Effects of Pond Age on Bottom Soil Quality

Tenth Work Plan, Pond Dynamics Research 1 (10PDR1)
Final Report

Claude E. Boyd and Taworn Thunjai
Department of Fisheries and Allied Aquacultures
Auburn University, Alabama, USA

Mali Boonyaratpalin
Department of Fisheries
Kasetsart University
Bangkok, Thailand

Abstract

Bottom soil samples were collected from 35 ponds in the vicinity of Samutprakarn, Thailand. Ponds ranged in age from 3 to 39 years and had been used continuously for production of tilapia. Liming materials had been applied in large amounts, and bottom soils of all ponds had pH above 7, low exchangeable acidity, and free carbonates. Pond soils often contained between 1 and 2% total sulfur, suggesting that they were potential acid-sulfate soils. However, acidity from sulfide oxidation was not expressed because carbonates in the soil neutralized it. Although farmers apply liming materials to ponds during each crop, this practice is no longer necessary in many of the ponds because of residual effects from previous years. Cessation of liming would be acceptable in ponds with soil pH above 7, but pH should be checked annually and applications resumed when necessary. Where liming is practiced, Thai fish farmers should be careful about the selection of liming materials. Evaluation of available liming products revealed that only about 50% of them were correctly labeled and of good quality. Concentrations of total carbon in pond soils seldom exceeded 4%, and the average for organic carbon was 1.90%. The correlations between pond age and both total carbon and organic carbon were weak (r = 0.34 and 0.36, respectively). Concentrations of nitrogen in bottom soils did not differ with pond age and ranged from 0.1 to 0.3% with an average of 0.19%. The average carbon:nitrogen ratio was 11:1 at both sites. Acid-extractable phosphorus concentrations averaged 217 ppm, but the phosphorus adsorption capacity averaged 768 ppm, suggesting that the soils still have considerable reserve capacity to adsorb phosphorus. Results of this study revealed that ponds can be used annually for semi-intensive production of tilapia and presumably other species for many years without serious deterioration of bottom soil quality.

Introduction

Water quality in aquaculture ponds is influenced by the exchange of substances between soil and water, but only a few studies have clearly demonstrated relationships between bottom soil quality and fish production in ponds (Boyd, 1995). Nevertheless, aquaculturists insist that soil quality deteriorates rapidly in semi-intensive and intensive aquaculture ponds and that older ponds tend to have lower pH and higher concentrations of organic matter in bottom soils than newer ones. There have been only a few studies of the relationship between pond age and bottom soil quality (Tucker, 1985; Munsiri et al., 1995, 1996; Tepe and Boyd, 2002), and the results of these studies do not support the opinion that pH declines markedly and organic matter accumulates to high concentrations in older ponds.

The most common practices used in pond soil management are liming, drying of pond bottoms between crops, and sediment removal (Boyd, 1995). It is well documented that liming increases bottom soil pH, concentrations of total alkalinity, and total hardness in pond water (Boyd et al., 2002). The necessity for annual or more frequent liming, as often done, is not supported by research findings. Moreover, fish farmers often do not have information on the properties and quality of liming materials applied to ponds. Drying pond bottoms between crops can accelerate the decomposition of fresh organic matter and oxidize reduced substances in soil. The benefit of sediment removal on sediment quality is not well established, and it likely is unnecessary unless sediment is so deep that it causes a loss of pond volume or interferes with pond management operations (Boyd et al., 2002). Concentrations of nitrogen and phosphorus increase in pond soils over time (Masuda and Boyd, 1994; Munsiri et al., 1995). It is not known if the carbon: nitrogen (C:N) ratio, which influences microbial activity, or the ability of the pond soil to adsorb or release phosphorus change enough with pond age to influence bottom soil-water interactions.

Knowledge of the relationships between pond age and bottom soil quality and of the influence of soil management procedures on soil quality is important. This information can indicate whether or not ponds can be expected to decline in productivity over time. It also can reveal if common pond management procedures can be beneficial in maintaining good bottom soil quality. Data on changes in bottom soil quality over time also might allow improvements in bottom soil management techniques.

There is an area near Samutprakarn, Thailand, in the central region of the country where tilapia has been produced continuously in the same ponds for up to 40 years. This study was conducted to obtain data on bottom soil quality in ponds of different ages in this area. Samples of liming materials available to farmers also were analyzed to determine their quality.

METHODS AND MATERIALS

Ponds and Management

The Thailand Department of Fisheries (DOF) located farmers willing to allow bottom soil samples to be collected from their ponds and to provide information about ponds and management. Bottom soil samples were collected from 35 ponds in the vicinity of Samutprakarn, Thailand in February 2002 (Figure 1).

