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Management of Organic Matter and Nutrient Regeneration in Pond Bottoms

Eighth Work Plan, Thailand Research 2 (TR2)
Final Report

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Abstract

This report presents the results of two experiments, which were conducted in 12 earthen ponds at the Asian Institute of Technology, Thailand, from November 1997 through April 1998. The first experiment was conducted for 149 days to assess the effect of aerobic and anaerobic conditions of pond bottoms on organic matter decomposition and nutrient release and the effectiveness of common carp in removing organic matter from pond sediments and recycling nutrients for tilapia ponds. The experiment consisted of four treatments: (A) tilapia monoculture with water mixing; (B) tilapia monoculture without water mixing; (C) tilapia/carp polyculture with water mixing; and (D) tilapia/carp polyculture without water mixing. Sex-reversed male Nile tilapia were stocked at 2 fish m^{-2} at a size of 8 to 12 g in all ponds, and common carp fingerlings were stocked at 0.3 fish m^{-2} at a size of 13 to 17 g. All ponds were fertilized with chicken manure at the rate 1000 kg ha^{-1} wk^{-1} (dry matter basis) to create anaerobic pond bottoms. Aerobic pond bottoms in treatments A and C were created by fixing a submersible pump (0.5 kW) 30 cm above the bottom of each pond to mix surface and bottom water. The second experiment was conducted for 30 days in the same ponds used for experiment 1 to assess physical and chemical conditions during microbial decomposition of organic matter and the resultant nutrient release during pond drying. Six of the 12 ponds were refilled immediately after fish harvest and soil sampling, while the other six ponds were dried over a period of one month and then refilled. The polyculture of common carp and Nile tilapia was effective in recycling nutrients and might be effective in removal of organic matter if more common carp are added. Water mixing in the experiments caused greatly reduced phytoplankton growth in both mono- and polyculture ponds. Water mixing did not affect the growth of Nile tilapia in monoculture ponds, but significantly ($P < 0.05$) reduced the growth of both Nile tilapia and common carp in polyculture ponds. Results also showed that pond drying did not result in significant microbial decomposition of organic matter.

Introduction

Accumulation of organic matter in pond soils during the grow-out cycle causes severe oxygen depletion at the sediment-water interface (Boyd, 1990). A small amount of organic matter in pond soils is beneficial. However, too much organic matter in pond soils can be detrimental because microbial decomposition can lead to the development of anaerobic conditions at the sediment-water interface, under which organic compounds are often decomposed to reduced substances such as NO_2, H_2S, NH_3, and CH_4, which are toxic to fish at relatively low concentrations (Boyd and Bowman, 1997). It is of primary importance to prevent such situations in fish ponds. Two methods commonly practiced by fish farmers are: 1) polyculture with detritivorous fish (Lin, 1982) and 2) pond drying between cycles of production (Boyd, 1990). Detritivores consume organic matter, but also disturb bottom sediment while feeding, which may increase turbidity and reduce water quality (Pillay, 1992). The drying process enhances oxidation of organic material as well as nutrient regeneration in pond soils, and also allows photo-oxidation and microbial decomposition of organic matter (Fast, 1986). All of these processes should enhance nutrient recycling in ponds.

Polyculture and pond drying are commonly practiced throughout Asia to mitigate the accumulation of organic matter on pond bottoms, but there are very few systematic studies carried out on these management practices. This study was conducted to understand the link between bottom soil characteristics and management techniques and the effect of polyculture and pond drying on organic matter accumulation. The study objectives were to assess:

1) The effect of aerobic and anaerobic conditions at the pond bottom on organic matter decomposition and nutrient release;
2) The effectiveness of common carp in removing organic matter from pond sediments and in recycling nutrients for tilapia ponds; and
3) The physical and chemical conditions during microbial decomposition of organic matter and the resultant nutrient release during pond drying.

