Effect of Mud Turbidity on Fertilization, and an Analysis of Techniques to Mitigate Turbidity Problems in Wet Season

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Abstract

The experiment was conducted in fifteen earthen ponds at the Asian Institute of Technology, Thailand, from June to November 1998 to assess the effects of various turbidity mitigation techniques on fish growth and water quality. The five treatments were: A) control; B) covering the upper 50 cm of pond dikes with black plastic to prevent turbidity from runoff; C) covering pond bottoms with green manure (terrestrial weeds) to alter soil texture; D) covering pond bottoms with small-mesh (1-cm) net to prevent turbidity from fish disturbance; and E) covering pond dikes with rice straw. All ponds were fertilized weekly with chicken manure at a rate of 500 kg ha^{-1} (dry matter basis) supplemented with urea and triple superphosphate (TSP) to provide 28 kg N ha^{-1} wk^{-1} and 7 kg P ha^{-1} wk^{-1}. Sex-reversed all-male Nile tilapia (*Oreochromis niloticus*) were stocked at 2 fish m^{-2} at a size of 19.0 ± 1.0 g. No significant differences of fish survival were found among all treatments. The straw- and weed-covered treatments resulted in significantly higher fish growth and yield. In contrast, the edge- and bottom-covered treatments neither increased fish yield nor improved water quality compared with the control, indicating that those mitigating techniques were not effective. The straw-covered treatment was the innovation of the experiment. Pond water in straw-covered ponds was green throughout the experimental period with low colloidal turbidity, which resulted in the highest fish yield among all treatments. The straw-covered treatment was probably the best mitigating technique in wet season.

Introduction

Mud turbidity is a global problem in fish ponds with heavy clay dikes and bottoms. Colloidal clay particles from the dikes and bottom (as well as from runoff and source water) suspended in the water column inhibit plankton growth by reducing light penetration and by binding with mineral nutrients from water as well as with plankton cells (Avinimelech et al., 1981, 1982). High mud turbidity usually causes acidity, low nutrient levels, and limited light penetration for photosynthesis (Boyd, 1990), and thus results in reduced primary production (Diana et al., 1991). With only fertilizer inputs, turbidity often limits production and growth of fish (Buck 1956; Banarjea and Ghosh, 1963). From these points of view, mitigation of mud turbidity is essential to enhance and allow normal phytoplankton growth in response to fertilization.

The purpose of this study was to evaluate several mud turbidity mitigation techniques in order to: 1) assess effects of different mitigation techniques on fish growth, and 2) find a suitable approach for turbidity mitigation during the rainy season.

Methods and Materials

The experiment was conducted in fifteen 200-m^2 earthen ponds with an average depth of 1.0 m at the Asian Institute of Technology (AIT), Thailand. All ponds were fertilized weekly with chicken manure at a rate of 500 kg ha^{-1} (dry matter basis) supplemented with urea and triple superphosphate (TSP) to provide 28 kg N ha^{-1} wk^{-1} and 7 kg P ha^{-1} wk^{-1}. Sex-reversed all-male Nile tilapia (*Oreochromis niloticus*) were stocked at 2 fish m^{-2} at a size of 19.0 ± 1.0 g (mean ± SE) on 24 June 1998.

The ponds were grouped randomly for five treatments, with triplicate ponds for each treatment. The five treatments were: A) control; B) covering upper 50 cm of pond dikes with black plastic to prevent turbidity from runoff (edge-covered); C) covering pond bottoms with green manure (terrestrial weeds) to alter soil texture (weed-covered); D) covering pond bottoms with small-mesh (1-cm) net to prevent turbidity from fish disturbance (bottom-covered); and E) covering pond dikes with rice straw (straw-covered).

Water quality analysis was conducted biweekly by taking integrated water column samples at 0900 h from walkways extending to the center of the ponds. Pond water samples were analyzed for dissolved oxygen (DO), temperature, pH, 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) using standard methods (APHA, 1980; Egna et al., 1987). Secchi disk depth was measured at 0900 h every two days in all the ponds throughout the experimental period. Diel measurements for temperature, DO, and pH were conducted monthly for each pond at three different depths (25 cm below water surface, middle, and 25 cm above pond bottom) at 0600, 0900, 1400, 1600, 1800, and 0600 h, and alkalinity and TAN were determined at 0900, 1600, and 0600 h.

