MANAGEMENT OF ORGANIC MATTER AND NUTRIENT REGENERATION IN POND BOTTOMS THROUGH POLYCULTURE

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Abstract

An experiment was conducted in twelve 200-m^2 earthen ponds at the Asian Institute of Technology, Thailand, during November 1997 through April 1998. The experiment was conducted for 149 days to assess effects of aerobic and anaerobic conditions at pond bottom on organic matter decomposition and nutrient release, as well as the effectiveness of common carp (*Cyprinus carpio*) in removing organic matter from pond sediments and recycling nutrients in Nile tilapia (*Oreochromis niloticus*) 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 all-male Nile tilapia were stocked at 2 fish m^{-2} at a size of 8-12 g in all ponds, while common carp fingerlings at 0.3 fish m^{-2} at a size of 13-17 g. All ponds were fertilized with chicken manure at the rate 1,000 kg ha^{-1} week^{-1} (dry matter basis) to create anaerobic bottoms. Aerobic pond bottoms in water mixing 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.

Results of the experiments indicate that inclusion of common carp into Nile tilapia ponds 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 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 ($P < 0.05$) reduced the growth of both Nile tilapia and common carp in polyculture ponds.

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 reduce 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.

Despite polyculture is commonly practiced throughout Asia to mitigate the accumulation of organic matter on pond bottom, there are very few systematic studies carried out in these lines. This study was conducted to understand the link between bottom soil characteristics and management techniques, and the effect of polyculture on organic matter accumulation. The purposes of this study were to investigate effects of aerobic and anaerobic environments of pond bottom on organic matter decomposition and nutrient release, and to assess the effectiveness of common carp in removing organic matter from pond sediments and in recycling nutrients for tilapia ponds.

Materials and methods

The experiment was conducted in a 2x2 factorial design in twelve 200-m^2 earthen ponds at the Asian Institute of Technology (AIT). The treatment combinations were aerobic versus anaerobic pond bottom and monoculture of Nile tilapia (*Oreochromis niloticus*) versus polyculture of Nile tilapia and common carp (*Cyprinus carpio*). 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. Four treatments with three replicates each were assigned randomly to the ponds.

Sex-reversed all-male Nile tilapia were stocked at 2 fish m^{-2} at a size of 8-12 g in all ponds, while common carp fingerlings at 0.3 fish m^{-2} at a size of 13-17 g on 04 November 1997. The water depth in all ponds was maintained at 1m throughout the experiment. All ponds were fertilized with chicken manure at the rate 1,000 kg ha^{-1} $week^{-1}$ (dry matter basis) to create anaerobic bottom. Aerobic pond bottom in the water mixing treatments (A and C) was 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 polythene sheet of a dimension of 10 m^2 (5 x 2 m) was fixed on the pond bottom below each pump to prevent disturbing bottom by the water jet.

Water samples of the entire water column were taken biweekly near the center of each pond at about 0900 h for the analysis of pH, total alkalinity, total ammonium nitrogen (TAN), nitrite nitrogen (nitrite-N), nitrate nitrogen (nitrate-N), total Kjeldahl nitrogen (TKN), soluble reactive phosphorus (SRP), total phosphorus (TP), chlorophyll *a*, total suspended solids (TSS) and total volatile solids (TVS) (APHA *et al.*, 1985). Un-ionized ammonia-nitrogen (UIA-N) was calculated by a conversion table for given pH and temperature (Boyd, 1990). Temperature and dissolved oxygen (DO) were measured with a YSI model 54 oxygen meter (Yellow Springs Instruments, Yellow Springs, OH, USA) before taking water samples. 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 total alkalinity and TAN were determined at 0900, 1600 and 0600 h.

Bottom soil samples were collected with 5-cm diameter plastic tubes from nine different locations in each pond, air-dried, and thoroughly mixed one day prior to stocking and harvest, respectively. A representative subsample was taken from each homogenized sample for analyses of moisture, total nitrogen (TN), TP organic matter.

During the experiment, about forty fish were sampled randomly by seining from each pond, and average fish weights were determined by bulk weighing monthly. All ponds were harvested on 02 April 1998 after 149-day culture. Final biomass and numbers were determined. Daily weight gain (g fish^{-1}d^{-1}), yield (kg pond^{-1}) and extrapolated yield (kg ha^{-1} year^{-1}) were calculated.

