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A Further Look into Fertilizer Recommendation Adequacy Regarding Phosphorus and Potassium

Farmer-specific goals should be incorporated into the decision-making process.

Summary: *There are several logical and appropriate approaches to managing phosphorus (P) and potassium (K) fertility. Within the bounds of environmental stewardship, it should be up to the individual producers to determine the appropriate fertility approach suitable for their production system. Nutrient sufficiency programs generally minimize fertility inputs in the early years but have increased risk of P or K limiting crop growth and long-term profitability. Build/maintenance programs may cost more in the initial years if soil tests must be built up, but they generally provide for maximum yield and long-term profitability while increasing fertilizer management flexibility in the coming years. In addition, an individual producer's attitude toward managing risk, the producer's long-term viewpoint in making investments in soil fertility, expected land tenure, and other farmer-specific goals and objectives should be incorporated into the decision-making process for determining the P and K fertility management program that best suits an individual producer's needs. To continue to increase crop yields in the future, it is important to note that research has shown that annual fertilizer applications may not fully substitute for high P and K soil fertility. Highest crop yields are often associated with soil tests greater than the established critical value. There may be a severe economic penalty associated with low P or K soil tests even when fertilizer is applied--especially in years/situations with high-yield potential.*

Profitable crop production requires adequate crop nutrition and there are few fields that do not require the addition of supplemental crop nutrients. As a result, there has been much investment in time, expertise, and money devoted to developing reliable soil tests that are well correlated to crop nutrient uptake and crop yield response. Once a reliable soil test is developed, the test is then calibrated to estimate the nutrient application rate required for optimum crop growth at various soil test levels. Historically, the soil test value and crop to be grown have been the main, and often only, factors used in making nutrient rate recommendations--although there are sometimes adjustments made for factors such as expected crop yield, soil type, and/or soil association. However, there are many other factors that affect crop growth, nutrient availability, nutrient uptake, and crop production efficiency that need to be taken into consideration in order to arrive at a nutrient management program that best fits a specific field. The cultural and tillage system used, planting dates, soil/environmental condition, equipment availability, an individual farmer's long-term approach to managing risk and land investment, crop fertilizer prices, and other factors are not estimated by soil testing but they generally influence crop nutrient rate decisions.

While plant-available nitrate and/or ammonium nitrogen (N) soil testing historically has been used for N recommendations in lower rainfall areas, such as the Great Plains and other western states, N soil testing has generally not been used in more humid regions such as the Corn Belt and southeastern states. Higher rainfall in these areas causes much more weather-induced variability in inorganic soil N supplies and much less reliability in assessing available N supply to the growing crop.

P, K interpretation

Nutrient recommendations. As cropping systems change with the increased adoption of reduced and no-till systems, it is possible that nutrient recommendations may also need to change as compared to those developed with past conventional, aggressive tillage. Additionally, as crop yields continue to increase year after year, the overall amounts of crop nutrients required and rate of crop nutrient uptake are also increasing. As yields continue to climb, farmers need to consider the total amount of nutrients required by these higher yielding crops and the daily nutrient requirements, especially at critical stages of crop development. Table 1 presents the very large total nutrient uptake and daily nutrient requirements of high-yielding corn and soybeans in a Rutgers University study. Since most P and K moves to the root surface across only very short distances by diffusion, questions sometimes arise about the adequacy of many current crop nutrient recommendations developed at much lower yield levels than are currently obtained by top producers.

Soil tests for P and K do not directly tell how much of a nutrient is available to a crop--nor do they accurately predict precisely how much of a nutrient to apply to a specific field situation. Instead, what soil tests do much better is estimate the soil's relative ability to supply a nutrient to a growing crop. This provides an index value of potential nutrient availability--not a quantitative amount. Through correlation and calibration research, these soil test index values provide the probability of obtaining a crop response to applied P and K. They also estimate the long-term average relative yield if no P or K is applied, compared to crop yield if fully adequate amounts of nutrients are applied (nutrient sufficiency).

Interpreting. There are two widely used general approaches for interpreting P and K soil test values and developing rate recommendations: nutrient sufficiency and build-maintenance. Various universities and individuals have adopted one of these approaches or an approach that falls somewhere in between and combines certain aspects of both. The goal of nutrient- sufficiency-based recommendations is to, on the average, apply just enough P and/or K to maximize profitability in the year of application with no consideration of future soil test values or required fertility programs. The objective of this approach certainly makes sense from an economical standpoint. In general, nutrient sufficiency recommendations will, on the average, provide about 90 to 95 percent of maximum yield. However, since there is always uncertainty in the amount of a crop nutrient actually required to maximize profitability for a specific field in a given year, more or less P and/or K is typically recommended for a specific situation than is actually needed. While there is no concern for future P and K soil test values with the nutrient sufficiency approach, over the long term soil test values will eventually stabilize in the crop responsive range somewhat below the critical soil test value. The critical soil test value is usually defined as the soil test level at which there is a relatively low probability of obtaining a yield response to added crop nutrients, and about 90 to 95 percent of maximum yield will be obtained if crop nutrients are not applied. Recommended

