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Chemical Budgets in Intensive Carp Ponds

Lei Peng, Sung-Yong Oh and Jae-Yoon Jo*
Department of Aquaculture, Pukyong National University, Busan 608-737, Korea

Budgets for water, nitrogen, and chemical oxygen demand (COD) were determined in two 0.012 ha earthy-bottom ponds stocked with Israeli strain common carp at an initial stocking density of 20 fish/m^3. Total ammonia nitrogen (TAN) concentrations increased continuously but later decreased in pond A as a consequence of high nitrification. COD concentrations increased during the experimental period due to the accumulation of feed input. Nutrient budgets showed that feed represented 94-95% of nitrogen input and about 99% of organic matter input. Fish harvest accounted for 40% of nitrogen and organic matter input. Seepage and water exchange removed 15-17% of nitrogen input but only 1-2% of organic matter. Draining of the ponds removed 20-26% of input nitrogen, mostly in inorganic forms, but removed only minus organic matter. Fish and water column respiration accounted for 39% of organic matter input, and benthic respiration accounted for 7-12% of organic matter input. No significant change of nitrogen and organic matter in both pond bottoms were found during the three-month growth period. The unrecovered input nitrogen, about 6.3-13%, was lost through denitrification and ammonia volatilization. On a dry matter basis, fish growth removed 31% of total feed input and left 69% as metabolic wastes.

Key words: Nutrient budgets, Nitrogen, COD, Nitrification, Pond culture

Introduction

At present, the majority of aquaculture installations are land-based pond farms. Recently, intensive aquaculture systems, especially those with little or no water exchange, are becoming more popular due to the scarcity of water, land, and labor resources. In intensive aquaculture ponds, large amounts of feed, manure, and fertilizer are introduced into the ponds in order to obtain rapid fish growth. Fish harvest removes a minor percentage of the added nutrients, about 22-26% of nitrogen, 30-57% of phosphorus, and 14-26% of organic matter was recovered in fish (Green and Boyd, 1995). As a result, many nutrients are accumulated in the fish culture ponds. Nutrients not removed by fish harvest are remained in the pond water and sediment, or lost from the system via respiration, nitrification, ammonia volatilization, and/ or water exchange.

Information on the fate of the added nutrients is essential for the assessment of the food utilization, pond fertility, water quality and processes in the sediment (Avnimelech and Lacher, 1979). Also, they are useful for qualifying environmental impacts of aquaculture and for environmental management (Teichert-Coddington et al., 2000). Chemical budgets have been estimated for freshwater ponds (Avnimelech and Lacher, 1979; Boyd, 1985a; Daniels and Boyd, 1989; Foy and Rosell, 1991a, b) and brackish-water ponds (Krom et al., 1985; Schroeder, 1987; Krom and Neori, 1989; Teichert-Coddington et al., 2000; Thoman et al., 2001). All these budgets were made for extensive or semi-intensive aquaculture. In present experiment, a chemical budget of nitrogen and organic matter has been developed in intensive aquaculture ponds.

The factors influencing water quality change in aquaculture ponds have been studied by many authors (Ram et al., 1982; Rimon and Shilo, 1982; Shilo and Rimon, 1982; Diab et al., 1992; Tucker and van der Ploeg, 1993; Seok et al., 1995) from different points of view. Monitoring the water quality in ponds will provide useful information for application of intensive aquaculture.

The purpose of the present study is to illustrate the water quality changes, to assess the fate of nitrogen and organic matter entering the intensive aquaculture

*Corresponding author: jyjo@pknu.ac.kr

ponds, and to describe the relative importance of the different resources over a three-month growth period.