Data were analyzed statistically by two-way analysis of variance (Steel and Torrie, 1980) using SPSS (version 7.0) statistical software package (SPSS, Chicago, USA). Differences were considered significant at an alpha level of 0.05. All means were given with ±1 standard error (S.E.).

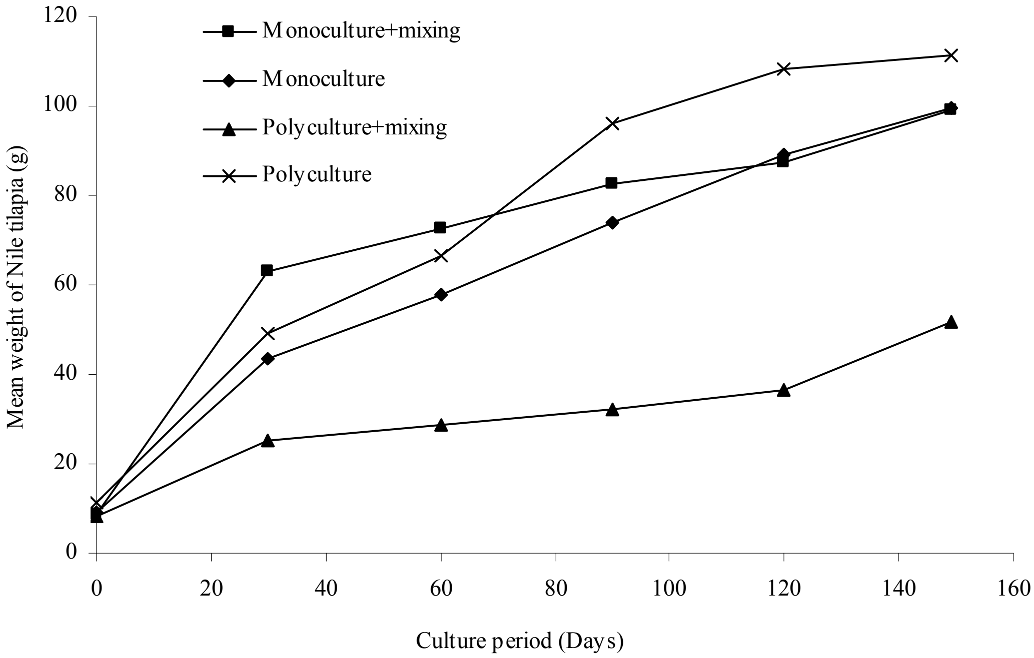
Results

Growth performance of Nile tilapia and common carp is shown in Table 1. Growth of both Nile tilapia and common carp differed markedly at the first sampling among all treatments (Fig. 1). Overall growth rate of Nile tilapia in the treatment of polyculture with water mixing was lower significantly than that in the other three treatments ($P < 0.05$). Survival of Nile tilapia in the two treatments without water mixing was significantly higher than that in the other two treatments with water mixing ($P < 0.05$). There were no significant differences in net yield of Nile tilapia among the treatments of polyculture without water mixing (4.3 t ha^{-1} year^{-1}), monoculture without water mixing (3.6 t ha^{-1} year^{-1}), and monoculture with water mixing (2.6 t ha^{-1} year^{-1}) ($P > 0.05$), which were significantly higher than that in the treatment of polyculture with water mixing (0.74 t ha^{-1} year^{-1}) ($P <0.05$). Growth of common carp was significantly higher in the treatments without water mixing than that in the treatment with water mixing (*P* < 0.05, Fig. 1). Similarly, survival of common carp in the treatments without water mixing was significantly higher than that in the treatments with water mixing (*P* < 0.05).

Table 1. Growth performance of Nile tilapia and common carp in the experiment for 149 days.