Table 1. Crop Nutrient Uptake By High Yielding Corn and Soybeans

308 Bu/A Corn Nutrient Uptake

R. Flannery, Rutgers University

Corn		Nutrient Uptake per Day			Cummulative Nutrient Uptake		
Stage	Days	N	P_2O_5	K_2O	N	P_2O_5	K_2O
		lb/a/day			lb/a		
a-leaf	32	0.4	0.1	0.6	12	3	19
8-leaf	12	1.6	0.4	3.4	32	7	59
12-leaf	15	3.4	0.9	3.4	83	20	109
Tassel	13	11.1	2.9	15.3	227	57	308
Silk	12	-1.4	0.9	2.6	210	68	340
Blister	18	1.0	0.7	0.7	228	80	352
Early Dent	31	3.7	1.4	1.4	343	125	396
Maturity	13	0.2	1.2	-1.7	345	140	375

101 bu/A Soybean Nutrient Uptake

R. Flannery, Rutgers University

Soybean		Nutrient Uptake per Day			Cummulative Nutrient Uptake		
Stage	Days	N	P_2O_5	K_2O	N	P_2O_5	K_2O
		lb/a/day			lb/a		
3rd trifoliate	40	0.8	0.3	0.7	30	10	27
6th trifoliate	11	1.5	0.6	2.7	46	16	57
Full Bloom	16	7.8	1.8	5.8	171	44	149
Early Pod	15	9.1	2.3	9.6	308	78	293
Soft Seed	21	11.4	2.8	2.4	548	136	344
Maturity	16	-3.4	-1.3	-2.3	494	116	308

Table 2. Effect of Bray P Soil Test On Corn and Soybean Yield Response To Fertilization

G. Randall, Univ. of Minnesota

		3-year Average Corn Yield			
		Low P	High P		
Application Method	P Rate[1]	Soil	Soil	High P Advantage	
	Lbs P2O5/A	----------------------Bu/A----------------------		Bu/A	%
None	0	148.0	192.8	44.8	30
Pop-Up	25/20	158.1	191.6	33.5	21
Deep Band	25/20	157.7	196.4	38.7	25
Broadcast	25/20	166.4	196.2	29.8	18
D. Band + Pop-Up	25/20 + 25/20	171.5	189.0	17.5	10
Pop-Up	50/40	165.7	194.5	28.8	17
Deep Band	50/40	166.0	186.4	20.4	12
Broadcast	50/40	167.0	190.2	23.2	14
	$p > f$	<0.001	0.39	---	---
	LSD (0.05)	10.5	NS	---	---
	Average	162.6	192.1	29.6	18
	Bray P1 Soil Test	6-9 ppm	20-27 ppm		

[1]Rates are for Low Test Site/High Test Sites

		3-year Average Soybean Yield			
	Residual	Low P	High P		
Application Method	P Rate[1]	Soil	Soil	High P Advantage	
		----------------------Bu/A----------------------		Bu/A	%
None	0	34.5	49.1	14.6	42
Pop-Up	25/20	36.4	49.1	12.7	35
Deep Band	25/20	34.7	48.8	14.1	41
Broadcast	25/20	36.7	50.3	13.6	37
D. Band + Pop-Up	25/20 + 25/20	40.8	49.3	8.5	21
Pop-Up	50/40	38.2	48.9	10.7	28
Deep Band	50/40	38.5	49.1	10.6	28
Broadcast	50/40	37.1	48.4	11.3	30
	$p > f$	0.01	0.84	---	---
	LSD (0.05)	3.5	NS	---	---
	Average	37.1	49.1	12.0	32
	Bray P1 Soil Test	6-9 ppm	20-27 ppm		

[1]Residual Rates are for Previous Corn Crop Low Test Site/High Test Sites

rates go to zero at the established critical soil test value for this approach.

Longer-term view. Because of the long-term, positive residual benefits of P and K applications in soils, coupled with the cost of annual soil testing and the uncertainty of being able to accurately predict the optimum application rate required for a specific field in an individual year, taking a longer-term view of P and K management is certainly appropriate. The objective of build-maintenance fertility programs is to manage soil test levels rather than trying to predict precisely how much P and/or K would be required for optimum crop production in a given year for a particular situation. At low soil test values, build-maintenance programs are designed to increase soil test levels to a desired soil test value (e.g., the critical value) over a specified time frame, and then maintain soil test levels within a targeted maintenance range. The identified maintenance range generally lies just above the critical soil test value. No fertilizer is suggested at soil test values greater than the maintenance range. In general, crop yield will be about 100 percent of maximum yield, and the risk of yield loss due to insufficient fertility is minimized with this approach.

