CHALLENGES FOR MAKING INTENSIVE SOIL SAMPLING AND VRT PAY. ONGOING IOWA STUDIES WITH PHOSPHORUS [1]

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Introduction

Soil fertility evaluation and management can be greatly improved with the use of precision agriculture technologies. Differential global positioning systems (DGPS), yield monitors, various forms of remote sensing, geographical information system (GIS) computer software, and variable rate technologies are available for use to producers. Intensive soil sampling, crop scouting, and other practices complete the new technological package. Soil testing is a diagnostic tool especially adapted for site-specific management and, at the same time, DGPS and GIS can greatly improve soil testing. The spatial variation of plant nutrients over a field makes soil sampling one of the most important sources of error in soil testing. A very small amount of soil needs to represent many tons of soil and large areas. Intensive soil sampling, soil test mapping, and fertilizer application with variable-rate technology can improve the efficacy of fertilization and liming compared with the conventional practice of collecting soil samples from large areas and applying a uniform single fertilizer rate over each field. Although variable-rate fertilization can be used on the basis of sampling areas identified according to soil types, landscape, or previous management, many believe that 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 likely high nutrient variation within units.

Commonly used grid sampling methods are based on the subdivision of a field into a systematic arrangement of small areas or cells (usually 2.5 to 4.4 acres). Composite samples usually made up of 4 to 12 cores are collected to represent each cell. Early users of this technique collected the cores using either a random or systematic pattern from the entire area of each cell (cell sampling). Lately, most people collect the cores from small areas (400 to 1200 sq. ft) located near the center of each cell (point or node sampling). The importance of the numbers of cores collected for each composite sample and how they are collected is often overlooked. This is a very important aspect in soil sampling because the sample must represent each area appropriately. Soil-test values collected by grid sampling may be directly mapped to represent the cells or can be used for gridding by several interpolation methods. Although many believe that choosing the best gridding and interpolation method is important, research has shown this is not the case. If each soil sample represents each sampling area appropriately and there are enough points over a field, the interpolation method used is not a major issue. This presentation discusses various soil sampling methods and summarizes ongoing research to evaluate variable-rate P fertilization.

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2. Associate Professor and Research Associate, respectively.

Comparison of Soil Sampling Methods

Results of sampling many corn and soybean fields using various sampling methods show that the spatial variability of P, K and other nutrients in soils is very complex. Variability patterns vary greatly between fields and are affected by previous fertilization history. Ongoing studies compare three soil sampling procedures for P, K, and other nutrients. In one procedure, fields are subdivided into 0.5-acre cells. About 20 soil cores (6-inch deep) are collected from a 900 sq. ft. area chosen randomly within each cell. Data for these points are used to simulate point sampling varying in intensity from 0.5-acre to about 4-acre cells by selecting all or only some points for mapping. In a second procedure, the fields are subdivided into about 4-acre cells and samples are collected from the entire area of each cell. The third procedure is a simulated sampling by soil map unit based on the numerous point samples collected with the 0.5-acre point sampling procedure. In addition, from some fields, samples are collected over transects with a spacing from 3 inches to 20 feet.

The maps in Fig. 1 show soil-test P data for three of the fields. Similar results were observed for P in other fields and for K. In this example, values were assigned to cells and no interpolation was used. Iowa State University soil-test P interpretations were used. The data show that no general rule applies. Conclusions other than many samples should represent the true levels and distribution better than fewer samples are not obvious.

