HOW CAN WE MAKE INTENSIVE SOIL SAMPLING AND VARIABLE-RATE P AND K FERTILIZATION COST-EFFECTIVE?

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Introduction

Precision agriculture technologies have potential for improving soil fertility evaluation and nutrient management. Global positioning systems (GPS), yield monitors, various forms of remote sensing, geographical information system (GIS) software, and variable rate technology are available to producers. Intensive soil sampling, crop scouting, and other practices complete the new technological package. Soil testing is a diagnostic tool that adapts well to site-specific management because it can evaluate nutrient availability of areas of different sizes. However, the spatial variation of nutrients within fields makes soil sampling one of the most important sources of error in soil testing. Intensive soil sampling, soil test mapping, and variable-rate application of fertilizers or manure can improve the efficacy of the conventional practice of collecting soil samples from large areas and applying a uniform fertilizer rate over a field. Although variable-rate fertilization can be used on the basis of sampling areas identified according to soil map units, topography, and/or previous management, many believe it should be based on grid sampling. The conventional sampling by soil map unit may not be appropriate for precision agriculture because available soil survey maps may not have the required precision and often there is high nutrient variation within soil map units.

This presentation discusses soil sampling methodology and summarizes results of ongoing Iowa research. The research compares various soil sampling methods and fixed-rate versus variable-rate P or K fertilization conducted in various producers' fields. The research is not based on simulations based just on soil test data. It evaluates the effectiveness of intensive grid sampling schemes and the effectiveness of current variable rate technology.

Comparison of Soil Sampling Methods

The amount and pattern of nutrient variability patterns vary greatly between fields and are affected by soil type, topography, previous fertilization history, and many other factors. Universities traditionally have recommended a sampling method based on soil map units and previous management, which is a type of stratified sampling. Sampling areas are separated within a field according to factors known to influence the availability of nutrients in fields, such as soil type, topography, and crop, soil, and fertilization management practices. At least one composite soil sample made up of 12 to 15 cores is collected at random from each sampling area. This approach seemed to work well until the late 80s, when dealers and producers began to adopt precision agriculture technologies. These technologies (mainly GPS) allowed for the combined recording of soil-test values and geographical coordinates of sampling points and the processing

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of information in many layers that could be easily visualized in maps. This new development lead to a full appreciation of the high nutrient variability in most fields. It became obvious that seemingly uniform soil map units had very high nutrient variability, especially P, K, and pH, and that variability patterns often did not follow patterns of soil map units. Thus, grid sampling methods that ignore landscape or soil mapping units began to be adopted at a fast rate.

Grid sampling subdivides of a field into a systematic arrangement of small areas or cells (usually 2.5 to 4.4 acres), and one composite sample usually made up of 6 to 12 cores is collected from each cell. Early users collected cores following either a random or a systematic pattern from the entire area of each cell, which is called grid-cell sampling. Lately, most collect the cores from small areas (500 to 1500 sq. ft.) located near the center of each cell, which is called grid-point sampling. Soil-test values collected by grid sampling may be directly mapped to represent the cells as such or data can be used for gridding by means of several interpolation methods available in computer software. If each soil sample represents each sampling area appropriately and there are enough points over a field, the interpolation method chosen usually is not a major issue. Initial cell sizes of about 4 acres soon did not seem small enough to describe the small-scale variability of fields, and a cell size of about 2.5 acres is now used by many. As a consequence, 20 to 30 samples are collected from fields where rarely more than four or five samples were collected before. Obviously this type of soil sampling is more expensive than the traditional method. This situation generates three important questions: One is if intensive grid sampling really describes nutrient variability better. The other is if current variable-rate fertilization practices makes efficient use of the information generated. The third is if the new technological package being implemented is cost-effective to producers. Ongoing studies in Iowa were designed to answer these questions.