Ponds were used for tilapia production and ranged in water surface area from 0.48 to 7.68 ha with an average of 2.72 ha (SD = 1.88 ha). Ponds were of the embankment type with average depths of 1.5 to 2 m. Pond age ranged from 3 to 39 years, and the average age was 15 years (SD = 10 years). Fish seldom were fed a commercial diet, but ponds were treated with organic fertilizer and liming materials. Chicken manure was applied at 1,200 kg ha^{-1} at the beginning of the crop, and additional applications were made when necessary. Records of manure applications were not available, but 5 to 10 tons ha^{-1} was given as the usual annual application rate. Agricultural limestone or lime was applied frequently. The usual method consisted of spreading 375 kg ha^{-1} of liming material over pond bottoms at the beginning of each crop and making additional applications as necessary. Farmers could not provide accurate information on amounts of liming materials applied. However, they indicated that 2 tons ha^{-1} or more had been applied during most years. Ponds were not aerated mechanically, and water exchange was not applied. Ponds were drained annually for fish harvest. According to pond owners, harvest weights of fish usually were between 4,000 and 6,000 kg ha^{-1}, but records for individual ponds could not be obtained. Sediment had been removed once or more from 17 ponds, but farmers could not provide the exact dates when this practice was applied.

Soil Samples

Bottom soil samples were taken with a 5-cm diameter, clear plastic core liner tube (Wildlife Supply Company, Buffalo, New York). Workers waded into ponds and inserted the tubes into the bottoms by hand at five places in the deep end of each pond where water was 1 to 1.5 m deep. Tubes were hammered with a wooden block to force them into the original pond bottom or P-horizon as defined by Munsiri et al. (1995). Upper ends of tubes were beneath the water, so by closing them with a plastic cap, the tubes could be withdrawn from the bottom with soil core and overlaying water intact. Caps were placed on the bottom ends of tubes to prevent cores from slipping out, and tubes were held vertically to avoid disturbing the surface of the core. Water was siphoned by aid of flexible plastic tubing from the liner tube leaving only 1 or 2 cm above the soil surface. The thickness of the S-horizon and the total sediment thickness (S- and M-horizons) were measured as described by Munsiri et al. (1995). Soil cores were pressed upward in tubes with a core removal tool. A core segment ring made from a piece of core liner tube (Munsiri et al., 1995) was placed on top of the liner tube, and the part of the soil core representing the S-horizon was pressed into the core segment ring. The S-horizon was separated by inserting a thin, wide spatula between the bottom of the core segment ring and the top of the core liner tube. The S-horizon from one core tube in each pond was placed in a tarred soil moisture canister. The S-horizons from the other four cores were cut and combined in a single plastic container. Soil samples were held on ice in an insulated chest for no more than 12 h before they arrived at the DOF laboratory in Bangkok, Thailand.

A sample of surface water was dipped from each pond and stored in a tightly sealed 500 ml plastic bottle.

Soil Analyses

At the DOF laboratory, samples in tarred canisters were dried to constant weight at 102°C and the dry bulk density was calculated. Composite samples were dried at 60°C for 72 h in a mechanical convection oven. Dry samples were transported to Auburn University (AU) where they were pulverized with a mechanical soil crusher (Custom Laboratory Equipment, Inc., Orange City, Florida) to pass through a 40-mesh (0.425 mm) screen and stored in plastic containers.

Soil pH was measured with a glass electrode inserted into a 1:1 mixture of dry, pulverized soil and distilled water. Exchangeable acidity was measured from the pH change in a buffer solution caused by adding 20 g soil to 40 ml buffer. The buffer was made by dissolving 10 g p-nitrophenol, 7.5 g boric acid, 37 g potassium chloride, and 5.25 g potassium hydroxide in distilled water, adjusting the pH to 8.00 ± 0.01, and diluting to 1,000 ml (Boyd and Tucker, 1992). A pH change of 0.10 unit in 40 ml of this buffer equals 0.08 meq of exchangeable acidity.

Total carbon concentration was measured with a Leco Model EC 12 induction furnace carbon analyzer (Leco Corporation, St. Joseph, Michigan). Organic carbon was measured by the Walkley-Black sulfuric acid-potassium dichromate oxidation procedure (Boyd and Tucker, 1992).

Sulfur was analyzed by incinerating samples in a Leco Sulfur Furnace HP10 and titrating the liberated sulfur with standard KIO_3 using a Leco Sulfur Titrator (Leco Corporation, St. Joseph, Michigan). Total nitrogen concentrations were determined with a Leco Carbon-Hydrogen-Nitrogen Analyzer CHN 600. Phosphorus was extracted from soil samples by the Lancaster (Mississippi) method for calcareous soils (Hue and Evans, 1986). The extractant is made as follows: add 900 ml glacial acetic acid, 65 g of malonic acid [$CH_2(CO_2H)_2$], 120 g of malic acid [$CH_2CHOH(CO_2H_2)_2$], and 13.8 g of ammonium fluoride to 7,500 ml of deionized H_2O; mix well to dissolve reagents; add 30 g of aluminum chloride and mix; adjust pH to 4.0 with ammonium hydroxide; dilute to 10 l with deionized water. Extraction consisted of placing 5 g soil in 20 ml extracting solution and shaking at 180 oscillations min^{-1} for 5 min. Phosphorus in filtered extracts (Whatman No. 1 filter paper) was determined with a Jarrel-Ash ICAP 9000 Plasma Spectrophotometer. Water-soluble phosphorus was measured by shaking 2 g soil samples with 100 ml of distilled water for 24 h and measuring phosphorus concentrations in extracts by the ascorbic acid method. The phosphorus adsorption capacity was determined as described by Boyd and Munsiri (1996).

