

## **Efficacy of Variable-Rate Application Technology for Phosphorus, Potassium, and Lime Management**

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### **Precision Agriculture and Nutrient Management**

Crop prices have been low for several years and farmers are trying to maintain or increase the profitability of crop production by reducing inputs. At the same time, 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 application (VRT), and geographical information systems (GIS) software are available for use by producers and crop advisers. Georeferenced soil sampling and crop scouting, and other practices complete the technological package. Use of soil testing for phosphorus (P), potassium (K), and pH and lime requirement is widespread and is a key diagnostic tool for making rational fertilization and liming decisions. Soil testing is a very well adapted to site-specific management to better describe nutrient or pH levels across a field and decide nutrient or lime application rates. Usually high within-field spatial variation of nutrients and pH at various scales makes soil sampling the most important and common source of error in soil testing. Nutrient removal with harvest also is a key piece of information for making P and K fertilization decisions because estimates of P and K removal are considered in different ways by recommendation systems used across the US. Field research has shown that yield level variation across and within fields is much more important at determining P and K removal variation than the concentration of P and K in harvested products. The practice of collecting just one composite soil sample from an entire field or very large field areas and consideration of P and K removal only for an entire field still predominates in many regions. Therefore, use of georeferenced soil sampling and yield monitors combined with VRT could greatly improve the efficacy and economic benefits of nutrient and lime management, especially with unfavorable crop prices.

### **Soil Sampling and Variable-Rate Application Technology**

Variable-rate P or K fertilization and liming can be used on the basis of sampling areas identified by soil-survey map units (which include slope and erosion phases) but research has shown that it should be based on additional information to delineate sampling zones or in dense grid sampling. The conventional sampling by soil-map unit often is not the best for precision agriculture because soil survey maps were not prepared with the 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 small areas or cells (usually 2.5 to 4.4 acres). 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 and introduces large temporal variation on long-term soil-test trends. Taking cores from a smaller area often results in more consistent trends over time, but the sampling "point" should not be too small, such as just around a pickup truck, especially with large grid sizes.

Zone sampling can reduce sampling and testing costs compared with grid sampling while maintaining acceptable information about nutrient or pH variation. Zone sampling assumes that sampling areas with relatively homogeneous soil-test P and K or pH values can be identified based on previous management and soil or crop characteristics which can be mapped using various precision agriculture tools. Soil series

or map units (with slope and erosion phases) are commonly used but elevation models, soil or crop canopy images, maps of yield and estimates of soil electrical conductivity (EC) could improve zone delineation. However, zones with homogenous basic soil properties or yield may not have homogeneous soil-test values because of variation of other non-measured soil properties or long histories of P, K, lime, or manure have created large soil-test variation and may mask natural variation. In the early 2000s Mallarino and Wittry compared sampling methods for P, K, pH, and organic matter 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 in several Iowa fields. They showed that no sampling approach was always the most effective in all fields at reducing the within-unit soil-test variability but sampling based 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 grid and zone sampling methods in Iowa fields compared with a very dense grid-point sampling (cells 0.2 to 0.7 acres). They found that grid sampling based on 2.5-acre cells was the most effective method, zoning based on soil maps, elevation and EC was intermediate, and sampling by soil series was by far the least effective. Figure 1 shows results of soil sampling for P for two contrasting fields. However, work Iowa and North Dakota showed that zone sampling including aerial images of soybean canopy can be better than grid sampling to assess soil pH and lime needs in fields with calcareous soils intermingled with neutral or acidic soils because the iron-induced chlorosis can map very well calcareous areas.

Research also has shown the importance of including more than just four or five cores in a composite soil sample, even with dense grid-point sampling. 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 mean actual value.