Prior to stocking, DO concentration in the weed-covered ponds was monitored at 0600 h daily for two weeks to check the changes in DO concentration. Weeds grown at the bottom of those ponds were uprooted or cut to 10–20 cm high before flooding.

Bottom soil samples collected from nine points in each pond were air-dried, mixed, and homogenized. A subsample was taken from the homogenized sample for analyzing total nitrogen, total phosphorus, and organic matter at the beginning and end of the experiment.

To avoid causing turbidity, fish were not sampled during the entire 149-day experimental period, until harvest on 20 November 1998. Final biomass and numbers were determined. Daily weight gain (DWG, g fish^{-1} d^{-1}), yield (kg pond^{-1}), and extrapolated yield (kg ha^{-1} yr^{-1}) were calculated.

Data 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. Results are reported with mean ± 1 standard error (SE).

RESULTS

Fish growth was best in the straw-covered treatment and poorest in the bottom-covered treatment (Table 1). Final mean weight, mean DWG, and net fish yield in the straw-covered treatment were significantly ($P < 0.05$) higher than those in the control, edge-, and bottom-covered treatments, but not significantly ($P > 0.05$) different from those in the weed-covered treatment. There were no significant ($P > 0.05$) differences of final mean weight, mean weight gain, or mean DWG among the control, edge-, bottom-, and weed-covered treatments although fish yields in the weed-covered treatment were significantly higher ($P < 0.05$). However, no significant

Table 1. Growth performance of Nile tilapia in the 149-day experiment.

Performance	Treatment				
	Control	*Edge-covered*	*Weed-covered*	*Bottom-covered*	*Straw-covered*
Initial Biomass (kg pond^{-1})	7.6 ± 0.1^a	8.0 ± 0.4^a	7.9 ± 0.3^a	7.9 ± 0.3^a	7.9 ± 0.4^a
Initial Mean Wt. (g fish^{-1})	19.1 ± 0.3^a	19.9 ± 0.6^a	19.7 ± 0.7^a	19.8 ± 0.5^a	19.8 ± 0.5^a
Final Biomass (kg pond^{-1})	22.2 ± 11.5^a	26.8 ± 7.4^a	56.6 ± 16.4^b	20.6 ± 11.7^a	68.3 ± 28.7^b
Final Mean Wt. (g fish^{-1})	124.9 ± 19.0^a	90.0 ± 32.8^a	184.4 ± 61.0^{ab}	83.4 ± 39.6^a	235.5 ± 123.1^b
Mean Wt. Gain (g fish^{-1})	105.8 ± 9.1^a	70.1 ± 16.0^a	164.8 ± 28.1^{ab}	63.6 ± 19.1^a	233.7 ± 58.0^b
Mean DWG (g fish^{-1} d^{-1})	0.67 ± 0.07^a	0.47 ± 0.12^a	1.10 ± 0.21^{ab}	0.43 ± 0.12^a	1.57 ± 0.37^b
Net Fish Yield (kg pond^{-1})	14.6 ± 5.3^a	18.8 ± 3.6^a	48.5 ± 7.6^b	12.7 ± 5.5^a	60.9 ± 13.6^b
Extrapolated Net Fish Yield (kg ha^{-1} yr^{-1})	1,459 ± 528^a	1,878± 366^a	4,853 ± 760^b	1266 ± 554^a	6,090 ± 1,366^b
Survival (%)	45.8 ± 12.9^a	75.8 ± 8.2^a	76.8 ± 1.3^a	64.8 ± 13.9^a	70.1 ± 9.8^a

* Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

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

Water Quality	Treatment				
	Control	*Edge-covered*	*Weed-covered*	*Bottom-covered*	*Straw-covered*
DO at Dawn (mg l^{-1})	0.9 ± 0.1^a	1.8 ± 0.1^b	2.5 ± 0.3^b	0.8 ± 0.3^a	1.2 ± 0.3^a
Temperature (°C)	27.7 ± 0.2^a	28.0 ± 0.2^a	28.6 ± 0.1^a	27.6 ± 0.3^a	28.1 ± 0.1^a
Alkalinity (mg $CaCO_3$ l^{-1})	130.0 ± 19.1^a	99.3 ± 8.4^a	90.7 ± 13.9^a	115.3 ± 16.2^a	152.0 ± 2.3^a
pH	7.8 ± 0.4^a	7.7 ± 0.2^a	8.1 ± 0.1^a	8.0 ± 0.5^a	8.2 ± 0.3^a
TKN (mg l^{-1})	7.56 ± 1.38^a	6.28 ± 1.34^a	5.74 ± 0.59^a	5.99 ± 0.50^a	6.54 ± 0.33^a
TAN (mg l^{-1})	0.57 ± 0.25^a	1.22 ± 0.12^b	0.72 ± 0.04^a	0.50 ± 0.43^a	0.69 ± 0.13^a
Nitrite Nitrogen (mg l^{-1})	0.11 ± 0.05^a	0.22 ± 0.08^a	0.07 ± 0.01^a	0.09 ± 0.04^a	0.13 ± 0.04^a
Nitrate-Nitrite Nitrogen (mg l^{-1})	0.69 ± 0.30^a	0.73 ± 0.05^a	0.21 ± 0.05^a	0.69 ± 0.36^a	0.32 ± 0.13^a
Total Phosphorus (mg l^{-1})	1.05 ± 0.08^a	0.86 ± 0.13^a	0.48 ± 0.04^b	0.85 ± 0.15^a	0.91 ± 0.06^a
SRP (mg l^{-1})	0.88 ± 0.06^a	0.38 ± 0.06^b	0.09 ± 0.09^c	0.64 ± 0.12^a	0.60 ± 0.19^a
Secchi Disk Depth (cm)	8.3 ± 0.3^a	12.7 ± 0.7^b	14.0 ± 1.5^b	10.0 ± 2.6^b	12.7 ± 3.7^b
Chlorophyll *a* (mg l^{-1})	153.2 ± 79.4^a	203.8 ± 19.6^a	171.6 ± 68.2^a	45.2 ± 18.1^a	93.3 ± 64.9^a
TSS (mg l^{-1})	201.9 ± 29.8^a	98.3 ± 19.9^b	107.1 ± 12.7^b	119.7 ± 17.8^b	103.6 ± 13.0^b
TVS (mg l^{-1})	39.9 ± 14.6^a	20.4 ± 5.6^a	32.0 ± 3.5^a	31.9 ± 13.6^a	30.3 ± 8.7^a

* Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

Table 3. Mean water quality variables throughout the experiment.

Water Quality	Treatment				
	Control	*Edge-covered*	*Weed-covered*	*Bottom-covered*	*Straw-covered*
DO at Dawn (mg l^{-1})	2.0 ± 0.2^{a}	3.0 ± 0.3^{b}	2.3 ± 0.2^{a}	2.1 ± 0.2^{a}	1.7 ± 0.2^{a}
Temperature (ºC)	29.7 ± 0.2^{a}	30.0 ± 0.2^{a}	30.7 ± 0.1^{b}	29.9 ± 0.2^{a}	30.1 ± 0.2^{a}
Alkalinity (mg $CaCO_3$ l^{-1})	101.5 ± 4.3^{a}	90.8 ± 2.6^{a}	93.9 ± 6.4^{a}	91.5 ± 3.9^{a}	158.0 ± 6.8^{b}
pH	7.7 ± 0.1^{a}	7.8 ± 0.1^{a}	7.5 ± 0.1^{a}	7.7 ± 0.1^{a}	8.1 ± 0.1^{b}
TKN (mg l^{-1})	5.26 ± 0.50^{a}	4.22 ± 0.37^{a}	4.17 ± 0.46^{a}	4.59 ± 0.42^{a}	4.81 ± 0.40^{a}
TAN (mg l^{-1})	1.26 ± 0.16^{a}	1.55 ± 0.14^{a}	1.14 ± 0.15^{a}	1.37 ± 0.17^{a}	0.78 ± 0.12^{b}
Nitrite Nitrogen (mg l^{-1})	0.14 ± 0.03^{a}	0.23 ± 0.03^{b}	0.07 ± 0.02^{a}	0.15 ± 0.03^{a}	0.12 ± 0.03^{a}
Nitrate-Nitrite Nitrogen (mg l^{-1})	0.69 ± 0.20^{a}	0.60 ± 0.07^{a}	0.21 ± 0.03^{b}	0.79 ± 0.19^{a}	0.26 ± 0.06^{b}
Total Phosphorus (mg l^{-1})	0.59 ± 0.06^{a}	0.43 ± 0.04^{a}	0.27 ± 0.02^{b}	0.49 ± 0.06^{a}	0.64 ± 0.03^{a}
SRP (mg l^{-1})	0.29 ± 0.05^{a}	0.18 ± 0.03^{a}	0.02 ± 0.00^{b}	0.25 ± 0.05^{a}	0.24 ± 0.04^{a}
Secchi Disk Depth (cm)	11.4 ± 0.3^{a}	14.8 ± 0.3^{b}	26.1 ± 0.9^{d}	15.3 ± 0.5^{b}	18.7 ± 0.5^{c}
Chlorophyll *a* (mg l^{-1})	84.4 ± 13.5^{ab}	48.2 ± 8.8^{a}	104.5 ± 11.8^{b}	49.2 ± 11.5^{a}	121.7 ± 11.3^{b}
TSS (mg l^{-1})	111.4 ± 10.9^{a}	82.2 ± 6.1^{b}	162.9 ± 42.2^{a}	103.4 ± 21.25^{a}	87.1 ± 10.3^{b}
TVS (mg l^{-1})	31.9 ± 3.7^{b}	22.1 ± 1.9^{a}	28.4 ± 3.0^{b}	29.0 ± 3.4^{b}	36.9 ± 4.6^{b}

