Variable-rate application for phosphorus and potassium: Impacts on yield and nutrient management

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Precision Agriculture, Soil Sampling, and Variable-Rate Technology

Soil fertility management can be improved by use of precision agriculture technologies. Global positioning systems (GPS), yield monitors, various forms of remote sensing, geographical information system (GIS) software, and variable-rate technology (VRT) are available for use by producers. Dense soil sampling, crop scouting, and other practices complete the new technological package. Soil testing is a diagnostic tool especially adapted for site-specific management. At the same time, GPS and GIS can greatly improve soil testing when these technologies are used to better describe nutrient levels across a field. The spatial variation of plant nutrients over a field makes soil sampling the most important and common source of error in soil testing. Therefore, Georeferenced soil sampling, soil test mapping, and fertilizer application with VRT can improve the efficacy of fertilization compared with the conventional practice of collecting a composite soil sample from large areas and applying a single fertilizer rate over a 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 dense 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 there high nutrient variation within mapping units. Grid 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). Composite soil 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 often is overlooked but is an 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.

On-Farm Research Comparing Variable-Rate Fertilization

We developed an on-farm research projects based on a very dense soil sampling method in order to assess the maximum possible potential of variable-rate fertilization in Iowa. Strip trials were conducted on 11 Iowa fields (six for P and seven for K), and each field was evaluated from one to three cycles of 2-year corn-soybean rotations. Treatments at separate P fields and K fields applied to replicated strips (experimental areas of 10 to 25 acres) were a non-fertilized control, a variable-rate method based on soil tests from samples taken using a dense grid soil sampling scheme, and a single-rate method based on the average soil test value for each experimental area. Treatments were replicated three to five times. Strip width usually was 60 to 70 feet and the length varied from 750 to 2000 feet across fields. The 2-year fertilizer recommendation for the corn-soybean rotation was applied every other year before corn or soybean crops depending on the field. The single-rate treatment was uniform within a field but varied among fields from 50 to 140 lb P_2O_5/acre in P fields and 50 to 140 lb K_2O/acre in K fields. The variable rates ranged from 0 to 140 lb P_2O_5/acre and from 0 to 180 lb K_2O/acre. Granulated fertilizers were applied using commercial fertilizer spreaders equipped with GPS receivers and controllers.

Composite soil samples (12 cores, 6-inch depth) were collected using a dense grid-point sampling method from about 900 square-ft areas located at the center of cells that were 0.5 to 1 acre acres in size across fields. Soil was analyzed for P (Bray-P1), K (ammonium acetate), and other nutrients. Iowa State University soil-test P and soil-test K classes were used to decide the P or K application rates. Grain yield was harvested with combined equipped with yield monitors and GPS receivers. Strip yield means were used to assess field-average yield responses. Also, yield and soil-test averages were calculated for small areas delimited by the width of the soil sampling cells. These averages were used o assess treatment effects for parts of the field testing within different soil-test interpretation classes and with different soil types.

Summary Results

Field-average yield responses to P fertilizer in the P fields and to K fertilizer in the K fields were statistically significant in more than two-thirds of the fields and years (site-years), although the size of the response varied greatly. In responsive fields, the average soil-test P or K of control strips always was Optimum or less. Study of soil-test values variation across the small sampling cells showed a very high soil-test variation in most fields. When GIS methods were used to study yield responses to the uniform P or K application, a very high yield response variation also became obvious. Figure 1 shows typical results for various soybean K trials. Approximately similar results were observed for corn and for P strip trials with both crops. These results show a very high potential in many fields for dense soil sampling to identify areas with contrastingly different soil-test values. The results also show a great potential for 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 has 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) that is not recommended for crop production.

In spite of the obvious variation in soil-test values and responses to uniform fertilizer rates applied to the strips, seldom there was a statistically significant grain yield difference between uniform and variable-rate fertilizer application methods. There were differences in four site-years for P and two-site year for K in approximately 50 site-years of research across all fields, years, and nutrients. However, the differences between methods were balanced because for each nutrient the uniform method increased yield more than the variable method in one-half of the instances and the opposite result was observed in the others. Figure 2 shows examples of the inconsistent differences between P fertilizer application methods for soybean. Approximately similar lack of significant and largely inconsistent differences was observed for corn and for K strip trials with both crops.