A large project has compared various sampling strategies for P, K, pH, and organic matter. The procedures used have included grid-point sampling of cell ranging from 0.5-acre to 4-acres in size, grid-cell sampling of about 4-acre cells, sampling by soil map unit and topography, and collecting composite or single-core samples along transects using a spacing that ranges from 3 inches to 20 feet. The maps in Fig. 1 show, as an example, soil-test P data for three typical fields. Values were assigned to cells following Iowa State University (ISU) soil-test interpretations. The results show that markedly different answers and fertilization rates result from using these schemes, and that no general rule applies. Conclusions other that many samples represent the true soil-test levels and distribution better than fewer samples are not obvious. Similar results were observed for K and pH, although organic matter tends to follow soil map units better. The results from intensive transect sampling show that the root of the problem is in very high small-scale variability in most fields. Figure 2 shows examples for soil-test P data collected from intensively sampled transects. Variation in soil types, topography, previous crops, or feeding lots usually create variation over a scale of several acres. Tillage, fertilization, and manure applications also create high variability on a scale of a few feet or inches. In many fields the variability does not follow the distribution of soil map units, the patterns differ between fields, the variability over a few feet often is similar to that of areas several acres in size, and variation patterns for P, K, and pH often do not coincide. A likely reason for these results is the long histories of fertilization and liming in Iowa. Cyclic variability patterns in many fields further suggest that much of the variability is created with equipment used to apply fertilizers or manure.

