THE ROLE OF TRANSPORTED SEDIMENT IN THE CYCLING OF PHOSPHATE IN GEORGIA PIEDMONT IMPOUNDMENTS

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Abstract. The high iron content in the soils and resident parent material of the Georgia Piedmont results in significant transport of iron in runoff to receiving waterbodies. Phosphorus cycling in lakes can be significantly affected by the iron cycle. The work presented here describes experiments to test sorption and desorption of phosphate from Bt horizon soil to help illuminate the role of transported sediment in the cycling of phosphorus in Georgia Piedmont impoundments. We conducted sorption capacity experiments on Bt horizon soil, Lake Lanier sediments, and catalyst grade FeOOH. We also describe experiments to test release of phosphate from Bt horizon soil under elevated pH conditions. Sorption capacity of Bt soil and Lake Lanier sediments is greater than that of FeOOH. Phosphate desorption from Bt horizon soil at pH values of 8-10 fits a linear model with greater desorption at higher pH values. The results presented here further support the alternative phosphorus cycling pathway proposed in Parker and Rasmussen (2001).

INTRODUCTION

Bt horizon soil in the Georgia Piedmont is high in oxidized metals, especially iron and manganese (USDA 1968). Oxidized metals are positively charged and thus can form chemical complexes with clay, organic colloids, and biologically important anions. Oxidized metals transported in runoff can bind important anions (e.g., phosphate) during transport and in the receiving waterbodies, reducing their biological availability. Oxidized metals, particularly oxidized iron can remain suspended in surface waters as colloidal particles for prolonged periods of time (Hutchinson 1957).

Once in a receiving waterbody, iron can be transformed via reduction, oxidation, and precipitation or biological consumption. The high iron content in the soils and resident parent material of the Georgia Piedmont results in significant transport of iron in runoff to receiving waterbodies as indicated by data from Lake Lanier tributaries (Figure 1). Soil particles form the Bt horizon are thought to be those most commonly transported in runoff. Evidence from studies of agricultural runoff indicates that the mechanical working of transported soil particles can decrease the size and increase the availability of reactive surfaces of these particles (McDowell et al. 2002), and thus may enhance their sorptive capacity. Oxidized metals may lose their positive charge and thus any sorbed or complexed anions at elevated pH. Release of anions from oxidized iron may be important in waters where algal photosynthesis locally increases the surface water pH.

Iron is abundant in the Bt horizon soils of the Southeastern Piedmont. Sediment transport in runoff introduces abundant iron and phosphorus to receiving waterbodies, e.g., suspended solids concentration is highly correlated with total P concentration in Lake Lanier (Figure 1). In the experiments described here, we describe the role of transported Bt horizon soil in the phosphorus cycle of Georgia Piedmont impoundments. We tested the sorption capacity of Bt horizon soil, Lake Lanier sediments, and FeOOH for dissolved inorganic phosphate (DIP). We also tested the release of sorbed phosphate from Bt horizon soil at elevated pH.
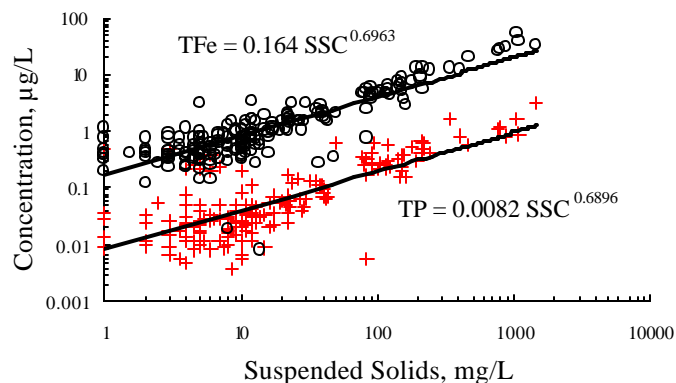

Figure 1. Total iron and total phosphorus versus suspended solids from Lake Lanier tributaries.

METHODS

Sorption Experiments

A series of experiment to explore the capacity of iron oxyhydroxide (FeOOH), Bt horizon soil, and Lake Lanier sediments to sorb phosphate were conducted. Soil and sediments were air dried, pulverized and sieved through 2 mm and 250 Ƒm sieves. Three grams of catalyst grade FeOOH, Bt horizon soil, or Lake Lanier sediments were added to 50 mL centrifuge tubes. Thirty mL of deionized water and stock phosphate solution (KH_2PO_4 + deionized H_2O) was added to create final phosphorus concentrations of 0, 100, 500, 1000, 1500 Ƒg P per tube. The tubes were shaken for 24 or 48 hours, vacuum filtered through a 0.45 Ƒm filter or centrifuged for 15 minutes at 3800 rpm, and the filtrate or supernatant was stored at 4ĒC until analyzed (within 24 hours of filtration or centrifugation). Solutions were analyzed for phosphate using Murphy-Riley analysis with a Shimadzu UV mini spectrophotometer following APHA (1999) methods.

