INFLUENCE OF SOIL TEST PHOSPHORUS ON PHOSPHORUS RUNOFF LOSSES FROM SOUTH DAKOTA SOILS

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Abstract

Applications of manure and fertilizer phosphorus (P) to soil in excess of optimal crop requirements leads to a buildup of soil test phosphorus (STP) and increases the risk of offsite transfer of P during heavy precipitation events. The first step to developing effective manure and fertilizer P application strategies for South Dakota is to evaluate the relationship that exists between soil and runoff P. The objectives of this study were to: 1) determine the relationship between STP and runoff P concentrations for several dominant agricultural soils, 2) evaluate the efficacy of using indoor simulation to predict field runoff P concentrations, and 3) to establish a relationship between % P saturation of the soils and STP. Ten conventionally tilled field sites possessing similar slope and topography and ranging from low to high agronomic STP were identified for specific soil series. Bulk soil samples (0-2 inch) from the ten field plots were collected, prepared, and evaluated by indoor rain simulation. Positive correlations have been observed for the field evaluations ($R^2 \geq 90$), which means that Olsen P is able to explain much of the variation in runoff P levels. Moreover, for the studied soils, indoor simulation is effective in predicting P levels in field runoff ($R^2 \geq 89$). Positive correlations were also observed for % P saturation and STP for all soils ($R^2 \geq 83$) indicating that this tool could be useful to environmental regulators. This information will be used to create a model of phosphorus loss as a function of STP and will be instrumental in the implementation of manure management in South Dakota.

Introduction

The application of macronutrients (nitrogen, phosphorus, and potassium) to farmland is essential in order to meet production goals set each year. The amount of nutrients applied varies from year to year and field to field. Animal waste is commonly used to achieve the nitrogen (N) requirement. When this is done, excess phosphorus (P) is applied and leads to a buildup of P in the soil system. During heavy runoff events, this excess P has the ability to run off the surface of the soil into surrounding streams, rivers, and lakes. A positive linear relationship between soil test phosphorus (STP) and phosphorus loss exist on grass covered soils (Pote, et. al., 1996, Cox and Hendricks, 2000 and Pautler and Sims, 2000).

Agronomic practices in South Dakota have led to an increase in STP over the past 40 years. From 1985 to 2000, the average STP level from manured fields has doubled, with the average being higher than needed for optimal crop growth (Gelderman, et al., 2000). Because of new manure nutrient management guidelines to be administered by the South Dakota Department of Environment and Natural Resources (SDDENR), agricultural producers have supported research studying the relationship of phosphorus in soil versus phosphorus loss in runoff on South Dakota soils. The objectives of this paper are to i) establish a relationship between soil test phosphorus

(STP) and P loss in South Dakota benchmark soils using rainfall simulation, ii) to correlate indoor simulation data with outdoor simulation data, and iii) to establish a relationship between % P saturation of the soils and STP.

Materials and Methods

The four benchmark soils chosen for this study include Vienna (fine-loamy, mixed, superactive, frigid Calcic Hapludoll), Kranzburg (fine-silty, mixed, superactive, frigid Calcic Hapludoll), Poinsett (fine-silty, mixed, superactive, frigid Calcic Hapludoll), and Moody (fine-silty, mixed superactive, mesic Udic Haplustoll). Ten plots for each soil series were chosen through a process of soil sampling (0-5 and 0-15 cm) with Olsen STP ranging from low to very high. Sites with similar management practices were chosen to avoid P differences due to tillage effects or past crops.

Because rainfall is naturally low in phosphorus and in flocculative cations such as calcium (Ca^{2+}) and magnesium (Mg^{2+}), it was collected in the Brookings, SD area and used for rainfall simulations. The rainfall simulator was constructed according to the National P Protocol (Southern Extension-Research Activity, 2004). The use of a rainfall simulator to produce runoff has been evaluated by Sharpley and Kleinman and is proven to be an effective measure of DRP (dissolved reactive phosphorus) loss and processes which control P release as DRP are similar for both simulated rainfall and natural rainfall (Sharpley and Kleinman, 2003). A TeeJet™ ½ HH-SS50WSQ nozzle was placed in the center of the rainfall simulator 10 feet above the plot surface, which applied rainfall at a rate of 70 mm/hr, which is in accordance with the National P Protocol (Southern Extension-Research Activity, 2004). Tarps were fitted to the simulator to provide shelter from wind during outdoor simulations.

