MANAGEMENT TO MINIMIZE THE ENVIRONMENTAL IMPACTS OF POND DRAINING: EFFECT OF HARVEST DRAINING TECHNIQUE ON WATER QUALITY AND FISH GROWTH

Eighth Work Plan, Thailand Research 3 (TR3)
Final Report

C. Kwei Lin, Madhav K. Shrestha, Raghunath B. Shivappa, and Dhirendra P. Thakur
Agricultural and Aquatic Systems Program
Asian Institute of Technology
Pathum Thani, Thailand

James S. Diana
School of Natural Resources and Environment
University of Michigan
Ann Arbor, Michigan, USA

ABSTRACT

An experiment was conducted to assess the effect of different harvest draining techniques of fish ponds on water quality and fish growth in subsequent culture cycles. Fifteen tilapia ponds of 200 m^2 were harvested using five different harvest draining techniques. After harvest, these ponds were stocked with Nile tilapia (*Oreochromis niloticus*) at 2 fish m^{-2}. Fish with an initial size of 11 to 13 g were cultured for 106 days in a fertilized pond system. Harvest draining techniques as treatments were: (A) Ponds were not drained, and fish were harvested by seining using tea seed cake as an anesthetic toxicant; (B) Ponds filled with canal water were completely drained after liming, and fish were harvested from a harvesting pit; (C) Ponds filled with canal water were completely drained, and fish were harvested from a harvesting pit; (D) Ponds filled with drainage water from harvest of adjacent ponds used in a previous experiment (equivalent to Treatment E of this study) were half-drained and seined twice, then completely drained to collect the remaining fish; and (E) Ponds filled with canal water were half-drained and seined twice, then completely drained to collect the remaining fish. None of the treatment means of water quality parameters (dissolved oxygen, pH, Secchi disk depth, alkalinity, total ammonium nitrogen, nitrite nitrogen, nitrate-nitrite nitrogen, total nitrogen, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, total suspended solids, and volatile suspended solids) were significantly different ($P > 0.05$) between treatments. Similarly, fish growth, net fish yield, and survival did not differ ($P > 0.05$) between treatments. Fish growth and net yield from undrained ponds (Treatment A) were 1.32 ± 0.15 g d^{-1} and 15.7 ± 4.2 kg ha^{-1} d^{-1}, respectively. Fish growth and net yield from ponds filled with drainage water of other ponds (Treatment D) were 1.11 ± 0.16 g d^{-1} and 17.3 ± 3.1 kg ha^{-1} d^{-1}. The results suggest that environmental impacts of pond draining can be minimized either by harvesting fish without draining or by draining pond water into empty ponds without affecting the water quality for fish growth.

INTRODUCTION

Pond fertilization is an essential management practice in aquaculture to enrich the nutrients in pond water (Boyd, 1990; Pillay, 1990). Nutrient application through a combination of organic and inorganic materials is an efficient system for tilapia ponds (Knud-Hansen et al., 1993). Moreover, supplemental feeding of tilapia in fertilized ponds increases harvest size as well as fish yield (Diana et al., 1996). Such fertilization results in minimal increases in concentrations of phosphorus (P) and nitrogen (N) in pond waters during grow-out (Diana et al., 1994). Overflow of such waters during rain events do not load nutrients in receiving waters beyond normal levels (Schwartz and Boyd, 1994b). However, the water quality of effluents discharged at harvest draining decreases considerably due to accumulation of materials in pond bottom water near the soil-water interface (Pillay, 1992). Moreover, draining of pond water after seining further increases pollutants in effluent waters (Boyd, 1978; Schwartz and Boyd, 1994a; Seok et al., 1995; Lin et al., 1998). Several strategies of draining and harvesting could minimize the environmental impacts of pond effluents (Hollerman and Boyd, 1985; Schwartz and Boyd, 1995; Kouka and Engle, 1996; Tucker et al., 1996; Ghate et al., 1997; Lin et al., 1998).

Management of draining and harvesting of aquaculture ponds may reduce effluent load; however, such management should not adversely affect the growth and production of aquaculture products. In this study we assess the effects of harvest draining techniques on pond water quality and fish growth in subsequent production cycles.

METHODS AND MATERIALS

This experiment was conducted in fifteen tilapia ponds of 200 m^2 surface area, which were previously harvested using five different harvest draining techniques in the first experiment of the study (Lin et al., 1998) at the Asian Institute of Technology, Thailand. The harvest draining techniques as experimental treatments were as follows:

- T_1) Fish were harvested by seining using tea seed cake to anesthetize fish and ponds were not drained;
- T_2) Ponds were limed (75 ppm calcium hydroxide) 24 hours prior to harvest, completely drained, and fish were collected from a harvesting pit;
- T_3) Ponds were completely drained and fish were collected from a harvesting pit;
- T_4) Ponds were drawn down to 50 cm and fish were harvested by two seinings, followed by complete

draining and collection of remaining fish from a harvesting pit; and

T_5) Ponds received the same draining and harvesting technique as in treatment T_4, but the pond water was drained into the empty ponds of treatment T_4 (not discharged).