### **Nutrient Removal with Harvest and Variable-Rate Application Technology**

The P and K removed with harvest can be useful as a complement to soil testing to decide P and K fertilization in fields with large yield variation, and most states (but not all) consider removal with harvest in some way for fertilizer recommendations. In some states the yield level (and estimated removal) is considered for the soil-test interpretation category for which only removal-based fertilization is recommended. This is the case in Iowa, where the interpretation class is called Optimum and is defined as the soil-test range with a 6-25 % probability of a small yield response (Mallarino et. al., 2013). In these states, fertilization rates for the low-testing categories (usually called very low and low) are based on empirical yield response data. In Iowa rates for low-testing soils are intended to attain maximum yield in most conditions including different yield potential, increase soil-test levels gradually depending on soil properties and the yield level although are not buildup rates except for a single application for the two-year corn-soybean rotation. In many states, however, rates for the low-testing categories also consider nutrient removal, presumably to approximately adjust the soil-test buildup with varying yield levels, some crop advisors recommend buildup rates for more than two years.

Many farmers and crop advisors are uncertain about the yield level that should be used to estimate P and K removal, and this is more complicated when using removal in prescriptions for VRT. Iowa State University guidelines provided continuous equations for VRT only for the low-testing categories because removal-based application is recommended only to maintain soil-test values within the Optimum category (Mallarino et. al., 2013). The guidelines provide frequently updated average P and K concentrations and default yield levels for different crops and harvesting systems, but indicates that yield (and removal) should be adjusted to prevailing actual yield levels in a field or portions of fields and should not be yield goal nor just yield for a single year before the application even if it is lower or higher than normal. This is

because, as Fig. 3 shows, there is a good relationship between P and K removal with harvest and soil-test levels over time only across more than 2 or 3 years. It is not well known how producers or agribusiness consider removal for VR application of P and K, even when yield monitor maps are available for several years because developing removal-based maps based on multiyear yield maps is not easy without sophisticated software.

### **Variable-Rate Impacts on Crop Yield and Nutrient or Lime Applied**

On-farm research projects assessed the potential of variable-rate fertilization and liming for corn and soybean in Iowa. Replicated strip-trials were evaluated from one to three cycles of the two-year corn-soybean rotation. In one type of trial, treatments for areas 10-30 acres in size were a non-fertilized or unlimed control, variable-rate based on soil-test results from samples taken by grid-point sampling (cell size varied from 0.5 to 4 acres across fields), and a uniform rate based on average soil-test results from the entire experimental area. Default yield levels (and estimated removal) were used in most fields because yield maps for the previous 3 or 4 years were not available. There were twelve fields for P, eight for K, two for lime, and two for P-based liquid swine manure. Additional replicated strip trials assessed how different soil sampling approaches for soil pH and lime requirement (14 fields) as well as P or K (37 fields) assessed within-field variation in soil tests and grain yield responses. In these simpler trials treatments were a control and a non-limiting fertilizer or lime rate. The applications were made using commercial fertilizer spreaders equipped with GPS receivers and controllers, grain yield was measured with calibrated yield monitors, and GIS was used to assess treatment effects for parts of the experimental areas testing within different soil-test categories or different soil types.

There was large within-field variation in many fields. Figure 4 shows typical results for some K strip trials. Approximately similar results were observed for other trials with K, P, or lime. These results show a 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. In spite of often large within-field variation in soil-test values, however, there were small and infrequent entire-field yield differences between uniform and variable-rate fertilizer application methods. Figure 5 shows examples of the inconsistent differences between K fertilizer application methods for yield. The variable results make sense and are explained by several reasons. Use of VRT often increased yield more than the uniform application in low-testing areas but not always, because sometimes the lower uniform rate applied enough nutrient or lime to maximize yield. This was explained by Iowa fertilizer and lime recommendations for low-testing soils designed to attain maximum yield in most conditions although are no buildup rates. Other times, large yield differences in favor of VRT occurred in small field areas and were not reflected for an entire field average due to no response or random differences in larger high-testing field areas. Scarce other work in the north-central region or the eastern Corn Belt have reported similar results.

The average amount of P, K, or lime applied per acre by each application method varied considerably among fields and nutrients, but often was less for the variable-rate method. Use of VRT resulted in much less product applied in about one-half of the fields, the two methods applied about the same amount in about one-fourth of the fields, and the VRT method applied more in the other one-fourth of the times. Obviously, the differences in materials applied by the two fertilization methods were greatly affected by the overall level and magnitude of the soil-test variation across a field.