Outdoor plots consisted of an area 2 m long by 1 m wide each resulting in one overall plot of 2m long by 2m wide. A metal frame built to the above specified dimensions was inserted into the soil to a height of 5 cm above the ground to isolate the study area. Collection troughs were devised to collect runoff from the plot area. All residual plant material was removed from the soil surface to ensure seedbed conditions and each plot was tilled to a depth of 6 inches.

Three rainfall simulations were conducted at each site at one day intervals, with days two and three representing field capacity. Total runoff collected via troughs at the downslope side of the plot was collected over a 30 minute period. Two composite samples, an unfiltered and filtered sample, were collected after all runoff had been collected and were kept at 4 ^{0}C until analyzed for total P and total dissolved P, respectively by the SDSU Water Quality Laboratory (EPA, 1983).

After rainfall simulations are completed for a site and the site has had ample time to dry, ten 0-5 cm and 0-15 cm. samples were collected and combined into two separate samples representing the 0-5 cm 0-15 cm depths. Phosphorus was determined on these samples by the Olsen method (Frank, et al., 1998), nitrate by the nitrate electrode method (Gelderman and Beegle, 1998), potassium as described by Warncke and Brown (1998), and pH by the method described by Watson and Brown (1998). The above tests were performed by the SDSU Soil Testing Laboratory.

The top 0-5 cm of soil were collected from each plot, dried, and sieved through a 19-mm sieve for use in indoor rainfall simulations. A subsample of the indoor soil was collected and ground to be used for laboratory analysis and analysis by the SDSU Soil Testing Laboratory, which included Olsen P, Bray P, and Mehlich-3 P (Frank et al., 1998), nitrate by the nitrate electrode method (Gelderman and Beegle, 1998), potassium as described by Warncke and Brown (1998), organic matter by loss of weight on ignition (Combs and Nathan, 1998), and pH by the method described by Watson and Brown (1998). Soil fractionation was also determined via the pipett method.

The soils were packed into runoff boxes constructed as per the National P Protocol guidelines (Southern Extension-Research Activity, 2004). They were constructed out of plastic and built to the specified dimensions of 1-m long, 20-cm wide, and 7.5-cm deep, containing nine drainage holes (5-mm) in the bottom of the box at the upper, middle, and lower sections to allow drainage to occur. Cheesecloth was placed over the drainage holes to prevent the soil from falling through the hole. To achieve consistent bulk density ($1.3 g/cm^3$), the soils were weighed to 2.87 kg and added to 350 mL of water. The boxes were packed in layers using a wooden tamper to achieve uniform bulk density over all plots. Each soil was replicated three times in randomly chosen boxes. The runoff boxes were placed on a large table at the corresponding slope to simulate field slope. To collect runoff, a V-shaped trough was constructed for each box, and a deflection shield attached to each box in order to prevent rainfall from entering the sample runoff.

The soils were wet the first day and then rained upon for three consecutive days. An unfiltered and filtered sample was collected at the end of each of the three days and analyzed as described above.

Soil P saturation was determined using the phosphorus sorption index (PSI) method of Bache and Williams (1971). This method has been shown to be highly correlated to the Langmuir P sorption maxima (Simard, et al., 1994, Zhou and Li, 2001) as long as the PSI does not exceed 1400 mg/kg (Mozaffari and Sims, 1994). The procedure used for this study was taken from Sims, 2000). P_{max} represents the sorption capacity of the soil and is calculated by the following equation:

$$P_{max} = (PSI+51.9)/0.5 \quad (1)$$

where

$$PSI = X/\log PF \quad (2)$$

and X (P sorbed) (mg/kg) = [(PI)(V) – (PF)(V)]/kg of soil, PI is the initial P concentration in sorption solution (mg/L), V is the volume of P sorption solution (L), and PF is the final P concentration in solution (mg/L) (Sims, 2000). % P saturation is determined by dividing water extractable P by P_{max} and multiplying the result by 100 (Pote et al., 1999).

$$\% \text{ P saturation} = (\text{water ext. P} / P_{max})*100 \quad (3)$$

Results

Selected physical and chemical properties of the soils (0-5cm) studied are given in Table 1. Sites were chosen to include below agronomic P up to the highest Olsen P found. The large range of STP per soil series should provide a good estimate of what relationships exist between STP and P loss in runoff.