Cation exchange capacity (CEC) was determined as the summation of cation concentrations (meq 100 g^{-1}) measured in neutral, 1.00 N ammonium acetate extracts of soils plus the exchangeable acidity.

Table 1. Comparison of the S-horizon thickness and total sediment depth between ponds with and without sediment removal at Samutprakarn, Thailand.

Pond	With Sediment Removal (n = 17)	Without Sediment Removal (n = 18)	t-score
S-Horizon Depth (cm)	7.23 ± 6.19	7.21 ± 8.61	0.81
Total Sediment Depth (cm)	17.86 ± 9.81	14.76 ± 12.51	0.01
Total Carbon (%)	2.84 ± 0.24	3.07 ± 0.16	0.83
Organic Carbon (%)	1.86 ± 0.15	1.94 ± 0.01	0.45

Figure 1. Map of Thailand with location of sampling area.

The technique used to measure soil respiration was modified from a procedure of Anderson (1982).

Water samples were analyzed for total alkalinity by titration to pH 4.5 with 0.020 N hydrochloric acid and for total hardness by titration to the eriochrome black-T endpoint with 0.01 Methylenediaminetetraacetic acid (Boyd and Tucker, 1992).

Liming Materials and Analyses

Samples of 45 different brands and grades of liming material were obtained from aquaculture supply stores and from farmers in Thailand. These samples were stored in plastic containers and transported to AU. They were analyzed for neutralizing value, fineness rating, calcium, magnesium, and pH by methods described by Boyd and Masuda (1994).

RESULTS AND DISCUSSION

Total Alkalinity and Total Hardness

Soils near Samutprakarn, Thailand often are highly acidic because of the presence of iron sulfide (Khaewreenrom, 1990). Surface waters in such areas usually have low concentrations of total alkalinity and total hardness (Boyd and Tucker, 1998). Nevertheless, heavy and frequent use of liming materials in ponds resulted in average total alkalinity and total hardness concentrations of 227 and 261 mg l^{-1}, respectively. Nearly all ponds contained more than 100 mg l^{-1} alkalinity and hardness. The equilibrium concentration for total alkalinity and total hardness in water in contact with solid phase calcium carbonate and normal atmospheric carbon dioxide concentration is about 60 mg l^{-1} (Boyd and Tucker, 1998). The higher concentrations of alkalinity and hardness observed in this study were possible because of additional carbon dioxide originating in microbial decomposition of organic matter in pond soils and water. It is common for natural waters and aquaculture pond waters to have alkalinity and hardness concentrations greater than 60 mg l^{-1} (Boyd and Tucker, 1998).

The correlation between hardness (x) and alkalinity (y) was not strong ($r = 0.42$; $P < 0.05$), but hardness usually was greater than alkalinity. This resulted because the basic anion of the liming material was consumed to neutralize acidity, and the calcium and magnesium portion of the liming material remained in the water (Boyd and Tucker, 1998). The concentration of total hardness often exceeds that of total alkalinity in ponds where highly acidic soils and waters have been neutralized by liming.

Sediment Depth

Sediment depth averaged 16.25 cm and ranged from 2.7 to 59.3 cm, and 28 ponds had sediment depth less than 20 cm. Sediment depth was no less in ponds from which sediment had been removed than in ponds from which sediment had not been removed (Table 1). Also, there was no relationship between pond age and sediment depth ($P > 0.05$) in ponds with and without sediment removal.

Munsiri et al. (1995) showed that sediment depth increased at the rate of about 1 cm yr^{-1} in research ponds used for 52 years for sunfish (*Lepomis* spp.) or channel catfish (*Ictalurus punctatus*) culture. Tepe and Boyd (2002) reported a comparable

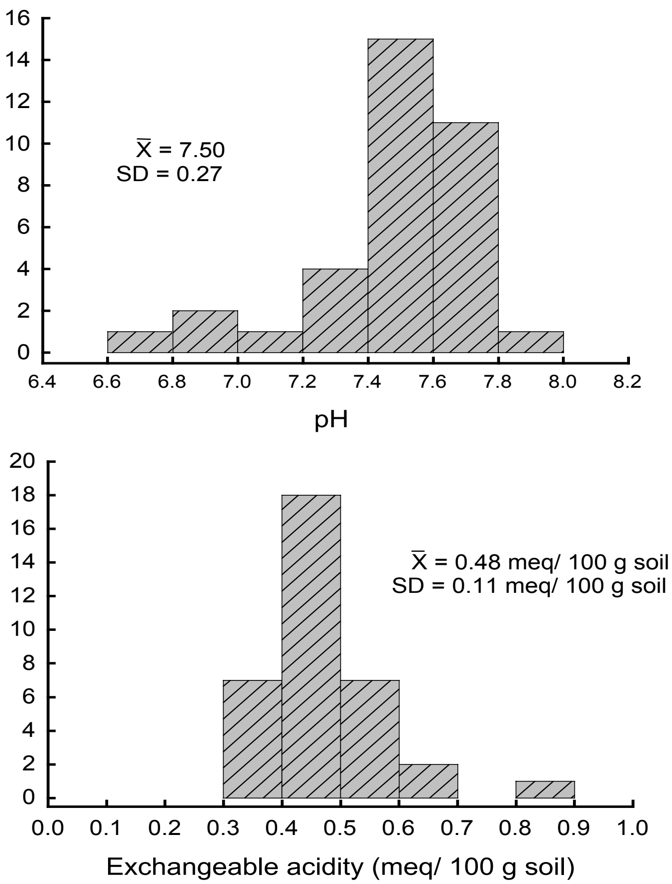

Figure 2. Frequency distribution histograms for fish pond bottom soil quality at Samutprakarn, Thailand; (a) pH, (b) exchangeable acidity.

