

Water Quality in Laboratory Soil-Water Microcosms with Soils from Different Areas of Thailand

Interim Work Plan, Africa Study 5

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Introduction

Interpretations of soil analyses for use in aquaculture endeavors are difficult because few data are available on relationships between soil chemical and physical properties and aqueous concentrations of water quality variables or between soil properties and aquatic animal production (Boyd, 1995). Banerjea (1967) related selected soil properties to fish production in ponds in India. He identified optimum ranges of soil carbon, nitrogen, phosphorus, and pH for fish production in fertilized ponds. However, he did not consider the influence of bottom soil characteristics on water quality in ponds. Several authors have demonstrated that edaphic factors influence the chemical composition of pond waters (Moyle, 1956; Boyd and Walley, 1975; Arce and Boyd, 1980), but equations for predicting water quality from soil characteristics were not provided. Boyd (1974) developed a method for determining the lime requirement of ponds based upon bottom soil analysis. Boyd et al. (1994) presented a large array of data on chemical characteristics of freshwater and brackish water pond soils and assigned concentration categories as very low, low, medium, high, and very high. However, no attempt was made to relate the soil characteristics to water quality or production in ponds. A recent study by Boyd and Munsiri (1996) indicated that the phosphorus status of pond soils for aquaculture could be assessed from phosphorus adsorption capacity and clay content.

In terrestrial agriculture, analyses of extracts from soil samples are commonly used to estimate nutrient availability, because the amounts of nutrients in these extracts are correlated with concentrations of nutrients in soil solution that are available to plants (Walsh and Beaton, 1973; Brady, 1990). Soil nutrient

extractions are the basis for soil testing methods to determine fertilizer requirements for crops at specific locations. It may be possible to predict the availability of nutrients in aquaculture ponds from bottom soil properties. The main obstacle to research on relationships among pond soil characteristics, water quality, and aquatic animal production is locating experimental ponds on soils of different physical and chemical characteristics. In terrestrial agriculture, greenhouse studies with small pots of soil as experimental units have been widely used in evaluating relationships between soil properties and plant growth (Rouse, 1968; Walsh and Beaton, 1973). Therefore, a study was conducted using laboratory soil-water microcosms under controlled conditions to determine if aqueous concentrations of substances could be predicted from soil characteristics.

Materials and Methods

Forty-five soil samples were collected from 23 provinces in central, eastern, and northern Thailand in September 1994. Twenty of the samples were used earlier in a study of the phosphorus adsorption capacity of soils from Thailand (Boyd and Munsiri, 1996). The other 25 samples were from areas nearby those indicated on a map provided by Boyd and Munsiri (1996), so further identification of sampling site locations will not be provided. Samples included the following soil orders: Alfisols, Entisols, Inceptisols, Mollisols, Ultisols, and Vertisols. This array of samples was quite diverse and included at least 14 soil suborders and about 40 soil series, but it was not possible to classify all samples to taxonomic levels below order with certainty. Samples were collected from

areas near fish ponds but not from bottoms of existing ponds. Soils were similar to those used for pond construction at the sampling sites, and they were considered representative of soils in the bottoms of newly-constructed ponds. Most sites had not been used for agriculture in the past, but we think that agricultural crops may have been cultivated on 8 or 10 of the sites within the past few years. Samples were collected from the 15-30 cm depth layer, and about 200-g quantities of each were placed in plastic bags for transport to Auburn, Alabama.

Samples were dried at 40°C in a forced-draft oven. Nutrients were extracted from soils by two solutions (a mixture of 0.05 N HCl plus 0.025 N H₂SO₄ and neutral, 1 N ammonium acetate) and analyzed by plasma spectrophotometry (ICAP). Soil pH was determined with a glass electrode in a 1:1 soil-distilled water mixture. Sand, silt, and clay analyses were made by the pipet method (Gee and Bauder, 1986). Total carbon concentrations were measured with an induction furnace carbon analyzer (Leco Model EC 12). To determine cation exchange capacity (CEC), the exchangeable acidity was measured and added to the sum of basic exchangeable cations (calcium, magnesium, sodium, and potassium) extracted by neutral, 1 N ammonium acetate. Base saturation was estimated by dividing the sum of basic exchangeable cations by CEC. Methods for soil analyses are described in greater detail by Munsiri et al. (1995).

