PREDICTING PHOSPHORUS RUNOFF FROM CALCAREOUS SOILS

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ABSTRACT

Studies have shown that as extractable soil P levels increase, runoff P levels also increase. This relationship has been found on many different soils, but tends to be unique for each soil series. Very little research exists evaluating this relationship in calcareous soils. The objectives of this study were to determine soil series specific relationships between soil test phosphorus (STP) and runoff P for three calcareous soils, to compare the use of different soil extractants for runoff P prediction from calcareous soils, and to evaluate the impact of calcium carbonate levels on the STP-runoff P relationship. Three sites were selected, one each in Colorado, Nebraska and Kansas, with calcium carbonate amounts ranging from 1-9% in the surface horizon. Eight manure rate treatments were established with two replications in a randomized complete block design. The manure was rototilled into the soil, and all residues were removed. Prior to rainfall simulation, soil samples were taken for Olsen P, Mehlich-3, and water-soluble P analysis. Rain was applied to 1.5 x 2 m (4.9 x 6.5 ft) plots at a rate of 8.3 cm/hr (3.3 in/hr) for 90 minutes (three consecutive 30 minute periods), and runoff samples were taken every 5 min. Mehlich-3 and Olsen extractants resulted in better correlations with runoff P than water-soluble P. At the same soil test P level, the total dissolved P concentration in runoff declined with increasing soil $CaCO_3$ concentration. A multiple regression equation was developed that predicts total dissolved P in runoff from Mehlich-3 STP and $CaCO_3$ level with an R^2 of 0.92 and $p<0.0001$. This relationship should be used to improve the P Index in states with calcareous soils.

INTRODUCTION

Few studies have been done to quantify the effect of manure applications on P runoff from calcareous soils, where phosphorus sorption occurs primarily through binding and precipitation with Ca ions (Whalen and Chang, 2002). A link has been shown to exist between soil test phosphorus (STP) and dissolved P in runoff in calcareous soils (Sharpley et al., 1989, 1994; Robbins et al., 2000). However, this relationship was established with laboratory-based rainfall simulation, and these studies did not include field studies of manure-amended soils.

Olsen, Water-soluble and Mehlich-3 are STP methods available for use with calcareous soils. We compared these three methods to find which STP was the most effective at estimating soluble phosphorus in runoff. The study was designed to evaluate and participate in the National Phosphorus Runoff Project which was developed by USDA Natural Resources Conservation Service and the SERA-17 (Southern Extension and Research Activity) workgroup. The development of a standard protocol (SERA-17 Work Group, 2001) was an effort to develop a means of comparing P runoff data from different researchers and locations.

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MATERIALS AND METHODS

The overall goal of this research was to characterize soil test P (STP) and runoff P relationships for Great Plains soils with varying free calcium carbonate amounts in the surface horizon. Three sites were selected, one each in Colorado, Nebraska and Kansas, with calcium carbonate amounts ranging from 1-9% in the surface horizon (Table 1).

Table 1. Soil properties for three study sites.

Soil Series	Slope	pH	Organic Matter	$CaCO_3$	Texture
	--cm m^{-1}--		--------g hg^{-1}--------		
Rosebud	2	7.9	1.07	1	Loam
Wagonbed	2	7.8	1.97	4	Silt Loam
Kim	1	7.9	1.89	9	Clay Loam

Plots were 4.6 meters wide by 6.1 meters long (15 x 20 ft) with the long axis of each plot oriented parallel to the slope. Eight manure rate treatments were established with two replications in a randomized complete block design. The manure was rototilled into the soil, and all residues were removed before simulating rainfall.

We used a portable rainfall simulator with constant intensity to compare measured parameters at each site. The use of a rainfall simulator allows comparison of different soils and management variables among locations (Humphry et al., 2002). We used a trailer outfitted with a water tank, gasoline-powered generator, electrical cords, water hoses, and electrical water pump. We kept the simulator assembled when working in a plot area, as the protocol called for three simulations on each of three succeeding days. For each 1.5 m by 2.0 m (4.9 x 6.5 ft) rainfall simulator plot, metal borders were installed [0.2 cm thick (0.08 in) and 15.2 cm (6.0 in) wide] 7 cm (2.8 in) above ground and 9.25 cm (3.6 in) below ground to isolate surface runoff. A runoff collector was installed at the down-slope edge of each plot to divert runoff to a collection point. A one liter bottle (autoclavable) was used to collect runoff at the collection point.