The experiment incorporated three blocks. The locations of the treatments within blocks were assigned on a random basis, with the exception that ponds in treatments T_4 and T_5 had to be adjacent to facilitate drainage of water from ponds in treatment T_5 to ponds in treatment T_4. All the ponds except those in treatments T_1 and T_4 were refilled with canal water. Ponds in treatment T_1 were undrained, whereas ponds in treatment T_4 were refilled with drainage water from ponds in treatment E (equivalent to treatment T_5) during harvest of the previous experiment (Lin et al., 1998).

Pond water depths were maintained at 1.2 ± 0.1 m by weekly topping with canal water. All ponds were fertilized weekly with 1.2 kg urea (28 kg N ha^{-1}) and 0.7 kg triple superphosphate (TSP) (7 kg P ha^{-1}). Sex-reversed male Nile tilapia of 11.5 to 13.2 g size were stocked at 2 fish m^{-2} on 15 July 1997. Fish were cultured for 106 days and harvested on 29 October 1997.

Pond water column samples, taken biweekly at 0900 h, were analyzed for total alkalinity, total ammonium nitrogen, nitrite nitrogen, nitrate-nitrite nitrogen, total nitrogen, soluble reactive phosphorus, total phosphorus, chlorophyll *a*, total suspended solids, and total volatile solids using standard methods (Raveh and Avnimelech, 1979; APHA, 1980; Egna et al., 1987). Temperature, dissolved oxygen, pH (at 20 cm below the surface), and Secchi disk depth were also measured *in situ* according to the same schedule. In addition, monthly diel measurements of temperature, dissolved oxygen, pH, alkalinity, and total ammonium nitrogen were conducted at 0600, 0900, 1400, 1600, 1800, and 0600 h in each pond.

Data were analyzed statistically by analysis of variance using the Statgraphics 7.0 statistical software package. Mean fish growth (g d^{-1}), net fish yield (kg ha^{-1} d^{-1}), and survival (%) were calculated for each treatment. Means and ranges of water quality parameters from biweekly measured data were also calculated for each treatment. All means were given with

Table 1. Mean stocking size, harvest size, growth, net fish yield, and survival of Nile tilapia cultured for 106 days in earthen ponds in different treatments: (T1) undrained ponds; (T2) limed, completely drained, and filled with canal water; (T3) completely drained and filled with canal water; (T4) half drained, seined, completely drained, and filled with drainage water of T5; and (T5) half drained, seined, completely drained, and filled with canal water.

Treatment	Pond #	Mean Stocking Size (g)	Mean Harvest Size (g)	Mean Growth (g d^{-1})	Net Fish Yield (kg ha^{-1} d^{-1})	Survival (%)
T_1						
	3	11.5	118.1	1.01	16.3	83
	6	12.0	170.3	1.49	22.6	78
	11	12.8	167.7	1.45	8.1	33
	Mean	12.1	152.0	1.32	15.7	65
	± SE	0.4	17.0	0.15	4.2	16
T_2						
	1	11.5	294.0	2.67	39.2	75
	7	12.2	113.3	0.95	15.0	81
	12	13.2	110.4	0.93	11.4	67
	Mean	12.3	172.6	1.52	21.9	74
	± SE	0.5	60.7	0.58	8.7	4
T_3						
	2	11.8	137.5	1.19	23.0	97
	8	12.5	61.1	0.46	4.4	59
	15	12.5	116.5	0.98	4.3	30
	Mean	12.3	105.0	0.88	10.6	62
	± SE	0.2	22.8	0.22	6.2	19
T_4						
	4	12.2	96.6	0.80	11.0	73
	10	12.2	148.1	1.28	20.3	81
	13	12.8	145.9	1.26	20.5	83
	Mean	12.4	130.2	1.11	17.3	79
	± SE	0.2	16.8	0.16	3.1	3
T_5						
	5	11.8	128.0	1.10	18.9	88
	9	12.2	113.1	0.95	16.0	86
	14	13.0	110.9	0.92	15.3	85
	Mean	12.3	117.3	0.99	16.7	86
	± SE	0.4	5.4	0.06	1.1	1