Soil-water microcosms were prepared in triplicate for each soil by adding 5.0 g soil and 150 ml of distilled water into a 250-ml Erlenmeyer flask. Flasks were placed on a rotating table shaker (150 rpm) at 25°C in the dark for 7 days. Water from the microcosms was filtered through a 0.45-μm membrane filter. The pH was measured with a glass electrode, and total alkalinity and total hardness were measured by standard titration procedures using a microburette (APHA et al., 1989). A portion of the filtered solution was used for soluble reactive phosphorus (SRP) analysis by the ascorbic acid method (APHA et al., 1989). Another portion of the filtered solution was analyzed for metallic cations and boron by plasma spectrophotometry.

Regression analyses to evaluate relationships between soil characteristics and aqueous concentrations of dissolved substances and pH were conducted using spreadsheet software. Linear, exponential, and logarithmic regressions were evaluated for each combination of variables.

Results and Discussion

For sake of brevity, only the ranges and medians of the soil physical and chemical variables are reported (Table 1). The set of samples included a wide range of most variables but did not include samples with high concentrations of total carbon. Medians of most variables are skewed to the right of the mid-points of the ranges. Using potassium as an example, the range was 8-442 ppm. The mid-point of the range was 217 ppm, but the median was only 59 ppm. Thus, there was a greater proportion of lower values than of higher ones. Nevertheless, the upper ends of the concentration ranges were represented by several samples of differing concentration.

The microcosms were held on the rotating shaker for 7 days, but the analysis of water from some extra microcosms included in the experiment indicated that concentrations of nutrients did not increase after the second day. Thus, it is reasonable to assume that equilibrium conditions had been reached in all flasks by the seventh day. Ranges and medians of concentration of water quality variables in the microcosms also are reported in Table 1. These data are skewed to the right in the same manner as the soil analysis data.

The average concentrations of water quality variables in microcosms are presented for each soil order in Table 2. Because of the large variation within orders, none of the means differed (ANOVA; $P > 0.05$). Therefore, knowledge of soil order is of no benefit in determining the concentrations of dissolved substances or pH in water in contact with soil. No further attempt was made to correlate soil taxonomy and water quality because of the inability to designate soil classification exactly for some samples and the small sample size that was represented by some taxonomic units.

Results of regression analyses between nutrient concentrations in soil and nutrient concentrations in waters of microcosms are provided in Table 3. In all cases, the highest correlation coefficients were for linear regressions. Also, regression coefficients obtained using dilute-acid extractable nutrients as independent variables generally were greater than those achieved with neutral, 1 N ammonium acetate extractable nutrients as independent variables. The strongest correlations were obtained for sodium, potassium, phosphorus, and calcium. Soil extracts would be more useful for predicting concentrations of these nutrients than for magnesium, manganese, and boron, for which correlations were weaker.

Table 1. Ranges and medians for chemical and physical characteristics of soils used in microcosm experiments. Soil nutrients were extracted with dilute acid (DA) and with neutral ammonium acetate (AA). Ranges and medians for concentrations of dissolved substances and pH in waters of microcosms also are presented.