Results showed that VRT does reduce unnecessary fertilizer or lime application to high-testing field areas and reduces within-field soil-test variability over time. Figure 6 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.

### **Profitability of Variable-Rate Application of Phosphorus, Potassium or Lime**

The on-farm research results suggest the impact of VRT on economic benefits from fertilization and liming will vary greatly depending on the overall level and range of within-field variation in soil-tests and yield and on the producers or crop advisors criteria used for fertilization or liming. Most Iowa producers maintain higher than recommended P and K soil-test levels and few maintain recommended soil-test levels or apply less fertilizer than recommended. Iowa field research has evaluated economic returns to investment in P and K fertilization of corn and soybean by using results from many on-farm and research-farm trials. Figure 7 summarizes net returns from fertilization for different soil-test values and scenarios for three grain prices while maintaining the same fertilizer prices. In soils testing Very Low, economic benefit from fertilization are very high and likely for all price scenarios. In low-testing soil benefits are lower but likely (most of the time well above break-even) even with lower grain prices than today. Therefore, producers are advised against reducing recommended P or K application rates for low-testing soils, because the benefits are large and likely even with current low prices. Application of removal-based rates to high-testing soils result in mostly negative returns for all price scenarios, so producers should not apply removal-based rates at those test levels. Therefore, it would not be surprising if in many Iowa fields increased yield response or savings on fertilizer or lime do not offset the additional cost of dense soil sampling and VRT application. Although infrequent in Iowa, benefits from VRT also are unlikely when soil-test results are mostly very low across a field.

The use of dense but still cost-effective grid or zone soil sampling approaches and VRT is particularly useful for P and water quality considerations. Numerous studies have documented exponential or linear increases in P loss from fields with tile drainage or surface runoff when excessive fertilizer or manure application increase soil-test P above optimum levels for crops. In practice, impacts of VR in P loss from fields and water quality can be limited because P loss is also greatly affected by other factors such as application methods, risk of soil erosion and surface runoff, and many soil and water conservation practices.

### **Summary Conclusions**

Variable-rate technology for P, K, lime, and manure P application greatly improves nutrient management and can potentially increase profits from crop production and improve water quality by reducing P loss from fields. However, the most significant issues for using VRT effectively is the soil sampling approach and the soil-test interpretations on which fertilization or liming is based. Variable-rate application will be agronomically and economically most effective when soil-test values vary from low to high and/or the yield variation is large for areas where removal-based maintenance of soil-test values is justified and when appropriate nutrient rates are applied.

Fertilization or lime application will not be cost-effective with any application method in fields with large high-testing areas and unneeded nutrients or lime is applied to the high-testing areas. The commonly used grid soil sampling approach with grid size of 2.5 acres and zone sampling using several information layers almost always describe within-field soil-test variability and predict crop yield response better than the traditional sampling by soil type method. Grid sampling with a grid size of 2.5 acres often is more effective for P and K than zone sampling in Iowa fields with long histories of fertilization or manure application because current soil-test values seldom relate well with stable soil properties or landscape features. In fields with very contrasting slopes or landscape forms, however, soil-test K often is higher areas that receive sediment and yield and both P and K removal variation often is well related to basic soil properties and landscape features that reflect well water availability or rooting depth. Also, zone sampling

using several layers of information will likely be better than a grid sampling with large grid sizes, mainly with grid sizes larger than about 4 to 5 acres. Consideration of soil sampling and testing costs together with crop and fertilizer prices suggests that dense grid sampling for VRT will be cost-effective practices even sampling every two years for P and K management when soil-tests vary from low to high. This may not be the case for pH and lime unless rates lower than recommended are applied.

Since in most fields in Iowa or the north-central region there is very high small-scale soil-test variability, especially for P and K, VR will not be effective unless composite samples include 10 to 15 cores and appropriate fertilizer rates are used no matter the soil sampling frequency or approach. A soil-test map will show nice different colors but provide only the perception of good nutrient management.

