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Precision agriculture and nutrient management

Crop prices are decreasing after several years of good prices and public concerns about nutrient application impacts on water quality are increasing. The profitability of nutrient management can be increased and impacts on water quality can be decreased by using a variety of precision agriculture technologies. Global positioning systems (GPS), yield monitors, various forms of remote sensing, variable-rate technology (VRT), and geographical information systems (GIS) software are available for use by producers and crop consultants. Georeferenced soil sampling and crop scouting, and other practices complete the technological package. Soil testing is a diagnostic tool very well adapted to site-specific management to better describe nutrient levels across a field and decide nutrient application rates. The spatial variation of nutrients over a field at various scales makes soil sampling the most important and common source of error in soil testing. Therefore, georeferenced soil sampling and fertilizer, manure nutrients, or lime application with VRT can improve the efficacy and the economics of nutrient management compared with the conventional practice of collecting a composite soil sample from large areas and applying a single nutrient over an entire field or to large areas within a field. A more precise nutrient application is even more important with unfavorable crop prices or higher than normal fertilizer prices.

Soil sampling and precision agriculture

Variable-rate P and K fertilization or liming can be used on the basis of sampling areas identified according to soil types, landscape, or previous management but many believe that it should be based on denser grid sampling. The conventional sampling by soil map unit often is not the best for precision agriculture because soil survey maps may not have the required scale and precision that may be required. Soil-test variability can be very large even within soil map units or seemingly uniform field areas, and tends to be larger in fields with long histories of cropping and fertilizer or manure application. Grid soil sampling is based on the subdivision of a field into a systematic arrangement of small areas or cells (usually 2.5 to 4.4 acres) or “points” at the intersection of grid lines. Composite soil samples usually made up of 4 to 12 cores are being collected to represent each cell or point. Early users collected the soil cores using either a random or systematic pattern from the entire area of each cell (cell sampling) but lately most collect the cores from areas 400 to 1200 sq. ft (point sampling). Iowa research has shown that not always cell or point sampling is better to identify within-field areas with different crop response to fertilization. Few cores taken from the entire cell area often does not represent small-scale variability well, which also introduces large temporal variation on long-term soil-test trends. Taking cores from a smaller area may result in more consistent trends over time. However, the sampling “point” should not be too small, such as from around a pick-up or four-wheeler.

Zone sampling can reduce sampling and testing costs compared with grid sampling while maintaining acceptable information about nutrient variation. Zone sampling assumes that sampling areas with relatively homogeneous soil-test values can be identified based on previous management and soil or crop characteristics which can be mapped using various precision agriculture tools. Criteria used to delineate zones vary widely. Soil map units and slope or erosion phases are common criteria, but elevation models, soil or crop canopy images, yield monitor maps, and estimates of soil electrical conductivity through on-the-go measurements of soil electro-magnetic inductance or direct sensing (EC) often are very useful zoning tools.

However, zones with homogenous basic soil properties or yield may not have homogeneous soil-test values due P because variation due to other non-measured soil properties and management often have a greater impact on variability. Work in Iowa and North Dakota has shown that zone sampling methods that include aerial images of soybean canopy may be as good, or even better, than grid sampling when fields have areas of calcareous soils intermingled with neutral or acidic soils because the iron-induced chlorosis can map very well the calcareous areas. However, research also has shown that often this is not the case for P and K. Work in the early 2000s on six Iowa fields by Mallarino and Wittry compared sampling methods based on soil survey maps, detailed soil maps (< 1:5,000 scale), cells 3 to 4.4 acres in size, elevation zones, and zoning based on several layers of information. They showed that no sampling approach was always the most effective in all fields in reducing the within-unit soil-test variability, but sampling based solely on soil survey maps always was the least efficient for P and K. In the late 2000s, Sawchik and Mallarino used differential within-field yield response of corn and soybean to fertilization to assess the efficacy of various grid and zone sampling methods in seven Iowa fields evaluated three to four years. They found that grid sampling based on 2.5-acre cells was the most effective method, zoning based on elevation and EC was intermediate (about one-half as effective as grid sampling), and sampling by soil series was by far the least effective. Figure 1 shows results of soil sampling for P in two contrasting fields using grid sampling by soil type or zones.

