Phosphorus and nitrogen budget for inland, saline water shrimp ponds in Alabama

by

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ABSTRACT

Phosphorus and nitrogen budgets were prepared for ponds in an inland low-salinity shrimp farm in the Blackland Prairie region of Alabama. The study was conducted during the first crop in three ponds which were newly constructed and had never before contained water.

Ponds were not fertilized, and the main input of phosphorus and nitrogen in feed averaged 47 kg/ha and 208.5 kg/ha respectively. These inputs respectively accounted for 98.9% and 95.5% of total input for phosphorus and nitrogen, other inputs of phosphorus and nitrogen were post larvae, well water, rainfall and runoff that combined averaged 0.5 kg/ha for phosphorus and 9.8 kg/ha for nitrogen.

The major output of phosphorus and nitrogen was shrimp harvest which averaged 5.2 kg/ha for phosphorus and 45.7 kg/ha for nitrogen. Only 10.9% of phosphorus and 21% of nitrogen applied in feed was incorporated into shrimp. Other losses of phosphorus and nitrogen that resulted from water outflows (seepage and harvest effluent) accounted for 3.2 kg/ha for phosphorus and 7.8 kg/ha for nitrogen.

It was difficult to measure the phosphorus and nitrogen increase in the bottom soil over a single crop especially for these new ponds. Phosphorus adsorption by bottom soil is the major pathway of phosphorus loss from pond water, and the difference between the inputs and outputs is thought to result from adsorption by bottom soils. For nitrogen, the discrepancy between input and output was caused by absorption by the bottom soil, denitrification and NH_3 volatilization. Nitrogen loss caused by denitrification and NH_3 volatilization was not measured in this study. Reuse of the water removed from ponds at harvest is a practical way to reduce the nutrient load to the environment and to save water.

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INTRODUCTION

Inland shrimp culture has become common in many areas worldwide. Inland ponds for shrimp culture often are supplied with low-salinity water from saline aquifers (Roy et al., 2010). Most environmental concerns of inland shrimp culture focus on salinization. However, like all other kinds of pond aquaculture, eutrophication caused by phosphorus and nitrogen in the discharge effluent from ponds is also a major environmental concern (Boyd, 2006).

Compared to natural waters, aquaculture pond waters are usually enriched with phosphorus and nitrogen because of the use of feeds and fertilizers. Nitrogen and phosphorus are the key nutrients that increase productivity of aquatic plants and lead to eutrophication.

Nitrogen is an essential component of protein and other constituents of cellular protoplasm. There is usually 7 to10 times more nitrogen than phosphorus contained in plants. However, since phosphorus is quickly removed from the water and bound in the sediment, an increase in phosphorus concentration usually will cause a greater response in plant growth than with an increase in nitrogen concentration. A major concern of nitrogen discharge in aquaculture results from nitrite and un-ionized ammonia. These two inorganic nitrogen compounds can be toxic to aquatic animals at relatively low concentrations (Boyd and Tucker, 1998).

The main inputs of phosphorus and nitrogen to ponds are fertilizers and feed (Boyd and Tucker, 1998). Except for the portion recovered in the harvest of the culture species, the rest of the added phosphorus is either adsorbed by pond bottom soil or discharged in effluent (Boyd et al., 2006).

Nitrogen is lost via the following pathways: shrimp harvest; harvest effluent; denitrification; NH_3 volatilization; accumulation in bottom soils (Gross et al., 2000).

The purpose of this study was to prepare phosphorus and nitrogen budgets for shrimp ponds and estimate the quantity of phosphorus and nitrogen released into natural waters through effluents.

LITERATURE REVIEW

Shrimp is presently the largest single commodity, by value, in international fish trade, accounting for 15% of the total value of internationally traded fishery products (FAO, 2008). The shrimp industry has grown exponentially in the past few decades (Leung and Engle, 2006). Global shrimp production, including wild caught fisheries and aquaculture, has significantly increased from 2.6 million tons in 1990 to 6.9 million tons in 2010 (FAO, 2008). Aquaculture plays an important role in shrimp industry, it supplies about 55 % (3,787,706 tons for aquaculture; 6,916,956 tons for total) of the total world supply of shrimp in 2010 (FAO, 2010).

In Asia, the dominant species traditionally was the Black Tiger shrimp (*Penaeus monodon*) which is native to tropical, coastal regions of the Indo-Pacific basin. In the western hemispheres, the dominant species was the Pacific white shrimp (*Litopenaeus vannamei*) which is native to the tropical Pacific coast of Latin America. In the late 90s, the non-native SPF (specific pathogen free) Pacific white shrimp was introduced to Asian, and its use in aquaculture spread through Southeast Asia rapidly. The widespread adoption of Pacific white shrimp cause a dramatic increase of Asian shrimp production. Pacific white shrimp has become the dominant species cultured in Thailand, China and Indonesia (Wyban, 2009). The main shrimp species currently produced in the shrimp culture industry is Pacific white shrimp as it has largely replaced the Black Tiger shrimp in the last decade (Josupeit, 2009).