Methods and Materials

Two experiments were conducted at the Asian Institute of Technology, Thailand. The first experiment involved culture of

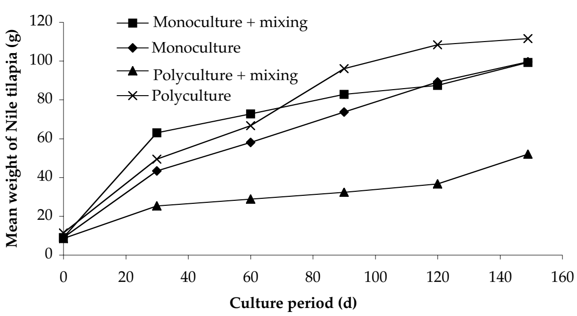
Nile tilapia (*Oreochromis niloticus*) and common carp (*Cyprinus carpio*) and tested four management strategies. The ponds after harvest were used to study the bottom soil characteristics in the second experiment.

Experiment 1: Culture of Nile Tilapia and Common Carp

The experiment was conducted in a 2x2 factorial design in 12 ponds. The ponds were divided randomly into four treatments, with triplicate ponds for each treatment. The treatment combinations were aerobic or anaerobic pond bottoms and monoculture of Nile tilapia or polyculture of Nile tilapia and common carp. Thus, the treatments were: (A) tilapia monoculture with water mixing; (B) tilapia monoculture without water mixing; (C) tilapia/carp polyculture with water mixing; and (D) tilapia/carp polyculture without water mixing.

Sex-reversed male Nile tilapia were stocked at 2 fish m^{-2} at a size of 8 to 12 g in all ponds, while common carp fingerlings were stocked at 0.3 fish m^{-2} at a size of 13 to 17 g on 4 November 1997. The water depth in all ponds was maintained at 1 m throughout the experiment. All ponds were fertilized with chicken manure at the rate 1000 kg ha^{-1} wk^{-1} (dry matter basis) to create anaerobic bottoms. Aerobic pond bottoms in treatments A and C were created by fixing a submersible pump (0.5 kW) 30 cm above the bottom of each pond to mix surface and bottom water. The pumps were modified to suck air above the water surface and release it along with the water jet. A 5x2-m polythene sheet was fixed on the pond bottom below each pump to prevent bottom disturbance by the water jet.

For analyses of most water quality parameters, combined water samples encompassing the entire water column were taken from walkways extending to the center of the ponds.



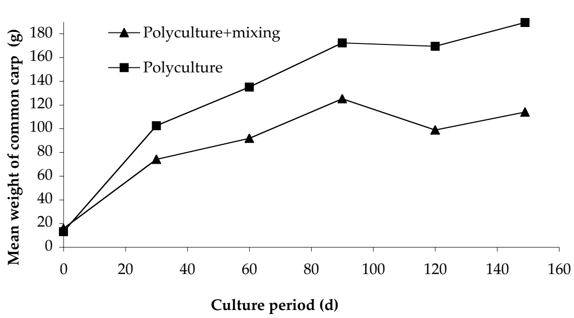


Figure 1. Changes in mean weight of Nile tilapia and common carp during experiment 1.

Pond water analyses including temperature, dissolved oxygen (DO), pH, Secchi disk depth, alkalinity, total ammonium nitrogen (TAN), nitrite nitrogen, nitrate-nitrite nitrogen, total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll *a*, total suspended solids (TSS), and total volatile solids (TVS) were conducted biweekly at 0900 h using standard methods (APHA, 1980; Egna et al., 1987). Monthly diel measurements for temperature, DO, and pH were determined in each pond at 0600, 0900, 1400, 1600, 1800, 2300, and 0600 h, and those for alkalinity and TAN were determined at 0900, 1600, and 0600 h.

Bottom soil samples from nine different locations in each pond were collected, air-dried, and thoroughly mixed one day prior to stocking and harvest. A representative subsample was taken from each homogenized sample for analyses of moisture, total nitrogen, total phosphorus, and organic matter.

During the experiment about 40 fish were seined from each pond and weighed monthly. All ponds were harvested on 2 April 1998 after a 149-day culture period. Final biomass and numbers were determined. Daily weight gain (g d^{-1}), net yield (kg $pond^{-1}$) and extrapolated net yield (kg ha^{-1} yr^{-1}) were calculated.