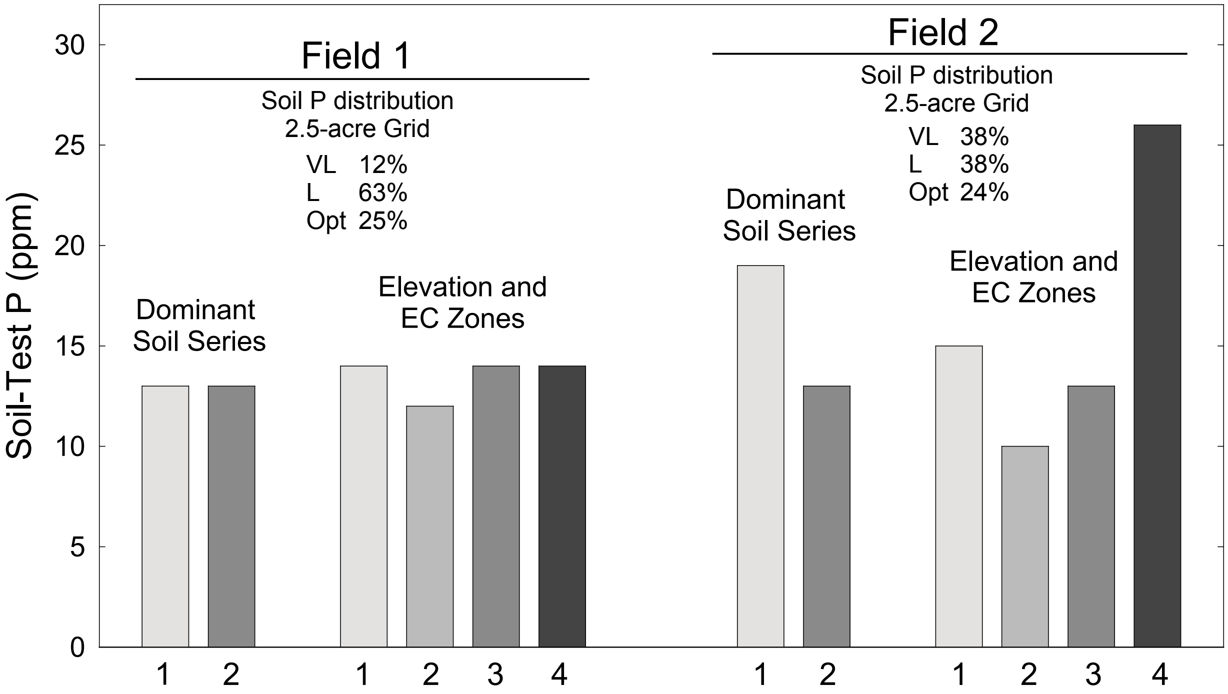

Figure 1. Soil-test P in two contrasting fields from samples taken using different sampling methods (adapted from Sawchik and Mallarino, 2007).

Research also has shown the importance of including more than just four or five cores in a composite soil sample, even with a dense grid-point sampling approach. Figure 2 shows an example for P. This is often the case for P and K, but to a lesser extent for pH and organic matter, in fields with long histories of fertilization or manure application because the very small-scale variability can be very large. Most often a minimum of 10 to 15 soil cores should be collected for composite samples within each sampling unit regardless of the sampling method used, if the expected soil-test results are to be within about 20% of the actual value.