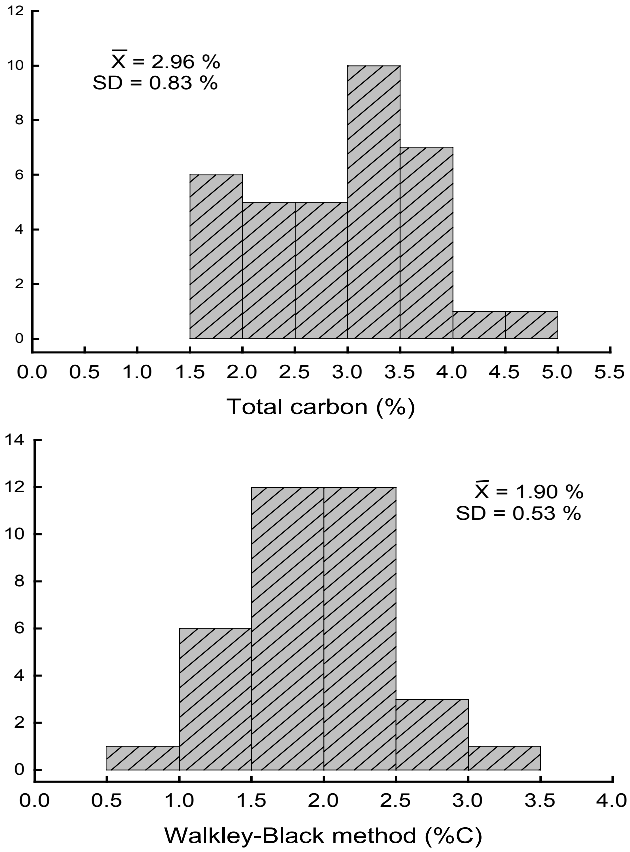

Figure 3. Frequency distribution histograms for pond bottom soil quality at Samutprakarn, Thailand; (a) total carbon, (b) organic carbon by Walkley-Black method.

rate of increase in sediment depth in bait minnow ponds in Arkansas. Sunfish, channel catfish, and bait minnows do not vigorously stir pond bottoms as do tilapia. Tilapia disturb the pond bottom greatly while hunting for benthic organisms, and they build large depressions in the pond bottom for nests. The lack of a relationship between pond age and sediment depth in tilapia ponds is not surprising because the fish are constantly stirring the pond bottom.

Thickness of S-Horizon and Bulk Density

The S-horizon (Munsiri et al., 1995) averaged 7.22 cm in depth and ranged from 1.1 cm to 39.8 cm. The dry bulk density of this layer averaged 0.23 g cm^{-3} with a range of 0.08 to 0.35 g cm^{-3}. There were no differences in the thickness of the S-horizon or its bulk density as a result of sediment removal from some of the ponds (Table 1). Moreover, the thickness of the S-horizon and bulk density were not correlated with pond age in ponds with or without sediment removal ($P > 0.05$).

Munsiri et al. (1995) used 0.3 g cm^{-3} as the upper limit for dry bulk density in defining the S-horizon in aquaculture pond bottom profiles based on data from cores collected from channel catfish ponds at AU. The S-horizons in all but five of the ponds at Samutprakarn had bulk density less than this value.

Soil pH and Exchangeable Acidity

Bottom soil pH ranged between 6.62 and 7.90 and averaged 7.50 (Figure 2a). This high pH reflects the effect of the large and frequent applications of liming materials and suggests that the soils are essentially at equilibrium with calcium carbonate. Soils containing free calcium carbonate usually have a pH of 7 to 8 (Boyd, 1995).

The exchangeable acidity was quite low, ranging from 0.32 to 0.85 meq 100 g^{-1} soil with an average value of 0.48 meq 100 g^{-1} soil (Figure 2b). The average CEC was 35 meq 100 g^{-1} (SD = 5 meq 100 g^{-1}), so the pond bottom soils were essentially base saturated as the result of large, frequent applications of liming materials.