Materials and Methods

Experiment design and procedure

This study was conducted at the Fish Culture Station of Pukyong National University, Busan, Korea. Two rectangular earthen ponds with concrete walls located in a greenhouse were selected for this experiment. The mean area, water depth and water volume were 120 m^2, 0.85 m and 100 m^3, respectively. These two ponds were drained and left dried for 20 days and then refilled by ground water. On August 8th, 2000 Israeli strain common carp fingerlings with an average weight of 6.3 g were stocked into each pond. Fish were fed 4-5 times a day and 7 days a week at satiation level. Commercial floating feed containing 41% protein was used in the first 4 weeks and feed with 39% protein content was used in the next 9 weeks. Feeding ring (1 m^2) was used in each pond to hold the floating feed. Cares have been taken to ensure the full consumption of feed by fish. Any dead fish, if found, were taken out, weighed and recorded during the experimental period. All the fish were harvested, counted and weighed on November 9th, 2000.

A 0.4-kw submerged pump is used to circulate water and then spray the water into the air and thus serving as aerator. Circulation rate is about 2.5 times the whole pond water volume per day. A 0.9-hp paddle wheel aerator was put into each pond for emergency use.

Sample and analysis

Water

Water samples were collected every day between 0900h to 1000h with a 5-cm-diameter water column sampler (Boyd and Tucker, 1992). Total ammonia nitrogen (TAN), nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), organic nitrogen, chemical oxygen demand (COD) were analyzed according to standard protocol recommended by APHA (Eaton et al., 1995). Dissolved oxygen (DO) and temperature were measured with a Yellow Spring polarographic DO meter everyday at 0900 and 1700.

Gross photosynthesis in the ponds was measured by the light-dark bottle oxygen technique once every two weeks (Boyd and Tucker, 1992). The decrease in DO concentrations in the dark bottle represented the water column respiration (WCR). Respiration rate was considered to be constant during a 24-hour period. Integration of the areas beneath the gross photosynthesis and WCR curves gave the corresponding values per unit area for the growth period (Boyd, 1985a).

Soil, fish and feed

The upper 10-cm soil samples were collected from six sites per pond prior to filling with water and just after draining. Soil samples in each pond were pooled together for analysis. Available free ammonia and total available ammonia were analyzed according to Acosta-Nassar et al. (1994). Dried samples were pulverized to pass through 425-μm screen. The filtrates were analyzed for total nitrogen (Beveridge et al., 1994) and organic matter (Boyd and Tucker, 1992).

Six fish were taken as sample before stocking and after harvest. Feed and fish samples were freeze-dried and pulverized to pass through a 0.85-mm screen. Their moisture and total nitrogen contents were measured according to standard method (AOAC, 1995). Chemical oxygen demand was estimated by potassium dichromate digestion method as described by Boyd (1973).

Water budget

A class-A evaporation pan was put beside pond to measure pan evaporation. A pan coefficient of 0.8 was assumed (Boyd, 1985b). Since the experiment ponds are located in greenhouse, there was no precipitation or runoff. Overflow was avoided at any time except during an emergency water exchange in pond A, thus the makeup water equals to the sum of water seepage and evaporation (Nath and Bolte, 1998).

Chemical budget

To calculate the chemical budgets of nitrogen and organic matter, inputs to the ponds including fish stock, supplied in water and feed, outputs from the ponds including fish growth, water seepage, water exchange, and uptake by the mud were considered. Measured quantities of water, fish, feed, and soil were multiplied by their respective concentrations of chemical substances to compute amounts of substances added to or removed from ponds. Since direct measurement of nutrients in seepage water was impossible, the nutrient contents in seepage water were assumed to be the same as those of the pond water (Boyd, 1985a).

Results and Discussion

Changes of water quality

The mean water temperature within the first, second, and third month were 30.2℃, 29.3℃, and 26.2℃, respectively. Concentrations of dissolved oxygen in the pond water were maintained above 3 mg/L. Secchi disk visibility showed that the turbidity was higher in pond A than in pond B (Fig. 1). Sediment was deposited more in the pump chamber in Pond B than in the pump chamber in Pond A, and this may have partially contributed to this difference. pH fluctuated within 7.7-8.0 during the experimental period. Later, pH decreased in pond A because of partial water exchange and high-rate nitrification.