Shrimp farming was originated in Southeast Asia where wild shrimp has been raised for centuries. Modern shrimp farming began in the 1930s when Japanese scientists discovered the method to nurture Kuruma shrimp (*Penaeus japonicus*) larvae to maturation on a large scale (Weidner and Rosenberry, 1992). Shrimp were mainly cultured in large extensive systems which provided low productivity before abundant marine shrimp seed were available from hatcheries and wild-caught sources (Fast, 1992).

Marine shrimp were traditionally cultured in coastal areas or estuarine waters (Davis et al., 2004). However, with the development of intensive shrimp farming technology, many environmental issues associated with intensive aquaculture activities have arisen. Destruction of mangrove and wetland for shrimp farm construction is considered as a major cause of loss of mangrove forest and wetland (Phillips et al., 1993). In coastal areas of Taiwan, the Philippines and Thailand, salinization of freshwater aquifers was caused by using groundwater for intensive shrimp culture (Primavera, 1989).

Diseases such as white spot syndrome virus and taura syndrome virus become the biggest obstacle for the development of shrimp aquaculture (Wickins and Lee, 2002). In order to control disease, reduce pollution and prevent damage to the coastal ecosystem, improved shrimp production methods have been developed to reduce the discharge of effluent and minimize the risk of disease outbreaks. Zero water exchange system using lined ponds and inland shrimp farming are two examples. Reducing water exchange rates can minimize the risk of introducing disease carriers into culture systems, so zero water exchange system is highly effective for disease control (Samocha et al., 2002).

Because the shrimp farms in inland areas are more scattered comparing to those in the coastal areas, the water supply sources for the farms are isolated and there are less contamination problems caused by neighboring farms. Moreover the land price of inland areas is much lower than that of coastal areas. The inland ecosystem is also less sensitive to pollution than the coastal ecosystem. Inland shrimp farming also avoids disturbance of mangrove habitat.

As a euryhaline species that can tolerate a wide range of salinities (0.5-45 g/l) (Menz and Blake, 1980; Bray et al., 1994), Pacific White Shrimp became an excellent candidate for inland low salinity farming. The healthy post-larvae of Pacific white shrimp are usually available year around (Davis et al., 2004).

Some of the first reports of raising the Pacific white shrimp in inland saline well water were from Smith and Lawrence (1990) in west Texas (USA). According to the report, shrimp were raised in earthen ponds (86.7% survival) at a stocking density of 25 shrimp/m^2. After 120 days, the shrimp grew from 1.2 g to about 20 g (Samocha et al., 2002).

After shrimp farming nearly collapsed as a result of diseases throughout coastal Thailand, the shrimp farm industry worldwide started to look for alternatives to maintain production (Kaosa-ard and Pednekar, 1996). Inland low-salinity shrimp farming became quite successful in Thailand. The techniques used in inland low-salinity farming in Thailand are similar to those used in coastal area. However, instead of using seawater to fill the ponds, inland low-salinity farms mix brine solution with freshwater. The brine solution is obtained from coastal evaporation ponds. The brine water is diluted to a salinity level of 3-5 ppt with fresh water to raise the shrimp. A study by Limsuwan (2002) showed that brine water with a salinity of 200 ppt, when diluted with fresh water to the level of 3-5 ppt, is appropriate for shrimp farming.

Freshwater inputs are also used to replace the water loss caused by evaporation and seepage during the production cycle, and this practice can reduce the salinity levels to near zero by the time of harvest if no more saline water or salt are added (Szuster, 2006).

Although the inland low-salinity farming techniques using brine solution in Thailand has been quite successful, producers in other countries are using saline ground water to raise marine species in the inland area.

In Ecuador, there are some areas that have saline groundwater that is suitable for rearing marine shrimp (Boyd, 2001, 2002). And there are reports about inland shrimp farming at sites near Palestina in the Guayas Province (Boyd, 2002). There also have been reports of shrimp culture in saline water in Brazil (Nunes and Lopez, 2001) and other South America countries, but the current status of using well water for shrimp culture in other countries is not well documented.

It has been estimated that about two-thirds of the continental area in USA are underlain by saline groundwater (Feth, 1970). The inland shrimp culture was first done in the US using groundwater with a salinity of 28 ppt. Nowadays, inland shrimp culture has become rather common in Florida, Alabama, Texas, Arizona and other states. However, the salinities of well water used in most areas for inland shrimp culture are less than 10 ppt (Roy et al., 2010).