* Mean values with different superscript letters in the same row are significantly different ($P < 0.05$).

difference of survival ($P > 0.05$) was found among all treatments.

The final and overall means of water quality parameters are listed in Tables 2 and 3, respectively. Water temperature and pH throughout the experimental period in all ponds ranged from 27.0 to 38.4°C and 5.8 to 10.1, respectively. There was no significant difference of pH among treatments at the end of the experiment; the overall mean of pH in the straw-covered treatment was significantly ($P < 0.05$) higher than the mean of pH in other treatments. The measured DO concentrations at dawn fluctuated between 0.2 and 7.4 mg l^{-1} over the entire culture period (Figure 1). The edge-covered treatment had significantly ($P < 0.05$) higher overall mean DO concentration than the mean DO concentrations in other treatments. Lowest overall mean DO concentration was observed in the straw-covered treatment, but not significantly ($P > 0.05$) different from the control, weed-, edge-, and bottom-covered treatments. Final DO concentration in the control, bottom-, and straw-covered treatments was significantly ($P < 0.05$) lower than DO concentration in the edge- and weed-covered treatments. In the straw-covered treatment the DO concentrations at dawn were low at the beginning of the experiment and were similar to other treatments after two months before dropping slightly at the end of the experiment (Figure 1). Un-ionized ammonia nitrogen concentrations were generally low and similar among all treatments (Figure 1). Overall mean alkalinity concentration over the experimental period in the straw-covered treatment was significantly ($P < 0.05$) higher than mean alkalinity concentration in other treatments (Table 3). No significant ($P > 0.05$) differences were found for overall mean TKN among all treatments. Overall mean nitrite nitrogen concentration was significantly ($P < 0.05$) higher in the edge-covered treatment than that in other treatments. Final nitrite and nitrate nitrogen concentrations were not significantly ($P > 0.05$) different among all treatments, but overall mean nitrate nitrogen concentrations in the control, edge-, and bottom-covered treatments were significantly ($P < 0.05$) higher than those in the other two treatments. Chlorophyll *a* concentrations increased over the experimental period in all treatments (Figure 1). The overall mean chlorophyll *a* concentration was significantly ($P < 0.05$) higher in the straw- and weed-covered treatments in comparison with the other treatments (Table 3). Overall mean TSS concentrations in the straw- and edge-covered treatments were significantly ($P < 0.05$) lower than mean TSS concentrations in the control, bottom-, and weed-covered treatments

