JOURNAL OF THE
WORLD AQUACULTURE SOCIETY

Vol. 42, No. 5
October, 2011

Pond Bottom Management at Commercial Shrimp Farms in Chantaburi Province, Thailand

VASIN YUVANATEMIYA

Faculty of Environment and Resource Studies, Mahidol University, Salaya, Nakhonpathom 73170, Thailand

CLAUDE E. BOYD[1]

Department of Fisheries and Allied Aquacultures, Auburn University, Auburn, Alabama 36849-5419, USA

PATANA THAVIPOKE

Faculty of Environment and Resource Studies, Mahidol University, Salaya, Nakhonpathom 73170, Thailand

Abstract

Most shrimp farmers in Chantaburi Province, Thailand, use water jets to dislodge sediment from empty pond bottoms, and wastewater is held for sedimentation before discharge into natural waters. Other pond bottom management practices used by a few farmers are sediment excavation, leave sediment but till entire pond bottom, and no mechanical treatment. All four methods of pond bottom treatment are followed by sun drying for 30 d. Soil organic carbon concentration in ponds following dry-out seldom exceeded 2%. Although shrimp production in 24 ponds supplied by the same source of water was negatively correlated with increasing soil organic carbon concentration ($r = -0.582$), this observation does not confirm a causative relationship. Moreover, in trials conducted at Burapha University, Chantaburi Campus, bottom soil organic matter concentration following dry-out differed little irrespective of treatment method. Lower soil moisture concentration revealed that dry-out was more complete with sediment removal than without, but better dry-out resulted in lower soil pH. Removal of sediment by excavation or flushing is expensive, and natural dry-out combined with liming and occasional sediment removal should be investigated as a less expensive and more environment-friendly alternative to removing sediment after each crop.

Intensive shrimp farming is dependent upon mechanical aeration to avoid low dissolved oxygen concentration in production ponds. Water currents generated by aerators erode pond earthwork and suspend particles of mineral soil and organic matter (Boyd 1995). These particles settle in areas of ponds where water currents are weak, forming sediment mounds that are particularly obvious because of their dark color when ponds are drained for harvest. Farmers in Thailand and other Southeast Asian countries often remove sediment from ponds or apply treatments to improve sediment quality while ponds are empty between shrimp crops. The proportion of farmers resorting to pond bottom treatment, the frequency of treatment in individual ponds, and the popularity of different methods of treating pond bottoms have not been documented.

According to Suresh et al. (2006), the objectives of pond bottom treatments between crops are as follows: oxidize wastes; eradicate predators, pathogens, and vectors of pathogens; improve soil pH; enhance availability of natural food organisms before restocking; remove or redistribute sediment. There are ample data to support use of liming materials and fertilizers to improve pH and enhance the availability of natural food organisms in ponds (Boyd 1995), and it is intuitive that thorough dry-out would eliminate or lessen the abundance of unwanted organisms in pond bottoms. However, there

[1] Corresponding author.

is less information to support the practice of routine sediment removal to minimize the accumulation of organic matter in ponds. Boyd (1995) and Boyd et al. (1994) proposed that routine sediment removal from ponds is unnecessary – besides being time consuming, expensive, and posing potential environment problems through disposal. Still, as ponds age, sediment accumulation may become so great that it interferes with management and must be removed (Yuvanatemiya and Boyd 2006).

The purpose of the present study was to assess methods of pond bottom management used at commercial shrimp farms in Chantaburi Province, a major shrimp farming area of Thailand. Methods used in Chantaburi Province are thought to be similar to ones used at shrimp farms in other areas of Thailand.

Materials and Methods

Survey

The study area (Fig. 1) was located in Chantaburi Province, Thailand, along the east coast of the Gulf of Thailand from Na Yai Am District to Laem Sing District. The study area extended about 1.5 km inland along 93 km of coastline ($\approx$140 km^2) and represents one of the major shrimp farming regions of the country. Native soils of the study area were sandy and acidic (Keoruanrom 1990), and shrimp farms were constructed in mangrove areas or in rice fields.

A sample of 218 shrimp farms were selected at random (by drawing lots) from a roster of registered shrimp farms maintained by the provincial office of the Thailand Department of Fisheries. Farm owners and managers were interviewed during the period June 2006–December 2007 and asked to complete a questionnaire to obtain the following information: former land use; method of pond construction; size, depth, age, and number of ponds on each farm; water source; stocking rate; aeration technique; water quality and bottom soil management techniques; production, survival, and feed conversion ratio (FCR).

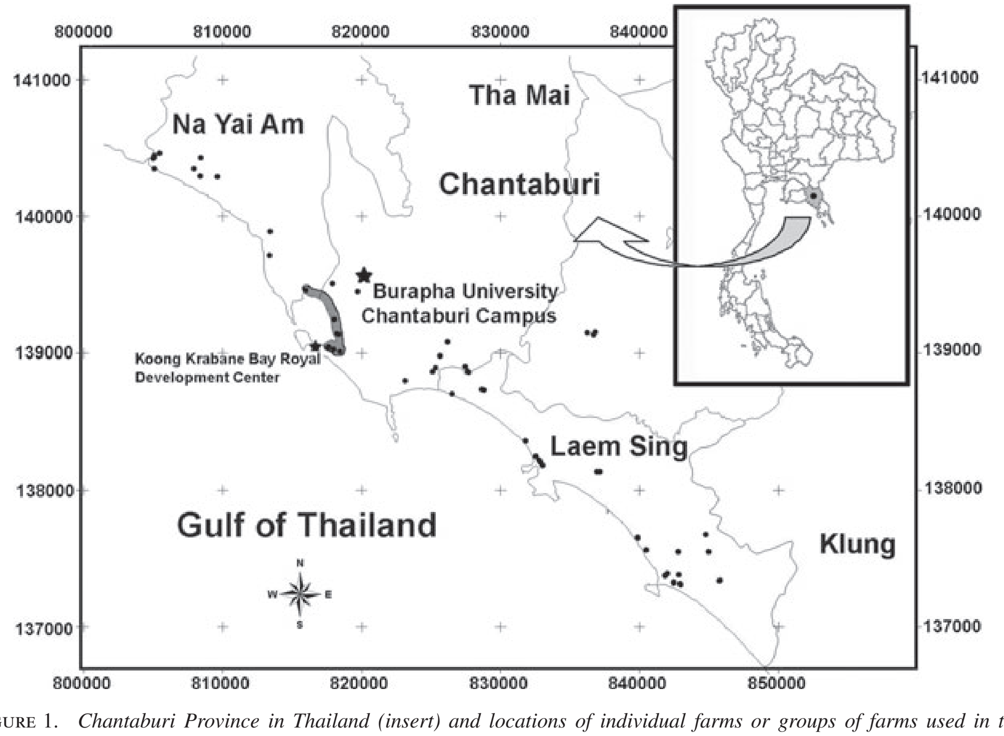

FIGURE 1. *Chantaburi Province in Thailand (insert) and locations of individual farms or groups of farms used in the study.*

Soil samples were collected from one pond on each of 40 farms at the end of the dry-out period between crop cycles. Farms and ponds on farms also were selected by drawing lots. Nine soil cores were collected along an S-shaped pattern in the bottom of each pond using 5-cm-diameter, core sampler liner tubes (Masuda and Boyd 1994). Cores were taken to a depth of 18 cm and cut into 2-cm-long segments (Boyd 1995), stored in plastic bags, placed on ice in an insulated chest, and taken to the laboratory for processing and analysis.