The rainfall intensity was 8.3 cm h^{-1} (3.3 in h^{-1}), with the nozzle pressure gauge set at 492 g cm^{-2}. The rain simulator was based on the design of Miller (1987) with a TeeJet™ ½ HH-SS50WSQ nozzle placed in the center of the simulator 3.05 meters (9.9 ft) above the soil surface. The nozzles and associated water piping, pressure gauge, and electrical wiring were mounted on an aluminum frame. A pressure regulator was used to establish a water flow rate of 210 mL sec^{-1} at the nozzle.

Prior to rainfall simulation, three soil samples were taken outside of established plots from 0-5 cm deep and composited to measure antecedent soil water conditions and soil test phosphorus. Soil samples were air dried and sieved (2 mm) to remove rocks, particles and most of the previous crop material. Samples were analyzed using Olsen P, Water- soluble P (0.01 M $CaCl_2$), and Mehlich-3 extractants (Olsen et al., 1954; Luscombe et al. 1979; Mehlich, 1984).

As runoff began in each plot, a stopwatch was started and run for 30 minutes. During this half-hour, at 2.5-minute intervals, 1 L of runoff was collected (12 discrete samples/plot). Records were kept on sample volumes and time required for collection, to calculate mean runoff flow rates and total runoff volumes. Samples collected at 2.5, 7.5, 12.5, 17.5, 22.5, and 27. 5 minutes were analyzed individually for their P content. A 40 mL sub-sample was taken from each of these samples, filtered (.45 μm pore diameter), and Total Dissolved P was measured by ICP. Samples collected at 0, 5, 10, 15, 20, and 25 minutes were analyzed for runoff and soil loss.

RESULTS AND DISCUSSION

Although there was no difference among the three soil extractants in their ability to predict runoff P from the Kim soil (the soil with the highest CaCO3 level), the Mehlich-3 and Olsen STP measurements were more highly correlated with runoff P on both the Rosebud and Wagonbed soils. The Mehlich-3 extract consistently resulted in the highest R2 values across all three soil types. Therefore, we present the Mehlich-3 data in this paper.

The available soil P responded differently to the P added as manure on the different soils (Figure 1). In particular, the slope of the line (change in Mehlich-3 per unit change in P added) was significantly lower for the Kim soil than for the other soils. On average, the Rosebud and Wagonbed soils experienced an increase of 0.35 mg/kg Mehlich-3 STP for every kg/ha increase in P added, while the Kim soil only increased by 0.02 mg/kg Mehlich-3 STP. There was no difference in the intercepts of the lines. All of the different sites received the same manure application rates; however, the manures had different P concentrations resulting in different amounts of P added. Nonetheless, the high CaCO3 soil (Kim) had lower Mehlich-3 levels at the same amount of P added, apparently due to the P being bound to Ca in forms that were unavailable to plants.

The relationship between total dissolved P in runoff and Mehlich-3 STP also differed significantly by soil (Figure 2). Again, the intercepts of the lines were not different, although the slopes were different. The slopes ranged from 0.0004 in the Kim soil (9% $CaCO_3$) to 0.0007 in the Wagonbed soil (4% $CaCO_3$) and 0.0022 in the Rosebud (1% $CaCO_3$). As soil $CaCO_3$ level increased, the total dissolved P in runoff decreased at the same STP level.

Next, we developed a multiple regression equation to predict the total dissolved P in runoff as a function of Mehlich-3 STP and $CaCO_3$ (Eq. 1). The regression has an R^2 value of 0.92 and $p<0.0001$.

$$TDP= 0.071 + 0.003*M3 + 3.112*CaCO_3 – 0.059*CaCO_3*M3 \qquad \text{(Eq. 1)}$$

TDP=total dissolved P in runoff (mg/L)
M3=Mehlich-3 soil test P (mg/kg)
$CaCO_3$=$CaCO_3$ content reported in decimal form

A similar equation was developed using Olsen P, but the R^2 value was only 0.81. Therefore, we recommend the use of Mehlich-3 for the prediction of runoff P from calcareous soils.

In conclusion, the higher the percentage of calcium carbonate in the soil surface layer, the less dissolved phosphorus ran off the field at the same STP level (Schierer et al., 2006). Although this research evaluated only three soils with many differences in their physical and chemical characteristics, the results should be considered for integration into the Phosphorus Index. This index is a planning tool used by producers and NRCS to evaluate the environmental hazard of applying organic fertilizers to cropland. This research indicates that soils with higher amounts of calcium carbonate are better suited to being sinks for excess P in manure. When producers are making decisions about where to apply manure, soil $CaCO_3$ level is an important consideration.

