Pond Soil Characteristics and Dynamics of Soil Organic Matter and Nutrients

Eighth Work Plan, Pond Dynamics Research 1 (PDR1)

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Introduction

A system to describe pond soil horizons was proposed by Munsiri et al. (1995). This system may be useful for the systematic characterization of pond soil and for soil descriptions used in research projects. It serves as a basis for developing a pond soil classification scheme similar to the system of soil taxonomy used in traditional soil science (Soil Survey Staff, 1975, 1994) and serves as an aid to aquaculture pond management (Boyd, 1995). The proposed system of soil description provides a framework for additional data on pond soil characteristics collected from Pond Dynamics/ Aquaculture CRSP prime sites. Data collected within this framework will also be extremely useful to the PD/A CRSP, because it will allow detailed descriptions of soils at the CRSP prime sites in several countries.

This report contains data on soil characteristics for PD/A CRSP ponds in Thailand and Honduras. Additional information will be obtained for ponds at the Kenya CRSP site during 1997.

Methods and Materials

Ponds

Freshwater ponds in this study are located on the campus of the Asian Institute of Technology (AIT), Bangkok, Thailand, and at the El Carao National Fish Culture Center, Comayagua, Honduras. All ponds are used for CRSP research. At AIT, three ponds were 12 years old and three ponds were three years old. These will be referred to as old and new ponds, respectively. The ponds at El Carao were constructed in the early 1980s, but they were extensively renovated in 1990. The three brackish water ponds used in this study are located on the Granjas Marinas San Bernardo shrimp farm near Choluteca, Honduras. The ponds have been in production for 12 years. The shrimp farm allows the CRSP to use the ponds for research.

Ponds at AIT were 500 to 1,000 m^2 with average depths of approximately 100 cm, while ponds at El Carao were 1,000 m^2 with average depths of 80 cm. The brackish water ponds were about 1 ha in size with average depths of 50 to 70 cm.

Sampling

Soil cores were taken with a hand-operated, 5-cm-diameter core sampler (Wildlife Supply Company, Saginaw, Michigan, USA). Procedures for separating the cores into successive 2-cm-long core segments are described by Munsiri et al. (1995). Core segments were dried at 102°C (for analysis of moisture content and dry bulk density) or at 60°C (for other analyses) and transported to Auburn University for analyses.

Physical and Chemical Analyses

Samples were analyzed for moisture content (gravimetry), dry bulk density (gravimetry), color (Munsell color chart), wet soil pH (direct, glass electrode), dry soil pH (1:1 slurry of dry soil and distilled water, glass electrode), exchangeable acidity (Adams-Evans buffer method), particle

Table 1. Profiles for moisture content in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as percentages of dry weight. Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	160.8 ± 7.9	279.2 ± 29.5	217.5 ± 21.9	209.7 ± 27.7
2-4	104.8 ± 1.0	189.6 ± 14.9	136.6 ± 17.0	164.1 ± 32.3
4-6	102.9 ± 5.8	186.3 ± 24.0	89.8 ± 5.3	114.6 ± 14.6
6-8	86.7 ± 9.0	170.3 ± 17.0	66.6 ± 1.5	91.7 ± 7.4
8-10	82.5 ± 10.2	162.5 ± 16.6	57.4 ± 0.7	95.4 ± 12.4
10-12	78.1 ± 9.9	130.7 ± 12.4	54.2 ± 0.8	76.9 ± 2.1
12-14	69.7 ± 8.1	120.0 ± 10.4	48.0 ± 1.9	72.0 ± 1.3
14-16	68.6 ± 7.6	108.5 ± 9.1	45.0 ± 0.9	69.1 ± 3.2
16-18	60.4 ± 4.8	103.1 ± 9.5	36.1 ± 2.1	63.7 ± 4.1
18-20	57.0 ± 5.0	102.8 ± 9.2	32.2 ± 2.1	55.4 ± 2.2
20-22		86.4 ± 5.3	31.3 ± 1.9	51.1 ± 2.6
22-24		74.3 ± 1.5	32.1 ± 1.9	52.4 ± 3.8
24-26		64.8 ± 3.7		51.1 ± 4.9
26-28		60.9 ± 2.9		53.6 ± 5.6
28-30		56.7 ± 2.5		
30-32		49.2 ± 1.8		
32-34		46.5 ± 1.6		
34-36		45.4 ± 2.0		

density (pycnometer method), total carbon and nitrogen (Leco CHN Analyzer), total phosphorus (perchloric acid oxidation), total sulfur (Leco Sulfur Analyzer), and acid-extractable phosphorus, and metal ions (extraction in a 0.075 N acid solution of 0.05 N HCl plus 0.025 N H_2SO_4 followed by plasma spectrophotometry). Details of all analyses are described by Munsiri et al. (1995).

