Predicting Phosphorus Runoff from Calcareous Soils

By R.A. Schierer, J.G. Davis, and J.R. Zimbrunnen

Soil calcium carbonate ($CaCO_3$) has a major impact on soil-phosphorus (P) interactions and can significantly influence levels of plant-available and soluble P in soils. This experiment investigated the effect of manure applications on soil test P (STP) and runoff of P from three soils with $CaCO_3$ contents ranging from 1 to 9%. The relationship between P added from manure and STP differed among soils, with the highest $CaCO_3$ soil showing the most resistance to changes in STP. Also, for any given STP level, surface runoff was reduced as soil $CaCO_3$ level increased. This work shows that soils with high levels of $CaCO_3$ are well suited as sinks for excess P in manure. Thus, soil $CaCO_3$ level should be considered in the P index in states with calcareous soils.

Few studies have investigated the effect of manure applications on P runoff from calcareous soils, where P sorption occurs primarily through binding and precipitation with Ca ions (Whalen and Chang, 2002). A link between STP and dissolved P in runoff in calcareous soils was demonstrated in previous work (Sharpley et al., 1989, 1994; Robbins et al., 2000). However, these relationships were established with laboratory-based rainfall simulation, and the work did not include field evaluations of manure-amended soils.

Our field study was designed and performed with the overall goal of characterizing STP and runoff P relationships for Great Plains soils with varying free $CaCO_3$ concentrations in the surface horizon. Three sites were selected, one each in Colorado, Nebraska, and Kansas. Three STP methods (Olsen, Mehlich-3 colorimetric, and water-soluble) were compared to find which was the most effective at estimating soluble P in runoff. The study was designed to meet the standards of and participate in the National Phosphorus Runoff Project which was developed by USDA Natural Resources Conservation Service (NRCS) and the Southern Extension and Research Activity (SERA-17) workgroup.

The specific objectives of this study were to determine soil series-specific relationships between STP and runoff P, to compare the use of different soil extractants for runoff P prediction, and to evaluate the impact of $CaCO_3$ levels on the STP/runoff P relationship.

Soil $CaCO_3$ contents of the sites ranged from 1 to 9% in the surface horizon (**Table 1**). Plots at each location were 15 ft. wide by 20 ft. long (4.6 by 6.1 m), 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 roto-tilled into the soil, and

Table 1. Soil properties for three study sites.

Soil series	State	Texture	pH	Slope	Organic matter	Calcium carbonate
				- - - - - -	%	- - - - - -
Rosebud	Nebraska	Loam	7.9	2	1.07	1
Wagonbed	Kansas	Silt loam	7.8	2	1.97	4
Kim	Colorado	Clay loam	7.9	1	1.89	9

all residues were removed before simulating rainfall.

A portable rainfall simulator with constant intensity was used 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). The rain simulator was based on the design of Miller (1987). 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 3.3 in./hour. As runoff began in each plot, a stopwatch was started and run for 30 minutes. During this half-hour, approximately 1 quart (1 liter) of runoff was collected at 2.5-minute intervals (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 sub-sample was taken from each of these samples and filtered, then 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.

Prior to rainfall simulation, three soil samples were taken from the established plots from 0 to 2 in. (5 cm) deep and composited to measure antecedent soil water conditions and soil test P. Samples were analyzed using Olsen P, water-soluble P (0.01 M $CaCl_2$), and Mehlich-3 extractants.

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 $CaCO_3$ 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 r^2 values across all three soil types. Therefore, only the Mehlich-3 data is presented in this paper.

Increase in available soil P with manure addition was not consistent among 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. Mehlich-3 STP in the Rosebud and Wagonbed soils on average increased 0.18 parts per million (ppm) for every lb P_2O_5/A of added P, while the Kim soil increased by only 0.0098 ppm 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 $CaCO_3$ soil (Kim) had lower Mehlich-3 levels at the same amount of P added, apparently due to the reaction between P and Ca and the consequent reversion to less available P

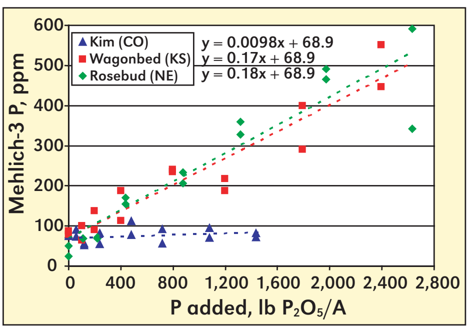

Figure 1. Mehlich-3 STP as a function of P added for three soils.

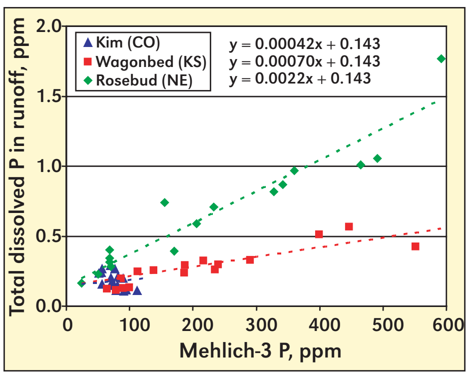

Figure 2. Total dissolved P in runoff as a function of Mehlich-3 STP for three soils.

There has been little previous study of P runoff from manure-amended calcareous soils in the Great Plains. Inset photo shows the rainfall simulator in action.

compounds.

The relationship between total dissolved P in runoff and Mehlich-3 STP also differed significantly by soil (**Figure 2**). Again, the slopes were different, but the intercepts of the lines were not. The slopes were in the order Kim soil (9% $CaCO_3$) < Wagonbed soil (4% $CaCO_3$) < Rosebud soil (1% $CaCO_3$). This means that at a given STP level as soil $CaCO_3$ level increased, the total dissolved P in runoff decreased.

A multiple regression equation was developed to predict the total dissolved P in runoff as a function of Mehlich-3 STP and $CaCO_3$. The equation is:

$TDP = 0.071 + 0.003\ (M3) + 3.11\ (CaCO_3) - 0.059\ (CaCO_3)\ M3$
TDP=total dissolved P in runoff, ppm
M3=Mehlich-3 soil test P, ppm
$CaCO_3$=$CaCO_3$ content in decimal form

The regression equation has an r^2 value of 0.92 and $p<0.0001$. 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.

Summing Up

In conclusion, the higher the percentage of $CaCO_3$ in the soil surface layer, the less dissolved P ran off the field at the same STP level. This research evaluated only three soils with many differences in their physical and chemical characteristics. Notable were differences in clay content. Therefore, clay content was inserted into the multiple regression equation with a subsequent increase in the r^2 value of only 0.01. $CaCO_3$ should be considered for integration into the P index, a planning tool used to evaluate the environmental hazard of applying organic P fertilizers to cropland. This research indicates that soils with high levels of $CaCO_3$ are well suited as sinks for excess P in manure. Accordingly, when producers are making decisions about where to apply manure, soil $CaCO_3$ level is an important consideration. BC

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