EROSION CONTROL AND REMOVAL OF SUSPENDED SOIL PARTICLES IN PONDS: EVALUATION OF GEOFABRIC LINERS AND CHEMICAL COAGULANTS

by

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Abstract

In an experiment conducted at the E. W. Shell Fisheries Center, Auburn, Alabama, three ponds each were lined with a permeable geotextile with 0.090-mm opening sizes, a permeable geotextile with 0.355-mm opening sizes, or served as unlined, controls. During the 2-yr study, geotextile liners did not tear or decay. This prevented erosion of the bottom of the ponds stocked with a high density of channel catfish and aerated nightly. The liners tended to float up in the water column; the liner with smaller opening sizes floated in all three ponds, while the other liner floated in only one pond. Fish production, survival, and feed conversion ratio did not differ ($P > 0.05$) among the control and lined ponds or between liner types. Water quality variables often differed between lined ponds and control ponds. The greatest difference was higher phytoplankton abundance in the lined ponds—especially in ponds lined with the less permeable geotextile – than in the control. This difference was attributed to differences in phosphorus uptake by bottom soils related to the liners and their permeability. However, in spite of more phytoplankton growth in lined ponds, the control ponds tended to have higher turbidity because of erosion of bottoms by aeration.

To investigate phosphorus uptake rate by soil through the geotextiles, six kinds of geotextile liners with apparent opening sizes ranging from 0.090 mm to 0.84 mm were installed in separate soil from water in aquaria. Water was treated with 0.75 mg/L of phosphorus from monopotassium phosphate. Phosphorus concentration did not decline in aquaria without soil, and all liners reduced the amount of phosphorus removed by the soil. Phosphorus removal by soil did not differ among liners with opening size < 0.200, but these liners interfered less with soil phosphorus uptake than did the liner with 0.090-mm opening size. Final phosphorus concentrations were 0.089 mg/L in the unlined aquaria with soil, 0.397 mg/L for the liner with 0.090-mm openings, and 0.157 to 0.202 mg/L for the liners with larger openings.

Geotextiles can reduce erosion resulting in less turbidity in water. However, fine particles settle very slowly and may remain suspended almost indefinitely restricting light penetration in the water column and reducing primary productivity. Particles of three soils – each containing a different type of clay – settled at different rates. Nevertheless, particles tended to settle faster as concentration of total dissolved solids (TDS) increased in diluted seawater. In freshwater, total hardness concentration increased as TDS concentration rose.

Several chemical coagulants were tested for their ability to remove suspended soil particles. Potassium and sodium chloride were comparatively ineffective for turbidity removal. Calcium sulfate was more effective than magnesium sulfate in removing turbidity. Aluminum chloride and sulfate tended to perform better than ferrous sulfate and ferric chloride.

Although there were some differences in effectiveness of coagulants among the types of soils, calcium sulfate (gypsum), aluminum sulfate (alum), and aluminum chloride appear to have the greatest potential for use in ponds. Aluminum compounds neutralize alkalinity and cause a decrease in pH. Treatment rates (mg/L) for aluminum sulfate and aluminum chloride should not exceed the total alkalinity (mg/L as CaCO3) to avoid low pH. Knowledge of conductivity, total alkalinity, total hardness, and type of clay mineral suspended in water can be useful in selecting a suitable coagulant.

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I. Introduction

Erosion of pond embankments is a ubiquitous and troublesome occurrence in aquaculture (Boyd 1995). Erosion degrades pond embankments, but soil particles suspended in water create turbidity that can limit phytoplankton productivity and availability of natural food organisms for aquacultural species. Moreover, suspended soil particles often settle in deeper areas of ponds to make ponds shallower and to create soft sediment that can interfere with various management procedures (Steeby et al. 2001). There have been some estimates of rates of sediment accumulation in ponds. Munsiri et al. (1995) found that in small, aquaculture research ponds (0.04 to 0.1 ha) ranging from 2 to 52 yr in age, the average rate of sediment accumulation was about 1 cm/yr. Sedimentation rates in 233 aquaculture ponds from nine countries ranged from 0.5 to 3.7 cm/yr and averaged 1.44 cm/yr (Boyd et al. 2010). Steeby et al. (2004) found that sedimentation rate in ponds in Mississippi ranged from 12.5 cm during the first year to 1.3 cm/yr in 16 to 21 yr-old ponds. Thus, sedimentation decreased as ponds aged.

Erosion of pond embankments can be minimized by designing side slopes of embankments in accordance with soil properties and establishing grass cover. Also, aerators should be installed in deeper water in a manner that avoids impingement of aerator-induced currents on embankments (Boyd et al. 2003). Erosion-prone areas of embankments should be lined with stone (rip-rap) or other material capable of lessening erosion. Nevertheless, traditional erosion control measures do not stop erosion of pond earthwork; they just lessen the rate of soil loss.

Several common aquaculture species also cause considerable disturbance of pond bottoms by stirring sediment in search of benthic food organisms and by making depressions or burrows during spawning activities. Occasionally, wild aquatic animal species may enter ponds and create burrows in pond bottoms.

One way to completely stop erosion of pond earthwork would be to cover pond bottoms and embankments with a plastic liner. Liners are frequently used in certain types of highly-intensive aquaculture – especially in heterotrophic, floc systems for pond culture of marine shrimp (Avnimelech 2012). Several research stations also have used liners to reduce seepage in ponds. However, liners that have previously been used in aquaculture were not porous and prevented contact of water with bottom soils. Phosphorus is strongly adsorbed from water by bottom soil (Masuda and Boyd 1994), and it will accumulate in ponds with impermeable liners causing dense unstable phytoplankton blooms (Leonard 1995). Where liners have been used to prevent seepage, a layer of soil usually is placed over pond bottoms increasing the already high price of lining ponds (Daniels and Boyd 1989; Leonard 1995).

Geotextile technology is expanding rapidly as new applications are found for these products. Some geotextiles are porous and less expensive than the thick, non-porous, plastic liners occasionally used in aquaculture. Permeable liners might allow exchange of dissolved substances – particularly phosphorus – between bottom soil and water, and because of their lower cost, porous geotextiles might have application for erosion control in ponds and especially in small ponds on research stations and hatcheries.

Turbidity in pond water also can originate from suspended solids in source water, and in some cases, ponds remain turbid even after all sources of turbidity have been eliminated. This results because clay particles settle slowly from water – some may remain in suspension permanently. Therefore, methods for clearing turbid water in ponds are needed. Chemical coagulations are probably the best choice for lined ponds, but relatively little research has been conducted on the relative effectiveness of different coagulants and of the influence of basic water quality on turbidity removal by coagulants.

The purpose of the present study was to evaluate porous, geotextile liners as potential pond lining material and to determine the relative effectiveness of common chemical coagulants in clearing turbidity from water.

II. Literature Review

Erosion in aquaculture ponds

Erosion is a natural process by which earthen material is removed from a land or earthwork surface and transported, usually by water, to another area away from the original location. Erosion is caused by strong wind, heavy rains, snow or ice, wave action, and activities of animals such as livestock, burrowing animals, and humans (Brady 1990). In aquaculture ponds, erosion occurs mainly on the side slopes of embankments. Soil material is eroded from embankments by strong waves, rainfall, and aerator-generated water currents. Embankments should be constructed with proper side slopes and thoroughly compacted at optimum moisture content for compaction (McCarthy 1998; Yoo and Boyd 1994). The above water portions of embankments should be lined with vegetation, rocks, or synthetic liners to minimize erosion. Erosion control will avoid high concentration of suspended solids and turbidity and reduces the cost of maintaining pond earthwork (Egna and Boyd 1997). It also reduces the rate of sediment accumulation in ponds.

In Alabama, erosion is an important issue at catfish farms. Hence, when the Alabama Catfish Producers, Auburn University, Alabama Department of Environmental Management (ADEM), and the United States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) collaborated to develop Best Management Practices for channel catfish farming in Alabama, techniques for erosion control were included in the BMPs (Boyd et al. 2003).

Water quality in fish ponds

Water quality in fish ponds includes physical, chemical, and biological factors that affect the suitability of the water for fish production (Hepher and Pruginin 1981). Wherever aquaculture takes place, water quality should be measured. If water quality is not optimum for survival, reproduction, and growth of fish or other aquaculture species, water quality management should be applied. Although there are many water quality variables, only a few of them play an important role in aquaculture. Nevertheless, these variables need to be measured, because a pond that has “good” water quality has more production and a greater survival rate than a pond that has “poor” water quality (Boyd and Tucker 1998).

Temperature

Temperature affects chemical and biological processes. The rate of chemical reactions and biological processes roughly doubles for every 10^{o}C increase in temperature (Williams and Williams 1964). Thus, aquatic organisms will use two times as much oxygen at 30^{o}C as they will use at 20^{o}C. Moreover, chemical reactions in pond waters and sediment will occur twice as fast at 30^{o}C as at 20^{o}C. Thus, the dissolved oxygen requirement for aquatic organisms is more critical in warm water than in cooler water (Boyd and Tucker 1998). Water temperature also influences management procedures. For example, in cooler water fertilizer dissolves slower and herbicides act slower.

In ponds and other water bodies, heat enters at the surfaces, and the surface water heats faster than deeper water. This can lead to thermal stratification of water bodies with warmer water at the surface and cooler water at the bottom (Wetzel 2001). Thermal stratification usually can be prevented in aquaculture ponds by avoiding water more than 2 m deep and by using mechanical aeration (Boyd and Tucker 1998).

In intensive aquaculture systems, deterioration of water quality can stress fish or other culture species making them more susceptible to diseases and parasites (Boyd and Tucker 1998). Disease outbreaks are especially likely if fish are stressed at a time when the environment is optimal for pathogens to reproduce. Temperature can play an important role in aquatic organisms, because temperatures may be either below or above the thermal limit affecting to the fish's immunity (Watt 2001). Channel catfish *Ictalurus punctatus* held at temperatures of 15, 20, 25, 30^{o}C had different immune and hematological responses after being vaccinated with live theronts of *Ichthyophtihrius multifillis* (ich). Vaccinated catfish held at 20^{o}C temperatures before being challenged with ich responded by having more red blood cells, white blood cells, thrombocytes, and monocytes. Tilapia held at a temperature of 15^{o}C gave bad results for survival and no sign of anti-ich antibodies following vaccination (Martins et al. 2008).

pH

The pH expresses the degree of acidic or basic conditions in water. The pH in freshwater ponds usually will be between 6 and 9, and in a given pond, pH can fluctuate daily by one or two units because of differences in the photosynthesis rate relative to the respiration rate (Boyd and Tucker 1998). Carbon dioxide reacts in water to produce acidity (Wetzel 2001) as shown in the equation below:

$$CO_2 + H_2O = HCO_3^- + H^+$$

From the equation, it can be seen that if CO_2 in water increases, H^+ will increase, and pH will decrease. On the other hand, if CO_2 in water decreases, H^+ will decrease, and pH will increase. Hence, in daytime, phytoplankton in the water column will lose CO_2 as plants use it in photosynthesis, and pH will increase. At night, phytoplankton no longer use CO_2, and organisms release CO_2 by respiration decreasing pH in the water column (Wetzel 2001).

The fingerlings of channel catfish and hybrid catfish (female channel catfish × male blue catfish *I. furcatus*) are sensitive to sudden changes in pH, but they become more tolerant to pH as they age and grow larger. A recent study of pH tolerance in channel catfish versus hybrid catfish at three states of growth: sac fry, swim-up fry, and fingerlings found that channel catfish sac fry were less tolerant than hybrid catfish to low rate changes of pH: 24-h LC10 (0.13 and 0.38 pH unit increase, respectively), and 24-h LC50 (0.36 and 0.48 pH unit increase, respectively). Conversely at a higher rate change of pH increase (0.62 pH unit), channel catfish were more tolerant than hybrid catfish.

For swim-up fry, the hybrid catfish were less tolerant of pH increase (24-h LC50 = 0.83 pH unit) than channel catfish (24-h LC50 = 1.28 pH unit.). However, fingerling channel catfish were less tolerant of pH increase (24-h LC50 = 1.33 pH unit) than were hybrid catfish (24-h

LC50 = 1.54 pH unit. However, the relationship between fish survival and pH levels reveals that catfish are less sensitive to consistently high pH than to abrupt pH change (Mischke 2012).

Suspended solids and turbidity

Turbidity in a water column results from suspended solids that block the light from penetrating into the water. There are three kinds of suspended solids (Wetzel 2001; Boyd and Tucker 1998) that can affect the level of turbidity in the water body.

- Phytoplankton, zooplankton, and bacterial blooms: algal blooms or eutrophication occur from additions of nutrients to water in fertilizer, organism waste, and pollution. This phenomenon can raise the pH up to 10 or more. Dense phytoplankton blooms also can lead to fish kills from oxygen depletion. Some algal species produce toxins which can harm aquatic animals.

- Suspended organic and humic acids: These substances reduce light penetration and some may even inhibit phytoplankton growth through toxic effects. Although organic substances stain water (tea or coffee color), they seldom cause dissolved oxygen depletion.

- Suspension of silt and clay particles: Colloidal clay particles resulting from erosion on watersheds or within ponds may remain suspended in water for a long time. They reduce photosynthesis, but clay turbidity usually is not toxic.

All sources of turbidity scatter and block sunlight, preventing its penetration into the water column. Thus, it has a negative effect on growth of phytoplankton and aquatic weeds which are the primary producers in water bodies. Freshwater organisms can tolerate more turbidity than brackishwater organisms, and seawater organisms are the least tolerant to turbidity.

Most channel catfish *Ictalurus punctatus* are produced mainly in the southeastern United States. They are raised in earthen ponds. In catfish ponds, phytoplankton will absorb and reduce NH_3-N concentrations from the water column (Hargreaves 1998). Blue-green algae or cyanobacteria commonly dominate the phytoplankton communities in eutrophic water bodies. They are able to control cell buoyancy by collapsing and reforming intracellular gas vesicles making them float to the water surface. This gives blue-green algae a competitive advantage over other kinds of phytoplankton for light (Paerl and Tucker 1995). Some species of cyanobacteria are unwanted because of odorous compounds that can affect the quality of fish flesh (Rimando and Schraeder 2003).

Total alkalinity and total hardness

Total alkalinity is the total concentration of titratable bases in water expressed as the concentration of equivalent calcium carbonate ($CaCO_3$) in milligrams per liter (Boyd and Tucker 1998). The bases in water include hydroxide, ammonia, borate, phosphate, silicate, bicarbonate, and carbonate, but bicarbonate and carbonate contribute most of the alkalinity to natural water (Wetzel 2001). Water with a pH above 4.5 contains alkalinity, and water contains carbon dioxide up to pH 8.3. Because carbon dioxide causes acidity, a water has acidity up to pH 8.3. Waters between pH 4.5 and 8.3 – because they contain both bicarbonate and carbon dioxide –

contain both acidity and alkalinity. Waters below pH 4.5 are said to contain mineral acidity, because carbon dioxide usually cannot depress pH below 4.5. Water above pH 8.3 does not contain acidity. There the concept of alkalinity and acidity in water is a little different from the traditional manner of calling water of pH 7 neutral, water below pH 7 acidic, and water above pH 7 alkaline (Boyd et al. 2011).

Total hardness is expressed as the concentration of all divalent cations expressed in milligrams per liter of calcium carbonate. Calcium and magnesium dominate the divalent cations in almost all pond waters. Copatti et al. (2011) found that raising water hardness can improve the growth rate of silver catfish *Rhamdia quelen* juveniles in acidic or alkaline water. Conversely, hardness did not affect growth of silver catfish at neutral pH. Investigation found that the highest concentrations of water hardness reduced silver catfish growth in acidic water as well as in water of pH 9.0. Silver catfish juveniles held under acidic conditions (pH 5.5) in soft water (30-60 mg/L $CaCO_3$) water for 30 days had significantly reduced growth rate when compared with those kept at pH 7.0 and the same level of hardness.

Phosphorus

Phosphorus is a key nutrient stimulating phytoplankton production in ponds. Thus, as feeding rates increase, phytoplankton abundance increases. Phytoplankton blooms in fish pond often contain a high frequency of blue-green algae that can cause off-flavor in fish flesh (Paerl and Tucker 1995), and species of algae that can be toxic to fish may sometimes occur (English et. al. 1993; Snyder et. al. 2002; Zimba et. al. 2001). In addition, low dissolved oxygen concentration – especially at night – may be a problem in ponds with dense plankton blooms

(Boyd and Tucker 1998). The main natural control of phosphorus concentrations in ponds is uptake by the bottom soil (Boyd 1995). Bottom soil adsorbs phosphorus, and once bound in the soil, it is sparingly soluble. Thus, ponds with impermeable liners that are not covered with soil can accumulate large amounts of phosphorus in their waters. The blooms become very dense in such ponds, and die-offs often occur. When the dead cells decompose, the phosphorus contained in them is released back into the water triggering another phytoplankton bloom, and the cycle repeats itself (Hopkins et al. 1993; Krom et al. 1989; Neori et al. 1989).

Nitrogen

Nitrogen can enter ponds from the air in N_2 form and some of this form can be fixed in organic compounds by certain species of blue-green algae and bacteria (Wetzel 2001). Some nitrogen can enter ponds in rain in the form of nitrate, and many forms of nitrogen may enter ponds via the water supply. Inorganic nitrogen may enter ponds in fertilizers and organic nitrogen or enter in manure or feed. A high rate of nitrogen recycling occurs in pond ecosystems when organic matter from dead blue-green algae and bacteria and other sources decompose. In aquaculture ponds, feeds can result in a high level of nitrogen in water. Ammonia enters the pond from metabolic wastes of the culture species and from decomposition of uneaten feed and feces. Hence, an important concern in intensive aquaculture is excessive concentration of ammonia (Boyd and Tucker 1998).

Nitrogen is recycled from dead plankton cells in ponds with impermeable liners as described for phosphorus above. However, soil is not a major control on nitrogen concentrations in ponds. Ammonia is lost from ponds by diffusion, and nitrate is denitrified to nitrogen gas by certain bacteria (Boyd and Tucker 1998). These processes can occur in a pond lined with an impermeable liner not covered with soil. However, in such ponds, there may not be an anaerobic zone that occurs in bottom soil. Denitrification possibly does not progress as rapidly in a pond with an impermeable liner as in an earthen-bottomed pond.

