Management to Minimize the Environmental Impacts of Pond Draining

Eighth Work Plan, Thailand Research 3 (TR3)

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Introduction

Nutrient enrichment of pond waters is an essential management practice in aquaculture (Pillay, 1990; Boyd, 1990). However, the discharge of nutrient-rich water, an environmental regulatory concern in many countries, may result in the deteriorated quality of receiving waters (Pillay, 1992). Means to minimize the environmental impacts of pond effluents include minimizing the use of nutrients, managing drainage to retain most nutrients in the pond system, and maximizing the use of surplus materials in sediments by fish during grow-out. Several of these topics are the subject of current CRSP research. Previous research in Thailand has indicated that the most efficient nutrient application systems include combined organic and inorganic materials (Knud-Hansen et al., 1993). Such inputs result in the production of approximately 4,800 kg ha^{-1} of Nile tilapia (*Oreochromis niloticus*) per 150-day grow-out (Diana et al., 1994). Moreover, supplemental feeding of tilapia, combined with fertilization, increases fish yield and the mean harvest size of fish. When fish reach 100 to 150 g supplementation of 50% satiation feeding, in addition to optimal fertilization, appears to be the most efficient system for growing large tilapia (Diana et al., 1996).

Nutrient analyses of source and pond waters in Thailand indicate that fertilization systems optimal for fish growth cause a minimal increase in concentrations of phosphorus (P) and nitrogen (N) in pond waters during the course of grow-out (Diana et al., 1994). While nutrients may be lost with overflow water, they do not load receiving waters beyond normal levels during rain events. However, the water quality of effluents discharged during draining at harvest may be considerably lower, due to the accumulation of materials in pond sediments or in pond water near the soil-water interface (Pillay, 1992).

In this study we assess several harvest strategies to:

1. evaluate the amount of N, P, and solids discharged from pond waters during harvest draining; and
2. identify fish harvest techniques that may reduce the loading of nutrients and solids in effluent waters.

Methods and Materials

Fifteen earthen ponds, 200 m^2 in surface area, with an average depth of 1.2 m were used to culture sex-reversed Nile tilapia at the Asian Institute of Technology, Thailand. 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}), increasing TSP application to 1.4 kg (14 kg P ha^{-1}) from week 9 through 17. On 25 February 1997 fish were stocked at 1.5 fish m^{-2} at a size of 103 ± 1 g (mean ± SE). Fish were fed with commercial floating feed (30% crude protein) at 50% satiation six days per week. Satiation feeding rates were determined for each pond by measuring the total amount of feed consumed during two feeding session from 1000 to 1100 h and from 1400 to 1500 h on the Wednesday of each week. The 50% satiation feeding rate was based on the mean satiation feeding rate of 15 ponds. This rate was applied to each pond from Thursday through Tuesday. Fish were cultured 113 to 119 days and then harvested from June 19-25. Tilapia reproduction occurred in all ponds.

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, organic carbon, chlorophyll *a*, total suspended solids, and total volatile solids using standard methods (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 temperature, dissolved oxygen, pH, alkalinity, and total ammonium-nitrogen were determined at 0600, 0900, 1400, 1600, 1800, 2300, and 0600 h in each pond.

The experiment incorporated five management procedures that tested three harvest techniques. The management procedures were as follows: (A) fish were partially anaesthetized by addition of tea seed cake (10 ppm), 1.5 h prior to harvest. The pond was then seine-netted three times—an operation involving four persons; (B) ponds were limed (75 ppm calcium hydroxide) 24 hours prior to harvest, completely drained, and then fish were collected from a harvesting pit; (C) ponds were completely drained and fish collected from a harvesting pit; (D) ponds were drawn down to 50 cm and fish harvested by two seinings, followed by complete draining and collection of the remaining fish from a harvesting pit; and (E) involved the same draining and harvesting technique as in treatment D, but the pond water was drained into the empty ponds of procedure D. Each procedure/treatment was replicated three times in a blocked design. The locations of treatments within blocks were assigned on a random basis, with the exception that ponds under treatments D and E had to be adjacent to facilitate drainage of water from ponds in treatment E to ponds in treatment D.