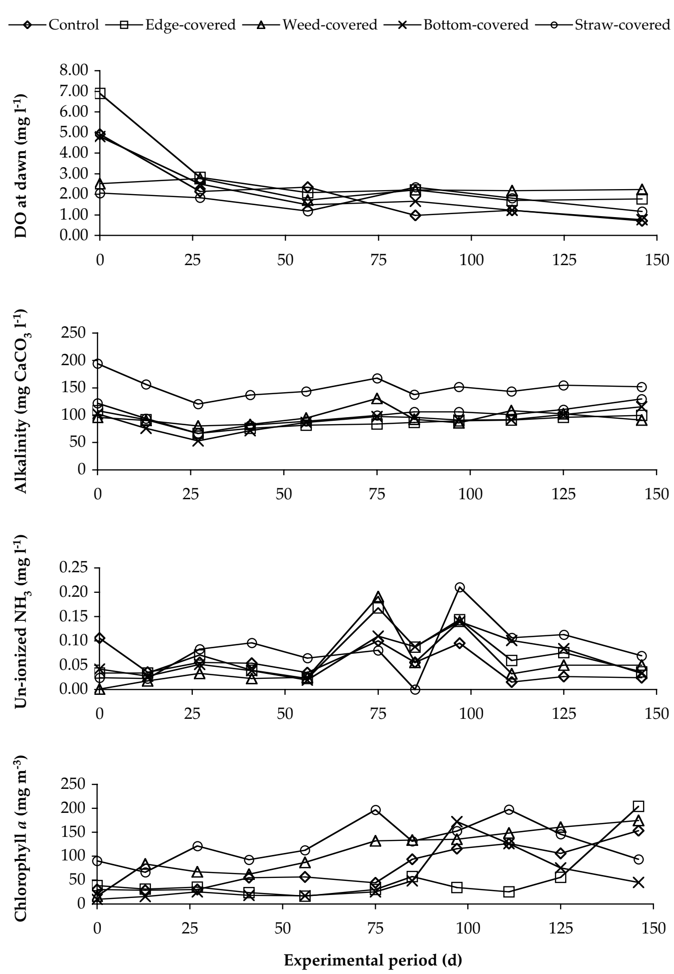

Figure 1. Changes in concentrations of dissolved oxygen (DO) at dawn, un-ionized ammonia nitrogen, alkalinity, and chlorophyll *a* in pond water during the 149-day experiment.

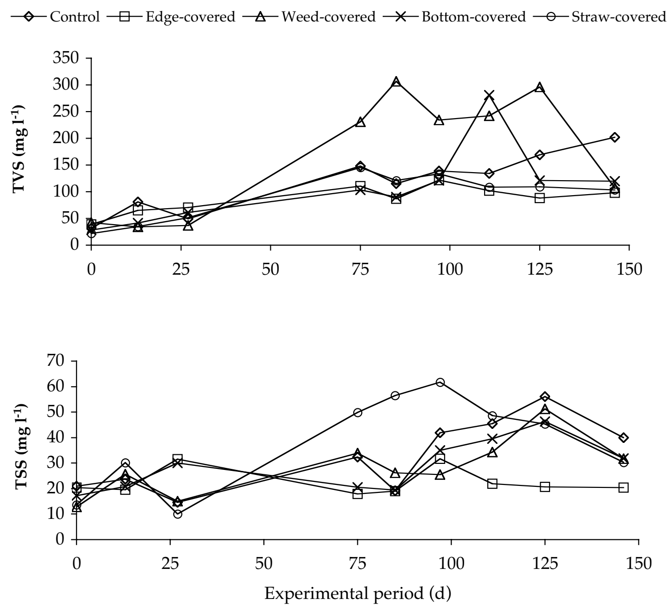

Figure 2. Changes in total suspended solids (TSS) and total volatile solids (TVS) in pond water during the 149-day experiment.

(Table 3). The straw-covered treatment had lower overall mean TSS, but higher TVS compared to the other treatments (Figure 2). Overall TSS was highest in the weed-covered treatment, but the control had the highest final TSS, which was significantly ($P < 0.05$) higher than the final TSS in other the treatments (Tables 2 and 3). Secchi disk depth declined over the experimental period (Figure 3). The overall mean value of Secchi disk depth in the weed-covered treatment was significantly ($P < 0.05$) higher than the overall mean value in the straw-covered treatment, which was further significantly ($P < 0.05$) higher than the overall mean value in the other treatments. The control had the lowest overall mean value of Secchi disk depth ($P < 0.05$).

DISCUSSION

Among the mitigation techniques, the straw- and weed-covered treatments, especially the straw-covered treatment, resulted in significantly ($P < 0.05$) higher fish growth rates and yields compared with the control ponds. DWG of fish and net fish yield in the straw-covered treatment were 2.3 and 4.2 times higher, respectively, than DWG and net fish yield in the control.