Liners in aquaculture ponds

There are two major kinds of materials that can be used to line ponds – a permeable geotextile liner that can let water and nutrients in the water body flow to them and impermeable plastic sheets that allow neither water nor nutrients to pass through. Impermeable liners have been used exclusively in aquaculture ponds. Unless soil is placed over impermeable liners, phosphorus concentration will increase in the water. This can lead to phytoplankton blooms that tend to increase to high density, crash, increase to high density again, etc. (Krom et. al. 1989; Barkoh 1996; Neori et. al. 1989) Thus, water quality is not stable in ponds that have impermeable liners without soil on top of them.

The possibility of using permeable liners in ponds should be investigated, because they might not interfere with phosphorus removal from water by bottom soil, lessening the problem with unstable phytoplankton blooms that occur in ponds with permeable liners. Impermeable pond liners are excellent for preventing erosion – especially if soil is not placed on top of them (Funge-Smith and Briggs 1998). Permeable liners likely could also be effective in avoiding erosion.

A basic problem for pond management is excessive macrophyte growth in ponds and embankments. Too much macrophytic biomass in a pond is undesirable; excessive vegetation can interfere with the use of ponds for recreation. In aquaculture ponds, macrophytes interfere with feeding and other management activities. After macrophytes die, they decompose, releasing nutrients back into the water. This cycle of growth, death, and decaying of aquatic plants results in overabundant pond vegetation which affects oxygen levels causing stress and mortality of fish. Bottom liners can be used to control rooted macrophytes in the pond, because they cover the soil and do not allow rooted plants access to the bottom. Of course, macrophytic algae that do not have roots, and floating, higher plants such as water hyacinths *Eicchornia crassipes* that do not root in the soil can grow in lined ponds. Permeable liners also would likely prevent the growth of rooted aquatic vegetation.

A polypropylene liner (DuPont Typar 3201 and 3301) was used to control macrophytes over the bottom of a lake. In summer time, the regrowth was counted in order to compare to a control area. Regrowth of macrophytes was slight in lined ponds – macrophyte biomass was at least 100 times greater in the controls. Even though the liner material was permeable to gases, it did not float or form a “balloon” problem (Cooke and Gorman 1980).

Geotextile fabric, a porous woven polyethylene material, is used for construction site erosion control (Rickson 2006). It is also used for improving drainage and enhancing reinforcement of marginally stable slopes (Vishnudas et al. 2003), and it can be used as covers for anaerobic odor control (Miner et al 2003). Double layers of geotextile bags filled with a variety of materials have been used to decrease bridge abutment scouring (Korkut et al. 2007) and for beach erosion reduction (Elko and Mann 2007; Oh and Shin, 2006; Allan and Komar 2004). Moreover, hydraulically loaded geotextile bags are used to dewater dredge slurry (Shin et al. 2002) dairy and swine lagoon waste (Worley et al. 2008; Baker et al. 2002), and sewage sludge in decentralize sites (Wett et al. 2005).

The major use of geotextiles in aquaculture has been to dewater (remove solids) effluent from intensive production facilities such as backwash water from indoor facilities (Sharrer et al. 2009) and intensive biofloc systems (Danaher et al. 2011). I did not find references to use of porous geotextiles for avoiding erosion in production ponds.

Catfish pond management

Feed is applied to catfish ponds in order to increase fish production beyond that possible in fertilized ponds. Almost all feed applied will be consumed by fish, and feed conversion ratios of 1.5 to 2.0 are possible (Bosworth et al. 2004; Dunham et al. 2008; Jiang et al. 2008; Green and Rawles 2010; Kumar and Engle 2010; Li et al. 2012). Growth rates of hybrid catfish were found to be 29.3% more than those of channel catfish (Green and Rawles 2010).

Aerators are used in catfish ponds to oxidize organic wastes from feeding and provide dissolved oxygen for the respiration of fish and other organisms (Boyd and Tucker 1998). Aeration allows production to be increased two to four times above that possible in un-aerated ponds. However, aerators generate strong water currents that contribute to erosion of pond embankments and bottoms.

Aquaculture facilities discharge nutrients, organic matter, and suspended solids when they overflow or are drained. Thus, the U.S. Environmental Protection Agency has made an effluent rule for US aquaculture (USOFF 2004). However, this rule does not apply to catfish ponds unless they discharge more than 30 days per year.

Pond draining effluents have high concentrations of total suspended solids. Songsawang and Boyd (2012) reported that settling basins can remove coarse, suspended soil particles from aquaculture pond effluents, but settling basins are not able to settle particles smaller than 10^{-5} m (Ozbay and Boyd 2003, 2004).

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III. Evaluation of Two, Porous, Geotextile Liners for Erosion Control in Small Aquaculture Ponds

Abstract

In an experiment conducted at the E. W. Shell Fisheries Center, Auburn, Alabama, three ponds each were lined with a permeable geotextile with 0.090-mm opening sizes, a permeable geotextile with 0.355-mm opening sizes, or served as unlined, controls. During the 2-yr study, geotextile liners did not tear or decay, they prevented erosion of the bottom of the ponds stocked with a high density of channel catfish and aerated nightly. The liners did tend to float up in the water column; the liner with smaller opening sizes floated in all three ponds, while the other liner floated in only one pond. Fish production, survival, and feed conversion ratio did not differ ($P > 0.05$) among the control and lined ponds or between liner types. Water quality variables often differed between lined ponds and control ponds. The greatest difference was greater phytoplankton growth in the lined ponds especially in ponds lined with the less permeable geotextile – than in the control. This difference was attributed to differences in phosphorus uptake by bottom soils related to the liners and their permeability. However, in spite of more phytoplankton growth in lined ponds, the control ponds tended to have higher turbidity because of erosion of bottoms by aeration.

Introduction

Erosion of pond embankments is a ubiquitous and troublesome occurrence in aquaculture (Boyd 1995). Erosion degrades pond embankments, but soil particles suspended in water create turbidity that can limit phytoplankton productivity and availability of natural food organisms for aquacultural species. Moreover, suspended soil particles often settle in deeper areas of ponds to make ponds shallower and to create soft sediment that can interfere with various management procedures (Steeby et al. 2001, 2004). There have been some estimates of rates of sedimentation in ponds. Munsiri et al. (1995) found that in small, aquaculture research ponds (0.04 to 0.1 ha) ranging from 2 to 52 yr in age sediment accumulation averaged about 1 cm/yr. Sedimentation rates in 233 aquaculture ponds from nine countries ranged from 0.5 to 3.7 cm/yr and averaged 1.44 cm/yr (Boyd et al. 2010). Steeby et al. (2004) found that sedimentation decreased as large, commercial catfish ponds ($\approx$ 8 ha) aged: annual sediment accumulation was 12.5 cm in 1-yr-old ponds, but only 1.3 cm in 16 to 21 yr-old ponds.

Erosion of pond embankments can be minimized by designing side slopes of embankments in accordance with soil properties and establishing grass cover. Aerators should be installed in deeper water in a manner that avoids impingement of aerator-induced currents on embankments (Boyd et al. 2003). Erosion prone areas of embankments should be lined with stone (rip-rap) or other material capable of lessening erosion. Nevertheless, traditional control measures do not stop erosion of pond earthwork; they just lessen the rate of soil loss.

Several common aquaculture species also cause considerable disturbance of pond bottoms by stirring sediment in search of benthic food organisms and by making depressions or burrows during spawning activities (Boyd 1995). Occasionally, wild aquatic animal species may enter ponds and create burrows in pond bottoms.

Erosion of pond bottoms can be stopped by lining bottoms and side-slopes of embankments with a plastic liner. Liners are frequently used in certain types of highly-intensive aquaculture – especially in heterotrophic, floc systems for pond culture of marine shrimp (Avnimelech 2009). Several research stations also have used liners to reduce seepage in ponds (Daniels and Boyd 1989). Liners that have previously been used in aquaculture were not porous and prevented contact between pond water and bottom soils. Phosphorus is strongly adsorbed from water by bottom soil (Masuda and Boyd 1994), and it will accumulate in waters of ponds with impermeable liners causing dense unstable phytoplankton blooms (Krom et al. 1989; Leonard 1995; Neori et al. 1989). Where liners have been used to prevent seepage, a layer of soil usually is placed over pond bottoms. This increases the already high price of lining ponds (Daniels and Boyd 1989; Hopkins et al. 1993; Leonard 1995).

Geotextile technology is expanding rapidly as new applications are found for these products. Some geotextiles are porous and less expensive than the thick, non-porous, plastic liners occasionally used in aquaculture. Permeable liners might allow exchange of dissolved substances – particularly phosphorus – between bottom soil and water, and because of their lower cost, porous geotextiles might have wide application for erosion control in ponds.

Materials and Methods

Ponds used in this study are located on the E. W. Shell Fisheries Center, 2101 North College Street, Auburn, Alabama. Ponds are embankment-type water bodies built on the

Piedmont Plateau; soils in the area are Typic, Kandiudults (clayey, kaolinitic, and thermic) (McNutt 1981). When filled to tops of standing overflow pipes, ponds are 28.3 m long × 14.1 m wide (≈ 400 m^2 surface area). Maximum depth was about 1.5 m with an average around 1.0 m following initial construction (1969 to 1971). A concrete retaining wall (15 cm wide) was installed to a depth of about 1 m around the inside of each pond (Fig. 1) to prevent bank erosion and to assure that water depth was not less than 50 cm when ponds were full in normal use. Ponds gradually filled over the years, and in 2004, a renovation project was initiated to remove sediment from the central areas, and the entire bottoms were graded (Yuvanatemiya and Boyd 2006).

In March 2008, nine ponds for which renovation had been completed in fall 2007 were selected for this study. Three ponds were lined with a black, porous, polypropylene geotextile (Style 307) manufactured by Belton Industries, Belton, SC, USA (Fig. 2). Three ponds were lined with a gray, porous, polypropylene geotextile (Style 3801 G) produced by Typar Geotextiles, Old Hickory, TN, USA (Fig. 2). Physical characteristics of the two geotextile materials are provided (Table 1). For brevity, liners will be referred to as black and gray liners. Three ponds were not fitted with liners and served as controls.

Bottoms of the ponds were further smoothed by hand raking. The 3-m-wide sheets of geotextile were sewed together with nylon thread at pond sites using a hand-held sewing device. A 25-cm deep by 25-cm wide ditch was excavated at a distance of 50 cm behind the concrete retaining wall. Liners were installed over pond bottoms and sides, and the geotextile fabric liner was made wide enough to line the ditch and extend 1 m beyond. The ditch was backfilled with soil to secure edges of the liner (Fig. 3). Steel pins (61 cm long × 1.27 cm diameter) that had one end sharpened to a point and a 5-cm diameter washer were welded on the other end. Each pin was forced through a 15 cm × 0.5 cm thick plastic tile. The washer kept the tile in place, and the tile prevented the washer from tearing through the liner. Ninety-eight pins were inserted through the liner on a 2 m × 2 m grid over the pond bottom. A 4-cm wide × 1-mm thick aluminum strip was attached over the liner around the inside top of the entire concrete wall. The attachment was made by inserting 5-cm long × 0.63-cm diameter screws through the metal and liner into the concrete wall. In addition, a 1.2-m long × 0.63-cm diameter steel pin was shaped to provide a rectangular bracket; the long side of the pin was inserted through the liner and into the embankment on the outside of the concrete wall, the rectangular part of the pin fitted over the top of the retaining wall and extended downward 50 cm over the liner (Fig. 4). Brackets were installed at 2-m intervals around the pond. Photographs (Fig. 5) show bottoms of lined ponds before filling with water.

Each pond was stocked on 5 June 2008 with 400 fingerling hybrid catfish (♀ *Ictalurus punctatus* × ♂ *I. furcatus*) weighing an average of 52.1 g/fish. Fish were fed a floating, pelleted, commercial feed (32% crude protein) at an estimated 3% of body weight per day. A 0.5-hp vertical pump aerator was placed in each pond and operated when low nighttime dissolved oxygen concentration was anticipated. Ponds were completely drained on 11 November 2008, and fish were counted and weighed.

Fish smaller than marketable size were placed in a holding tank and returned to ponds on 14 November. On 3 December, additional fish similar in size to fish returned to ponds on 14 November were stocked to provide a total of 400 fish/pond. Fish added to ponds had an average individual weight of 302 g. Ponds were managed in 2009 according to procedures used in 2008. Ponds were completely drained on 14 October 2009, and all fish harvested and weighed.

Between 15 June to 1 December 2008 and 6 February to 14 October 2009, dissolved oxygen concentrations and water temperatures were measured weekly between 0600 and 0700 h at a depth of 10 cm using a polarographic dissolved oxygen meter with thermistor. Water samples were dipped from the pond surface following dissolved oxygen measurement. These samples were transported to the laboratory and water quality analyses immediately initiated using standard protocol (Eaton et al. 2005) for the following variables: pH (glass electrode); turbidity (laboratory turbidimeter); total suspended solids (glass fiber filtration and gravimetry); total alkalinity (titration with 0.02 N H_2SO_4 to pH 5.1); total hardness (titration with 0.01 M ethylenediaminetetraacetic acid to erichrome black-T endpoint); BOD (standard, 5-d test); total ammonia nitrogen (phenate method); nitrite-nitrogen (diazotization procedure); soluble reactive phosphorus (ascorbic acid method). Nitrate-nitrogen was determined by the szechrome reagent (4-phenylamino-benzenesulfonic acid) method (van Rijn 1993). Unfiltered water samples were digested in an alkaline persulfate solution to convert all phosphorus and nitrogen to phosphate and nitrate, respectively. Phosphate and nitrate concentrations were determined by ascorbic acid procedure and ultraviolet spectrophotometric screening technique, respectively (Eaton et al. 2005; Gross et al. 1999).

Results and Discussion

The gray liner pulled free from the bottom and floated upward in the water column in all ponds, and the black liner floated up in one pond (Fig. 6). Fifty concrete blocks (40 cm × 20 cm × 20 cm) were placed over the liner, and this alleviated, but did not prevent completely, the floating liner problem. Concrete blocks were left in ponds during the second year of the study.

Because liners tended to float, it was decided by the manager of the E. W. Shell Fisheries Center that they were unacceptable, and they were removed after fish harvest in 2009. Nevertheless, liners were quite effective in maintaining the original shape of pond bottoms (Fig. 7). Unlined ponds exhibited considerable bottom erosion and sediment accumulation in deeper portions. Bottom of the lined ponds showed no alteration of bottom shape. Moreover, liners did not tear or develop holes because of fabric decay; they were completely intact after 2 yr. Of course, the liners were not left in ponds long enough to allow comment on manufacturers' estimates of service life (Table 1).

Results of weekly water analyses are given (Figs. 8-12). Values for water quality variables differed considerably among replicate ponds, but averages of variables for individual dates often were similar. Thus, standard error bars were not plotted with means because the many overlaps would have made them impossible to distinguish. Some trends in concentrations of water variables among treatments and control were noted.

Water temperature ranged from 20.7 to 30.9 C in 2008 and from 10.0 to 33.9 C in 2009. The greater water temperature range in 2009 resulted because measurements were initiated in February rather than in June as in 2008. However, there were no differences in water temperature among control and treatments (Fig 8). Thus, the dark color of liners did not increase heat absorption in lined ponds.

Average pH of pond waters usually was above 7.5, and, values higher than 9.0 were observed (Fig. 8). Higher pH values corresponded to periods with clear weather and abundant phytoplankton, while dips in pH – most notable in mid May 2008 and early September 2009 – were related to extended periods of cloudy weather. Differences in pH did not result from the presence of liners.

Total alkalinity and total hardness concentrations tended to be greater in lined ponds than in control ponds in 2008 (Fig. 8). In 2009, lined ponds had slightly greater total alkalinity, but hardness was about the same as in control ponds. Greater total hardness and total alkalinity in ponds in 2008 as compared to 2009 deserves comment. In 2008, ponds that were used as controls – but not the ponds that were lined – were treated with agricultural limestone before the decision was made to conduct this study. Agricultural limestone treatment increased total hardness and total alkalinity concentrations in control ponds. Because lined ponds were not treated with agricultural limestone, concrete blocks placed in lined ponds likely caused increased total alkalinity and total hardness.

Concrete blocks consist of about 2 parts aggregate (sand, gravel, crushed stone, etc.) and 1 part concrete. Concrete contains Portland cement that consists of tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, and gypsum. When mixed with water, the tricalcium silicate in Portland cement reacts to form a solid mass with the other ingredients (Taylor 1997). The basic reaction is:

$$2Ca_3SiO_5 + 7H_2O \rightarrow 3(CaO) \cdot Z(SiO_2) \cdot 4(H_2O)(gel) + 3Ca(OH)_2$$

Components of concrete are slightly soluble and can increase calcium (total hardness) in water, and calcium hydroxide can react with carbon dioxide to produce bicarbonate (total alkalinity).

Ponds were drained in December 2008, and refilled with water of relatively-low total alkalinity and total hardness. Agricultural limestone was not applied after refilling. Draining of control ponds and refilling caused lower total alkalinity and total hardness relative to 2008 in control ponds. Solubility of calcium-containing, alkaline substances in concrete blocks probably occurred most rapidly in 2008, and the already weathered blocks contributed less to total alkalinity and total hardness in 2009.

During 2008, there was little difference in dissolved oxygen concentration among control and treatment ponds (Fig. 9). Only once did average dissolved oxygen concentration fall below 6 mg/L. Dissolved oxygen concentrations also were typically above 6 mg/L in 2009, but in late winter and early spring, dissolved oxygen concentration tended to be greater in lined ponds than in control ponds. Dissolved oxygen concentrations never fell to concentrations considered dangerous to fish (Boyd and Tucker 1998; Torrans 2008), because aerators were operated often at night during periods when water temperature was above 25 C.