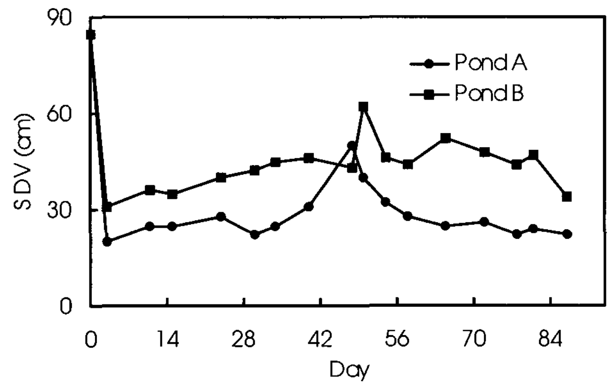

Fig. 1. Secchi disk visibility (SDV) measured on sunny day in Pond A and Pond B during experimental period.

Ponds receiving appreciable inputs of nutrients usually have abundant plankton, and the primary production was higher in the more intensive ponds than that in less intensive ponds (Zur, 1981). However, in the present study, the average values were only 37.3 mg C/m^2/day in pond A and 47 mg C/m^2/day in pond B (Fig. 2.). In freshwater ponds, primary production was reported to range from 0.3-8.5 g C/m^2/day (Hepher, 1962; Nuriega-Curtis, 1979; Zur, 1981; Green and Boyd, 1995). Primary production in the present study was less than 1% of the commonly reported values. Nutrient was not the limiting factor inhibiting phytoplankton bloom in present experimental ponds. The ponds were shaded with black net for reducing the temperature. The reduced light intensity should be the main limiting factor since phytoplankton is more sensitive to light intensity (Boyd, 1990). The high turbidity induced by water circulation and stirring-up of muddy bottom sediment

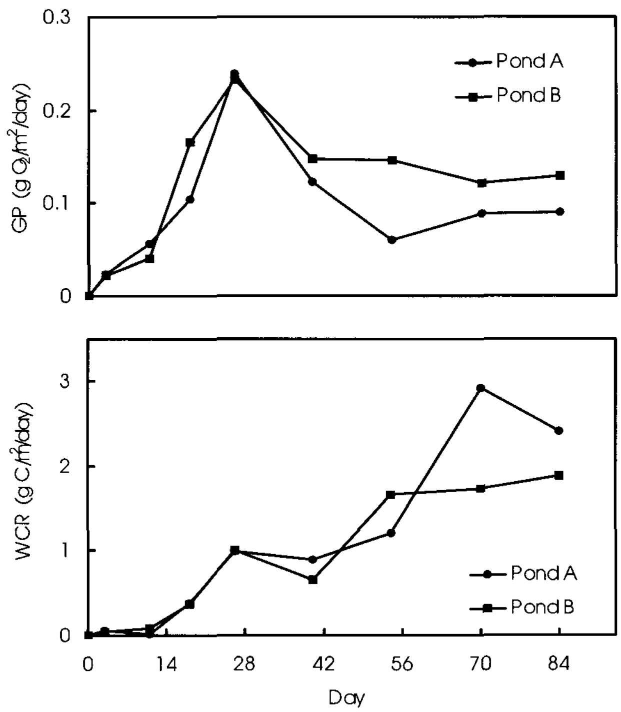

Fig. 2. Change of gross photosynthesis (GP, upper) and water column respiration (WCR, lower) in Pond A and Pond B during experimental period.

by fish also could limit primary production as reported by Thomforde and Boyd (1991) and Ludwing (1996).

Water column respiration (WCR) gradually increased in the present experiment ponds (Fig. 2). The average water column respiration rates were 0.94 g C/m^2/day in pond A and 0.75 g C/m^2/day in pond B. Zur (1981) reported that the average water respiration rates in the fed fish ponds of 7000, 10000, and 20000 carp/ha were 2.56, 3.51, and 3.44 g C/m^2/day, respectively. Average daily respiration in channel catfish ponds was 2.73 g C/m^2 (Boyd, 1985a). Mean WCR was 2.61 g C/m^2/day in manured and fed fish ponds (Schroeder, 1975), and 2.43 g C/m^2/day in Hawaiian prawn ponds (Madenjian et al., 1987). In all these researches cited above, plankton respiration contributed heavily to the water column respiration. The WCR valuesand phytoplankton densities in the present study were much lower than other values cited. However, water column respiration in the present study mainly constituted of bacterial respiration rather than phytoplankton.

