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Relationship of Soil Test Phosphorus and Sampling Depth to Runoff Phosphorus in Calcareous and Noncalcareous Soils

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By H. A. Torbert, T. C. Daniel, J. L. Lemunyon, and R. M. Jones

In a 1998 U.S. EPA report, agricultural nonpoint source pollution was estimated to cause 60%, 50% and 34% of river, lake and estuarine impairment, respectively. The greatest potential for nonpoint P contribution to surface waters usually occurs in watersheds with intensive animal production. Manure collected from concentrated animal feeding operations (CAFO) has traditionally been applied to fields near the operation. However, long-term manure application to soils at rates in excess of crop uptake can result in elevated soil P levels.

Research in 1993 showed that the contribution of P from soils with elevated levels of soil test P is potentially more important and difficult to manage than improper land application of animal manure. This study found that elevated soil test P levels were responsible for 65% to 90% of annual P loss from the watershed even when a major surface runoff event occurred one day after manure was applied to fescue pasture.

Recent EPA draft guidelines for manure applications for CAFOs limit application to "threshold P holding capacity of all major soil types within the land application areas." However, the threshold P levels of soils are yet to be developed. Recent research has shown that the level of soil P is directly related to runoff losses of P, which would indicate that a threshold level could be developed, but studies have demonstrated that the relationship between the level of soil P and runoff P varies markedly depending on the soil type. Further, it cannot be assumed that soil tests designed for crop production can be used to predict surface runoff enrichment potential.

Using the relationship of soil test P to runoff losses of P could be a valuable management tool for protecting watersheds from excessive nutrient loading. However, the potential of these relationships has not been fully developed, especially for calcareous soils. The objective of this project was to examine the relationships between soil test P levels and runoff losses of P for benchmark soils in the Bosque River watershed in Texas and to examine the practical aspects of the data (i.e., depth of sampling and P extractant used) for potential use in development of a soil test for environmental P losses.

Materials and Methods

Rainfall simulations were conducted on four soils representative of the major soil types in the Bosque River basin in Texas. The soils included two noncalcareous soils, a Windthorst sandy loam and a Blanket clay loam, and two calcareous soils, a Purves clay and a Houston Black clay. The soils were under permanent Bermuda grass pasture.

At each site, six surface runoff plots were constructed and a collection gutter was placed at the downslope edge to divert runoff to a pit where samples could be collected. A range in the level of soil test P was established by surface application of dairy manure from a local dairy operation. A target range of soil test P levels of 0, 60, 120, 180, 240 and 360 mg kg^{-1} was used. Following application of manure over an 18-month period, approximately six months were allowed before initiation of rainfall simulation so the effect of surface manure application on runoff P concentration would be minimized. The grass was mowed periodically.

A composite soil sample was collected from each plot immediately after simulated rain applications to permit correlation of soil test and surface runoff P levels. Soil cores were taken at 0- to 2.5-, 0- to 5- and 0- to 15-cm depths.

A rain simulator generated 30 minutes of surface runoff from each plot. Runoff samples were filtered, acidified to pH 2 with HCl and frozen until analyzed for dissolved molybdate reactive phosphorus (DMRP). Rainfall simulations were repeated three times at each site so that regression analysis could be used to evaluate the relationship between soil test P and surface runoff P.

Results

The soils were very different with respect to texture and $CaCO_3$ content, especially in the upper few centimeters, which is expected to have the greatest influence on runoff P concentrations. While $CaCO_3$ is present in all four soils, levels in the surface horizon of the Houston Black and Purves soils (considered calcareous) are 10-fold higher than the Windthorst and the Blanket soils.

Soil samples collected at the four locations indicated that the concentrations of extractable P were reasonably close to the target levels of 0, 60, 120, 180, 240 and 360 mg kg^{-1}.