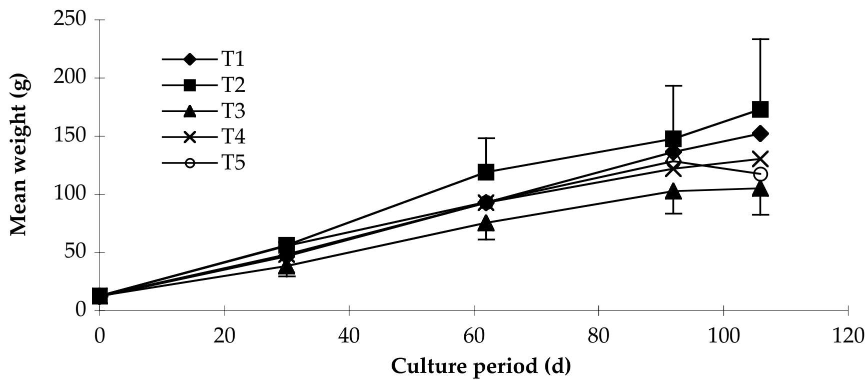

Figure 1. Mean monthly growth of tilapia in different treatments listed in Table 1.

± 1 standard error (SE), and differences were considered significant at an alpha level of 0.05.

Results

Mean values for harvest size, growth, net yield, and survival of tilapia obtained from each pond and treatment are shown in Table 1. All means for growth, net yield, and survival were not different ($P > 0.05$) between treatments. Mean fish growth ranged from 0.88 ± 0.22 g d^{-1} in treatment T_3 to 1.52 ± 0.58 g d^{-1} in treatment T_2; similarly, harvest size varied from 105.0 ± 22.8 g in T_3 to 172.6 ± 60.7 g in T_2 (Figure 1). The lowest mean value in T_3 and highest in T_2 were affected by exceptionally low and high growth, respectively, in one replicate of each treatment (Table 1). The lowest mean survival in treatment T_3 (62 ± 19%) and highest mean survival in T_5 (86 ± 1%) were also not different ($P > 0.05$; Figure 2). Lower survival rates were obtained in Pond 15 (30%), Pond 11 (33%), and Pond 8 (59%), where hybrid catfish (*Clarias gariepinus* x *C. microcephalus*) and snakehead (*Channa striatus*) were found during harvest. Mean net fish yield ranged from 10.6 ± 6.2 kg ha^{-1} d^{-1} in T_3 to 21.9 ± 8.7 in T_2. Fish growth and net yield obtained from undrained ponds (treatment T_1) were 1.32 ± 0.15 g d^{-1} and 15.7 ± 4.2 kg ha^{-1} d^{-1}, respectively. Similarly, fish growth and net yield from ponds filled with drainage water during harvest draining (treatment T_4) were 1.11 ± 0.16 g d^{-1} and 17.3 ± 3.1 kg ha^{-1} d^{-1}. Tilapia reproduction occurred in only two ponds, with little recruitment in Pond 7 and 3.5 kg of recruitment in Pond 13.

Table 2 presents a summary of the physico-chemical parameters of pond waters measured at biweekly intervals at 0900 h for each treatment. Biweekly mean values of dissolved oxygen, pH, alkalinity, total ammonium nitrogen, nitrite nitrogen, total nitrogen, soluble reactive phosphorus, total phosphorus, Secchi depth, chlorophyll *a*, total suspended solids, and volatile suspended solids over time during the experimental period are shown in Figures 3 and 4. Similarly, mean monthly diel dissolved oxygen, pH, alkalinity, and total ammonium nitrogen recorded over a 24- hour period are shown in Figure 5 and Table 3. Mean values for water quality

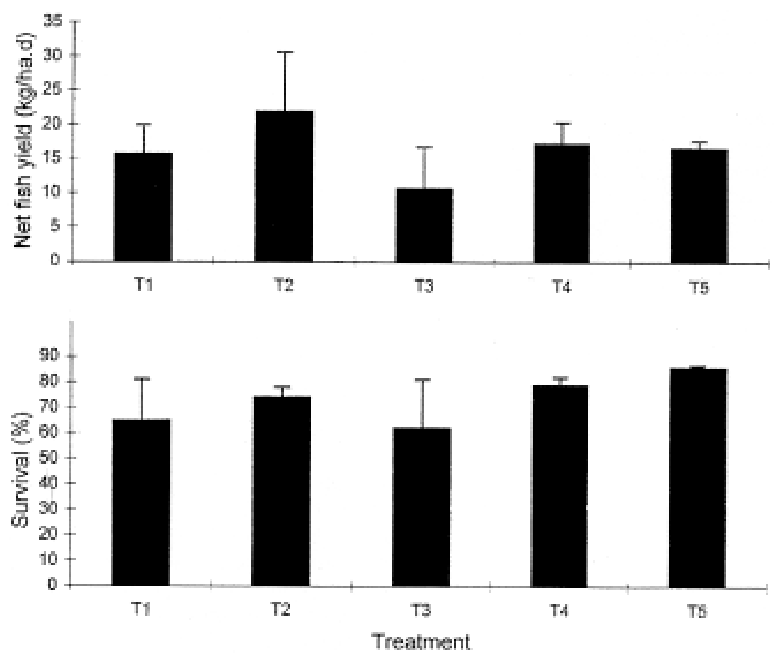

Figure 2. Mean (± SE) net fish yield and survival for different treatments listed in Table 1.