Soil samples were dried in a forced-draft oven at 60 C, and pulverized with a porcelain mortar and pestle to pass a sieve with 2-mm openings. Samples were analyzed for selected physical and chemical properties (Table 1).

Soil Properties and Shrimp Production

The Koong Krabane Bay Royal Development Center (KKBRDC) (Fig. 1) was developed under the auspices of the King of Thailand to allow selected individuals to acquire shrimp farms and to operate these farms as a demonstration project to promote shrimp farming in the region. The project was constructed along the edge of the mangrove, but none of the ponds were sited in former mangrove habitat. All farms received seawater from a single canal and discharged effluent to the bay. Because KKBRDC is a demonstration project, it was possible to obtain reliable estimates of shrimp production.

Twenty-four shrimp ponds were randomly selected (by drawing lots), and soil samples were collected from them at the end of the dry-out period between crops in November and December 2006. In six selected ponds, samples also were collected immediately after ponds were drained for harvest. Cores were taken to a depth of 15 cm, divided into 5-cm-long segments, processed, and analyzed for chemical and physical properties (Table 1). Water and soil management information and shrimp production records were obtained from farm owners or managers, but these farmers were not asked to complete the questionnaire used in the general survey.

Pond Bottom Treatment Trials

Two trials were conducted in four, 800-m^2, earthen, research ponds at the Marine Technology Research Center (MTRC), Burapha University, Chantaburi Campus, to compare the effectiveness of different methods of treating pond bottoms after shrimp harvest. These ponds were new and had not been previously used for aquaculture.

In Trial 1, ponds were stocked with *Penaeus monodon* at 40 postlarvae/m^2 on October 1, 2006; feed was applied four times per day with amounts offered based on feeding tray results; ponds were operated as closed systems; aeration was applied at 12 hp/ha; ponds were drained for harvest after 120 d. Each bottom treatment was applied to one pond, because only four ponds were available. The following pond bottom treatments were applied the day after harvest:

- Flushing treatment – a 75-hp pump was used to transfer water from the water supply canal and discharge it through a 10-cm-diameter hose fitted with a high-pressure nozzle. The water jet from the nozzle was used to dislodge sediment (identifiable as

TABLE 1. *Methods used to measure selected soil properties in samples from bottoms of shrimp ponds in Chantaburi Province, Thailand.*

Soil property	Method	Reference
pH	1:1 mixture of dry soil : distilled water; glass electrode	Thunjai et al. (2001)
Organic carbon	Sulfuric acid-potassium dichromate oxidation (Walkley-Black)	Nelson and Sommers (1982)
Total nitrogen	Kjeldahl procedure	Bremmer and Mulvaney (1982)
Available phosphorus	Bray method	Olson and Sommers (1982)
Soil texture	Particle size by hydrometer meter; texture class by soil triangle	Gee and Bauder (1986)

a low mound of dark-colored soil material in the central area of the pond). Wash water and suspended sediment flowed to the center of the pond where a 10-cm-diameter pipe was installed and connected to a 90-hp pump positioned on the pond embankment. The pump quickly removed the wash water and transferred it to a settling basin for removal of settleable solids before discharge into natural water bodies.

- Excavation treatment – the sediment mound was removed from the pond with care not to remove underlying soil by use of a backhoe. The sediment was transported by truck to an off-site disposal area.
- Tilling treatment – the pond bottom (including the sediment mound) was tilled four times 15 d after harvest with a 7.5-hp rice-field power tiller. Each successive tilling application was made at 90° to the previous application.
- Sun drying – no mechanical bottom treatment was applied.

After application of treatments, ponds were left empty for 35 d. Liming materials and fertilizers were not applied to pond bottoms during dry-out.

Soil samples (5-cm-diameter cores) were collected to a depth of 15 cm from three places in the bottom of each pond immediately following draining for harvest (but before applying bottom treatments) and at the end of the 35-d dry-out period. All samples were analyzed for pH, organic carbon, total nitrogen, and available phosphorus (Table 1). Samples taken at the end of the dry-out period also were analyzed for soil moisture (Gardner 1986), total bacterial plate count (Germida and de Freitas 2008), and soil respiration (Xinglong and Boyd 2006).

Following the 35-d dry-out period, ponds were refilled with water, restocked with *P. monodon* at 60 postlarvae/m^2 on April 25, 2007, and Trial 2 was initiated. The culture techniques described above also were used in Trial 2, and after 120 d, ponds were drained and shrimp harvested.

To allow statistical analysis of effects of methods of pond bottom treatment on bottom soil quality in Trial 2, the bottom of each pond was divided into four quadrats that intersected at the center drain. Each of the four treatments was applied randomly to one quadrant in each pond to provide a split-plot design with ponds being the main plot.

The excavation treatment was completed first using a backhoe. Next, one or two sheet metal barriers were driven into the bottom as necessary to isolate the flushing treatment quadrants from the quadrats for the tilling treatment and the treatment without mechanical intervention. The flushing method was applied as described above, but care was taken to ensure that the wash water was removed from the center drain area fast enough to prevent it from accumulating and flowing onto the other two quadrants. The tilling treatment was applied as described for Trial 1, and the quadrat that received no mechanical soil treatment was left undisturbed.

Sediment samples (5-cm diameter $\times$ 15-cm deep cores) were collected from three places in each quadrat at the end of the 35-d dry-out period. However, in Trial 2, samples were only analyzed for organic carbon, total nitrogen, and available phosphorus.

Data Analysis

Survey data were assessed by simple techniques: means, ranges, standard deviations, box plots, and correlation analysis. Effects of pond bottom treatments in Trial 2 were analyzed by analysis of variance and Duncan's new multiple range test. SigmaPlot version 8.0 Statistical software (Aspire Software International, Ashburn, VA, USA) was used for the data analyses. The data on chemical composition versus soil depth from 40 ponds in the survey area were averaged for each depth and the averages were plotted. A line was drawn using the software to depict the apparent trend of change in chemical composition with soil depth.

Results

Farm Survey

Interviews and questionnaires were completed for 137 of 218 farms in the random sample. Some farms had closed, others could not be located, and owners of a few farms did not participate. Of individuals representing the farms in the interviews, 71% were farm owners and 29% were managers.

Ponds in the study area were sited in former rice fields and mangrove habitat, but some of the former rice fields had been installed in mangrove habitat. It was often impossible to establish whether a pond was sited in former mangrove habitat. Special effort was made to determine whether the 40 ponds for soil sampling were in former mangrove habitat. Farm owners and managers were only able to state with certainty that 10 of the ponds had been built in former mangrove areas and that 10 had been sited outside the mangrove zone.

Ponds were constructed by a common technique. Land was cleared and leveled, and earth from the area to become the pond bottom was used to construct embankments to impound water from an external source. The O and A horizons of original soil profiles were removed for making embankments, and pond bottoms lay within the B horizon which is typically lower in concentrations of organic matter and nutrients than O and A horizons (Brady 2002).

Farms had 1–19 ponds ($\bar{x} \pm \text{SD} = 5 \pm 7$). Ponds varied in size from 1920 to 4000 m^2 ($\bar{x} \pm \text{SD} = 3200 \pm 1049$ m^2), and average depth was 1.5 m. Pond age ranged from 1 to 20 yr ($\bar{x} \pm \text{SD} = 8 \pm 5$ yr).