Analysis of runoff P concentrations across all four soil types ranged from 0.023 to 1.73 mg L^{-1} for DMRP and from 0.044 to 1.8 mg L^{-1} for total P. For all soils, runoff P concentrations increased as the level of soil test P increased. However, the amount of particulate P (particulate P = total P – DMRP) in runoff remained relatively constant with increasing levels of P in runoff and contributed a very small portion of the total P in runoff at the higher levels of runoff P observed. Since the greatest potential for increased eutrophication of surface water results from DMRP components, regression analysis presented here will be for DMRP.

It has been speculated that a "change point" may exist for soil test P concentrations where increasing P application (i.e., manure application) contributes increasing concentrations of DMRP to runoff. Within the range of soil test P used in this study, no breakpoints for soil test P concentrations were observed.

Soil Depth. A strong relationship exists between soil test P and DMRP in surface runoff with both soil test extractions using water and Mehlich III. Similar results have been reported by others, and our results are further evidence that an environmental soil test can be developed that relates the level of P measured in soil to the amount susceptible to losses in surface runoff.

While similar, significant regression equations were observed for all four soils and all three soil depths, examination of the differences and similarities can provide some indications as to the best soil test for P relating to potential environmental loss of P. For example, while the relative response was different between the four soil types, the relative response between the four soil types for changing soil depth was consistent. The greater the soil depth, the steeper the curve response to increasing soil test P. We believe this is primarily a factor of dilution of the manure P spread on the surface of the established pasture with the inclusion of deeper sampling increments. In this system, the manure P must move through the sod and down through the soil profile. Consequently, the highest concentrations of P were observed in the soil surface and decreased with increasing depth.

The Windthorst soil is a sandy loam soil compared with the other three, which were clay and clay loams. With the sandy soil, manure additions to the soil surface can move through the soil profile more quickly; consequently, there is less dilution effect of the soil test P values. This resulted in a reduction of the relative change in steepness of regression equations for soil depth in the Windthorst soil compared with the heavier-textured soil types.

While not always the case, the best fit for the regression lines for both Mehlich III and water-extractable P was generally observed with soil collected from the 0- to 5-cm depth. It is believed that this was caused by competing phenomena relative to manure application on the soil surface.

Statistical techniques were used to compare differences between regression equations at each soil depth between the four soil types. With the water-extractable P, significant differences were observed between the regression equations of the four soil types for both the 0- to 2.5- and 0- to 5-cm depths but not the 0- to 15-cm depth. At the 0- to 15-cm depth, only the soil P concentration level was found to have a significant effect on the regression equations. This indicates that the equations for each soil type would be parallel with a different intercept for each soil type. However, given the response observed at the other two soil depths, this response would not seem to be realistic. It is believed that this response at the 0- to 15-cm depth is actually a diminishment in the effectiveness to describe the relationship, with only the strongest component (P concentration) remaining significant compared with the responses observed at the 0- to 2.5- and 0- to 5-cm depths. At the 0- to 15-cm depth, while the clear relationship between soil test P level and runoff P losses could be observed, differences between the soil types were not significant. While this may be desirable for providing a "one fits all" line for making an environmental P soil test, it would potentially eliminate important differences in soils for management purposes.

At the 0- to 2.5-cm depth, a significant difference was observed for water-extractable P concentration and soil type, but only the Houston Black soil was significantly different from the other three. This lack of significance for the other soil types was probably due to increased variability in the P concentration data at the 0- to 2.5-cm depth. At the 0- to 5-cm depth, the Blanket, Houston Black and Purves soils were all significantly different from each other. The Windthorst soil was significantly different from the Houston Black soil, but was only close to being significantly different from the other two soil types.

Similar results were observed for differences among the regression equations developed for the Mehlich III extractant. As with the water-extractable P at the 0- to 15-cm depth, P concentration was the only significant effect observed. However, with the Mehlich III extractant, differences could be observed between soil types at the 0- to 2.5- and 0- to 5-cm depths. This indicates that Mehlich III may be less variable with P concentration data at the 0- to 2.5-cm depth for developing these types of relationships compared with water-soluble P extraction. However, both extractants resulted in a highly significant relationship at the 0- to 5-cm depth, indicating that this may be the best depth for examining DMRP losses regardless of the extractant used. As was seen with the water-extractable P, at the 0- to 5-cm depth, the Blanket, Houston Black and Purves soils were significantly different and the Windthorst soil was close to being significantly different from the Purves and Blanket soil types.

