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Environmental Contamination and Toxicology

Nitrogen Discharge from Aquacultural Ponds and the Possible Impacts on Aquatic Environment

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Modern pond aquaculture can be a profitable enterprise and has developed rapidly in China in recent decades (Zhu 2000; Zhang and Tan 1989). The total area of pond culture was 2,219,976 ha by 2000, mostly distributed along the middle and low Yangtse River Basin and the Zhujiang Delta. This development has brought environmental problems in its wake, especially in the Yangtse River Basin with both nitrogen and phosphorus eutrophication threatening the freshwater environment (Li and Xia 1997).

Nitrogen is clearly limiting upon the productivity of pond aquaculture, but the efficiency of utilisation by farmed organisms is also low (Gross and Boyd 2000; Wang 1996). Uneaten feed, fish excreta and other organic matterials decompose and release volatile N compounds into the water. A high content of TAN (total ammonia nitrogen = sum of NH_3 and $NH4^+$ in water) is harmful for some aquatic organisms such as fish and shrimp. Outflow from the ponds to a fresh water body may also export eutrophication (Boyd and Massaut 1999; Zhang 1999; Li and Xia 1997). The purpose of the present study was to examine N discharge from ponds under different feeding and management regimes to assess the impact upon nitrogen discharge to the aquatic environment, and to assess the efficiency and environmental impact of the systems.

MATERIALS AND METHODS

Nine ponds under three cultivation models were investigated between August 2001 and July 2002. Cultivated organisms were: 1. Mitten crab (*Eriocheir sinensis* (Milne-Edwards)) plus oriental river prawn (*Macrobrachium nipponense* (de Haan)); 2. West Coast white shrimp (*Litopenaeus vannamei* (Boone)) plus silver carp, *Hypophthalmichthys molitrix* (Val.) and bighead carp *Aristichthys nobilis* Rich.; 3. Oriental river prawn alone (*Macrobrachium nipponense).*

Ponds are located 50km north of Suzhou in low-lying swampy land of the Tai Lake

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region. They were constructed in former rice paddies with clay sides and bottoms. The ponds are above the level of surrounding agricultural drainage.

Each treatment (and species complement) had three replicate ponds. Ponds of model 1 covered 0.6 ha each, with water depth 0.8m~1.0m from October to April and 1.0m~1.5m in the other months. These were drained for drying in January or February of 2001 and 2002 and dried for one month. Water was pumped in and 6000 crabs (average weight 7.14g) plus 150,000 juvenile shrimp were stocked in March and May of 2001 respectively. Growth of freshwater macrophytes was encouraged in this treatment to imitate the preferred habitat of the crabs. Ponds of model 2 were each 0.5 ha in area with a water depth in the range 1.0~1.5m. These were drained for drying twice a year, in November/December and in May. The drying period in December was three to four weeks, in May, one week. Mature fish was stocked in December for a total of five months, and shrimp for six months. Stocking density in model 2 was 472,500 shrimp per ha and 7,500 kg mature fish per ha. In model 3 all ponds (1ha each) were dried in April for 30 days and in August for 5 days respectively, then filled with water. Shrimp juveniles were stocked at 525,000 per ha in May and mature shrimp at 90kg per ha in September. Ponds of models 2 and3 were machine-aerated from May to September. All ponds were sterilized with slaked lime (CaO) after use. Harvest and the management of the ponds were investigated for one year.

Pond water was sampled at 20cm depth monthly and water input and output of the ponds were sampled during water changing from Aug.2001 to July 2002. Two polythene tubes were installed in each pond bottom and seepage at 50cm in the sediment was sampled monthly. Water samples were digested in alkaline $K_2S_2O_8$ solution, and TN (total nitrogen) content was determined by UV spectrophotometer method (Gross and Boyd, 1998). Ammonium-N was determined by phenol and hypocloride alkalescency color metric method; and Nitrate-N was determined by UV spectrophotometer (Liu and Zhang1999). Total-N was also measured for feed, and harvested shrimp, fish and crab by the Kjeldahl method (Liu and Zhang1999). Monthly Evaporation was estimated using a 1m-diameter bucket set in each pond. Reduction in water level in the ponds, measured using a standard scale, distracted the estimated evaporation loss and gave an estimate of seepage loss.