Water supplies for farms were as follows: brackish water canals (58%); the sea (27%); tidal streams (10%); saline groundwater (5%). None of the farm intakes were closer than 500 m of each other, but some farms used water from the same canal.

At the beginning of a crop cycle, farm reservoirs (100 farms or 73% had reservoirs) and ponds were filled from the water supply. Reservoirs at 63 farms held enough water to replace evaporation and seepage in ponds throughout the grow-out period. At farms with smaller reservoirs, it was necessary to add water from the water supply to reservoirs one or more times during the grow-out period. Ponds at farms without reservoirs (27%) were operated as open systems to which water was added directly from the water source to replace evaporation and seepage.

Disease organisms and their vectors in source water was a major concern of shrimp farmers. At 52% of farms, water initially added to fill ponds and reservoirs was treated before each crop with about 300 kg/ha of calcium hypochlorite or 1.5 L/ha of 90% iodine solution. These two treatments were made before starting crops at an additional 26% of farms when farmers suspected that the source water contained one or more shrimp diseases.

Black tiger prawn, *P. monodon*, the traditional shrimp aquaculture species of Thailand, was cultured at only three farms – the other farms produced non-native, Pacific white shrimp, *Litopenaeus vannamei*. This was not surprising, because production of *P. monodon* and *L. vannamei* by aquaculture in Thailand was 8000 and 498,800 t, respectively, in 2008 (FAO 2008). Stocking rates ranged from 30 to 60 postlarvae/m^2 (Table 2). All farms reported that they purchased postlarvae documented to be free of specific pathogens (SPF postlarvae).

All farms applied feed four or five times per day, and feeding trays were used at all farms to avoid overfeeding. All farmers used feed containing 38% crude protein for the first 2 mo and 37% crude protein after 2 mo.

During the grow-out period, 85% of farmers applied liming materials to increase total alkalinity, nitrogen and phosphorus fertilizers to stimulate plankton blooms, and microbial

TABLE 2. *Shrimp production data obtained from questionnaire answered by 137 shrimp pond owners and managers in Chantaburi Province, Thailand, during a survey conducted over a 140-km² area between June 2006 and December 2007.*

Variable	*n*	%	Variable	*n*	%
Survival (%)			Feed conversion ratio		
≤25	3	2	<1.50	41	30
25–50	26	19	1.51–1.75	77	56
51–75	64	47	1.76–2.00	15	11
76–100	44	32	>2.00	4	3
Production (kg/ha)					
<3000	18	13			
3000–6000	48	35			
>6000	71	52			

preparations to enhance water quality. However, rates and application frequencies of these amendments were based on judgment of pond managers, and reliable records of amounts applied were not available.

Ponds at all farms were aerated 16–20 h/d with paddlewheel aerators. Where ponds had electrical service, 2- or 3-hp, floating, electric, paddlewheel aerators were used. Aeration rate averaged 23.4 $\pm$ 10.7 hp/ha with a range of 12.5–37.5 hp/ha. Ponds without electrical service used floating, "long-arm" paddlewheel aerators powered by Kubota diesel engines mounted on the pond bank – 9.5-hp engines for ponds $\leq$3000 m^2 and 11.5-hp engines for larger ponds. These aerators have long shafts ("long arms") with multiple paddlewheels that extend from the pond edge to the center of the pond. There was considerable variation in the number of individual paddlewheels installed on the shafts of the aerators, and it was impossible to estimate the effective rate of aeration applied to ponds. According to farmers, aeration was sufficient to maintain adequate dissolved oxygen concentrations. Thus, none of the farms practiced daily or periodic water exchange that was formerly a common practice in Thailand.

Shrimp grow-out period typically was about 120 d, but shrimp were sometimes harvested early when disease problems occurred. Ponds were completely drained for harvest, and effluent rules implemented by the Thailand Department of Fisheries require farmers to discharge water through settling basins (Tookwinas 1996). All farms had settling basins of at least 10% of production pond area.

Survival rate exceeded 50% on 79% of farms and production was more than 6000 kg/ha per crop at 52% of farms. Most farms produced at least two crops per year. On the basis of the survey, 9% of farms produced one crop per year, 64% grew out two crops per year, and 27% reared three crops per year. FCR was >2.00 at only 3% of farms, and 30% of farms had FCR <1.50 (Table 2).

Aerators usually were positioned around shrimp ponds to cause circular water movement, and currents were stronger near embankments and weaker in the central area. Water currents generated by aerators eroded insides of embankments and pond bottoms to suspend mineral soil particles as well as particles of organic matter originating from uneaten feed, shrimp excrement, and dead plankton. These particles settled in the central area of ponds creating a low mound over 30–50% of the pond bottom area (estimated visually).

Because of the relatively high stocking densities, large feed inputs, increasing use of closed systems, and the obvious accumulation of sediment in ponds, farmers in Chantaburi Province, and throughout the shrimp farming area of Thailand, place importance on pond bottom management. The survey revealed that ponds at all farms were dried out between crops, and at 99% of farms, mechanical treatment of bottoms was applied before the beginning of the dry-out period which typically lasted for 30 d. Farmers in the survey believed that sediment contained large amounts of organic matter that would be problematic during the next crop and that shrimp disease could be carried over from one crop to the next by organisms in the sediment. Most farmers felt that the best approach was to remove sediment from a pond after each crop.

Three mechanical sediment management techniques were used. The most common practice used by 95% of survey farms was hydraulic sediment removal or flushing. After ponds were drained and shrimp harvested, a pump was used to discharge relatively clean water from an external source through a high-pressure nozzle to wash sediments from pond bottoms. The force of water dislodges sediment from the bottom, and wash water and resuspended sediment collect in the deepest part of the pond. The force of the water also dislodges some original soil material beneath the sediment, but no estimate of the amount removed was made. A second pump transfers sediment-laden water to a sedimentation pond before it is discharged into natural waters. The hydraulic retention time of sedimentation basins and the effectiveness of the removal of solids from effluent were not investigated. Ponds were left empty for about 30 d after flushing to allow bottoms to dry and naturally aerate before refilling.

At 3% of farms, sediment is removed from pond bottoms by aid of backhoes or bulldozers and backhoes. Sediment is loaded onto a dump truck, and transported to a disposal area. This study did not investigate the suitability of the disposal sites. Following sediment removal, bottoms were allowed to dry for about 30 d. Excavation of sediment was once a common practice in Thailand (Boyd et al. 1994), but it has largely been replaced by the flushing method. Sediment removed from ponds usually has a salt burden originating from the saline water used in ponds, and disposal in non-saline soil areas can lead to salinization (Boyd et al. 1994). Following sediment removal, bottoms were allowed to dry for about 30 d.

The third mechanical practice used by only 1% of farms was tilling. Midway through the dry-out period of about 30 d, bottoms of ponds were tilled with a rice-field power tiller. The farmers believe that tilling improves natural aeration to enhance microbial decomposition of organic matter and that it hastens drying. After tilling, the dry-out period was continued, but immediately before refilling ponds with water, bottoms were compacted with a concrete-tube roller. The purpose of compaction is to reduce the tendency of aerator-induced erosion of the bottom soil during the following crop.