The appropriate tea seed cake concentration (10 ppm) that was used to anesthetize the fish in treatment A was determined using a preliminary toxicity test that exposes tilapia (mean weight 500 g) to a series of tea seed cake concentrations over a 3-hour period. To establish the harvest efficiency of ponds in this treatment, ponds received a lethal dose of tea seed cake (15 ppm) one week post harvest. Pond water and tilapia fingerlings (5-10 g size) were tested for toxicity one week after harvest and found to be safe.

Similarly, a preliminary experiment on lime flocculation of suspended solids determined the liming dose used in treatment B.

Complete draining of pond water in treatments B and C was achieved by sequential draining. Ponds were first drained to 50 cm, then to 25 cm, and finally to 0 cm by lowering the pump to the respective water depths. The fish were then harvested from a harvesting pit. The draining and harvest technique described for treatments D and E is commonly practiced in Thailand; the pump was placed at the bottom of the pond.

Sediment deposition on the pond bottom was measured for ponds of treatments B and C; these ponds were completely drained, without seining. To measure pond mud deposition, bamboo sticks marked with a scale were inserted at three representative points in each pond at the beginning of the experiment. Sediment level increases in reference to previous marks were measured once ponds were completely drained at the end of experiment.

Pond water column samples were collected from treatment A and effluent samples, taken during harvest draining from treatments B, C, D, and E were collected when pond water levels were 100-50 cm, 50-25 cm, and 25-0 cm. For each treatment three effluent samples were collected for each water level, and mixed to provide a single representative sample for each depth. Column water samples of treatment A and effluent samples of treatments B, C, D, and E were analyzed for total N, total P, total solids, total volatile solids, suspended solids, volatile suspended solids, settleable matter, and five-day biochemical oxygen demand (BOD_5).

Data were analyzed using the Statgraphic 7.0 statistical package. Fish growth (g d^{-1}), survival (%), net yield (kg ha^{-1} d^{-1}) and extrapolated yield (kg ha^{-1} yr^{-1}) were calculated for each pond. Food conversion ratio (FCR) was calculated as the feed applied over the entire experiment divided by the net yield of each pond. Means include standard error, and differences were considered significant at an alpha level of 0.05 unless otherwise stated.

Table 1. Stocking and harvest size, fish growth, survival, food conversion ratio, and production of Nile tilapia cultured in fertilized ponds and supplemented with 50% satiation feeding.

Pond	Mean Stocking Size (g)	Mean Harvest Size (g)	Mean Growth (g d^{-1})	Survival (%)	Food Conversion Ratio	Net Fish Yield (kg ha^{-1} d^{-1})	Extrapolated Yield (kg ha^{-1} yr^{-1})
1	101	539	3.8	90	1.4	50.8	18554
2	101	565	4.1	100	1.2	61.6	22481
3	102	551	3.8	97	1.4	54.8	19998
4	102	540	3.7	100	1.3	56.2	20512
5	106	493	3.3	99	1.5	48.6	17724
6	106	518	3.5	95	1.5	48.7	17759
7	106	509	3.5	96	1.5	50.5	18426
8	111	529	3.7	96	1.4	53.0	19332
9	103	541	3.7	90	1.4	49.0	17876
10	101	543	3.8	98	1.3	55.3	20169
11	103	448	2.9	99	1.6	42.7	15597
12	100	514	3.6	97	1.4	52.6	19211
13	99	581	4.1	96	1.2	58.7	21432
14	105	528	3.6	93	1.5	49.3	17987
15	98	522	3.7	100	1.3	56.2	20527
Mean ± SE	103 ± 1	528 ± 8	3.7 ± 0.1	97 ± 1	1.4 ± 0.03	52.5 ± 1.2	19173 ± 449

Results

Mean values for harvest size, growth, survival, food conversion ratio, net yield and extrapolated yield of tilapia obtained from each pond (culture period of 113 to 119 days) are shown in Table 1. The mean satiation feeding level for tilapia, calculated weekly, ranged from 43.04 ± 1.4 to 165.3 ± 7.1 kg ha^{-1} d^{-1}, over the course of the experiment. The actual amount of feed applied to each pond at the rate of 50% mean satiation ranged from 21.5 kg ha^{-1} d^{-1} during the initial week to 82.5 kg ha^{-1} d^{-1} during the final weeks of the trials (Figure 1). Based on the satiation feeding level and fish biomass in each pond at stocking and harvest, mean satiation feeding rates were 2.8 ± 0.1% BWD for the initial week and 2.0 ± 0.1% BWD for the final week with actual feeding rates of 1.4% BWD for the initial week and 1.0% BWD during the final week of the experiment. The final week feeding rate decreased to 0.9% BWD when the weights of tilapia fry produced in ponds were taken into account.