RESULTS AND DISCUSSION

The ratios of TN in production at harvest and TN input in feed and fertilizer to the system were 0.18, 0.45 and 0.32 for models 1, 2 and 3 respectively. A much lower efficiency of N utilization and lower overall productivity is evident in Models 1 and 3 compared to Model 2. Shrimp alone, but more particularly, in combination with crab, appears to make less efficient use of resources than when fish are present.

Table 1. Average nitrogen balance (kg $ha^{-1} yr^{-1}$) ± standard error, for three Models of pond culture using combinations of shrimp, crab and carp.

Variable (+/- balance)	Model 1	Model 2	Model 3
Fertilizer and feeds (+)	224.48±13.59	260.13±6.41	177.18±5.09
Accumulation in harvest (-)	39.91±3.07	116.07±15.72	56.03±4.19
Drainage (-)	15.24±4.16b	92.68±39.70a	63.52±11.40a
Drainage (drying) %	95±4.99a	50.11±11.7b	77.63±19.27ab
Seepage (-)	19.74±0.99b	19.68±3.33b	27.72±1.02a
Ammonium N:TN ratio	0.23±0.16	0.17±0.08	0.26±0.04
Nitrate N:TN ratio	0.67±0.02	0.74±0.14	0.64±0.02

Letters appended to values indicate significance of differences for figures within a row at the 0.05 level, where the letters are different. No significant difference exists where the letters are the same.

Over the three treatments, water pumped out of the ponds contained 11.08~132.38kg ha^{-1}TN, averaging 71.73 kg ha^{-1} i.e. an average of 32.51% of the sum of N input from the feeds and fertilizers averaged over treatments (Table 1). The amount of N discharge from drainage far surpassed the loads (31.6 kg ha^{-1}per year on average) of nitrogen in drainage from agriculture rice fields nearby (Ma *et al.* 1997), but was lower than similar ponds where fish alone were cultivated (Wang 1998). Drainage losses were significantly different between treatments (Table 1) with highest losses in Model 2 and lowest losses in Model 1.In Model 1 ponds, freshwater macrophytes grew without interruption and fixed a substantial amount of nitrogen, appearing to reduce loss rates through improved water condition and the reduced need for water changes.

TN discharge in drainage for drying as a percentage of TN discharge for drying plus discharge through water changes (drainage (drying) %) was 95 ± 4.99a for model 1, but 50.11 ± 11.7b and 77.63 ± 19.27ab for models 2 and 3 respectively. Drainage for drying caused major TN discharge in drainage. A higher content of TN fixed (within macrophytes) in pond water and fewer water changes contributed to the high percentage in Model 1 compared to the other two. The variation of TN discharge in drainage was closely related to the frequency of drainage (table 2), which in turn was regulated by the peak TN contents of water (table 3). In Model 2 and 3, about double the frequency of drainage for drying created twice the TN losses compared to Model1. Increasing the frequency of drainage for drying was necessitated by management considerations but had the unfortunate consequence of

Table 2. Drainage for drying and for water change (cm $ha^{-1}yr^{-1}$).

Variable	Model1	Model2	Model3
Drainage for drying	93.3±11.6	193.5±21	225±16.3
Drainage for change	6.7±1.5	126.5±5.1	75±7

proportionately increasing nitrogen loss with consequence risk of environmental pollution

An outline of the changes in TN content of the pond water of the three models is given in Table 3. The range of TN content overall was 0.66~7.55 mg l^{-1}. However , the TN content of pond water in Model 1 was lower than that for the other two models, probably due,as previously hypothesized, to the assimilation of TN by aquatic macrophytes. TN content of water in ponds of Model 2 rose quickly in May 2002 and varied about the level of 3.00 mg l^{-1} until August i.e. for the duration of the main shrimp growing season. In ponds of model 3 TN content of water followed a similar trend from May to August, but from December to March results were more variable and high (2.12 ~5.6 mg l^{-1}TN) with the sum of volatile N i.e. ammonium-N and nitrate-N, being the major component (table 4). From May to August, the temperature and light intensity was high enough for maximal phytoplankton growth that was fixed in associated animal growth. Also during this period, a large amount of TN was probably released by mineralization from the sediment, which comprised mainly uneaten feed, faeces and dead organisms. An equilibrium existed between the formation of ammonium-N and nitrate-N from mineralization processes and their assimilation by phytoplankton (Ding. 2000). However, after the growing season, with the decrease of temperature, the biological assimilation of the inorganic N from sediments decreased i.e. from August to February. The sum of ammonium-N and nitrate-N was a high percentage of soluble TN in the water column for Model 1 and for Model 3. For Model 2, the ratios of the sum of ammonium-N and nitrate-N to TN were stable because of the continuing activity of the mature fish in this treatment and the high rates of excretion from these (table 4). Ratios of ammonium-N to TN increased significantly with time after fish stocking (relationship: $y = 0.0643x - 0.02$, $r=0.98$; where y = ratio of ammonium-N to TN, x = time after stocking in months). Fish excrete NH_3 through their gills. Ammonia reacts with water to form NH_4^+ and equilibrium is set up between NH_3 and NH^{4+} in water (Zhang et al.1989).