A fourth practice used by 1% of farms in the survey was to allow pond bottoms to dry naturally for about 30 d without mechanical sediment treatment.

At 55% of farms, bottoms were limed before refilling ponds with water for the next crop. The usual treatment rate was about 160 kg/ha of burnt lime (CaO) or hydrated lime [$Ca(OH)_2$] and 320 kg/ha of agricultural limestone. The lime was spread manually as uniformly as possible over pond bottoms. This treatment is intended to raise soil pH and disinfect pond bottoms. It is doubtful that such a low treatment rate with lime will raise pH above 10 and kill unwanted organisms – the usual amount of burnt or hydrated lime recommended for pond bottom disinfection is 1000–1500 kg/ha (Boyd and Tucker 1998).

After a few years of production, farmers sometime decide that certain areas in a pond bottom are unsuitable for shrimp production. The upper 15- to 30-cm layer of bottom soil is removed from the questionable area and replaced with soil of better quality from an outside source. Although 36% of farmers in the survey claimed to have applied this method to one or more ponds, it was not clear how much soil had usually been replaced. However, the practice is only applied as a last resort to specific ponds in which chronic low survival and production of shrimp is thought to be caused by poor quality soil.

Soil Evaluation

In the survey ponds, soil samples were taken after bottom treatments had been applied and the pond bottoms allowed to dry. Available phosphorus was slightly greater in the 5-cm soil layer than in deeper layers, and pH showed a tendency to decline with increasing soil depth (Fig. 2). There was no clear pattern in organic carbon and total nitrogen concentration with soil depth. The bottom soil treatments applied to shrimp ponds prevented the typical depth stratification of soil composition observed in ponds without bottom soil treatments between crops. Where sediment has not been removed, the upper 5- to 10-cm layer of bottom soil typically has a higher pH and greater organic carbon, total nitrogen, and total and available phosphorus concentrations than found in deeper layers of soil (Masuda and Boyd 1994; Munsiri et al. 1995). This pattern results from the inputs of liming materials, organic matter (feed), and nutrients to support aquacultural production.

The data from all soil depths in each pond were averaged and grand mean, standard deviation, and range calculated for each variable (Table 3). The average soil pH for all ponds was 6.18 – less than the optimum pH of 7.0–7.5 (Boyd 1995). Ponds also had low concentrations of organic carbon, total nitrogen, and available phosphorus. This condition is desirable at the beginning of a new crop, for it does not support a high sediment oxygen demand. It is interesting to note, however, that previous studies of ponds without sediment removal, including shrimp ponds, seldom have

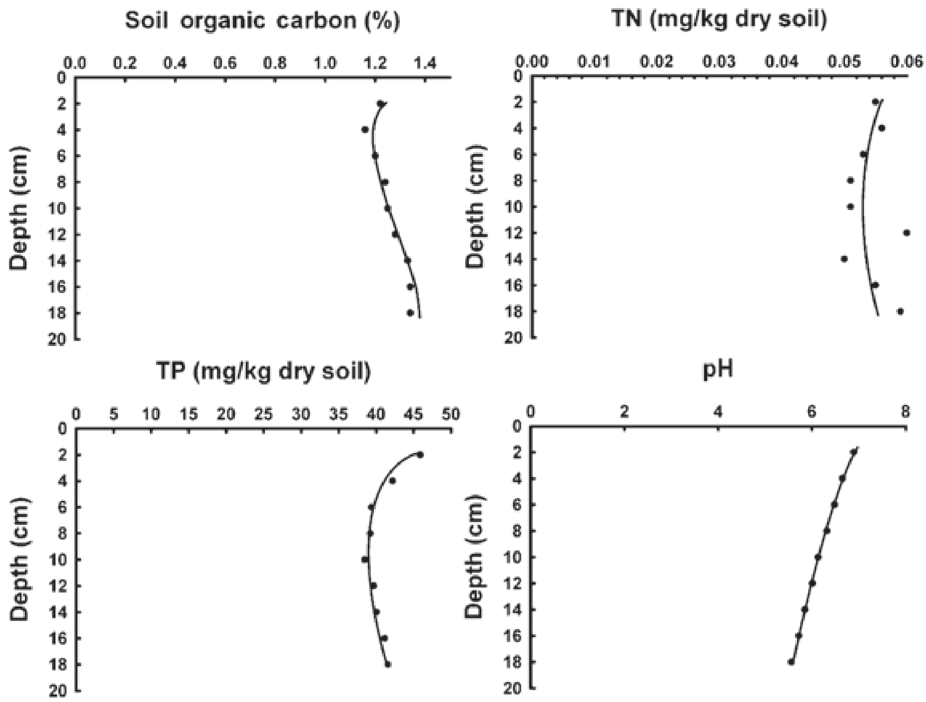

FIGURE 2. *Averages for pH and concentrations of chemical variables at different depths in bottom soils of shrimp ponds in Chantaburi Province, Thailand. Samples were taken at the end of dry-out period from 40 ponds spread over a 140-km^2 area.*

TABLE 3. *Means, SD, and ranges for values of soil properties in bottom soils from 64 shrimp ponds in Chantaburi Province, Thailand.*[1]

	Survey ponds ($n = 40$)		Ponds at KKBRDC ($n = 24$)	
Soil property	Mean ± SD	Range	Mean ± SD	Range
pH	6.18 ± 1.80	2.60–7.95	6.42 ± 0.70	4.40–6.87
Organic carbon (%)	1.26 ± 0.82	0.12–4.79	1.47 ± 0.84	0.12–4.03
Total nitrogen	0.053 ± 0.033	0.014–0.106	—	—
Available phosphorus (mg/kg)	41.1 ± 29.4	3.0–101.1	—	—
Sand (%)	63 ± 12	48–92	66 ± 10	49–89
Silt (%)	29 ± 11	4–50	25 ± 9	4–42
Clay (%)	8 ± 3	1–12	9 ± 3	0–17

[1]The survey ponds were spread over a 140-km^2 area, but ponds located at the Koong Krabane Bay Royal Development Center (KKBRDC) were located within a 1-km^2 area and supplied by water from a single source. Samples were collected following sediment removal by the flushing method and a 30-d dry-out period.

revealed organic carbon concentrations above 3% (Boyd 1995; Steeby et al. 2004; Boyd et al. 2010). Moreover, there was no correlation between pond age and soil organic carbon concentration ($r = 0.212$; $P > 0.05$) in samples of the soil survey. Although this might suggest that sediment removal is responsible for avoiding high organic carbon concentrations, several studies have revealed either no correlation or a weak correlation between pond age and soil organic matter concentration in ponds without sediment removal (Tucker 1985; Munsiri et al. 1995; Steeby et al. 2004; Thunjai et al. 2004; Wudtisin and Boyd 2006; Boyd et al. 2010). Of course, in ponds without sediment removal, organic carbon concentration is usually higher than in original pond bottoms, and the total quantity of organic matter in pond bottoms is obviously greater in ponds without sediment removal than in ponds from which sediment is removed regularly (Munsiri et al. 1995; Yuvanatemiya and Boyd 2006).