All three combined nitrogen fractions (total ammonia nitrogen, nitrite-nitrogen, and nitrate-nitrogen) were unexpectedly low in concentration during 2008 (Fig. 10). Analytical procedures were checked for accuracy and found to be reliable. The likely reason for low total ammonia nitrogen concentration was relatively-low fish standing crops. Daily feed input was rather low in response to small fish biomass, and phytoplankton were able to absorb most of the ammonia nitrogen resulting from decomposition of uneaten feed, fish feces, and metabolic waste of fish (Tucker et al. 1994). Without appreciable total ammonia nitrogen in water, nitrification occurred at low rates and nitrate-nitrogen concentrations also remained low. There also was less opportunity for nitrite-nitrogen being produced as an intermediate in nitrification or from reduction of nitrate in anaerobic zones (Boyd and Tucker 1998; Hargreaves 1998).

Total nitrogen increased during the 2008 growing season. Most of the total nitrogen probably was contained in phytoplankton cells. Although average total nitrogen concentration did not exceed 3 mg/L (Fig. 10), it tended to be slightly greater – especially in September and October – in lined ponds than in control ponds.

In 2009, total ammonia- and nitrate-nitrogen concentrations were fairly low until late spring, but they increased greatly during late summer and fall in response to large daily feed inputs when fish biomass was high. There were no clear differences among control and lined ponds for total ammonia nitrogen concentration (Fig. 10). However, other than for two spikes of nitrate-nitrogen in ponds with gray liners, control ponds had the highest nitrate-nitrogen concentrations from June onward. Nitrite concentration tended to be much greater in control ponds than in lined ponds in 2009. Less nitrite-nitrogen in lined ponds may have resulted because organic matter was captured on liners and was prevented from entering anaerobic zones of sediment as it did in unlined ponds. Nitrate is reduced to nitrite in anaerobic sediment by denitrifying bacteria and stirred into the water column by aerators as described by Hollerman and Boyd (1980). Aerator-generated water currents likely provided plenty of dissolved oxygen in water at the liner surface preventing anaerobic conditions. Nevertheless, nitrite concentrations in unlined, control ponds did not reach levels reported to be harmful to channel catfish (Boyd and Tucker 1998).

In 2009, total nitrogen concentrations increased to much higher levels than in 2008 in response to greater feed input (Fig. 10). Lined ponds tended to have higher total nitrogen concentrations than found in control ponds, but there was no difference between gray and black liners with respect to this variable.

Soluble reactive phosphorus concentrations fluctuated considerably among sampling dates during both years (Fig. 11). There were a few periods during both years when soluble reactive phosphorus concentration in lined ponds were elevated above those in control ponds.

Total phosphorus concentrations were low and similar among control and treated ponds in 2008 (Fig. 11). Concentrations of total phosphorus were greater in 2009 in all ponds, and in late summer and fall, total phosphorus concentrations were markedly greater in lined ponds. Most of the total phosphorus in water was probably contained in living phytoplankton cells or in their particulate remains (Masuda and Boyd 1994).

Turbidity tended to be higher during August and September 2008 in ponds with the gray liner, and ponds with the black liner and control ponds were similar in turbidity (Fig. 12). Throughout most of the growing season in 2009, control ponds had much greater turbidity than ponds with either liner. Total dissolved solids concentrations varied more among ponds of the same treatment and among treatments than did turbidity (Fig. 12). But, on many sampling dates in 2008, total dissolved solids concentrations were as high or higher in ponds with the gray liner than in other ponds – the same can be said for control ponds in 2009.

Chlorophyll a concentrations (Fig. 12) also varied greatly among treatments and among ponds within treatments, but in general, chlorophyll a concentration was consistently higher in lined ponds – especially in 2009.

Higher turbidity and total dissolved solids concentrations in control ponds in 2009 as compared to 2008 are likely related to several factors. Ponds were newly renovated; sediment was removed and bottoms reshaped and compacted. Fish were not stocked until 5 June in 2008, and the fingerlings were small. Aeration was not necessary for several weeks, and bottoms were not disturbed greatly by fish activity and aerator-generated water currents. It is likely that turbidity in both lined ponds and control ponds resulted primarily from plankton rather than suspended soil particles. After harvest in 2008, ponds were restocked with relatively large fish in November and December. Thus, in 2009, fish standing crop was much higher than in 2008 at the beginning of the grow-out period, and aeration was needed more frequently. Fish activity and aerator-generated water currents likely caused much erosion of bottoms of unlined ponds resulting in suspension of soil particles. Low chlorophyll a concentrations in unlined ponds supports this hypothesis; low chlorophyll a concentration would be expected because of light limitation imposed by turbidity from suspended soil particles. However, when all data were considered, there was a high correlation between turbidity and total suspended solids both years (Table 2), but chlorophyll a concentration was not correlated with either of these two variables.

The 5-d biochemical oxygen demand (BOD) tended to be elevated in lined ponds as compared to control ponds during both years (Fig. 9). High BOD concentration in lined ponds in early 2009 cannot be explained, because chlorophyll a, turbidity, and total suspended solids were not elevated at this time. There is no reason to believe that there was a high concentration of dissolved organic matter in ponds at this time, and we assume there was an analytical error. However, BOD concentrations in lined ponds were within the range typically found in commercial channel catfish ponds (Boyd and Gross 1999).

Grand means for water quality data from 2008 and 2009 were computed (Table 3). A few differences were found among grand means. The pH averaged higher in ponds with the gray liner than in controls or ponds with black liners in 2009. Dissolved oxygen concentration was greater in lined ponds than in control ponds both years. In 2008, total nitrogen concentration did not differ among lined ponds and control ponds. In 2009, ponds with both liners had a higher mean concentration ($P < 0.05$) of total nitrogen than did unlined ponds. Total phosphorus did not differ among control and treatments in 2008 ($P > 0.05$), but in 2009 when fish biomass was greater, the two lined-pond treatments had higher concentrations of this variable than control ponds ($P < 0.05$). Ponds with the gray liner also had greater phosphorus concentration than ponds with the black liner ($P < 0.05$). This most likely is the result of the gray liner being more porous than the black liner. However, in spite of total phosphorus being elevated in the lined ponds, there were no differences among control and treatments with respect to soluble reactive phosphorus ($P > 0.05$). This probably was caused by rapid uptake of soluble phosphorus by phytoplankton

Turbidity was greater in ponds with the gray liner in 2008 than it was in the other ponds. However, in 2009, turbidity was highest in the lined ponds. This probably resulted from suspension of soil particles by the aerators. Chlorophyll a concentration was greater in ponds with the gray liner than in control ponds in 2008 ($P < 0.05$), but there was no difference in chlorophyll a concentration between ponds with the two types of liners. In 2009, unlined, control ponds were very low in chlorophyll a concentration as compared to 2008 (Table 3), and ponds with both types of liners had more chlorophyll a than was found in control ponds. Nevertheless, there was no difference in chlorophyll a concentrations between ponds with the two types of liners in 2009.

The BOD was greater in lined ponds than in control ponds both years, but the gray liner and black liner ponds did not differ in BOD. The greater BOD in lined ponds likely was related to higher phytoplankton abundance in these ponds, because much of the BOD in channel catfish ponds results from plankton respiration (Boyd and Gross 1999).

Fish production data (Table 4) show that good survival of fish was achieved in all ponds, and net production was equivalent to 2,492 to 2,555 kg/ha in the abbreviated 2008 grow-out period. In 2009, production ranged from 3,108 to 3,605 kg/ha – levels commiserate with the stocking density (Boyd and Tucker 1998). There were no differences in survival and production among controls and lined ponds ($P > 0.05$).

In conclusion, permeable geotextile liners prevented erosion in ponds, and fish survival and production were typical of that realized in unlined ponds. However, permeable liners did not seem to allow normal uptake of phosphorus by bottom soil, because total phosphorus and chlorophyll _a_ concentrations tended to be elevated in lined ponds as compared to control ponds. Unfortunately, it was not economically possible to have three ponds with impermeable liners for comparison with permeable liners. Geotextiles of larger apparent opening size than present in the liners of this study are available. Future research probably should focus on more permeable geotextiles.

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Table 1. Characteristics of the two, geotextile liner materials as reported by manufacturers.

Variable	Belton Industries Style 307	Typar Geotextile Style 3801 G
Composition of fabric	Polypropylene	Polypropylene
Type	Woven fiber	Woven fiber
Color	Black	Gray
Weight (g/m^2)	105.2	272
Specific gravity	0.93	0.91
Apparent opening size (mm)	0.355	0.090
Water flow rate (L/min/m^2)	509	328

Table 2. Correlation coefficients for relationships of turbidity, total suspended solids, and chlorophyll a for pooled data from geotextile-lined and control ponds.

Variables	Pearsons Correlation Coefficient
Turbidity versus total suspended solids	
2008	0.600**
2009	0.482**
Turbidity versus chlorophyll a	
2008	0.008
2009	0.001
Total suspended solids versus chlorophyll a	
2008	0.013
2009	0.005

**Significant at $P < 0.01$.

Table 3. Grand means for 2008 and 2009 in control ponds and ponds lined with one of two permeable, geotextiles.

	Year		Year		Year	
Liner	2008	2009	2008	2009	2008	2009
	pH		Water temperature (^{o}C)		Total alkalinity (mg/L)	
None (control)	8.24 a	8.24 a	27.08 a	26.45 a	64.16 a	42.46 a
Black	8.26 a	8.26 a	26.93 a	26.67 a	76.03 a	38.05 a
Gray	8.67 a	8.67 b	26.77 a	26.57 a	71.85 a	42.68 a
	Total hardness (mg/L)		Dissolved oxygen (mg/L)		Total ammonia nitrogen (mg/L)	
None (control)	51.8 a	31.9 a	7.75 a	8.18 a	0.12 a	0.30 a
Black	63.7 ab	29.5 a	8.15 b	9.82 b	0.14 a	0.24 a
Gray	71.9 b	37.6 a	8.36 b	9.34 b	0.14 a	0.18 a
	Nitrate-nitrogen (mg/L)		Nitrite-nitrogen (mg/L)		Total nitrogen (mg/L)	
None (control)	0.0 a	0.4 a	0.01 a	0.11 a	0.44 a	1.40 a
Black	0.0 a	0.09 a	0.0 a	0.01 b	0.58 ab	2.11 b
Gray	0.0 a	0.16 a	0.0 a	0.01 b	0.73 b	2.17 b

	Soluble reactive phosphorus (mg/L)		Total phosphorus (mg/L)		Turbidity (NTU)	
None (control)	0.03 a	0.06 a	0.15 a	0.46 a	26.72 a	109.28 a
Black	0.04 a	0.07 a	0.10 a	0.61 b	19.72 a	47.64 b
Gray	0.04 a	0.06 a	0.13 a	1.00 c	41.56 b	52.88 b

	Chlorophyll a (µg/L)		5-d biochemical oxygen demand (mg/L)	
None (control)	225 a	54 a	3.06 a	4.48 a
Black	387 ab	391 b	5.68 b	7.03 b
Gray	510 b	453 b	6.08 b	7.00 b

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*Means indicated by the same letter did not differ at $P < 0.05$ as determined by Duncan's multiple range test – vertical comparisons only.

Table 4. Fish production data for 2008 and 2009 in control ponds and ponds lined with one of two permeable, geotextiles.

	2008			2009		
Variable	Control	Black liner	Gray liner	Control	Black liner	Gray liner
Number stocked	400	400	400	400	400	400
Stocking weight (kg/fish)	0.052	0.052	0.052	0.302	0.287	0.306
Stocking weight (kg/pond)	20.8	20.8	20.8	120.8	114.8	122.4
Harvest weight (kg/pond)	120.5	123.0	122.7	245.1	259.0	266.0
Net production (kg/pond)	99.7	102.2	101.9	124.3	144.2	143.6
Survival (%)	93.6	90.8	90.2	79.8	88.2	76.3
Feed applied (kg/pond)	151.36	151.36	151.36	198.88	198.88	198.88
Feed conversion ratio	1.52	1.48	1.48	1.60	1.38	1.38

Figure 1. Concrete retaining wall in earthen ponds at the Auburn University E. W. Shell Fisheries Center, Auburn, Alabama.

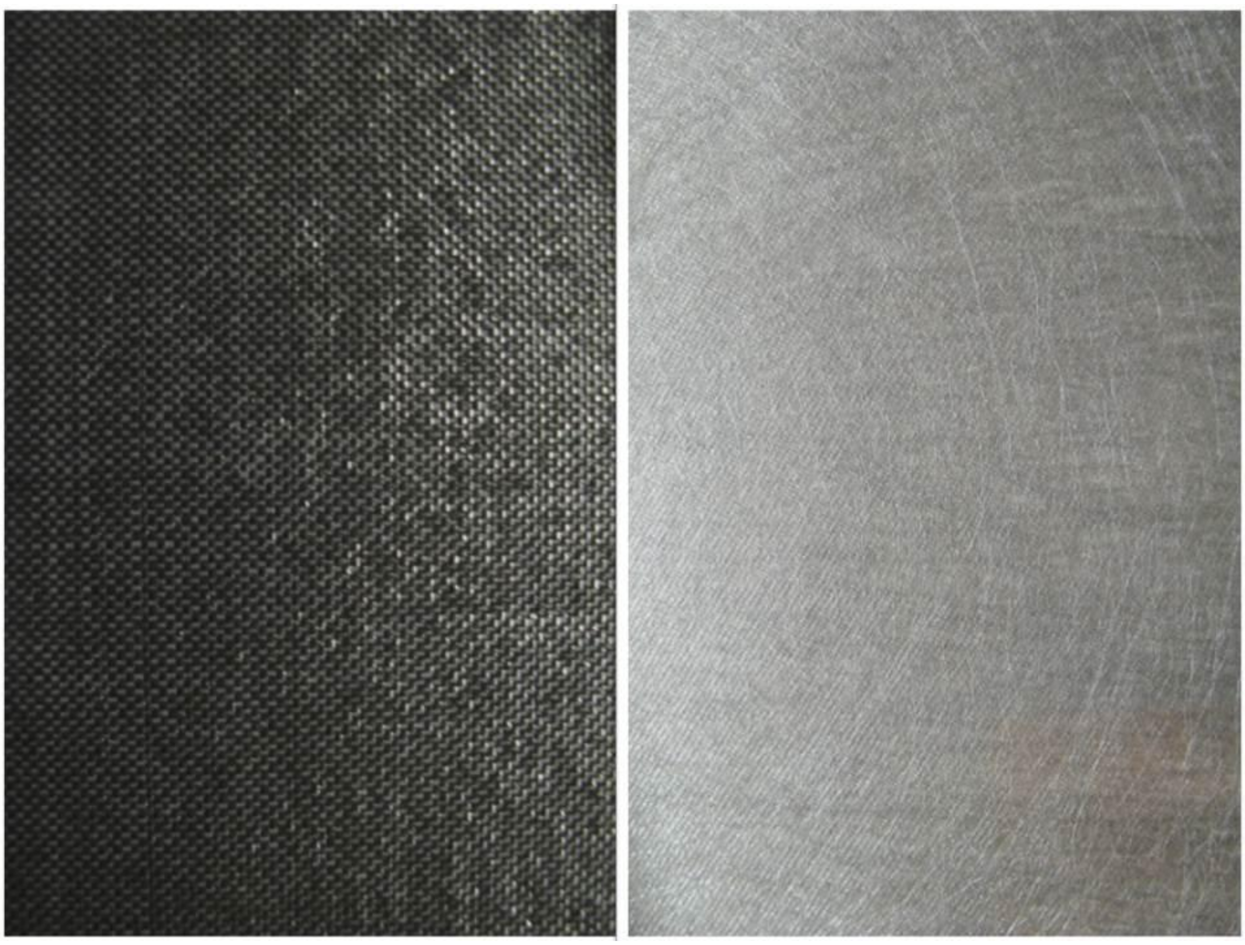


Figure 2. Geotextile material used to line ponds at the Auburn University E.W. Shell Fisheries Center, Auburn, Alabama: Left – Style 307, (Bolton Industries); Right – Style 3801G (Typar Geotextiles).

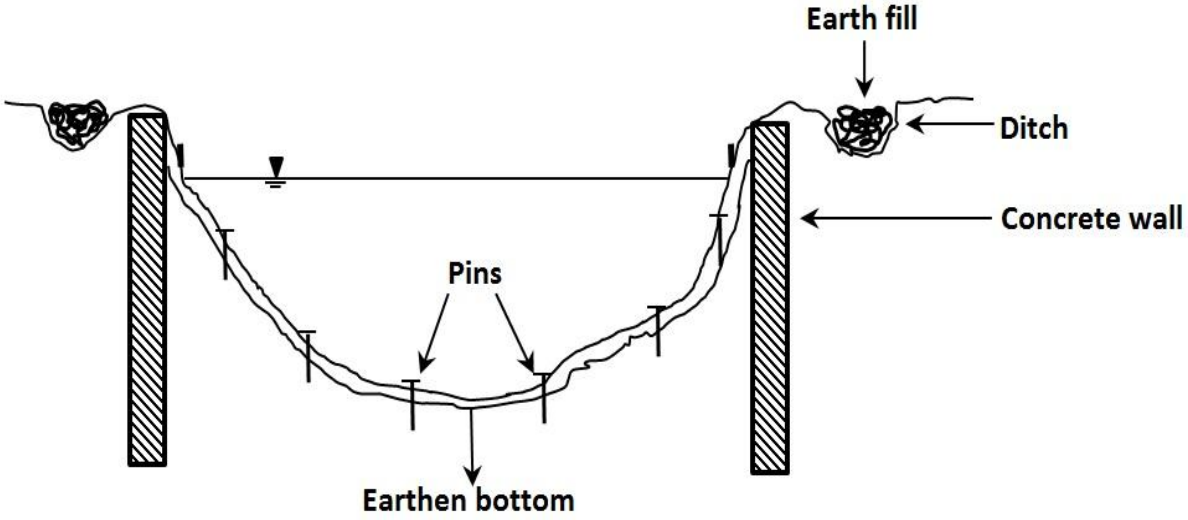


Figure 3. Sketch (not to scale) of attachment of geotextile liners to bottoms of earthen ponds.