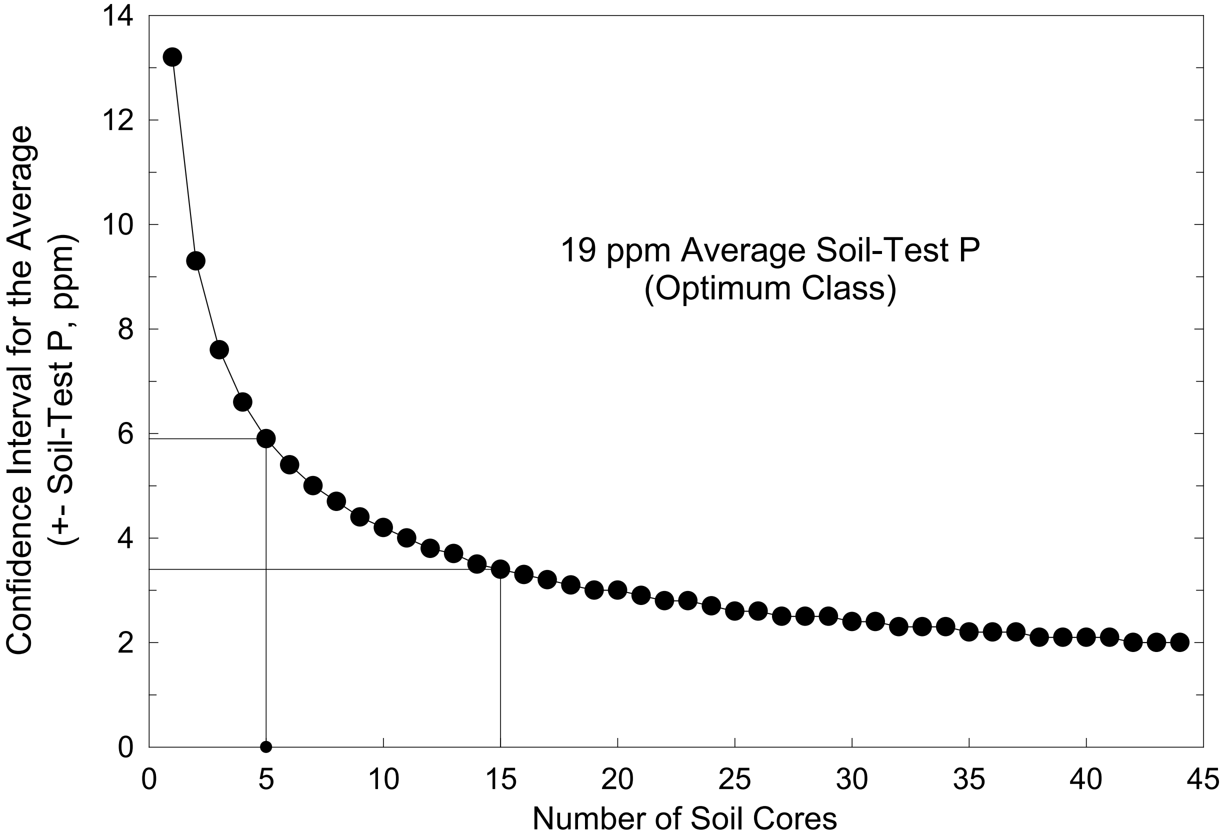

Figure 2. Example of error from the actual soil-test P average by including different numbers of cores in soil samples (estimated by testing many single cores from an about one acre are).

Variable-rate impacts on crop yield and nutrient or lime applied

On-farm research projects have been developed over the years to assess the potential of variable-rate fertilization and liming in Iowa. Replicated strip trials were conducted on many fields that were evaluated from one to three cycles of two-year corn-soybean rotations. In one type of trials (twelve fields for P, eight for K, two for lime, and two with P-based liquid swine manure) treatments applied to experimental areas 10 to 25 acres in size were a non-fertilized or unlimed control, a variable-rate application based on soil-test results from samples taken by dense grid-point sampling, and a uniform rate based on the average soil-test value for each experimental area. In another type of strip trial for lime (14 fields) and K (37 fields) treatments were a control (no lime or no K) and a fertilized or lime uniform rate. The nutrients were applied using commercial fertilizer spreaders equipped with GPS receivers and controllers. Strip yield averages were used to assess field-average yield responses. Yield and soil-test averages also were calculated for small areas delimited by the width of the soil sampling cells, which were used to assess treatment effects for parts of the field testing within different soil-test categories or different soil types.