Twenty-four of 40 ponds (60%) from which soil samples were collected were limed – this compares favorably to the general survey in which 55% of 137 farms practiced liming. Soil pH averaged over three units greater in limed ponds than in unlimed ponds (Fig. 3). Ponds in Chantaburi Province need to be limed because of the acidic nature of native soils. It appears that where liming is used, it is used at an adequate rate. However, a considerable proportion of ponds are not limed, and liming these ponds should be beneficial. Soils of limed ponds had almost twice as much available soil phosphorus as soils of unlimed ponds (Fig. 3) as would be expected (Boyd 1995). No obvious differences were noted in the concentrations of total organic carbon and total nitrogen or in carbon : nitrogen ratio between limed and unlimed ponds.

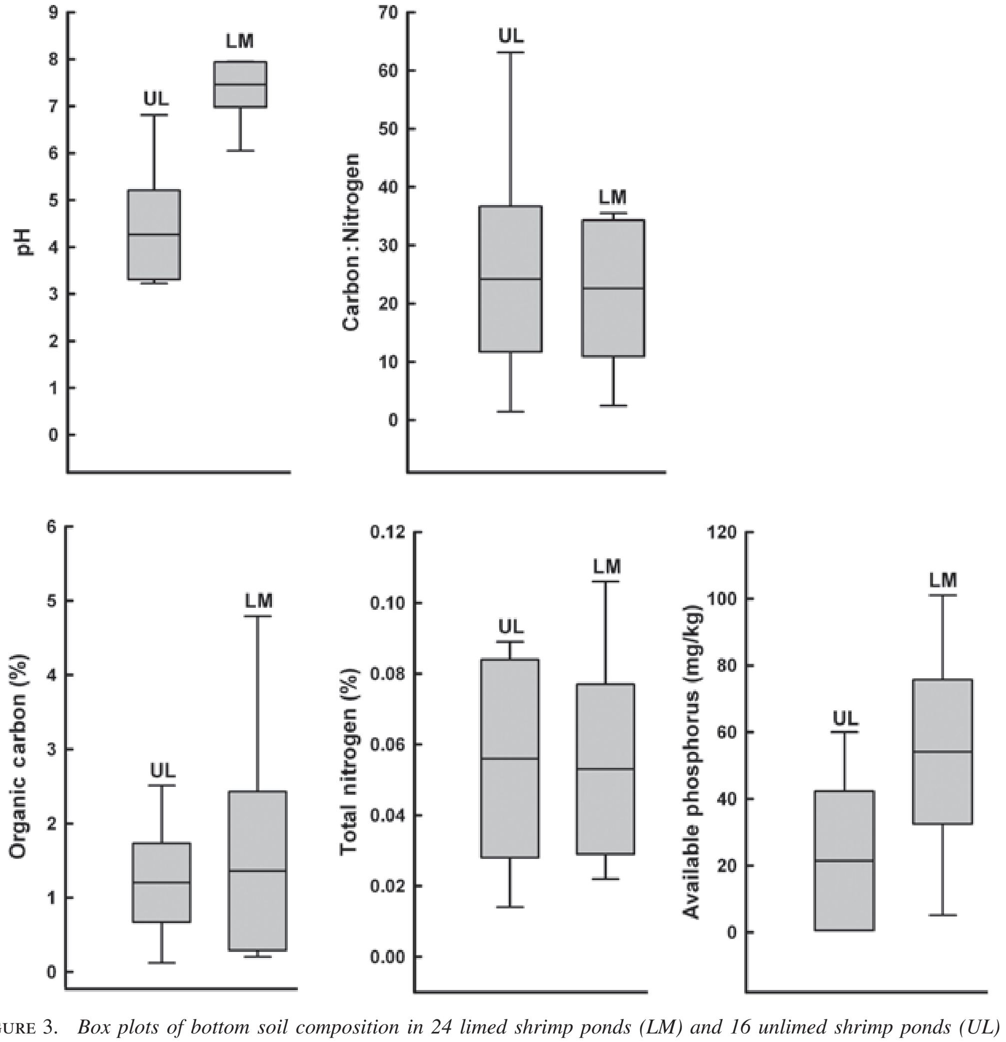

FIGURE 3. *Box plots of bottom soil composition in 24 limed shrimp ponds (LM) and 16 unlimed shrimp ponds (UL) in Chantaburi Province, Thailand. Soil samples were taken at the end of the 35-d dry-out period following removal of sediment by flushing with a high-pressure water jet.*

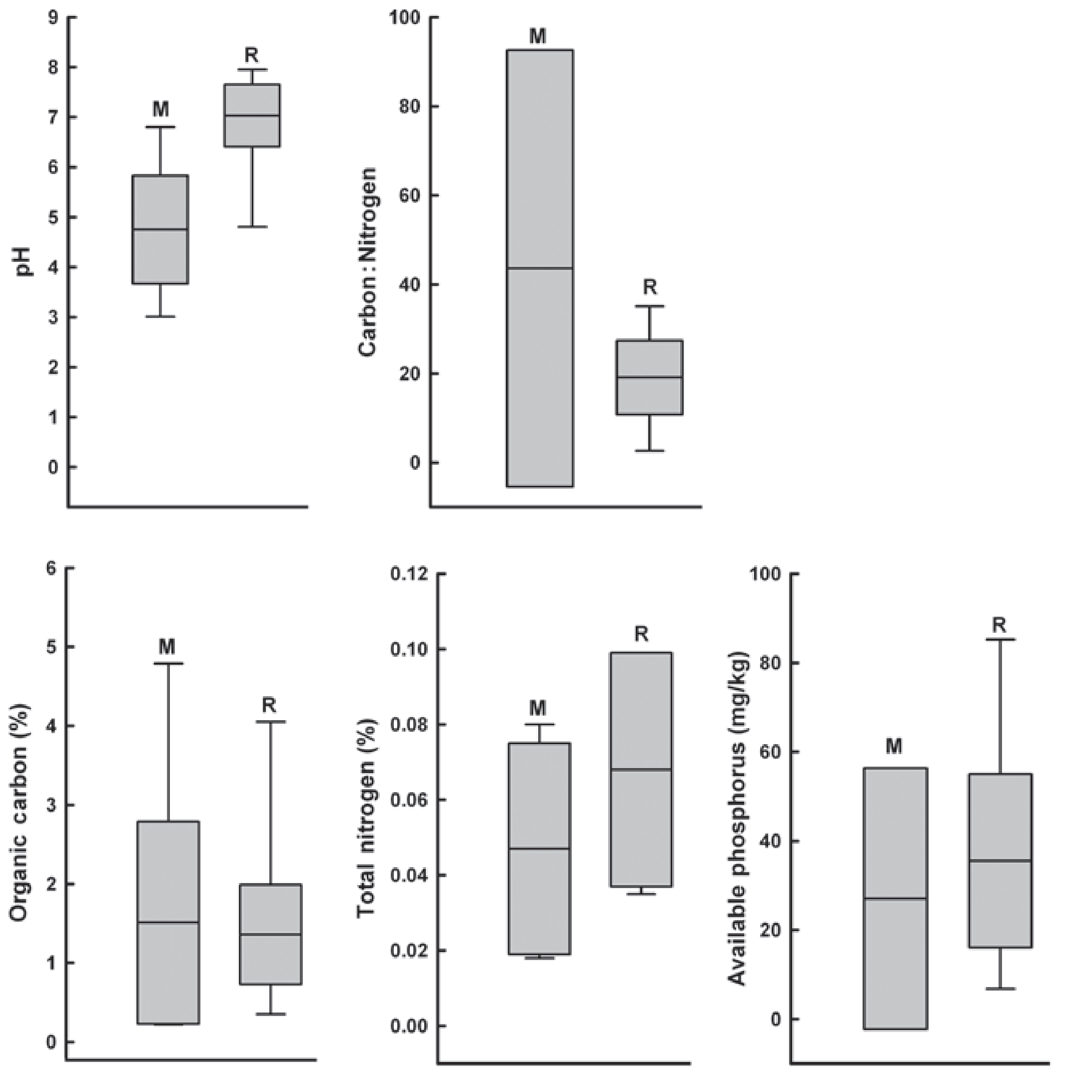

FIGURE 4. *Box plots of data on bottom soil composition in 10 ponds constructed in mangrove areas (M) and 10 ponds built in former rice fields outside the mangrove zone (R) in Chantaburi Province, Thailand. Soil samples were taken at the end of the 35-d dry-out period following removal of sediment by flushing with a high-pressure water jet.*