Variable	Range	Median	Variable	Range	Median
SOIL			WATER IN MICROCOSMS		
P			P	0.1 - 0.95	0.1 mg/l
(DA)	1.7 - 76.5	7.4 ppm	Ca	0.1 - 30.9	6.0 mg/l
(AA)	0.0 - 5.8	0.5 ppm	Mg	0.1 - 25.0	1.1 mg/l
Ca			K	0.1 - 12.9	1.0 mg/l
(DA)	36 - 5,415	1,495 ppm	Fe	0.01 - 2.90	0.25 mg/l
(AA)	37 - 6,949	1,514 ppm	Mn	0.01 - 2.85	0.30 mg/l
Mg			B	0.01 - 0.25	0.11 mg/l
(DA)	23 - 1,263	189 ppm	pH	3.8 - 8.5	6.6
(AA)	27 - 2,386	253 ppm	TA*	0.0 - 73.8	21.8 mg/l
K			TH*	0.5 - 174.2	21.7 mg/l
(DA)	8 - 442	59 ppm			
(AA)	7 - 491	131 ppm			
Na					
(DA)	18 - 2,192	64 ppm			
(AA)	22 - 2,238	74 ppm			
FE					
(DA)	4 - 368	32 ppm			
(AA)	3 - 15	8 ppm			
Mn					
(DA)	0.6 - 182	47 ppm			
(AA)	0.3 - 99	9 ppm			
B					
(DA)	0.1 - 4.1	0.7 ppm			
(AA)	0.1 - 2.0	0.2 ppm			
C	0.17 - 2.49	0.91%			
BS*	0.5 - 75.0	17.6%			
CEC*	1.9 - 44.7	25.6 meq/100 g			
pH	3.9 - 8.2	7.1			
Sand	4 - 80	28%			
Silt	12 - 68	36%			
Clay	7 - 67	25%			

* BS = base saturation

CEC = cation exchange capacity

Table 2. Average concentrations and standard errors of dissolved substances and pH laboratory soil-water microcosms containing soil of different orders (n = sample size).

	Alfisols (n = 10)	Entisols (n = 4)	Inceptisols (n = 8)	Mollisols (n = 4)	Ultisols (n = 16)	Vertisols (n = 3)
Phosphorus	0.20 ± 0.09	0.32 ± 0.10	0.22 ± 0.07	0.15 ± 0.25	0.25 ± 0.04	0.23 ± 0.03
Calcium	10.3 ± 3.5	11.1 ± 3.0	13.0 ± 3.6	23.1 ± 4.8	4.7 ± 1.7	29.0 ± 8.3
Magnesium	1.7 ± 0.5	2.8 ± 1.7	4.8 ± 2.9	2.6 ± 0.4	0.9 ± 0.3	3.4 ± 2.7
Potassium	2.2 ± 1.2	3.7 ± 2.3	2.5 ± 0.9	1.7 ± 0.3	1.1 ± 0.6	2.2 ± 1.2
Sodium	8.5 ± 3.6	25.1 ± 21.0	11.1 ± 3.5	3.4 ± 0.6	6.6 ± 1.9	5.1 ± 2.8
Iron	0.21 ± 0.03	0.22 ± 0.06	0.25 ± 0.05	0.23 ± 0.03	0.7 ± 0.42	0.33 ± 0.17
Manganese	0.35 ± 0.14	0.31 ± 0.12	0.70 ± 0.39	0.03 ± 0.02	0.42 ± 0.21	0.81 ± 0.80
Boron	0.09 ± 0.01	0.04 ± 0.02	0.11 ± 0.02	0.02 ± 0.02	0.04 ± 0.02	0.01 ± 0.02
Total Alkalinity	25.9 ± 6.9	57.0 ± 25.4	18.7 ± 6.1	56.4 ± 8.6	14.3 ± 3.4	55.2 ± 16.7
Total Hardness	32.7 ± 10.4	39.4 ± 11.4	52.4 ± 19.5	68.3 ± 10.4	15.7 ± 5.4	86.6 ± 36.7
pH	6.7 ± 0.2	7.8 ± 0.5	5.6 ± 0.4	7.5 ± 0.1	6.3 ± 0.2	7.5 ± 0.3

Table 3. Correlation matrix for linear regressions of soil nutrient concentrations (X) versus concentrations of dissolved nutrients in laboratory soil-water microcosms (Y).^a There are two regression coefficients for each comparison. The upper one is for soil nutrients extracted in dilute acid. The lower one in parentheses is for the soil nutrient extracted in neutral, ammonium acetate.