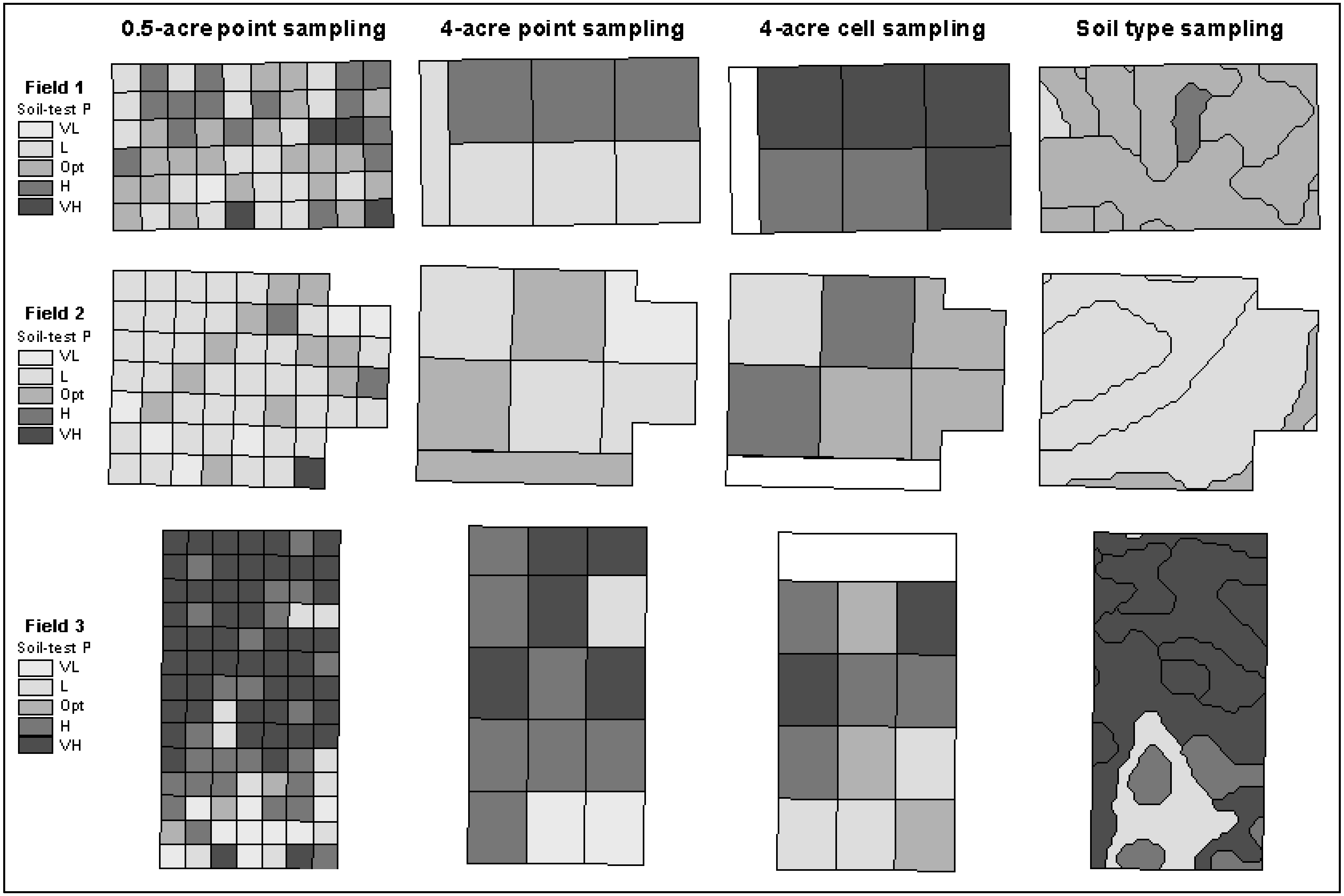

Fig. 1. Effect of the soil sampling method on estimates of soil-test P for three Iowa fields.