Total Sulfur

The ponds had an average total sulfur concentration of 1.18% with a range of 0.22 to 3.03%. A total sulfur concentration of 0.75% or above is one criterion necessary to classify a soil as a potential acid-sulfate soil (Boyd, 1995). Although this measurement alone is not adequate to classify a soil as a potential acid-sulfate soil, it is well known that potential acid-sulfate soils are common in the Samuthprakarn area (Khaewreenrom, 1990). Twenty-seven of the samples contained more than 0.75% total sulfur and would be expected to be highly acidic. However, the presence of carbonate in acid-sulfate soils can prevent the expression of acidity. Soils in the present study have been heavily limed and acidity produced by oxidation of iron sulfide was

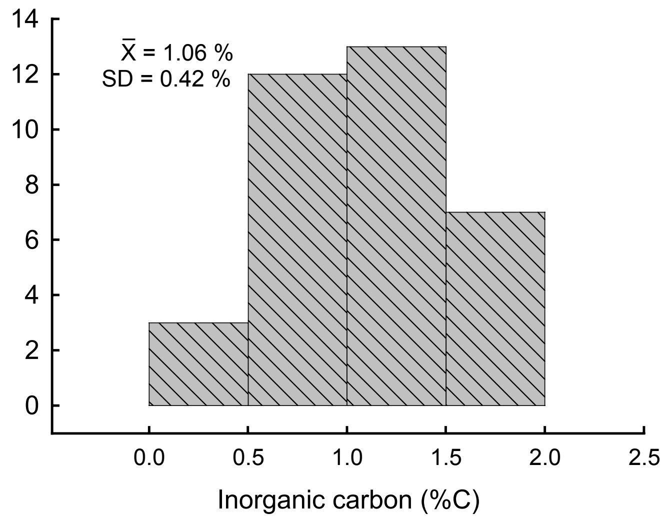

Figure 4. Frequency distribution histograms for inorganic carbon concentration in pond bottom soils at Samutprakarn, Thailand.

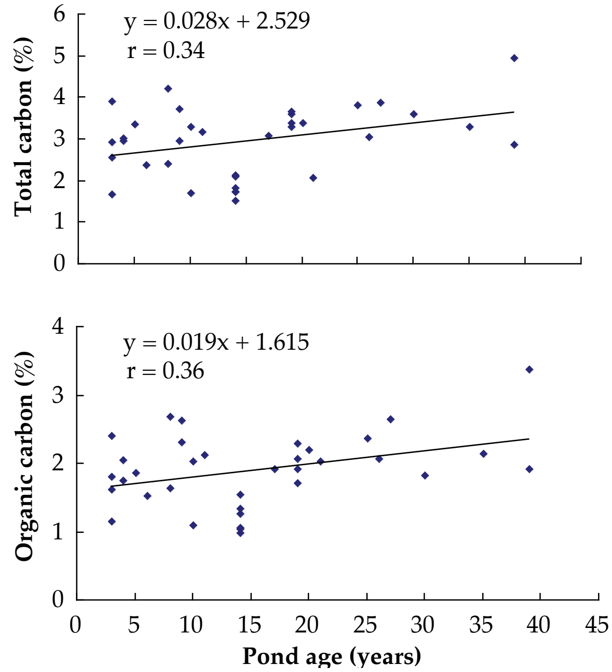

Figure 5. Regression line for relationship between pond age in years and carbon in pond bottom soil at Samutprakarn, Thailand; (a) total carbon, (b) organic carbon by Walkley-Black method.

neutralized by reaction with residual liming material.

Soil Carbon

Total carbon concentrations ranged from 1.55 to 4.96% and averaged 2.96% (Figure 3a). Organic carbon averaged 1.90% with a range of 0.65 to 3.39% (Figure 3b). Ponds have not accumulated high concentrations of carbon as often believed by fish farmers. Findings also agree with the observation that aquaculture ponds situated on mineral soil seldom contain more than 3% organic carbon (Boyd, 1995).

The difference in total carbon concentration measured by the Leco analyzer and organic carbon determined by the Walkley-Black method represents mainly inorganic carbon in carbonates. The concentration of inorganic carbon averaged 1.06% (Figure 4). Assuming that all of the inorganic carbon is bound in calcium carbonate with a carbon content of 12%, the average calcium carbonate concentration in the soil is 8.8%. The dry bulk density of the S-horizon in the ponds averaged 0.23 g cm^{-3} or 230 kg m^{-3}. Assuming a 7.22-cm thickness of the S-horizon, the S-horizon would weigh 166 tons ha^{-1}. This much soil with 8.8% calcium carbonate would contain 14.6 tons of calcium carbonate. Such a high value in soils that originally were free of calcium carbonate is possible given large applications of liming materials over a long time. A pond of average age (15 yr) may have been treated with about 30 tons of liming material. Some of this liming material was used up in reactions with soil acidity, and some was lost when sediment was suspended and discharged from ponds in effluents during pond draining for fish harvest. However, a considerable quantity is still present in the sediment of ponds.

Average carbon concentrations in soils of ponds from which sediment had been removed did not differ from those in ponds from which sediment had not been removed ($P > 0.05$, Table 1). This does not suggest that sediment removal is not beneficial because a deep accumulation of sediment in ponds reduces pond volume and interferes with harvest and other pond management activities.