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**Figures**

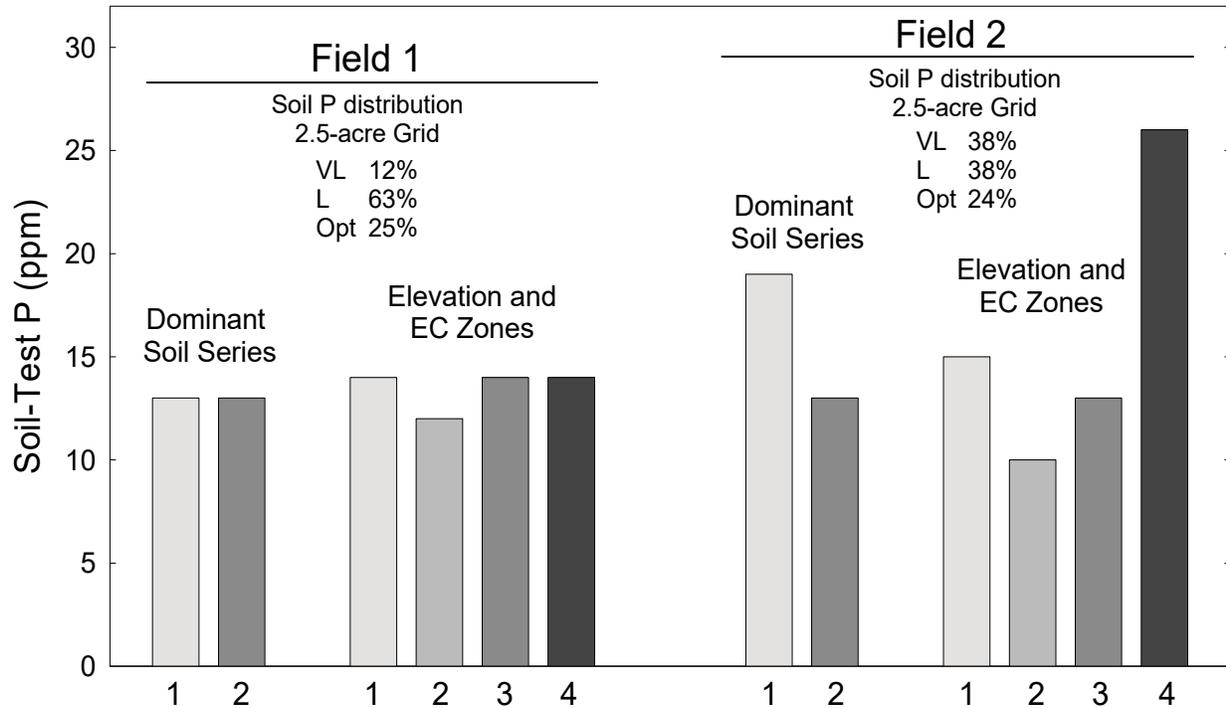


Fig. 1. Soil-test P distribution among Iowa State University interpretation categories very low (VL), low (L), and optimum (Opt, for which removal-based P is recommended) for different sampling methods in two contrasting Iowa fields.

