Sedimentation of Soils from Three Physiographic Regions of Alabama at Different Salinities

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Abstract

This study evaluated the rate of sedimentation from water under various salinities, over a time period of 72 hours. The particles come from soils that are commonly found in shrimp growing areas of Alabama: Black Belt Prairie, Piedmont Plateau, and Upper Coastal Plain. These factors affect the growth and survival of shrimp: the soil-water transition zone of aquaculture ponds; water quality; re-suspended organic material increase turbidity and total suspended solids (TSS), which can decrease productivity; and soil characteristics. Different salinity treatments and settling times resulted in significant differences ($P \leq 0.05$) in the reduction of turbidity and total suspended solids for each soil type. Solutions containing 2 ppt salinity had a similar rate of turbidity reduction as the solutions with 5, 10, or greater ppt treatments. Concentrations of turbidity and TSS decreased rapidly between 1 and 12 h of sedimentation; very little decline was observed during the time intervals 12 - 72 h so those results are not reported here. Higher salinity treatments (5, 10, or more) yielded settling patterns similar to the 2 ppt salinity treatment and so the results of higher salinity treatments are not reported here. After 1 h, turbidity was removed by around 65% in the control compared to greater than 85% salinity treated samples. TSS was reduced by more than 95% in the control group. Variations in turbidity and TSS concentrations among the three sediments suggest that finer particles, as found in the Piedmont Plateau soils, settled at a slower rate than larger particles. This difference occurs because the percentage of turbidity and TSS removed was significantly higher in mineralized waters compared to freshwater. Therefore, a small amount of salt, about 2 ppt, can be used in pond aquaculture treatments to reduce the turbidity and total suspended solid concentrations in shrimp ponds.

Introduction

Shrimp farming has gotten a “bad press” (Johnston 1997) for various environmental and social problems. Some of the problems result from discharge. Shrimp disease often follows the problems. In the United States, discharge from shrimp facilities often flows into the fragile Upper Coastal Plain ecosystems and can cause eutrophication due to nitrogen loading, detritus, low dissolved oxygen levels, and sedimentation (Villalon 1991). Government agencies and environmentalists keep a close watch on shrimp farming. The industry has persevered, mainly because the possibility of high profits continues to make shrimp farming an attractive business. It is no longer possible to practice negligent husbandry and still make big profits. The only route left is responsible management with progressive solutions. As Johnson (1997) said, ultimately it is in everyone's interest, both the public and private sectors, to ensure that the industry succeeds. Shrimp farming has found methods to reduce environmental impacts and to increase productivity via best management practices (Boyd et al. 2001). In Thailand, inland low salinity water of 2 and 5 ppt salinity, which is obtained by mixing seawater with freshwater, is being used to farm shrimp and has stimulated appropriate procedures. The methods are being used in other areas, including the United States. As a contribution toward better management, this study shows relations between salinity and sedimentation for various kinds of soils in which shrimp are likely to be farmed in the United States.

Environmental problems primarily are caused from excessive stocking and feeding, high demands for water exchange, turbidity due to shrimp on the pond bottom, and by the semi-benthic nature of shrimp. Organism activity, soil chemistry, soil-water chemistry, and water-particle physics all contribute to problems of persistent suspended material in discharge water.

Brackish water white shrimp (*Penaeus vannamei*) and bristled river shrimp (*Macrobrachium olfersii*) live on and near pond bottoms. Their growth and survival depend in part on the soil-water transition zone of aquaculture ponds, where nutrients and organic particles accumulate (Avnimelech and Ritvo 2003; Boyd 1995). Reactions with pond bottom soil cause changes in the composition of low salinity ponds used for culturing shrimp (Boyd 2002).

Nutrients in pond soils are typically more concentrated than in the water (Avnimelech and Ritvo 2003); however, organic material from soils can be re-suspended by aerators and by shrimp moving through bottom soils, which increase turbidity and suspended solids.

Shrimp pond soils are comprised of 90 – 95% mineral matter and 5 – 10% organic matter. Large particles of mineral matter are inert, but colloidal-sized mineral particles are highly reactive (Boyd 1995). As described in many textbooks (Bohn et al. 1985; Boyd 1990), colloidal particles of organic matter and clay minerals in mud have negative charges and attract cations. Equilibrium exists between concentrations of cations in water and concentrations of the cations adsorbed onto the colloidal particles (Boyd 1990). Sodium (Na^+), a monovalent ion, is adsorbed by soil particles and increase precipitation of soils suspended in water (Boyd 1990, see Figure1 here). Average ocean water consists of 10,500 mg/L sodium whereas freshwater aquaculture ponds contain approximately 100 mg/L (Boyd 1995, p. 106). If mineralized water has a higher removal rate of suspended solids compared to freshwater then it may be used in pond treatments to reduce the turbidity and total suspended solids (TSS) in shrimp ponds.

Water quality does influence shrimp productivity (Boyd and Massaut 1998). Yet because farmers cannot always choose the soil type of their farms, it is important to look at the original soil type of the farm and how that influences resultant water and soil chemistry. Particular management practices depend on soil characteristics. Munsiri et al. (1996) stated that even though bottom-soil quality has long been recognized as a factor influencing water quality and aquatic animal production in ponds, relatively few investigations have been conducted on the role of pond soils in aquaculture. As expected, soil quality deteriorates over time, and many techniques for treating pond soils to improve their condition have been arranged. Munsiri et al. (1996) listed sediment removal, tilling, liming, drying, and nitrogen fertilization as widely used techniques to treat pond bottom, but even these treatments may not be effective.