Experiment 2: Pond Drying

All 12 ponds from the previous experiment were used. Soil samples were taken immediately after draining from nine locations in each pond for the analyses of nitrogen, phosphorus, organic matter, moisture, and pH.

Six of the 12 ponds (Ponds #1, 3, 5, 7, 9, and 11) were refilled immediately after soil sampling. The water samples from the source and pond water were taken at the beginning and end of the experiment to determine dissolved inorganic nitrogen (DIN), TKN, SRP, and TP.

The other six ponds (Ponds #2, 4, 6, 8, 10, and 12) were dried over a period of one month. Soil samples from nine locations in each of the dried ponds were taken weekly to analyze moisture, organic carbon, temperature, and pH. After one month, the dried ponds were refilled, and water samples were taken from the source and pond water for analyses of DIN, TKN, SRP, and TP.

Data from both experiments were analyzed statistically by analysis of variance (ANOVA) using the SPSS 7.0 statistical software package. Differences were considered significant at an alpha level of 0.05. All means were given with ± one standard error (SE).

RESULTS

Experiment 1

Growth of Nile tilapia and common carp differed at the first sampling among all treatments (Figure 1; Table 1). Overall growth rate of Nile tilapia in the treatment of polyculture with water mixing was significantly lower ($P < 0.05$) than in the other three treatments. Survival of Nile tilapia in the two treatments without water mixing was significantly ($P < 0.05$) higher than in the two treatments with water mixing. There were no significant differences ($P > 0.05$) in extrapolated fish yield of Nile tilapia among the treatments of polyculture without water mixing (4.3 t ha^{-1} yr^{-1}), monoculture without

Table 1. Growth performance of Nile tilapia and common carp in experiment 1 after a 149-day culture period.

Performance measures	Nile tilapia				Common carp	
	Monoculture with water mixing	*Monoculture*	*Polyculture with water mixing*	*Polyculture*	*Polyculture with water mixing*	*Polyculture*
STOCKING						
Biomass (kg pond^{-1})	3.6 ± 0.3	3.6 ± 0.3	3.4 ± 0.0	4.5 ± 0.2	0.9 ± 0.0	0.8 ± 0.0
Mean wt. (g fish^{-1})	8.9 ± 0.6	9.0 ± 0.6	8.4 ± 0.1	11.3 ± 0.4	15.7 ± 0.8	13 ± 0.0
HARVEST						
Biomass (kg pond^{-1})	28.9 ± 1.6	32.6 ± 1.8	9.4 ± 5.1	39.8 ± 4.8	6.1 ± 0.6	11.5 ± 0.8
Mean wt. (g fish^{-1})	90.5 ± 7.5	99.5 ± 5.6	51.9 ± 11.2	111.5 ± 6.3	112.0 ± 8.9	189.5 ± 2.6
Weight gain (g fish^{-1})	81.6 ± 8.1	90.5 ± 6.3	43.4 ± 11.1	104.2 ± 6.0	96.4 ± 8.5	178.2 ± 6.0
Daily wt. gain (g fish^{-1} d^{-1})	0.6 ± 0.1	0.6 ± 0.0	0.3 ± 0.1	0.7 ± 0.1	0.6 ± 0.1	1.2 ± 0.1
Net fish yield (kg pond^{-1})	21.4 ± 0.5	29.7 ± 1.5	6.0 ± 5.1	35.0 ± 3.4	5.1 ± 0.6	10.6 ± 0.8
Extrapolated yield (t ha^{-1} yr^{-1})	2.6 ± 0.06	3.6 ± 0.18	0.74 ± 0.62	4.3 ± 0.42	0.63 ± 0.1	1.3 ± 0.1
Survival (%)	70.9 ± 7.4	84.2 ± 4.0	37.0 ± 13.1	88.1 ± 3.2	90 ± 1.6	100 ± 0.8