Outdoor rainfall simulation of the Vienna, Moody, and Poinsett soils resulted in a positive linear relationship (Fig. 1). STP (0-5cm) of the Vienna and Moody soils were highly correlated to total dissolved P loss (0.94 and 0.93, respectively), while the Poinsett soil exhibited more variability (0.76). The Kranzburg soil exhibited an exponential increase in TDP loss as STP increased (Fig. 2).

Results of the indoor rainfall simulations of the Vienna and Kranzburg soils were almost identical to the results of the outdoor rainfall simulations (Fig. 3). This indicates that indoor rainfall simulations of soils could be used as a tool to understand the relationships of STP vs. P loss for other soils without having to determine these relationships in the field. Results for the Moody and Poinsett indoor rainfall simulations are not complete at this time.

The use of % P saturation of soils to supplement the use of traditional STP methods to determine and environmental P level in soils has been suggested by Pautler and Sims (2000). A positive linear relationship was found for all four soils when examining Olsen P and % P saturation of the soils (Fig. 4). If using the critical value of 25 % P saturation in soils (Sharpley, et al., 1996), at 100 ppm Olsen P no excess P should be applied to soil (Fig. 4). This relationship has been useful to SDDENR when determining a critical level of soil phosphorus above which no manure can be applied to confined animal feeding operations (Fig. 5).

Summary

As STP increases, an increase in the loss of total dissolved phosphorus from the field occurs. Vienna, Poinsett and Moody soils exhibited a linear increase in TDP, while the Kranzburg soil exhibited an exponential increase in TDP as STP increased for the outdoor rainfall simulations, indicating that soils release dissolved phosphorus differently. Outdoor rainfall simulation TP losses were greater than TDP losses, but were not as strongly correlated to STP due to site specific erosion differences (data not shown). The indoor rainfall simulations on Vienna and Kranzburg soils are able to predict TDP from outdoor rainfall simulations. This indicates that indoor rainfall simulations could be used to determine the relationships between STP and TDP in runoff for a variety of soils in a quicker manner than performing outdoor rainfall simulations. Indoor rainfall simulation TP losses were higher than outdoor rainfall simulation TP losses, as well as indoor TDP losses, indicating that indoor rainfall simulations are not a good tool to predict outdoor TP losses (data not shown). Indoor rainfall simulations need to be completed for the other soils studies before any generalizations should be made about its efficiency.

STP has been used in conjunction with % P saturation of soils to determine environmentally sound phosphorus levels in soil. As STP increases, an increase in the percentage of phosphorus saturation in soils also increases. The South Dakota State Department of Environment and Natural Resources has established regulations restricting the spreading of manure to soil for confined animal feeding operations above a level of 100 ppm Olsen P. At this STP, the soil is 25% saturated with phosphorus and previous research has indicated that this is an environmentally critical level of phosphorus saturation (Sharpley, et al., 1996).

Acknowledgements

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Tables and Figures

Soil	pH	OM %	Bray P	Olsen P	Mehlich-III P	K	NO_3-N	% Sand	% Silt	% Clay
			ppm							
Kranzburg n=9	5.9-7.1 (6.6)	3.8-5.6 (5.7)	24-257.5 (128.6)	16-202.5 (90.0)	26.5-185 (100.3)	233-1264 (704.2)	5.2-45.8 (18.7)	9.7-48.2 (18.5)	34.7-57..5 (51.7)	17.2-34.4 (29.8)
Vienna n=10	6.2-7.1 (6.7)	2.8-4.8 (3.7)	19-280 (122)	11-295 (101)	*	188-1970 (662.4)	7.8-36.4 (20.7)	27.3-50.3 (35.3)	31.2-47.5 (42.0)	18.1-25.3 (22.6)
Poinsett n=10	6.1-7.8 (7.0)	*	36-381.7 (163.1)	14-321.7 (123.2)	18-441.7 (154.4)	254-1530 (913.2)	3.6-40.6 (14)	4.5-25.7 (9.4)	50.8-62.7 (58.1)	23.6-39.5 (32.5)
Moody n=10	6-7.5 (6.7)	3.6-7.6 (5.5)	6-226.7 (122.41)	2-173.3 (80.7)	3-336.7 (151.1)	204-1590 (791.9)	6.6-138 (35.9)	2.2-5.9 (3.4)	61.7-68.7 (66.0)	26.4-32.8 (30.6)

