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Wheat Yield Modeling: How Important Is Soil Test Phosphorus?

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Crop response to fertilizer nutrients such as P and potassium (K) is commonly predicted using soil test information. Fertilizer recommendations from soil tests are usually based on calibration curves. These curves are made by comparing yield of a specific crop at a specific soil test level to yield where the nutrient in question is not limiting. When these yield observations are made in many locations with different soil test levels, a calibration curve is developed where relative yield is plotted against soil test level. A common characteristic among calibration curves is that decreasing soil test level results in decreasing relative yield.

A unique approach to describing the relationship between yield and phosphorus (P) fertility has been developed by economists and agronomists at Kansas State University. This approach uses farm level information to estimate a function, or mathematical expression, for yield.

Crop yield at a given location and time is dependent on several variables. The objective of the mathematical modeling approach used in this research was to predict yield with specific levels of selected variables, such as nitrogen (N) and P fertilization rates. Developing a reliable yield function is a four-step process. First, variables thought to be the most important in affecting yield are selected. Second, data are collected from either planned experiments or from farm level information. The final steps involve selecting a specification for the function (linear, quadratic, etc.) and estimating parameter values to maximize accuracy of the predictions.

Detailed information from a farming operation in northwest Kansas (Rawlins

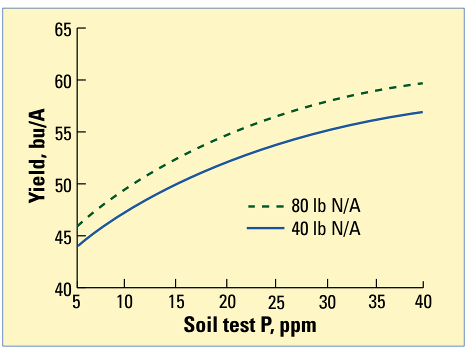

Figure 1. Relationship between field soil test P and predicted field wheat yield for two levels of N fertilization and no P fertilization. All other variables were kept at average values.

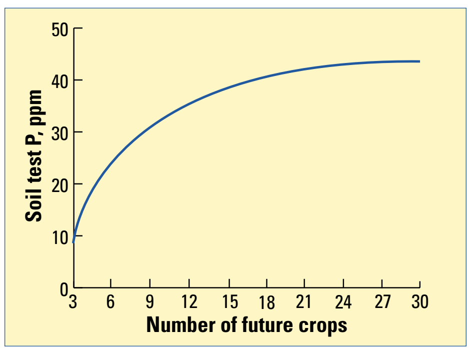

Figure 2. Most profitable steady state soil test P level by number of future wheat crops anticipated. Assumes that soil P level is built in the first year and maintained with yearly applications thereafter.

County) was used to produce a model that estimates dryland wheat yield for the farm. Data were collected from 1994 to 1999. The number of records (crop fields) by year were 1994 (17), 1995 (17), 1996 (13), 1997 (10), 1998 (20), and 1999 (15). For each year and field, average wheat yield, preplant soil test N and P, N and P fertilizer rates, soil organic matter, soil pH, and soil texture were measured. An expression was also added that accounted for the effects of late frost on yield.

The modified asymptotic mathematical function chosen for the yield model captured the following characteristics: 1) plateau-type convergence where predicted yields flatten out over broad levels of high inputs; 2) a "limiting-factor" framework, where no factor can fully compensate for the lack of another; 3) some factors, such as fertilizer P and soil test P, must behave as substitutes; and 4) some variables, such as soil pH, are allowed to peak mid-range rather than at endpoints. The R^2 value of the estimated model was 0.40.

Interestingly, the model showed that fertilizer P had little effect on wheat yield; however, soil test P had a substantial effect (**Figure 1**). This required that thinking and decisions be turned to increasing soil test P to optimum levels. Therefore, the influence of fertilizer P on soil test P had to be defined. The following assumptions were made: wheat removes 0.6 lb P_2O_5/bu, fertilizer P in excess of crop removal results in build-up of soil P, and that for each 15 lb P_2O_5/A applied above crop removal, soil test P (Bray-1 P) increases by one part per million (ppm).