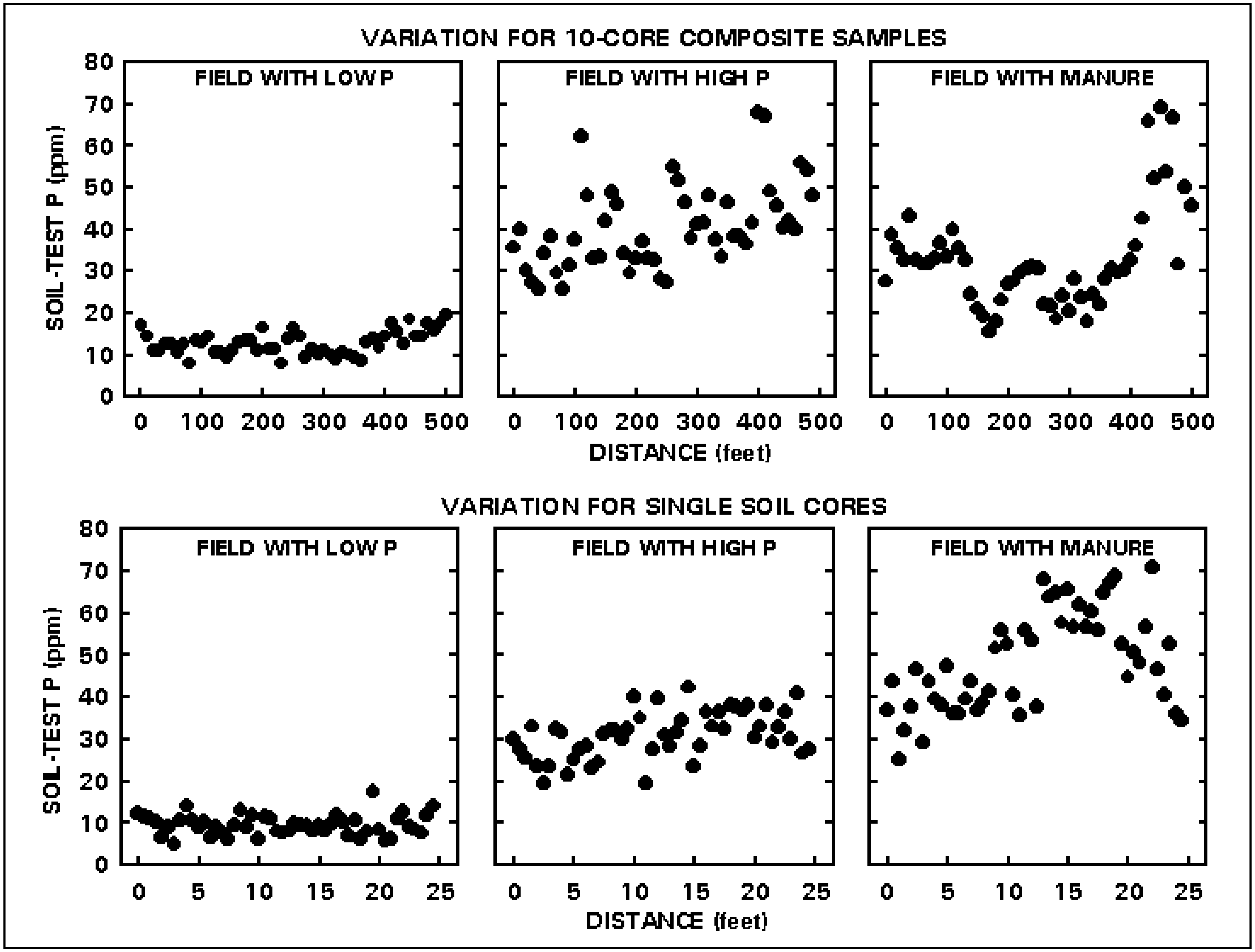

Fig. 2. Small-scale variability of soil-test P along intensively sampled transects for three Iowa fields.

Attempts to find a sampling scheme that is the best across fields have been unsuccessful. Moreover, a sampling scheme that is best for one nutrient but may not be the best for others. The particular amount and pattern of variability for each nutrient in a field determines the most appropriate sampling intensity and strategy. How any grid sampling scheme compares with the traditional less expensive sampling by soil map unit vary across fields and nutrients depending on the amount of small-scale variation (which is higher in fields with long fertilization histories and when banding or manure is used), how contrasting the soil map units of the field are in terms of properties that influence nutrient availability and removal by crops, and on the scale (detail) of the soil survey map used. A sampling by soil map unit does not emphasize measuring the nutrient variation within map units, and attempts to represent areas with apparently uniform soil types under the assumption that the variation within map units is smaller than the variation across units. The complexity of nutrient variability largely explains results of on-farm evaluation of the effectiveness of grid sampling and variable-rate fertilization.

Comparison of Variable-Rate and Fixed-Rate P and K Fertilization

Several separate strip-trials for P or K were established on producers' fields since 1996. Soil samples were collected following a systematic grid-point sampling scheme with a sampling area approximately 900 sq. ft. in size at the center of 1/5-acre to 3/4-acre cells. This sampling method is much more intensive than any method a producer could afford. The fertilizer treatments were applied for either corn or soybeans to long strips measuring 60 feet in width with commercial fertilizer spreaders equipped with DGPS receivers and controllers, and were replicated four to five times across each field. The ISU P and K recommendations for the two-year corn-soybean rotation were used. The fixed fertilization rate was uniform within a field but varied between fields because field-average soil-test values and yield potential usually differed. Grain yields were harvested and recorded with combines equipped with yield monitors and real-time DGPS receivers. The procedures used minimized errors due to borders, yield monitor calibration, waterways or grass strips, and others. Grain from each strip was weighed at some fields, and there was little or no yield differences with the yield monitor estimates.

Tables 1 and 2 show summaries of soil-test values and treatment differences for the P and K trials. There was high soil-test variation in most fields, and values encompassed several soil-test interpretation classes. Large to moderate yield responses to P or K should be expected in the very low and low classes, little or no response should be expected in the optimum class, and no response should be expected in the higher classes. The field-average yield response to P fertilizer was large or moderate in Fields 2, 3, 4, and 8, was small in Fields 5, 7, and 11, and there was no significant response in Fields 1, 6, 9, and 10. The field-average response to K fertilizer was large or moderate in Fields 2 and 3, was small in Field 5, and there was no significant response in Fields 1 and 4. There was no yield difference between the fixed and variable rate application methods in most fields. Exceptions were Fields 2 and 5 for P, and Field 2 for K where the variable-rate method produced slightly higher yield than the fixed-rate method. The average amount of P or K fertilizer applied usually was lower with the variable-rate method, except for three fields. The differences in fertilizer amounts applied varied greatly between fields depending on the levels and distribution of soil test values.