Calcareous versus Noncalcareous Soil. Comparison of the four sites indicates another difference among the regression equations. The two calcareous soils have a much lower concentration of DMRP in runoff at all levels of soil test P compared with the two noncalcareous soils. With the noncalcareous soils, DMRP concentration in runoff varies from 0.2 to 1.5 mg L^{-1}, while the DMRP concentration in the calcareous soils started well below 0.2 mg L^{-1} and at the highest soil test P level only reached a concentration of 0.6 mg L^{-1}. In fact, the Houston Black soil only reached a value of 0.4 mg L^{-1} at the highest soil test P concentration. These results have important implications for regulations using soil test P values because these relatively large differences in DMRP losses were observed at the same measurement of soil test P using the same laboratory techniques for determination.

Calcareous soils by definition contain sufficient free $CaCO_3$ to effervesce visibly when treated with cold 0.1 *M* HCl. Soluble P will react with Ca in soil to form insoluble minerals such as hydroxyapatite and fluorapatite. Therefore, calcareous soils will probably contain less soluble P at higher levels of total soil P (higher manure application). The presence of free $CaCO_3$ in calcareous soils will probably reduce the amount of soluble P present in soil and prevent it from being released into runoff.

Soil P extractants were developed to measure the amount of P that would be released during the growing season for plant production. Therefore, most extractants will dissolve some of the insoluble Ca-phosphate minerals present in soil. The data presented here demonstrate that while the P concentrations present in extractants are directly related to the potential P release into runoff, the relationship can be highly influenced by the presence of soil components that form insoluble P minerals.

While measuring differences between soil types is important, it is necessary to develop a practical soil test P for environmental concerns. Therefore, predictive equations are needed that will work satisfactorily for groups of soils to predict DMRP in runoff. In this study, an attempt was made to develop regression equations by grouping the two calcareous soils and the two noncalcareous soils. Significant regression lines were developed for comparing soils for both the water-extractable and the Mehlich III extractants, but not for all three soil depths. With the Mehlich III data, no significant regression lines could be developed for the 0- to 2.5-cm depth, and the regression equations developed at the 0- to 15-cm depth were not significantly different from each other. However, at the 0- to 5-cm depth, regression equations were developed with reasonable r^2 values and a highly significant soil type effect. With the water-extractable P, regression lines could be developed at all depths, but no significant differences were observed with the 0- to 15-cm depth. A significant difference was observed between the regression models for the 0- to 2.5 depth, but only at the $\alpha = 0.1$ probability level ($P = 0.097$). A highly significant difference was observed between the two models at the 0- to 5-cm depth ($P = 0.004$) with reasonable r^2 values for the two lines.

Discussion

The data presented in this study indicate significant differences in the potential for runoff losses of DMRP at the same concentration of soil test P between different soil types within the same watershed. Also, the data indicate there is a potential to group classes of soil types for their soil DMRP loss potential. These differences could be used in tools such as the Phosphorus Index for manure management.

If a soil test for P is to be used as a management tool for land application of manure, soils will need to be grouped into reasonable management categories and reliable predictive equations for potential P loss developed for those soil categories. Grouping soils by chemical characteristics (calcareous vs. noncalcareous) allowed development of significant predictive equations.

Differences observed between depths of soil sampling may also be very important in developing a P soil test for environmental response purposes. Besides the physical problem of obtaining a consistent soil sample on the soil surface, soil sampling at the 0- to 2.5-cm depth tended to increase variability, indicating that sampling at this depth may be problematic.