Some catfish farmers in west-central Alabama started to experiment with shrimp culture in ponds using ground water from wells which contained 2 to 6 ppt salinity in 1999 and 2000. Actually, some channel catfish farmers in west-central Alabama (about 200 miles inland) have been culturing catfish in waters of 2 to 6 ppt salinity for years. There are fewer disease problems for catfish culture in ponds using saline water than those using normal fresh water (Boyd et al., 2000). The water used for this inland shrimp culture was pumped from brackish water aquifers about 1300 ft below ground (Teichert-Coddington, 2002).

Previous studies showed that the proportions of major ions of pond waters prepared by diluting brine solution with freshwater in Thailand were similar to those in normal seawater. However, ionic composition of saline groundwater is different from seawater diluted to the same salinity (Boyd et al., 2002; Roy et al., 2010).

The concentrations of calcium and bicarbonate tend to be much higher in saline ground water than that in seawater. The high proportion of calcium and bicarbonate is considered to be desirable for aquaculture pond waters (Boyd and Tucker, 1998).

The concentrations of potassium, magnesium and sulfate tend to be lower in saline groundwater than those in seawater diluted to the same salinity. A low proportion of sulfate also is desirable because sulfate is the source of hydrogen sulfide in anaerobic pond soils (Boyd, 2001; Boyd et al., 2002; Boyd and Thunjai, 2003; Saoud et al., 2003). Low concentrations of potassium and magnesium in inland low-salinity shrimp ponds using saline groundwater will decrease shrimp survival rate and production (Roy et al., 2010). Adding potassium and magnesium fertilizers to the ponds will significantly increase survival and production (McNevin et al., 2004; Boyd et al., 2007).

The most common material used as potassium fertilizer in the ponds is potassium chloride (KCl), also known as muriate of potash. Another material used as both potassium and magnesium fertilizer is sulfate of potash magnesia ($K_2SO_4 \cdot 2MgSO_4$) which is sold under the trade name K-Mag.

Potassium and magnesium in pond waters are lost through overflow, seepage, harvest effluent, shrimp harvest and soil adsorption. Potassium and magnesium budgets were made for ponds receiving muriate of potash and Kmag as fertilizers in Alabama (Boyd et al., 2007; Pine and Boyd, 2010). Bottom soil can fix potassium by both exchangeable and non-exchangeable processes, and over half of the potassium inputs were lost to these processes (Boyd et al., 2007). Unlike the potassium, nearly all of the magnesium is considered to be exchangeable (Pine and Boyd, 2010).

Compared to shrimp culture in coastal areas, inland farming has several advantages as mentioned before. The water supply is not shared with other farms and the control over water use is much easier. The disease problem also can be greatly reduced. The use of land and water resources is more efficient because inland shrimp farming tends to be more intensive than coastal shrimp farming (Boyd, 2001). However, with the rapid growth of inland low-salinity shrimp aquaculture industry, there have been more and more concerns about the environmental impacts of this industry. Most concerns focus on salination of streams, aquifers and soils caused by pond discharge (Roy et al., 2010). In other types of aquaculture, there are also environmental concerns about eutrophication caused by discharge of nutrients, organic matter and suspended solids. Although salination is the major concern in inland shrimp culture, eutrophication is also a problem. The reason that people pay more attention to salination is that the potential for salination is more obvious and effort to reduce salt discharge will also lessen release of other pollutants (Prapaiwong and Boyd, 2012).

Effluents from pond aquaculture typically are enriched in suspended solids, nutrients, chlorophyll *a* and biochemical oxygen demand (BOD). Elevated concentrations of phosphorus and nitrogen in pond effluents also will stimulate the growth of algae and cause eutrophication problem in receiving waters (Schwartz and Boyd, 1994).

In the catfish industry, feed is the major source of phosphorus to channel catfish ponds (Boyd, 1985). Phosphorus budgets had been made for channel catfish ponds receiving diets with different phosphorus concentrations in Auburn, Alabama by Gross et al. (1998). That study revealed that phosphorus levels in diets did not have significant influence on phosphorus concentrations in pond water and phytoplankton activity. The uptake of phosphorus by bottom soil adsorption processes was the major factor controlling phosphorus dynamics in ponds. Bottom soils usually have a large capacity to absorb phosphorus, but the capacity has limits (Masuda and Boyd, 1994; Boyd and Munsiri, 1996). It usually will take 20 years or more to saturate bottom soils with phosphorus at normal feeding rates in catfish culture in the southeastern United States (Boyd, 1995). Therefore, reducing phosphorus inputs to ponds in feed can extend the time to saturate pond soils (Gross et al., 1998).

Feed is also the major input of phosphorus and nitrogen in the shrimp aquaculture industry. Some applied phosphorus is recovered in the harvest of the culture species, and the rest is lost through adsorbing by pond bottom soil and harvest effluent (Boyd et al., 2006). Nitrogen was lost via the following ways: shrimp harvest; harvest effluent; denitrification; NH_3 volatilization; accumulation in bottom soils (Gross et al.,2000).