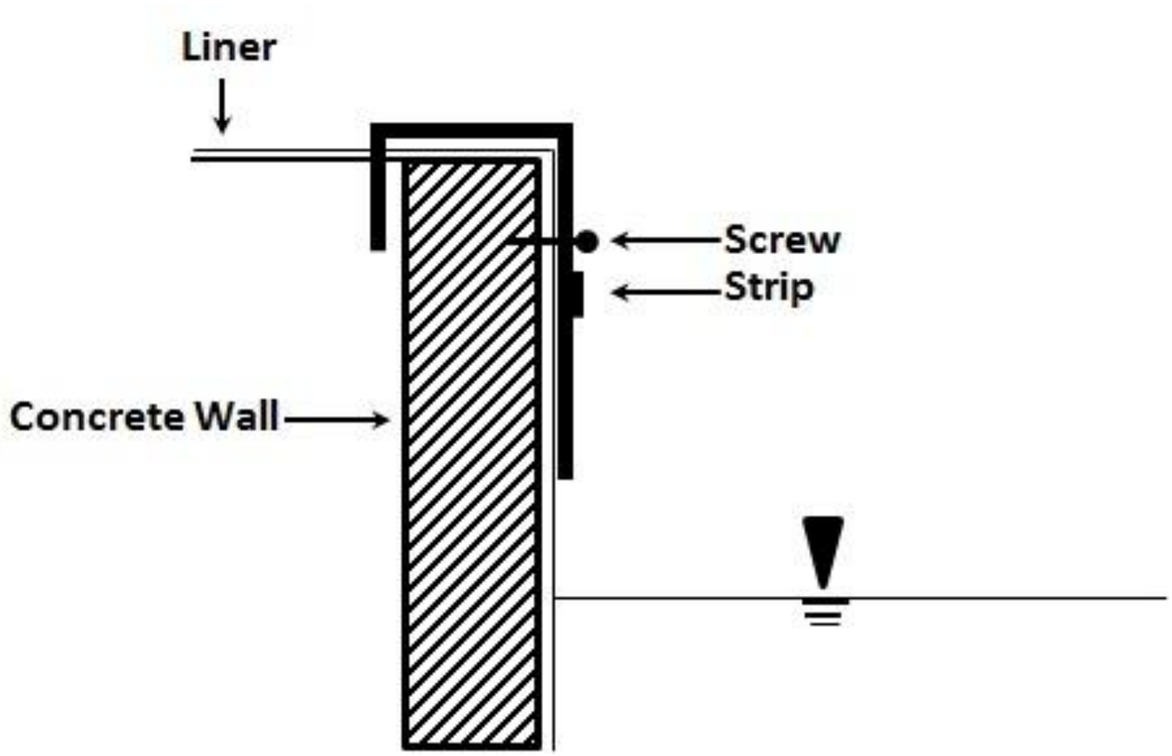


Figure 4. Sketch (not to scale) showing the method of securing geotextile liners to concrete retaining walls in ponds.

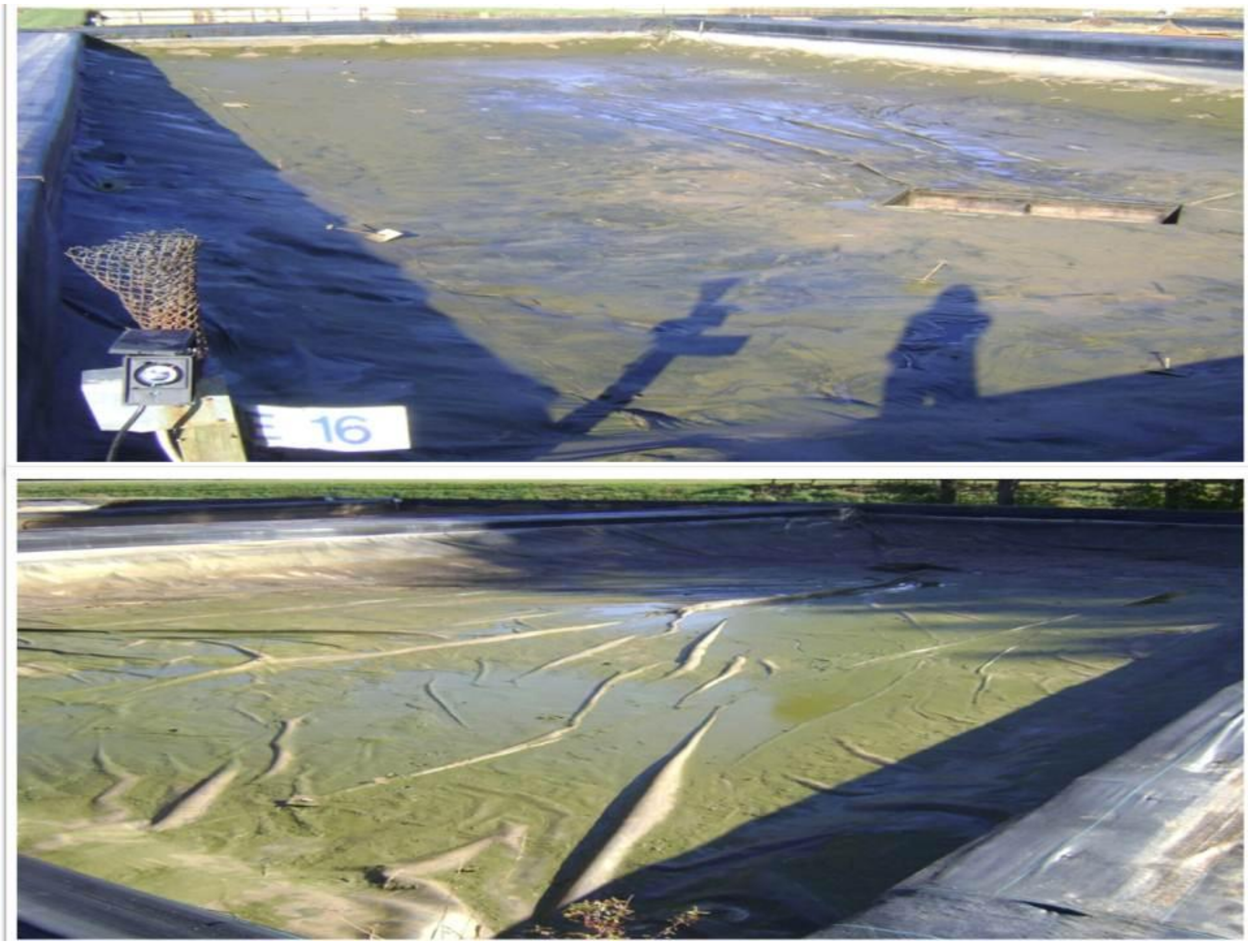


Figure 5. Photographs showing ponds lined with the black, Style 307 geotextile (upper) and the gray, style 3801G geotextile (lower).

Figure 6. Photograph of a pond in which the gray liner floated

Figure 7. Photographs of an unlined pond bottom following fish harvest (upper) and of a lined pond following fish harvest and removal of the liner.

Figure 8. Mean values for pH, water temperature, and concentrations of total alkalinity and total hardness in ponds lined with two types of geotextile liners and in unlined, control ponds.

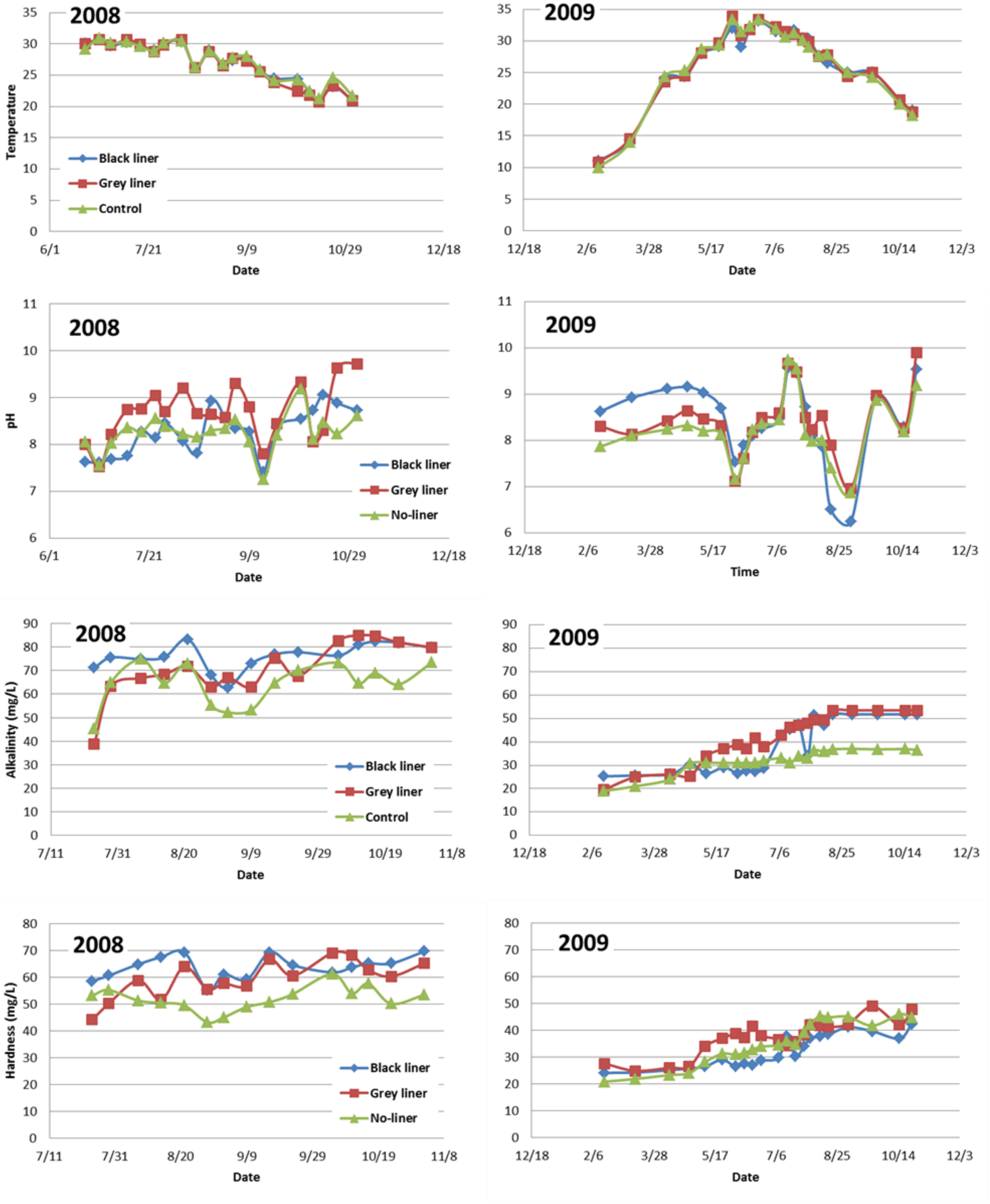


Figure 9. Mean values for concentrations of dissolved oxygen (DO) and 5-d biochemical oxygen demand (BOD_5) in pond lined with two types of geotextile liners and in unlined, control ponds.

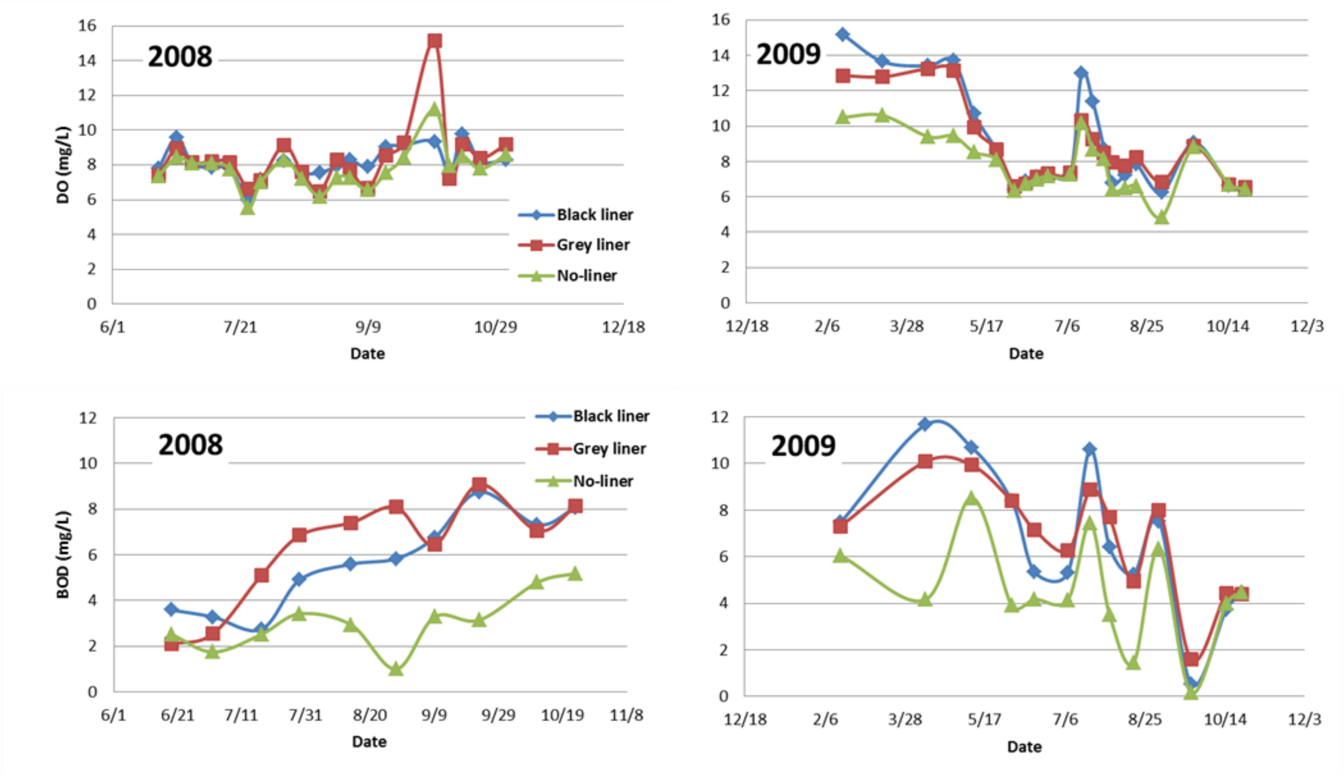


Figure 10. Mean values for concentrations of total ammonia nitrogen (TAN), Nitrate (NO_3-N), Nitrite (NO_2-N), and total nitrogen in pond lined with two types of geotextile liners and in unlined, control ponds.

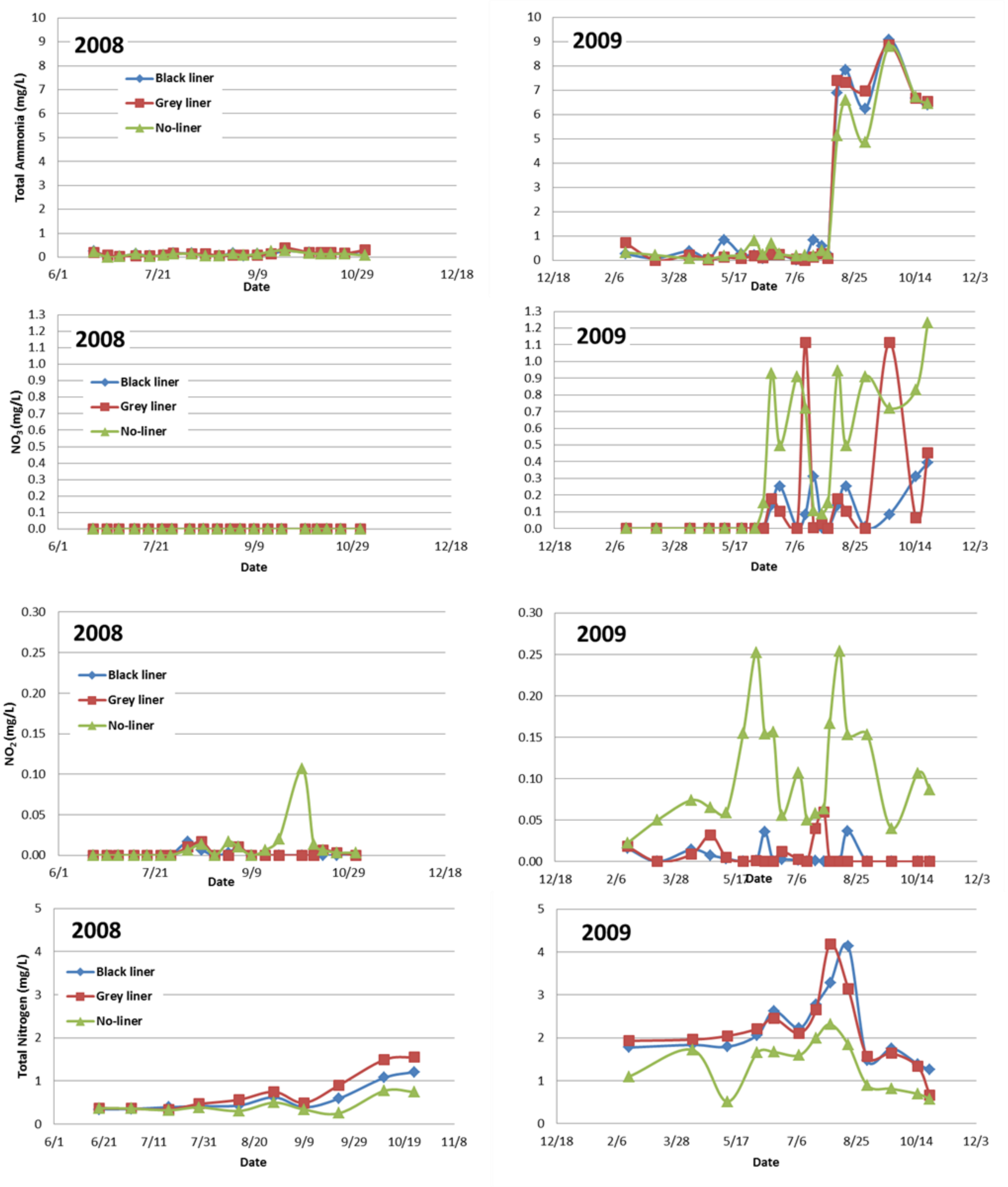


Figure 11. Mean values for concentrations of soluble reactive phosphorus and total phosphorus in pond lined with two types of geotextile liners and in unlined, control ponds.