Table 1. Physical and Chemical Properties of Studied Soils (0-5cm). (number in parentheses indicates average) *-data not analyzed yet

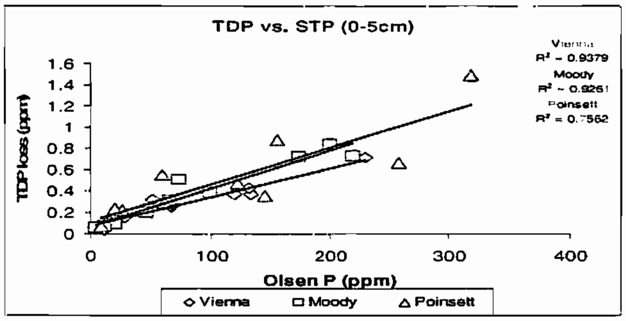

Figure 1. Total Dissolved P (ppm) loss versus Olsen P (ppm) for Outdoor Vienna, Moody, and Kranzburg Simulations.

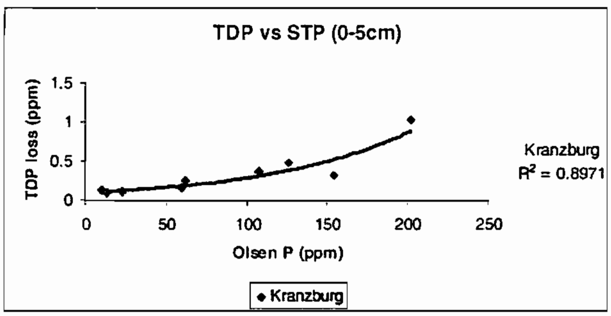

Figure 2. Total Dissolved P (ppm) loss versus Olsen P (ppm) for Outdoor Kranzburg Simulations.

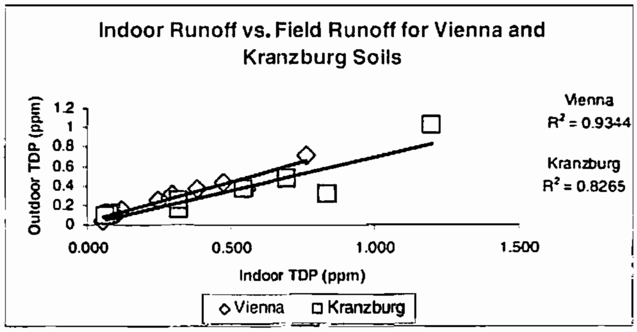

Figure 3. Outdoor vs. Indoor P loss (ppm) for Vienna and Kranzburg Simulations.

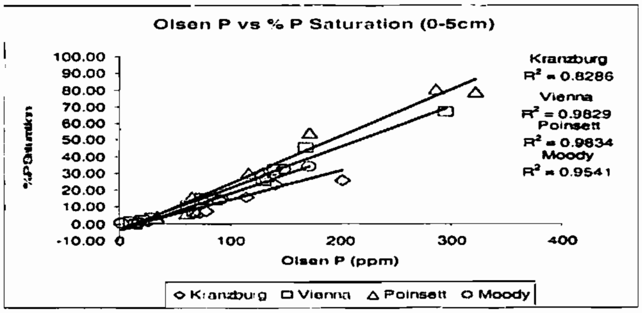

Figure 4. Olsen P (ppm) vs. % P Saturation for Kranzburg, Vienna, Poinsett, and Moody Soils (0-5cm).

Manure Application Guidlines

Olsen Soil Test P, 0-6 inch	----------Erosion estimate (sheet and rill), tons/a ---------				
	----- <4 -----		----- 4 - 6 -----		---- >6 ---
	Filter strip		Filter strip		
	yes	no	yes	no	
ppm					
0 - 25	N need	N need	N need	N need	none
25 - 50	N need	N need	N need	P removal	none
50 - 75	N need	P removal	P removal	P removal	none
75 - 100	P removal	P removal	P removal	P removal	none
>100	none	none	none	none	none

Figure 5. Manure Application guidelines based on STP. (South Dakota Department of Environment and Natural Resources, 2003).

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