Methods such as reducing feeding rates, managing ponds to minimize effluents and discharging effluent through settling ponds can reduce the nutrition load to the environment (Schwartz and Boyd, 1996).

MATERIAL AND METHOD

Ponds and management

This study was conducted in ponds located on a commercial inland shrimp farm next to Alabama Highway 43 about 5 km north of Forkland in the Blackland Prairie region of west-central Alabama. Three newly constructed, embankment ponds were selected in the study. These ponds had not contained water before. Pond water surface areas were as follows: N-10, 1.62 ha; N-11, 1.53 ha; N-12, 1.92 ha. The average depth for three ponds N-10, N-11 and N-12 were 1.11 m, 0.95 m and 0.95 m, respectively When water levels are 10 cm below the top of overflow pipes, watershed areas were as follows: N-10, 2075 m^2; N-11, 2509 m^2; N-12, 2718 m^2.

Ponds N-10 and N-11 were stocked with post larval shrimp at $20/m^2$ and $21/ m^2$ on 20 April and N-12 were stocked with post larval shrimp at $21/m^2$ on 12 May. Feed containing 35% crude protein was used throughout the production cycle. Ponds were not treated with nitrogen and phosphorus fertilizers. Each pond was equipped with an electrically –powered paddlewheel aerator to avoid low dissolved oxygen concentration.

Ponds were filled with saline ground water from a well. The drop-fill practice was implemented to provide storage capacity of rainfall and prevent overflow after normal rainfall events (Boyd, 1982; Cathcart et al., 1999). The initial water levels in the ponds were about 10 cm below the tops of the overflow pipes when shrimp were stocked, and pumped water was added to the ponds to replace evaporation and seepage. Water levels were maintained 10-15 cm below the top the overflow pipe.

Shrimp were harvested during September. Pond N-12 was harvested earlier on 10 September after 128 days of culture due to the low survival rate. Ponds N-10 and N-11 were harvested on 22 September and 13 September after 155 days and 146 days of culture, respectively. During the harvest, water drained from the ponds was pumped to the next ponds that had already been harvest to save water for reuse.

Water budget

Water budget for the three ponds are based on the method proposed by Boyd (1982), which uses the hydrologic equation as follow:

Inflows = Outflows ± Change in storage

Inflows included well water, precipitation and runoff. Outflows were evaporation, seepage, overflow and draining for harvest.

Precipitation and evaporation were measured by a standard rain gauge and a class A evaporation pan that were installed near the ponds. The pan coefficient of 0.81 was used in estimating pond evaporation (Boyd, 1985). The equation for pond evaporation was

$$E = E_{pan} (0.81)$$

where E_{pan} is class A pan evaporation.

Staff gauges were attached to the piers of each pond to measure the water level. Discharge from the well could not be measured directly, and it was calculated (Boyd, 1982) by the following equation:

$$W = (E+S+O+H) - (P + R)$$

where W= water from well, E= evaporation, O = overflows, H= pond water depth, P=precipitation, R= run-off.

According to the curve number method (Yoo and Boyd, 1994), approximately 67% rain falling on the watershed would enter the ponds in run-off. The equation for calculation run-off for a pond was:

$$R = 0.67\,(a/A)P$$

where a= watershed area (m^2) and A =pond surface area (m^2).

Seepage was estimated during dry periods when there were no inflows to the ponds (Boyd, 1982). The difference in the decline in water level and evaporation is seepage:

$$S = \Delta H - E$$

The water levels were maintained 10 cm below the top the overflow pipe to avoid overflow, but staff gauges were read within a few hours after the major rainfall event to check if the water level exceeded the top of the stand pipe. Overflow was estimated as

$$O = H - T$$

where T= elevation of top of drain pipe.

Phosphorus and Nitrogen determinations

The feed samples were obtained during the production cycle and shrimp samples were collected at harvest. The samples were dried at 60 °C in a mechanical convection oven and pulverized with an IKA Economic Analytical Mill (Cole-Parmer, Vernon Hills, IL, USA). The pulverized samples were sent to the Auburn University Soil Testing Laboratory for total nitrogen determination.

Analyses for phosphorus were made according to the method proposed by Boyd and Teichert-Coddington (1995). Portions of 1g each were incinerated at 500 °C for 8 h in a muffle furnace. A 2.0 N acid solution was prepared by mixing equal volumes of 1 N HNO_3 and 1 N HCL. Five milliliters of this solution were added to the ash. The mixture was then rubbed with a rubber policeman and put on a hot plate until nearly dry. The residual was dissolved and transferred to a 100-ml volumetric flask and diluted to volume with the 2.0 N acid solution. The resulting solution was filtered through Whatman Number 42 filter paper to get the final solution. The final solution was sent to the soil testing laboratory for determination of the concentration of total phosphorus.