Sorption/Desorption Experiments

4g of Bt horizon soil was placed in each of 18 50 mL centrifuge tubes. Stock phosphate solution and deionized H_2O were added for a final solution concentration of 50 Ƒg P/mL. The centrifuge tubes were shaken for 24 hours, and centrifuged to separate the sediment from the supernatant. The concentration of phosphate in the supernatant was determined as described above. The amount of phosphate sorbed to the soil was calculated by difference. Desorption at multiple pH values was tested by adding HCl and/or NaOH to deionized water to make solutions of pH 7, 8, 9, 10. Thirty ml of water at each pH was added to three centrifuge tubes, with deionized water added to the rest (pH 5.9) as a control. The tubes with soil and specific pH solution were shaken for 24 hours. Tubes were centrifuged and the phosphate concentration of the supernatant was measured. Desorption was calculated by difference.

RESULTS

Experiments to investigate the capacity of iron oxyhydroxide, Piedmont soil from the Bt horizon, and Lake Lanier sediments to adsorb phosphate were conducted in a series of treatments. Lake Lanier sediments had the greatest capacity to sorb phosphate in all treatments, and sorbed all the phosphate in solution in most experiments (Table 1). Bt horizon soil sorbed more phosphorus than iron oxyhydroxide (FeOOH). The
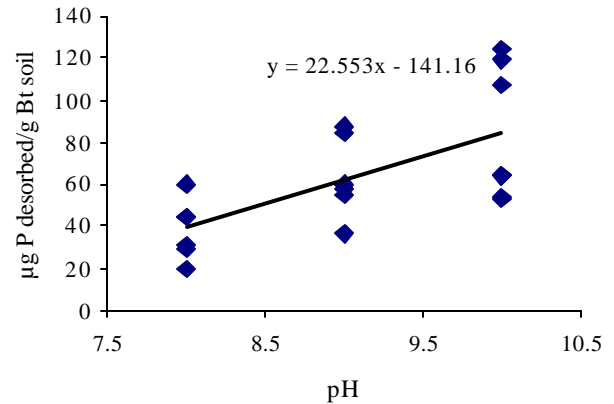

$$y = 22.553x - 141.16$$

Figure 2. Desorption of P at alkaline pH.

amount of phosphate sorbed by Bt horizon soil and iron oxyhydroxide was greater in the 48 hour experiments than in the treatment shaken for 24 hours (Table 1). There was substantial sorption to sediment or soil in all treatments, with the majority of the phosphate bound to the soil or sediment rather than in solution at the end of all experiments.

Alkaline desorption experiments were conducted with Bt horizon soil. Average initial sorption in these experiments was 806 Ƒg P/ g soil (out of a possible 1000 Ƒg P/g soil). Desorption of phosphate occurred at pH values greater than 8. The higher the pH the greater the desorption of phosphate from Bt horizon soil (Figure 2).

DISCUSSION

The sorption capacity experiments show that the iron-rich Bt horizon soil has the capacity to bind large amounts of phosphorus. Lake Lanier sediments sorbed all P in solution in all treatments, and the sorption capacity of Bt horizon soil was >90%. This high degree of sorption indicates that the maximum sorption capacity of Bt soil

Table 1. Sorption capacity of Lake Lanier sediment, Bt horizon soil, and catalyst grade FeOOH for phosphate.

	Sorption (Ƒg P/g solid)	
	24 Hour	**48 Hour**
Sediment	500 (100%)	500 (100%)
Bt Soil	472 (94.4%)	488 (97.6%)
FeOOH	406 (81.2%)	377 (75.4%)

and Lake Lanier sediments is likely much greater than 500 μg P/g soil or sediment, as is further evidenced by the high sorption of P (806 μg P/ g soil) in the desorption experiments, and by the regression relationship of 2 μg P/ mg SSC from log transformed data collected from Lake Lanier tributaries (Figure 1). Hatcher (1994) estimated that 80-90% of the P load to Lake Lanier does not leave the lake and is probably sequestered by sediments. This binding of phosphate is the likely reason that much of the phosphate delivered to Lake Lanier is never seen in the biological response of this waterbody. The oxidized iron transported with sediments has the capacity to bind phosphate and thus remove it from the biologically available fraction.

