Understanding Phosphorus Investment in Crop Production

By T.L. Kastens, J.P. Schmidt, and K.C. Dhuyvetter

Anecdotal evidence seems to be mounting that farm operators in the Great Plains want to consider P as more than an annual fertilizer issue, even to the point they consider soil test P (STP) as a capital investment with the usual time dimension associated with investments. Both landowners and tenants increasingly want to be compensated for their investments that presumably "caused" STP levels to be in the higher ranges. Quotes such as: "I'm sure not going to apply P on land that I won't have after next year" or "I've built up soil test P and want to be sure my tenant doesn't mine it out" are becoming ever more common. Although few fertilizer recommendations from university or commercial soil testing laboratories currently consider the capital investment aspect of P, this topic should increase in importance over the coming years if producer concerns are any indication.

> Differences in philosophies and/or implicit yield response models result in differences in phosphorus (P) fertilizer recommendations among laboratories. Those wanting to improve the P investment decision would be wise to consider several agronomic and economic factors.

That farmers observe STP levels do change over time is probably an artifact of fertilizer recommendations, which typically suggest fertilizer P (fertP) rates that are higher than crop removal on low testing soils. Thus, STP will increase over time when following the fertilizer recommendations. Additionally, a location's STP will change over time in the face of uniform application rates coupled with crop yields that vary due to other limiting factors that persist over time.

What is not well known is whether farmers view the situation passively or actively. That is, do they view "accidentally" higher STP sites to represent potential fertilizer savings in the future, thus imparting value to those sites? Or, do they wish to managerially target higher STP levels by applying additional fertilizer, believing that such strategies enhance profitability over time?

Because fertilizer recommendation providers (and users) vary in their perception of P as a short- or long-term issue, two classes of P recommendations have evolved over time. First, the traditional "sufficiency" recommendations, which are conditional on STP levels that happen to be observed, are provided as a guide to 1-year profit maximization. Second, "build and maintain" recommendations are provided in an attempt to account for the fact that longer-term managers might enhance profit by using some build program, followed at some point in the future by rates that try to maintain STP at some target level.

At least two recent *Better Crops with Plant Food* articles suggest that producers might benefit by explicitly targeting STP over time. Considering P investment over a 10-year horizon, each article suggested that an especially fast (essentially over 1 year) build up of STP would be appropriate. In one article (Lowenberg-DeBoer and Reetz, 2002), the authors compared a 1-year build, followed by a maintenance fertilizer P

application in the corn year of a corn-soybean rotation, to a more gradual build program. Relative to the 1-year build program, the more gradual program applied roughly the same total fertilizer over the study period, but placed less in year 1 and more in each successive application. Since the 1-year build program allowed more years to recoup the investment of additional fertilizer, it was easy to show that the 1-year program netted more profit. However, the authors did not reveal whether the underlying yield response model considered only response to STP and not fertilizer P, nor whether a strategy closer to some sufficiency recommendation might have been even more profitable over the 10-year horizon.

In another article (Kastens et al., 2000), the authors used a wheat yield response (to both fertilizer P and STP) model generated from farm-level data to show that applying a large amount of fertilizer in year 1, followed by none in successive years of the 10-year period, was the most profitable strategy. The authors indicated that this result arose because the estimated yield model happened to reveal a large response to STP and a weak response to fertilizer P. Other work by these authors suggested a more balanced model would be more appropriate for the same farm's data. Further, the "STP build" recommended by the more balanced model would be much more gradual than the 1-year build suggested by the Kastens et al. *Better Crops* article.

Whatever the outcome to the farmer perception questions posed earlier, what will be most needed from interested researchers is a better understanding of the substitutability of fertilizer P and STP in the yield response function. Closely related to that need is a better understanding of how STP changes over time given fertilizer rates and crop yields. More explicitly, is the transformation of excess (above crop removal) fertilizer P (EfertP) to a change in STP a constant? Or, does it vary significantly by soil type, by level of STP, by time, or by some other factor? Information about EfertP-to-STP transformation allows "costing" STP on a per unit basis, such as parts per million (ppm). Then, given an expected number of future years or crops, information about fertP-STP substitutability (or, more simply, yield response to STP) allows "valuing" STP on a per unit basis. Finally, the cost and value of STP, along with the decision-maker's time horizon, should determine the optimal P investment strategy.