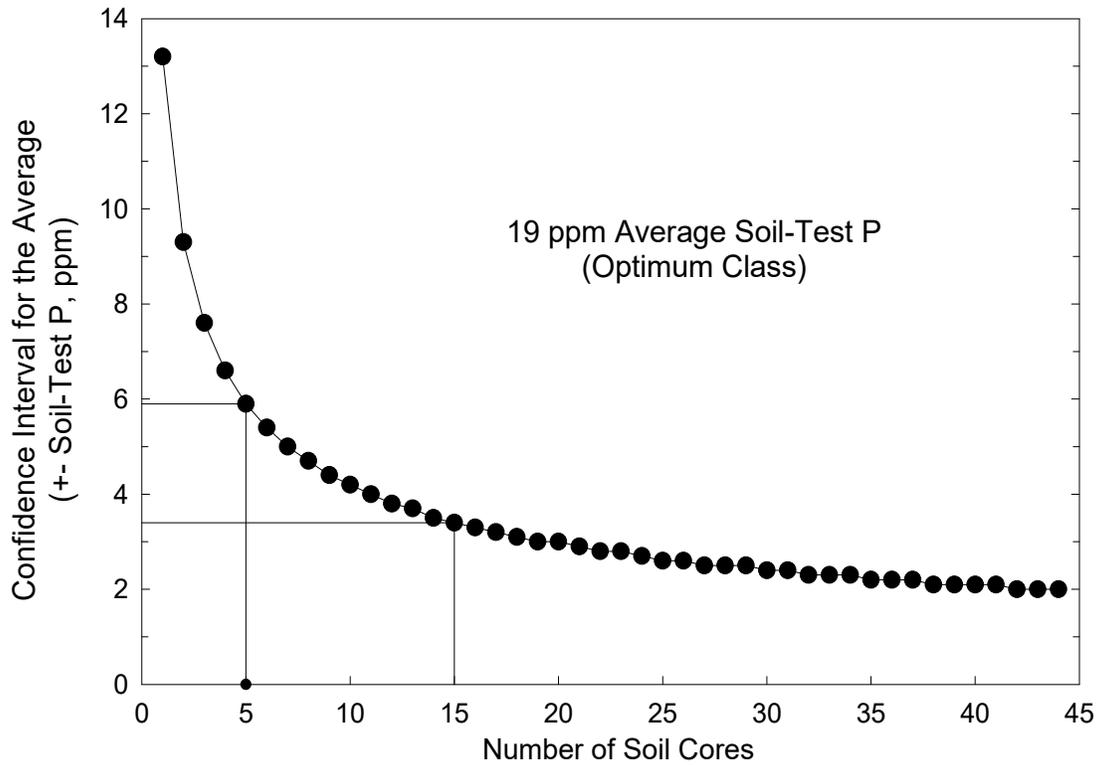


Fig. 2. Estimated error from the actual soil P average obtained by analyzing many individual cores from a one-acre portion of an Iowa field when using different numbers of soil cores for a composite sample.