Results and Discussion

A flocculent layer of water with a high concentration of recently-settled solids extended 1 to 3 cm above the soil-water interface in all core samples. This is the F horizon described by Munsiri et al. (1995). The moisture content (Table 1) and the dry bulk density (Table 2) of core segments decreased with depth in cores, and as a result, the dry bulk density of core segments increased (Table 2). The 0-2 cm segment was much lower in dry bulk density than deeper segments. Thus, the S horizon, defined as the layer with a bulk density of 0.3 g cm^{-3} or less (Munsiri et al., 1995) was confined to the upper 2 cm layer. Actually, the new ponds at AIT had an S horizon less than 2 cm in depth, because the 0-2 cm layer had a bulk density greater than 0.3 g cm^{-3}. To delineate the thickness of the S horizon (bulk density less than 0.3 g cm^{-3}) in the new ponds at AIT, thinner core segments were necessary; however in practice it was not possible to cut thinner core segments. Dry bulk density was below 0.7 g cm^{-3} between the following depths in the different ponds: 2 to 6 cm in new ponds at AIT; 2 to 22 cm in old ponds at AIT; 2 to 4 cm in freshwater ponds in Honduras; 2 to 8 cm in brackish water ponds in Honduras. This layer represents the M horizon or the mature, bulk sediment (Munsiri et al., 1995). Munsiri et al. (1995) decided upon a bulk density of 1.4 g cm^{-3} to divide the original pond soil from the sediment. In the present work, the core extended into the original soil in all ponds, but none of the bulk density values reached 1.4 g cm^{-3}. Munsiri et al. (1996a) also reported bulk density values for core segments from ponds at former PD/A CRSP sites in Egypt, and none of them exceeded 1 g cm^{-3}. Thus, many original pond soils do not have bulk densities as high as those found in the ponds at Auburn, Alabama, that were used by Munsiri et al. (1995) to develop the proposed system for separating pond

Table 2. Profiles for dry bulk density in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as grams dry soil solids per cubic centimeter (g cm^{-3}). Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	0.41 ± 0.00	0.29 ± 11.02	0.34 ± 0.04	0.31 ± 0.01
2-4	0.62 ± 0.01	0.41 ± 11.60	0.57 ± 0.08	0.46 ± 0.08
4-6	0.67 ± 0.02	0.41 ± 11.65	0.80 ± 0.04	0.58 ± 0.06
6-8	0.83 ± 0.08	0.44 ± 11.95	0.87 ± 0.02	0.68 ± 0.03
8-10	0.84 ± 0.07	0.45 ± 12.06	0.89 ± 0.03	0.68 ±0.06
10-12	0.87 ± 0.06	0.55 ± 12.31	0.99 ± 0.03	0.71 ± 0.00
12-14	0.84 ± 0.06	0.57 ± 12.52	1.10 ± 0.04	0.79 ± 0.04
14-16	0.94 ± 0.02	0.63 ± 13.03	1.14 ± 0.02	0.88 ± 0.09
16-18	0.96 ± 0.07	0.67 ± 13.25	1.20 ± 0.02	0.98 ± 0.10
18-20	0.95 ± 0.08	0.69 ± 13.35	1.32 ± 0.03	0.89 ± 0.00
20 22		0.73 ± 13.82	1.34 ± 0.04	1.08 ± 0.04
22-24		0.81 ± 14.61	1.31 ± 0.04	1.05 ± 0.06
24-26		0.93 ± 15.26		1.03 ± 0.11
26-28		0.94 ± 15.43		1.03 ± 0.08
28-30		0.96 ± 15.58		
30-32		1.12 ± 16.83		
32-34		1.16 ± 16.97		
34-36		1.14 ± 16.89		

soil profiles into horizons. Clayey soils have lower bulk densities than coarser soils; the soils in Egypt (Munsiri et al., 1996a) and in the present study were more clayey than those at Auburn. This suggests that a lower bulk density value should be used to separate the sediment from the original soil. Based on results obtained in the present study, a bulk density value of 1.0 g cm^{-3} appears to be a suitable division. Use of this value would also be appropriate for soils at Auburn University because it would not result in appreciable differences in depths of the P horizons that were originally delineated by the higher value of 1.4 g cm^{-3}. Thus, the P horizon (original, undisturbed pond soil) occurred below a depth of 16 cm in new ponds at AIT, below 28 cm in old ponds at AIT, below 10 cm in freshwater ponds in Honduras, and below 20 cm in brackish water ponds in Honduras. The T horizon (transitional layer) should now be defined as the layer with a bulk density between 0.8 and 1.0 g cm^{-3}.

Results for ponds at AIT agree with findings of Munsiri et al. (1995) that the sediment layer, and particularly the depth of the M horizon, increases as ponds become older. The S horizon is very fluid and thought to be the layer in which most reactions between soil and water occur. Initial work by Munsiri et al. (1995, 1996a) suggests that the upper 5-cm layer was most reactive with the water, but of the present findings suggest that the most reactive layer may be even thinner in some ponds.

Color values obtained with the Munsell color chart are summarized in Table 3. Colors tended to be darkest in the S and M horizons and lighter in the T and P horizons. The greater concentration of organic matter in the S and M horizons results in a darker color than in the two deeper horizons. Also, the organic matter provides a substrate for microbial activity which drives the redox potential down, and at lower redox potentials, soil color is darker. The color measurement was taken at the mid-point of core segments. The surface layer to a depth of 1 or 2 mm was brown in all 0 to 2 cm core segments, but below this the color was much darker. Thus, the oxidized layer (S_O horizon) was very thin as compared to the S_R horizon (reduced part of the S horizon). Munsiri et al. (1995) reported that the S_O horizon in pond soil profiles at Auburn also was only a few millimeters thick.