Table 2 presents a summary of the physico-chemical parameters of pond waters measured at biweekly intervals at 0900 h. Similarly, the mean monthly diel temperature, dissolved oxygen, pH, alkalinity, and total ammonium-nitrogen recorded over a 24-hour period at 0600, 0900, 1400, 1600, 1800, 2300, and 0600 h are shown in Table 3.

The efficiencies of three different harvest techniques used during this experiment are given in Table 4. Efficiencies are expressed as the number of fish captured as a percentage of all surviving fish at the time of harvest.

Sediment deposition ranged from 3.6 to 10.2 cm with a mean of 6.3 ± 1.0 cm (Table 5). Sediment deposition varied slightly between three locations within a pond—the base of the dike slope, the center of the pond bottom and half-way between these points.

Water quality data from column water samples in treatment A and effluent water samples from treatments B, C, D, and E are presented in Table 6. Values for all parameters, except total nitrogen (BOD_5, settleable matter total solids, total volatile solids, total suspended solids, volatile suspended

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

Physico-Chemical Parameters	Mean ± SE	Range
Temperature (°C)	30.2 ± 0.0	30.0 - 30.6
Dissolved Oxygen (mg l^{-1})	3.1 ± 0.1	2.2 - 3.8
pH	6.9	6.5 - 7.7
Secchi Disk Visibility (cm)	19 ± 1	10 - 29
Alkalinity (mg l^{-1} $CaCO_3$)	86.8 ± 8.9	31.1 - 154.4
Total Ammonium-Nitrogen (mg l^{-1})	3.81 ± 0.59	0.82 - 8.25
Nitrite-Nitrogen (mg l^{-1})	0.28 ± 0.03	0.15 - 0.53
Nitrate- and Nitrite-Nitrogen (mg l^{-1})	1.10 ± 0.14	0.42 - 2.04
Total Nitrogen (mg l^{-1})	6.61 ± 0.43	4.62 - 9.44
Soluble Reactive Phosphorus (mg l^{-1})	0.11 ± 0.05	0.01 - 0.69
Total Phosphorus (mg l^{-1})	0.53 ± 0.06	0.27 - 1.20
Organic Carbon (mg l^{-1})	93.2 ± 2.9	76.7 - 120.4
Chlorophyll *a* (µg l^{-1})	132 ± 15	62 - 226
Total Suspended Solids (mg l^{-1})	113.5 ± 11.5	63.0 - 219.5
Volatile Suspended Solids (mg l^{-1})	30.8 ± 1.7	19.5 - 48.8
Pond Water Depth (m)	1.16 ± 0.02	1.05 - 1.33