A 30-cm diameter plastic funnel was placed in a 2-L plastic bottle to collect rainwater samples. Water samples were collected from ponds every 2 weeks throughout the production cycle and at harvest. Samples of well water were collected when well water was pumped into the ponds. All the water samples were put into 2-L plastic bottles, stored in insulated ice chests and transported to Auburn University for analysis. The samples were subjected to persulfate digestion in an alkaline environment (Eaton et al., 1995). In this procedure, 10 ml of water sample were pipette into 30-mL test tubes, 5 mL of 0.075N NaOH and 0.1g of potassium persulfate was added to the test tubes. Capped test tubes were mixed by inverting twice and autoclaved at 110 C for 30 min. After the samples cooled to room temperature, 1 mL of borate buffer (61.8 g boric acid H_3BO_3 and 8 g NaOH in 1,000 mL of distilled water) were added. After digestion, 5 ml of resulting solution was transferred to another set of tubes to analyze total phosphorus by the ascorbic acid method (Gross and Boyd, 1998).The remaining solution in the tubes was read by ultraviolet spectrophotometry for determination of total nitrogen concentration. Filtered water samples were measured for soluble reactive phosphorus using membrane filtration and the ascorbic acid method (Gross and Boyd, 1998). Water samples were also filtered and analyzed for NO_3-N with the NAS reagent method (Gross and Boyd, 1998) and for TAN with the salicylate-hypochlorite method (Bower and Holm-Hansen, 1980).

Soil samples were collected at nine locations in an S-shaped pattern in each pond bottom before ponds were filled with water. Samples were taken with a shovel to depth of 15 cm. The nine samples were thoroughly mixed to provide a single composite sample for analysis. Ponds were completely drained for harvest in September. After ponds were drained, 18 sediment samples from ponds N-10 and N-11 were collected as described above. Since water drained from the ponds was pumped to the next ponds that had already been harvest to save water for reuse, pond N-12 still contained water when the bottom soil samples were collected. Cores were taken with a 5-cm core sample tubes. Because the heavy clay soil was so sticky, the tube core tube could not be forced more than 10 cm into the soil. Only samples of 0-10 cm layers were obtained from pond N-12. The samples were dried at 60 °C in a mechanical convection oven and pulverized with a mechanical soil crusher (Custom Laboratory Equipment, Orange City, Florida, USA) to pass a 40-mesh screen. Methods used for determination of total phosphorus and total nitrogen concentration in soil samples were the same as the ones used for feed and shrimp samples.

Phosphorus and Nitrogen budget

Phosphorus and nitrogen budgets were prepared for each pond by summing the inputs and outputs of phosphorus and nitrogen. For phosphorus, the inputs were post larval shrimp, feed, well water, rainfall and run-off. The outputs were shrimp harvest, overflow, seepage, and sediment accumulation. For nitrogen, the inputs were post larval shrimp, feed, well water, rainfall, run-off and N_2 fixation. The outputs were shrimp harvest, overflow, seepage, sediment accumulation, NH_3 volatilization, and denitrification. The quantities of the post larvae, feed and weight of harvested shrimp were obtained from the production record provided by the owner. Volumes of well water, rainfall, run-off, seepage, overflow, and drainage effluent were obtained by multiplying the depth of water measured in water budgets by pond areas. Quantities of inputs and outputs of phosphorus and nitrogen were obtained by multiplying the quantities of inputs and outputs of water by their phosphorus and nitrogen concentrations.

RESULT AND DSICUSSION

Precipitation and class A pan evaporation data collected at the shrimp farm and obtained from an National Weather Service (NWS) gauging station at Demopolis Lock and Dam about 30 km southeast of the farm are provided in Table 1, Table 2 and Table 3. For evaporation, only normal values were obtained from the NWS gauging station. Total rainfall for May and July was slightly higher at the station than at the farm and the total rainfall throughout the production cycle was higher at the farm than at the station. The normal value for evaporation was higher at the station than at the farm except pond N-12 which had a shorter production cycle than N-10 and N-11 because of the low survival rate.

Both the water budget method and the bucket method were used to estimate the seepage of ponds in this study. For the water budget method, seepage was calculated only during the dry period when there were no inflows or outflows other than seepage and evaporation (Boyd, 1982). Seepage was measured three times for each pond and the average values and standard deviations for three ponds were as follows: N-10, 0.128 ± 0.10 cm/day; N-11, 0.139 ± 0.09 cm/day; N-12, 0.09 ± 0.08 cm/day. The results of the bucket method were inconsistent and considered less accurate than the water budget-based estimates. Thus, they were not used.

Water from the well was the major inflow during the budget cycle (Table 4).

Precipitation and runoff replaced about 70% of water losses caused by evaporation and seepage. Overflow events were not observed throughout the production cycle. The effluent discharge during harvest was the largest loss of water. Evaporation was a major loss from ponds and seepage was a much smaller loss as compared to harvest effluent and evaporation.