The mean TAN, NO_2-N, and NO_3-N concentrations in the make-up water were 0.01, 0.003, and 2 mg/L, respectively. Changes of the TAN, NO_2-N and NO_3-N concentrations in the pond water were shown in Fig.

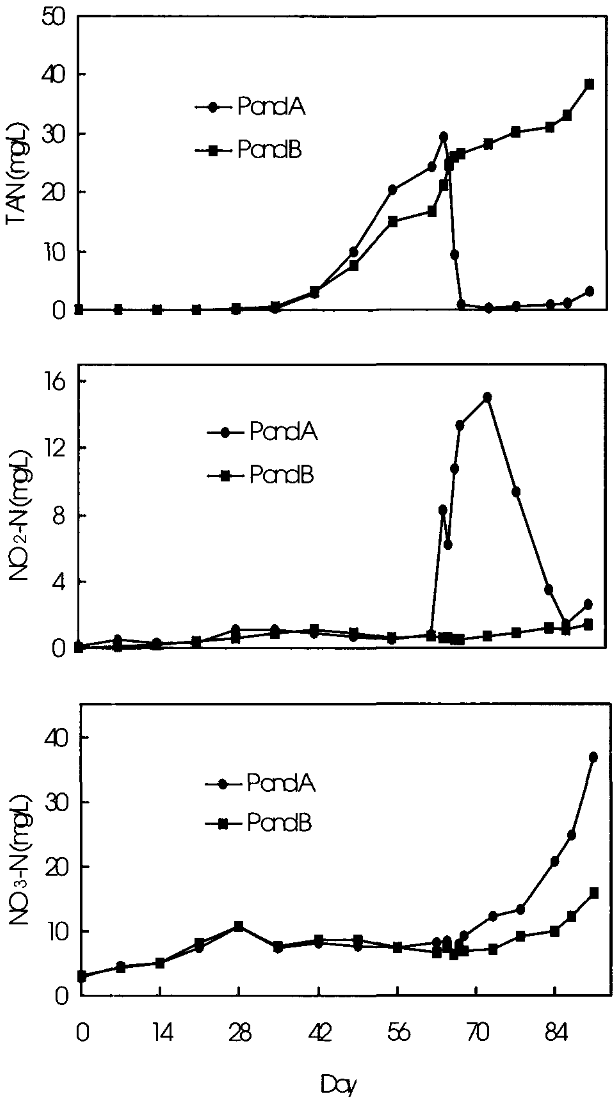

Fig. 3. Change of concentrations of TAN (upper), NO_2-N (middle), and NO_3-N (lower) in experiment pond waters during the experimental period.

3. TAN concentrations were low in the first 30 days and steadily increased in the second 30 days. The trends of the TAN changes were same within the first two months. At the end of the experiment, TAN concentration reached 42 mg/L in Pond B but suddenly decreased to around 2 mg/L in pond A as a consequence of the high nitrification occurred in this pond. NO_2-N and NO_3-N concentrations were stable within the first two months except increases after filling the ponds. However, NO_3-N concentration rose to 38 mg/L in pond A at the end of the experiment. Organic nitrogen concentrations fluctuated within 0.8 to 1.65 mg/L during the experimental period.

High nitrification rate occurred in pond A was unexpected but reasonable. High water temperature and TAN concentrations are favorable for nitrification. At that time, DO was above 3 mg/L which was also not a limiting factor for nitrification (Wheaton et al., 1994). The most important reason is that high concentration of the suspended and dissolved particles as indicated by high turbidity provided surface for nitrifiers to attach on. The combination of these favorable conditions should have resulted in the peak nitrification.