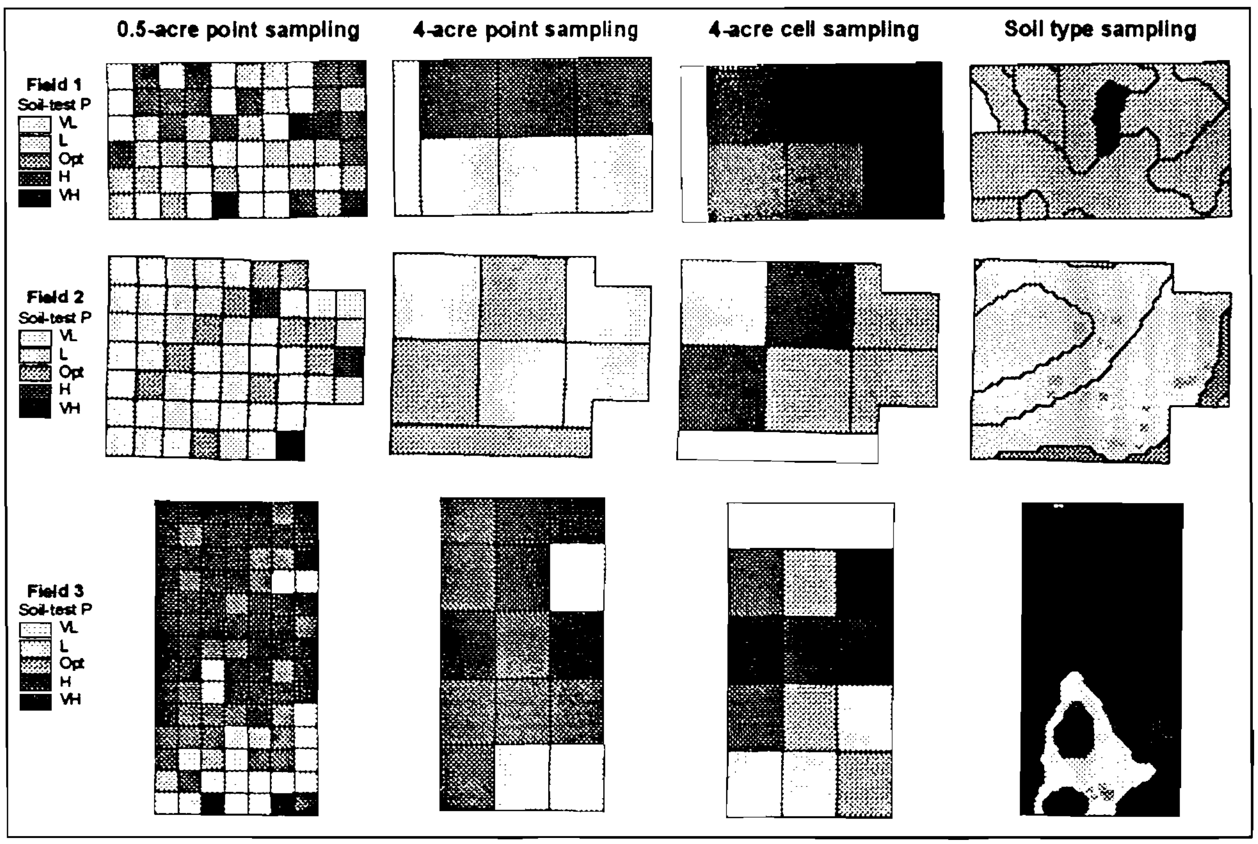

Fig. 1. Effect of the soil sampling method on estimates of soil-test P for three Iowa fields.

The results from intensive sampling of transects not shown here, demonstrate that the root of the problem is in the high small-scale variability present in most fields. Factors such as soil types, landscape, previous crops, or feeding lots usually create variation over a scale of several acres. Fertilization and manure applications also create high variability on a scale of a few feet or even inches. In very few fields the spatial variation for P, K, and pH follow the distribution of soil types or landscape characteristics. In most fields, the variability does not follow the distribution of soil types and the patterns differ between fields. Moreover, the variability over a few feet often is similar to that of areas measuring many acres and variation patterns for P, K, and pH often do not coincide. A likely reason for these results is the originally low testing soils and long histories of fertilization and liming in Iowa. Periodic patterns and high small-scale variability in most fields further suggests that much of the variability is created with equipment used to apply fertilizers or manure.

Attempts to find a valid optimum sampling scheme across fields have been unsuccessful. There is no single optimum sampling scheme, optimum number of points, or number of cores per sample across all fields. In many fields, commonly used grid sampling intensities still misrepresent the P and K availability. Sampling points within 4-acre or larger cells usually do not represent P and K levels appropriately because the variation within those areas is as large as the variation over the entire field. Interpolated maps based on these sampling schemes will always show some kind of neat soil test distribution but may not be an acceptable representation of the field. On the other hand, collecting many point samples could represent well a field (within acceptable margins of error) but may be too expensive for producers. How any of these grid sampling schemes or intensities compare with a traditional sampling by soil type vary depending on the amount of small scale variation. This depends mostly on fertilization history (rates, placement, years), how contrasting the soil types are in terms of properties influencing nutrient cycling and removal by crops, and on the scale (detail) of the soil survey map used. A sampling by soil type purposely does not emphasize measuring the nutrient variation within units and attempts to represent larger soil type areas for which, in theory, the variation within units is smaller than the variation across units.

Variable-Rate Fertilization

An intensive soil sampling plan will not be cost-effective for producers unless the intensive sampling and resulting change in fertilization method or rates result in higher yields and/or lower fertilization rates. This part of the presentation discusses preliminary results of ongoing work comparing fixed-rate versus variable-rate P fertilization using common grid sampling methods. Strip-trials were established on six fields from 1996 to 1998, and four additional P experiments were established this year but have not yet been harvested. 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 4.4-acre cells until 1997 and 0.2-acre cells since 1998. Approximately 12 cores were collected from each sampling area and the soil was analyzed for P and other nutrients. The treatments were applied to long strips measuring 60 feet in width and were replicated four to five times with a bulk fertilizer spreader truck equipped with a DGPS receiver and a controller. Local P recommendations for the two-year corn-soybean rotation were used for the fixed and variable P rates. The fixed P rate used was uniform within a field but varied between 90 and 140 lb P_2O_5/acre among fields. For the variable-rate treatment, no P was applied when soil-test P was in the high classes, and for other classes the rate varied from 70 to 140 lb P_2O_5/acre. Grain yields were recorded using combines equipped with yield monitors and real-time DGPS receivers. The procedures used minimize errors due to borders, yield monitor calibration, waterways or grass strips, and others. Weigh wagons were used to weigh grain from each strip at some fields. The yield responses were analyzed by various statistical procedures that will not be detailed here.