Field-average yield increases from P fertilizer, K fertilizer, manure P, or lime were statistically significant in more than two-thirds of the fields and years, although the magnitude of the responses varied greatly. Study of soil-test values across the small sampling cells showed a very high soil-test variation in most fields. When GIS methods were used to study yield responses a very high yield response variation also became obvious. Figure 3 shows typical results for some K strip trials. Approximately similar results were observed for other strip trials with P or K and corn or soybean. These results show a very high potential in many fields for dense soil sampling and VRT, because this technology allows for application of the nutrient needed at rates needed across a field, as long as the soil-test variation is identified appropriately. The data in the figure have to be interpreted with care, however, because the soil sampling used for that research was based on a very dense grid-point sampling approach (0.5 to 1 acre cells) which was denser than the usual 2.5-acre grid sampling.

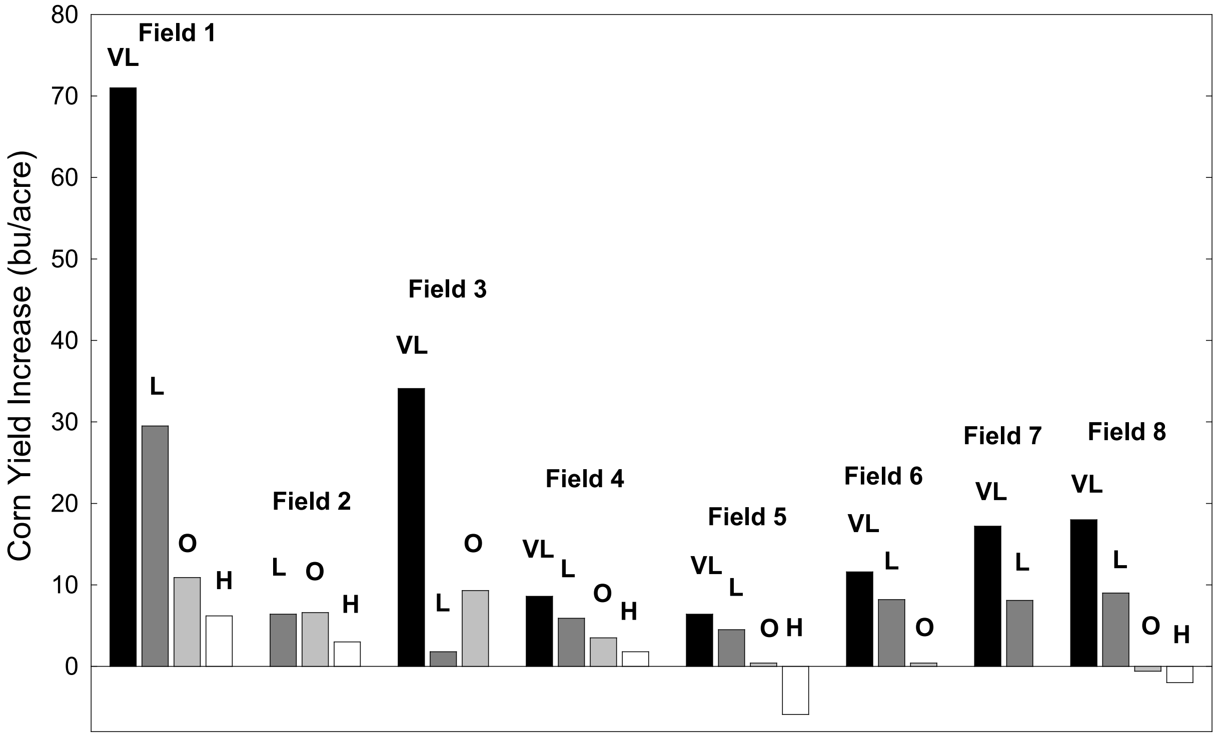

Figure 3. Within-field variation of corn yield response to K fertilization in several Iowa fields having initial soil-test K testing within different interpretation classes.