In results reported previously, (Mayhew et al. 2001), an experimental test of the effect of Bt horizon soil on the availability of phosphate in a small impoundment is described. A small pond was fertilized on multiple occasions with different fertilizer treatments. Twice the pond was fertilized with ammonium polyphosphate pond fertilizer (11-27-0 N-P-K) alone, and the third time the fertilizer was sorbed to Bt horizon soil prior to distribution

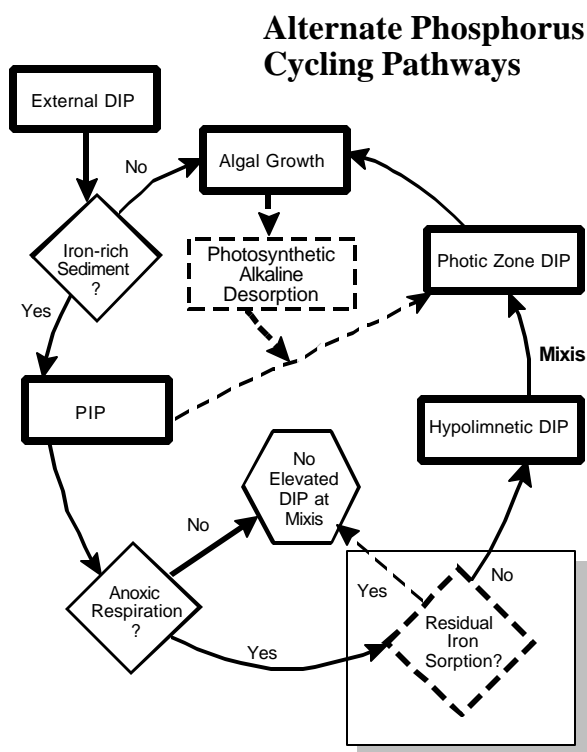## Alternate Phosphorus Cycling Pathways

Figure 3. The conventional phosphorus cycling paradigm is indicated by the heavy solid lines. The alternative pathway is indicated by the heavy dashed lines.

in the impoundment. The Bt horizon soil plus fertilizer treatment resulted in no significant increase of phosphate to the water column. The work described here provides information about sorption of phosphate to Bt horizon soil, emphasizing the role of transported sediment in the formation of particulate inorganic phosphate (PIP), and lending further support to the hypothesis that oxidized iron in transported sediment reduces the bioavailability of DIP in Georgia Piedmont impoundments. Thus, transported sediment plays a more significant role in the phosphorus cycle in impoundments of the Georgia Piedmont than in the north temperate systems where the traditional phosphorus cycling paradigm was developed (Figure 3).

Lake Lanier sediment has a greater capacity for sorbing phosphate than either FeOOH or Bt horizon soil. This may be due to the size of the particles in Lake Lanier sediments, as compared to the Bt horizon soil and FeOOH. Lake Lanier sediments used in these experiments are primarily composed of silt and clay sized particles. The larger quantity of smaller particles provides for greater reactive surface area for sorption of anions and cations in solution, and consequently have a greater capacity for phosphate sorption than do the larger sized particles in the Bt horizon Piedmont soil and catalyst grade FeOOH. In addition, the greater the concentration of phosphate in solution, the greater the capacity for Bt horizon soil and FeOOH to bind the phosphate. This effect may be due to the difference in ionic strength. Solutions with a greater ionic strength can effectively increase the area of sorption by increasing the area of the diffuse charge around the oxidized iron molecule which results in more phosphate binding in the diffuse layer as ionic strength increases.

Desorption of phosphate from Bt soil at elevated pH provides evidence that increased pH can increase availability of phosphate in surface waters. In the poorly buffered waters of the Georgia Piedmont, algal photosynthesis can cause temporary pH elevation. The elevated pH can, in turn result in release of sorbed phosphate from transported Bt soil. Results from the chemical equilibrium model Visual MINTEQ (Figure 4) indicate that alkaline desorption of phosphate from oxidized iron occurs at pH values greater than 8. The data presented here indicate that this elevated pH values also can release sorbed phosphate from Georgia Piedmont Bt soil. pH values as high as 11 have been measured in impoundments in the Piedmont region of Georgia. The results of the sorption experiments indicate that alkaline desorption can play a significant role in the cycling of phosphorus in surface waters. These experiments provide support for the hypothesis that alkaline desorption
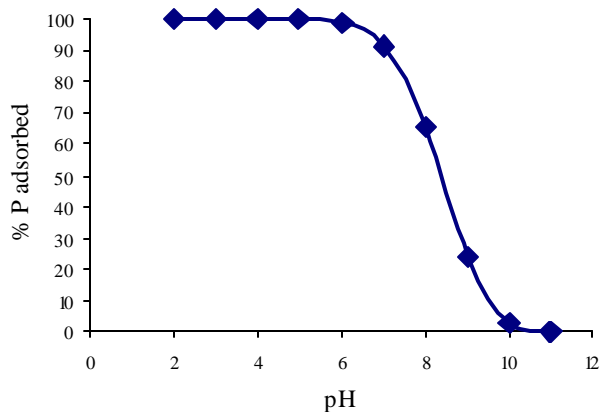
Figure 4. Visual MINTEQ output, P adsorbed to Fe: pH sweep.

(Parker and Rasmussen 2001) may increase local phosphate availability in the surface waters of Piedmont impoundments. Phosphate may also be released when oxidized iron is used as an electron acceptor for carbon oxidation in the anoxic hypolimnetic waters and sediments as described in Parker and Beck (2003).

ACKNOWLEDGMENTS

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