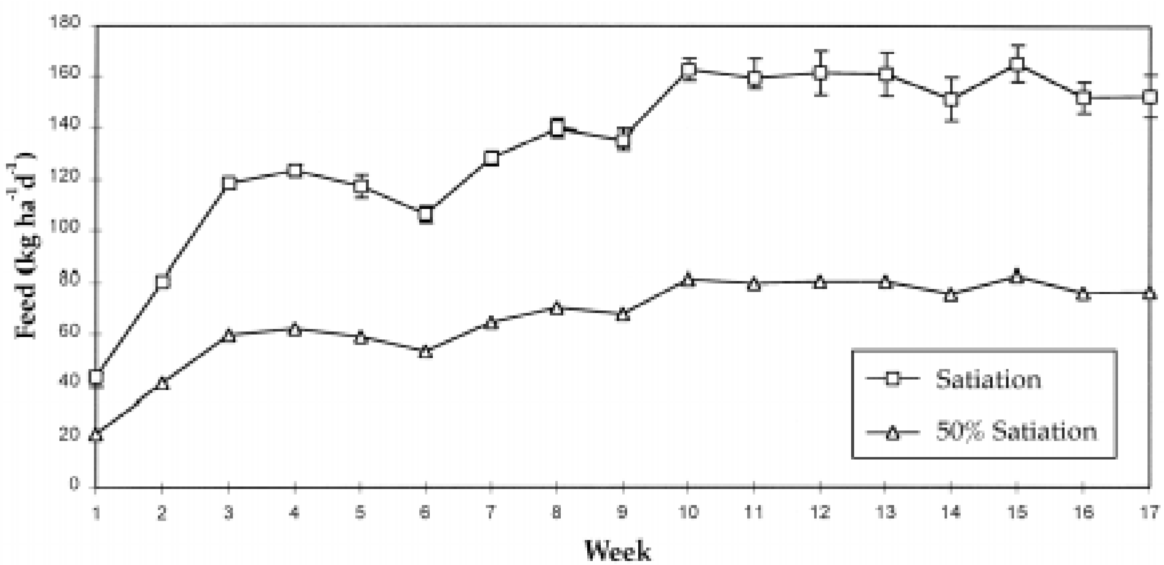

Figure 1. Mean satiation feeding level (kg ha^{-1} d^{-1}) (n = 15 ponds) and mean feeding rate (50% of mean satiation level) applied to each pond. Mean stocking size of fish was 103 ± 1 g at a stocking density of 1.5 fish m^{-2}. Mean harvest size of fish was 528 ± 8 g.

solids, and total phosphorus), were greater in effluent waters, for all harvest techniques, than they were in water column samples (of treatment A). Values for effluent water parameters increased significantly as pond water level was lowered during draining. Effluent values were also greatly increased after seining, in treatment D. Liming (treatment B) reduced the concentration of total suspended solids and phosphorus in the water column from the surface to 25 cm depth. However, the concentrations of solids and nutrients were substantially greater in the bottom water (0-25 cm).

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

Parameters	0600 h	0900 h	1400 h	1600 h	1800 h	2300 h	0600 h
Temperature (°C)	29.8 ± 0.1	30.0 ± 0.0	31.6 ± 0.1	32.0 ± 0.1	31.5 ± 0.2	30.5 ± 0.0	29.4 ± 0.1
Dissolved Oxygen (mg l^{-1})	0.3 ± 0.0	1.6 ± 0.1	5.1 ± 0.3	6.4 ± 0.4	6.4 ± 04	1.8 ± 0.2	0.3 ± 0.0
pH	6.8	6.9	7.0	7.1	7.2	6.8	7.1
Alkalinity (mg l^{-1} $CaCO_3$)		91.1 ± 9.0		88.7 ± 8.9			94.6 ± 9.2
Total Ammonium Nitrogen (mg l^{-1})		3.1 ± 0.5		2.8 ± 0.5			3.4 ± 0.5

Table 4. Efficiency of three harvest techniques. 1. Seining undrained pond after application of tea seed cake (treatment A); 2. Drainage of pond and collection of fish in a harvesting pit (treatments B and C); 3. Partial drainage of pond, followed by seining, then complete drainage of pond and collection of the remaining fish in a harvesting pit (treatments D and E).

Activity	Harvest Technique		
	1 (n = 3) *	2 (n = 6)	3 (n = 6)
Stocked (fish $pond^{-1}$)	300	300	300
1st Seining (%)	76 ± 5		66 ± 1
2nd Seining (%)	15 ± 4		19 ± 2
3rd Seining (%)	6 ± 1		
Collection from Harvest Pit (%)		100	15 ± 2
Harvest (fish $pond^{-1}$)	282 ± 4	290 ± 4	288 ± 4
Survival (fish $pond^{-1}$)	291 ± 3	290 ± 4	288 ± 5
Harvest Efficiency (%)	97 ± 3	100	100

* The number of fish not collected during seining was determined by the application of a lethal dose of tea seed cake (15 ppm) to ponds.

Table 5. Pond sediment deposition over the course of the experimental period.

Pond #	Sediment Deposition (cm)			
	Base of dike slope	*Midway between base of slope and pond center*	*Pond center*	*Mean*
1	1.5	6.1	3.3	3.6
2	5.5	5.5	6.5	5.8
7	5.5	7.0	7.6	6.7
8	6.3	4.7	2.0	4.3
12	6.9	6.7	8.6	7.4
15	10.5	11.5	8.5	10.2
Mean ± SE	6.0 ± 1.2	6.9 ± 1.1	6.1 ± 1.1	6.3 ± 1.0

Table 6. Comparison of water quality of column water samples from undrained ponds (A) and effluent quality during draining (B, C, D, and E). A = Harvesting fish by three seinings, without pond draining, after anaesthetizing fish using tea seed cake (n = 3). B = Complete draining of pond water after liming and fish harvested from harvest pit (n = 3). C = Complete draining of pond water and fish harvested from harvesting pit (n = 3). D and E = Draw down of water to 50 cm and fish harvested by two seinings and followed by complete draining and fish collection from harvesting pit (n = 6).