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Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	0.41 ± 0.00	0.29 ± 11.02	0.34 ± 0.04	0.31 ± 0.01
2-4	0.62 ± 0.01	0.41 ± 11.60	0.57 ± 0.08	0.46 ± 0.08
4-6	0.67 ± 0.02	0.41 ± 11.65	0.80 ± 0.04	0.58 ± 0.06
6-8	0.83 ± 0.08	0.44 ± 11.95	0.87 ± 0.02	0.68 ± 0.03
8-10	0.84 ± 0.07	0.45 ± 12.06	0.89 ± 0.03	0.68 ±0.06
10-12	0.87 ± 0.06	0.55 ± 12.31	0.99 ± 0.03	0.71 ± 0.00
12-14	0.84 ± 0.06	0.57 ± 12.52	1.10 ± 0.04	0.79 ± 0.04
14-16	0.94 ± 0.02	0.63 ± 13.03	1.14 ± 0.02	0.88 ± 0.09
16-18	0.96 ± 0.07	0.67 ± 13.25	1.20 ± 0.02	0.98 ± 0.10
18-20	0.95 ± 0.08	0.69 ± 13.35	1.32 ± 0.03	0.89 ± 0.00
20 22		0.73 ± 13.82	1.34 ± 0.04	1.08 ± 0.04
22-24		0.81 ± 14.61	1.31 ± 0.04	1.05 ± 0.06
24-26		0.93 ± 15.26		1.03 ± 0.11
26-28		0.94 ± 15.43		1.03 ± 0.08
28-30		0.96 ± 15.58		
30-32		1.12 ± 16.83		
32-34		1.16 ± 16.97		
34-36		1.14 ± 16.89		

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Table 4. Profiles for wet soil pH by direct measurement in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as standard pH units. Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	7.65 ± 0.19	7.28 ± 0.03	7.28 ± 0.06	7.28 ± 0.06
2-4	7.35 ± 0.09	7.30 ± 0.07	7.48 ± 0.06	7.48 ± 0.06
4-6	7.17 ± 0.12	7.32 ± 0.02	7.47 ± 0.08	7.47 ± 0.06
6-8	7.27 ± 0.07	7.31 ± 0.04	7.49 ± 0.13	7.49 ± 0.13
8-10	7.35 ± 0.05	7.34 ± 0.01	7.54 ± 0.19	7.54 ± 0.19
10-12	7.37 ± 0.05	7.31 ± 0.02	7.44 ± 0.24	7.44 ± 0.24
12-14	7.27 ± 0.02	7.44 ± 0.01	7.51 ± 0.21	7.51 ± 0.21
14-16	7.19 ± 0.04	7.49 ± 0.05	7.67 ± 0.24	7.67 ± 0.24
16-18	7.12 ± 0.06	7.46 ± 0.04	7.76 ± 0.30	7.76 ± 0.30
18-20		7.43 ± 0.04	7.92 ± 0.18	7.92 ± 0.18
20-22		7.40 ± 0.04	8.16 ± 0.20	8.16 ± 0.20
22-24		7.33 ± 0.02	8.40 ± 0.19	8.40 ± 0.19
24-26		7.25 ± 0.03		
26-28		7.04 ± 0.09		
28-30		6.88 ± 0.08		
30-32		6.32 ± 0.16		
32-34		5.51 ± 0.29		
34-36		5.30 ± 0.14		

Table 5. Profiles for dry soil pH measured in 1:1 slurries of dry soil and distilled water in soil cores of aquaculture ponds. Averages and standard errors are given as standard pH units. Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	6.37 ± 0.04	6.32 ± 0.05	7.15 ± 0.02	6.92 ± 0.12
2-4	6.05 ± 0.06	6.23 ± 0.05	7.07 ± 0.03	6.72 ± 0.06
4-6	6.55 ± 0.15	6.20 ± 0.06	7.10 ± 0.02	6.73 ± 0.04
6-8	6.43 ± 0.15	6.13 ± 0.04	7.10 ± 0.10	6.67 ± 0.02
8-10	6.30 ± 0.08	6.05 ± 0.04	7.15 ± 0.17	6.70 ± 0.02
10-12	6.23 ± 0.13	6.00 ± 0.02	6.95 ± 0.14	6.85 ± 0.03
12-14	6.17 ± 0.14	6.15 ± 0.09	6.92 ± 0.15	6.92 ± 0.05
14-16	5.90 ± 0.29	6.15 ± 0.08	7.35 ± 0.17	6.87 ± 0.08
16-18	5.52 ± 0.47	6.10 ± 0.07	7.45 ± 0.09	6.73 ± 0.08
18-20	5.22 ± 0.52	6.03 ± 0.07	7.87 ± 0.15	6.87 ± 0.07
20-22		6.07 ± 0.13	7.67 ± 0.09	6.68 ± 0.11
22-24		5.93 ± 0.14	7.45 ± 0.15	6.70 ± 0.14
24-26		5.60 ± 0.22		
26-28		5.28 ± 0.15		
28-30		5.75 ± 0.64		
30-32		4.10 ± 0.20		
32-34		3.38 ± 0.05		
34-36		3.13 ± 0.05		

Table 6. Profiles for exchangeable acidity in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as milliequivalents per 100 grams dry soil (meq 100 g^{-1}). Each entry is the average of three ponds.