This study determined the particle removal efficiencies of five different salinity treatments over nine time intervals in water clarification by using the soils collected from Black Prairie, Piedmont Plateau, and the Upper Coastal Plain in Alabama, USA. Black Belt Prairie, located between the northern and southern parts of the East Gulf Coastal Plains, is primarily used for farming livestock and cotton. East-central Alabama, also known as the Piedmont region, contains low hills and ridges separated by sandy valleys. In this region the main industry is textile production due to its deposits of coal, iron ore, limestone, and marble. The last region was the Upper Coastal Plains. The shoreline is composed of small bays and inlets, and this region extends for 85 kilometers (Barnard and Weaver 1997). The majority of aquaculture farming (four of five shrimp farms) is in the Upper Coastal Plains with one farm located in the Black Belt Prairie of Alabama.

Since the ponds in these regions have limited quantitative information pertaining to discharges of shrimp pond effluents by the United Stated Environmental Protection Agency (USEPA), it is important to determine the settling properties of soils obtained from each region of concern at different salinity levels.

Materials and Methods

Soil samples of 12 L were collected from Black Prairie, Piedmont Plateau, and the Upper Coastal Plain ponds of Alabama; 6 each from the 3 types for a total of 18 samples. Each sample was collected from 10 - 15 cm below the surface of the deepest part of the pond using an Ekman Dredge (Wildlife Supply Co., Saginaw, MI) and stored in a 5 mm plastic bag. Samples were stored at 10ºC in a dark room for 24 h, placed in thin layers on plastic sheets, and exposed to warm air in a forced-draft oven at 60ºC with good ventilation. To homogenize the samples, soils were pulverized using a mechanical soil crusher (Custom Lab Equipment Co., Orange City, FL) according to Boyd and Tucker (1992). Instant Ocean (Aquatic Eco-Systems Inc., Apopka, FL), a commercial sea salt mixture containing trace elements, was mixed in city tap water to provide the desired salinities: 0, 2, 5, 10, 20, and 35 ppt. The values were measured using a hand-held portable refractometer 10ATC (Fisher Scientific, Pittsburg, PA). Soil (2 L) was mixed with 15 L saline waters in buckets and stored at 20ºC. Large coarse particles from soil samples were removed or pulverized. Weight specific ration was used to introduce similar volume of soils to each sample jar. Soil pH was determined using a glass electrode pH Meter (Fisher Scientific, Pittsburg, PA).

After mixing vigorously with 2.5 cm plastic PVC pipe for 0.25 h, 3 sub-samples, taken from each of the 18 solutions, were placed in 5 L glass jars immediately**.** The containers were stored at room temperature (20-22ºC). Settling characteristics for turbidity and TSS were recorded at 0, 1, 2, 4, 6, 12, 24, 48, and 72 h intervals for each sub-sample using the method described by Boyd and Tucker (1992). A turbidity standard was prepared from a formazin suspension and a specific concentration of this standard was defined as a turbidity unit (NTU) (Boyd and Tucker 1992). Turbidity measurements were obtained using 20 mL from each sub-sample and recorded with a Turbidimeter Model 965 - 10A (Orbeco – Hellige, Farmingdale, NY). TSS analysis was conducted by vacuum filtration of 100 mL of each sub-sample through a 0.7 µm glass fiber filters

(Millipore Corp., Bedford, MA). Glass filtration apparatus were used during the filtration process (Fisher Scientific, Pittsburg, PA) and filtered samples were dried in an oven at 103ºC for 24 h as described by Clesceri et al. (1998) and Boyd and Tucker (1992).

Total suspended solids in the filters were calculated according to Boyd and Tucker (1992):

$$TSS\ (mg/L) = ((F - T) * 1,000) / V$$

Where:

F = final weight of filter and residue in milligrams

T = tare weight of filter in milligrams

V = sample volume in milliliters

Data were analyzed using two-way ANOVA statistical tests with StatView® 4.5 (SAS Institute Inc. 1998). ANOVA tests were run to find any significant differences between soil types, salinity treatments, and time intervals. In addition, ANOVA were run to determine differences between the three soil types, in settling characteristics of individual soil solutions over each time interval and in settling characteristics of soil types in regards to salinity treatment and time interval. Statistically significant differences ($P \leq 0.05$) were determined for particle removal efficiency, turbidity and TSS between treatments and for each settling time interval for each soil type.

Results

Two liters of soils produced 3.3, 2.8, and 3.7 g of sediment for Black Belt Prairie, Piedmont Plateau, and Upper Coastal Plain soils, respectively. Soil pHs were 6.9, 6.3, and 4.9 for the same soils, respectively.