The amount of post larval shrimp, feed used during the production cycle, and harvested shrimp are provided in Table 5. Table 5 also provides the phosphorus and nitrogen concentrations of the post larval shrimp, feed and harvested shrimp. The survival rates and the FCR were not particularly good for all three ponds. Pond N-12 had the lowest survival rate (Table 6). Only 10.9% of phosphorus and 21 % of nitrogen of the feed applied was incorporated into shrimp.

The recovery of applied phosphorus in harvested shrimp was much less than the recovery of applied nitrogen. However, the recovery of these two elements is about equal in fish culture (Boyd and Tucker, 1998). The major reason that causes this difference is that fish have bones which contain calcium phosphate but shrimp do not have bones. Live fish usually contain about 0.5-0.75% phosphorus (Boyd et al., 2007), while the live Pacific white shrimp in this study only contained 0.36% phosphorus. Molting of shrimp could also be a reason causes the low nutrient recovery because the molted shells also contain phosphorus and nitrogen.

The phosphorus and nitrogen concentrations in rainfall, well water and pond water are provided in Table 7 and Table 8. Although the well was the major source of water for the ponds, well water was not a major input of phosphorus because the total phosphorus concentration in the well water was low.

The average concentrations of total phosphorus and total nitrogen in pond water measured at intervals during the grow-out period (Table 7 and Table 8) were used to estimate the quantities of phosphorus and nitrogen lost in seepage and overflow. The concentrations of phosphorus and nitrogen in the pond water at harvest (Table 7 and Table 8) were measured for estimating the amount of these two elements in the harvest effluent. The average concentrations of soluble reactive phosphorus, total ammonia nitrogen and nitrate nitrogen in rainfall, well water and pond water are provided in Table 9, Table 10 and Table 11.

The harvested shrimp was the largest nutrient output accounting for about 61% of the total output for phosphorus and 85% of the total output for nitrogen (Table 12).

The difference between the average inputs and outputs were 39.1 kg/ha for phosphorus and 164.8 kg/ha for nitrogen. The discrepancy for phosphorus was assumed to have resulted from absorption by the bottom soils, but it was not possible to measure the increase of phosphorus in the bottom soil during a single crop. Since all three ponds in this study were new ponds that never contained water before and the duration of this study was just one single crop, the phosphorus concentration of soils across the pond bottom had wide variation (Masuda and Boyd, 1994) and the increase of phosphorus concentration in pond bottom soil during one single crop was small. Moreover, the precision of total phosphorus analysis for pond soils are relatively low (Tavares and Boyd, 2003). Boyd (1985) reported the same problem in demonstrating a change on phosphorus concentration in channel catfish pond soils during a single crop. However, when considered over many crops, it has been shown that about two-third of phosphorus applied in feed to catfish ponds (Masuda and Boyd, 1994) and shrimp ponds accumulates in bottom soil (Boyd et al., 2006).

Bottom sediment of pond strongly adsorbs phosphorus through various processes. Phosphorus is bound in acidic soil mainly as aluminum phosphate, but some also is bound as iron phosphate. In soil neutral or basic reaction, phosphorus is bound in calcium phosphate. Clay particles in soil also can adsorb phosphorus (Boyd, 2000). Phosphorus availability in water depends on the pH of water and mud (Masuda and Boyd, 1994). Under acidic conditions, phosphorus concentration in water is controlled by solubilities of iron and aluminum phosphates. In near-neutral and high alkalinity condition, phosphorus concentration in water is determined by solubilities of calcium and iron phosphorus (Moore and Reddy, 1994). The previously mentioned study by Masuda and Boyd (1994) showed that although about two-thirds of phosphorus applied to ponds in feeds and fertilizers accumulate in bottom soils, this phosphorus was tightly bound and only a small amount was water soluble. Bottom soils usually have a large capacity to absorb phosphorus, but the capacity has limits (Masuda and Boyd, 1994; Boyd and Munsiri, 1996). It usually will take 20 years or more to saturate bottom soils with phosphorus at normal feeding rates in catfish culture in the southeastern United States (Boyd, 1995). Therefore, reducing phosphorus inputs to ponds in feed can extend the time to saturate pond soils (Gross et al., 1998).

Nitrogen is lost from ponds via the following pathways: shrimp harvest; harvest effluent; denitrification; NH_3 volatilization; accumulation in bottom soils (Gross et al., 2000). The difference between input and output for nitrogen was caused by deposition in the bottom soil, denitrification and NH_3 volatilization. Nitrogen loss caused by denitrification and NH_3 volatilization was not measured in this study. It is also difficult to measure the nitrogen increase in the bottom soil over a single crop for the same reason mentioned earlier for phosphorus.

The pH values of three ponds are quite close. The values of total dissolved solids, salinity, and conductivity in pond N-12 are higher than those in N-10 and N-11(Table 13).