Depth (cm)	**Thailand**		**Honduras**	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	3.47 ± 0.31	4.53 ± 0.43	1.73 ± 0.08	1.33 ± 0.20
2-4	5.87 ± 0.31	4.80 ± 0.23	2.00 ± 0.13	0.93 ± 0.08
4-6	4.00 ± 0.13	4.80 ± 0.27	2.00 ± 0.13	1.33 ± 0.08
6-8	4.53 ± 0.15	5.07 ± 0.28	1.87 ± 0.08	1.33 ± 0.08
8-10	4.67 ± 0.28	5.60 ± 0.27	1.87 ± 0.15	1.47 ± 0.28
10-12	4.80 ± 0.35	5.73 ± 0.08	1.87 ± 0.15	1.20 ± 0.00
12-14	5.07 ± 0.28	5.20 ± 0.23	1.60 ± 0.00	0.93 ± 0.08
14-16	5.60 ± 0.58	5.33 ± 0.08	1.87 ± 0.08	0.93 ± 0.08
16-18	4.40 ± 0.35	5.33 ± 0.15	1.33 ± 0.08	0.67 ± 0.08
18-20	4.67 ± 0.28	5.60 ± 0.00	1.47 ± 0.15	1.07 ± 0.08
20-22		5.60 ± 0.00	1.20 ± 0.13	0.93 ± 0.08
22-24		5.87 ± 0.20	1.07 ± 0.15	0.67 ± 0.08
24-26		5.87 ± 0.41		
26-28		6.40 ± 0.23		
28-30		7.33 ± 0.28		
30-32		6.27 ± 0.50		
32-34		6.13 ± 0.20		
34-36		5.87 ± 0.31		

Table 7. Profiles for total carbon in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as percentages. Each entry is the average of three ponds.

Depth (cm)	**Thailand**		**Honduras**	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	1.82 ± 0.24	2.28 ± 0.05	2.35 ± 0.06	1.77 ± 0.16
2-4	1.63 ± 0.29	2.13 ± 0.05	1.56 ± 0.33	1.68 ± 0.07
4-6	1.82 ± 0.18	2.03 ± 0.02	2.08 ± 0.14	1.80 ± 0.03
6-8	1.46 ± 0.10	1.88 ± 0.06	2.08 ± 0.13	1.72 ± 0.08
8-10	0.88 ± 0.16	1.80 ± 0.05	1.98 ± 0.07	1.40 ± 0.03
10-12	1.17 ± 0.04	1.75 ± 0.04	2.05 ± 0.08	1.35 ± 0.06
12-14	1.15 ± 0.04	1.39 ± 0.11	1.19 ± 0.22	1.14 ± 0.04
14-16	0.72 ± 0.20	1.83 ± 0.08	1.70 ± 0.09	1.20 ± 0.08
16-18	0.98 ± 0.11	1.62 ± 0.01	1.34 ± 0.02	1.15 ± 0.10
18-20	0.67 ± 0.08	1.47 ± 0.06	1.39 ± 0.06	0.96 ± 0.15
20-22		1.69 ± 0.09	1.14 ± 0.20	0.75 ± 0.09
22-24		1.29 ± 0.11	1.33 ± 0.23	0.63 ± 0.06
24-26		1.14 ± 0.15		
26-28		1.71 ± 0.45		
28-30		0.83 ± 0.09		
30-32		0.83 ± 0.12		
32-34		0.54 ± 0.05		
34-36		0.50 ± 0.02		

Table 8. Profiles for total nitrogen in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given in percentages. Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	0.12 ± 0.02	0.17 ± 0.39	0.29 ± 0.01	0.23 ± 0.02
2-4	0.13 ± 0.01	0.15 ± 0.38	0.19 ± 0.03	0.24 ± 0.00
4-6	0.10 ± 0.01	0.15 ± 0.36	0.25 ± 0.01	0.23 ± 0.01
6-8	0.11 ± 0.00	0.13 ± 0.34	0.24 ± 0.00	0.20 ± 0.01
8-10	0.06 ± 0.01	0.13 ± 0.33	0.23 ± 0.01	0.17 ± 0.01
10-12	0.09 ± 0.00	0.13 ± 0.33	0.21 ± 0.02	0.17 ± 0.01
12-14	0.08 ± 0.01	0.10 ± 0.29	0.15 ± 0.03	0.14 ± 0.01
14-16	0.04 ± 0.01	0.14 ± 0.35	0.20 ± 0.01	0.14 ± 0.01
16-18	0.06 ± 0.01	0.13 ± 0.28	0.15 ± 0.01	0.13 ± 0.01
18-20	0.05 ± 0.00	0.11 ± 0.25	0.12 ± 0.01	0.11 ± 0.02
20-22		0.12 ± 0.31	0.08 ± 0.01	0.10 ± 0.01
22-24		0.06 ± 0.21	0.09 ± 0.01	0.08 ± 0.01
24-26		0.09 ± 0.16		
26-28		0.08 ± 0.55		
28-30		0.06 ± 0.12		
30-32		0.05 ± 0.19		
32-34		0.04 ± 0.09		
34-36		0.04 ± 0.08		

Auburn (Munsiri et al. 1995). Values at Auburn seldom exceeded 7.5:1. The reason for the difference is not known, but it may be related to the fact that ponds at Auburn had received large applications of high-protein fish feed over the years while the CRSP ponds have not received large applications of feed. Ponds at AIT and freshwater ponds in Honduras have been fertilized and manured heavily, while brackish water ponds in Honduras have had quite low nutrient inputs, because they have been managed as extensive shrimp production ponds.