Performance measures	Nile tilapia				Common carp	
	Monoculture water mixing	Monoculture	Polyculture water mixing	Polyculture	Polyculture 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} day^{-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})						
Extrapolated net yield (tons ha^{-1} year^{-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
	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

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



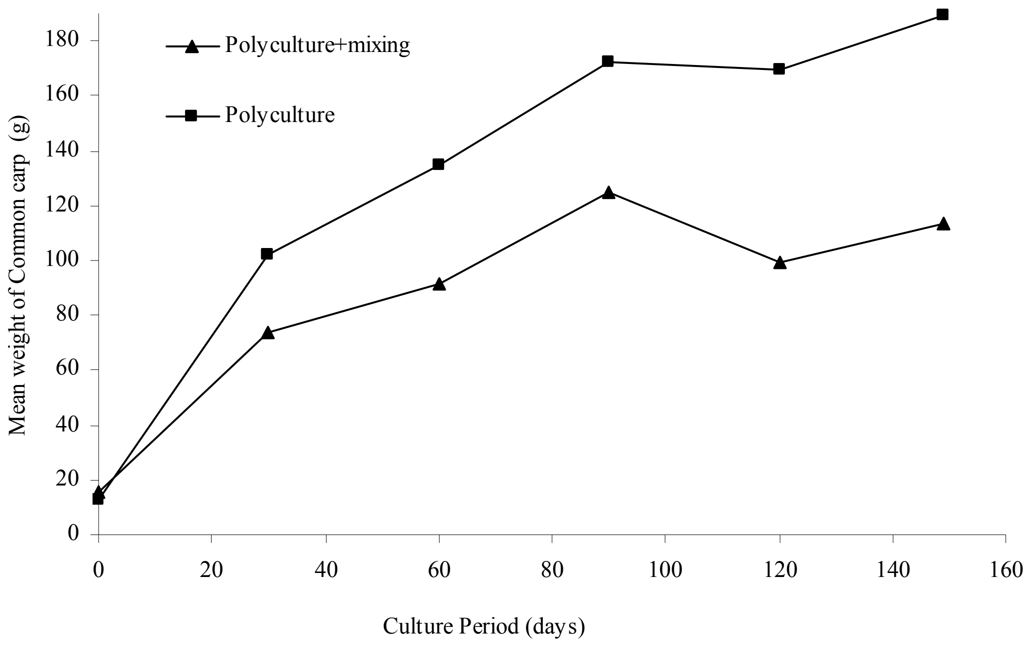


Figure 1. Changes in mean weight of Nile tilapia and common carp during the experiment.

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

The soil analyses showed that there were no significant differences of changes in organic matter, TN and TP among all treatments ($P > 0.05$, 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, ranging from 6.8 to 16.6 mg g^{-1} soil or from 8.4 to 17.7%, occurred in other three treatments. TP content reduced in the monoculture treatments, but increased in the polyculture treatments. However, nitrogen accumulated in sediments of all treatments after 149-day culture period.

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

Parameters	Treatments			
	Monoculture Water mixing	Monoculture	Polyculture 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} as $CaCO_3$)	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