Effluent Parameter	Treatment	Pond Water Level During Draining			Weighted Mean	Probability
		100-50 cm	*50-25 cm*	*25-0 cm*		
Biological	A*	n/a	n/a	n/a	31 ± 4	Harvest
Oxygen	B	57 ± 7	56 ± 5	228 ± 27	100 ± 4	Technique
Demand	C	51 ± 10	47 ± 13	87 ± 22	59 ± 13	$P > 0.05$
(BOD_5)	D + E	63 ± 21	167 ± 46	149 ± 33	111 ± 27	Depth Level
(mg l^{-1})	Mean ± SE	59 ± 10	109 ± 28	153 ± 23		$P < 0.05$
Settleable	A*	n/a	n/a	n/a	0.0 ± .0	Harvest
matter	B	0.1 ± 0.0	0.2 ± 0.1	37.0 ± 10.0	9.3 ± 2.5	Technique
(ml l^{-1})	C	0.2 ± 0.1	0.3 ± .1	10.7 ± 6.8	2.9 ± 1.7	$0.1 > P > 0.05$
	D + E	3.2 ± 1.1	28.1 ± 12.9	22.0 ± 4.8	14.2 ± 4.0	Depth Level
	Mean ± SE	1.7 ± 0.7	14.2 ± 7.4	22.9 ± 4.5		
						$P < 0.05$
Total	A*	n/a	n/a	n/a	842 ± 65	Harvest
Solids	B	1013 ± 17	1132 ± 38	5978 ± 1347	2284 ± 322	Technique
(mg l^{-1})	C	1053 ± 29	1058 ± 80	3575 ± 1251	1685 ± 345	$0.1 > P > 0.05$
	D + E	1589 ± 187	5937 ± 2234	4536 ± 564	3413 ± 686	Depth Level
	Mean ± SE	1311 ± 123	3516 ± 1291	4656 ± 541		
						$P < 0.05$
Total	A*	n/a	n/a	n/a	124 ± 23	Harvest
Volatile	B	163 ± 14	159 ± 16	692 ± 128	295 ± 27	Technique
Solids	C	150 ± 20	149 ± 20	382 ± 123	208 ± 43	$P < 0.05$
(mg l^{-1})	D + E	190 ± 16	589 ± 165	549 ± 62	380 ± 42	Depth Level
	Mean ± SE	173 ± 11	371 ± 103	543 ± 58		$P < 0.05$
Total	A*	n/a	n/a	n/a	205 ± 50	Harvest
Suspended	B	119 ± 10	178 ± 33	5682 ± 1480	1525 ± 361	Technique
Solids	C	276 ± 22	274 ± 50	1957 ± 691	696 ± 186	$0.1 > P > 0.05$
(mg l^{-1})	D + E	749 ± 201	5180 ± 2320	3913 ± 632	2648 ± 729	Depth Level
	Mean ± SE	473 ± 128	2703 ± 1335	3866 ± 608		$P < 0.05$
Volatile	A*	n/a	n/a	n/a	52 ± 11	Harvest
Suspended	B	39 ± 10	48 ± 8	577 ± 130	176 ± 26	Technique
Solids	C	53 ± 8	49 ± 13	223 ± 65	94 ± 21	$P < 0.05$
(mg l^{-1})	D + E	100 ± 12	502 ± 174	408 ± 50	278 ± 51	Depth Level
	Mean ± SE	73 ± 10	275 ± 107	404 ± 54		$P < 0.05$
Total	A*	n/a	n/a	n/a	13.9 ± 3.4	Harvest
Nitrogen	B	10.1 ± 1.7	15.3 ± 2.4	20.3 ± 3.4	13.± 1.6	Technique
(mg l^{-1})	C	4.9 ± 0.4	5.1 ± 0.7	8.5 ± 0.7	5.9 ± .2	$P < 0.05$
	D + E	6.6 ± 0.7	11.6 ± 2.0	12.2 ± 0.9	9.3 ± 0.8	Depth Level
	Mean ± SE	7.1 ± 0.7	10.9 ± 1.5	13.3 ± 1.6		$P < 0.05$
Total	A*	n/a	n/a	n/a	0.97 ± 0.24	Harvest
Phosphorus	B	0.58 ± 0.10	0.63 ± 0.08	2.23 ± 0.26	1.01 ± 0.03	Technique
(mg l^{-1})	C	0.88 ± 0.21	0.87 ± 0.21	1.53 ± 0.06	1.04 ± 0.15	$P > 0.05$
	D + E	0.80 ± 0.09	0.95 ± 0.12	1.24 ± 0.16	0.95 ± 0.10	Depth Level
	Mean ± SE	0.76 ± 0.07	0.85 ± 0.09	1.56 ± 0.16		$P < 0.05$