Turbidity results for the three soil types showed significant differences ($P \leq 0.05$) in particle removal efficiency from the time (0 h) salt was added to 1 h. For Black Belt Prairie soil, at a salinity of 2 ppt and control without salt addition, turbidity ranged respectively from 848 to 9.5 NTU and from 1,269 to 117 NTU from time interval 0 – 12 h. Figure 2a shows the trends of reduction in turbidity for the Black Belt Prairie soil suspension. Turbidity levels changed significantly ($P \leq 0.05$) with salinity and time. After 1 h, turbidity reduced more in the salinity treatments (≈ 85%) than in the control (≈ 65%). Turbidity decreased by more than 96% after 1 h in salinity treatments of 2-35 ppt. By 48 h all salinity treatments had 99.99 % (3-Log_{10} reduction) turbidity reduction, while the control with no additional salt had an 85% decline in turbidity caused by the settling of the particles. A salinity treatment of 2 ppt reduced the turbidity by more than 90% after 1 h and 95% after 2 h, which would seemingly have the least environmental impact in removing turbidity from shrimp ponds. Piedmont Plateau soil also showed a significant ($P \leq 0.05$) decline in turbidity (Figure 2b) in the first hour. The turbidity of 2 ppt salinity treatment and the control ranged respectively from 1,057 to 12.7 NTU and 1,831 to 597 NTU from time interval 0 - 12 h. Turbidity declined approximately 98% (almost 3-Log_{10} reduction) in all salinity treatments, except for 0 ppt salinity, from 0 - 6 h. After 6 h, the turbidity declined 51% for the control treatment. Turbidity decreased the fastest when the salinity was 2 ppt. The control, 0 ppt, was the most turbid water during each time interval. At 1 h, turbidity reduced more than 99% for all salinity treatments except 0 ppt. Turbidity for Upper Coastal Plain soils ranged from 2,312 to 45 NTU for the salinity treatment of 2 ppt and from 2,747 to 61 NTU for the control over the time intervals 0 - 12 h, respectively (Figure 2c). Turbidity decreased faster in water with Upper Coastal Plain soil than in solutions made with Black Belt Prairie and Piedmont soils. One hour gave the highest turbidity reduction for the mineralized water samples. There was more than 98% reduction in turbidity at salinity treatments 2, 5, and 10 ppts at 1 h.

For each soil type, turbidity declined significantly ($P \leq 0.05$) from the first time intervals, 0 – 1 h to later times. Turbidity in the control without salt addition continued to decrease, however, turbidity was always higher than in those treatments with higher salinity levels. Approximately 60% of turbidity removal was achieved with 1 h sedimentation for all soil suspensions in the controls. At 12 h, turbidity removal was approximately 67% for the Piedmont Plateau, 92% for Black Belt Prairie, and 98% for Upper Coastal Plain soils at 0 ppt salinity. Turbidity decreased faster in Upper Coastal Plain soil suspensions than in the suspension made with Black Belt Prairie soils. Turbidity levels decreased rapidly at 1 h and 12 h of sedimentation while little further decline occurred during 12 - 72 h in salinity treated suspensions. Therefore, the data from 12 to 72 h time interval is not presented. Piedmont Plateau soil had a faster rate of reduction than Black Belt Prairie soil. Turbidity was the highest at Upper Coastal Plain, followed by Piedmont Plateau, and Black Belt Prairie, respectively (Table 1).

Total Suspended Solids (TSS) results for the three soil types also showed significant differences ($P \leq 0.05$) in particle removal efficiency from the time (0 h) salt was added to 1 h. TSS for Black Belt Prairie soil for 2 ppt treatment and the control ranged respectively from 82,763 to 19 mg/L and from 71,533 to 66 mg/L at 0 – 12 h, respectively. TSS declined significantly in each Black Belt Prairie soil sample between time intervals 0 – 1 h (Figure 3a). The control experienced an exponential decline in TSS. Furthermore, there was an inverse relationship between salinity and TSS in each sample; higher salinity concentrations resulted in higher levels of TSS reduction over time. There were significant differences ($P \leq 0.05$) in removal of TSS between salinity treatments and time intervals for Black Belt Prairie soil. Adding 2 ppt of salt to the soil sample resulted in the largest overall decline of TSS. There was a 99% reduction in TSS over each salinity treatment at 1 h. During the second time interval there was more than 99% reduction (3-Log_{10}

reduction) in TSS in all salinity treatments.

TSS in Piedmont Plateau soil suspensions decreased for each salinity treatment from 0 to 1 h. TSS ranged from 52,610 to 423 mg/L and from 63,797 to 20 mg/L at 0 – 12 h for salinity treatments of 0 ppt and 2 ppt, respectively. Each salinity treatment and time interval resulted in significant differences (($P \leq 0.05$) in TSS. A salinity treatment of 2 ppt showed the lowest TSS levels at 6 h (Figure 3b). Prior to these time intervals, 5 ppt had the lowest TSS levels. Reduction in percent TSS was the greatest for 2, 5, 10, and 20 ppts for every time interval from 1 h to 12 h (Table 2). TSS for Upper Coastal Plain soils ranged from 27,683 to 387 mg/L at 0 ppt and from 27,973 to 23 mg/L at 2 ppt salinity treatment for 0 – 12 h, respectively (Figure 3c). There were significant changes between salinity treatments and time intervals for Upper Coastal Plain soil. One hour gave the highest removal for TSS values for the mineralized water samples. There was more than 99% reduction in TSS for salinity treatments 2, 5, and 10 ppts after 1 h. The TSS reduction was 97% in the control after 1 h, proving that after 6 h sedimentation was effective enough to remove particles in the water suspension.