Statistical and GIS analyses of treatment effects for areas within each field with different soil test values (which cannot be shown in this short report) showed that, as expected, the yield response usually was higher when soil-test P or K was in the very low or low interpretation classes compared with the optimum class, and that seldom there was a yield response in areas testing in the high class or higher. This statement does not imply that there was always a yield response in low-testing areas. This is not surprising because crop yield also is affected by other growth factors which could have precluded or masked any response to fertilization. There was another important reason, however, which may also explain the little or no advantage of the variable-rate method even when there were some low-testing areas in most fields. In many fields the areas testing low corresponded to isolated sampling cells, not to contiguous and large low-testing areas. Thus, and because of very high small-scale variability (over a few feet) is observed in many fields, it is possible that those isolated cells represent just the small area sampled and not a larger area. If this were the case, neither the variable rate technology nor the yield monitor are precise enough to apply fertilizer or to measure yield at such a small scale. When low-testing areas were contiguous and large, such as in Fields 2 and 5 for P and Field 2 for K, the responses were significant and the variable-rate method produced higher yields than the fixed-rate method, likely because the uniform fertilizer rate was lower than needed to maximize yield.

Table 1. Effect of fixed and variable-rate phosphorus fertilization for the corn-soybean rotation on grain yield and phosphorus fertilizer used.

					Difference Variable minus Fixed †		
	Initial Soil-Test P			Fertilized		Grain Yield	
Field	Min	Mean	Max	crop	P_2O_5 used	1st crop	2nd crop
	---------- ppm ----------				lb/acre	--------- bu/acre -------	
1	8	18	34	Corn	4	1.6	na
2	6	15	35	Corn	-6	2.2 *	-0.1 ‡
3	2	11	66	Corn	-19	0.8 ‡	0.4 ‡
4	6	18	43	Corn	13	1.0 ‡	na
5	5	9	22	Corn	17	3.8 *	na
6	13	22	96	Soybean	-5	-0.6	na
7	8	16	24	Soybean	-11	-0.7 ‡	-1.5
8	4	11	23	Soybean	-28	0.0 ‡	-0.9 ‡
9	6	20	53	Soybean	-21	0.5	na
10	4	21	72	Soybean	-17	0.3	na
11	10	21	40	Soybean	-52	1.2 ‡	na

† Recommendations for a one-time P application for the 2-year rotation were used. Negative numbers indicate less fertilizer applied with the variable rate method.
‡ Significant response to P fertilization but no difference between fertilization methods.
* Additional significant difference between fertilization methods.
na = Yields for the 2nd crop of the rotation were not harvested or are being processed at this time.

It is fairly obvious that with current costs of variable-rate application, the yield advantage and savings (sometimes) in fertilizer used would offset additional costs in very few fields. If the costs of intensive grid soil sampling (2.5-acre and once for the 2-year rotation) are considered, the technology package probably would have offset additional costs only in Field 2 for K. Of course, these differences cannot be extrapolated to other fields because differences depend on the rates used and on the level and distribution of soil test values within a field. Consideration of differences in the amounts of fertilizer applied, crop yields, and costs (equipment, soil sampling, etc.) determine the economic benefit of variable-rate fertilization.

Table 2. Effect of fixed and variable-rate potassium fertilization for the corn-soybean rotation on grain yield and potassium fertilizer used.

Field	Initial Soil-Test K Min	Initial Soil-Test K Mean	Initial Soil-Test K Max	Fertilized crop	Difference Variable minus Fixed † K_2O used	Difference Variable minus Fixed † Grain Yield
	----------	ppm	----------		lb/acre	bu/acre
1	132	172	219	Corn	-67	-2.3
2	38	85	161	Corn	-17	6.9 *
3	70	129	276	Corn	18	-0.8 ‡
4	117	140	221	Soybean	-29	-0.1
5	56	88	136	Soybean	-22	-0.2 ‡

† Recommendations for a one-time K application for the 2-year rotation were used. Negative numbers indicate less fertilizer applied with the variable rate application. Yields for the 2nd crop of the rotation (2000 season) are being processed at this time.
‡ Significant response to K fertilization but no difference between fertilization methods.
* Additional significant difference between fertilization methods.

