SOIL TEST P AND P SOURCE IMPACTS ON P RUNOFF
FROM CALCAREOUS SOILS

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INTRODUCTION

Long-term application of phosphorus (P) to soils at rates in excess of crop uptake can result in elevated soil P levels (Snyder et al., 1993), which previous research has shown directly influences the amount of P in runoff (Sharpley et al., 1977, 1978, 1995; Daniel et al., 1994; Pote et al., 1996). Because soil test and runoff P concentrations are related, excessive soil P levels may result in significantly high runoff P levels, which accelerate surface-water eutrophication. Eutrophication has been identified as a major symptom of impaired surface water quality (USEPA, 1996). The incidence of harmful algal blooms has been linked to an increase of P in fresh water (Sharpley and Tunney, 2000). Increasing surface soil P concentrations exacerbate P loss in surface runoff and subsurface flow (Hesketh et al., 2000). This increased surface P content leaves the agricultural field dissolved in runoff water and bound to sediment eroded from the field. Research data is needed to provide a sound, scientific relationship between manure application and runoff phosphorus (P) concentrations for calcareous soils. The objectives of these experiments were to determine (a) if a significant relationship exists between soil test P (Olsen) and runoff P levels for each of the soils and (b) if a significant relationship between P source and runoff P concentrations exists.

MATERIALS AND METHODS

Field research was conducted on four sites containing calcareous soils. The first experiment was performed on three field sites: a Rosebud loam (fine-loamy, mixed, mesic Aridic Agriustoll) containing 4% $CaCO_3$ by weight located near Sidney, Nebraska; a Ulysses silt loam (fine-silty, mixed, mesic Aridic Haplustoll) containing 1% $CaCO_3$ by weight located near Tribune, Kansas; and on a Kim clay loam (fine-loamy, mixed (calcareous), mesic Ustic Torriorthents) containing 9% $CaCO_3$ by weight soil located near Wellington, Colorado. The second experiment was conducted on a Kim heavy clay loam (fine-loamy, mixed (calcareous), mesic Ustic Torriorthents) soil near Fort Collins, Colorado.

In experiment one, each of the three sites had eight treatments randomly assigned with two replications, totaling 16 plots. The manure application rates were the same for all three sites: 11 Mg manure ha^{-1}, 22 Mg manure ha^{-1}, 45 Mg manure ha^{-1}, 90 Mg manure ha^{-1}, 135 Mg manure ha^{-1}, 202 Mg manure ha^{-1}, and 269 Mg manure ha^{-1}, although the makeup of the manure varied by state. The actual P_2O_5 applied at each location based on manure application rate are listed in Table 1. The manure was tilled into the soil as soon as the ground thawed, less than one month after application. All three plots were tilled again just prior to raining. Kansas was tilled in September 2001, Nebraska in late October 2001, and Colorado in April 2002.

Table 1. Actual P_2O_5 applied at each location based on manure application rate.

Manure Application rate	Actual P_2O_5 Applied		
	Nebraska	Kansas	Colorado
-----Mg/ha------	----------------------------kg/ha------------------------		
11	123	112	67
22	247	224	135
45	493	448	269
90	986	897	538
135	1480	1345	807
202	2219	2018	1211
269	2959	2690	1614

In experiment two, the following nine treatments were applied at two rates (90 kg P_2O_5 ha^{-1} and 180 kg P_2O_5 ha^{-1}) during the fall of 2001: Raw dairy manure (three replications at each rate were applied), windrow compost (three replications at each rate were applied), and vermicompost (three replications were applied at the low rate and one at the high rate). All three of the treatments were sourced from the same dairy manure collected behind the feeding troughs at a local dairy. The entire field was disked after the final treatments were applied. In the spring of 2002 and 2003, rainfall simulations were conducted on the field plots.

Runoff plots, in both experiments, were constructed with dimensions of 2 m long and 1.5 m wide. The long axis was oriented down the slope. Metal borders (0.2 cm thick and 15 cm wide) were installed 5 cm above ground to isolate surface runoff. A runoff collection gutter was installed at the downslope edge of each plot to divert runoff to a collection point.

Six soil cores were collected and composited for each sampling depth (0-5 cm and 0-15 cm) from outside the rainfall collection area, before rainfall simulation began. These samples were used to determine soil P levels. Soil samples were air-dried and sieved (2-mm) to remove larger rock particles and most of the grass thatch material. Samples were analyzed for Olsen P (Olsen et al., 1954) because of the calcareous nature of the soils.

Our rainfall simulator is based on the design of Miller (1987). It has one Tee Jet^{TM} ½ HHSS50WSQ nozzle placed in the center of the simulator and 305 cm (10 ft) above the soil surface. The nozzles and associated water piping, pressure gauge, and electrical wiring are mounted on an aluminum frame. A pressure regulator was used to establish a water flow rate of 210 mL/sec at the nozzle. This produced a rainfall rate of 74 mm/hr. Rainfall distribution uniformity was measured for each experiment and results were greater than 88%.