For all soil solutions, approximately 96% of TSS removal was achieved with a 1 h sedimentation interval with a 2 ppt salinity treatment; at 12 h, turbidity removal was 92% for Black Belt Prairie, 67% for the Piedmont Plateau, and 98% for Upper Coastal Plain soil solutions in the control with no salinity treatment. Concentration of TSS decreased rapidly at 1 h and 12 h of sedimentation; there was little decline observed during 12 h - 72 h. Therefore, the TSS results for this duration were not included in our tables and figures. Generally, turbidity and TSS removals were gradually increased after a 1 h sedimentation interval and then no significant removal ($P > 0.05$) was obtained after 12 h intervals (Table 3).

Overall, we obtained significant differences ($P \leq 0.05$) in settling characteristics by salinity for all three soil types. Although there were significant differences between soil types in the control without salinity, there were no significant differences in the effects of salinity between soil types. There were non-significant differences ($P > 0.05$) between the soil types in early time periods. Even such statistically non-significant differences can be important. All three soils used in suspensions were initially mixed vigorously; all settled more than 90% after 1 h; and all settled almost 99% after 12 h with 2 ppt salt treatment. Additional salt (5, 10, 20, and 35 ppt) resulted in results similar to the 2 ppt treatment. In addition, turbidity and TSS removals had similar patterns for each soil type used in the suspension with minor differences in their settling characteristics; TSS was removed more efficiently after 1 h and continued to decline throughout 72 h. We recorded more than 75% decline in soil particles in solutions after 6 h in control samples, treated with no salt. Settling characteristics of soils were much higher for Upper Coastal Plain soil than Black Belt Prairie and Piedmont Plateau soils in the control. TSS removal followed similar and almost equal patterns of removal for all soil types in the sample suspensions.

Discussion

Turbidity and TSS reduction rates were similar between the three soil types. Regardless of soil type, salinity and time both played important roles in decreasing the turbidity and TSS parameters. Upper Coastal Plain TSS varied more than the other soil types. This study confirmed the assumption that turbidity and TSS levels would decrease faster by means of sedimentation in mineralized waters; the percentage turbidity removal through sedimentation was much faster in mineralized waters in Piedmont Plateau soil. TSS removal was similar regardless of salinity whereas turbidity decreased with increased levels of salinity up to certain level. Day et al. (1989) observed that suspended solids settled faster in saline water due to the ionic strength of dissolved salts, which neutralize the charges of suspended material.

Turbidity decreased faster in the Upper Coastal Plain soil suspensions, which may be related to particle size in the solutions. Variations in turbidity and TSS concentrations among the three sediments suggest that finer particles, in the Piedmont Plateau, settled much slower than soils with larger particles.

Most clay carries a net negative charge and negative charges on soil colloids attract cations while positive charges attract anions. In general, coagulants destabilize colloids, thereby permitting suspended particles to form aggregates that can settle out of the suspension. The salinity treatments used in this study had a coagulant property even at small levels. As most colloids are negatively charged and settled by the additions of positively charged molecules, sea-salt mixtures provided substantial coagulation effects in the solution. Furthermore, there is a relationship between the charges and soil suspensions' pH because many types of clay have pH-dependent charges; therefore an increase in pH increases charges. Soil pH was 6.3, 6.9, and 4.9 for the Piedmont Plateau, Black Belt Prairie, and Upper Coastal Plain sediments, respectively. Settling characteristics of soils were much higher for Upper Coastal Plain soil than Black Belt Prairie and Piedmont Plateau soils in the control with no salt treatment. TSS removal followed similar and almost equal patterns of removal for all soil types in the sample suspensions. Turbidity decreased faster in water with Upper Coastal Plain soil than in solutions made with Black Belt Prairie and Piedmont soils. This result suggests that soil samples from the Upper Coastal Plain had more cations along with larger particles, which made the settling faster. Furthermore, gram weight variations among these physiographic regions resulted in some differences in their particle distributions in suspensions.

Residence time played a significant role in the removal of turbidity and total suspended solids in the soil-water mixture. Teichert-Coddington et al. (1999) studied the final effluent from draining shrimp ponds and settling ponds, and obtained near maximum sedimentation of most variables within 6 h, with a removal of 88% of total suspended solids, 100% of settleable solids, 63% of 5 day - biochemical oxygen demand and 55% of total phosphorus. Ozbay and Boyd (2004) obtained a significant decline in total suspended solids (79% after 24 h and 84% after 48 h) over a 72 h sedimentation study. Turbidity in this study exhibited similar patterns of change to those observed for total suspended solids in the study conducted by Ozbay and Boyd (2004). Considering long resident time requirements and limited space availability for sedimentation basins in aquaculture farms, it does not seem cost-effective that sedimentation basins be used to treat effluents from channel catfish ponds in Alabama as suggested by Ozbay and Boyd (2004).

Since the percentage removal was significantly higher in the mineralized waters compared to that of freshwater (less than 0.5 ppt), it seems that a small amount of salt (≈ 2 ppt) can be effective in pond treatments to reduce the turbidity and TSS concentrations in shrimp aquaculture ponds. Aquaculture managers may consider salt treatment in densely populated shrimp farming locations by using 2 ppt salinity to decrease suspended solids and turbidity in order to reduce sediment loads and increase productivity.