Total phosphorus concentrations in ponds at AIT tended to be greater in S and P horizons than in T and P horizons (Table 9). Dilute acid-extractable phosphorus concentrations were lower in P horizons of old ponds at AIT than in S, M, and T horizons, but differences in acid-extractable phosphorus with depth were not obvious in new ponds (Table 10). The total phosphorus concentrations in ponds in Honduras did not differ with soil depth (Table 9), but in the freshwater ponds, acid-extractable concentrations were much greater in the upper soil layers than in the P horizon (Table 10). Results suggest that phosphorus inputs in fertilizer have raised phosphorus concentrations in the old ponds at AIT and in the freshwater ponds in Honduras. However, increases in phosphorus are not obvious in the other ponds.

New ponds at AIT had similar concentrations of sulfur at all depths, but in old ponds at AIT, core segments from depths of 28 cm or more had a higher concentration of sulfur than segments taken from depths of less than 28 cm (Table 11). Sulfur concentrations above 0.75% suggest that soils are potentially acid-sulfate in nature (Boyd, 1995). There is a layer of acid-sulfate soils below the old ponds at AIT. The freshwater ponds in Honduras had unexpectedly high sulfur concentrations and some core segments can be classified as potential acid-sulfate soil material. However, the soil does not have a low pH when dried. This suggests that there is enough natural base, probably calcium carbonate, in the soil to neutralize acidity created by pyrite oxidation. These samples will be analyzed again to verify the sulfur determination. The deeper samples from the brackish water ponds in Honduras contained less sulfur than the upper soil layers.

Table 9. Profiles for total phosphorus in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given in percentages. Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	0.10 ± 0.01	0.09 ± 0.01	0.09 ± 0.01	0.08 ± 0.00
2-4	0.06 ± 0.01	0.11 ± 0.00	0.10 ± 0.01	0.09 ± 0.00
4-6	0.08 ± 0.01	0.12 ± 0.00	0.09 ± 0.01	0.11 ± 0.00
6-8	0.17 ± 0.06	0.11 ± 0.01	0.10 ± 0.01	0.11 ± 0.01
8-10	0.04 ± 0.00	0.11 ± 0.00	0.09 ± 0.01	0.10 ± 0.00
10-12	0.04 ± 0.01	0.10 ± 0.01	0.12 ± 0.02	0.10 ± 0.00
12-14	0.04 ± 0.01	0.10 ± 0.01	0.09 ± 0.02	0.10 ± 0.00
14-16	0.03 ± 0.01	0.15 ± 0.01	0.13 ± 0.03	0.10 ± 0.00
16-18	0.02 ± 0.00	0.07 ± 0.01	0.12 ± 0.02	0.09 ± 0.01
18-20	0.05 ± 0.02	0.11 ± 0.01	0.09 ± 0.02	0.09 ± 0.00
20-22		0.09 ± 0.01	0.10 ± 0.02	0.09 ± 0.00
22-24		0.10 ± 0.02	0.09 ± 0.01	0.08 ± 0.01
24-26		0.07 ± 0.01		
26-28		0.06 ± 0.00		
28-30		0.05 ± 0.00		
30-32		0.02 ± 0.01		
32-34		0.02 ± 0.00		
34-36		0.02 ± 0.00		

Table 10. Profiles for dilute acid extractable phosphorus in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	4.77 ± 0.43	10.24 ± 0.88	153.87 ± 17.96	11.74 ± 1.93
2-4	4.58 ± 0.41	11.63 ± 0.78	169.73 ± 27.39	10.17 ± 1.27
4-6	3.76 ± 0.67	11.98 ± 0.95	185.00 ± 19.87	12.20 ± 0.88
6-8	3.94 ± 0.59	13.21 ± 1.48	198.94 ± 38.87	11.82 ± 0.75
8-10	3.03 ± 0.39	13.99 ± 2.35	175.30 ± 28.27	10.32 ± 1.33
10-12	2.60 ± 0.18	16.73 ± 4.1	181.70 ± 43.84	11.15 ± 1.69
12-14	2.95 ± 0.28	16.08 ± 3.97	179.62 ± 50.22	9.42 ± 0.74
14-16	5.31 ± 0.55	18.32 ± 3.99	163.73 ± 70.62	11.25 ± 2.34
16-18	4.07 ± 0.86	16.36 ± 3.90	56.57 ± 22.93	11.04 ± 2.37
18-20	5.02 ± 0.53	13.24 ± 2.65	37.12 ± 14.26	12.70 ± 2.23
20-22		13.56 ± 2.02	25.19 ± 8.09	22.09 ± 1.48
22-24		13.50 ± 0.91	18.43 ± 8.63	21.21 ± 1.75
24-26		14.82 ± 1.34		
26-28		14.06 ± 1.16		
28-30		12.02 ± 2.56		
30-32		9.51 ± 1.53		
32-34		6.18 ± 0.45		
34-36		5.53 ± 0.54		