The average amount of P or K fertilizer applied per acre by each method varied considerably among fields, but often was less for the variable-rate method. This method applied less P or K than the uniform method in approximately one-half of the fields (6 to 60 lb P_2O_5/acre), the two methods applied about the same amount of fertilizer in about one-fourth of the fields, and the variable-rate method applied more than the uniform-method in the reminder of the fields (12 to 22 lb P_2O_5/acre). On average across fields, the variable rate method applied 9 lb P_2O_5/acre less than the uniform method. It is important to remember that the rates applied each time were those for the 2-year rotation. The results for the K fields were similar to those described for P fields, and on average the variable rate method applied 15 lb K_2O/acre less.

Analyses of grain yield responses for field areas initially testing within different soil-test classes showed frequent yield response to P or K only when STP or STK was Optimum or less (as shown in Fig. 1). However, the yield response in these low-testing areas seldom differed between the two application methods. In fact, sometimes yield for the uniform method was higher (probably due to random variation) and non-significant trends in favor of one method or the other sometimes were observed for high-testing field areas. Study of yield responses to P or K from field areas with different soil types sometimes showed different yield responses for contrasting soil types within a field but no differences between application methods. These results, although surprising for the low-testing areas because the variable-rate method was set to apply more P or K, agree with the general lack of differences for strip averages.

Several reasons could explain infrequent, small, and inconsistent differences observed between uniform and variable fertilization methods, even for low-testing field areas. One reason may be inadequate assessment of within-field soil-test variability, even with the very dense sampling approach used in the study. Previous soil sampling research that we conducted in many Iowa fields showed a very high soil-test variation that sometimes was as large over distances of a few feet as over many acres. Another possible reason is that we applied fertilizer amounts for the 2-year crop rotation applied once before the first crop. However, this only could explain a lack of difference between application methods for the first crop (because excess P or K likely was applied by both methods) but not for the second crop. Another possible reason might be that although there were yield responses to fertilization, in many fields responses were small because producers try to maintain Optimum or higher soil-test levels. Therefore, differences in small field areas would be diluted by no response or random differences in larger field areas.

We believe, however, that the most likely reason for a lack of difference between application methods is the use of P and K recommendations for low-testing soils designed to maximize yield and slowly build-up soil-test levels to Optimum levels over a few years. This reason was suggested before for similar results of approximately similar research conducted in the late 1990s for P-K mixtures in Illinois by N. W. Anderson and D. G. Bullock. If the P application rates are higher than needed to maximize yield, any higher P application with the variable-rate method compared with the uniform method would not result in higher yield unless the low-testing field areas are very large and test extremely low in P or K.

Variable-Rate Application Effects on Soil-Test Variation

Results of dense soil sampling after fertilization and crop harvest showed that the technology does reduce unnecessary fertilizer application to high-testing field areas and reduces within-field soil-test variability. Figure 3 shows, as an example, results from samples collected from six P strip trials after two corn-soybean rotation cycles and two fertilizer applications. The soil-test P variability was lower for the variable-rate method with the only exception of Field 2, which had a much higher variability (at least twice) than all other fields, even in non-fertilized strips. Therefore, although variable-rate application seldom increased crop yield compared with a uniform application, it did manage P application better. Similar results were observed for K fertilization, but this was a particularly useful result for P because several studies have documented linear or exponential increases in P loss from fields when soil P increases. The results strongly suggest that variable-rate P application can reduce P loss from fields compared with a uniform application over low-testing or high-testing field areas and could result in improved water quality.

Summary and Conclusions

The results of these on-farm trials suggest that the most significant issue to use variable-rate fertilization effectively is the soil sampling method and the soil test map on which it should be based. The findings suggest that a major question is if the high small-scale P and K variation can really be measured cost-effectively. Dense soil sampling and variable-rate fertilization will result in better and more environmentally sound distribution of fertilizer but seldom will produce significantly higher yields, at least in the short term. This result might be explained by high small-scale soil-test variability that current soil sampling methods and variable-rate technology cannot manage. However, we believe another very likely reason is the use of a fertilization management philosophy common to the Midwest that encourages sufficiently high fertilizer rates for low-testing soils in order to maximize yield and slowly build-up soil P and K over time.