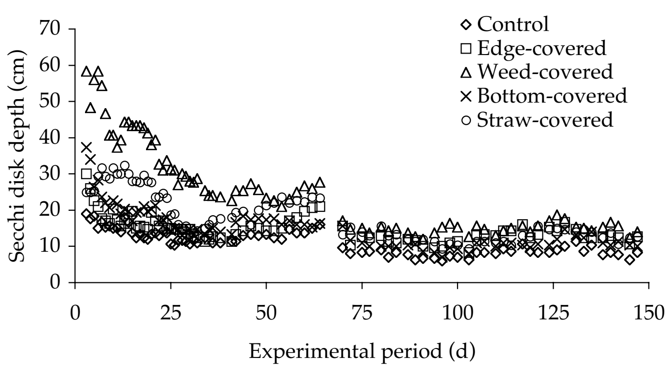

Figure 3. Changes in Secchi disk depth during the 149-day experiment.

Due to the decomposition of rice straw, DO concentration at dawn in the straw-covered treatment was rather low during the first two months, but increased towards the end of the experimental period. In contrast, DO concentration in the bottom-covered treatment decreased with time, from a relatively high level at the beginning to quite a low level at the end of the experiment. This probably indicated the accumulation of organic matter derived from fertilization with chicken manure and fish wastes on undisturbed pond bottoms. Decreasing DO concentration and probably low primary productivity, as indicated by low concentrations of chlorophyll *a* in these ponds, attributed to the retarded growth and low yield of fish.

In the bottom-covered treatment, netting material prevented turbidity caused by fish disturbance of pond bottoms; however, this may have reduced nutrient release from pond mud. Compared to the control, total phosphorus and chlorophyll *a* were relatively low in the bottom-covered treatment. Plankton growth is regulated to some extent by the concentration of phosphorus in the mud of natural waters (Boyd, 1990). However, compared to the control, ponds with covered bottoms did not evidence a significant reduction in fish growth, implying that Nile tilapia feed mainly on phytoplankton in the water column rather than graze on the pond bottom, which is consistent with the results obtained during the dry season in a previous experiment (Lin et al., 1999).

The edge-covered treatment was designed to prevent turbidity caused by dike runoff during the rainy season. In the dry season, there was no significant difference in most water quality parameters and fish growth performance between the control and the edge-covered treatment (Lin et al., 1999). In contrast, the overall TSS and Secchi disk depth in the edge-covered treatment were significantly different from TSS and Secchi disk depth of the control in the present experiment conducted during the wet season, indicating that the edge-covered treatment was effective in mitigating turbidity problems caused by runoff. However, the overall mean chlorophyll *a* level in the edge-covered treatment was apparently lower than the chlorophyll *a* level of the control, although there was no significant difference. Also the edge-covered treatment did not result in increased fish yields compared with the control. The results revealed that grazing on pond edges by Nile tilapia was less important than feeding on phytoplankton in the water column.

In a previous dry-season experiment, high fish mortality was observed in the weed-covered treatment due to DO depletion caused by the decomposition of terrestrial weeds in ponds during the first month of the experiment (Lin et al., 1999). However, there were no significant differences in survival among all treatments in the present experiment due mainly to the better timing of stocking fish. Ponds containing macrophytes usually had clearer water and, upon decay, dead vegetation increased the concentration of carbon dioxide, decreased pH, and resulted in the precipitation of colloidal clay (Irwin and Stevenson, 1951). In the present experiment, significantly higher Secchi disk visibility and lower TSS were observed in the weed-covered treatment at the end of the experiment compared with the control.

Reasonable Secchi disk visibility (20 to 30 cm) with a high level of chlorophyll *a* resulted in significantly greater fish yield in the straw-covered treatment. The decay of rice straw at the beginning of the experiment, although it reduced DO concentration, provided additional nutrients for plankton growth. Meanwhile, turbidity from dike runoff was mitigated. The straw-covered treatment was probably the best mitigating technique in wet season. However, more research on physical and chemical changes of pond water caused by rice straw is needed.

ANTICIPATED BENEFITS

The results generated in this study, in addition to similar studies in turbidity control at the other CRSP sites, will link bottom soil characteristics and water quality management for semi-intensive fish ponds. Turbidity problems prevail in many rain-fed ponds in Thailand, Cambodia, and Laos, where the available fertilizer input is reduced in effectiveness by turbidity, resulting in poor fish yields and a lack of interest in managing such ponds. The topic of turbidity control has been considered a priority by the Royal Thai Government Department of Fisheries and also by the Asian Institute of Technology outreach project.

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