In spite of the obvious within-field variation in soil-test values, often there were no large entire-field yield differences between uniform and variable-rate fertilizer application methods. Figure 4 shows examples of the inconsistent differences between K fertilizer application methods for yield. This variable result makes sense and is explained by several reasons. Use of VRT often increased yield more than the uniform application in areas with very low soil-test values, but not always because sometimes the uniform rate applied enough nutrient to maximize yield. Other times, large yield differences in favor of VRT were not reflected for an entire field average because the low-testing areas were small and even large differences were diluted by no response or random differences in larger high-testing field areas. Also, in many fields the yield responses were small because producers try to maintain Optimum or higher soil-test levels, so there was no large crop response. Therefore, the actual impact of VRT on crop yield and the profitability of fertilization will vary greatly depending on the level at which soil-tests and yield (impacting estimated removal) vary across a field and the proportion of low-testing areas.

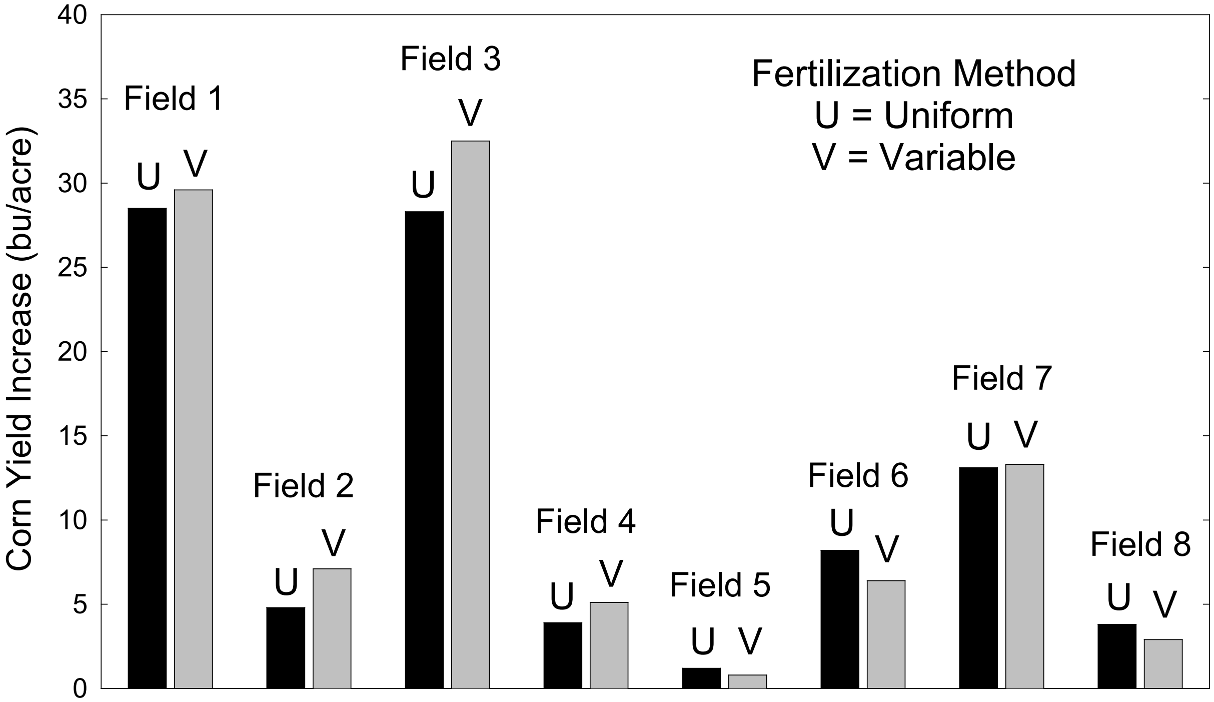

Figure 4. Average corn yield response to K fertilization across each of eight Iowa fields using uniform- or variable-rate application methods.