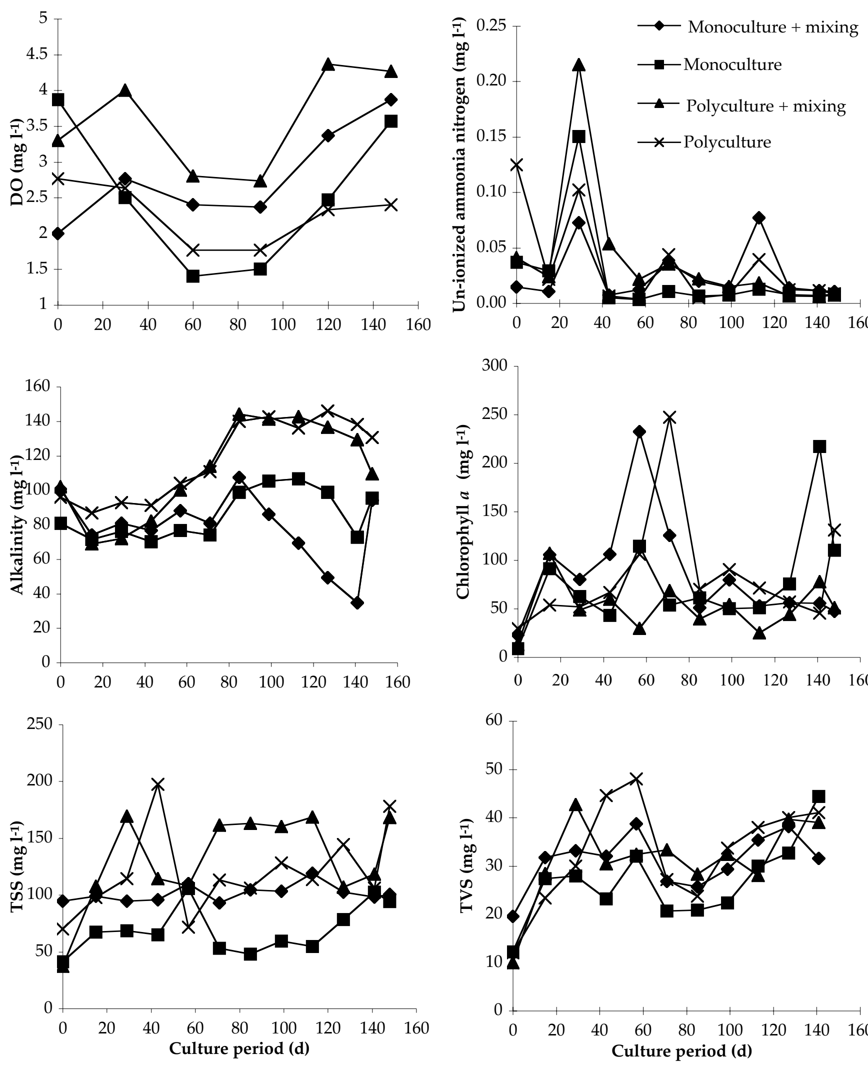


Figure 2. Changes in concentrations of dissolved oxygen (DO) at dawn, un-ionized ammonia nitrogen, alkalinity, chlorophyll *a*, total suspended solids (TSS), and total volatile solids (TVS) in pond water during experiment 1.

Table 2. Water quality parameters at the end of experiment 1.

Water quality	Treatment			
	Monoculture with water mixing	*Monoculture*	*Polyculture with water mixing*	*Polyculture*
DO (mg l^{-1})	5.4 ± 0.1	7.3 ± 0.5	7.0 ± 1.6	6.4 ± 0.1
Temperature (°C)	31.8 ± 0.2	31.8 ± 0.1	31.6 ± 0.1	31.7 ± 0.2
pH	7.2 ± 0.0	7.5 ± 0.1	7.6 ± 0.4	7.2 ± 0.1
Secchi disk depth (cm)	18.3 ± 3.0	21.3 ± 2.6	12.3 ± 1.5	11.0 ± 2.0
Alkalinity (mg l^{-1})	73 ± 20.1	95 ± 11.0	130 ± 15.1	131 ± 18.6
TAN (mg l^{-1})	1.04 ± 0.19	0.52 ± 0.24	0.48 ± 0.15	0.60 ± 0.14
TKN (mg l^{-1})	5.01 ± 3.41	12.26 ± 8.47	2.99 ± 0.78	5.44 ± 1.99
TP (mg l^{-1})	0.31 ± 0.08	0.68 ± 0.22	0.33 ± 0.07	0.39 ± 0.06
SRP (mg l^{-1})	0.17 ± 0.04	0.43 ± 0.13	0.11 ± 0.04	0.11 ± 0.02
Chlorophyll *a* (mg m^{-3})	47 ± 6.8	110 ± 112.2	51 ± 38.9	131 ± 68.0
TSS (mg l^{-1})	100 ± 20.1	94 ± 36.0	168 ± 32.1	178 ± 27.8
TVS (mg l^{-1})	21 ± 2.5	23 ± 10.1	33 ± 2.5	37 ± 13.8