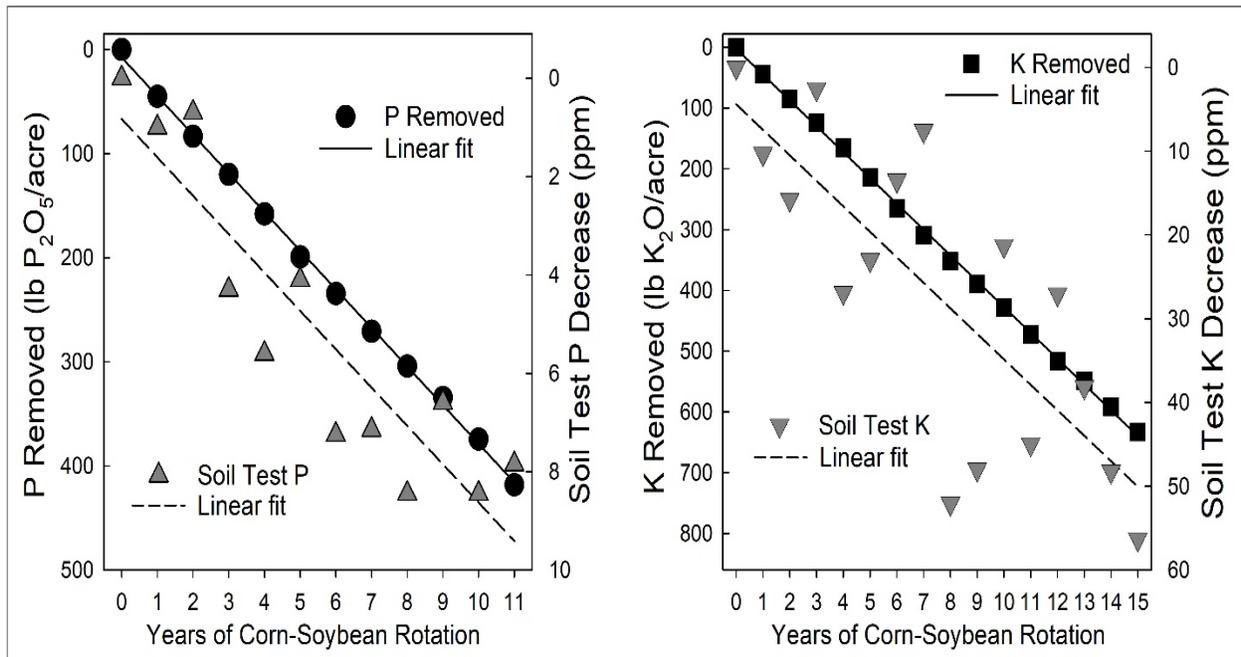


Fig. 3. Relationship between cumulative P and K removed with grain harvest and soil-test change in plots of Iowa long-term trials not fertilized with P or K (Bray-1 for P, ammonium-acetate or Mehlich-3 for K).

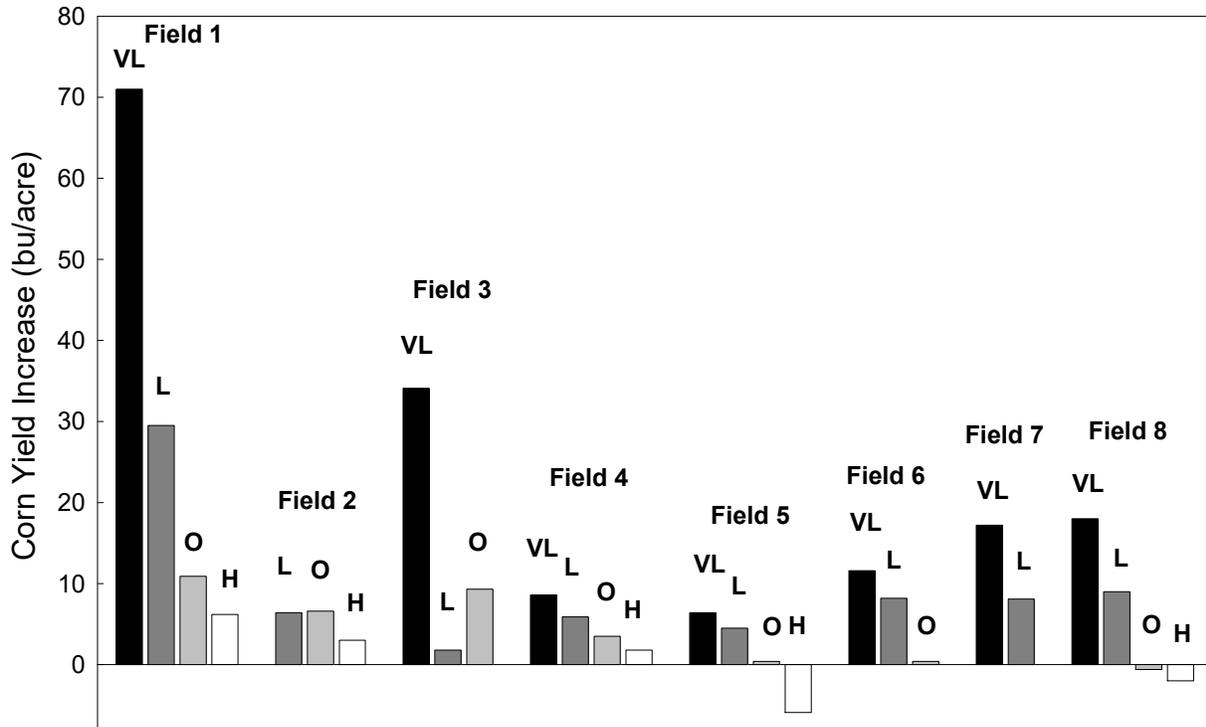


Fig. 4. Within-field variation of corn yield response to K fertilization in several Iowa fields having initial soil-test K testing within different interpretation categories.