Table 11. Profiles for total sulfur in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	0.57 ± 0.13	0.86 ± 0.13	0.79 ± 0.16	0.58 ± 0.06
2-4	0.49 ± 0.08	0.76 ± 0.11	1.08 ± 0.11	0.50 ± 0.12
4-6	0.49 ± 0.05	0.90 ± 0.15	0.89 ± 0.08	0.66 ± 0.10
6-8	0.45 ± 0.06	0.85 ± 0.14	1.02 ± 0.12	0.67 ± 0.07
8-10	0.46 ± 0.08	0.83 ± 0.13	0.70 ± 0.06	0.70 ± 0.06
10-12	0.37 ± 0.09	0.70 ± 0.10	3.39 ± 1.57	0.64 ± 0.04
12-14	0.44 ± 0.08	0.65 ± 0.07	3.42 ± 1.63	0.73 ± 0.07
14-16	0.42 ± 0.09	0.70 ± 0.04	0.48 ± 0.05	0.61 ± 0.06
16-18	0.34 ± 0.04	0.73 ± 0.01	0.43 ± 0.05	0.35 ± 0.07
18-20	0.33 ± 0.07	0.77 ± 0.05	0.31 ± 0.07	0.43 ± 0.08
20-22		0.83 ± 0.06	0.52 ± 0.07	0.28 ± 0.05
22-24		0.81 ± 0.06	0.49 ± 0.04	0.15 ± 0.01
24-26		0.60 ± 0.04		
26-28		0.73 ± 0.14		
28-30		1.01 ± 0.21		
30-32		1.40 ± 0.18		
32-34		1.55 ± 0.18		
34-36		1.88 ± 0.21		

We suspect that iron pyrite is actively being formed in these ponds. Earlier work on pond soil at Granjas Marinas (Munsiri et al., 1996b) showed that surface layers of soil in old ponds had more sulfur than those in newer ponds. This observation also suggests active pyrite formation.

Large inputs of calcium to ponds at AIT in liming materials resulted in greater calcium concentrations in upper soil layers than in deeper ones (Table 12). Soil at the freshwater site in Honduras is naturally high in calcium, and core segments from all depths were high in calcium. Calcium concentrations were much lower in the brackish water ponds in Honduras than in the freshwater ponds. The native soils in the area of the shrimp farm are acidic, and therefore, low in calcium. Liming has not been a normal practice on the farm, and brackish water has a rather low proportion of calcium in relation to other basic cations (Boyd, 1990).

The upper soil layers at AIT were enriched with magnesium, suggesting that the liming materials used there contained magnesium (Table 13). Little difference in magnesium concentration occurred with depth in the freshwater ponds in Honduras. Magnesium has accumulated in the surface layers of soil in the brackish water ponds in Honduras (Table 13). This has resulted from the high concentrations of magnesium in brackish water.

The deeper layers of soil in all freshwater ponds tended to contain less potassium and sodium than upper layers, and there was an obvious accumulation of these two ions in surface layers of brackish water ponds (Tables 14 and 15). Accumulation of sodium and potassium in the upper layers of brackish water ponds obviously resulted from inputs of these ions in salt water. Reasons for the increases in the freshwater ponds cannot be determined from available data.

Concentrations of iron, manganese, zinc, and copper are provided in Tables 16 through 19. Values for iron varied somewhat with depth, but obvious patterns were not found. Pond soils in Thailand contained much higher iron concentrations than those in Honduras. Manganese tended to accumulate in upper soil layers, but the reason for this process is not known. Brackish water pond soils contained greater manganese concentrations than freshwater ones. Zinc concentrations were much greater in freshwater pond soils than in brackish water ones. In freshwater pond soils,

Table 12. Profiles for calcium in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	4971 ± 217	3580 ± 263	5849 ± 887	844 ± 69
2-4	4687 ± 187	3091 ± 209	5738 ± 704	721 ± 80
4-6	5040 ± 147	3148 ± 238	6290 ± 1044	681 ± 10
6-8	5325 ± 314	3032 ± 97	5949 ± 825	600 ± 28
8-10	5187 ± 171	3018 ± 97	5827 ± 671	723 ± 70
10-12	5105 ± 124	3258 ± 174	5789 ± 749	597 ± 20
12-14	4666 ± 131	3493 ± 49	5709 ± 733	700 ± 59
14-16	4094 ± 322	3328 ± 137	6052 ± 816	817 ± 75
16-18	4033 ± 290	3712 ± 104	6933 ± 1353	526 ± 23
18-20	3404 ± 374	3659 ± 130	7088 ± 1418	620 ± 148
20-22		3678 ± 165	7326 ± 1481	434 ± 29
22-24		3270 ± 271	5617 ± 2074	445 ± 60
24-26		2857 ± 360		
26-28		2606 ± 263		
28-30		2503 ± 439		
30-32		2195 ± 486		
32-34		1708 ± 440		
34-36		1810 ± 542		

Table 13. Profiles for magnesium in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	645 ± 20	771 ± 39	460 ± 93	1517 ± 101
2-4	516 ± 22	751 ± 20	421 ± 103	1274 ± 91
4-6	511 ± 19	744 ± 26	402 ± 86	1173 ± 49
6-8	531 ± 14	726 ± 24	402 ± 85	1065 ± 49
8-10	498 ± 27	699 ± 15	423 ± 121	1091 ± 56
10-12	473 ± 5	694 ± 12	416 ± 73	1019 ± 22
12-14	434 ± 13	685 ± 24	448 ± 100	964 ± 32
14-16	422 ± 9	670 ± 23	366 ± 86	866 ± 15
16-18	419 ± 11	655 ± 13	367 ± 72	955 ± 26
18-20	402 ± 4	614 ± 18	331 ± 71	899 ± 55
20-22		583 ± 9	355 ± 55	894 ± 39
22-24		556 ± 20	305 ± 109	852 ± 56
24-26		503 ± 23		
26-28		473 ± 8		
28-30		475 ± 13		
30-32		418 ± 16		
32-34		342 ± 36		
34-36		327 ± 39		