Several simulations using the yield model were performed. Soil test information from four different data sets collected on the study farm was used. These included the model estimation data set, another field-level data set, and two grid-sampled fields. Profits calculated from the yield simulations were based on $3.30/bu wheat, $0.18/lb N, and $0.27/lb P_2O_5. Since soil P had a substantial effect on yield, an important question that was addressed was: "What is the most profitable steady state soil test P level for different periods of production or land tenure?" The results indicate that as the anticipated number of crops increases, the optimum soil test P level increases in an asymptotic fashion (**Figure 2**). Where land is owned, an unlimited number of crops might be anticipated. The profit maximizing soil test level in this scenario is about 46 ppm (high, Bray-1 P). On the other hand, if land tenure is expected to be only five years, the optimal soil test P is about 21 ppm (medium, Bray-1 P). This analysis assumes that enough P fertilizer is applied in the first year to increase soil P to the optimum level, and that the level is maintained (steady state) by yearly maintenance applications.

In another simulation, this time on 10 crops, the steady state, or build and maintain, approach was compared to whatever P

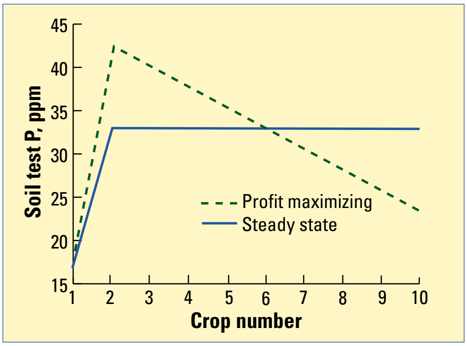

Figure 3. Most profitable steady state soil P level compared to the profit maximizing program for 10 wheat crops. The steady state scenario assumes that soil P level is built in the first year and maintained with yearly applications thereafter.

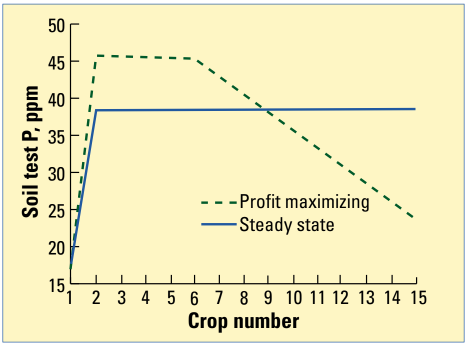

Figure 4. Most profitable steady state soil test P level compared to the profit maximizing program for 15 wheat crops. The steady state scenario assumes that soil P level is built in the first year and maintained with yearly applications thereafter.

fertilizer program the model determined to be profit maximizing (**Figure 3**). The model determined that optimum P fertilization with the build and maintain approach was to apply 279 lb P_2O_5/A the first year followed by 35.7 lb P_2O_5 for each following crop. This resulted in a per-crop average of 60 lb P_2O_5/A. The profit maximizing decision, however, was to apply 423 lb P_2O_5/A the first year, followed by no P_2O_5 for each following crop, for a per-crop average of only 42.3 lb P_2O_5/A. This is due to the responsiveness of yield to soil test P and not to fertilizer P estimated in the model. Although average soil test P over the 10 crops was virtually equal for the two scenarios, the profit maximizing approach was estimated to be $4.77/A per crop more profitable than the steady state approach. Simulations at longer land tenures showed that the advantage to the profit maximizing approach over the steady state approach diminishes, declining to 0 at an infinite number of crops. For example, at 15 crops, the advantage was $3.13/A per crop (**Figure 4**).

Crop production is affected by many biological, chemical, and physical factors. Any effort at predicting yield will have weaknesses because of the diversity and dynamic nature of the system. Nevertheless, some variables are more important in determining yield than others. For years, research has shown that P fertility is one of the important factors affecting yield. The modeling approach used in this research has further demonstrated the importance of soil test P in maximizing profit in wheat production. Although this research showed benefits to very large initial applications of P fertilizer, followed by a period of mining soil P in the last years of a land tenure, the steady state approach is less risky. That is, for farmers who found they incorrectly estimated land tenure on either the short or the long side, the steady state, or build and maintain approach would likely be the most profitable. Regardless, except for very short land tenures, recommendations were to build and maintain soil test P to the high level to maximize profitability and ensure the long-term sustainability of crop production.

This research represents a non-traditional approach to evaluating and predicting influences on yield that uses field level instead of small plot information. This technique of mathematical modeling, not to be confused with crop growth modeling, uses field level crop yield and fertility data to generate response functions that are used to guide fertilizer management decisions. It showed yield benefits to higher levels of soil P than would be expected from previous calibration research. Nevertheless, the production paradigm shift that is being brought about by site-specific management technologies suggests that this approach merits consideration. More investigation in the area of mathematical yield modeling is needed; therefore, this work should be considered exploratory and caution should be exercised in extrapolating from the specific results of this analysis. BC

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