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, the additional costs, and grain/fertilizer price ratios. The effectiveness of higher cost sampling and fertilizer application methods increases when fertilizer prices are high, especially with variable-rate application because, as this study showed, on average the variable rate method applies slightly less fertilizer. Because savings in fertilizer usually were small for reasonable managed fields, VRT may result in significant profitability increases only if the philosophy of fertilization is changed to a more strict response based philosophy. However, results showing that VRT does reduce both fertilizer application to high-testing field areas and within-field soil-test variability also indicate a clear value for environmentally friendly fertilizer application.

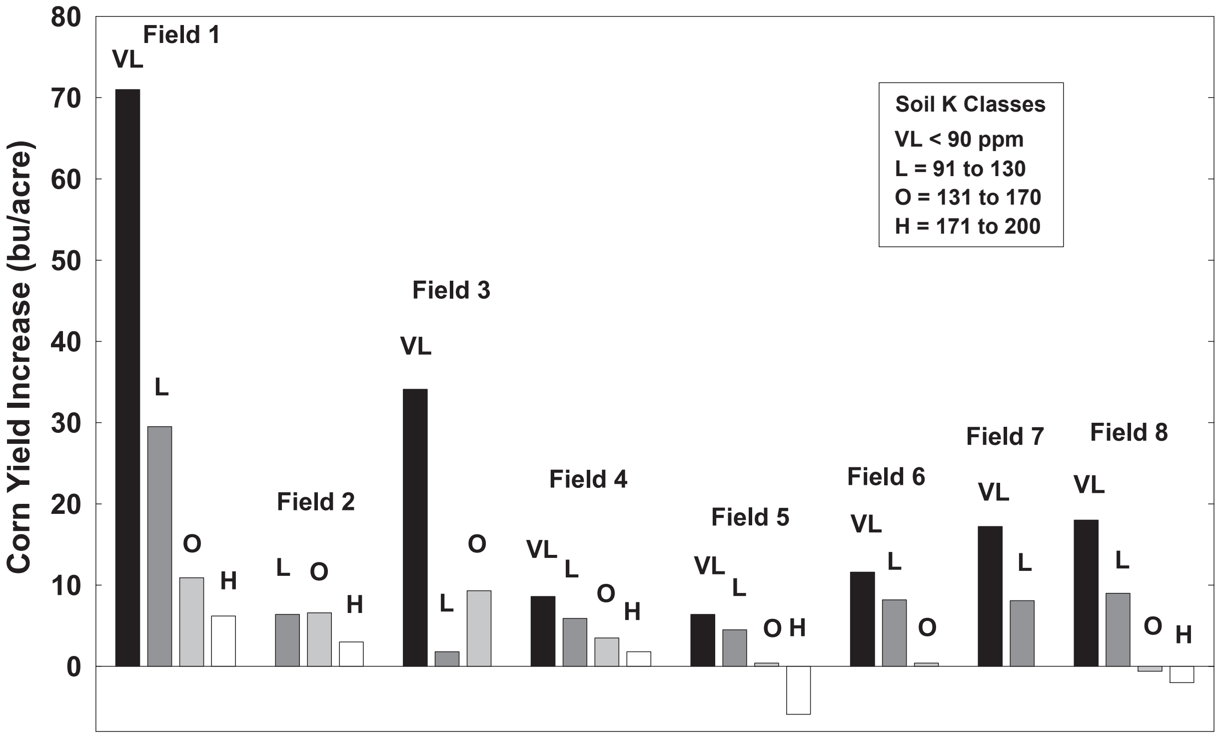

Figure 1. Within-field soil-test K variability and yield response variability from eight representative strip trials conducted in Iowa (field identifiers are arbitrary codes).