Soil	Water							
	<i>P</i>	<i>Ca</i>	<i>Mg</i>	<i>K</i>	<i>Na</i>	<i>Fe</i>	<i>Mn</i>	<i>B</i>
<i>P</i>	0.816 (0.095)							
<i>Ca</i>	0.261 (0.032)	0.685 (0.605)						
<i>Mg</i>	0.167 (0.045)	0.141 (0.063)	0.470 (0.401)					
<i>K</i>	0.683 (0.538)	0.045 (0.179)	0.205 (0.378)	0.959 (0.866)				
<i>Na</i>	0.109 (0.095)	0.063 (0.032)	0.307 (0.298)	0.045 (0.045)	0.977 (0.975)			
<i>Fe</i>	0.032 (0.077)	0.195 (0.349)	0.265 (0.395)	0.063 (0.032)	0.071 (0.521)	0.141 (0.224)		
<i>Mn</i>	0.032 (0.032)	0.212 (0.000)	0.366 (0.619)	0.243 (0.134)	0.438 (0.224)	0.089 (0.000)	0.462 (0.434)	
<i>B</i>	0.341 (0.032)	0.243 (0.077)	0.510 (0.416)	0.276 (0.063)	0.794 (0.728)	0.053 (0.130)	0.197 (0.063)	0.399 (0.303)

^a Correlation coefficients (*r*) greater than 0.291 and 0.376 are significant at probability levels of 5% and 1%, respectively.

Dissolved iron concentration in microcosms was not correlated with soil iron. Few significant correlations were found between other combinations of soil nutrients and nutrients in solution. However, there was a very strong correlation between boron in soil and sodium in water. This correlation is not surprising, since sodium and boron are cyclic marine salts with similar geochemical cycles (Boyd and Walley, 1972).

Correlations among other soil properties and pH, nutrient concentrations, total alkalinity, and total hardness are provided in Table 4. Correlations between soil particle size classes (sand, silt, and clay) and dissolved concentrations of variables were weak or lacking. Soil pH was highly correlated with total alkalinity and pH in waters of microcosms. There were significant correlations between both CEC and base saturation of soils and several variables in microcosm waters, but the best correlations were between these two soil variables and total alkalinity. Total alkalinity also was correlated with the sum of soil calcium and magnesium extracted with either of the extracting agents. Total hardness was related to concentrations of soil calcium plus magnesium, but, surprisingly, soil carbon

provided the strongest correlation with total hardness. The reason for this correlation is possibly related to soil organic matter contributing to CEC, and soils with a higher CEC tend to adsorb more calcium, magnesium, and other cations than soils of lower CEC. The correlation between CEC and total hardness was significant but not as great as the one between soil carbon and total hardness. It is possible that some of the soils with high pH contained free calcium carbonate that contributed to alkalinity.

Equations for predicting concentrations of dissolved substances and pH in microcosms are not provided because they would not be reliable for use in aquaculture ponds that are much more complex chemically, physically, and biologically than the microcosms. Nevertheless, the data suggest that soil analyses can indicate the concentrations of water quality variables that will occur in ponds built on a particular soil. It also is noteworthy that extraction of soil in the dilute-acid solution provided better estimates of nutrient concentrations than the neutral, ammonium acetate extraction. The dilute-acid solution is easier to prepare and store than the ammonia acetate solution. Although soil

Table 4. Correlation coefficients for soil properties versus pH and nutrient, total alkalinity (TA), and total hardness (TH) concentrations in waters of soil-water microcosms.^a Regression coefficients are for linear regression except in parenthesis (exponential regression) or brackets [logarithmic regression].