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Literature Cited

Avnimelech, Y. and G. Ritvo. 2003. Shrimp and fish pond soils: processes and management. Aquaculture 220:549 – 567.

Barnard, W. D. and D.C. Weaver. 1997. Alabama: The Heart of Dixie. Reprinted from the World Book of Encyclopedia. World Book, Inc. 525 West Monroe, Chicago, IL.

Bohn, H.L., B.L. McNeal and G.A. O'Connor. 1985. Soil chemistry, 2nd Edition. A Wiley-Interscience Publication, John Wiley and Sons, New York, NY.

Boyd, C.E. and L. Massaut. 1998. Soils in pond aquaculture. Aquaculture Asia. 3:6-9.

Boyd, C.E. and C.S. Tucker. 1992. Water quality and pond soil analyses for aquaculture, Laboratory Manual. Alabama Agricultural Experimental Station, Auburn University, Auburn, AL.

Boyd, C.E. 1990. Water quality in ponds for aquaculture. Department of Fisheries and Allied Aquacultures, Auburn University, Auburn, AL, printed Shrimp Mart (Thai) Co. Ltd., Hatyai, Songkhla, Thailand.

Boyd, C.E. 1995. Chemistry and efficacy of amendments used to treat water and soil quality imbalances in shrimp ponds, Pages 183-199 *in* C.L. Browdy and J.S. Hopkins, editors. Proceedings of the Special Session on Shrimp Farming. The World Aquaculture Society, Baton Rouge, LA.

Boyd, C.E. 1998. Bottom soils, sediment, and pond aquaculture. Chapman & Hall, New York, NY.

Boyd, C.E., M.C. Haws and B.W. Green. 2001. Improving shrimp mariculture in Latin America: Good Management Practicies (GMPs) to reduce environmental impacts and improve efficiency of shrimp aquaculture in Latin America, and an assessment of practices in the Honduran shrimp industry. Coastal Resources Center, University of Rhode Island, Narraganset, Rhode Island. 88 pp.

Clesceri, L.S., A.E. Greenberg and A.D. Eaton. 1998. Standard methods for the examination of water and wastewater, 20th Edition. American Public Health Association, Washington, DC.

Day, J.W., Jr., C.A.S. Hall, W.M. Kemp, and A. Yanez-Aranchibia. 1989. Estuarine ecology. Wiley, New York, NY.

Johnston, M. 1997. Thailand shows the way in sustainable shrimp farming. AAHRI Newsletter Article 6(2). Bangkok, Thailand.

Teichert-Coddington, D.R., D.B. Rouse, A. Potts, and C.E. Boyd. 1999. Treatment of harvest dischards from intensive shrimp ponds by settling. Aquaculture Engineering. 19:147 – 161.

TABLE 1. Average percentage reduction in concentrations of turbidity (NTU) in solutions mixed with three different soil types in control and treated samples with three different salinity levels.

Soil	Time	Salinity Treatment (ppt)			
Type	**Interval (h)**	**0**	**2**	**5**	**10**
	0	0.0	0.0	0.0	0.0
Black Belt	**1**	58.8	92.4	94.9	96.7
Prairie	**6**	87.5	98.0	98.8	99.1
	12	90.8	98.9	99.3	99.6
	0	0.0	0.0	0.0	0.0
Piedmont	**1**	58.8	87.1	92.4	92.2
Plateau	**6**	51.3	97.4	96.8	96.3
	12	67.4	98.8	98.3	96.0
	0	0.0	0.0	0.0	0.0
Upper Coastal	**1**	69.5	98.1	98.0	98.8
Plain	**6**	95.6	98.2	98.7	98.5
	12	97.8	98.1	98.3	97.5

TABLE 2. Average percentage reduction in concentrations of total suspended solids (mg/L) in solutions mixed with three different soil types in control and treated samples with three different salinity levels.

Soil Type	Time Interval (h)	Salinity Treatment (ppt) 0	2	5	10
Black Belt Prairie	**0**	0.0	0.0	0.0	0.0
	1	99.5	99.9	99.9	99.9
	6	99.9	100.0	99.9	99.9
	12	99.9	100.0	100.0	99.9
Piedmont Plateau	**0**	0.0	0.0	0.0	0.0
	1	96.6	99.8	99.8	99.7
	6	98.7	99.9	99.9	99.8
	12	99.2	100.0	99.9	99.8
Upper Coastal Plain	**0**	0.0	0.0	0.0	0.0
	1	97.3	99.8	99.6	99.8
	6	99.7	99.9	99.8	99.7
	12	99.9	99.9	99.8	99.7

TABLE 3. ANOVA results for differences in soil type in regard to salinity treatment and time intervals. There are significant differences ($P \leq 0.05$) in soil type with the same salinity treatment and time interval. Letters with "a" indicates significantly differences ($P \leq 0.05$) while letter "b" shows no significant differences ($P > 0.05$). Each treatment had three replicates. Particle settling efficiencies varied significantly ($P \leq 0.05$) between the soil suspensions during 6 h for most salinity treatments.