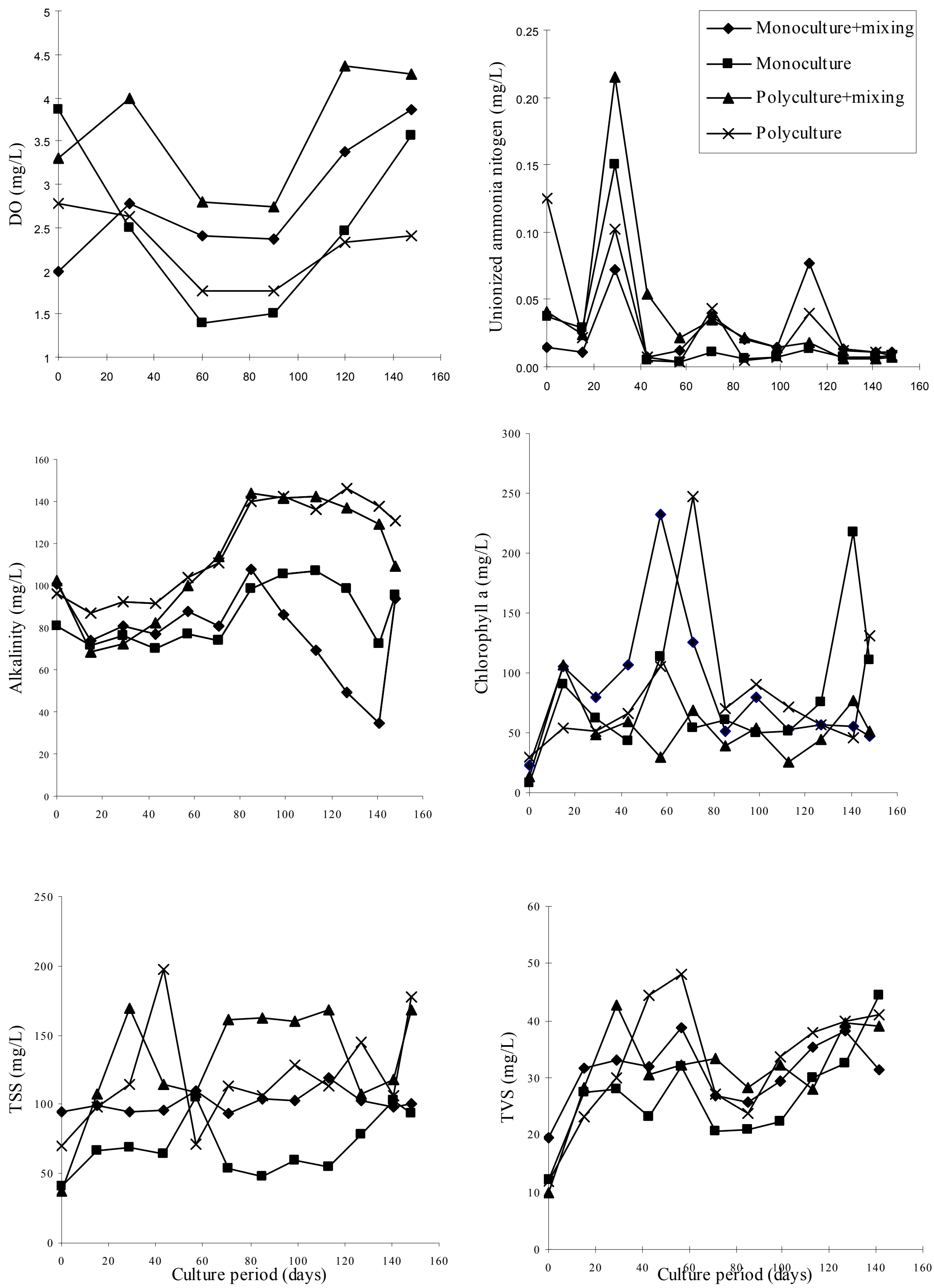


Figure 2. Changes in concentrations of DO at dawn, unionized ammonia-N, total alkalinity, chlorophyll *a,* TSS, and TVS in pond water during the experiment.

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

Treatments	Organic matter	Total phosphorus	Total nitrogen
Monoculture with water mixing			
Initial levels (mg g^{-1})	83.3±18.4	2.1±0.1	7.8±1.0
Final levels (mg g^{-1})	66.7±1.0	2.1±0.6	8.1±0.9
Changes (mg g^{-1})	- 16.6±17.5	- 0.1±0.7	0.3±1.2
Changes (%)	- 17.7±15.1	- 2.7±32.6	5.3±16.4
Monoculture without water mixing			
Initial levels (mg g^{-1})	71.1±2.2	2.0±0.8	6.9±0.7
Final levels (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
Changes (%)	- 9.4±4.8	- 13.3±25.1	21.9±20.4
Polyculture with water mixing			
Initial levels (mg g^{-1})	74.1±9.2	2.5±0.2	7.4±0.9
Final levels (mg g^{-1})	82.8±21.0	3.2±0.2	9.6±0.8
Changes (mg g^{-1})	8.7±17.5	0.7±0.3	2.1±0.2
Changes (%)	11.5±21.9	29.1±14.4	28.9±6.0
Polyculture without water mixing			
Initial levels (mg g^{-1})	80.2±5.8	1.8±0.1	8.1±0.9
Final levels (mg g^{-1})	73.3±8.1	2.0±0.5	8.7±0.2
Changes (mg g^{-1})	- 6.8±8.1	0.2±0.6	0.6±1.0
Changes (%)	- 8.4±9.5	10.9±33.9	7.7±13.3

Discussion

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

Water mixing seemed to stimulate phytoplankton growth (Sanares *et al*., 1986), and continuous water mixing and resultant resuspension of the organic particles in ponds led to high rates of microbial activity and recycling of nutrients in ponds (Avnimelech *et al.,* 1986). In the present experiment, however, water mixing caused the 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.

Results of the present experiment indicate that inclusion of common carp into Nile tilapia ponds was effective in recycling nutrients, and might be effective in 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.

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