Table 2. Mean and range values for physico-chemical parameters of pond water measured biweekly at 0900 h over the experimental period in different treatments.

Physico-Chemical Parameters	T_1	T_2	T_3	T_4	T_5
Temperature (°C)	28.9 ± 0.2 (28.5-29.3)	29.1 ± 0.2 (28.9-29.4)	29.1 ± 0.1 (29.0-29.4)	29.0 ± 0.1 (28.9-29.2)	29.0 ± 0.1 (28.9-29.2)
Dissolved Oxygen (mg l^{-1})	1.4 ± 0.2 (1.2-1.8)	2.0 ± 0.6 (1.4-3.2)	1.9 ± 0.1 (1.7-2.1)	1.3 ± 0.2 (0.9-1.7)	1.8 ± 0.1 (1.7-2.0)
pH	8.2 (8.0-8.7)	8.4 (8.1-9.0)	8.1 (7.9-8.3)	8.0 (7.8-8.4)	8.4 (8.3-8.5)
Secchi Disk Visibility (cm)	12.5 ± 1.8 (10.4-16.1)	13.3 ± 2.0 (11.0-17.3)	15.1 ± 1.8 (12.1-18.4)	11.3 ± 0.6 (10.0-12.0)	15.0 ± 0.8 (13.5-16.4)
Alkalinity (mg l^{-1} $CaCO_3$)	166.8 ± 17.2 (142.8-200.0)	171.9 ± 17.7 (139.3-200.3)	157.2 ± 8.1 (144.5-172.4)	132.7 ± 26.2 (83.0-172.0)	162.1 ± 3.1 (159.0-168.3)
Total Ammonium Nitrogen (mg l^{-1})	1.3 ± 0.3 (0.8-1.4)	0.8 ± 0.1 (0.6-0.9)	1.4 ± 0.3 (1.0-1.9)	1.0 ± 0.3 (0.7-1.6)	1.0 ± 0.2 (0.7-1.3)
Nitrite Nitrogen (mg l^{-1})	0.3 ± 0.1 (0.2-0.4)	0.3 ± 0.1 (0.1-0.5)	0.4 ± 0.0 (0.4-0.4)	0.4 ± 0.1 (0.3-0.5)	0.4 ± 0.1 (0.2-0.5)
Nitrate and Nitrite-Nitrogen (mg l^{-1})	1.4 ± 0.2 (0.7-1.8)	1.2 ± 0.5 (0.3-1.9)	1.0 ± 0.3 (0.6-1.5)	1.5 ± 0.2 (1.1-2.0)	1.0 ± 0.2 (0.7-1.4)
Total Nitrogen (mg l^{-1})	5.7 ± 0.7 (4.8-7.1)	5.0 ± 0.3 (4.6-5.7)	5.0 ± 0.3 (4.5-5.4)	5.6 ± 0.2 (5.2-5.4)	5.3 ± 0.2 (5.0-5.8)
Soluble Reactive Phosphorus (mg l^{-1})	0.5 ± 0.2 (0.2-0.8)	0.4 ± 0.0 (0.3-0.5)	0.4 ± 0.1 (0.2-0.5)	0.3 ± 0.1 (0.1-0.4)	0.2 ± 0.0 (0.2-0.2)
Total Phosphorus (mg l^{-1})	0.9 ± 0.2 (0.6-1.3)	0.8 ± 0.1 (0.7-0.9)	0.7 ± 0.1 (0.5-0.8)	0.8 ± 0.0 (0.7-0.8)	0.6 ± 0.0 (0.6-0.7)
Chlorophyll *a* (μg l^{-1})	123.1 ± 19.5 (91.7-158.8)	127.8 ± 30.6 (78.1-183.5)	67.3 ± 14.6 (38.3-85.1)	117.1 ± 33.2 (68.8-180.8)	124.8 ± 23.3 (98.4-171.3)
Total Suspended Solids (mg l^{-1})	163.6 ± 32.1 (114.4-223.9)	115.6 ± 23.7 (69.8-149.2)	116.8 ± 24.9 (74.3-160.7)	120.8 ± 3.9 (113.7-127.3)	150.7 ± 25.2 (114.7-199.2)
Volatile Suspended Solids (mg l^{-1})	34.5 ± 0.7 (33.3-35.8)	31.7 ± 2.6 (27.3-36.3)	24.3 ± 5.0 (15.6-32.9)	31.1 ± 4.5 (23.1-38.7)	33.1 ± 1.9 (29.3-35.6)

parameters were not significantly different ($P > 0.05$) between treatments. However, there were lower alkalinity levels in ponds filled with water drained during harvest (treatment T_4), soluble reactive phosphorus and total phosphorus in seined and drained ponds (treatment T_5), and chlorophyll *a* and volatile suspended solids in completely drained ponds without seining (treatment T_3) (Figures 3 and 4). Mean monthly diel profiles also showed lower alkalinity in T_4 where ponds were filled with drainage water from ponds treated similarly to T_5 (Figure 5). Mean concentrations of total ammonium nitrogen were lowest in limed and completely drained ponds (treatment T_2) and highest in completely drained ponds without liming (treatment T_3).