Table 14. Profiles for potassium in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	176 ± 8	240 ± 14	463 ± 94	582 ± 48
2-4	201 ± 20	234 ± 13	456 ± 103	473 ± 52
4-6	175 ± 13	236 ± 13	458 ± 98	426 ± 33
6-8	232 ± 34	241 ± 12	458 ± 100	389 ± 19
8-10	170 ± 14	239 ± 13	456 ± 101	406 ± 19
10-12	160 ± 14	244 ± 12	472 ± 93	388 ± 6
12-14	154 ± 13	241 ± 19	466 ± 98	388 ± 13
14-16	150 ± 8	259 ± 21	442 ± 96	357 ± 3
16-18	146 ± 6	269 ± 15	412 ± 70	360 ± 13
18-20	134 ± 1	258 ± 25	366 ± 61	323 ± 15
20-22		259 ± 25	361 ± 55	298 ± 2
22-24		273 ± 29	291 ± 97	265 ± 7
24-26		265 ± 26		
26-28		266 ± 29		
28-30		265 ± 28		
30-32		227 ± 24		
32-34		358 ± 117		
34-36		159 ± 26		

Table 15. Profiles for sodium in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	455 ± 4	629 ± 52	729 ± 38	10179 ± 957
2-4	418 ± 21	507 ± 35	642 ± 133	7475 ± 919
4-6	405 ± 10	470 ± 34	537 ± 51	6567 ± 474
6-8	424 ± 15	428 ± 23	609 ± 83	5498 ± 408
8-10	366 ± 8	380 ± 15	588 ± 163	5697 ± 349
10-12	326 ± 10	369 ± 18	792 ± 89	4947 ± 232
12-14	291 ± 12	366 ± 19	874 ± 163	4754 ± 232
14-16	274 ± 4	352 ± 15	464 ± 41	4420 ± 199
16-18	284 ± 2	363 ± 10	668 ± 160	4389 ± 196
18-20	262 ± 7	336 ± 14	447 ± 28	4178 ± 238
20-22		328 ± 6	777 ± 110	4042 ± 307
22-24		313 ± 9	712 ± 208	3926 ± 465
24-26		292 ± 6		
26-28		281 ± 6		
28-30		293 ± 9		
30-32		262 ± 10		
32-34		228 ± 26		
34-36		212 ± 26		

Table 16. Profiles for iron in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	128 ± 38	269 ± 63	17 ± 5	24 ± 3
2-4	148 ± 47	359 ± 45	22 ± 8	33 ± 10
4-6	135 ± 41	364 ± 52	15 ± 4	23 ± 8
6-8	129 ± 36	355 ± 46	19 ± 7	18 ± 8
8-10	121 ± 30	320 ± 31	15 ± 5	12 ± 7
10-12	126 ± 21	293 ± 19	14 ± 5	14 ± 3
12-14	123 ± 33	276 ± 52	14 ± 5	8 ± 2
14-16	157 ± 31	346 ± 61	12 ± 4	2 ± 1
16-18	202 ± 22	283 ± 33	7 ± 2	5 ± 0
18-20	213 ± 17	187 ± 43	5 ± 1	2 ± 1
20-22		312 ± 29	5 ± 0	4 ± 2
22-24		379 ± 52	5 ± 1	14 ± 7
24-26		350 ± 63		
26-28		334 ± 28		
28-30		322 ± 15		
30-32		233 ± 14		
32-34		184 ± 17		
34-36		198 ± 15		

Table 17. Profiles for manganese in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	Thailand		Honduras	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	26 ± 2	72 ± 11	167 ± 55	282 ± 24
2-4	23 ± 1	66 ± 7	157 ± 56	234 ± 16
4-6	23 ± 2	65 ± 6	148 ± 48	206 ± 20
6-8	23 ± 1	62 ± 5	126 ± 50	183 ± 12
8-10	24 ± 1	58 ± 2	108 ± 46	183 ± 26
10-12	23 ± 3	59 ± 3	90 ± 31	213 ± 15
12-14	20 ± 4	63 ± 5	90 ± 34	194 ± 17
14-16	20 ± 3	63 ± 6	69 ± 33	171 ± 19
16-18	20 ± 3	63 ± 8	41 ± 18	168 ± 8
18-20	19 ± 3	58 ± 7	19 ± 9	131 ± 6
20-22		58 ± 9	10 ± 3	129 ± 24
22-24		51 ± 8	8 ± 3	78 ± 2
24-26		43 ± 9		
26-28		35 ± 6		
28-30		31 ± 4		
30-32		25 ± 3		
32-34		19 ± 1		
34-36		17 ± 1		