Salinity Treatment (ppt)	**Time Interval (h)**				
	0	**1**	**2**	**4**	**6**
0	0.000327[a]	0.000032[a]	0.000033[a]	0.000207[a]	0.002502[a]
2	0.000047[a]	0.001548[a]	0.000963[a]	0.001890[a]	0.009749[a]
5	0.000001[a]	0.026767[a]	0.044012[a]	0.044526[a]	0.098885[b]
10	0.000001[a]	0.000726[a]	0.016190[a]	0.467243[b]	0.134429[b]

Figure Captions

FIGURE 1. The exchange between soils, cations, and Na^{+} adsorption (courtesy of Boyd 1990).

FIGURE 2. Log scale reduction in A) Black Belt Prairie; B) Piedmont Plateau; and C) Upper Coastal Plain soils turbidity (NTU) over 12 h time interval for each salinity treatment.

FIGURE 3. Log scale reduction in A) Black Belt Prairie; B) Piedmont Plateau ; and C) Upper Coastal Plain soils total suspended solid (mg/L) over 12 h time interval for each salinity treatment.

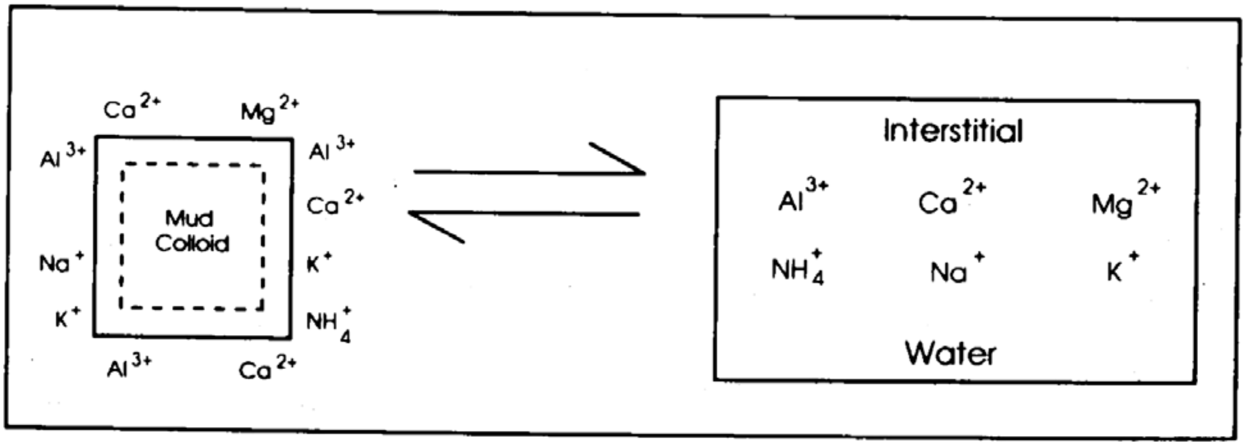
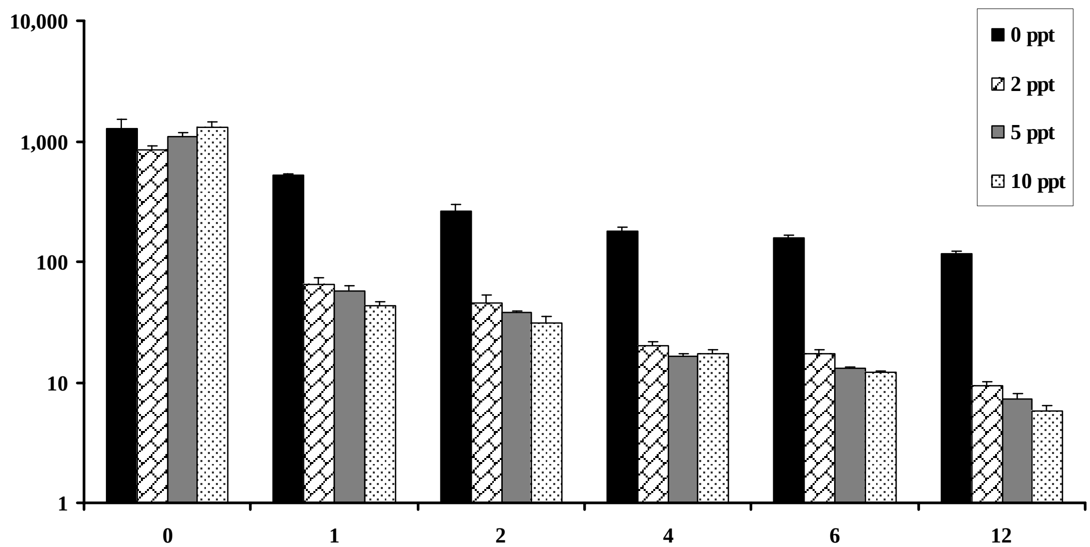
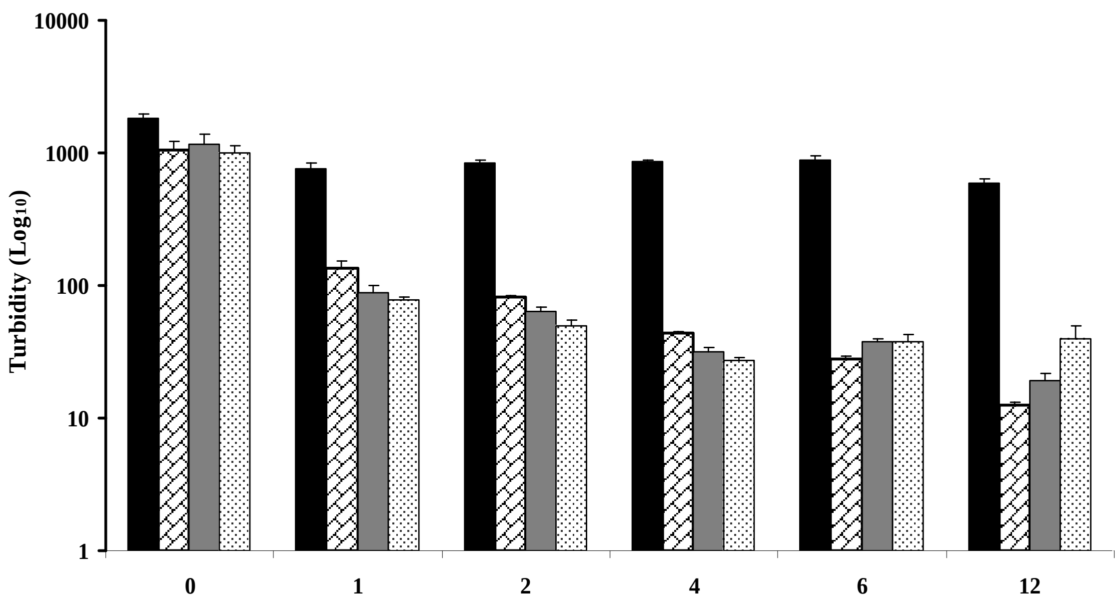