DISCUSSION

The mean growth of tilapia in undrained ponds (1.32 ± 0.15 g d^{-1}) was not different ($P > 0.05$) than the growth in drained and filled ponds (0.88 ± 0.22 to 1.52 ± 0.58 g d^{-1}). Similarly, growth in ponds which were filled with harvest drainage water (1.11 ± 0.16 g d^{-1}) was similar to growth in ponds filled with fresh canal water. Mean net yield and mean survival were also not different ($P > 0.05$) between drained and undrained ponds and between ponds filled with pond drainage water and ponds filled with canal water. The amount of waste discharged during harvest draining of 1-ha fish ponds is estimated to be 161 to 1,100 kg of BOD_5, 39 to 141 m^3 of settleable matter, 59 to 98 kg of total nitrogen and 3.2 to 10.4 kg of total phosphorus using the techniques of complete draining with and without seining (Schwartz and Boyd, 1994a; Seok et al., 1995; Lin et al., 1998). Harvesting fish without draining or by draining pond water into empty ponds allows the ponds to retain nutrients and minimizes the environmental impacts of pond draining without affecting fish growth and yield.

Though mean water quality parameters were not significantly different between treatments, total alkalinity in ponds filled with drainage water was lower than in those filled with canal water. However, alkalinity of undrained ponds was comparatively high, which might be due to the application of tea seed cake. Total ammonium nitrogen was lower in limed and drained ponds. Liming followed by draining increases nitrogen concentration in the effluent, which may be resuspended from the bottom (Lin et al., 1998). Removal of nitrogen in larger quantities during draining of limed and drained ponds (as in treatment T_2) might have resulted in lower total ammonium concentrations in effluent. Fish mortality was higher (40 to 70%) in ponds with mean total ammonium nitrogen > 1.5 mg l^{-1} (Table 1; Figure 3). Total phosphorus and soluble reactive phosphorus concentrations were lower in ponds in which both seining and draining procedures were performed. Ponds with lower chlorophyll *a* (38.3 and 68.8 µg l^{-1}) and volatile suspended solids (15.6 and 23.1 mg l^{-1}) in Pond 8 of treatment T_3 and Pond 4 of treatment T_4, respectively, resulted in lower fish growth (0.46 and 0.80 g d^{-1}, respectively) (Table 1).

As there were no significant differences between harvest draining techniques on subsequent water quality and fish growth, the results suggest that the environmental impacts of pond draining could be minimized either by harvesting fish without draining or by using drainage water in empty ponds where plankton feeder fish like tilapia can be stocked. Similarly, insignificant differences to fill water quality have been reported between annually drained and undrained ponds (Hollerman and Boyd, 1985; Seok et al., 1995).

ACKNOWLEDGMENTS

We would like to acknowledge the Asian Institute of Technology, Thailand, for providing the research field and laboratory facilities. The aquaculture laboratory technicians are greatly appreciated for water quality analyses. Assistance of R.B. Shivappa and M.A.K. Chowdhury in data processing is greatly appreciated.