Pond Age and Soil Carbon

There was a slight increase in carbon concentration ($P < 0.05$) with increasing pond age for both methods of carbon analysis (Figure 5), but correlation coefficients (r) were low (Leco Analyzer, $r = 0.334$; Walkley-Black procedure, $r = 0.358$). Thus, pond age alone is not a good predictor of bottom soil carbon concentrations. Pond age was no better as a predictor of soil carbon concentration when ponds from which sediment had been removed were omitted from the regression.

Failure to demonstrate a strong increase in soil organic carbon with increasing pond age corroborates earlier studies. Tucker (1985) reported a slight increase in bottom soil carbon concentration with increasing age in channel catfish ponds in Mississippi. Munsiri et al. (1996) found slightly greater concentrations of organic carbon in bottom soils of 11-year-old shrimp ponds than of three-year-old shrimp ponds in Honduras. Moreover, organic carbon concentrations in bottoms of 3-, 26-, and 52-year-old ponds at the AU Fisheries Research Unit were similar (Munsiri et al., 1995). Organic carbon concentrations in bottom soils of young (seven-year-old), intermediate-aged (20-to 25-year-old), and old (30- to 35-year-old) bait minnow ponds in Arkansas also were similar (Tepe and Boyd, 2002). In the studies mentioned above, sediment depth increased with pond age, and the total mass of organic carbon in pond bottoms is greater in older ponds even though the organic carbon concentration does not differ greatly with pond age. Nevertheless, the sediment below a depth of a few centimeters does not react with the pond water and is essentially inert with respect to its influence on water quality and fish production.

The present study and studies referenced above did not contain new ponds that previously had not been used in

Table 2. Neutralizing value, fineness rating, percentages of calcium (Ca) and magnesium (Mg), pH of non-equilibrium slurries, and correct product identification for five classes of liming materials in Thailand.

Sample	Neutralizing Value (%)	Fineness Rating (%)	Ca %	Mg (%)	pH of Slurry	Identification
Sold as Ground Calcium Carbonate						
1	98	96	36.9	1.9	9.5	Ag. limestone (calcitic)
2	96	100	36.8	1.4	9.4	Ag. limestone (calcitic)
3	98	100	38.0	1.2	9.9	Ag. limestone (calcitic)
4	99	96	37.7	1.4	9.7	Ag. limestone (calcitic)
5	99	98	37.4	1.4	9.5	Ag. limestone (calcitic)
6	101	95	37.6	1.3	9.7	Ag. limestone (calcitic)
7	98	100	36.4	1.9	9.6	Ag. limestone (calcitic)
8	99	65	36.0	1.2	9.4	Ag. limestone (calcitic)
9	81	55	33.4	1.1	9.3	Ag. limestone (calcitic)
10	99	100	32.2	5.3	9.7	Ag. limestone (ordinary)
Sold as Ground Dolomite						
11	107	96	21.4	12.0	9.2	Ag. limestone (dolomitic)
12	105	97	21.5	12.4	9.3	Ag. limestone (dolomitic)
13	106	99	21.0	13.1	9.2	Ag. limestone (dolomitic)
14	107	99	20.8	13.2	9.4	Ag. limestone (dolomitic)
15	106	99	20.8	13.3	9.2	Ag. limestone (dolomitic)
16	108	96	21.8	13.0	9.3	Ag. limestone (dolomitic)
17	105	100	21.8	12.8	9.4	Ag. limestone (dolomitic)
18	104	98	26.0	9.7	9.5	Ag. limestone (ordinary)
19	105	97	23.7	11.1	9.6	Ag. limestone (ordinary)
20	104	98	24.8	10.2	9.5	Ag. limestone (ordinary)
21	42	48	11.0	3.8	9.5	Ag. limestone (ordinary)
22	41	51	9.5	6.1	9.4	Ag. limestone (ordinary)
23	98	45	29.8	6.1	9.4	Ag. limestone (ordinary)
24	53	45	10.9	6.6	9.5	Ag. limestone (ordinary)
25	107	99	20.8	5.5	11.3	Lime (ordinary)
26	107	100	21.1	13.7	9.4	Ag. limestone (dolomitic)
Sold as Marl						
27	94	77	35.7	0.0	9.4	Ag. limestone (calcitic)
28	71	63	29.1	2.7	9.8	Ag. limestone (ordinary)
29	88	56	34.9	1.3	9.3	Ag. limestone (calcitic)
Sold as Ground Seashell						
30	72	45	26.0	1.6	12.4	Lime (calcitic)
31	103	64	41.1	1.2	12.4	Lime (calcitic)
32	82	60	31.0	1.2	12.3	Lime (calcitic)
33	97	57	38.8	1.0	12.4	Lime (calcitic)
34	90	59	29.7	5.3	12.3	Lime (ordinary)
Sold as Lime						
35	133	86	48.8	1.8	12.6	Lime (calcitic)
36	138	100	48.4	1.9	12.2	Lime (calcitic)
37	124	85	41.2	1.6	12.3	Lime (calcitic)
38	157	98	30.7	18.5	12.5	Lime (dolomitic)
39	130	85	41.3	3.9	12.4	Lime (ordinary)
40	124	90	44.6	2.3	12.5	Lime (ordinary)
41	124	85	41.7	2.9	12.5	Lime (ordinary)
42	100	97	38.4	0.6	12.4	Lime (calcitic)
43	104	99	38.3	1.4	12.6	Lime (calcitic)
44	109	59	39.5	1.9	12.6	Lime (calcitic)
45	108	71	43.5	1.9	12.3	Lime (calcitic)