Table 1 shows a summary of soil-test P values and treatment differences. According to commonly used interpretations for corn and soybean, large to moderate yield responses to P 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 within the high or very high classes. The average response to P fertilizer was moderate in Fields 2 and 5, and large in Fields 3 and 6. The results in the table show little or no yield differences between the fixed and variable rate treatments. In spite of the statistical significance, the differences were agronomically meaningful only for corn in Field 2. Another aspect to consider when comparing fixed or variable fertilization rates is the total amount of fertilizer applied by each method. In this study, the average amounts of P fertilizer used were lower with the variable-rate treatment, except for one field. Of course, this difference varies greatly between fields depending on the levels and distribution of soil test values.

Table 1. Effect of fixed and variable rate P fertilization for six corn or soybean Iowa fields.

					Difference Variable minus Fixed †		
	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*	na
4	8	16	24	Soybean	-5	-0.6	na
5	13	22	96	Soybean	-11	-0.7**	-1.5**
6	4	11	23	Soybean	-28	0.0*	na

* Significant average response to P fertilization but no difference between fertilization methods.
** Significant response to P and between fertilization methods.
† Negative numbers indicate less fertilizer applied or lower yield for the variable rate application.
‡ na = Yields for the 2nd crop were not evaluated or are not harvested yet (Fields 3 and 4).

Analyses of treatment effects within each field showed that the response to P for areas with different soil-test P was different only in Fields 2, 3, and 6. As expected, the yield response was higher when soil-test P was low or very low. At Fields 1, 4, and 5, however, statistical analyses did not show a relationship between yield response and grid-sampled soil-test P. The result for these fields, although not expected, is not rare in field experimentation. One likely reason is that no cell tested very low in Field 5 (0 to 8 ppm, Bray-1) and only one tested very low in Fields 1 and 4, which were borderline with the low class. Another likely reason is that crop yields are affected not only by soil P but also by other growth factors, which could have had greater influence in yield and may have masked any response to P fertilization. In responsive low-testing areas, however, that there was a statistically significant yield difference between fixed or variable rates only for corn at some cells in Field 2, which explains the overall advantage of the variable rate at this field. Obviously, the additional fertilizer applied to low-testing areas with the variable rate method compared with the fixed rate method seldom resulted in significant additional yield increases.

A complete economic analysis is beyond the scope of this article because of the variety of assumptions and scenarios that should be involved, and because data for second crops of some fields are not available yet. It is fairly obvious, however, that given common costs of variable-rate application the yield response to variable rate compared with fixed rate offset additional cost only in Field 2. If one also considers the additional cost of grid sampling cells of 2.5 to 4 acres compared with the traditional sampling by soil mapping unit, the package did not offset the additional costs in any field. 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 amount of fertilizer applied, crop yields, and costs (equipment, soil sampling, etc.) determine the economic benefit of variable-rate fertilization.

Soil Sampling and Yield Response to Variable Rate

An intensive soil sampling plan will not be cost-effective unless the intensive sampling and resulting change in fertilization method or rates result in higher yields and/or lower rates. The results of field comparisons show little economic advantage for the variable rate in many fields. Obviously, a compromise between soil sampling accuracy and economic feasibility is needed. The impact of intensive soil sampling and variable-rate application on yields and economic benefits will depend on the nutrient levels, nutrient variability and distribution over a field, expected crop response, and additional costs. Given the high small-scale variability found, the major question is whether the small-scale P and K variation can be measured cost-effectively. The answer from ongoing research is probably no, and major efforts should be dedicated to apply fertilizer more uniformly. To invest in expensive sampling schemes on fields with predominantly high soil tests will not be cost-effective unless the sampling is spaced over 4 to 6 years (which usually is not recommended) due to the low probability of response, even if some cells test low. In most of these fields the low-testing areas often are a small proportion of the field and correspond to small isolated areas difficult to manage separately with variable-rate technology. Also, the fact that a point sample tests low does not necessarily mean that soil a few feet away also is low. And, the reliability of any interpolation method is in doubt when the small-scale variation is high and the sampling points are few.

On the other hand, producers could use several tools to improve the traditional sampling by soil map unit. Yield maps, aerial photographs of bare soil and/or crop canopy (which do not have to be taken every year), and field histories can be used to target specific areas for sampling. This sampling method has to be based on several cores per composite sample (not just 4 to 8 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 (herbicide management, for example). This approach is more likely to increase economic benefits to producers.

Conclusions

The results observed suggest that the major problem in using variable-rate fertilization effectively is the soil test map on which it should be based. The findings suggest that the major question is if the high small-scale P and K variation can really be measured cost-effectively. Also, with current fertilizer and crop prices and unless environmental aspects are considered, the traditional fixed-rate fertilization method seems more cost effective for most producers. Intensive soil sampling and variable rate fertilization will result in better and more environmentally sound distribution of fertilizers but seldom will produce significantly higher yields, at least in the short term. The cost-effectiveness of these practices for each field will depend on the variation in soil-test levels in relation to amounts required by crops, the large-scale variation of soil tests across a field, the expected yield response to fertilization, and the additional costs.

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