Also, acclimation to the local environment by bacteria may have played some important role in controlling high nitrification rate. In a mesocosm experiment, Cline et al. (1994) observed that sediment resuspension by common carp increased nitrite and nitrate concentrations in the overlying water. Hargreaves and Tucker (1996) already demonstrated that periodic suspension of sediment associated nitrifying bacteria by water currents produced by aeration device and by the activities of fish might expose these bacteria to favorable conditions and result in a high nitrification in the water column. In Pond A, water column nitrification should have contributed significantly to the high nitrification rate. This can be roughly evaluated from the high BOD_5 values measured during the high nitrification period. However, further understanding of the relative contribution of water column and sediment nitrification to the production of nitrite and nitrate in the water column is required as suggested by Hargreaves (1997).

Concentrations of toxic, unionized ammonia (NH_3-N) were calculated according to Emerson et al. (1975). Sub-lethal ammonia and nitrite levels may reduce growth, damage gills and other organs, and may be a predisposing factor in several diseases (Colt and Armstrong, 1981; Meade, 1985; Lewis and Morris, 1986). Flis (1968) reported 16-18% mortality of common carp (125-260 g) at an NH_3-N concentration of 0.71-0.98 mg/L. In present study, the NH_3-N concentrations steadily rose to sub-lethal concentrations (1.36 mg/L). High levels of NO_2-N concentrations (15 mg/L) also were encountered. However, no high fish mortality was found here. Acclimation from low to high levels of ammonia should have increased the resistance of fish to lethal levels since ammonia is a noncumulative poison (Hasan and Macintosh, 1986). High rate of water exchange and high DO level also prevent the high fish mortality due to the sudden increase of NO_2-N concentrations. So, at present periodical checking of TAN, NO_2-N, NO_3-N, and DO concentrations in intensive aquaculture ponds and careful observation, at least on a daily basis, is required. Also, a predictable database and control system is needed.

Chemical oxygen demand and BOD_5 increased during the experimental period. Concentrations of COD and BOD_5 were higher in Pond A than in Pond B throughout the experimental period (Fig. 4). This was due to the high turbidity in Pond A. The BOD_5 values were close to the COD values in Pond A waters. However, it is not unreasonable in that the high BOD_5 values were coincidence with the high rate of nitrification in that pond. The high nitrification contributed to the higher BOD_5 in this pond. Boyd and Gross (1999) already demonstrated that an averaged 37.5% of the BOD_5 was contributed from nitrogenous BOD_5 in channel catfish ponds. This means nitrification contributed heavily to BOD_5. A new or modified method for BOD measurement in aquaculture should be developed as suggested by Boyd and Gross (1999).