Table 3. Initial and final concentrations and changes in concentrations and percent change for organic matter, total phosphorus, and total nitrogen in sediments of all treatments for experiment 1.

Treatment	Organic matter	Total phosphorus	Total nitrogen
(A) MONOCULTURE WITH WATER MIXING			
Initial level (mg g^{-1})	83.3 ± 18.4	2.1 ± 0.1	7.8 ± 1.0
Final level (mg g^{-1})	66.7 ± 1.0	2.1 ± 0.6	8.1 ± 0.9
Change (mg g^{-1})	-16.6 ± 17.5	-0.1 ± 0.7	0.3 ± 1.2
Change (%)	-17.7 ± 15.1	-2.7 ± 32.6	5.3 ± 16.4
(B) MONOCULTURE WITHOUT WATER MIXING			
Initial level (mg g^{-1})	71.1 ± 2.2	2.0 ± 0.8	6.9 ± 0.7
Final level (mg g^{-1})	64.3 ± 1.8	1.6 ± 0.1	8.3 ± 0.7
Changes (mg g^{-1})	-6.8 ± 3.7	-0.4 ± 0.7	1.4 ± 1.3
Change (%)	-9.4 ± 4.8	-13.3 ± 25.1	21.9 ± 20.4
(C) POLYCULTURE WITH WATER MIXING			
Initial level (mg g^{-1})	74.1 ± 9.2	2.5 ± 0.2	7.4 ± 0.9
Final level (mg g^{-1})	82.8 ± 21.0	3.2 ± 0.2	9.6 ± 0.8
Change (mg g^{-1})	8.7 ± 17.5	0.7 ± 0.3	2.1 ± 0.2
Change (%)	11.5 ± 21.9	29.1 ± 14.4	28.9 ± 6.0
(D) POLYCULTURE WITHOUT WATER MIXING			
Initial level (mg g^{-1})	80.2 ± 5.8	1.8 ± 0.1	8.1 ± 0.9
Final level (mg g^{-1})	73.3 ± 8.1	2.0 ± 0.5	8.7 ± 0.2
Change (mg g^{-1})	-6.8 ± 8.1	0.2 ± 0.6	0.6 ± 1.0
Change (%)	-8.4 ± 9.5	10.9 ± 33.9	7.7 ± 13.3

water mixing (3.6 t ha^{-1} yr^{-1}), and monoculture with water mixing (2.6 t ha^{-1} yr^{-1}), which were significantly higher ($P < 0.05$) than the extrapolated fish yield in the treatment of polyculture with water mixing (0.74 t ha^{-1} yr^{-1}). Growth of common carp was significantly higher ($P < 0.05$) in the treatment without water mixing than in the treatment with water mixing (Figure 1). Similarly, survival of common carp in the treatment without water mixing was significantly higher ($P < 0.05$) than in the treatment with water mixing.

The best growth performance of both Nile tilapia and common carp was achieved in the treatment of polyculture without water mixing. Adding common carp to Nile tilapia ponds had no significant ($P > 0.05$) effect on the growth of Nile tilapia. Water mixing did not significantly ($P > 0.05$) affect growth of Nile tilapia in the monoculture treatments, but significantly ($P < 0.05$) reduced growth of both Nile tilapia and common carp in the polyculture treatments.