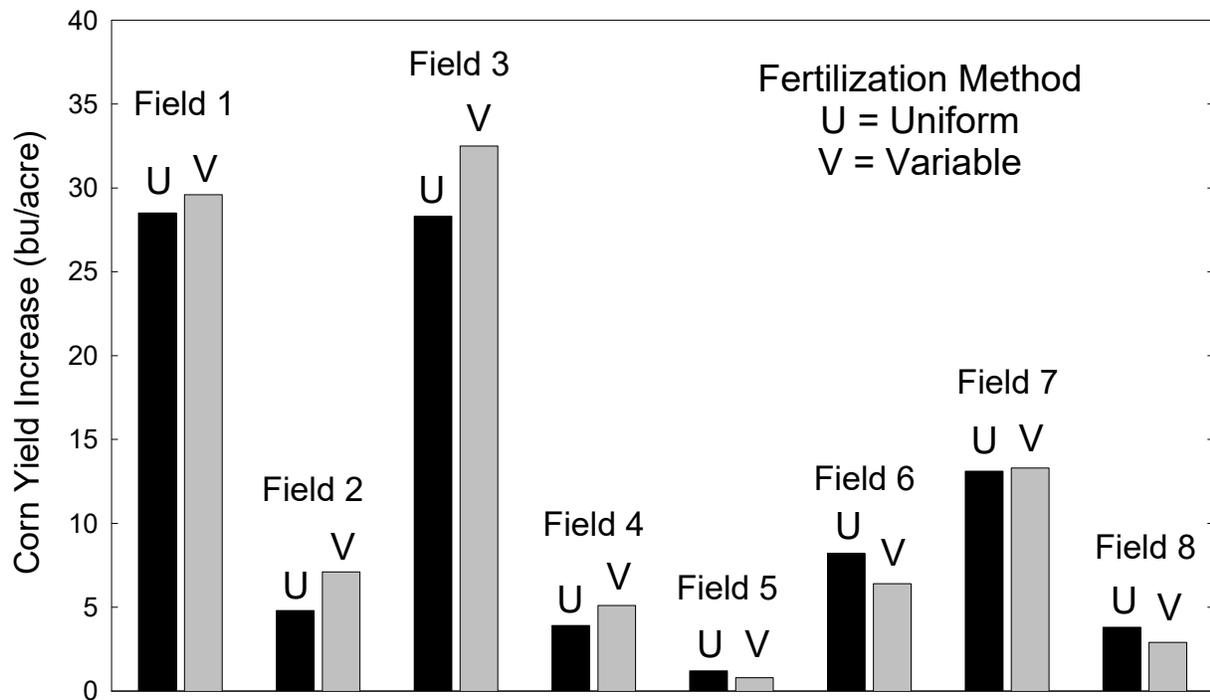


Fig. 5. Average corn yield response to K fertilization across each of eight Iowa fields using uniform- or variable-rate application methods.

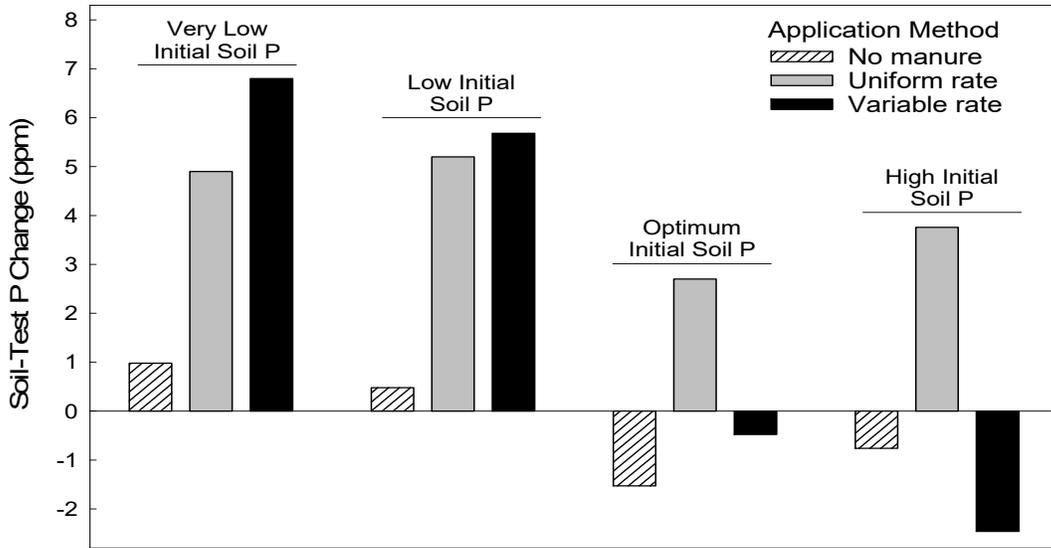


Fig. 6. Effect of no P application and uniform- or variable-rate P application on soil-test P change for an Iowa field after two corn-soybean rotation cycles.