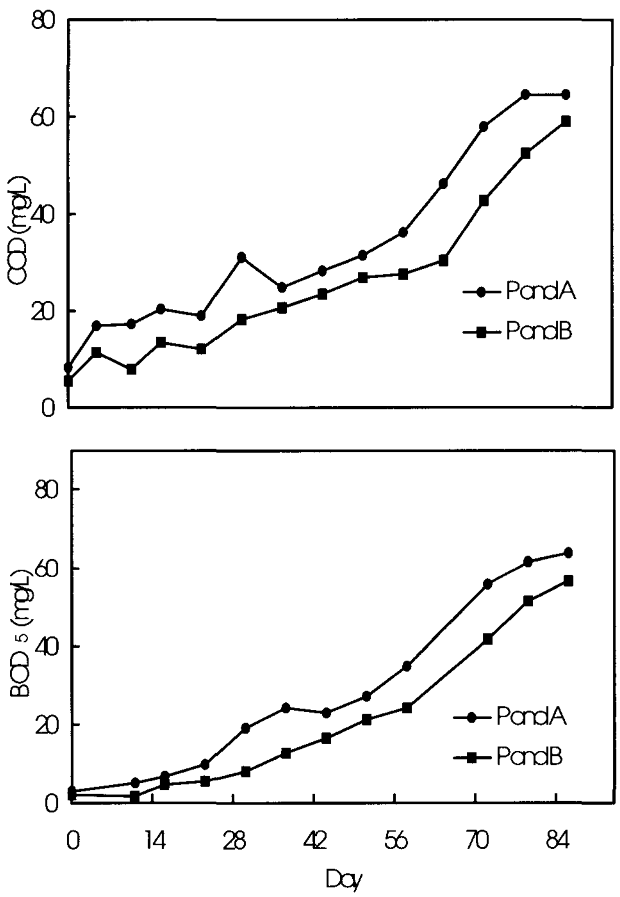

Fig. 4. Change of concentrations of COD (upper) and BOD_5 (lower) in Pond A and Pond B during experimental period.

Feeding and fish growth

Feed input, fish growth, and mortality were summarized in Table 1. The averaged daily feeding rate was 390 kg/ha. Mortality was 3.1% (63 fish) in Pond A and 2.3% (45 fish) in Pond B. The recorded numbers of dead fish were only 4 in Pond A and 6 in Pond B. The lost fish that were not recorded seemed to be eaten by birds or unknown predators. So the unrecorded fish mortality was assumed to distribute evenly within the experimental period. Over a 3-month growth period, the averaged weight gain was 190.3 g in both ponds. The overall daily growth rate was 2.1 g/day/fish, and the overall feed conversion rate (FCR) was 1.05 in both ponds. High water temperature, good feeding strategy contributed to the high fish growth rate.

On a dry matter basis, small fish contained more nitrogen but less organic matter than large fish at harvest (Table 2).

Bottom soil

There were no significant change of nitrogen and organic matter in the pond bottom through the 3-month growth period (Table 3). Total ammonia nitrogen in the pond bottom soil increased about 4-5 times at the end of the experiment and most ammonia was particle bound but not free ammonia (Table 4). The ammonia level in the pond bottom was lower than that in the water column. This possibly indicated the saturation of the cation exchange capacity of the sediment clays (Mikkelsen, 1987).

Water budget

Total makeup water supplied was 174.3 m^3 in Pond A and 174.6 m^3 in Pond B. Water was partially exchanged on day 65 in Pond A for reducing the high nitrite level. Evaporation was assumed to be same in these two ponds since they are adjacent ponds. The water loss via seepage was 96.8 m^3 in Pond A and 163.1 m^3 in Pond B (Table 5). Seepage was much greater than evaporation in both ponds. The high relative humidity and low wind speed in the green house should have resulted in the low evaporation in the present experiment ponds compared with other values reported (Boyd, 1985b).

Nitrogen and organic matter budgets

Table 1. Summary of fish growth, survival, and feed applied in Pond A and Pond B.

Date	Average weight (g)		Feed input (kg)		Mortality (fish)	
	Pond A	Pond B	Pond A	Pond B	Pond A	Pond B
Initial	6.3	6.3				
1-4th week	26.2	26.8	35.1	34.9	1	3
5-8th week	86.4	86.2	104.6	104.7	3	3
9-13th week	197.3	196.5	210.8	213.6	1	0
Total			350.6	353.2	63	45

Table 2. Compositions of fish and feed (M±SE).

Variables	Feed	Fish	
		Initial	Final
Dry matter (%)	92.75±0.1	22.04±0.4	28.91±0.9
Nitrogen (% of dry matter)	6.24±0.1	10.00±0.1	8.27±0.1
Chemical oxygen demand (kg/kg dry matter)	1.22±0.0	1.38±0.0	1.58±0.1

Table 3. Average percentages of nitrogen and organic matter compositions and standard errors for mud samples collected from bottom of Pond A and Pond B at initial (August, 8) and final (November, 9). Values are percentage of oven-dried weight.

Item		August 8	November 9
Nitrogen			
	Pond A	0.117±0.013	0.123±0.003
	Pond B	0.129±0.003	0.128±0.005
Organic matter			
	Pond A	3.401±0.023	3.511±0.026
	Pond B	3.617±0.016	3.443±0.057

Table 4. Available and total ammonia in the pond bottom soil at initial (August 8) and final (November 9) of experimental period. Values are in mg N/kg wet soil.