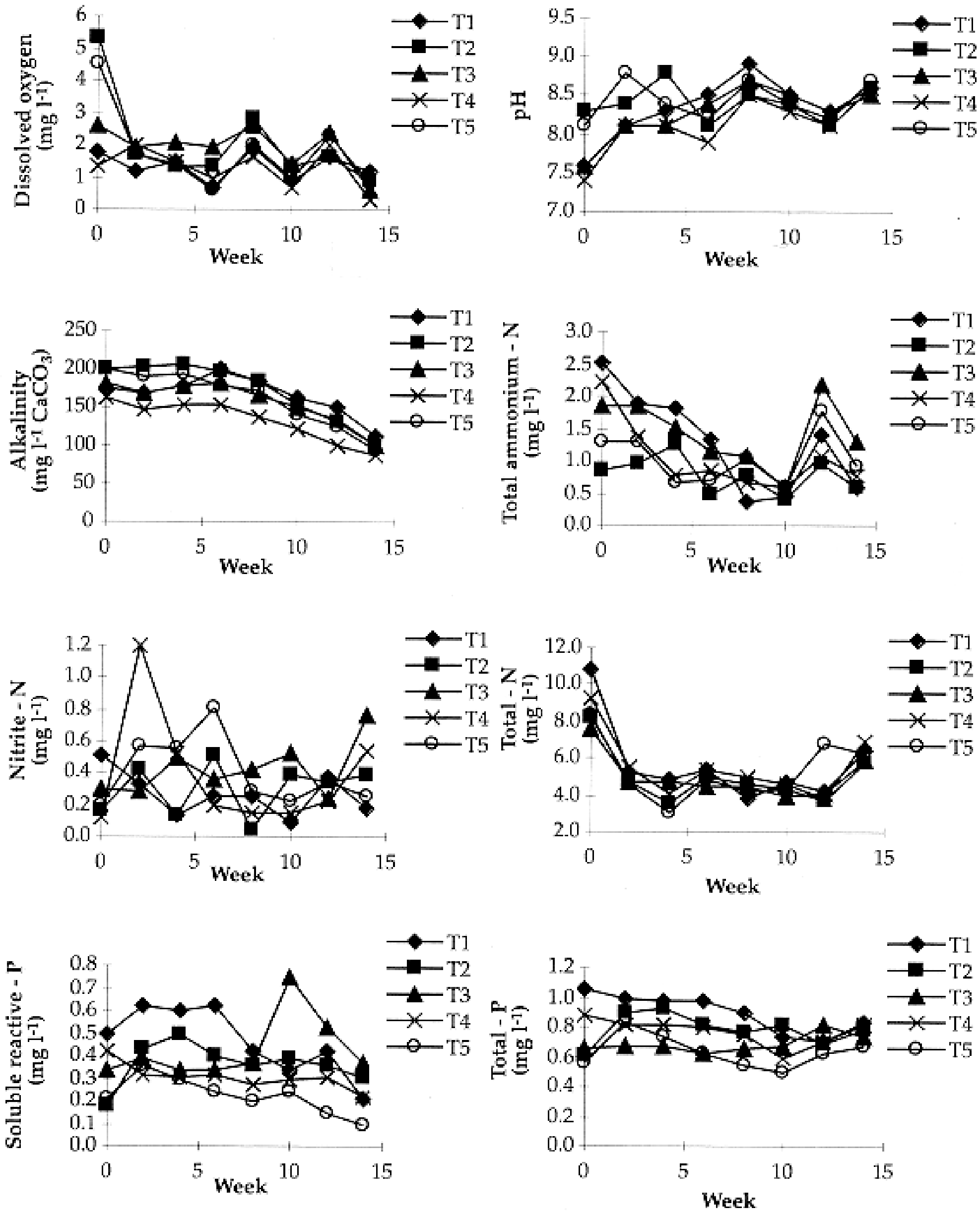

Figure 2. Means net fish yield and survival for different treatments listed in table 1.

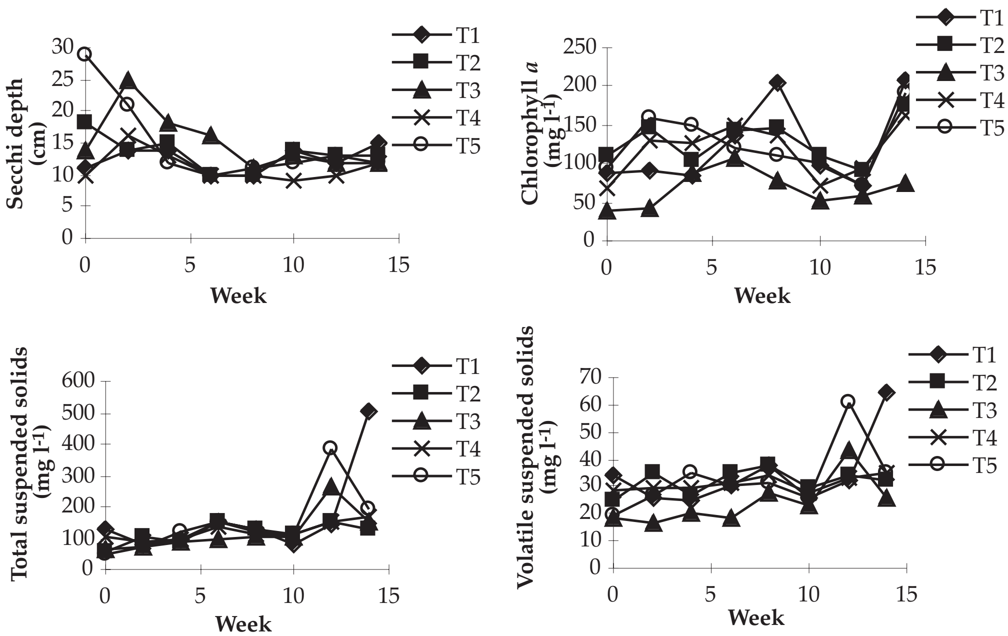

Figure 4. Mean biweekly Secchi depth, chlorophyll *a*, total suspended solids, and volatile suspended solids measured at 0900 h over the experimental period for treatments listed in Table 1.