Ponds constructed in former mangrove habitat also had lower soil pH than found in ponds constructed outside the mangrove zone (Fig. 4). Soils in mangrove areas are typically acidic (Boyd 1995), but in this case, the entire study area has acidic soils (Keoruanrom 1990), and ponds at farms with low pH located in the mangrove zone had not been limed. Concentrations of organic carbon and available phosphorus in soils were similar between ponds in former mangrove soil and those outside the mangrove zone. However, total nitrogen concentration tended to be lower and carbon : nitrogen ratio greater in ponds located on former mangrove soil (Fig. 4). A high carbon : nitrogen ratio also was reported for shrimp ponds constructed in the mangrove zone in Ecuador (Sonnenholzner and Boyd 2000).

Soil analyses were made for 24 ponds at KKBRDC, but unfortunately, the data for total nitrogen and available phosphorus were lost. The other soil variables for soils at KKBRDC were similar to those reported for the 40 ponds of the soil survey (Table 3).

Soil Properties and Shrimp Production

Seventeen ponds at the KKBRDC operated as open systems had soil organic carbon concentration of 1.35 ± 0.81% as compared to 1.77 ± 0.88% in seven ponds operated as closed systems. Farmers at KKBRDC operated a higher proportion of open systems than farmers interviewed in the general survey. Shrimp production averaged 3708 ± 2342 kg/ha in the open systems and 1719 ± 1761 kg/ha in the closed systems; thus, farms at the KKBRDC also reported lower production than farms in the general survey. Of course, farmers at the KKBRDC provided records of shrimp production while those in the general survey only answered multiple-choice questions about production. Soil organic carbon concentration and shrimp production were negatively correlated ($r = -0.582$; $P < 0.05$) (Fig. 5), but this correlation does not confirm a causative relationship between soil organic matter concentration and shrimp production.

It was possible to compare the composition of bottom soils before and after application of the flushing method in six ponds at KKBRDC – two for each of three soil texture classes (Fig. 6). There was a moderate reduction in organic carbon concentration and a marked decrease in pH following flushing treatment. This suggested that as a result of feed input, liming, and contact with saline water, sediment was higher in organic carbon concentration and pH than underlying soil. In addition, flushing appeared to increase the proportion of coarse particles in pond bottom soil. This was not surprising, because clay particles would be suspended easier by the water jets, and they would remain suspended longer than coarse particles, thereby increasing the likelihood that they would be discharged from ponds.

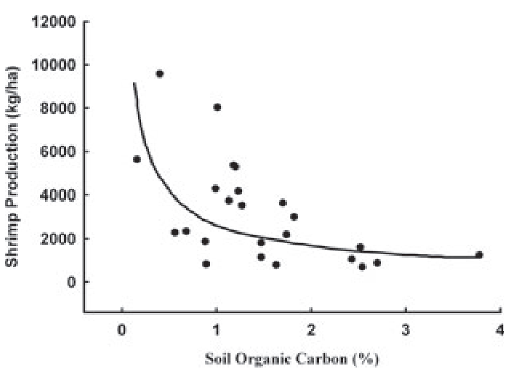

FIGURE 5. *Plot of bottom soil organic carbon concentration and shrimp production in ponds at the Koong Krabane Bay Royal Development Center, Chantaburi Province, Thailand. Soil samples were collected immediately after ponds were drained for harvest and before bottom treatment.*

The flushing method was used exclusively by farmers at the KKBRDC, and it also was the preferred technique for farmers interviewed in the general survey. Thus, it was not possible to obtain data from commercial farms for comparing the different methods of soil treatment.

Pond Bottom Management Trials

Four ponds at the MTRC were stocked with shrimp at the same rate and managed in the same manner during the grow-out period. After draining for harvest, pond bottom soils had similar pH ($\bar{x} \pm SD = 7.18 \pm 0.07$; range = 7.10–7.25) and concentrations of organic carbon ($\bar{x} \pm SD = 2.68 \pm 0.29\%$; range 2.34–2.93%), total nitrogen ($\bar{x} \pm SD = 0.305 \pm 0.01\%$; range = 0.288–0.314%), and available phosphorus ($\bar{x} \pm SD = 13.4 \pm 1.1$ mg/kg; range 11.9–14.3 mg/kg). These data reveal that organic carbon concentration was similar to that reported in aquaculture ponds from which sediment had not been removed (Munsiri et al. 1995; Steeby et al. 2004; Boyd et al. 2010). However, the concentrations of organic carbon and total nitrogen were more than twice the averages reported (Table 3) for survey ponds and ponds at KKBRDC from which sediment had been removed by flushing before soil samples were collected.

A different pond bottom treatment was applied to each pond, and after the 35-d dry-out period, soil organic carbon concentrations in ponds that received flushing and tilling treatments and no mechanical treatment

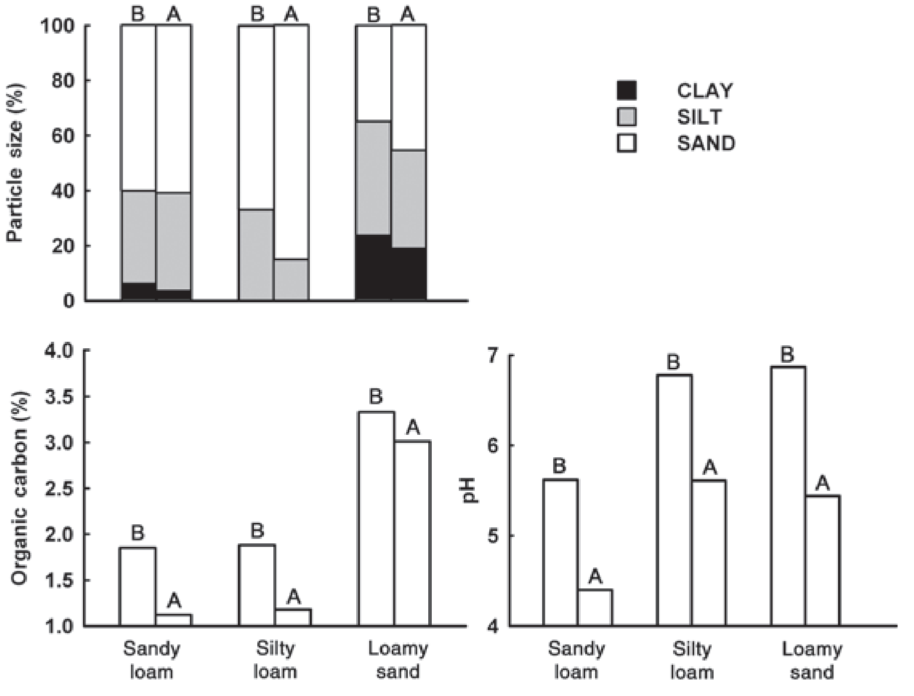

FIGURE 6. *Intensities of bottom soil properties in shrimp ponds before (B) and after (A) removal of sediment by flushing with a high-pressure water jet. The ponds were located within a 1-km^2 area on the Koong Krabane Bay Royal Development Center, Chantaburi Province, Thailand. There were two ponds for each soil texture class.*