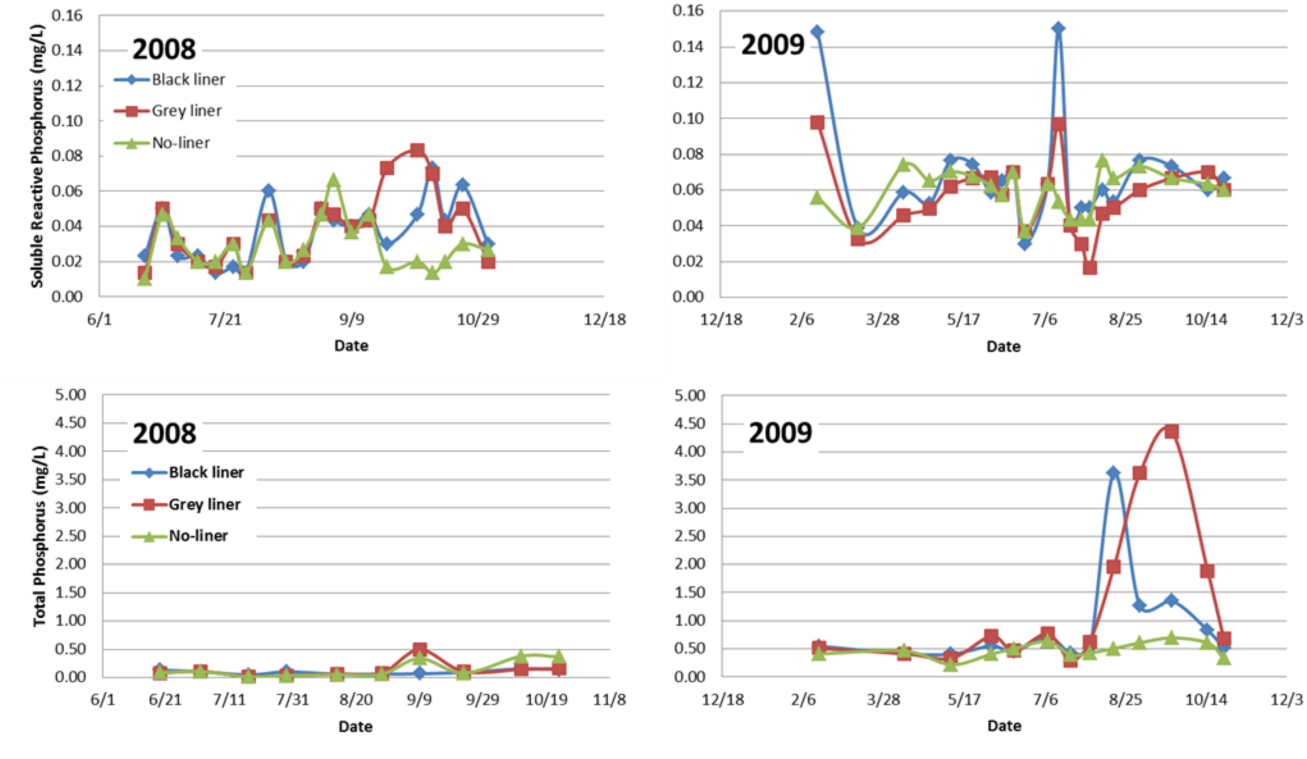
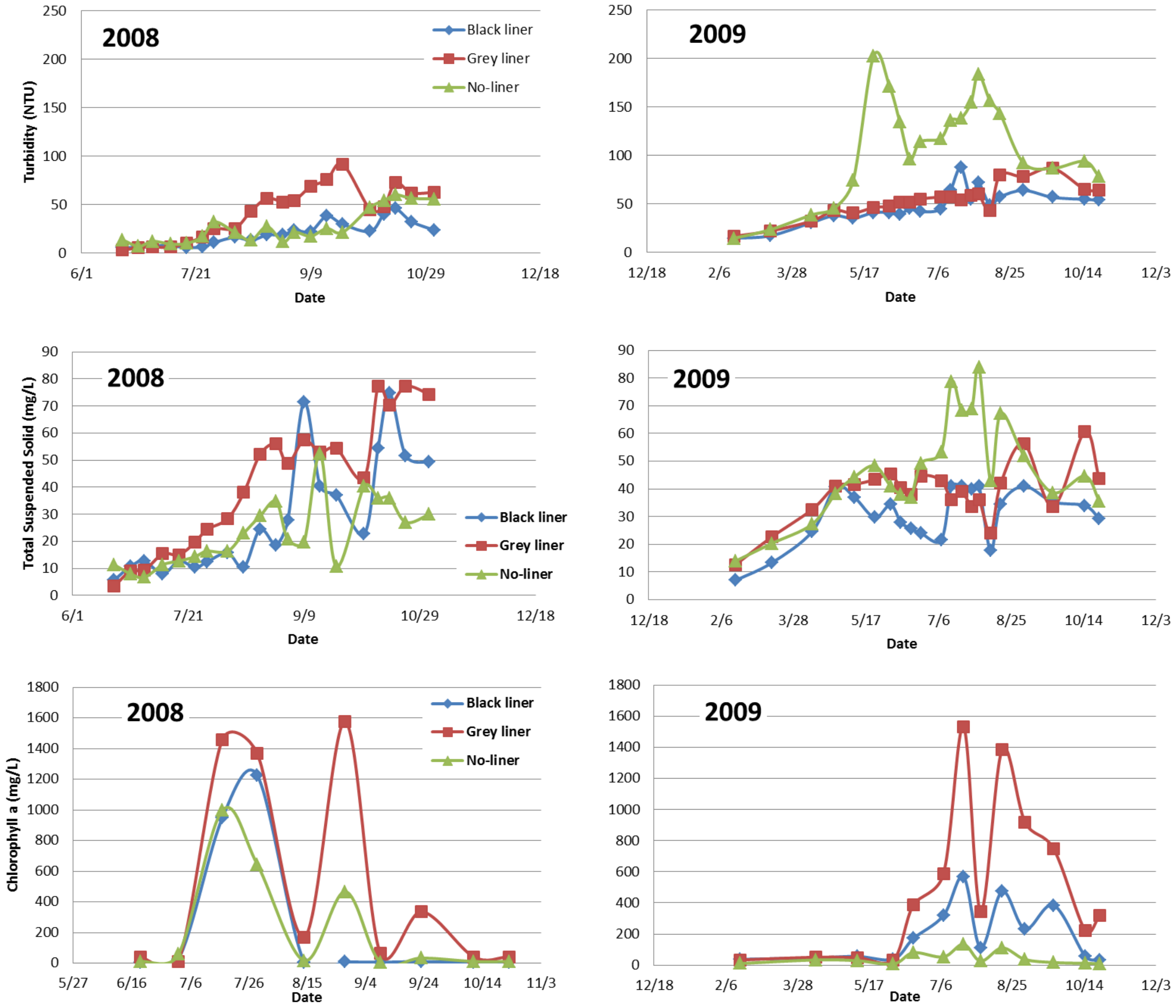


Figure 12. Mean values for concentrations of turbidity, total suspended solids, and chlorophyll a in pond lined with two types of geotextile liners and in unlined, control ponds.



IV. Phosphorus Removal by Soil Separated from Water by Permeable, Geotextiles

Abstract

Six, geotextile liners with apparent opening sizes ranging from 0.090 mm to 0.84 mm were used to separate soil from water in aquaria. Water was treated with 0.75 mg/L of phosphorus from monopotassium phosphate. Phosphorus concentration did not decline in aquaria without soil, and all liners reduced the amount of phosphorus removed by the soil. Phosphorus removal by soil did not differ among liners with opening size < 0.200, but these liners interfered less with soil phosphorus uptake than did the liner with 0.090 mm opening size. Final phosphorus concentrations were 0.089 mg/L in the unlined aquaria with soil, 0.397 mg/L for the liner with 0.090-mm opening, and 0.157 to 0.202 mg/L for the liners with larger openings.

Introduction

The study of water quality and fish production in ponds lined with permeable, geotextiles revealed that these liners prevent erosion of pond earthwork by waves, aerator-generated water currents, and bioturbation (Boyd 1995). Although fish survival and production were as good in the ponds lined with geotextiles as in the control ponds, the liners had a tendency to float, and they interfered with the uptake of phosphorus by bottom soil. Phosphorus concentration and the abundance of phytoplankton were greater in the lined ponds than in the control ponds.

The two geotextiles used in the previous experiment had a relatively small apparent pore sizes – 0.090 and 0.355 mm. Therefore, a laboratory study was conducted to determine if geotextiles with larger, apparent pore sizes would allow greater uptake of phosphorus by bottom soil.

Materials and Methods

Samples of six, geofabrics were obtained from Fiberweb, Old Hickory, Tennessee (Table 1). A sample of soil was obtained from the B horizon of the soil profile exposed by a road cut on the E. W. Shell Fisheries Center at Auburn, Alabama. This area is in the Alabama Piedmont Plateau and the soil material was a Typic, Kandiudult (clayey, kalonitic, and thermic) (McNutt 1981).

A 5-cm layer of the soil was placed in the bottom of each of 21 aquaria (20-L). Three liners were made from each geofabric. The material was cut and sewed to make liners of the same dimensions as the insides of the aquaria. The liners were placed in aquaria – their bottoms on top of the soil – preventing direct contact of water with soil. Three aquaria with soil did not receive liners, and three more aquaria were not supplied with either soil or liners. Aquaria were filled with 18-L of tap water and monopotassium phosphorus (KH_2PO_4) applied to provide 0.75 mg/L of soluble orthophosphate. An air stone was placed 10 cm above the bottom in each aquarium, and air from an air pump was gently introduced to effect continuous water circulation. The aquaria were held in a dark room at 23 to 26^{o}C. A 50-mL water sample was collected from each aquarium after 1, 2, 3, 4, 6, 8, 10, 14, and 18 days. These samples were analyzed for soluble reactive phosphorus by the ascorbic acid method (Eaton et al. 2005).

Results and Discussion

The phosphorus concentration remained fairly constant in aquaria without soil, but it declined rapidly in aquaria with soil, reaching a concentration of about 0.1 mg/L after 18 days (Fig. 1). The phosphorus concentration in aquaria that contained the Typar 3801 geotextile liner – the one used to line ponds for the experiment described in earlier – declined to an average concentration of 0.397 mg/L after 18 days (Fig. 1). In aquaria lined with the other Typar geotextiles, phosphorus concentration declined much faster than in those lined with Typar 3801 geotextile. After 18 d, phosphorus concentrations averaged 0.157 to 0.202 mg/L – lower than for the Typar 3801 geotextile, but higher than the control (Table 2).

The Typar 3801 geotextile has the smallest apparent opening size and water flow rate (Table 1) – 0.090 mm and 328 L/min/m^2, respectively. Thus, the low permeability of this fabric likely was the reason that phosphorus concentration was greater in aquaria lined with it than in aquaria lined with more permeable fabrics. Nevertheless, in spite of the wide range in apparent opening sizes (0.200 to 0.840 mm) and water flow rates (2,050 to 9,635 L/min/m^2) in the other geotextile materials, there were no differences in phosphorus concentration after 18 d (Table 2).

The trapezoidal tear strength and puncture strength of the geotextiles decrease rapidly with increasing permeability (Table 1). Thus, for use in ponds, it would be desirable to select one of the materials with apparent opening sizes of 0.2 to 0.3 mm. These three geotextiles would be stronger than the two geotextiles with larger apparent opening sizes (Table 1). In the phosphorus uptake study, phosphorus loss from the water was as great for these three geotextiles as for the two with larger apparent opening sizes.

The results of this small effort suggest that it might be fruitful to repeat the pond lining study presented earlier using a geotextile of greater apparent opening size. Such a fabric should interfere less than a finer fabric with normal uptake of phosphorus by bottom soils. The coarse-weave geotextile might also have less tendency to float.

Literature Cited

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

Eaton, A. D., L. S. Clesceri, E. W. Rice, and A. E. Greenberg. 2005. Standard Methods for the Examination of Water and Wastewater, 21st edition. American Public Health Association, Washington, DC, USA.

McNutt, R. B. 1981. Soil Survey of Lee County, Alabama. USDA Soil Conservation Service, U.S. Government Printing Office, Washington, DC, USA.

Table 1. Characteristics of six, geotextile materials.

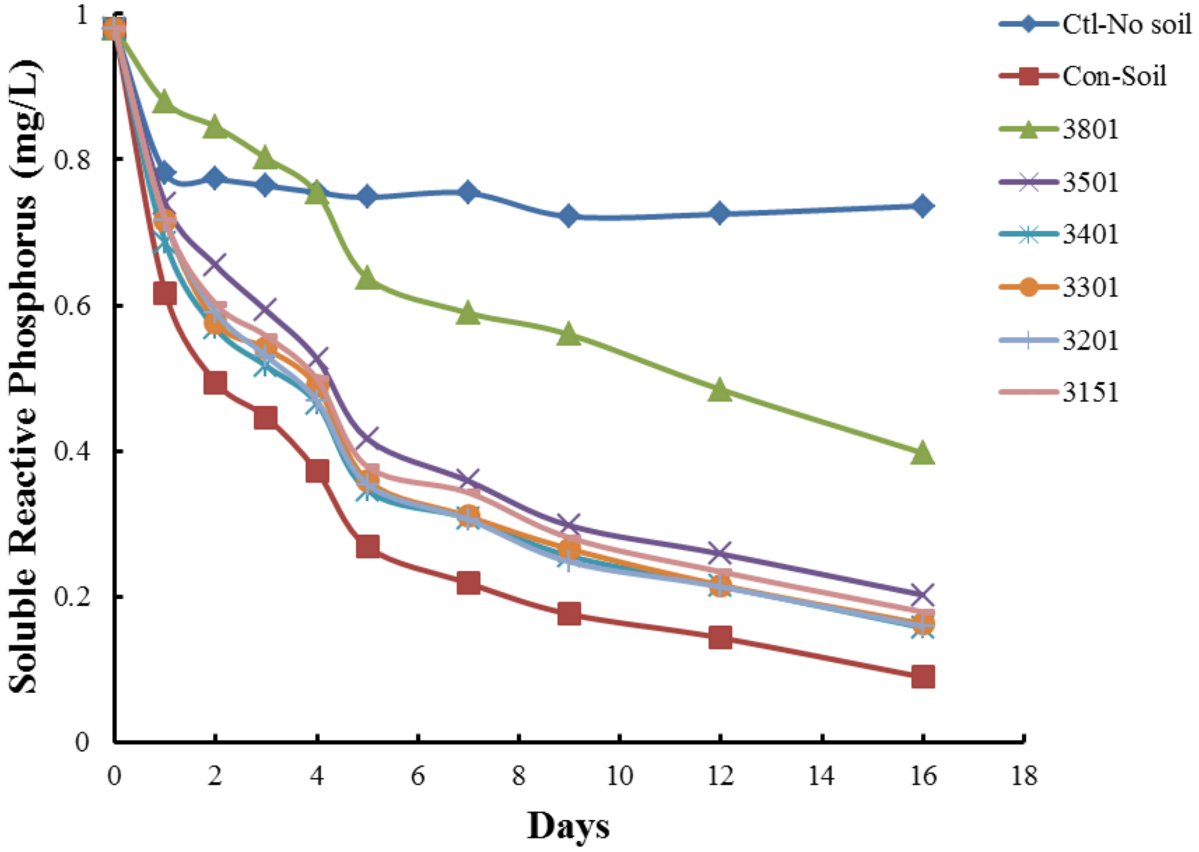
	Apparent opening size (mm)	Water flow rate (L/min/m^2)	Trapezoidal tear strength (N)	Puncture strength (N)
Typar 3801	0.090	328	425	415
Typar 3501	0.200	2,050	270	250
Typar 3401	0.212	2,460	270	180
Typar 3301	0.300	3,895	155	110
Typar 3201	0.590	7,790	110	80
Typar 3151	0.840	9,635	70	45

Table 2. Mean concentrations and standard deviations (SD) for soluble reactive phosphorus concentrations (mg/L) after 18 days in aquaria (n = 3) with soil separated from water by different types of geotextiles as compared to controls.

Treatment	Mean ± SD*
Control (no soil)	0.737 ± 0.020 a
Control (soil, no liner)	0.089 ± 0.020 b
Typar 3801 geotextile liner	0.397 ± 0.066 c
Typar 3501 geotextile liner	0.202 ± 0.019 c
Typar 3401 geotextile liner	0.157 ± 0.020 c
Typar 3301 geotextile liner	0.163 ± 0.013 c
Typar 3201 geotextile liner	0.159 ± 0.015 c
Typar 3151 geotextile liner	0.179 ± 0.013 c

*Means indicated by the same letter did not differ at P = 0.05 by Duncan's multiple range test.

Figure. 1. Mean concentration of soluble reactive phosphorus over a period of 18 days in aquaria (n = 3) with soil separated from water by differenct type of geotextiles as compared to controls.



V. Effects of Water Quality and Chemical Coagulants on Sedimentation of Suspended Soil Particles from Water

Abstract

Particles of three soils – each containing a different type of clay – settled at different rates. Nevertheless, particles tended to settle faster as concentration of total dissolved solids (TDS) increased in diluted seawater and in freshwater in which total hardness concentration increased as TDS concentration rose. Several chemical coagulants were tested for their ability to remove suspended soil particles. Potassium and sodium chloride were comparatively ineffective for turbidity removal. Calcium sulfate was more effective than magnesium sulfate. Aluminum chloride and sulfate tended to perform better than ferrous sulfate and ferric chloride. Although there were some differences in effectiveness of coagulants among the types of soils, calcium sulfate (gypsum), aluminum sulfate (alum), and aluminum chloride appear to have the greatest potential for use in ponds. Aluminum compounds neutralize alkalinity and cause a decrease in pH. Treatment rates (mg/L) for aluminum sulfate and aluminum chloride should not exceed the total alkalinity (mg/L as $CaCO_3$) to avoid low pH. Knowledge of conductivity, total alkalinity, total hardness, and type of clay mineral suspended in water can be useful in selecting a suitable coagulant.