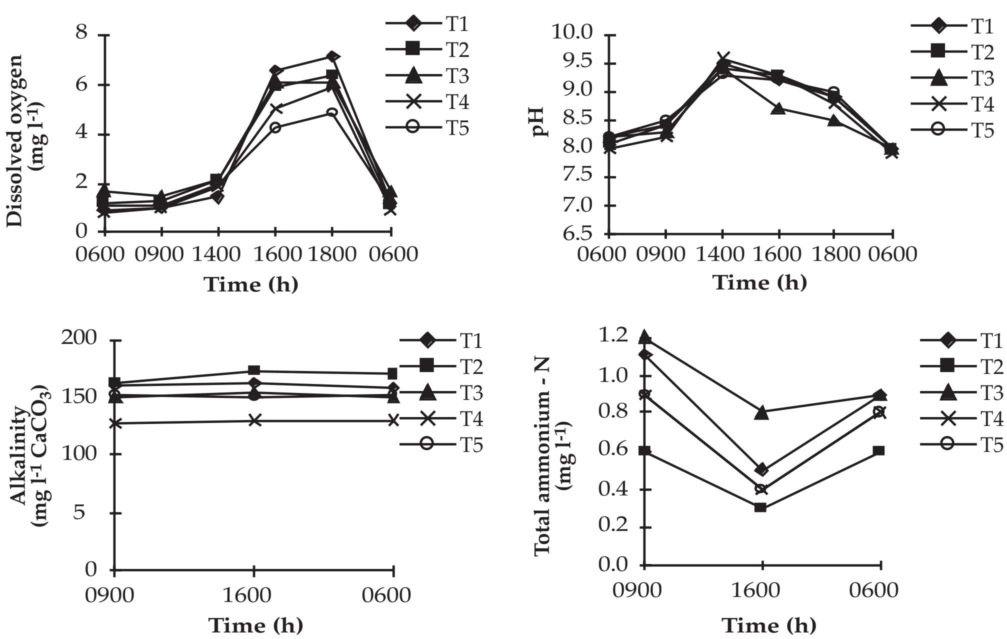

Figure 5. Mean monthly diel profile of dissolved oxygen, pH, alkalinity, and total ammonium nitrogen over the experimental period for treatments listed in Table 1.

Table 3. Mean monthly diel profile of water quality parameters over experimental period.

Parameters	Treatment	0600 h	0900 h	1400 h	1600 h	1800 h	0600 h
Temperature (°C)	T1	28.9 ± 0.2	29.0 ± 0.2	30.3 ± 0.2	30.8 ± 0.1	30.5 ± 0.2	29.0 ± 0.2
	T2	29.0 ± 0.2	29.1 ± 0.2	30.0 ± 0.3	30.4 ± 0.3	30.5 ± 0.1	28.9 ± 0.2
	T3	29.1 ± 0.2	29.2 ± 0.1	30.2 ± 0.1	30.9 ± 0.1	30.7 ± 0.3	29.1 ± 0.1
	T4	29.0 ± 0.0	29.2 ± 0.1	29.9 ± 0.1	30.6 ± 0.3	30.4 ± 0.1	29.0 ± 0.0
	T5	28.9 ± 0.1	29.1 ± 0.1	29.8 ± 0.1	30.3 ± 0.1	30.3 ± 0.0	29.0 ± 0.1
Dissolved Oxygen (mg l^{-1})	T1	0.9 ± 0.2	1.0 ± 0.1	1.4 ± 0.5	6.5 ± 0.6	7.1 ± 0.2	1.2 ± 0.1
	T2	1.2 ± 0.5	1.3 ± 0.6	2.1 ± 1.4	5.8 ± 2.3	6.4 ± 2.0	1.1 ± 0.7
	T3	1.7 ± 0.2	1.4 ± 0.0	2.2 ± 0.7	6.1 ± 1.5	6.1 ± 1.3	1.6 ± 0.1
	T4	0.8 ± 0.1	1.0 ± 0.3	1.8 ± 0.6	5.0 ± 1.4	5.9 ± 1.5	0.9 ± 0.1
	T5	1.1 ± 0.2	1.1 ± 0.2	2.0 ± 0.4	4.2 ± 0.3	4.8 ± 0.8	1.2 ± 0.2
pH	T1	8.2	8.4	9.5	9.2	8.9	8.0
	T2	8.1	8.4	9.4	9.3	8.9	8.0
	T3	8.2	8.3	9.7	8.7	8.5	8.0
	T4	8.0	8.2	9.6	9.3	8.8	7.9
	T5	8.2	8.5	9.3	9.2	9.0	8.0
Alkalinity (mg l^{-1} $CaCO_3$)	T1		161 ± 16		162 ± 3		158 ± 16
	T2		163 ± 18		172 ± 23		170 ± 22
	T3		150 ± 7		159 ± 9		150 ± 7
	T4		127 ± 24		130 ± 24		130 ± 26
	T5		152 ± 4		149 ± 5		152 ± 3
Total Ammonium Nitrogen (mg l^{-1})	T1		1.1 ± 0.2		0.5 ± 0.2		0.9 ± 0.2
	T2		0.6 ± 0.2		0.3 ± 0.1		0.6 ± 0.1
	T3		1.2 ± 0.1		0.8 ± 0.2		0.9 ± 0.3
	T4		0.9 ± 0.2		0.4 ± 0.1		0.8 ± 0.1
	T5		0.9 ± 0.2		0.4 ± 0.1		0.8 ± 0.0