Likewise, soil sampling at the 0- to 15-cm depth may also be problematic for soil testing for potential environmental P losses. The potential problem with the data developed for the 0- to 15-cm depth is the steepness of the curve, with differences between agronomic response levels and excessive levels being small. The result of a steep response curve is that small differences in soil test P concentration could result in huge differences in interpretation. This would in turn put more pressure on sampling methods in the field and measuring equipment in the laboratory to assure accuracy of measurements. Since large changes in the field would be measured with small differences in soil test P results, it would be difficult for operators to follow the progress of P enrichment in their fields. In addition, a reduction in the capacity to distinguish difference between soil types may result in difficulty for developing predictive equations over a large grouping of soil types.

The data indicate that sampling at the 0- to 5-cm depth may arrive at the best results both from limiting management problems and by increasing the likelihood of developing reliable predictive equations across a large number of soil types.

The data presented in this study demonstrate two important points: (1) differences exist in soil that may affect the level of DMRP contributed to the environment at the same level of soil test P and (2) these differences could potentially be used in the management of CAFOs to reduce DMRP levels in runoff. Also, the data demonstrate that there may be chemical or physical characteristics of soils that can be used to develop application criteria in predictive tools such as the Phosphorus Index.

Editor's note: *Content was adapted from the paper "Relationship of Soil Test Phosphorus and Sampling Depth to Runoff Phosphorus in Calcareous and Noncalcareous Soils," which was published in the Journal Environ. Qual, 2002 31 and is courtesy of the authors H. A. Torbert, T. C. Daniel, J. L. Lemunyon, and R. M. Jones.*

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Relationship of Soil Test Phosphorus and Sampling Depth to Runoff Phosphorus in Calcareous and Noncalcareous Soils

October Self-Study Examination

DETACH HERE

1. Impairment of rivers, lakes and estuaries by agricultural nonpoint source pollution has been reported at:

[ ] a. 60%, 50% and 34% respectively.
[ ] b. 55%, 45% and 32% respectively.
[ ] c. 50%, 40% and 30% respectively.
[ ] d. 45%, 35% and 28% respectively.

2. Usually the greatest potential for nonpoint P contribution to surface waters occurs in watersheds with:

[ ] a. intensive urban development.
[ ] b. intensive crop production.
[ ] c. intensive animal production.
[ ] d. extensive wildlife habitat.

3. Elevated soil P levels can be the result of:

[ ] a. poor soil structure.
[ ] b. long-term manure application to soils at rates in excess of crop uptake.
[ ] c. long-term manure application to soils at a rate equivalent to crop uptake.
[ ] d. long-term fallow.

4. Studies have found that the relationship between the level of soil P and runoff P varies depending on:

[ ] a. soil type.
[ ] b. sample techniques.
[ ] c. statistical analysis.
[ ] d. topography.

5. Runoff samples were analyzed for:

[ ] a. runoff P.
[ ] b. particulate P.
[ ] c. total P.
[ ] d. dissolved molybdate reactive phosphorus.

6. The greatest potential for increased eutrophication of surface waters results from:

[ ] a. total P.
[ ] b. particulate P.
[ ] c. DMRP components.
[ ] d. runoff P.

7. The study found the best depth for examining DMRP losses regardless of the extractant used was:

[ ] a. 0 to 1 cm.
[ ] b. 0 to 2.5 cm.
[ ] c. 0 to 5 cm.
[ ] d. 0 to 15 cm.

8. Compared to noncalcareous soil, the two calcareous soils have a much lower concentration of DMRP in runoff at:

[ ] a. the 0 to 2.5 cm zone.
[ ] b. the 0 to 5 cm zone.
[ ] c. the 0 to 15 cm zone.
[ ] d. all depths.

Over

9. A regression equation with a reasonable r^2 was developed for:

[ ] a. the 0 to 2.5 cm depth.
[ ] b. the 0 to 5 cm depth.
[ ] c. the 0 to 15 cm depth.
[ ] d. all of the sampling depths used in the study.

10. The data in this study demonstrate that significant predictive equations could be developed:

[ ] a. using the 0 to 2.5 cm sampling depth.
[ ] b. by grouping soils by chemical characteristics.
[ ] c. by ignoring runoff losses of DMRP.
[ ] d. by grouping soils according to geography.

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