Soil	Water										
	P	Ca	Mg	K	Na	Fe	Mn	B	TA	TH	pH
Carbon	0.176	0.690	0.518	0.114	0.308	0.032	0.366	0.077	0.631	0.710	0.155
Base Saturation	0.000	0.469	0.330	0.000	0.508	0.187	0.045	0.176	0.729	0.475	0.424
Cation Exchange	0.094	0.446	0.417	0.000	0.502	0.200	0.000	0.254	0.664	0.491	0.197
pH	0.316	0.375	0.134	0.184	0.032	0.105	0.145	0.341	(0.877)	0.228	[0.937]
Sand	0.224	0.200	0.324	0.189	0.318	0.130	0.045	0.279	0.224	0.274	0.192
Silt	0.032	0.077	0.063	0.187	0.045	0.071	0.126	0.100	0.000	0.084	0.000
Clay	0.263	0.195	0.360	0.100	0.430	0.217	0.045	0.279	0.307	0.285	0.232
Calcium + Magnesium (Dilute-acid Extractable)	---	---	---	---	---	---	---	---	(0.843)	(6.35)	0.641
Calcium + Magnesium (Ammonium Acetate Extractable)	---	---	---	---	---	---	---	---	(0.753)	(0.520)	0.487

^a Correlation coefficients (r) greater than 0.291 and 0.370 are significant at probability levels of 5% and 1%, respectively.

clay content provides a good estimate of the capacity of pond soil to adsorb phosphorus (Boyd and Munsiri, 1996), clay content was not a good predictor of nutrient concentrations in waters of the microcosms.

Findings of this study reveal the need for research to compare water quality in ponds with bottom soils of different physical and chemical characteristics. Such studies could lead to the development of more precise methods for estimating water quality and productivity from soil characteristics. These methods could be used as a basis for recommending nutrient management programs for ponds in a given area. They also would allow for better use of existing soil survey data in planning aquaculture projects. Hajek and Boyd (1994) pointed out that soil survey reports contain much useful information for site selection, design, and construction of ponds, but further use of soil survey reports is limited by lack of knowledge about soil-water interactions in ponds.

Literature Cited

- American Public Health Association (APHA), American Water Works Association, and Water Pollution Control Federation, 1989. Standard methods for the examination of water and wastewater, 17th Edition. APHA, Washington, D.C., USA.
- Arce, R.G. and C.E. Boyd, 1980. Water chemistry of Alabama ponds. Bulletin 522, Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.
- Banerjea, S.M, 1967. Water quality and soil condition of fish ponds in some states of India in relation to fish production. Indian Journal of Fisheries, 14:113-144.
- Boyd, C.E., 1974. Lime requirements of Alabama fish ponds. Bulletin 459, Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.
- Boyd, C.E., 1995. Bottom soils, sediment, and pond aquaculture. Chapman and Hall, New York, USA.
- Boyd, C.E. and P. Munsiri, 1996. Phosphorus adsorption capacity and availability of added phosphorus in soils from aquaculture areas in Thailand. Journal of the World Aquaculture Society, 27:160-167.
- Boyd, C.E. and W.W. Walley, 1972. Studies of the biogeochemistry of boron. I. Concentrations in surface waters, rainfall, and aquatic plants. American Midland Naturalist, 88:1-14.
- Boyd, C.E. and W.W. Walley, 1975. Total alkalinity and hardness of surface waters in Alabama and Mississippi. Bulletin 465, Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.
- Boyd, C.E., M. E. Tanner, M. Madkour, and K. Masuda, 1994. Chemical characteristics of bottom soils from freshwater and brackishwater aquaculture ponds. Journal of the World Aquaculture Society, 25:517-534.
- Brady, N.C., 1990. The nature and properties of soils, 10th edition. Macmillan Publishing Company, New York, USA.
- Hajek, B.F. and C.E. Boyd, 1994. Rating soil and water information for aquaculture. Aquacultural Engineering, 13:115-128.
- Moyle, J.B, 1956. Relationships between the chemistry of Minnesota surface waters and wildlife management. Journal of Wildlife Management, 20:303-320.
- 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 system for describing pond soil horizons. Journal of the World Aquaculture Society, 26:346-377.
- Rouse, R.D., 1968. Soil testing theory and calibration for cotton, corn, soybeans and coastal bermudagrass. Bulletin 375, Alabama Agricultural Experiment Station, Auburn University, Alabama, USA.
- Walsh, L.M. and J.D. Beaton, 1973. Soil testing and plant analysis. Soil Science Society of America, Madison, Wisconsin, USA.