A high content of ammonium-N may be avoided by improved feeding efficiency, in particular by adjusting animal stocking density. For model 1 and model 3, high ratios of ammonium-N exist in January or December and last only a few months before the need for water exchange. To reduce nitrogen discharge through drainage, other measures should be taken to improve water conditions, which avoid the large export of nitrogen associated with this process. These include the use of healthy

Table 3. Monthly variation in average TN concentration ± standard error (mg l^{-1})of pond water under three models of management.

Month	Model 1	Model 2	Model 3
Aug.01	1.91±0.19c	3.49±0.61a	1.93±0.64bc
Sep.01	1.48±0.46	1.89±0.78	1.73±0.71
Oct.01	1.37±0.34	1.79±1.2	1.61±0.8
Nov.01	0.78±0.12	-	1.7±0.93
Dec.01	1.99±0.27b	-	5.44±1.6a
Jan.02	1.83±0.94c	2.07±0.43bc	4.31±0.56a
Feb.02	1.25±0.72b	1.88±0.34ab	2.69±0.57a
Mar.02	1.62±0.75b	2.24±0.29ab	2.76±0.58a
Apr.02	2.22±0.18	2.48±0.46	-
May.02	1.85±0.38b	4.14±1.17 a	4.07±2.56ab
Jun.02	1.95±0.56c	7.16±0.39a	4.47±0.55b
Jul.02	1.56±0.86	3.58±2.31	2.18±0.41

Letters appended to values indicate significance of differences for figures within a row at the 0.05 level, where the letters are different. No significant difference exists where the letters are the same.

juveniles, use of adequate pond sterilization and use of increased machine aeration (Boyd and Gross 1999; Boyd and Clay 1998). The frequency of drainage for pond drying is also a major factor in TN export, a reduction in the frequency of which would reduce the high TN output associated with the process.

Table 4. Ratios of the concentration of AN (ammonium N) and NN (nitrate N) to TN concentration in pond water on average.

Variable	Model1		Model2		Model3	
Month	AN/TN	NN/TN	AN/TN	NN/TN	AN/TN	NN/TN
Aug.01	0.02	0.39	0.16	0.41	0.02	0.53
Sep.01	0.13	0.49	0.13	0.47	0.16	0.64
Oct.01	0.22	0.55	0.13	0.49	0.14	0.57
Nov.01	0.21	0.71	-	-	0.16	0.28
Dec.01	0.36	0.44	-	-	0.26	0.50
Jan.02	0.17	0.49	0.03	0.39	0.42	0.50
Feb.02	0.13	0.71	0.13	0.42	0.30	0.49
Mar.02	0.15	0.50	0.17	0.39	0.21	0.36
Apr.02	0.14	0.27	0.25	0.28	Dry	Dry
May.02	0.17	0.27	0.27	0.15	0.14	0.18
Jun.02	0.10	0.25	0.38	0.19	0.26	0.23
Jul.02	0.05	0.27	0.19	0.45	0.12	0.43

The range of TN loading in seepage of all ponds was from 18.75kg $ha^{-1}yr^{-1}$ to 28.74 kg $ha^{-1}yr^{-1}$, which was above that reported for rice paddy in the vicinity (Ma *et* *al.* 1997). The sum of ammonium-N and nitrate-N output from the seepage was 90% of the total nitrogen output through seepage. Nitrate-N output by itself was 64%~74% of TN output (table 1).

High levels of seepage and the large amounts of TN present in seepage are two further factors affecting TN losses to ground water. A properly paddled clay bottom is essential in reducing seepage and in the fixation of ammonium-N. Site selection and sediment treating (Seo and Boyd. 2001) appear to be the key paths to reducing TN loss through seepage.

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