ranged from 2.40–2.54% – similar to pretreatment concentrations. The excavation treatment had a soil organic carbon concentration of 1.62% (Table 4). Total nitrogen concentration (0.221–0.308%) also was not much lower than pretreatment values. Available phosphorus concentration declined slightly in all ponds, and especially in the flushing and excavation treatments. Soil pH was considerably lower at the end of the dry-out period than before bottom treatments were applied – especially in the flushing and excavation treatments (Table 4).

The higher pH in ponds from which sediment was not removed than in ponds from which sediment was removed (Table 4) resulted because ponds had been limed during the crop and sediment had been in contact with liming material and with seawater or brackish water causing

TABLE 4. *Effect of shrimp pond bottom treatment on soil properties in new ponds at the Marine Technology Research Center, Burapha University, Chantaburi Campus, Thailand (Trial 1 in text).*[1]

	Pond bottom treatment			
Variable	Flushing	Excavation	Tilling	None
Organic carbon (%)	2.43	1.62	2.40	2.54
Total nitrogen (%)	0.250	0.221	0.238	0.308
Available phosphorus (mg/kg)	6.7	8.0	10.0	11.6
pH	3.77	3.49	5.33	6.34
Soil moisture (%)	19.9	18.4	39.0	39.0
Bacterial abundance (10^7 cfu)	0.37	0.66	1.19	1.29
Soil respiration (mg O_2/g soil)	0.22	0.33	0.42	0.56

[1]Treatments were not replicated and applied immediately following shrimp harvest. Soil variables were measured on samples taken after pond bottoms dried for 35 d.

a greater pH. The decline in soil pH in all ponds and the lower pH of the flushing and excavation treatments also attest to the highly acidic nature of soils in the area. Soils in this area are potential acid-sulfate soils, that is, they contain iron pyrite that can oxidize to form sulfuric acid (Keoruanrom 1990). The higher pH in the ponds with intact sediment would favor a greater concentration of available phosphorus (Boyd 1995). However, because of the lack of replication, statistical significance cannot be assigned to any of the apparent differences mentioned above.

The higher soil moisture concentration (Table 4) in the ponds receiving the tilling treatment or no mechanical treatment was expected, because sediment mounds dry from their surfaces downward, and a dry surface layer is a barrier to evaporation within the soil mass (Boyd 1995). Tilling did not appear to increase evaporation in sediment. In the flushing and excavation treatments, sediment was removed from the ponds, and the original soil that was more highly compacted and of lower moisture content was exposed.

Low soil moisture content does not support high levels of microbial activity (Boyd and Pipoppinyo 1994). It is intuitive that bottoms of ponds from which sediment was not removed would support higher microbial abundance and respiration than bottoms of ponds from which sediment had been removed as was observed.

Each bottom treatment was applied to one quadrat in each of the four ponds in Trial 2 to allow statistical assessment of results. There were no differences among treatments ($P > 0.05$) in organic carbon or total nitrogen concentrations, but available phosphorus was less in the flushing treatment (Table 5). Other soil variables were not measured in Trial 2.

Because Trial 1 was conducted in new ponds, previous bottom soil treatment was not a factor influencing shrimp survival or growth. Shrimp production ranged from 3375 to 4375 kg/ha ($\bar{x} \pm \text{SD} = 3766 \pm 485$ kg/ha), survival averaged 39.2 ± 5.4%, and FCR averaged 1.55 ± 0.093. Shrimp survival in Trial 2 was 42.0 ± 8.0% and FCR was 1.41 ± 0.10. However, the stocking rate was 20 postlarvae/m^2 greater than in Trial 1, and shrimp production averaged 6750 ± 489 kg/ha. The range in shrimp production was only 6125–7000 kg/ha; thus, the method of pond bottom treatment used following Trial 1 did not appear to influence shrimp production in Trial 2. Because of the split-plot design for applying pond bottom treatments following Trial 2, it was not possible to evaluate the effect of these treatments on the following shrimp crop. It should be noted that the ponds at the MTRC were stocked with *P. monodon*, because the mission of this center is to conduct research on this species. However, *P. monodon* production in the two trials was as high as production of *Penaeus vannamei* reported by farmers in the survey and at KKBRDC.

TABLE 5. *Concentrations of organic carbon, total nitrogen, and available phosphorus in shrimp pond soils at the Marine Technology Research Center, Burapha University, Chantaburi Campus, Thailand (Trial 2 in text).*[1]

Bottom treatment	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (mg/kg)
Flushing	1.37a	0.050a	5.7a
Excavation	1.59a	0.063a	10.4b
Tilling	1.27a	0.066a	8.7ab
None	1.39a	0.066a	10.3b

[1]Each treatment was applied to a quadrat in the bottom of each of four ponds. Samples were collected following bottom treatment and 35-d dry-out period. Entries indicated by the same letter did not differ at $P = 0.05$ as determined by the Duncan's new multiple range test – vertical comparisons only.

The amounts of equipment and fuel required for conducting the different pond bottom treatments in Trial 1 are depicted (Table 6). Both flushing and excavation treatments require expensive equipment, and the excavation treatment requires a large amount of fuel compared to the flushing treatment and especially the tilling treatment. Of course, no equipment or fuel is necessary for natural drying of pond bottoms.

Discussion

The survey revealed that 97% of shrimp farms in Chantaburi Province have adopted

TABLE 6. *Fuel use for three methods of mechanical treatment of shrimp pond bottoms in Chantaburi Province, Thailand.*

Treatment	Operation time (h/ha)	Equipment	Fuel use rate	Total fuel use (L/ha)
Flushing[1]	20	75-hp pump	4.5 L/h	230
		90-hp pump	7 L/h	
Excavating[2]	38	Backhoe	18 L/ha	851 L/ha
		Truck[1]	3.0 km/L	
Tilling[3]	12.5	7.5-hp tiller	0.5 L/ha	15 L/ha

[1]Sediment removed by washing pond bottom with high-pressure water jet.

[2]Sediment was removed with a backhoe. The following assumptions were made in calculating truck fuel use of 167 L/ha: 300 m^3 sediment/ha; 6 m^3 sediment per load; 10-km round-trip to disposal site.

[3]Bottoms tilled four times, but sediment not removed from ponds.

the flushing technique of pond bottom management. This procedure completely removes all sediments from the previous crop, allows pond bottoms to dry thoroughly, and ensures that organic carbon concentrations are low at the beginning of crops. The flushing technique requires expensive equipment and consumes considerable fuel. It also creates a sediment disposal problem, because farm settling basins must be cleaned out periodically to maintain sufficient hydraulic retention time for effective sedimentation. The sediment has a large salt burden, and its off-farm disposal can cause soil and water salinization.