Seepage is not easy to control, and it is unavoidable unless impermeable liners are installed. The high cost of pond liners is not acceptable at the intensity of culture employed in inland shrimp ponds in Alabama. However, seepage rates in the Blackland Prairie usually are not very large because of the heavy clay soils in most places (Yoo and Boyd, 1994). Moreover, seepage can be reduced by carefully selecting the sites and using good construction methods (Boyd et al., 2004).Overflow should be controlled by providing storage volume for rain falling into ponds as was done in ponds of the present study. Harvest effluents should be recycled to conserve water as describe by Boyd et al. (2006). Reusing the water can reduce loss of nutrients to the environment and reduce pollution.

Table 1: Precipitation and class A pan evaporation data for the period 20 April – 22 September 2011 in pond N-10 at an inland shrimp farm in Alabama:

Month	**Precipitation (cm)**		**Class A pan evaporation (cm)**	
	Farm	NWS	Farm	Normal
20-30 April	4.6	4.6	4.7	5.4
May	4.6	7.5	17.3	16.5
June	4.7	2.3	18.2	17.7
July	13.6	16.3	17.1	18.2
August	4.7	2.4	15.7	17.1
1-22 September	21.1	14.8	10.4	10.3
Total	53.3	47.9	83.4	85.2

NWS: 2011, Demopolis Lock and Dam Station
NWS Normal: 1956-2002, Demopolis Lock and Dam Station

Table 2: Precipitation and class A pan evaporation data for the period 20 April – 13 September 2011 in pond N-11 at an inland shrimp farm in Alabama:

Month	**Precipitation (cm)**		**Class A pan evaporation (cm)**	
	Farm	NWS	Farm	Normal
20-30 April	4.6	4.6	4.7	5.4
May	4.6	7.5	17.3	16.5
June	4.7	2.3	18.2	17.7
July	13.6	16.3	17.1	18.2
August	4.7	2.4	15.7	17.1
1- 13 September	17.7	10.8	5.9	6.3
Total	49.9	43.9	78.9	81.2

NWS: 2011, Demopolis Lock and Dam Station
NWS Normal: 1956-2002, Demopolis Lock and Dam Station

Table 3: Precipitation and class A pan evaporation data for the period 12 May – 10 September 2011 in pond N-12 at an inland shrimp farm in Alabama:

Month	**Precipitation (cm)**		**Class A pan evaporation (cm)**	
	Farm	NWS	Farm	Normal
12-31 May	3.7	5.6	17.3	11
June	3.8	2.3	18.2	17.7
July	13.6	16.3	17.1	18.2
August	6.2	2.4	15.7	17.1
1- 10 September	13.5	10.8	4.1	4.8
Total	40.8	37.4	72.4	68.8

NWS: 2011, Demopolis Lock and Dam Station
NWS Normal: 1956-2002, Demopolis Lock and Dam Station

Table 4: Water budgets for ponds N-10, N-11 and N-12:

Variable	**N-10**		**N-11**		**N-12**		**Mean volume ± S.D. (m^3/ha)**
	Depth(cm)	Volume(m^3)	Depth(cm)	Volume(m^3)	Depth(cm)	Volume(m^3)	
Inflows							
Well	137.8	22302.2	121.9	18653.4	113.4	21750.8	12436.5±1237.1
Precipitation	53.3	8621.4	49.9	7672.1	45.3	8681.8	4956± 403
Run-off	7.5	740.6	7	838.2	6.4	824.2	478± 62
Outflows							
Harvest effluent	111.1	17994.1	94.5	14466.8	94.9	18205.2	10021± 948
Evaporation	67.6	10938.5	63.9	9779.3	58.6	11249.1	6338± 449
Seepage	19.8	3205.1	20.3	3105.3	11.5	2205.9	1719.9±494.2
Overflow	0	0	0	0	0	0	0

Table 5: Amounts and concentrations of phosphorus and nitrogen (dry matter basis) of post larvae, feed and of shrimp for three ponds (N-10, N-11 and N-12):

Variable	**Dry matter (% wet weight)**	**Phosphorus (%)**	**Nitrogen (%)**	**N-10 (kg)**	**N-11 (kg)**	**N-12 (kg)**	**Mean ± S.D (kg/ha)**
Post larvae	25	1.29	10.9	3	3	4	2±0.1
Feed	91.4	1.388	6.16	6572	5616	6479	3703±342
Shrimp	29	1.244	10.89	3568	2339	1170	1448±800

Table 6: Days of stocking, amount of feed used, stock density, Feed conversion ratios and survival rate during production cycle:

	Days of stocking	**Feed (kg)**	**Stock density (post larvae/m^2)**	**FCR (Feed Conversion ratios)**	**Survival (%)**
N-10	155	6572.4	20	1.84	30.1
N-11	146	5615.9	21	2.40	18.9
N-12	128	6479.1	21	5.54	9.2