aquaculture. Munsiri et al. (1995) took cores from pond bottoms and found that the original bottom soil often contained less than 0.5% C, while the sediment usually contained 2 to 4% C. Native soils in the Samutprakarn area of Thailand normally have less than 0.5% C (Thailand Department of Land Development, pers. comm., 2001). This suggests that pond sediment tends to contain more carbon than the original pond bottom, but that the sediment has a relatively uniform carbon concentration with respect to depth and pond age. Pond soil at Samutprakarn apparently reached near equilibrium with carbon concentration very quickly as suggested by Boyd (1995) as the general tendency for pond soils.

The carbon fraction measured by the Walkley-Black method is organic carbon that is more readily oxidized by bacteria than other fractions. Thus, for aquaculture purposes it is more useful to know the organic carbon concentration than the total carbon concentration. This is fortunate because the Walkley-Black method can be conducted with simple laboratory apparatus or with a soil organic carbon kit (CEL/700 Organic Matter Laboratory, Hach Chemical Company, Loveland, Colorado).

Nitrogen and Phosphorus

Total nitrogen concentrations ranged from 0.10 to 0.30% with an average of 0.19%, and C:N ratios (based on total carbon data) were between 5.1 and 19.2 (to 1) with an average of 11:1. This C:N ratio is within the range of 10:1 to 15:1 determined to be best for fish production by Banerjea (1967). The correlations between pond age and both total soil nitrogen and C:N ratio were not significant at $\alpha = 0.05$.

Concentration of acid-extractable phosphorus in the pond soils ranged from 78 to 944 ppm with an average of 217 ppm. Water extractable phosphorus concentrations averaged 9 ppm with a lowest value of 5 ppm and a highest value of 31 ppm. Compared with concentrations of acid extractable and water extractable phosphorus found in natural soils at sites suitable for freshwater aquaculture ponds in Thailand (Boyd and Munsiri, 1996), these are rather high concentrations and reflect the input of phosphorus in fertilizers and feeds. Nevertheless, there was no correlation between pond age and phosphorus concentration. The soils had phosphorus adsorption capacities of 561 to 1,072 ppm with an average of 768 ppm. These high phosphorus adsorption values are the result of high soil pH and calcium concentration. The soils have a huge capacity to continue to adsorb phosphorus applied to ponds in fertilizers and feeds.

Soil Respiration

The respiration rate of samples of pond bottom soil averaged 3.0 mg CO_2 g^{-1} soil during a one-week incubation period. The lowest and highest soil respiration values were 0.60 and 6.77 mg CO_2 g^{-1} soil, respectively. About half of the samples had respiration values between 1 and 3 mg CO_2 g^{-1} soil. There was no correlation between pond age and soil respiration rate. The soil respiration rates were similar to those reported for channel catfish ponds in the United States (mean = 3.29 mg CO_2 g^{-1} soil; range = 2.04 to 4.85 mg CO_2 g^{-1}) and shrimp ponds in Ecuador (mean = 1.41 mg CO_2 g^{-1} soil; range = 1.07 to 1.09 mg CO_2 g^{-1}) (Sonnenholzner and Boyd, 2000).

Liming Materials

The results of the analyses of liming materials are summarized in Table 2. The criteria for identifying compounds and assessing quality of materials follow:

- Calcitic agricultural limestone : pH of slurry < 10; calcium 35–40%; neutralizing value > 85%; fineness rating > 85%.
- Dolomitic agricultural limestone : pH of slurry < 10; magnesium > 12%; neutralizing value > 90%; fineness rating > 85%.
- Ordinary agricultural limestone : pH of slurry < 10; neutralizing value > 85%; fineness rating > 85%.
- Lime : neutralizing value > 120%; fineness rating > 85%.

Based on these criteria, 33 of the 45 samples (73%) were labeled correctly, and 23 or roughly half of the samples were both correctly labeled and of good quality. Most of the products sold as ground calcium carbonate or ground dolomite (agricultural limestone) were of good quality, but several were incorrectly labeled as dolomitic although they were ordinary agricultural limestone. Fish farmers in Thailand obviously would benefit greatly if liming materials were labeled as to neutralizing value, fineness rating, and calcium and magnesium concentrations.

CONCLUSION

Findings of this study suggest that ponds in Thailand can be used for many years for the semi-intensive culture of tilapia. Some of the ponds were over 30 years old, but their bottom soils had not accumulated extremely high concentrations of organic matter or become saturated with phosphorus. The ponds contained high soil sulfur concentrations, but frequent applications of liming materials have prevented low soil pH from sulfur oxidation and maintained high alkalinity and hardness concentrations in pond waters. Applications of liming materials also have resulted in the accumulation of calcium carbonate in bottom soils, and this enhances the ability of soils to remove phosphorus from water by sequestering it as calcium phosphate. The use of liming materials in many of the ponds could be postponed until soil pH declines below 7. However, there probably are no adverse effects of heavy liming on bottom soil quality or fish production (Boyd, 1995). Sediment removal, as practiced in some of the ponds, had not resulted in reduction in the thickness of the sediment or improved soil quality. This unexpected observation probably is the result of tilapia continually stirring the bottom in search of food and disturbing the bottom when building nests.