We collected two runoff samples of approximately 1 L at 5-min intervals during the runoff event beginning 0 and 2.5 min after the start of continuous runoff (twelve discrete samples /plot /rainfall event), giving a total runoff time of 30 minutes. The discrete samples which were collected at 2.5, 7.5, 12.5, 17.5, 22.5, and 27.5 minutes, were analyzed individually. We filtered (0.45 μm pore diameter) a subsample of each composite sample to remove particulate matter. Then we acidified the filtered and unfiltered runoff samples with concentrated HCl (1 drop of concentrated HCl to each 10 mL of runoff sample). Runoff samples were analyzed following procedures in APHA (1992; Pierzynski, 2000) for: Ortho-P (dissolved inorganic P), total dissolved P, and total P.

The remaining samples collected at 0, 5, 10, 15, 20, and 25 min were analyzed for a characterization of water and sediment volumes in the runoff. The samples were weighed, acidified, and left to stand over night. The following morning the clear water was poured off of the sample and then the remainder of the sample was placed in an oven at 105° C. After the water was evaporated from the sample, it was weighed again to collect the sediment weight of the sample.

Sample measurements were analyzed using a general linear model (Proc Mixed; SAS, 2001) with the dependent variables (erosion mass, runoff mass, Olsen P, total P, dissolved inorganic P, and total dissolved P) modeled as a function of treatment in experiment one and as a function of rate nested within treatment for experiment two. The least significant difference (LSD) test was used for mean comparison.

RESULTS AND DISCUSSION

Phosphorus rate and source variation inherently provides different fractions and availabilities of P to the soil and runoff, in the case of a rainfall event. Since no treatment, in either study, provided significantly greater rates of runoff or erosion than control plots, the concentration of P in the runoff water from different rate and source amended plots is of crucial importance.

Olsen P values (0-15 cm) from the first study were significantly different among treatments in Nebraska and Kansas's soils. No difference in soil test P values was measured in Colorado. In Nebraska, the 202 and 269 kg manure ha^{-1} rates were significantly higher than all other treatments. All rates greater than 22 kg manure ha^{-1} had Olsen P contents significantly greater than the control plots. In Kansas, the 269 kg manure ha^{-1} rate was significantly greater than all other treatment soil test P values. However, treatments greater than 11 kg manure ha^{-1} all provided Olsen P values significantly greater than the control. Therefore, these two sites present evidence that application rate influenced Olsen P and may potentially translate into runoff P concentration variations.

Olsen P values (0-15 cm) from the Fort Collins experiment were significantly greater in plots amended with the high rates of raw and composted manure; however the same rate of vermicompost did not increase Olsen's soil test P levels. These results concur with Ebeling et al. (2003) in indicating that P availability in soil does not depend solely on the total amounts of added P, but rather upon the physical and chemical characteristics of the P source applied to the soil. The consistent differences over time illustrate a potential relationship between runoff P and soil test P values in calcareous, alkaline soils.

In study one, total P runoff means among treatments were not predicted by Olsen's soil test means. The runoff total P losses from the plots were primarily a function of soil erosion mass. As there were no significant differences among plot erosion losses, this measurement of P in runoff was not a good indicator of manure type or amount applied. The two fractions of runoff dissolved P (total dissolved P and dissolved inorganic P) provided significantly different values among states. In Nebraska, the 135 Mg ha^{-1}, 202 Mg ha^{-1}, and 269 Mg ha^{-1} rates contained significantly greater concentrations of total dissolved P and dissolved inorganic P. The Kansas site provided significantly greater total dissolved P concentrations at 202 Mg ha^{-1} and 269 Mg ha^{-1} manure rates compared to control. Also, the dissolved inorganic P levels in Kansas were significantly different from the control at the 90 Mg ha^{-1} manure rate and greater. Regressions were run on total dissolved P and dissolved inorganic P for Nebraska and Kansas

soils. The slopes ranged from 0.00287 to 0.00711 and the intercepts ranged from –0.02018 to 0.11446, respectively.

Study two illustrated that various sources provide different concentrations in P runoff. In 2003, all three fractions of P measured in the runoff water (total P, total dissolved P, and dissolved inorganic P) were significantly greater in plots amended with the high rate of raw dairy manure than all other treatments, including the two other high rate treatments. The 2002 total dissolved P and dissolved inorganic P data also show a significantly greater P concentration from plots amended with the high rate of raw manure. These measurements reinforce our findings that both source and rate affect the P runoff potential from an agricultural field. Ebeling et al. (2003) also found that total P concentrations varied among various organic sources during a lab study. Possibly, the microbial activity that occurs during the composting process fixes P into forms that are less mobile after the organic material has dissolved into the soil matrix.

In conclusion, Olsen's P proved useful in predicting dissolved runoff P in Nebraska and Kansas soils in study one. Study two illustrates the effectiveness of Olsen's P measurement on predicting total and dissolved forms of P in runoff over two years. However, Olsen P values were better predictors of runoff P concentrations from the soils with lower calcite concentrations (NE and KS), probably due to lower P sorption. The moisture regime and cropping sequence differences in the experimental fields may have also provided an environment in the NE and KS soils to allow better measurement of Olsen's P than did these management practices in CO.

Also, study two led us to conclude that source matters. The addition of raw manure provided greater concentrations of runoff and soil test P than did the composted and vermicomposted manures. Therefore, choosing a correct source and agronomic rate will potentially decrease environmental pollution.

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