Water quality parameters varied among treatments in the experiment (Figure 2; Table 2). Water temperature and pH throughout the experimental period in all ponds ranged from 27.0 to 35.1°C and 6.4 to 10.7, respectively. The measured DO concentrations at dawn fluctuated over the entire culture period, with the treatments with water mixing having significantly ($P < 0.05$) higher DO values than the treatments without water mixing. Un-ionized ammonia nitrogen concentrations in all treatments were generally low and had no significant ($P > 0.05$) differences among treatments. Alkalinity concentrations in the polyculture treatments were significantly ($P < 0.05$) higher than in the monoculture treatments. Both TSS and TVS concentrations were significantly ($P < 0.05$) higher in the polyculture treatments than in the monoculture treatments, implying that the difference in TSS was attributable at least partially to phytoplankton. However, chlorophyll *a* concentrations were not significantly different ($P > 0.05$) among all treatments, due probably to the extremely high level of chlorophyll *a* in a replication of the monoculture treatment without water mixing.

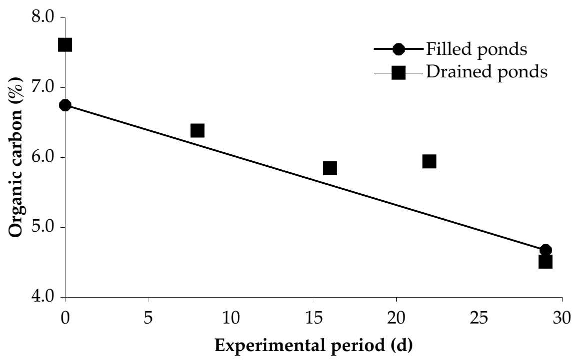


Figure 3. Changes in organic matter content in pond sediments during experiment 2.

The soil analyses showed that there were no significant ($P > 0.05$) differences for changes in organic matter, total nitrogen, and total phosphorus among all treatments (Table 3). While the organic matter content in the treatment of polyculture with water mixing increased by 8.7 mg g^{-1} soil or 11.5%, the reduction of organic matter in other three treatments ranged from 6.8 to 16.6 mg g^{-1} soil or from 8.4 to 17.7%. The content of total phosphorus decreased in the monoculture treatments, but increased in the polyculture treatments. However, nitrogen accumulated in sediments of all treatments after a 149-day culture period.

Experiment 2

The initial and final levels of organic matter, total nitrogen, and total phosphorus in the pond sediments were not significantly ($P > 0.05$) different between filled and drained treatments (Table 4). The organic matter content of the pond sediments of both treatments decreased over the one-month experimental period (Figure 3). However, pond draining for one month in the experiment did not result in the significant ($P > 0.05$) reduction of organic matter in pond sediments, as compared with ponds refilled immediately after harvest in experiment 1 (Table 4). In both experiments total nitrogen accumulated while total phosphorus content decreased in pond sediments (Table 4).

The measured water quality parameters (TKN, DIN, TP, and SRP) did not show any significant ($P > 0.05$) difference between the filled and drained treatments at the end of the experiment

Table 4. Initial and final concentrations and changes in concentrations and percent change for organic matter, total phosphorus, and total nitrogen in sediments of all treatments for experiment 2.

Treatment	Organic matter	Total phosphorus	Total nitrogen
FILLED PONDS			
Initial levels (mg g^{-1})	67.5 ± 2.5	2.2 ± 0.7	8.6 ± 0.8
Final levels (mg g^{-1})	46.7 ± 5.9	1.3 ± 0.4	13.0 ± 6.0
Changes (mg g^{-1})	-20.8 ± 6.1	-0.9 ± 0.6	4.4 ± 6.2
Changes (%)	-30.8 ± 9.0	-38.8 ± 18.7	53.0 ± 72.1
DRAINED PONDS			
Initial levels (mg g^{-1})	76.1 ± 16.6	2.2 ± 0.8	8.7 ± 0.8
Final levels (mg g^{-1})	45.0 ± 1.8	1.4 ± 0.2	13.9 ± 2.3
Changes (mg g^{-1})	-31.1 ± 18.0	-0.8 ± 0.9	5.2 ± 2.8
Changes (%)	-38.6 ± 12.8	-26.5 ± 30.6	61.0 ± 34.2

Table 5. Water quality parameters (mg l^{-1}) at the beginning and end of experiment 2.