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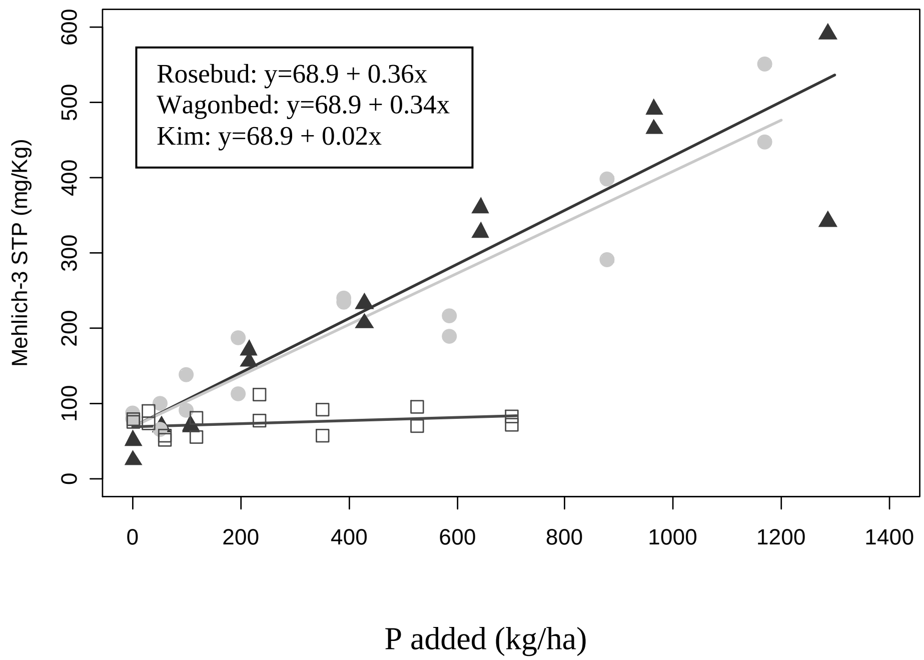

Figure 1. Mehlich-3 STP (mg/kg) as a function of P added (kg/ha) for three soils (▲=Rosebud, ●=Wagonbed, □=Kim).

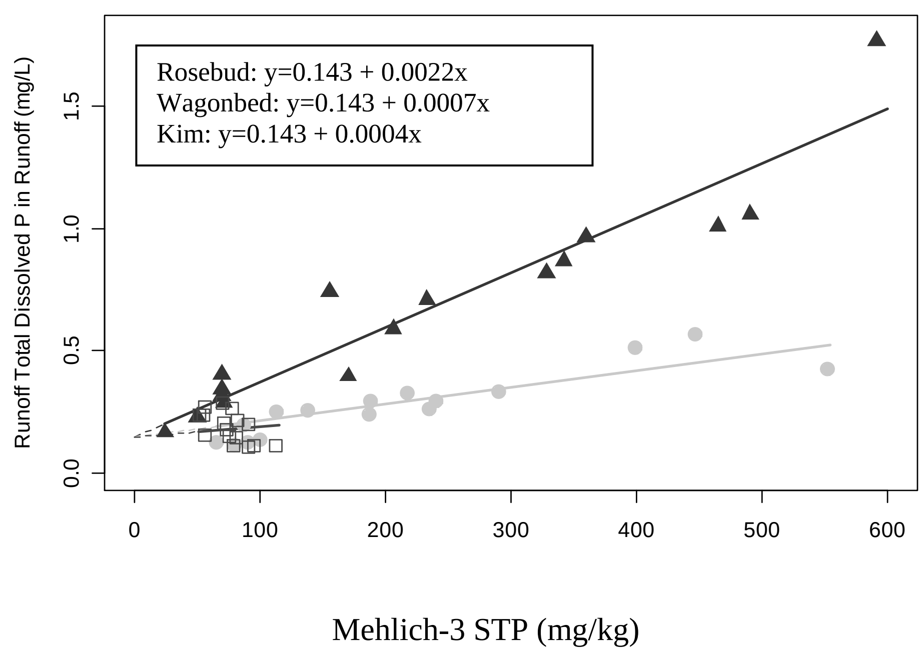

Figure 2. Total Dissolved P in runoff (mg/L) as a function of Mehlich-3 STP (mg/kg) for three soils (▲=Rosebud, ●=Wagonbed, □=Kim).

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