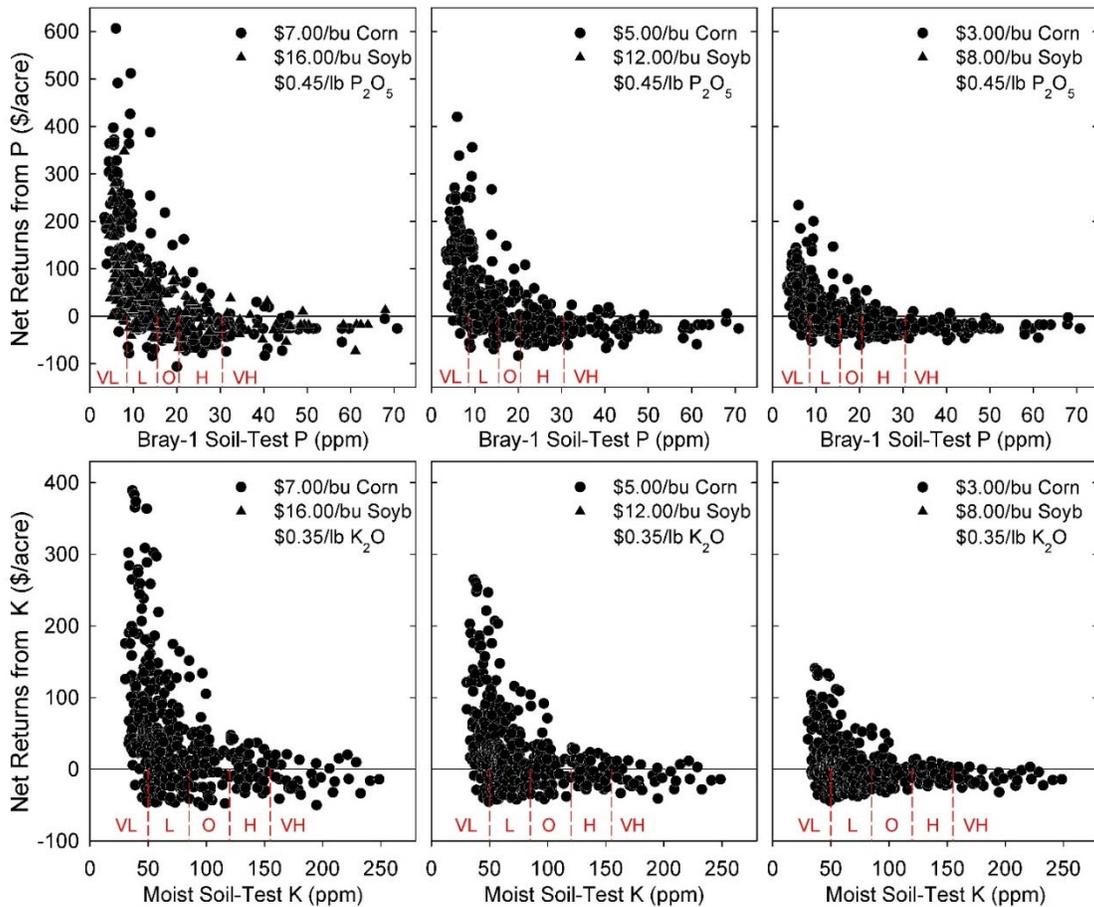


Fig. 7. Net returns to P or K for corn and soybean with different soil-test values and shown prices in Iowa soils. VL, L, O, H, and VH; Iowa State Univ. categories Very Low, Low, Optimum (removal-based application is recommended), High, and Very High (only starter is recommended in some conditions).