Treatment	TKN	DIN	TP	SRP
FILLED PONDS				
Source water	0.80 ± 0.28	0.21 ± 0.18	0.15 ± 0.02	0.01 ± 0.00
Initial levels	0.96 ± 0.21	0.30 ± 0.37	0.12 ± 0.03	0.01 ± 0.00
Final levels	8.79 ± 1.18	1.08 ± 0.10	0.27 ± 0.18	0.07 ± 0.05
Net change	8.00 ± 1.18	0.87 ± 0.10	0.12 ± 0.18	0.06 ± 0.05
DRAINED PONDS				
Source water	5.06 ± 0.18	0.47 ± 0.00	0.06 ± 0.00	0.02 ± 0.01
Initial levels	------------	------------	------------	------------
Final levels	8.65 ± 0.64	1.12 ± 0.13	0.17 ± 0.05	0.07 ± 0.05
Net change	3.59 ± 0.64	0.65 ± 0.13	0.11 ± 0.05	0.06 ± 0.05

(Table 5). The net increase (final levels minus those in source water) of TKN and DIN in the filled treatments was significantly ($P < 0.05$) higher than that in the drained treatments (Table 5). However, there was no significant ($P > 0.05$) difference of the net increment of TP and SRP between these two treatments (Table 5).

DISCUSSION

The presence of common carp in polyculture ponds did not reduce the growth of Nile tilapia compared with Nile tilapia growth in monoculture ponds. Actually, the best growth of Nile tilapia was achieved in polyculture ponds, indicating that the stirring of bottom sediments into the water column by common carp oxygenates the pond bottom and recirculates nutrients into the water column (Cohen et al., 1983), thereby increasing phytoplankton production and food for Nile tilapia (Edirisinghe, 1990). The addition of a benthic detritivore such as the common carp produced extra fish and also resulted in higher system productivity because the unutilized benthic matter (characteristic of Nile tilapia monoculture ponds) was converted into fish flesh. However, soil analyses in the present experiment showed no significant removal of organic matter by common carp, implying that more common carp could be stocked in tilapia ponds.

Water mixing seemed to stimulate phytoplankton growth (Sanares et al., 1986), and continual water mixing, which resulted in the resuspension of the organic particles in ponds, led to high rates of microbial activity and the recycling of pond nutrients (Avnimelech et al., 1986). In the present experiment, however, water mixing largely reduced phytoplankton growth in both mono- and polyculture ponds. Water mixing did not affect the growth of Nile tilapia in monoculture ponds, but significantly reduced the growth of both Nile tilapia and common carp in polyculture ponds.

Pond drying is a common practice between grow-out periods in freshwater and brackishwater aquaculture ponds. Pond drying can greatly retard the rate of organic matter accumulation in pond bottom soil (Boyd and Bowman, 1997). This process is believed to improve the bottom soil conditions. When pond bottoms are dried and exposed to air—which contains 21% oxygen by volume compared to less than 0.001 to 0.002% in water—enhanced oxygen availability may permit greater rates of microbial decomposition of organic matter (Boyd and Bowman, 1997). However, pond drying in the present experiment did not result in significant oxidation of organic matter and releases of nutrients from pond sediments compared with the ponds filled immediately after harvest. One possible reason is that the ponds were not dried completely and deep cracks had not developed. The optimum soil moisture for microbial decomposition ranges from 12 to 20% (Boyd and Pippopinyo, 1994). However, the soil moisture concentration during drying in this study ranged from 50 to 68%, probably due to rain and leaching from the adjacent canal.

Results of the present experiment indicate that the inclusion of common carp in Nile tilapia ponds was effective in recycling nutrients, and might be effective in the removal of organic matter if more common carp are added. Water mixing together with stirring activities of common carp adversely affected the growth of both Nile tilapia and common carp in polyculture ponds. Results also showed that pond drying did not result in significant microbial decomposition of organic matter.

ANTICIPATED BENEFITS

The results generated in this study will link bottom soil characteristics and management techniques. The use of polyculture to mitigate the accumulation of organic material on pond bottoms is a common practice throughout Asia, but has been little studied. Pond drying is also a common practice. Both have strong likelihood of improving pond bottoms and therefore production of fish in ponds.

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