Date	Pond A	Pond B	Pond A	Pond B
August 8	ND[1]	ND[1]	4.6	0.6
November 9	7.3	6.3	33.5	25.7

[1]ND, not detectable.

Table 5. Water budgets for Pond A and Pond B.

	Evaporation		Makeup water		Water seepage	
	Pan (cm)	Pond (cm)	Pond A (m^3)	Pond B (m^3)	Pond A (m^3)	Pond B (m^3)
Day 1-28	4.7	3.8	47.3	69.2	43.5	65.4
Day 29-56	4.6	3.7	30.5	47.1	26.8	43.4
Day 57-93	5.0	4.0	30.5	58.3	26.5	54.3
Subtotal	14.3	11.5	108.3	174.6	96.8	163.1
Water exchange			66.0			
Total	14.3	11.5	174.3	174.6	96.8	163.1

Feed application and fish harvest represented the major gain and loss of nitrogen in these two ponds (Table 6). Feed input contributed about 90% of total nitrogen entering ponds. Fish growth accounted for approximately 40% of the total nitrogen input. This value is higher than those reported (Avnimelech and Lacher, 1979; Boyd, 1985a; Krom et al., 1985; Acosta-Nassar et al., 1994). Nitrogen fixation can be an important source of nitrogen in aquaculture ponds, but usually there is an inverse relationship between nitrogen fixation rate and inorganic nitrogen concentrations (Horne and Goldman, 1972). Nitrogen fixation is associated with blue-green algae (El Samra and Olah, 1979; Howarth et al., 1988; Boyd, 1990). Based on the extremely low photosynthesis and high inorganic nitrogen concentrations in our ponds, nitrogen fixation is negligible in nitrogen budgets and assumed to be zero here. Makeup water and initial filling added minor nitrogen into both ponds. Water exchange and seepage removed 15-17% of total nitrogen input. Another high loss of nitrogen is through draining, about 20-26% of total nitrogen input, mostly in inorganic nitrogen form, would loss through this way. Total available ammonia in the bottom soil was approximately 1.7-2.0% of the total nitrogen input. These values are higher than those reported by Diab and Shilo (1986).

The discrepancy of nitrogen input and output should be lost through denitrification and ammonia volatilization (Boyd, 1985a). Ammonia volatilization has been reported from waters with high TAN concentrations under conditions of high pH (Weiler, 1979; Murphy and Brownlee, 1981). Ammonia volatilization should be low considering the low ammonia nitrogen concentration in present experiment ponds. Denitrification is a significant sink for nitrogen in anaerobic lake sediments provided adequate substrate, nitrite and nitrate (Andersen et al., 1984). Even though the nitrification rates were not significant in these two ponds during the first 60 days, the nitrification may have been processed and converted ammonia to nitrite and nitrate, which may have been imme-

Table 6. Gains (input) and their proportions (%) of nitrogen and organic matter (COD) in experiment Pond A and Pond B.

	Nitrogen				Organic matter (COD)			
	Pond A		Pond B		Pond A		Pond B	
	kg	%	kg	%	kg	%	kg	%
Feed	22.98	94.9	22,15	94.0	427.7	98.9	430.9	98.8
Fish stock	0.28	1.2	0.28	1.2	3.88	0.9	3.83	0.9
Initial filling	0.41	1.8	0.41	1.7	0		0	
Makeup water	0.48	2.1	0.72	3.1	0		0	
Photosynthesis					0.95	0.2	1.34	0.3
Fixation	0		0					
Total	23.15	100	23.6	100.0	432.53	100.0	436.1	100.0

Table 7. Losses (output) and their proportions (%) of nitrogen and organic matter (COD) in experiment Pond A and Pond B.