Ca 2+
Mg 2+
Al 3+
Al 3+
Ca 2+
Mud
Colloid
Na +
K +
K +
NH 4 +
Al 3+
Ca 2+
Interstitial
Al 3+
Ca 2+
Mg 2+
NH 4 +
Na +
K +
Water

FIGURE 1.

A)


10,000
1,000
100
10
1
0 ppt
2 ppt
5 ppt
10 ppt
0
1
2
4
6
12

B)


10000
1000
100
10
1
Turbidity (Log10)
0
1
2
4
6
12

C)

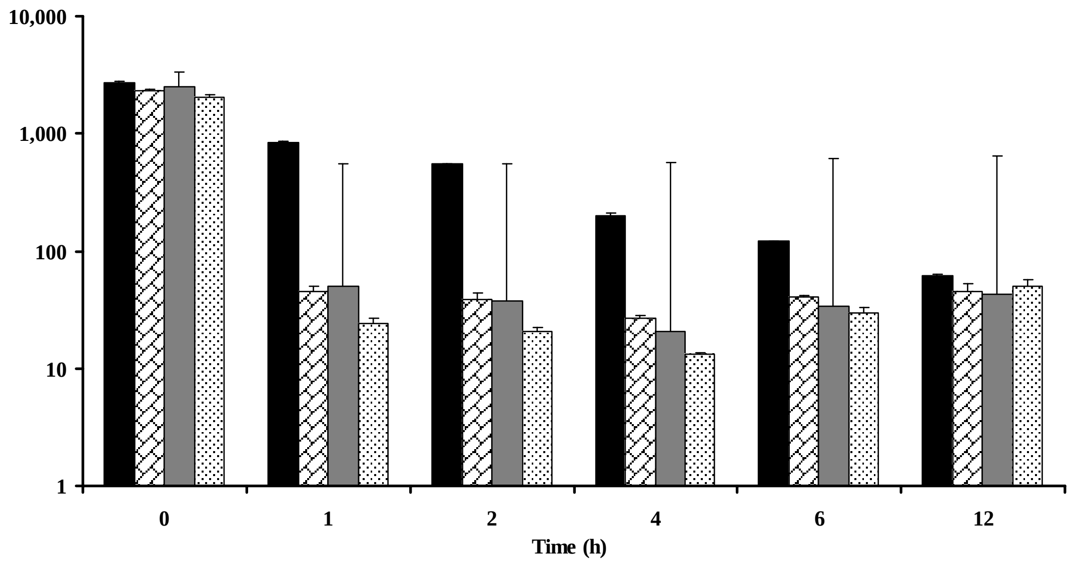
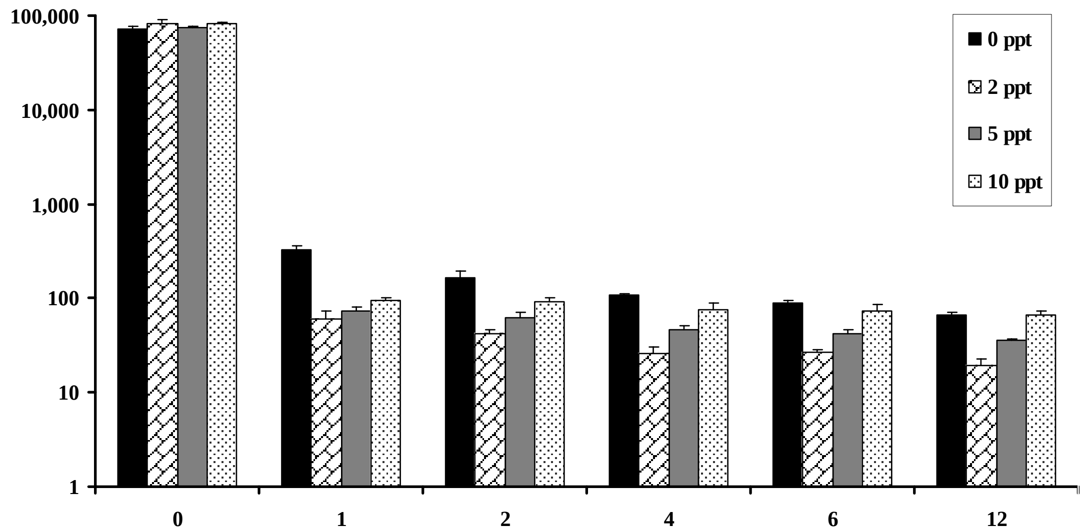
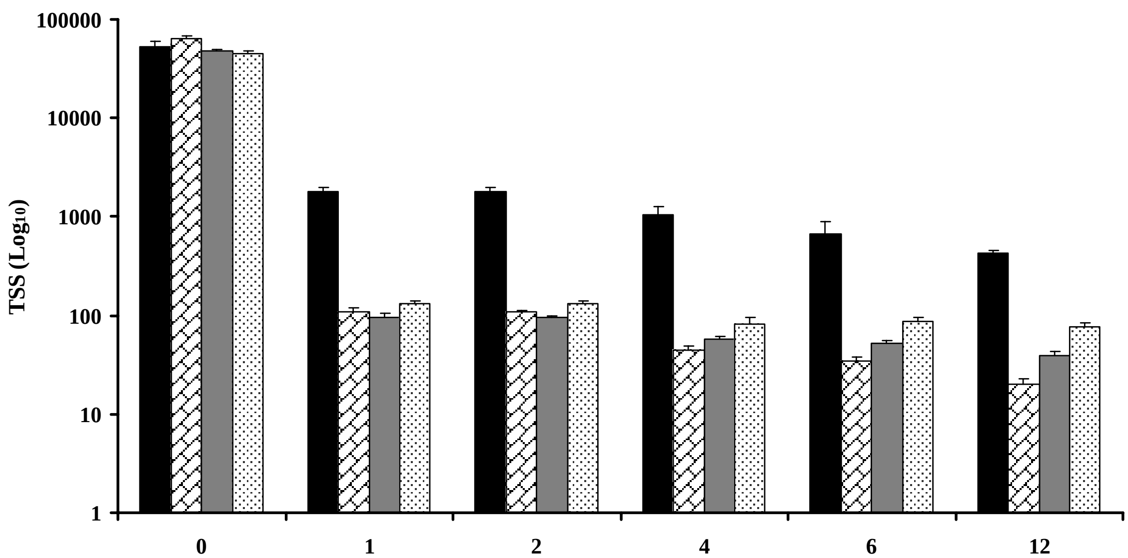