Introduction

Turbidity from suspended soil particles resulting from external erosion on watersheds or internal erosion of earthwork by wave action, bioturbation, and aerator-generated water currents is a common problem in ponds used for sportfishing or commercial production of aquaculture species (Boyd 1995). Reduction in erosion will lessen the concentration of suspended particles to the water column of ponds, but fine soil particles – especially colloidal ones – may remain suspended indefinitely. The two most common recommendations for clearing turbidity from ponds are to apply organic matter such as barnyard manure and cut grass or to treat ponds with calcium sulfate. However, neither of these procedures has been highly successful, because application rates usually are not great enough (Boyd 1995). Aluminum sulfate – the coagulant frequently used to remove turbidity from drinking water – was shown to be highly effective in clearing pond water of turbidity (Boyd 1979; Boyd and Tucker 1998).

The mechanism responsible for mutual repulsion of colloidal clay particles and the process that causes these particles to coagulate are complex (Stumm and Morgan 1996). A highly-simplified explanation is that a negatively-charged layer around particles causes them to repel each other, but introduction of positively-charged cations in surrounding water will neutralize the negatively-charged layer allowing the particles to coagulate and the resulting floc will be massive enough to settle (Boyd 1995). It is well known that the greater the charge on cations, the better they function in removing colloidal clay particles from water (Sawyer et al. 2003) – the reason that aluminum sulfate is widely used for removing turbidity from potable water.

More information is needed on the effectiveness of various salts that could be used in aquaculture to remove turbidity from water. It would be particularly useful if a substitute for alum could be found. Because alum has a highly acidic reaction in water, the doses necessary to remove turbidity from some low-alkalinity waters can cause an excessive reduction in pH (Boyd and Tucker 1998). Therefore, a laboratory study was conducted to determine the effect of basic water quality characteristics on the sedimentation rate of soil particles, to evaluate several possible chemicals as coagulants, and to consider effects of coagulants on water quality.

Materials and Methods

Clayey soil from each of three locations for use in this study were obtained from the B-horizon of soil profiles. A sample of West Gulf Coastal Plain soil was taken from the catchment of Lake Rodemacher, the cooling water reservoir for the Cleco Corporation electricity generating plant near Boyce, Louisiana. This soil was selected because it was responsible for a persistent turbidity problem that developed in the reservoir following a logging operation and associated erosion on the catchment (C. E. Boyd, Auburn University, unpublished data).

A sample of soil from the Piedmont Plateau was collected from a road cut at the Alabama Agricultural Experiment Station near Auburn, Alabama. Ponds built in this physiographic area typically have persistent turbidity problems following erosion on watersheds (Boyd 1979).

hA sample of Blackland Prairie soil was excavated from a field beside an inland shrimp farm located near Forkland, Alabama. Ponds in this area may become turbid following erosion on watersheds, but turbidity usually subsides after a few days. Soils will be referred to as BP (Blackland Prairie), CP (West Gulf Coastal Plain), and PP (Piedmont Plateau) soils.

The pH of soil samples was measured in a 1:1 mixture of pulverized soil and distilled water by aid of a glass electrode (Thunjai et al. 2001). Particle-size analysis was done by a simplified, hydrometric method (Weber 1977; Boyd and Tucker 1992). Organic carbon was determined by the Walkley-Black, sulfuric acid-potassium dichromate oxidation procedure (Nelson and Sommers 1982). Cation exchange capacity was measured by the ammonium acetate method (Jackson 1958; Rhoades 1982).

Waters of several compositions were used in sedimentation trials. These included Auburn, Alabama, municipal tap water diluted 1:1 with distilled water. The diluted tap water contained 38 to 40 mg/L total alkalinity, 32 to 36 mg/L total hardness, and 70 to 80 mg/L total dissolved solids (TDS). Waters containing different concentrations of total alkalinity, total hardness, and TDS (Table 1) were prepared by adding different amounts of sodium bicarbonate ($NaHCO_3$), calcium sulfate ($CaSO_4 \cdot 2H_2O$), magnesium chloride ($MgCl_2 \cdot 6H_2O$), sodium chloride (NaCl), and potassium sulfate (K_2SO_4) to diluted tap water. Sodium bicarbonate provided alkalinity and calcium sulfate and magnesium chloride were sources of hardness. The other compounds were added to adjust TDS concentration. These solutions included alkalinity ≈ hardness, alkalinity > hardness, and alkalinity < hardness – the usual situations encountered in natural waters (Boyd 2000).

Waters of widely different salinities were obtained by diluting seawater (28.9 ppt salinity) obtained from the Gulf of Mexico at the Auburn University Shellfish Laboratory, Dauphin Island, Alabama with tap water. Aliquots containing 0.5, 1.0, 2.5, 10, 15, 20, and 25 ppt salinity – as measured with a refractometer – were prepared.

Sedimentation trials were conducted in soil test cylinders (35 cm tall × 6 cm diameter) placed on a laboratory bench at temperature of 23 to 26 C. Cylinders were filled with 990 mL of test water. Soil (20 g) to be used in a sedimentation trial was placed in 300 mL of tap water in a 500-mL beaker. The mixture was vigorously stirred with a wide-bladed spatula to separate and suspend soil particles, and the beaker was held on a magnetic stirrer to assure uniform dispersion of suspended particles. A 10-mL portion of turbid water from the beaker was removed (without stopping the stirrer) using a pipet with a wide-bore tip and transferred to each soil test cylinder. If chemical coagulants were used in a trial, appropriate quantities of each chemical were weighed, transferred to soil test cylinders, and the chemical thoroughly mixed with the water using a 60-cm long × 1.25-cm diameter dowel pin.

At the beginning of each trial, the content of each cylinder was stirred thoroughly with the dowel pin, and a 20-mL sample was removed from a depth of 10 cm using a pipet with a wide-bore tip. Turbidity of the sample was measured with a Orbeco-Hellige Model 965-10 A Direct Reading Turbidimeter (Orbeco Analytical Systems, Inc, New Jersey, USA), and the sample was returned to the cylinder. Additional samples were taken from 10-cm depth using a pipet with a wide-bore tip for turbidity measurement after 1, 2, 3, 4, 5, 8, 12, and 24 h, but the content of the test cylinder was not stirred before samples were removed. At the end of a trial, pH and specific conductance were measured using an Orion 3 Star pH Meter (Thermo Scientific, Singapore) and an Orion 3 Star Conductivity Meter (Thermo Scientific, Singapore), respectively.

The following concentrations of several chemical coagulants were tested initially: sodium chloride, 271 mg/L; potassium chloride (KCl), 346 mg/L; calcium chloride ($CaCl_2 \cdot 2H_2O$), 339 mg/L; calcium sulfate, 400 mg/L; magnesium sulfate ($MgSO_4 \cdot 7H_2O$), 559 mg/L; ferrous sulfate ($FeSO_4 \cdot 7H_2O$), 100 mg/L; ferric chloride ($FeCl_3 \cdot 6H_2O$), 64.9 mg/L; aluminum chloride ($AlCl_3 \cdot 6H_2O$), 57.9 mg/L; aluminum sulfate [$Al_2(SO_4)_3 \cdot 18H_2O$], 80 mg/L. These concentrations equated to 4.62 meq/L of sodium, potassium, calcium, and magnesium and to 0.72 meq/L of iron and aluminum. Based on results of preliminary trials, chemicals were selected for further investigation of the relationship between concentration and degree of turbidity removal.

Results and Discussion

Water Quality and Sedimentation Rate

The CP and PP soils were acidic, but the BP soil was basic (Table 2). All soils were low in organic matter concentration. The PP and BP soils each contained more than 50% clay, and CECs were 4.6 and 50.2 meq/100 g, respectively. The difference in CEC resulted from the type of clay mineral in soils. Soils in Lee County Alabama typically contain kaolinite (McNutt 1981), and those in the Blackland Prairie region of Alabama usually contain smectite (Dixon and Nash 1968). Typical CECs for pure kaolinite and smectite are 1 to 10 meq/100 g and 80 to 120 meq/100 g, respectively (Goldberg et al. 2000). The size of the soil sample from the West Gulf Coastal Plain in Louisiana proved inadequate to allow analyses of particle-size distribution and CEC, and it was not possible to obtain an additional quantity of this soil. However, the sample had a very high clay content as obvious from feel and from the amount of the material that remained suspended in water when a small amount mixed with water was allowed to stand overnight. Dr. Joey Shaw of the Department of Agronomy and Soils at Auburn University thought that the clay in the CP soil likely consisted mainly of vermiculite. This clay mineral has a very high CEC – typically 120 to 150 meq/100 g (Goldberg et al. 2000). Thus, the CP soil likely had a CEC value greater than that of the BP soil.

Soils each resulted in a different turbidity when introduced into diluted tap water in soil test cylinders (Fig. 1). In the trial depicted in Fig. 1, initial turbidity ranged from 156 nephelometer turbidity units (NTU) for the CP soil to 405 NTU for the BP soil. In addition to variation in initial turbidity among test cylinders with different soils, there also were variations in initial turbidity within test cylinders receiving the same soil. The average initial turbidities were as follows: BP soil – mean = 286 ± 100 NTU, range = 182 to 540 NTU; CP soil – mean = 177± 43 NTU, range = 109 to 252 NTU; PP soil – mean = 381 ± 86 NTU, range = 216 to 547 NTU. This variation was between trials; all cylinders for a given trial were filled from the same soil-water mixture and had equal turbidities. In order to facilitate evaluation and presentation of data, the percentage of initial turbidity remaining at each sampling time was estimated as follows:

$$\text{Turbidity remaining at a given time (\%)} = (100)\,\frac{\text{Turbidity at that time (NTU)}}{\text{Initial turbidity (NTU)}}$$

It also can be seen from Fig. 1 that sedimentation of particles of the three soils in diluted tap water occurred at different rates. Turbidity quickly declined by about 50% with the BP soil in about 8 h, and an even greater decline was observed after 8 h with the PP soil. However, turbidity declined little in diluted tap water containing the CP soil. After 8 h, sedimentation rate became quite slow for all soils. Soils differed in particle-size distribution (Table 2), and in sedimentation trials (Fig. 1), most particles that settled quickly were likely sand or silt size. The rather stable turbidity during trials in cylinders containing the CP soil probably resulted from the soil being mostly clay. Residual turbidity after 24 h was much greater for the CP and BP soils than for the PP soil. This probably is the result of clay fractions of these two soils having a high CEC and a great degree of mutual repulsion among particles.

Increasing salinity in test water had a marked influence on sedimentation of particles – especially for the CP soil (Fig. 2). Turbidity remaining after 4 h decreased from about 80% at 0.075 ppt salinity to about 35% at 0.5 ppt salinity and about 15% at 2.5 ppt salinity for the CP soil. Although the trial included salinities up to 25 ppt, data presentation was limited to 10 ppt, because there was no difference in sedimentation rate at greater salinities. Because sedimentation continued slowly after 8 h, it was decided to present only 24-h data in describing most trials.

Freshwater is considered to contain no more than 1,000 mg/L TDS (Boyd 2000), and salinity and TDS usually have almost equal concentrations. Thus, increasing the degree of mineralization of freshwater should favor sedimentation. However, the salinity trial (Fig. 2) was conducted in diluted seawater. Such water is high in concentration of all major ions (Brown et al. 1989), and it has a much greater total hardness than total alkalinity – the undiluted sample used in this study contained 6,495 mg/L total hardness but only 121.3 mg/L total alkalinity.

For the CP soil in water of similar alkalinity and hardness (TA = TH), the percentage of turbidity remaining after 12 h (Fig. 3) was greater for water with low TDS concentration (75 mg/L) than at greater TDS (369 and 663 mg/L). Turbidity remaining tended to be greater in the water with moderate TDS concentration for several hours; but, after 24 h, there was much less difference between the two waters. Moreover, at this time, loss of turbidity was much greater for both 369 and 663 mg/L TDS than for 75 mg/L TDS. When trials with the CP soil were conducted in water of low total alkalinity but high total hardness (TA < TH), but at the same TDS concentrations used for the trial with (TA = TH), turbidity removal in the two higher salinity water was much greater than in diluted tap water (75 mg/L TDS). There was, however, no appreciable difference in turbidity removal related to time between sedimentation trials conducted in waters of 369 and 663 mg/L TDS. When total hardness concentration was 38 mg/L (75 mg/L TDS) and alkalinity increased to 138 mg/L (369 mg/L TDS) and 238 mg/L (663 mg/L TDS), there was no apparent increase in turbidity decline in the more highly-mineralized waters (Fig. 3).

A similar pattern with respect to relationships of alkalinity, hardness, and TDS concentrations to sedimentation rate was observed for the BP soils, but particles of the BP soil settled faster than those of the CP soil (Fig. 3). Turbidity loss was fairly great for the BP soil even in diluted tap water. The PP soil particles settled fairly well in all three types of water (Fig. 3). It should be noted that salinity concentrations in waters used in trials depicted in Fig. 3 were the same as TDS concentration. In natural waters, salinity also is usually about the same concentration as TDS (Boyd 2000).

Results of sedimentation trials depicted in Figs. 2 and 3 reveal interesting information about sedimentation of soil particles. They settle very quickly in highly-diluted seawater – even at 0.5 ppt salinity; particles of all three soils had almost completely settled within 24 h. This does not necessarily imply, however, that as total dissolved solids concentration increases, soil particles will settle more quickly from freshwater. Freshwater can vary considerably in composition; waters of the same salinity may differ in concentrations of ions responsible for alkalinity and hardness: (1) a large part of TDS concentration in many waters results from the anion bicarbonate and the divalent cations calcium and magnesium – sources of alkalinity and hardness, respectively; (2) a large part of the TDS in a second type of water is contributed by bicarbonate and monovalent cations sodium and potassium (this water has distinctly greater alkalinity than hardness); (3) in a third type of water, much of the TDS is from calcium and magnesium ions that are associated with the anions chloride and sulfate (hardness is considerably greater than alkalinity).

Sedimentation rate results for the CP soil revealed that water must increase in calcium and magnesium concentration as TDS concentration increases if a positive relationship between TDS concentration and settling rate is to occur. The results for the BP soil tend to show the same trend as the CP soil, but the PP soil particles settled rather quickly in all three types of water. Thus, all soil particles cannot be expected to settle at the same rate at a particular TDS concentration or in a specific type of freshwater.

Coagulants for Turbidity Removal

Results of preliminary trials of chemical coagulants (Fig. 4) revealed that calcium chloride, calcium sulfate, magnesium sulfate, ferrous sulfate, aluminum sulfate, and aluminum chloride provided the best overall removal of soil particles. Although sodium chloride, potassium chloride, and ferric chloride were removed from further consideration because of lower, overall efficiency in particle removal, in some cases these compounds actually did as well or better than one or more of the compounds selected for further investigation – especially for the PP soil.

Calcium sulfate – often called gypsum – was quite effective in precipitating suspended particles of the CP and BP soils – 40 mg/L of this compound removed over 90% of turbidity (Fig. 5). It was less effective for removing turbidity caused by the PP soil; a concentration of 120 mg/L removed only about 50% of turbidity. Gypsum has been widely recommended for removing turbidity from farm ponds (Boyd and Tucker 1998). It is a safe compound to handle, and it does not cause a change in pH (Fig. 6). The increase in specific conductance resulting from gypsum (Fig. 7) is from calcium and sulfate ions. These ions will not be removed from water bodies quickly by chemical reactions, and calcium will remain to provide protection against turbidity until flushed from ponds in overflow after rainfall events.

Calcium chloride was quite similar to calcium sulfate in removing soil particles (Fig. 5) – an observation that is not surprising as results in Fig. 3 show that divalent cations rather than associated anions are responsible for accelerating sedimentation of soil particles. However, calcium chloride is less commonly available and more expensive than calcium sulfate – especially agricultural gypsum.

Magnesium sulfate was of similar effectiveness as calcium sulfate for removing BP and PP soil particles. However, it is surprising and not clear why magnesium sulfate was less effective than calcium sulfate in removing turbidity when the source of particles was the CP soil (Fig. 5). Magnesium sulfate and calcium sulfate had similar effects on pH and conductivity (Figs. 6 and 7).

Ferrous sulfate caused a marked reduction in turbidity at 20 mg/l for all soils, but at higher concentrations turbidity removal was less (Fig. 5). There was a decrease in pH – although not particularly large in comparison to that observed for aluminum compounds – with increasing concentrations of ferrous sulfate (Fig. 6). This probably was the result of hydrolysis of ferrous iron (Boyd 2000):

$$Fe^{2+} + H_2O = Fe(OH)^{+} + H^{+}.$$

Sawyer et al. (2003) warned that turbidity removal by aluminum sulfate commonly used for clearing turbidity from water for municipal water supply will be ineffective in low alkalinity waters, and they recommended liming before application of aluminum sulfate in such waters. The increase in conductivity per concentration unit was greater for ferrous sulfate than for calcium and magnesium compounds (Fig. 7). This observation also is not surprising, because of the decline in pH – increase in hydrogen ion. The equivalent conductance of hydrogen ion is 349.8 mho·cm^2/eq while those of calcium, magnesium, and other cations are less than 75 mho·cm^2/eq (Laxen 1977). However, hydrogen ion is not very effective as a coagulant for colloidal soil particles.

Aluminum sulfate and aluminum chloride were highly effective in removing turbidity when used at 10 mg/L. There was a tendency of less turbidity removal when these compounds were used at greater concentrations. This resulted because both compounds caused a marked decline in pH when used at concentrations above 10 mg/L (Fig. 6). The source of acidity from aluminum sulfate and aluminum chloride is hydrolysis of aluminum ion (Boyd 2000) as follows:

$$Al^{3+} + H_2O = Al(OH)_3 + 3H^+$$

Hydrogen ion neutralizes alkalinity causing a decline in pH:

$$HCO_3^- + H^+ = H_2O + CO_2.$$

Alkalinity concentration is expressed in milligrams per liter of equivalent calcium carbonate – at least in the United States. The following stoichiometric relationship exists for alum:

$$Al_2(SO_4)_3{\cdot}18H_2O = 2Al^{3+} = 6H^+ = 3CaCO_3.$$

Thus, 1 mg/L of alum (m.w. = 666.42) would theoretically neutralize 0.45 mg/l $CaCO_3$ (m.w. = 100) or total alkalinity. Using this approach, the neutralization of total alkalinity ($CaCO_3$) by aluminum chloride (m.w. = 241.43) and ferrous chloride (m.w. = 270.32) would be 0.62 mg/L and 0.55 mg/L, respectively. Thus, an alkalinity reduction of 0.45 to 0.62 mg/L per each 1 mg/L of the coagulating agents would occur. Excessively low pH could be avoided by never applying a concentration of one of these three coagulating agents that exceeds the total alkalinity. Liming before using these three coagulating agents also could avoid a low pH.

