used in this study. Shishehchian et al. (1999) and Shishehchian and Yusoff (1999) reported that benthos were abundant in shrimp ponds during the early stage of culture period when the sediment was good.

This study showed that aeration alone was as effective as alum or carbonate in decreasing the release of SRP from sediment to the overlying water. In aquaculture ponds however, surface aeration is not effective in oxidizing the anaerobic sediment surfaces. In spite of the use of paddlewheels, the sediments of intensive shrimp culture ponds are mainly anaerobic with a strong smell of hydrogen sulphide. Furthermore, any available oxygen in the bottom sediment would continuously be used due to heavy loadings of organic matter from allochthonous and autochthonous sources. Thus, addition of alum or carbonate to ponds would accelerate the adsorption of SRP to the sediment. However, past studies on the effects of calcium carbonate on SRP released were not consistent. Williams et al. (1970) and Shukla et al. (1971) found that non-calcareous sediments were more efficient in adsorbing the phosphate than calcareous, while Morse and Cook (1978) showed high phosphate adsorption in calcareous sediments. Enell and Löfgren (1988) reported that the adsorption capacity is dependent not only on substrate types, but on the number of adsorption sites which can vary with the amount of adsorbent, competition between phosphate and other ligands, or be reduced as a result of organic coatings on the surfaces.

Similar to SRP, the unaerated tanks had significantly higher ($p<0.05$) total ammonia concentrations than aerated systems before the application of alum and calcium carbonate, indicating that aeration alone could effectively reduce ammonia in water (Fig. 2). Seven days after the application of the chemicals, the total ammonia in alum-unaerated treatment had significantly lower ammonia concentrations compared to carbonate-unaerated and unaerated control tanks, demonstrating the effectiveness of alum in decreasing ammonia in the water columns. In fact, ammonia totally disappeared in alum-aerated treatment on day 7. This observation indicates that alum and aeration were effective in decreasing ammonia concentrations in pond water. From day 14 onwards, ammonia concentrations were not detected in all treatment tanks, probably due to the adsorption by the sediment and nitrification of ammonia to nitrate. Lerat et al. (1990) reported that ammonium was quantitatively the most abundant nutrient measured in pore water, and its concentrations were 20 to 70 times higher than those in the water column.

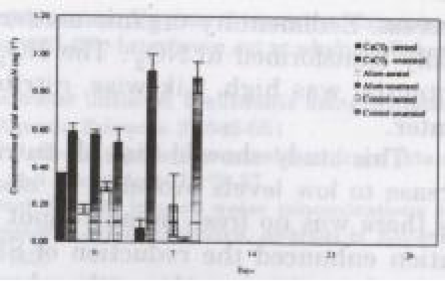

Fig. 2. Concentrations of total ammonia nitrogen in the overlying water of different treatments. Vertical bars are standard errors of the means, n = 3. From day 14 to day 28, ammonium concentrations were undetectable.

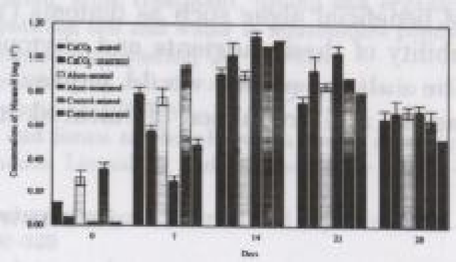

Fig. 3. Concentrations of nitrate-nitrogen in the water column of different treatments. Vertical bars are standard errors of the means, n = 3.

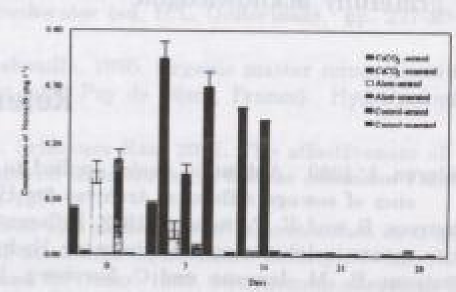

Fig. 4. Concentrations of nitrite-nitrogen in the water column of different treatments. Vertical bars are standard errors of the means, n = 3.

Nitrite and nitrate depicted different trends from SRP and ammonia. Before the addition of chemicals, aerated tanks had significantly higher ($p< 0.05$) concentrations of nitrate-N and nitrite-N compared to unaerated tanks, indicating oxidation of ammonia in the presence of high dissolved oxygen concentration (Figs. 3 and 4). Nitrate concentrations continued to increase, especially in aerated tanks, reaching maximum values on days 14 and 21, coinciding with the absence of ammonia in the water column in all tanks (Figs. 2 and 3). Aeration and chemical treatment did not seem to be affective in reducing the nitrate levels in the water (Fig. 3). Lerat et al. (1990) reported that net exchanges of nutrients across sediment-water interface were strongly dominated by a nitrate and silicate release. Ammonium release was 50% lower and nitrite release was negligible. In aquaculture ponds with high organic matter, heterotrophic metabolism increases ammonium formation, which is then oxidized to nitrate through the increase of the nitrifying activity. Thus, in the absence of aeration or alum, ammonia accumulation in pond water may lead to deterioration of water quality.

From day 7 to day 14, the concentrations of nitrite in alum and lime-aerated tanks were significantly lower than in unaerated tanks. Aeration alone could significantly ($p<0.05$) reduce nitrite concentrations in the water column (Fig. 4). Nitrite concentrations decreased to low levels (<3 $(\mu g \cdot l^{-1})$ in all treatments after day 21. According to Lerat et al. (1990), whatever the organic matter source was, the degradation pattern in the sediment followed the same process. Sedimentary organic matter was oxidized to NH_4^+, which was partially transformed to NO_2^-. The NO_3^- production occurred only when redox potential was high. Likewise, nitrite was always higher in the interstitial water.

This study showed that all nutrients in the water column seemed to decrease to low levels probably by absorption to sediment as early as day 14 as there was no fresh organic input into the system. Aeration and alum addition enhanced the reduction of SRP and ammonia in the water column. Loss of nutrients such as phosphorus and inorganic nitrogen in water is desirable in shrimp ponds with large accumulation of excess feed and excreted wastes as nutrients are the key factors contributing to excessive phytoplankton blooms, especially in the late phase of the culture cycle. However, alum treatment is not necessary in the first month of the culture period as the nutrients are still relatively low and they are necessary for the growth of beneficial algae such as diatoms (Yusoff et al. 2002). Optimizing the availability of these nutrients and phytoplankton abundance in ponds throughout the culture period would improve the pond water quality and promote health and production of cultured organisms.

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