FIGURE 2.

A)


100,000
10,000
1,000
100
10
1
0 ppt
2 ppt
5 ppt
10 ppt
0
1
2
4
6
12

B)


TSS (Log10)
100000
10000
1000
100
10
1
0
1
2
4
6
12

C)

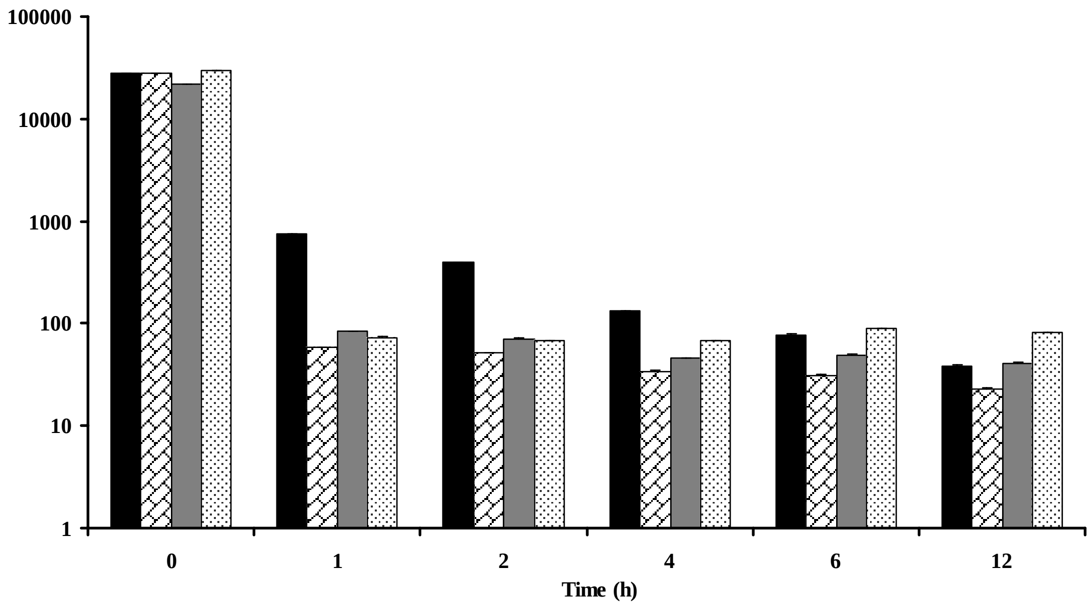


FIGURE 3.