Fertilizer P recommendation models from soil testing laboratories provide an indication of what soil scientists behind the recommendations likely believe about yield response to fertilizer P and STP. As such, the implicit underlying yield response models have the potential to significantly further the study of the P investment decision. Unfortunately, the implicit yield response models are not always consistent across soil testing laboratories covering the same
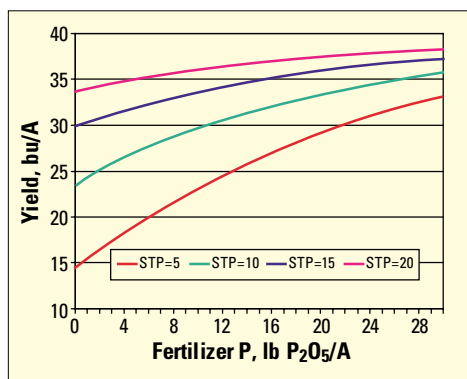

Figure 1. Predicted wheat response to fertilizer P (OAL-based model).
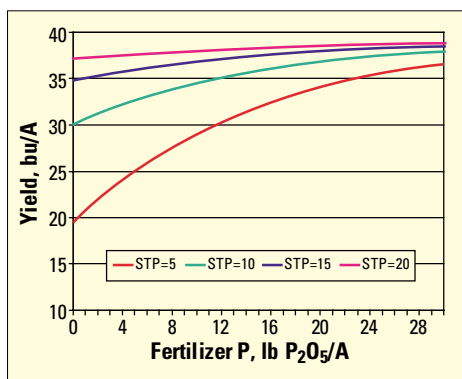

Figure 2. Predicted wheat response to fertilizer P (KSU-based model).

geographical production area, complicating the P investment decision.

We examined fertilizer nitrogen (N) and P recommendations for wheat from four soil testing laboratories (one private, three public): Olsen's Agricultural Laboratory, McCook, Nebraska (OAL); Kansas State University (KSU); University of Nebraska (UNL); and Colorado State University (CSU). Each laboratory's recommendations were considered suitable for wheat production in northwest Kansas (Rawlins County). Each was considered to be a sufficiency recommendation, thus assuming a 1-year management horizon for the farm operator. **Figures 1** and **2** depict expected yield response to fertilizer P at different Bray P-1 STP levels for two of the laboratories studied. As seen by the slope of the lines and relative to the KSU model (shifted down), the OAL model suggests that wheat yield is more responsive to fertilizer P at each of the STP levels considered.

The different yield responsiveness implied by the different laboratories' recommendations greatly impacts the STP annual value for farm operators following the laboratories' (sufficiency) fertilizer recommendations over time. Given the non-linear EfertP-to-STP transformation rate from our work, where it takes more EfertP to change STP by 1 ppm at low levels of STP than at high levels, **Figure 3** shows the expected STP at the beginning of each year (starting at 5 ppm)

associated with each of the different laboratories. The steady-state (SS) STP levels, where the recommended fertilizer P rate equals crop removal (here assumed to be 0.6 lb P_2O_5/bu of wheat), vary substantially across the four models. It is worth noting that using a constant EfertP-to-STP transformation rate would change the shape of the curves but not the final STP levels. Clearly, if laboratories use this approach to target some "build and maintain" STP level in an attempt to guide the P investment decision, the recommendations will appear inconsistent across laboratories.

What if laboratories approached the P investment decision from the standpoint of choosing the fertilizer P rate each year that maximized discounted future profits? **Figure 4** shows the resultant STP annual value for these four laboratories. For operators with especially long horizons, such as those who might own their land, the difference between the ending STP (30 years in the future) can be large. For example, KSU followers end up at an STP level of about 21 ppm and OAL followers at about 36 ppm. Although not shown, OAL followers start out applying 82 lb/A of P_2O_5 and end up applying around 24, which approximately equals crop removal. Though KSU followers also ended up applying 24 lb/A, they start out applying only 55.