The average amount of P, K, or lime applied per acre by each method varied considerably among fields and nutrients, but often was less for the variable-rate method. The savings often were much larger for lime than with P or K fertilizers because of the large amounts applied. Use of VRT resulted in less product applied in about one-half of the times, the two methods applied about the same amount in about one-fourth of the times, and the VRT method applied more in the other one-fourth of the times. Similarly to impacts on yield, the impact of VRT on the amount of fertilizer or lime applied over a field, and increased farmer profits from less product applied while maintaining yield, will depend on the level at which soil-tests vary across a field and the proportion of low-testing areas.

Variable-rate application effects on soil-test variability

Results of dense soil sampling after fertilization and crop harvest showed that VRT without any doubt does reduce unnecessary fertilizer or lime application to high-testing field areas and reduces within-field soil-test variability. Figure 5 shows, as an example, soil-test P results from samples collected after two corn-soybean rotation cycles and applying no P, a uniform single P rate, and a variable P rates before corn. Using VRT increased soil P of low-testing areas more than a uniform rate application but reduced soil-test levels in high-testing areas. Therefore, although variable-rate application may not always increase yield for an entire field compared with a uniform application, it manages fertility better.

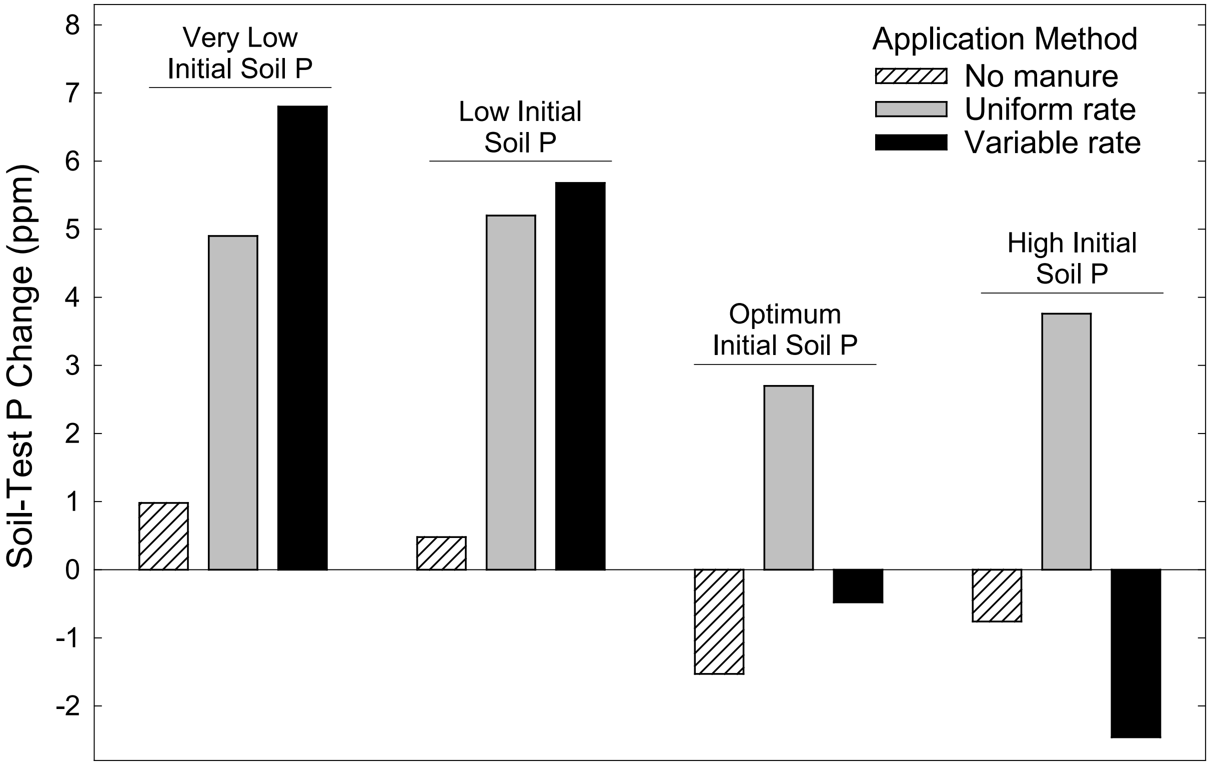

Figure 5. Effect of no P application and uniform- or variable-rate manure P application on within-field soil-test P change after P fertilization for two corn-soybean rotation cycles.

Implications for phosphorus water quality

The use of cost-effective soil sampling approaches suitable for use of VRT is particularly useful for P because several studies have documented linear increases in P loss from fields when soil P levels increase. The research mentioned above strongly suggests that variable-rate P application can reduce P loss from fields compared with a uniform application and likely results in reduced P loss from fields and improved water quality. However, the potential for P delivery from fields also is greatly affected by other soil properties and erosion, surface water runoff, and subsurface drainage that control P delivery off fields. Phosphorus assessment tools, or P indices, have been developed and are in use to better estimate the risk of P loss from fields compared with estimates provided solely by soil-test P and planned P application methods or rates. Therefore, few argue against the potential value of dense grid soil sampling coupled with VRT for improving STP assessment and P application management. Zone sampling also adapts well to VRT because the criteria to delineate zones based on many layers of information can be adapted to essentially any desirable number of zones and soil sampling density.