Table 7: Average concentrations (mg/L) and standard deviations for total phosphorus in rainfall, well water, and pond water in ponds N-10, N-11, and N-12 at an inland shrimp farm in Alabama:

Variable	**N-10**	**N-11**	**N-12**
Rainfall	0.018±0.01	0.018±0.01	0.018±0.01
Well water	0.032±0.034	0.032±0.034	0.032±0.034
Pond water			
Average for crop	0.281±0.310	0.252±0.149	0.285±0.318
At harvest	0.252	0.277	0.291

Table 8: Average concentrations (mg/L) and standard deviations for total nitrogen in rainfall, well water, and pond water in ponds N-10, N-11, and N-12 at an inland shrimp farm in Alabama:

Variable	**N-10**	**N-11**	**N-12**
Rainfall	0.649±0.362	0.649±0.362	0.649±0.362
Well water	0.49±0.088	0.49±0.088	0.49±0.088
Pond water			
Average for crop	0.427±0.235	0.519±0.338	0.421±0.257
At harvest	0.628	0.792	0.718

Table 9: Average concentrations (mg/L) and standard deviations for soluble reactive phosphorus (SRP) in rainfall, well water, and pond water in ponds N-10, N-11, and N-12 at an inland shrimp farm in Alabama:

Variable	**N-10**	**N-11**	**N-12**
Rainfall	0.011±0.006	0.011±0.006	0.011±0.006
Well water	0.019±0.019	0.019±0.019	0.019±0.019
Pond water			
Average for crop	0.051±0.061	0.06±0.063	0.06±0.061
At harvest	0.172	0.166	0.172

Table 10: Average concentrations (mg/L) and standard deviations for total ammonia nitrogen (TAN) in rainfall, well water, and pond water in ponds N-10, N-11, and N-12 at an inland shrimp farm in Alabama:

Variable	**N-10**	**N-11**	**N-12**
Rainfall	0.179±0.063	0.179±0.063	0.179±0.063
Well water	1.855±0.859	1.855±0.859	1.855±0.859
Pond water			
Average for crop	0.161±0.19	0.177±0.227	0.166±0.192
At harvest	0.382	0.329	0.542

Table 11: Average concentrations (mg/L) and standard deviations for nitrate nitrogen (NO_3) in rainfall, well water, and pond water in ponds N-10, N-11, and N-12 at an inland shrimp farm in Alabama:

Variable	**N-10**	**N-11**	**N-12**
Rainfall	0.394±0.381	0.394±0.381	0.394±0.381
Well water	0.343±0.187	0.343±0.187	0.343±0.187
Pond water			
Average for crop	0.468±0.35	0.488±0.321	0.506±0.368
At harvest	0.245	0.307	0.335

Table12: Phosphorus and nitrogen budgets for ponds N-10, N-11, and N-12 at an inland shrimp farm in Alabama

Variable	**N-10 (kg)**		**N-11 (kg)**		**N-12 (kg)**		**Mean ± S.D. (kg/ha)**	
	P	N	P	N	P	N	P	N
Inputs								
Post larvae	0.04	0.4	0.04	0.4	0.05	0.4	0.03±0.0008	0.2±0.03
Feed	83.4	370.1	71.2	316.2	82.2	364.8	47 ±4.4	208.5 ±19.3
Rainfall & Run-off	0.2	6.1	0.2	5.5	0.2	6.2	0.1 ± 0.01	3.5± 0.3
Well water	0.7	10.9	0.6	9.1	0.7	10.7	0.4±0.03	6.1±0.6
Sum	84.34	387.5	72.04	331.2	83.15	382.1	47.5±4.4	218±20
Outputs								
Seepage	0.9	1.4	0.8	1.3	0.6	0.9	0.5±0.1	0.7±0.2
Draining	4.5	11.3	4	11.5	5.3	13.1	2.7 ±0.1	7.1± 0.4
Shrimp harvest	12.9	112.7	8.4	73.9	4.2	36.9	5.2 ±2.9	45.7±29.3
Sum	18.3	125.4	13.2	86.7	10.1	50.9	8.4±3	53.6±25.6
Difference	66.04	262.1	58.84	244.5	73.05	331.2	39.1±1.5	164.8±6.9

Table 13: pH, total dissolved solids, salinity and water temperature:

	N-10	**N-11**	**N-12**
pH(surface)	8.7±0.5	8.9±0.6	8.6±0.4
pH(Bottom)	8.4±0.5	8.4±0.5	8.2±0.3
TDS (mg/l)	3883±363	3796±336	4602±370
Salinity	3.2±0.3	3.1±0.3	3.9±0.3
Conductivity (us/cm)	6280±1242	6130±1188	7523±1393
Temperature(°c) (surface)	33.4±0.5	33.7±0.4	33.1±0.7
Temperature(°c) (bottom)	31.6±1.3	31.7±1.4	31.5±1.2

All the water parameters were measured during 2:00p.m-3:00p.m.

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