Table 18. Profiles for zinc in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	**Thailand**		**Honduras**	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	9.98 ± 5.60	10.22 ± 2.56	4.28 ± 2.02	0.40 ± 0.12
2-4	4.46 ± 1.28	14.05 ± 1.48	4.85 ± 2.61	0.94 ± 0.12
4-6	21.86 ± 10.60	16.45 ± 0.97	4.25 ± 2.03	1.03 ± 0.08
6-8	12.96 ± 6.57	19.27 ± 0.45	5.32 ± 2.89	1.11 ± 0.16
8-10	19.56 ± 10.28	19.69 ± 1.57	4.90 ± 2.71	0.85 ± 0.08
10-12	12.88 ± 5.90	16.72 ± 0.86	4.34 ± 2.38	0.79 ± 0.04
12-14	3.87 ± 0.99	13.81 ± 1.59	3.54 ± 1.84	0.62 ± 0.04
14-16	8.99 ± 2.40	15.25 ± 0.89	2.51 ± 1.45	0.45 ± 0.14
16-18	3.88 ± 0.36	15.25 ± 0.64	0.47 ± 0.27	0.72 ± 0.08
18-20	3.53 ± 0.64	12.08 ± 0.64	0.00 ± 0.00	0.44 ± 0.13
20-22		10.09 ± 0.84	0.00 ± 0.00	0.87 ± 0.05
22-24		6.48 ± 1.62	0.00 ± 0.00	0.70 ± 0.05
24-26		11.91 ± 2.23		
26-28		11.75 ± 1.59		
28-30		8.53 ± 1.18		
30-32		3.87 ± 0.25		
32-34		1.88 ± 0.37		
34-36		1.81 ± 0.07		

Table 19. Profiles for copper in soil cores from bottoms of aquaculture ponds. Averages and standard errors are given as parts per million (ppm). Each entry is the average of three ponds.

Depth (cm)	**Thailand**		**Honduras**	
	New ponds	*Old ponds*	*Freshwater ponds*	*Brackish water ponds*
0-2	0.06 ± 0.02	0.55 ± 0.29	0.67 ± 0.18	0.00 ± 0.00
2-4	0.25 ± 0.07	0.43 ± 0.25	0.70 ± 0.31	0.00 ± 0.00
4-6	0.04 ± 0.01	0.47 ± 0.15	0.41 ± 0.14	0.00 ± 0.00
6-8	0.15 ± 0.08	0.28 ± 0.10	0.58 ± 0.33	0.00 ± 0.00
8-10	0.00 ± 0.00	0.47 ± 0.20	0.43 ± 0.25	0.00 ± 0.00
10-12	0.00 ± 0.00	0.39 ± 0.15	0.40 ± 0.23	0.00 ± 0.00
12-14	0.46 ± 0.15	0.05 ± 0.03	0.43 ± 0.25	0.00 ± 0.00
14-16	1.10 ± 0.24	0.01 ± 0.01	0.29 ± 0.17	0.00 ± 0.00
16-18	0.89 ± 0.29	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
18-20	0.82 ± 0.21	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
20-22		0.19 ± 0.11	0.00 ± 0.00	0.00 ± 0.00
22-24		0.49 ± 0.15	0.00 ± 0.00	0.37 ± 0.21
24-26		0.98 ± 0.31		
26-28		1.13 ± 0.22		
28-30		1.64 ± 0.15		
30-32		1.41 ± 0.18		
32-34		1.06 ± 0.05		
34-36		3.47 ± 1.43		

zinc concentrations were higher in upper layers than in deeper ones, but this trend was not obvious in brackish water pond soils. Copper concentrations were very low in soils of all ponds.

Only the upper 5 to 10 cm of pond bottom soil influences water quality in ponds (Boyd, 1995), so from a management standpoint, the composition of this surface layer is of most importance. Nevertheless, the characteristics of the soil profile can be of interest in classifying pond soils, determining the effects of aquaculture on the pond bottom soil, and providing clues to chemical processes in pond soils. Boyd et al. (1994) made chemical analyses of soil samples (upper 5-cm layer) from over 300 brackish water ponds and more than 300 freshwater ponds from several nations. Arrays made from the data permitted classification of samples as very low, low, high, and very high in concentrations of each variable. Nearly all of the data for 0-2 cm and 2-4 cm core segments in the present study were medium with respect to chemical properties.

Data collected in this study show that the proposed system for delineating pond soil horizons suggested by Munsiri et al (1995) can be applied to pond soils at a diversity of sites. The patterns of change in soil properties with depth that were noted in this study were similar to those found in ponds at Auburn (Munsiri et al., 1995).

Brackish water ponds had much higher concentrations of sodium, potassium, and magnesium in surface layers than did freshwater ponds because of large inputs of these ions in brackish water. There were some differences in soil properties among sites that were related to the native characteristics of site soils, and some changes in soils could be associated with aquacultural operations. Once soil profile data are obtained from further sites, it will be possible to develop a system of pond soil taxonomy based on physical and chemical properties.

Anticipated Benefits

This research will provide valuable information on pond soils at the prime sites that can be used by PD/A CRSP investigators for describing bottom soils of ponds in research papers, in designing experiments, and in evaluating experiment results. The data also provide further verification that the method of delineating pond soil horizons suggested by Prasert Munsiri, C.E. Boyd, and B.F. Hajek of Auburn University is applicable to a diversity of sites. The findings enhance our knowledge of chemical characteristics of soil profiles that can be used to develop a system of pond soil taxonomy similar to the system of soil taxonomy used in traditional soil science. The physical and chemical changes in soil profiles will also be useful in making inferences about the influence of pond management on pond bottom soils. Knowledge of soil properties also aids pond management decisions regarding inputs that are needed to improve environmental quality within culture systems.

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