Phosphorus index ratings estimated for different field areas could be used to establish sampling zones as another information layer to complement other information layers discussed above. The information available in digitized soil survey maps can be complemented with high precision elevation maps (from which more accurate estimates of slopes can be obtained), EC maps, waterway maps, or imagery of bare soil or crop canopies to produce an approximate index of the risk of P loss. The results of many studies did show that field zoning is useful to prioritize field areas that require significant changes in soil conservation or P management practices to reduce the risk of P delivery to water resources.

Summary and recommendations

1. Variable-rate technology for P, K, lime, and manure application greatly improves nutrient management and can potentially reduce nutrient loss from fields and improve water quality. However, the most significant issue to use VRT effectively is the soil sampling method and the soil-test interpretations on which it should be based. It will be agronomically and economically most effective with large within-field soil-test and yield response variation and when appropriate nutrient rates are applied. Use of VRT in overall high-testing fields with application of unneeded nutrients will not be effective from either farmer's economy or water quality perspectives.
2. Grid and zone sampling methods describe within-field soil-test variability and predict crop yield response better than the traditional sampling by soil type method. Grid sampling often is more effective for P and K than zone sampling in fields with long histories of fertilization or manure application because often there is no good relationship between soil-test values and stable soil properties or landscape features in these conditions.
3. Consideration of soil sampling and testing costs together with crop and fertilizer prices suggests that grid sampling will be a cost-effective practice compared with zone sampling when soil-test values vary from low to high and/or the variation in yield levels is large. There may be more justification of denser sampling for environmental purposes, but this will likely come at a significant cost. Also, a more frequent soil sampling (e.g., every 2 years) can be better justified for zone sampling because often results in fewer samples than grid sampling.
4. A significant issue in soil sampling that can be addressed at a low cost is the number of soil cores required for each composite sample to provide a reasonable estimate of the average soil-test level within a sampling area. Most often a minimum of 10 to 15 soil cores should be collected for composite samples within a sampling unit regardless of the sampling method used.