Further testing of lower concentrations of aluminum sulfate revealed that concentrations of 5 mg/L or less of this chemical would not reduce turbidity below 60% of the initial concentration after 24 h when the sources of turbidity were PP or BP soils (Table 3). However, 2 mg/L of aluminum sulfate removed nearly 95% of turbidity when CP soil was the source of turbidity.

Aluminum chloride at 5 mg/L reduced turbidity to 50% of initial concentration for the PP soil in 24 h (Table 3). However, 5 mg/L of this chemical reduced turbidity by BP soil to 14.7% of the initial value, and 4 mg/L reduced turbidity caused by CP soil to 1.2% of the starting concentration.

Conclusions

This study suggests that particles of some soils – possibly those with high cation exchange capacities – may be expected to cause more persistent turbidity than others. Nevertheless, the findings clearly reveal that the tendency of fine particles of the three soils to remain suspended in marine or estuarine water decreases with greater TDS concentration (salinity). The same also may be said for freshwater provided total hardness concentration increases as TDS concentration rises. Freshwaters most likely to develop persistent turbidity following input of suspended clay particles are those with low total hardness concentration.

The findings also revealed that calcium sulfate is effective at 20 to 40 mg/L in removing suspended clay particles of soil with a high CEC – soils CP and BP, but it was not effective for removing particles of the low CEC, PP soil. Aluminum sulfate and aluminum chloride concentrations 5 mg/L or less lead to effective removal of suspended particles of CP soil, but about 10 mg/L was necessary for similar removal of particles of the other two soils.

Considering the variability in turbidity resulting from different clay minerals and water chemistries, and the differences in response to coagulating suspended clay particles by the chemical coagulants, water should be analyzed for conductivity, total hardness, and total alkalinity before deciding upon a coagulant. The type of clay causing the turbidity also could help choose the coagulant. Finally, it would be desirable to conduct a trial with the selected coagulant to determine the optimum treatment concentration.

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Table 1. Total alkalinity (TA), total hardness (TH), and total dissolved solids (TDS) concentrations and pH in freshwater samples used in sedimentation rate trials.

Alkalinity to hardness	TDS level	Concentration (mg/L)			pH
		TA	TH	TDS	
TA ≈ TH	Low	38	36	75	7.25
	Medium	138	136	369	8.05
	High	238	236	663	8.40
TA > TH	Medium	138	36	369	8.01
	High	238	36	663	8.45
TA < TH	Medium	38	136	369	7.09
	High	38	236	663	7.27

Table 2. Properties of soils used as sources of suspended solids in sedimentation trials.

Property	Soil[a]		
	PP	BP	CP
pH	5.00	7.44	4.16
Organic carbon (%)	0.63	1.92	0.20
Sand (%)	23.3	5.0	--
Silt (%)	24.3	26.0	--
Clay (%)	52.4	69.0	--
Cation exchange capacity (meq/100 g)	4.6	50.2	--

[a] PP = Piedmont Plateau; BP = Blackland Prairie; CP = West Gulf Coastal Plain.

Table 3. Effectiveness of low concentrations of aluminum sulfate and aluminum chloride for turbidity removal.

Concentration	Soil used to create turbidity		
(mg/L)	PP	BP	CP
		Aluminum sulfate	
0	100.0	100.0	100.0
1	100.0	90.9	14.9
2	77.8	81.8	5.4
3	77.8	81.8	3.6
4	66.7	81.8	3.0
5	66.7	63.6	3.0
		Aluminum chloride	
0	100.0	100.0	100.0
1	61.1	73.5	23.6
2	61.1	52.9	5.9
3	61.1	47.0	2.4
4	50.0	26.4	1.2
5	50.0	14.7	1.2

[a] PP = Piedmont Plateau; BP = Blackland Prairie; CP = West Gulf Coastal Plain.

Figure 1. Changes in turbidity over time in cylinders containing water and suspended particles of three, different soils: CP soil, West Gulf Coastal Plain; BP Soil, Blackland Prarie; PP soil, Piedmont Plateau.

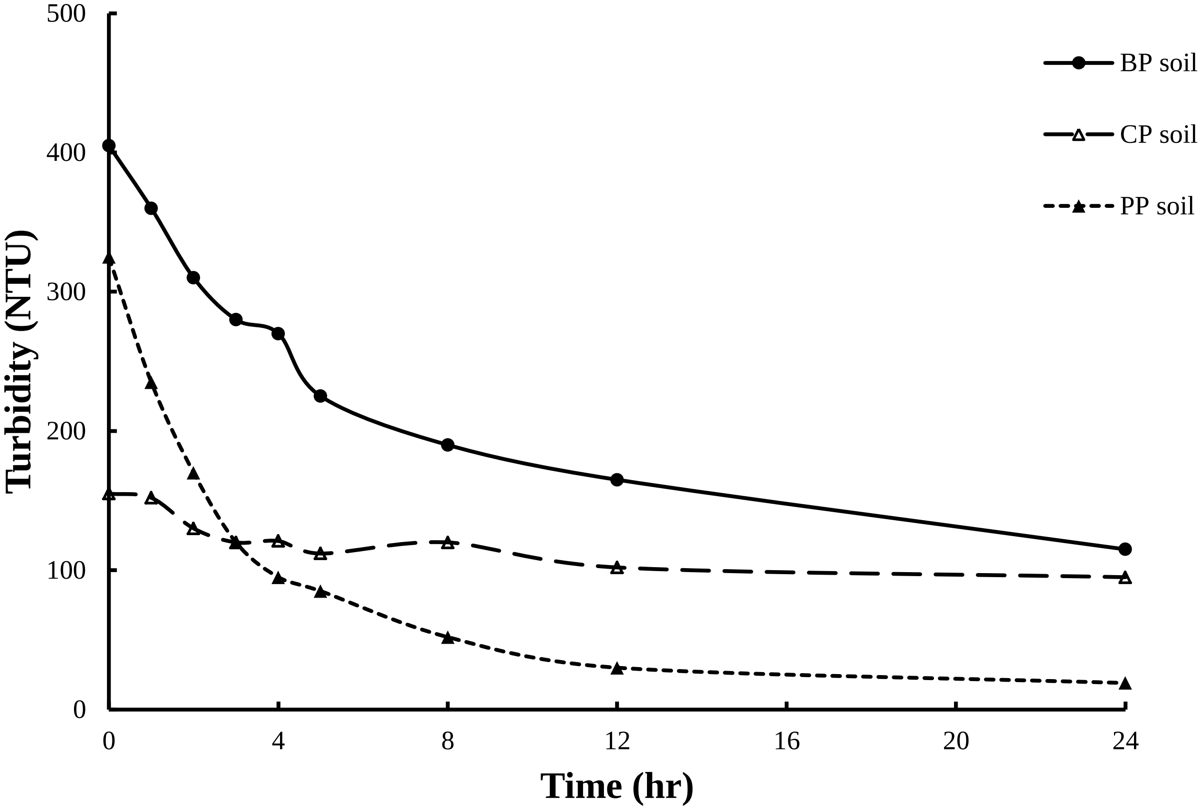
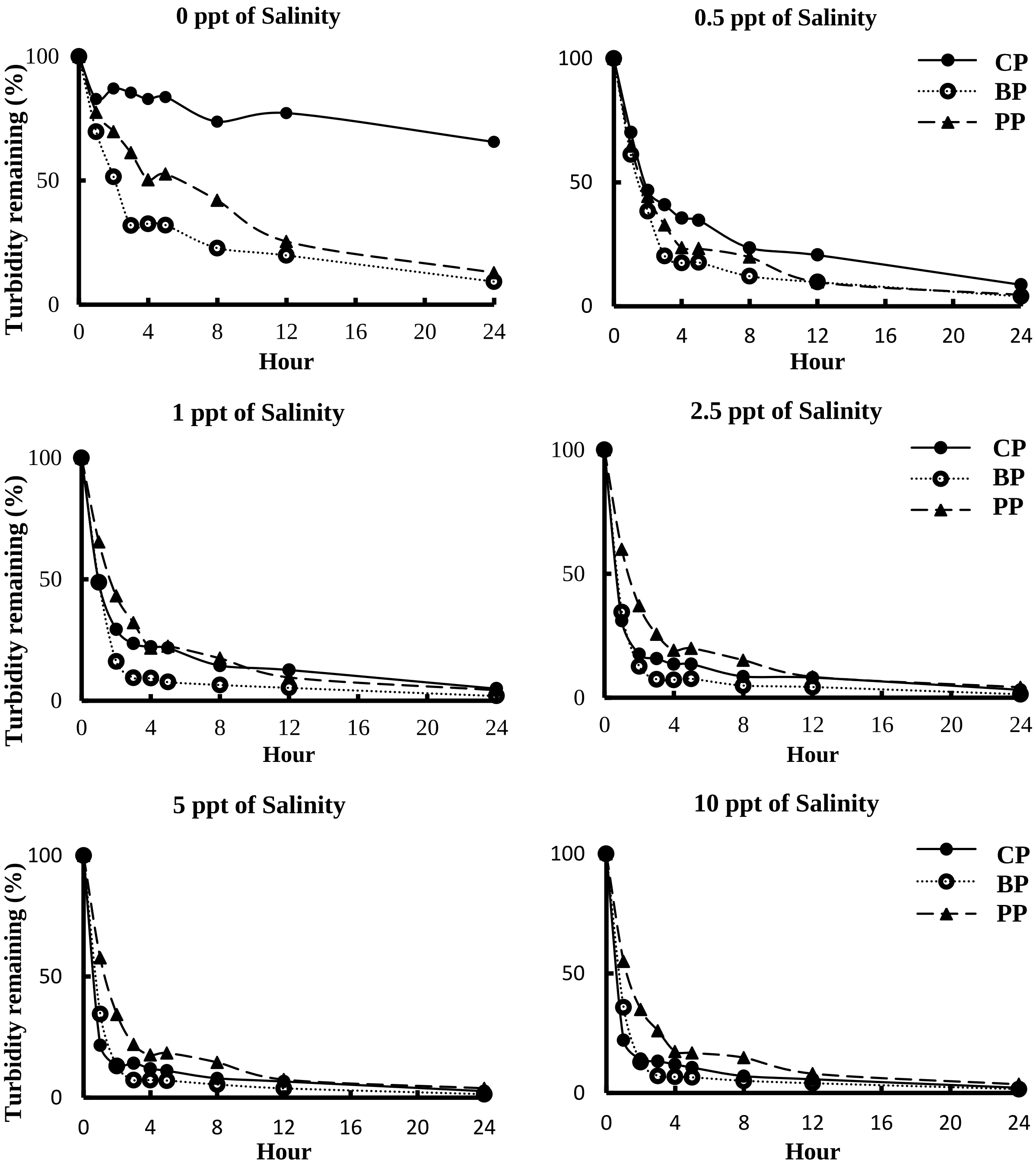


Figure 2. Changes in turbidity in cylinders containing waters of different salinity (diluted seawater) and suspended particles of three, different soils: CP soil, West Gulf Coastal Plain; BP soil, Blackland Prarie; PP soil, Piedmont Plateau.



0 ppt of Salinity

0.5 ppt of Salinity

1 ppt of Salinity

2.5 ppt of Salinity

5 ppt of Salinity

10 ppt of Salinity

Figure 3. Change in turbidity in cylinders containing freshwater of three compositions and suspended particles of three, different soils: CP soil, West Gulf Coastal Plain; BP soil, Blackland Prarie; PP soil, Piedmont Plateau.

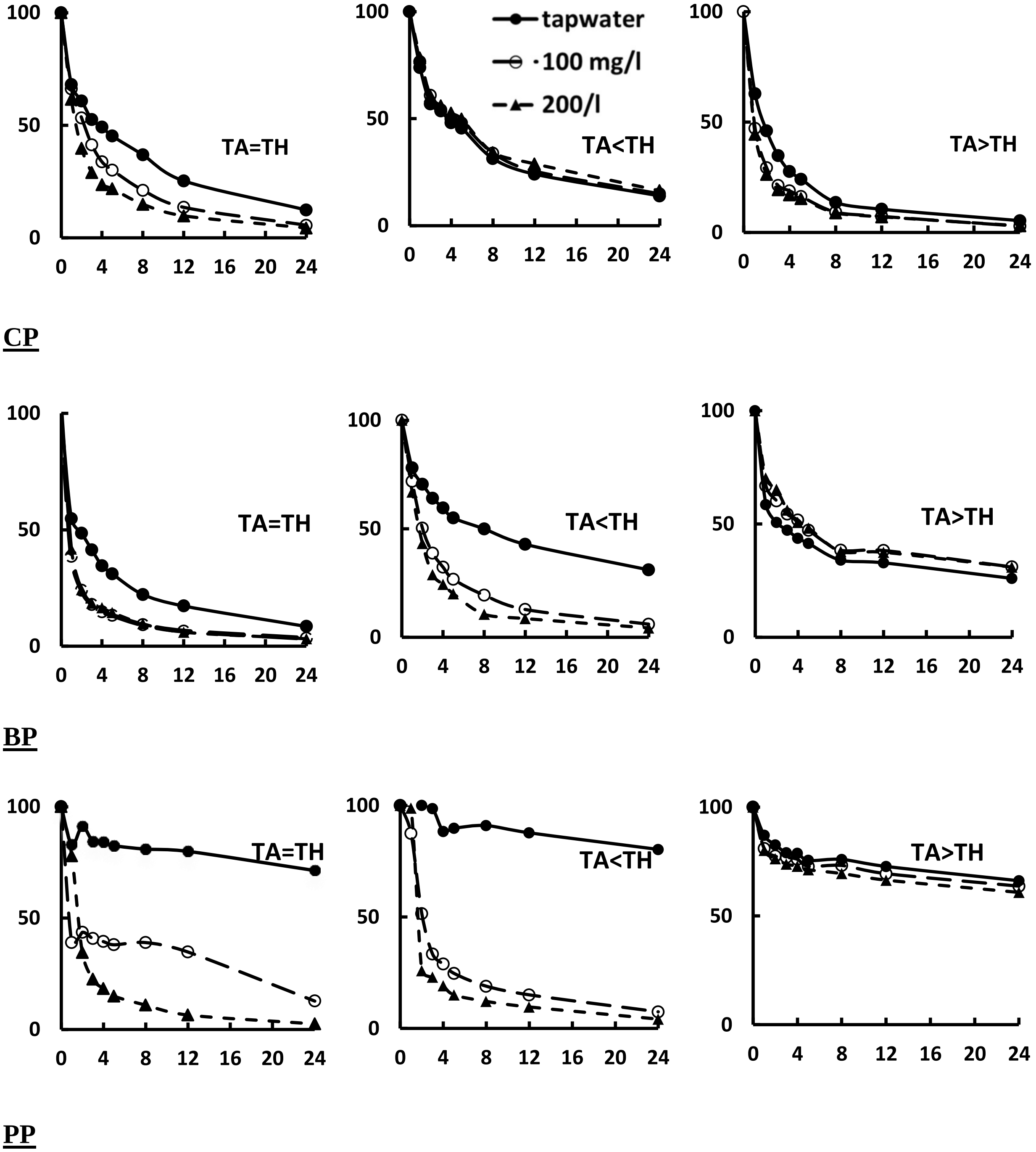


Figure 4. Results of preliminary tests of nine, potential, chemical coagulants for moving turbidity from water. Each test was conducted in water containing particles of three, different soils: CP soil, West Gulf Coastal Plain; BP soil, Blackland Prarie; PP soil, Piedmont Plateau.