* Column water sample of ponds which were not drained and fish were harvested only by seining.

Discussion

The growth of tilapia in the current experiment averaged 3.7 g d^{-1}. Tilapia grew from 103 to 528 g over a mean culture period of 116 days, giving a mean yield of 52.5 kg ha^{-1} d^{-1}. This growth is comparable to, or higher than, that achieved in other studies (Green, 1992; Diana et al., 1994; Diana et al., 1996). This suggests that the feeding (daily feeds of 1.4% BWD dropping to 1% BWD), fertilization (urea at 28 kg N ha^{-1} and TSP at 7 kg P ha^{-1}, increasing to 14 kg P ha^{-1}, weekly), and stocking (1.5 fish m^{-1}) regimes utilized during the course of this experiment were sufficient to ensure good growth rates.

Mean total ammonium-nitrogen concentrations increased constantly after the fifth week of the experiment; however, the increase did not cause fish mortality. Perhaps this is because of continually low pH values, that did not exceed 7.7 (see Table 2) possibly suggesting that to further improve the feeding system nitrogen fertilization can be reduced.

The commonly used Thai practice of partially draining a pond, seining, then completely draining to collect the remaining fish (as incorporated in treatments D and E) results in a large amount of waste being discharged. The wastes discharged from a one-hectare pond would be equivalent to 1.1 t of BOD_5, 142 m^3 of settleable matter, 34.1 t of total solids, 3.8 t of total volatile solids, 26.5 t of total suspended solids, 2.8 t of volatile suspended solids, 93 kg of total nitrogen and 9.5 kg of total phosphorus. Adoption of the technique of complete drainage, to allow collection of fish (as used in treatment C) results in the following reductions of effluent levels: 47% of BOD_5, 80% of settleable matter, 51% of total solids, 45% of total volatile solids, 74% of total suspended solids, 68% of volatile suspended solids and 37% of total nitrogen.

The water quality of pond effluent in the limed treatment (B) indicates that liming concentrates pollutants in the pond bottom waters. Hence, if ponds are limed, then careful treatment of bottom water during drainage disposal should be considered.

It is possible to use fish culture ponds, without draining them, for several years because natural microbial and physico-chemical processes remove nutrients and organic matter from pond water (Tucker et al., 1990). For example, in the southeast United States channel catfish (*Ictalurus punctatus*) are cultured in ponds which are not drained for as long as 20 years. In spite of large inputs of metabolic waste, resulting from feeding practices, nutrients and organic matter in the water column do not reach deleterious levels (Hollerman and Boyd, 1985; Seok et al., 1995). The present study shows that the use of tea seed cake to anesthetize tilapia can allow effective harvest by seining, without draining the pond. Harvest efficiency of 97% was achieved using this technique. Alternatively, the discharge of drainage water into the environment can be reduced by using drained water to refill empty ponds, as in treatment E. However, accumulation of sediment will necessitate eventual drainage of culture ponds. Deposition of sediments occurred at a rate of 6.3 ± 1.0 cm over the four months of the grow-out period. To minimize the discharge of waste products, and to avoid excessive accumulation of sediment we propose that ponds be drained every four or five years.

Anticipated Benefits

This study has evaluated the content and quantity of tilapia pond effluent of harvest draining and demonstrated the potential for tilapia harvest that do not involve draining. Results of the study have shown that modified harvest draining techniques reduce the amount of waste discharged. Implementation of the techniques suggested in this study will greatly minimize the environmental impacts of pond draining.

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