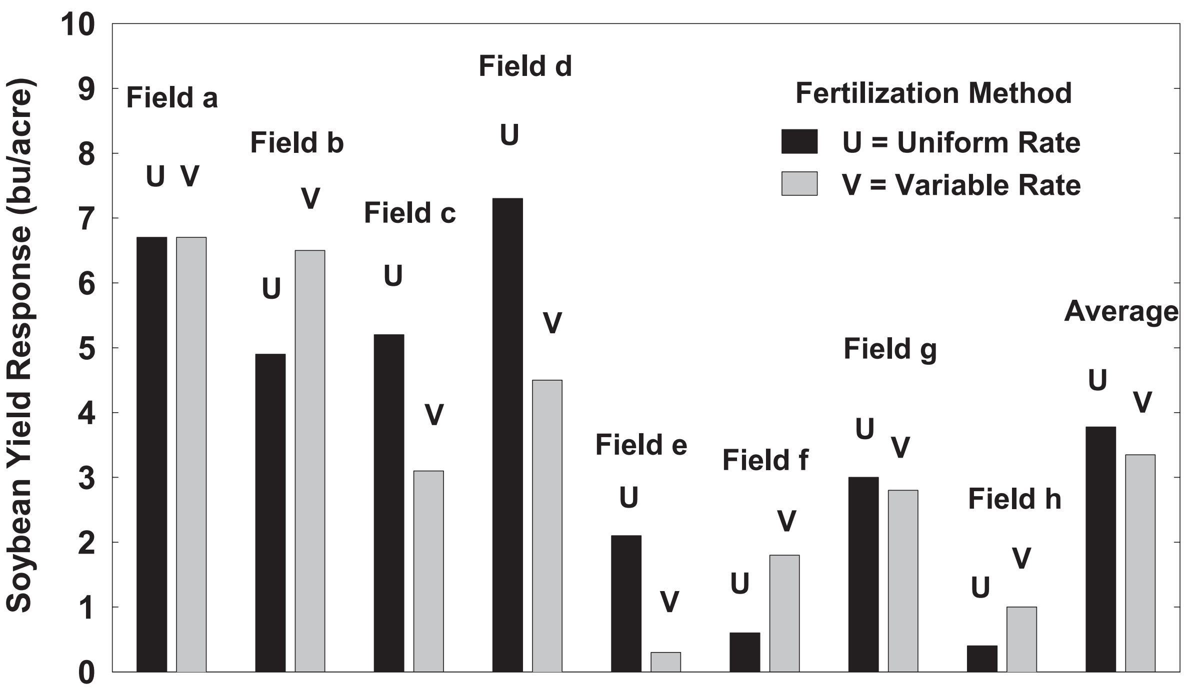

Figure 2. Soybean yield response to P fertilization with uniform and variable-rate application methods for eight representative Iowa fields (field identifiers are arbitrary codes).

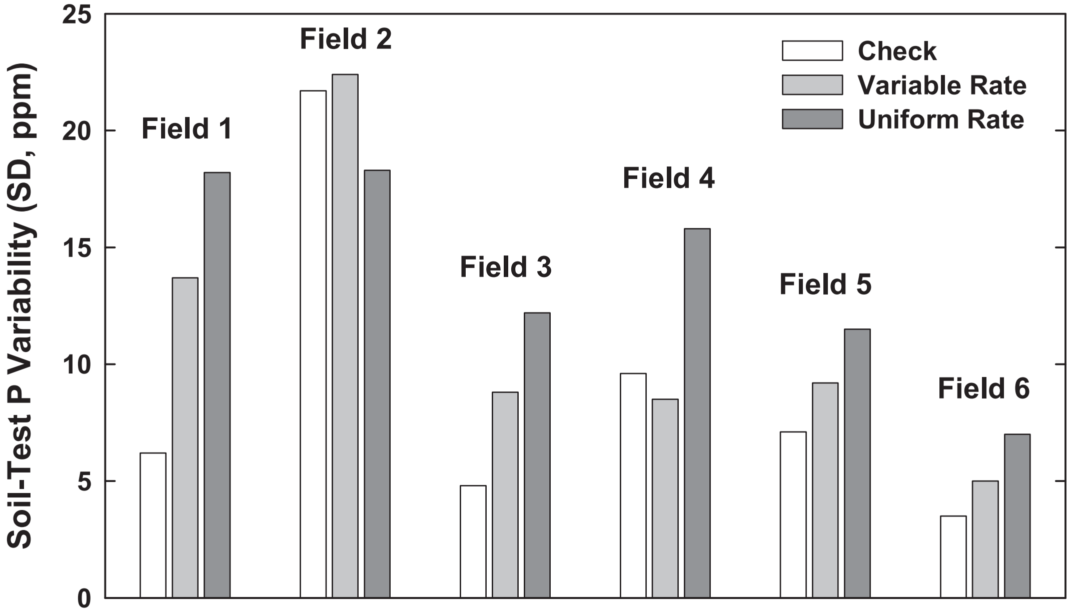

Figure 3. Effect of no P fertilization (check) and variable-rate or uniform P application methods on within-field soil-test P variability (Standard Deviation) measured by dense soil sampling after P fertilization for two corn-soybean rotation cycles in six Iowa fields (field identifiers are arbitrary codes).