The work conducted at the MTRC suggests that removal of sediment from ponds after each crop is unnecessary for reducing organic carbon concentration. In addition, soil pH did not fall as low in ponds without sediment removal as it did in ponds with sediment removal – this effect would be much less in non-acid-sulfate soils.

A possible alternative to the flushing technique would be to leave sediment intact, lime pond bottoms as necessary for neutralizing acidity or destroying unwanted organisms, and allow bottoms to dry for about a month before refilling with water. Sediment accumulation is inevitable in aquaculture ponds, and after several years – the time period would vary among sites – sediment would have to be removed and pond bottoms and embankments renovated. Nevertheless, less total sediment would likely need to be removed from ponds with occasional sediment removal than from ponds with sediment removal after each crop. Support for this assumption is a study of channel catfish ponds (with daily aeration) in the USA that showed sedimentation rates to decrease over time: 12.5 cm during Year 1; 3 cm/yr during years 2–5; 1.8 cm/yr during years 6–10; 1.3 cm/yr during years 11–21 (Steeby et al. 2004). The practice of flushing shrimp pond bottoms to remove sediment after each crop likely maintains a high sedimentation rate as ponds age. A reduction in the amount of sediment for removal and off-farm disposal would be both economically and environmentally beneficial. Moreover, ponds sequester carbon in sediment (Boyd et al. 2010), and retention of sediment in ponds would counteract a portion of the carbon emissions resulting from shrimp production.

A less expensive and more environment-friendly method of treating shrimp pond bottoms is needed. Further research should be conducted to ascertain whether or not good survival and production of shrimp can be maintained in ponds without sediment removal after each crop. This research also should consider ways of reducing erosion in ponds and establish guidelines for determining when sediment should be removed from ponds. The economic and environmental returns from investment in this research could be tremendous.

Literature Cited

Boyd, C. E. 1995. Bottom soils, sediment, and pond aquaculture. Chapman and Hall, New York, New York, USA.

Boyd, C. E. and S. Pipoppinyo. 1994. Factors affecting respiration in dry pond bottom soils. Aquaculture 120:283–293.

Boyd, C. E. and C. S. Tucker. 1998. Pond aquaculture water quality management. Kluwer Academic Publishers, Boston, Massachusetts, USA.

Boyd, C. E., P. Munsiri, and B. F. Hajek. 1994. Composition of sediment from intensive shrimp ponds in Thailand. World Aquaculture 25:53–55.

Boyd, C. E., C. W. Wood, P. L. Chaney, and J. F. Queiroz. 2010. Role of aquaculture pond sediments in sequestration of annual global carbon emissions. Environmental Pollution 158:2537–2540.

Brady, N. C. 2002. The nature and properties of soils. Prentice Hall, Upper Saddle River, New Jersey, USA.

Bremmer, J. M. and C. S. Mulvaney. 1982. Nitrogen – total. Pages 595–624 *in* A. L. Page, R. H. Miller, and D. R. Keeney, editors. Methods of soil analysis, part 2, Chemical and microbiological properties. American Society of Agronomy, Madison, Wisconsin, USA.

FAO (Food and Agriculture Organization of the United Nations). 2008. Yearbook of fishery statistics: summary tables. FAO, Rome, Italy. Accessed Nov. 2010 at http://www.fao.org.

Gardner, W. H. 1986. Water content. Pages 493–544 *in* A. Klute, editor. Methods of soil analysis, part 1, Physical and mineralogical methods. American Society of Agronomy, Madison, Wisconsin, USA.

Gee, G. W. and J. W. Bauder. 1986. Particle size analysis. Pages 383–411 *in* A. Klute, editor. Methods of soil analysis, part 1, Physical and mineralogical methods. American Society of Agronomy, Madison, Wisconsin, USA.

Germida, J. J. and J. R. de Freitas. 2008. Cultural methods for soil and root-associated microorganisms. Pages 341–397 *in* M. R. Carter and E. G. Gregorich, editors. Soil sampling and methods of analysis. Canadian Society of Soil Science, CRC Press, Boca Raton, Florida, USA.

Keoruanrom, E. 1990. Soils of Thailand. Characteristics, distribution and uses. Department of Soils, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand.

Masuda, K. and C. E. Boyd. 1994. Phosphorus fractions in soil and water of aquaculture ponds built on clayey, Ultisols at Auburn, Alabama. Journal of the World Aquaculture Society 25:379–395.

Munsiri, P., C. E. Boyd, and B. F. Hajek. 1995. Physical and chemical characteristics of bottom soil profiles in ponds at Auburn, Alabama, USA, and a proposed method for describing pond soil horizons. Journal of the World Aquaculture Society 26:346–377.

Nelson, D. W. and L. E. Sommers. 1982. Total carbon, organic carbon, and organic matter. Pages 539–579 *in* A. L. Page, R. H. Miller, and D. R. Keeney, editors. Methods of soil analysis, part 2, Chemical and microbiological properties. American Society of Agronomy, Madison, Wisconsin, USA.

Olson, S. R. and L. E. Sommers. 1982. Phosphorus. Pages 403–430 *in* A. L. Page, R. H. Miller, and D. R. Keeney, editors. Methods of soil analysis, part 2, Chemical and microbiological properties. American Society of Agronomy, Madison, Wisconsin, USA.

Sonnenholzner, S. and C. E. Boyd. 2000. Chemical and physical properties of shrimp pond bottom soils in Ecuador. Journal of the World Aquaculture Society 31: 358–375.

Steeby, J. A., J. Hargreaves, C. S. Tucker, and S. Kingsbury. 2004. Accumulation, organic carbon and dry matter concentration of sediment in commercial channel catfish ponds. Aquaculture Engineering 30: 115–126.

Suresh, A. V., C. Aceituno, and L. Oliva. 2006. Pond preparation. Pages 54–60 *in* C. Boyd, D. Jory, and G. Chamberlain, editors. Operating procedures for shrimp farming. Global Aquaculture Society, St. Louis, Missouri, USA.

Thunjai, T., C. E. Boyd, and K. Dube. 2001. Pond soil pH measurement. Journal of the World Aquaculture Society 32:141–152.

Thunjai, T., C. E. Boyd, and M. Boonyaratpalin. 2004. Bottom soil quality in tilapia ponds of different age in Thailand. Aquaculture Research 35:698–705.

Tookwinas, S. 1996. Environmental impact assessment for intensive marine shrimp farming in Thailand. Thai Fisheries Gazette 48:119–133.

Tucker, C. S. 1985. Organic matter, nitrogen, and phosphorus content of sediments from channel catfish, *Ictalurus punctatus*, ponds. Research Report 10, Mississippi Agricultural Forestry Experiment Station, Mississippi State University, Stoneville, Mississippi, USA.

Wudtisin, I. and C. E. Boyd. 2006. Physical and chemical characteristics of sediments in catfish, freshwater prawn, and carp ponds in Thailand. Aquaculture Research 37:1202–1214.

Xinglong, J. and C. E. Boyd. 2006. Relationship between organic carbon concentration and potential pond bottom soil respiration. Aquacultural Engineering 35:147–151.

Yuvanatemiya, V. and C. E. Boyd. 2006. Physical and chemical changes in aquaculture pond bottom soil resulting from sediment removal. Aquacultural Engineering 35:199–205.