	Nitrogen				Organic matter (COD)			
	Pond A		Pond B		Pond A		Pond B	
	kg	%	kg	%	kg	%	kg	%
Fish harvest	9.14	39.5	9.39	39.9	174.5	40.3	175.4	40.2
Seepage	1.95	8.4	3.58	15.2	3.6	0.8	4.6	.0
Water exchange	2.26	9.8	0	0	3.6	0.8	0	
Draining	4.62	20.0	6.11	25.9	5.4	1.3	5.9	1.3
WCR					32.3	7.5	24.3	5.6
Benthic respiration					?		?	
Fish respiration					141.3	32.7	141.3	32.4
Uptake by mud								
Pump chamber	0.82	3.5	2.51	11.0	20.6	4.8	54.8	12.6
Adsorbed ammonia	0.46	2.0	0.40	1.7				
Organic nitrogen	0.95	4.1						
Volatilization & denitrification	?		?					
Total	20.2	87.3	22.0	93.7	381.3	88.2	406.2	93.1
Unaccounted	2.95	12.7	1.57	6.3	51.2	11.8	29.9	6.9

diately used by denitrification occurring in the pond bottom. Denitrification accounted for only 6-13% of total nitrogen input in our budgets. This result made a remarkable contrasts with those reported that substantial nitrogen sink was via denitrification (Boyd, 1985a; Daniels and Boyd, 1989) and coincident with the observation of Kaspar et al. (1988) and Acosta-Nassar et al. (1994). In a simulated intensive pond system, Avnimelech et al. (1992) found mixing and aeration, to a large extent, inhibited denitrification. Aeration and circulation, which increased oxygen level in the pond bottom and water column, also should be the main factor depressing denitrification in present experiment ponds.

Feed input also represented most organic matter input into ponds and about 99% were via feed input (Table 7). Ground water containing almost no organic matter was used as flooding and makeup water, so organic matter input via inflow water was assumed to be zero. Contribution of primary production was only about 0.2-0.3% of total organic matter input. In channel catfish fish ponds with high phytoplankton biomass, Boyd (1985a) reported that photosynthesis accounted for 62% of total organic matter input and a corresponding high water column respiration rate. Phytoplankton growth was reduced by the shading net above the ponds, and primary production was also reduced.

Fish harvest accounted for most of the organic matter sink, about 40% of the total organic matter input. Fish respiration was calculated using the equation $Y=10^{-3}W^{-0.82}$ where Y is the fish respiration in g O_2/h and W is the fish weight in g (Schroeder, 1975). Another 32% of total organic matter input was lost through fish respiration. Water column respiration (WCR) only accounted for 5-7% of total organic matter input. Organic matter retained in the biofilter chambers was about 5-13% of total input.

Benthic respiration was not measured in this experiment. Mean benthic respiration in manured carp ponds was reported to range from 1 to 3 g C/m^2/day (Schroeder, 1975). Mean daily benthic respiration was 0.92 and 1.57 g C/m^2 in ponds stocked with 7000 and 20000 carp/ha, respectively (Shapiro and Zur, 1981). In the intensively managed carp and tilapia production ponds in Israel, an averaged benthic respiration rate was 1.3 g C/m^2/day (Zur, 1981). If all the unaccounted organic matter was lost through benthic respiration, the corresponding value should be 1.05 g C/m^2/day in Pond B and 1.81 g C/m^2/day in pond A These values are well within the range of the values cited above.

On a dry matter basis, fish growth removed about 31% of total feed input, which means that 69% of total feed input entering the ponds was left as metabolic waste.

In conclusion, feed and cultured species are the many factors affecting the nitrogen and organic matter in ponds with low primary production. High nitrification rate in intensive aquaculture ponds were mainly associated with the high turbidity. This would be very useful for culture of some fish species such as tilapia, carp that can endure high turbidity. Further detailed research would be required for evaluation the in situ nitrification in aquaculture ponds. Periodical checking of TAN, NO_2-N, and DO concentrations in intensive aquaculture ponds and careful observation, at least on a daily basis, would be required at present. Also, developing predictable database and controlling system is needed.

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