Cost-Effective Alternatives for Producers

Adoption of a more intensive and expensive soil sampling plan will not be cost-effective unless the new plan and the resulting change in fertilization method result in higher yields and/or lower fertilization costs. Results of ongoing short-term field evaluations of variable-rate and fixed-rate fertilization methods suggest that the yield advantage of variable fertilization usually is small or nonexistent. The results do show, however, that variable-rate fertilization tends to reduce soil-test variability (although not as much as many expected), reduces fertilizer application to high-testing areas, and allows for better maintenance of P and K because yield-monitor maps provide good estimates of yield potential for different parts of a field. Also, there is little doubt that P fertilizer or manure application using variable-rate technology can reduce potential P delivery to surface water resources. The ongoing experiments will be continued to evaluate crop and soil responses over various cycles of the corn-soybean rotation.

Obviously, a compromise is needed between soil sampling precision and economic feasibility. The impact of intensive soil sampling and variable-rate technology on yield and economic benefits will depend on the nutrient levels, nutrient distribution over a field, expected crop responses, and additional costs. Given the usually high small-scale P and K variability found in most Iowa fields, a major question is whether it can be measured cost-effectively. The answer from ongoing research is that it cannot possibly be done unless the sampling is spaced several years, and that major efforts should be dedicated to apply fertilizer more uniformly. Investing on expensive sampling schemes on predominantly high-testing fields will be even less cost-effective. Although there are low-testing cells in most fields that test optimum or high on average, usually they correspond to small isolated areas difficult to manage separately with variable-rate technology.

Two alternatives seem viable for reducing soil sampling costs and making variable-rate fertilization more cost effective. One is to space an intensive grid sampling scheme (2.5 acres or less) about four years over time. Many producers use this sampling frequency even though most universities recommend soil sampling on a two-year basis. This strategy reduces sampling costs and may produce precise estimates once every four years, but adds uncertainty at the same time. Because most Iowa producers apply P and K fertilizers once for the 2-year corn-soybean rotation and are maintaining P and K levels, previous yield maps could be used to spread fertilizers according to expected P and K removal for the second rotation cycle (two years after the grid-based fertilization). On the other hand, producers could take fewer samples every two years and improve the traditional sampling by soil map unit by doing a directed soil sampling, which is may also be referred to as management zone sampling. Yield maps, aerial photographs of bare soil and/or crop canopy (which do not have to be taken every year), electrical conductivity maps, and field histories can be used to separate distinct field areas for sampling. This sampling method should be based on several cores per composite sample (not just on the 4 to 8 cores as many take) and will not consider the small-scale variation. This approach is compatible with the fact that soils are sampled not only for P and K but also for other nutrients and for purposes other than fertilization. A combination of these two procedures by conducting an intensive initial grid-soil sampling and continuing with a management zone sampling could also be useful when producers begin to crop fields with essentially unknown history.

Conclusions

The major aspects that determine the effectiveness of variable-rate fertilization are the amount and pattern of soil test variability and the cost and quality of the soil test map on which it is based. Ongoing research suggests that a major question is if the high small-scale P and K variation can really be measured cost-effectively. Intensive soil sampling and variable rate fertilization will result in better distribution of fertilizers but will seldom produce higher yields unless large, contiguous areas of a field have contrasting soil test values. These soil test differences could be the result of soil properties that affect nutrient availability directly (for example, sandy, and very acid or alkaline soils) or indirectly through their influence on yield levels and P and K removal. Variable rate fertilization will not be cost effective when low testing areas are isolated small pockets across a field and/or when yield potential differences across a field are small. There is little doubt that P fertilizer or manure application using variable-rate technology could reduce potential P delivery to surface water resources.

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