LITERATURE CITED

APHA (American Public Health Association), 1980. Standard Methods for the Examination of Water and Wastewater, Fifteenth Edition. American Public Health Association, Washington, D.C., 1134 pp.

Boyd, C.E., 1978. Effluents from catfish ponds during fish harvest. J. Environ. Qual., 7:59-62.

Boyd, C.E., 1990. Water Quality in Ponds for Aquaculture. Agriculture Experiment Station, Auburn University, Alabama, 482 pp.

Diana, J.S., C.K. Lin, and K. Jaiyan, 1994. Supplemental feeding of tilapia in fertilized ponds. J. World Aquacult. Soc., 25:497-506.

Diana, J.S., C.K. Lin, and Y. Yi, 1996. Timing of supplemental feeding for tilapia production. J. World Aquacult. Soc., 27:410-419.

Egna, H.S., N. Brown, and M. Leslie, 1987. Pond Dynamics/ Aquaculture Collaborative Research Data Reports, Volume 1, General Reference: Site Descriptions, Materials and Methods for the Global Experiment. Pond Dynamics/Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, 84 pp.

Ghate, S.R., G.J. Burtle, G. Vellidis, and G.L. Newton, 1997. Effectiveness of grass strips to filter catfish (*Ictalurus punctatus*) pond effluent. Aquacult. Eng., 16:149-159.

Hollerman, W.D. and C.E. Boyd, 1985. Effects of annual draining on water quality and production of channel catfish in ponds. Aquaculture, 46:45-54.

Knud-Hansen, C.F., C.D. McNabb, and T.R. Batterson, 1993. The role of chicken manure in the production of Nile tilapia (*Oreochromis niloticus*). Aquacult. Fish. Manage., 24:483-493.

Kouka, P.J. and C.R. Engle, 1996. Economic implications of treating effluents from catfish production. Aquacult. Eng., 15:273-290.

Lin, C.K., M.K. Shrestha, D.P. Thakur, and J.S. Diana, 1998. Management to minimize the environmental impacts of pond draining. In: D. Burke, J. Baker, B. Goetze, D. Clair, and H. Egna (Editors), Fifteenth Annual Technical Report, Pond Dynamics/ Aquaculture CRSP, Office of International Research and Development, Oregon State University, Corvallis, Oregon, pp. 132-139.

Pillay, T.V.R., 1990. Aquaculture: Principles and Practices. Fishing Book News, London, 575 pp.

Pillay, T.V.R., 1992. Aquaculture and the Environment. Fishing Book News, London, 189 pp.

Raveh, A. and Y. Avnimelech, 1979. Total nitrogen analysis in water, soil and plant material with persulphate oxidation. Water Res., 13:911-912.

Schwartz, M.F. and C.E. Boyd, 1994a. Effluent quality during harvest of channel catfish from watershed ponds. Prog. Fish-Cult., 56:25-32.

Schwartz, M.F. and C.E. Boyd, 1994b. Channel catfish pond effluents. Prog. Fish-Cult., 56:273-281.

Schwartz, M.F. and C.E. Boyd, 1995. Constructed wetlands for treatment of channel catfish pond effluents. Prog. Fish-Cult., 57:255-266.

Seok, K., S. Leonard, C.E. Boyd, and M.F. Schwartz, 1995. Water quality in annually drained and undrained channel catfish ponds over a three-year period. Prog. Fish-Cult., 57:52-56.

Tucker, C.S., S.K. Kingsbury, J.W. Pote and C.L. Wax, 1996. Effects of water management practices on discharge of nutrients and organic matter from channel catfish (*Ictalurus punctatus*) ponds. Aquaculture, 147:57-69.

Cite as: [Author(s), 1999. Title.] *In*: K. McElwee, D. Burke, M. Niles, and H. Egna (Editors), Sixteenth Annual Technical Report. Pond Dynamics/ Aquaculture CRSP, Oregon State University, Corvallis, Oregon, [pp. ___.]