Of course sediment removal can be beneficial in ponds that have accumulated deep layers of soft sediment and become excessively shallow. It is considered a good practice for maintaining bottom soil quality (Boyd et al., 2002).

Soil quality in tilapia ponds in Thailand was similar to the composition of that in channel catfish ponds in Alabama (Munsiri et al., 1995), bait minnow ponds in Arkansas (Tepe and Boyd, 2002), and shrimp ponds in Honduras (Munsiri et al., 1996). This suggests that similar processes regulate bottom soil quality in all types of aquaculture and that ponds can be used many years without serious degradation of soil quality.

ANTICIPATED BENEFITS

This research has demonstrated the following important points about tilapia ponds in Thailand:

- Ponds can be used for many years without serious degradation of bottom soil quality.
- Liming can increase the pH of acidic bottom soils, but formerly acidic soils have to be treated with liming materials after each crop if pH is below 7.0.
- Sediment removal did not appear to improve bottom soil quality, but it may be necessary in ponds with high external sediment loads or heavy internal erosion.

These observations suggest that tilapia ponds are sustainable for many years. This is a useful observation that should be used in defense of aquaculture because some environmental groups argue that aquaculture is not sustainable. Tilapia farmers in Thailand have limed ponds heavily for many years. Soil pH is above 7 in most ponds, and the results of this study could be used to promote the use of soil pH as an indicator for the need to lime ponds. The findings also should be used to discourage the routine removal of sediment from ponds. Of course, sediment removal may be necessary where accumulation of sediment has caused ponds to become too shallow or where sediment is so deep that pond bottoms cannot be dried during fallow periods between crops.

The quality of liming materials available for use in Thai aquaculture varies greatly. Therefore, fish and shrimp farmers cannot be sure about the properties and quality of liming materials that they purchase for use in ponds. This study could provide the basis for educating farmers on the properties of liming materials, developing standards for liming materials, or at least convincing manufacturers and vendors to label their products as to compound(s) and composition.

The findings and potential benefits of this study should be applicable both in Thailand and in other nations.

ACKNOWLEDGMENTS

The assistance of Kom Silapajarn in conducting the free carbonate analyses is greatly appreciated.

LITERATURE CITED

Anderson, J.P.E., 1982. Soil respiration. In: A.L. Page, R.H. Miller, and D.R. Kenney (Editors), Methods of Soil Analysis Part 2 – Chemical and Microbiological Properties. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, pp. 831–871.

Banerjea, S.M., 1967. Water quality and soil condition of fish ponds in some states of India in relation to fish production. Indian J. Fish., 14:113–144.

Boyd, C.E., 1995. Bottom Soils, Sediment, and Pond Aquaculture. Chapman and Hall, New York, 348 pp.

Boyd, C.E. and K. Masuda, 1994. Characteristics of liming materials used in aquaculture ponds. World Aquacult., 25:76–79.

Boyd, C.E. and P. Munsiri, 1996. Phosphorus adsorption capacity and availability of added phosphorus in soils from aquaculture areas in Thailand. J. World Aquacult. Soc., 27:160–167.

Boyd, C.E. and C.S. Tucker, 1992. Water Quality and Pond Soil Analyses for Aquaculture. Alabama Agricultural Experiment Station, Auburn University, Alabama, 183 pp.

Boyd, C.E. and C.S. Tucker, 1998. Pond Aquaculture Water Quality Management. Kluwer Academic Publishers, Boston, Massachusetts, 700 pp.

Boyd, C.E., C.W. Wood, and T. Thunjai, 2002. Aquaculture Pond Bottom Soil Quality Management. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, 41 pp.

Hue, N.V. and C.E. Evans, 1986. Procedures Used for Soil and Plant Analysis by the Auburn University Soil Testing Laboratory. Departmental Series No. 106. Alabama Agricultural Experiment Station, Auburn University, Alabama, 31 pp.

Khaewreenrom, 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. J. World Aquaculture Society, 25:379–395.

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

Munsiri, P., C.E. Boyd, D. Teichert-Coddington, and B.F. Hajek, 1996. Texture and chemical composition of soils from shrimp ponds near Choluteca, Honduras. Aquacult. Int., 4:157–168.

Sonnenholzner, S. and C.E. Boyd, 2000. Vertical gradients of organic matter concentration and respiration rate in pond bottom soils. J. World Aquacult. Soc., 31:376–380.

Tepe, Y. and C.E. Boyd, 2002. Sediment quality in Arkansas bait minnow ponds. J. World Aquacult. Soc., 33:221–232.

Thailand Department of Land Development, personal communication, 2001.

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

Cite as: [Author(s), 2004. Title.] In: R. Harris, I. Courter, and H. Egna (Editors), Twenty-First Annual Technical Report. Aquaculture CRSP, Oregon State University, Corvallis, Oregon, [pp. ___.]