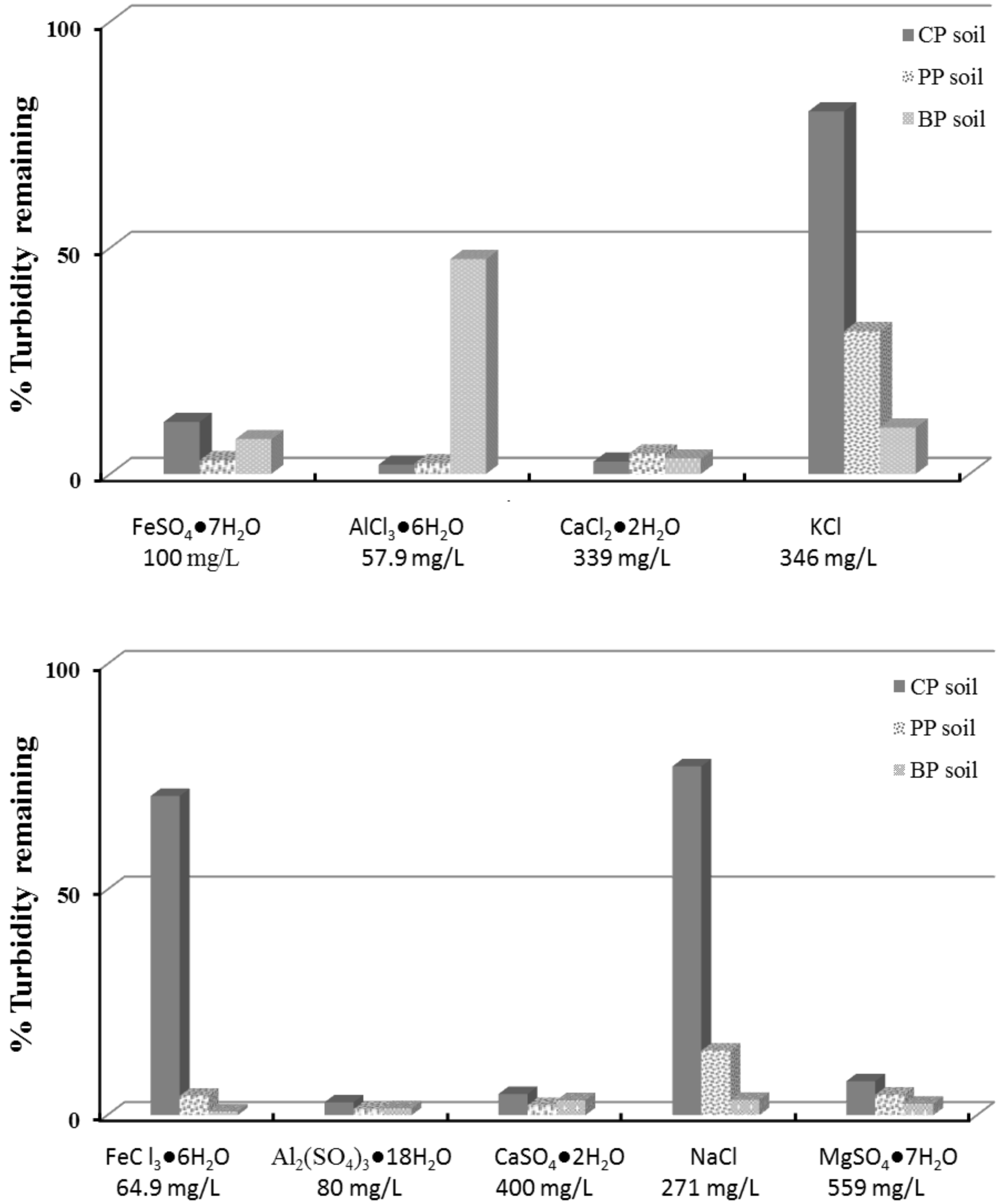


Figure 5. Effectiveness of different coagulants in removing turbidity from water. Each test was conducted in water containing particles of three, different soils: CP soil, West Gulf Coastal Plain; BP soil, Blackland Prarie; PP soil, Piedmont Plateau.

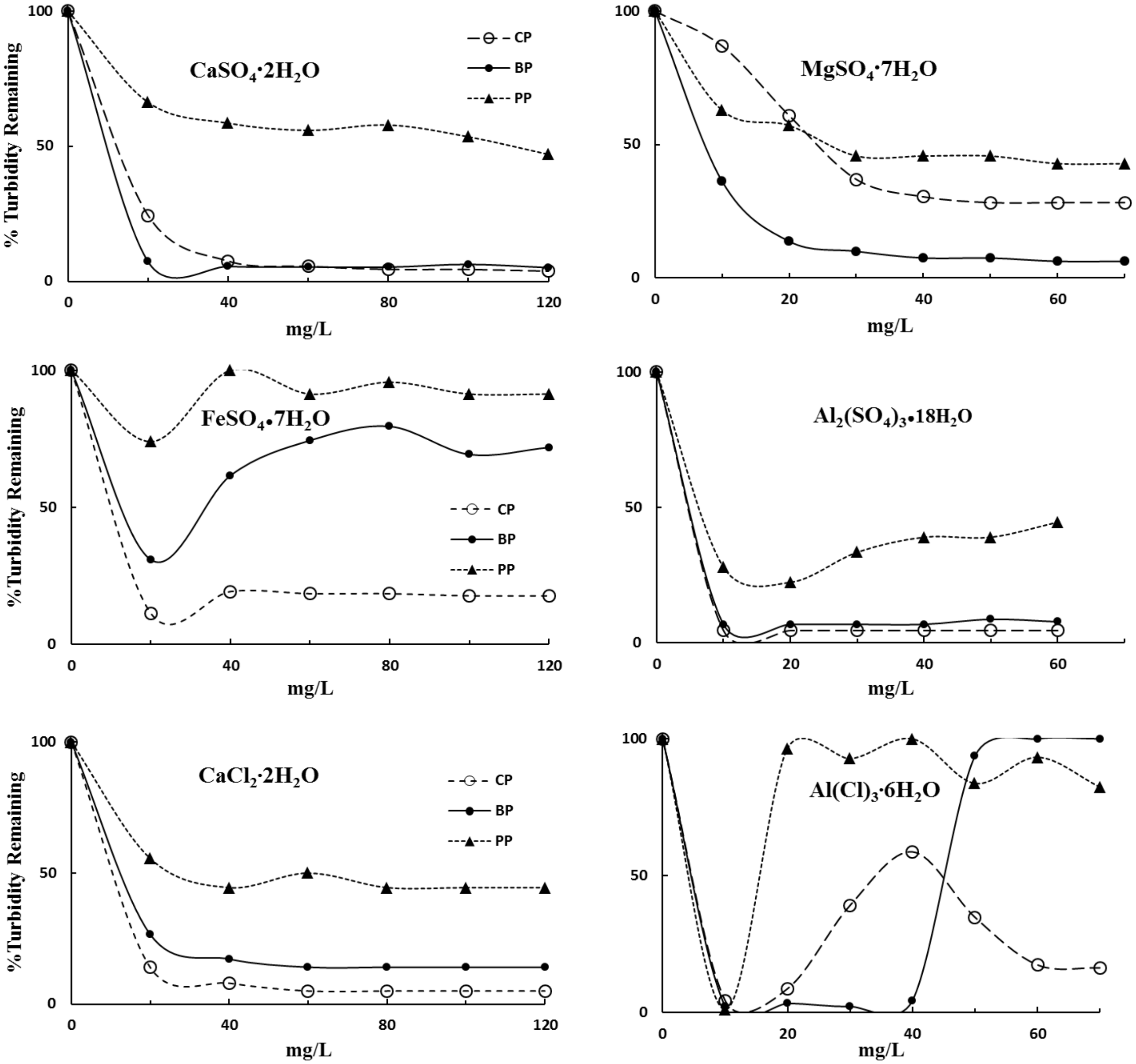
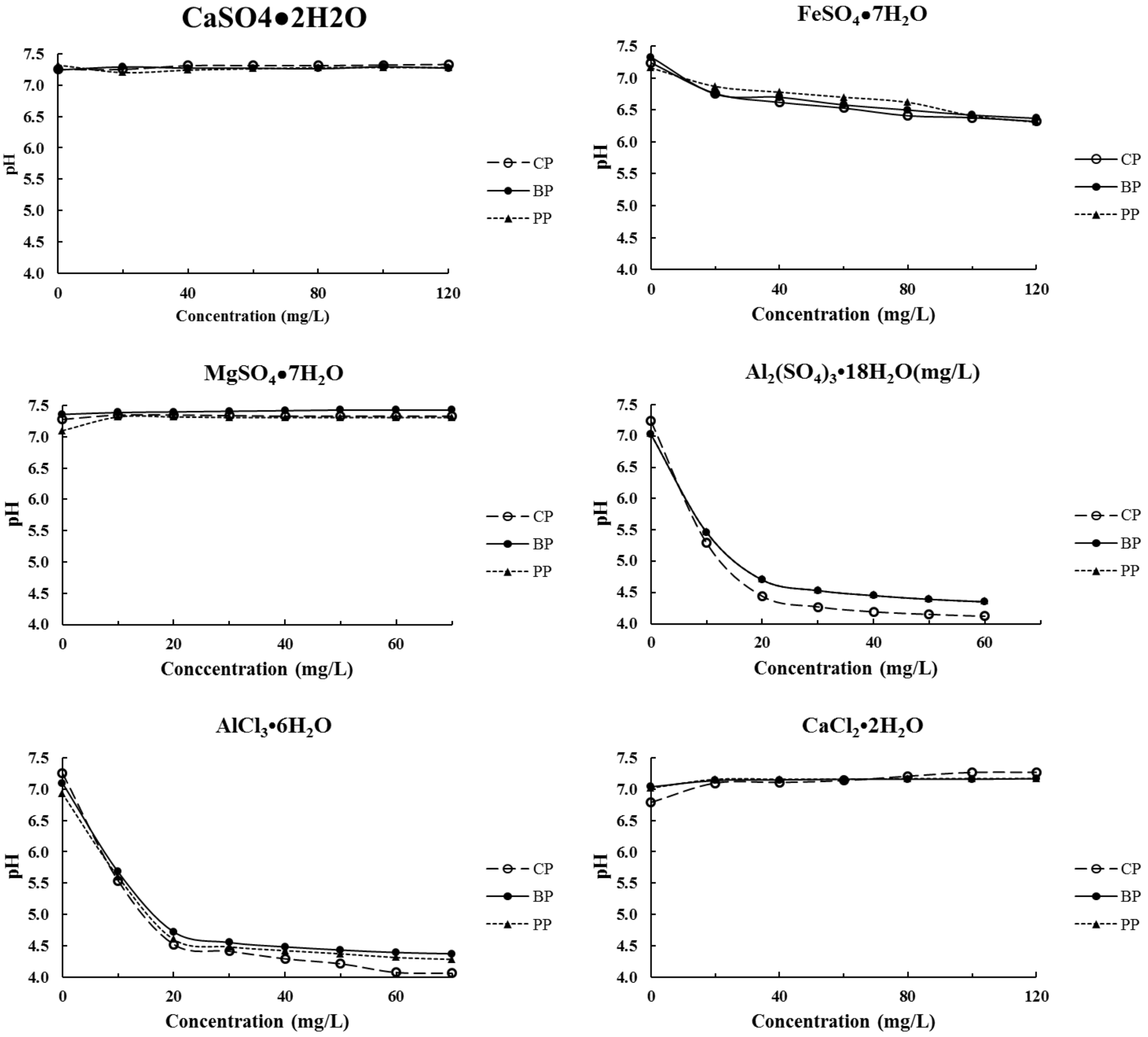


Figure 6. Effectiveness of different concentration of six, chemical, coagulants on pH. Each test was conducted in water containing particles of three, different soils: CP soil, West Gulf Coastal Plain; BP soil, Blackland Prarie; PP soil, Piedmont Plateau.


CaSO4●2H2O

$FeSO_4 \bullet 7H_2O$

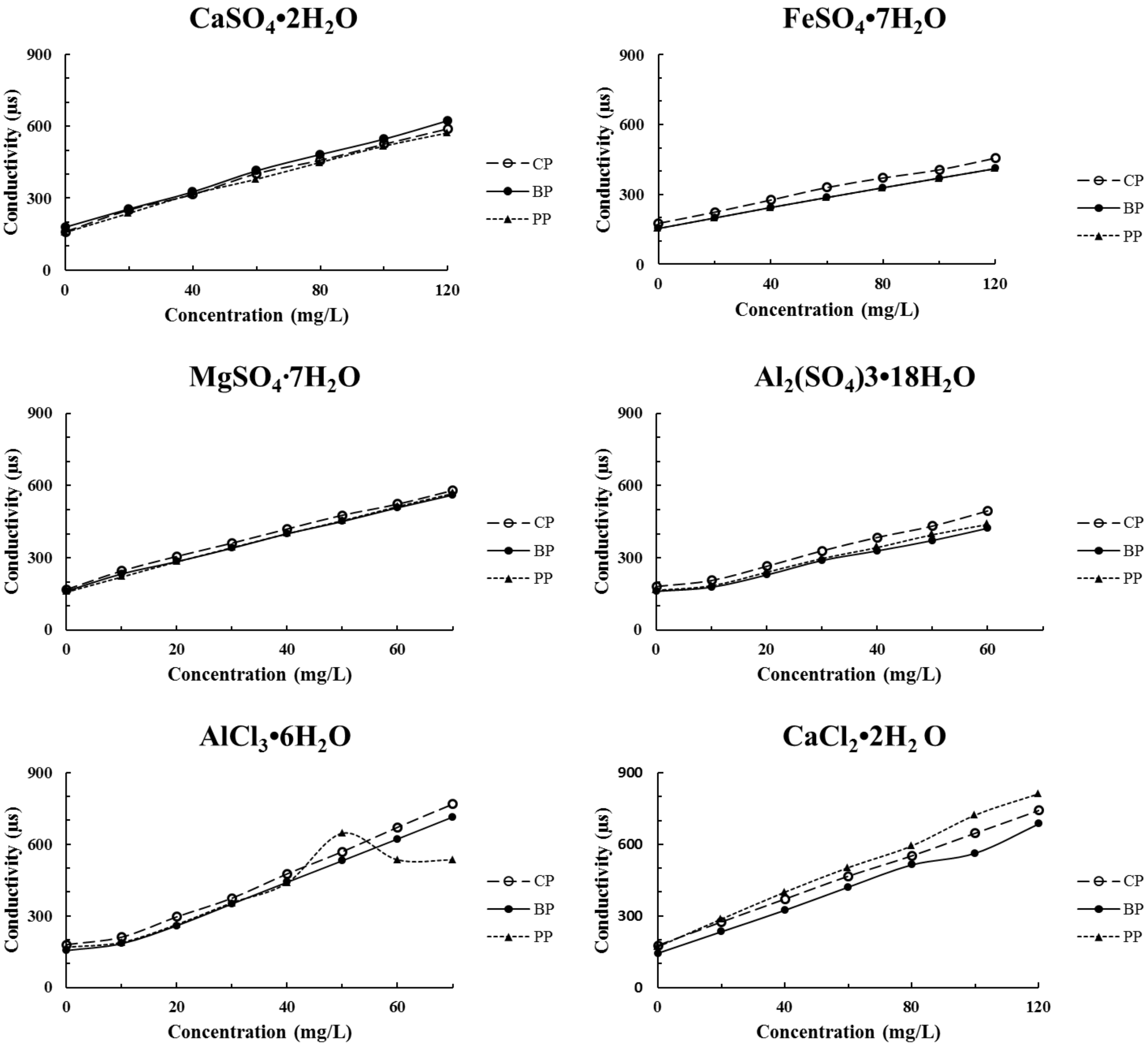
$MgSO_4 \bullet 7H_2O$

$Al_2(SO_4)_3 \bullet 18H_2O$(mg/L)

$AlCl_3 \bullet 6H_2O$

$CaCl_2 \bullet 2H_2O$

Figure 7. Effectiveness of different concentration of six, chemical, coagulants on conductivity. Each test was conducted in water containing particles of three, different soils: CP soil, West Gulf Coastal Plain; BP soil, Blackland Prarie; PP soil, Piedmont Plateau.



VI. Conclusions

Erosion control in production ponds is important to maintain the integrity of the earthwork and avoid excessive sediment accumulation in the bottom of ponds. Control of erosion on watersheds and embankments can decrease the input of solids to ponds, reduce turbidity, and reduce concentrations of suspended solids in effluents (Boyd 2003). The three experiments in this study were designed to identify solutions to erosion and associated problems in aquaculture ponds.

Evaluation of two, porous, geofabric liners for erosion control in small aquaculture ponds

Three ponds each were lined with a permeable geotextile with 0.090-mm opening sizes, a permeable geotextile with 0.355-mm opening sizes, or served as unlined, controls. During the 2-yr study, geotextile liners did not tear or decay. This prevented erosion of the bottom of the ponds stocked with a high density of channel catfish and aerated nightly. The liners tended to float up in the water column; the liner with smaller opening sizes floated in all three ponds, while the other liner floated in only one pond. Fish production, survival, and feed conversion ratio did not differ ($P > 0.05$) among the control and lined ponds or between liner types.

Water quality variables often differed between lined ponds and control ponds. The greatest difference was higher phytoplankton abundance in the lined ponds—especially in ponds lined with the less permeable geotextile – than in the control. This difference was attributed to differences in phosphorus uptake by bottom soils related to the liners and their permeability. However, in spite of more phytoplankton growth in lined ponds, the control ponds tended to have higher turbidity because of erosion of bottoms by aeration.

Phosphorus removal by soil separated from water by permeable, geotextiles

Six kinds of geotextile liners with apparent opening sizes ranging from 0.090 mm to 0.84 mm were installed in separate soil from water in aquaria. Water was treated with 0.75 mg/L of phosphorus from monopotassium phosphate. Phosphorus concentration did not decline in aquaria without soil, and all liners reduced the amount of phosphorus removed by the soil. Phosphorus removal from soil did not differ among liners with opening size < 0.200, but these liners interfered less with soil phosphorus uptake than did the liner with 0.090-mm opening size. Final phosphorus concentrations were 0.089 mg/L in the unlined aquaria with soil, 0.397 mg/L for the liner with 0.090-mm openings, and 0.157 to 0.202 mg/L for the liners with larger openings.

Effects of water quality and chemical coagulants on sedimentation of suspended soil particles from water

Particles of three soils – each containing a different type of clay – settled at different rates. Nevertheless, particles tended to settle faster as concentration of total dissolved solids

(TDS) increased in diluted seawater and in freshwater in which total hardness concentration increased as TDS concentration rose. Several chemical coagulants were tested for their ability to remove suspended soil particles. Potassium and sodium chloride were comparatively ineffective for turbidity removal. Calcium sulfate was more effective than magnesium sulfate. Aluminum chloride and sulfate tended to perform better than ferrous sulfate and ferric chloride. Although there were some differences in effectiveness of coagulants among the types of soils, calcium sulfate (gypsum), aluminum sulfate (alum), and aluminum chloride appear to have the greatest potential for use in ponds. Aluminum compounds neutralize alkalinity and cause a decrease in pH. Treatment rates (mg/L) for aluminum sulfate and aluminum chloride should not exceed the total alkalinity (mg/L as CaCO3) to avoid low pH. Knowledge of conductivity, total alkalinity, total hardness, and type of clay mineral suspended in water can be useful in selecting a suitable coagulant.

Future studies

For the future, studies of geotextile should investigate the exchange rate of nutrients between the soil and water with more porous geotextiles, because the lined-pond study involved geotextiles with relatively fine mesh size, but larger size may have different effects. Moreover, the durability of the fabric should be carefully studied, and ways of preventing the fabric from floating most be devised.

The economics of the use of geotextiles also must be considered. In research ponds, economics may not be the major concern, provided the techniques stabilize earthwork. Erosion control in ponds could save on maintenance and also provide a more controlled environment in which to investigate aquaculture issues. However, in commercial production the geofabric liners would have to be cost effective.

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