Notice that none of the optimal STP time paths in **Figure 4** suggests especially
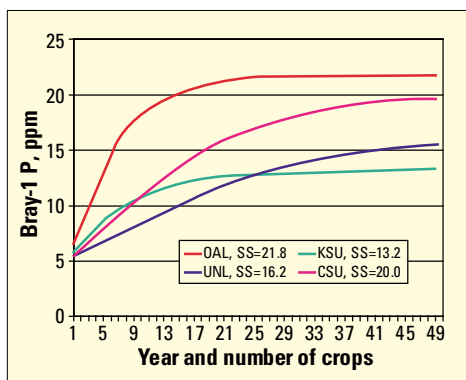

Figure 3. STP over time for different yield models (profit maximizing 1 year at a time, i.e., sufficiency).
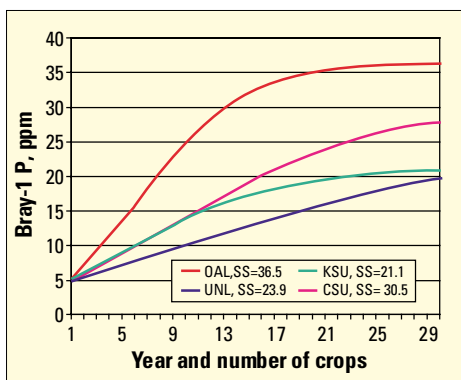

Figure 4. Optimal STP over time for different yield models (first 30 years of a 50-year or longer time horizon).

fast build programs. Rather, they suggest a continued build of STP, though at a diminishing rate, across the 30 years shown. Thus, assuming these laboratories have confidence in their sufficiency recommendations, it probably would be inappropriate for them to accommodate the P investment framework by suggesting an especially fast build program. To evaluate this issue, we consider two P investment strategies: a) an infinite-horizon optimal strategy (referred to as IHO), such as that underlying the lines in **Figure 4**, and b) an infinite-horizon 6-year build and maintain program (referred to as B&M). With B&M steady-state STP values shown in **Figure 4** are targeted by applying each year for 6 years an amount of fertilizer P equal to crop-removal P plus one-sixth of the amount needed to reach the SS target in 6 years, followed by only crop-removal P thereafter. Then, we can ask the question: How much more profitable would a producer following these infinite-horizon strategies be over simply following sufficiency recommendations? The answer is conditional on having the land for only 1 year, 2 years, and so on.

Figure 5 shows the expected outcome of the two P investment strategies described, and for only two of the soil testing laboratories, OAL and KSU. Results are presented as annually amortized $/A, thus $/A/year. For example, an OAL B&M program follower who happened to lose his land after 6 years would have been $8.62/A worse off each year of the 6 years than he would have been if he had simply followed the sufficiency recommendations over the 6 years. Clearly, large losses accrue to those who lose their land in the early years of a fast build program. Also, the B&M program is not more profitable than a sufficiency program, unless the operator controls the land for at least 20 years (OAL) or 28 years (KSU). On the other hand, the IHO strategy is not more profitable than a sufficiency program unless the operator controls the land for at least 14 years (OAL) or 15 years (KSU). Despite the seemingly small profits associated with the P investment strategies of **Figure 5**, it should
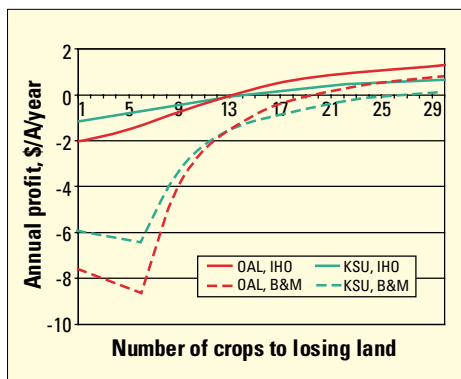

Figure 5. Returns to P investment over sufficiency (OAL and KSU).

be noted that, if an operator knows in advance exactly how long he will control land, then optimal P investment strategies will be more profitable than those shown. That's because he can intentionally "mine" P in the last years of his time horizon.

Given the large variations in results shown, it should not be surprising to see a number of successful farms, especially those adopting precision agriculture technologies, wanting to generate their own yield response and fertilizer recommendation models.

Whether farmers or university researchers, those wanting to improve the P investment decision would be wise to consider: a) the substitutability of fertilizer and STP (i.e., develop accurate yield response models); b) how to quantify expected changes in STP over time given fertilizer P rates (i.e., understand the transformation rate); c) the explicit purpose behind build and maintain P programs; d) time-value-of money issues; and e) the risk associated with making the wrong recommendation.

Failure to consider each of these issues simultaneously can easily lead to fertilizer decisions that are less profitable and more risky than ignoring the P investment idea altogether. BC

Dr. Kastens (e-mail: tkastens@ksu.edu), Dr. Schmidt, and Dr. Dhuyvetter are with Kansas State University, Manhattan.