The nutrient sufficiency approach generally suggests lower P and/or K application rates in the early years of adoption (if soil test values are low initially) and will eventually approach crop removal as soil tests equilibrate in the crop responsive range. Build-maintenance rates will generally be higher in the initial years (if soil test values are low initially) until soil test values are increased to the desired soils test value when crop removal application rates maintain soil test values in the desired soil test range. Some states slowly build soil tests to a soil test value near (but below) the critical value and then maintain them with crop removal maintenance rates. Other states may have a different variation with portions adapted from both the nutrient sufficiency and build-maintenance approaches.

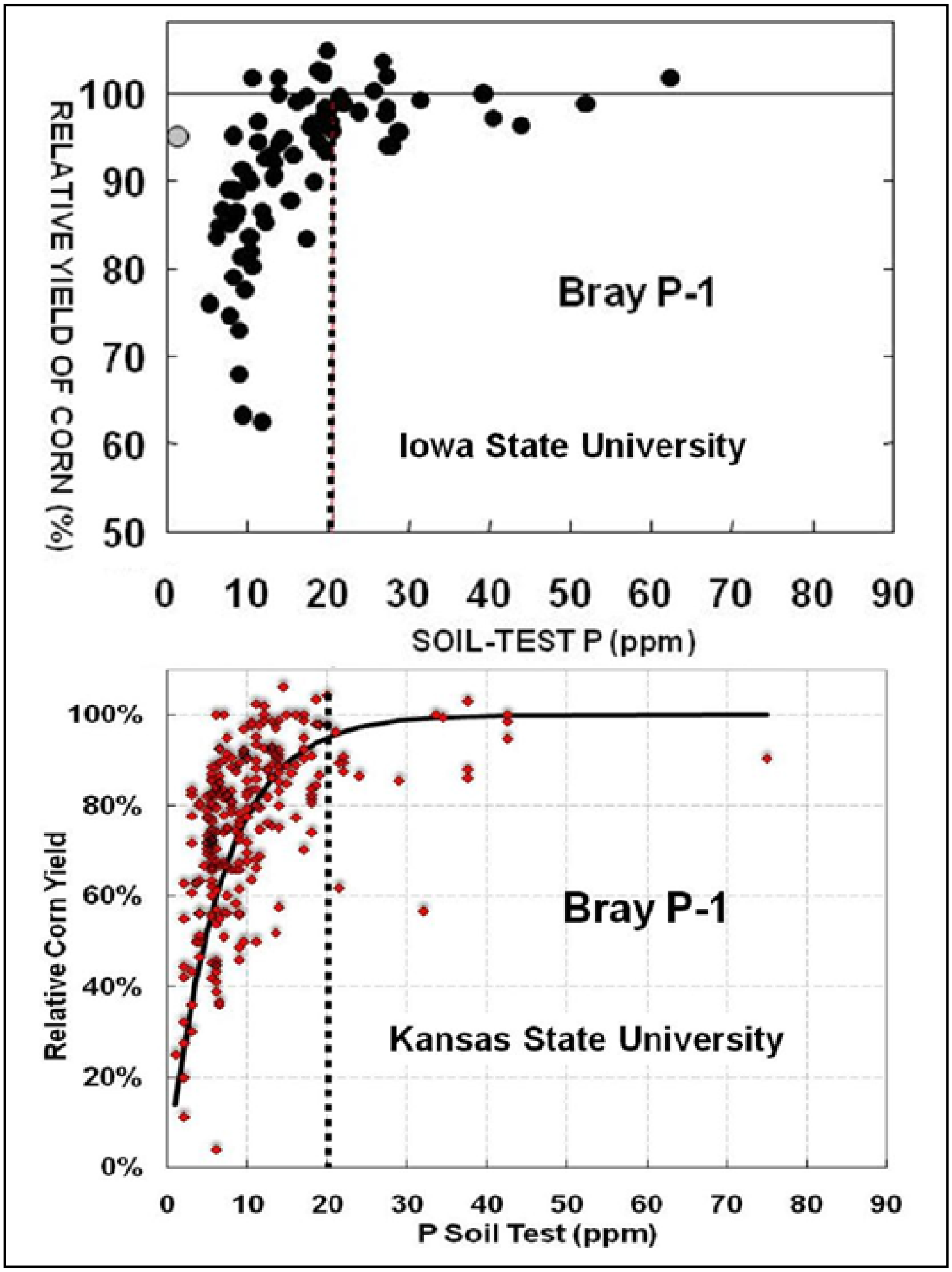

Figure 1. Iowa State University and Kansas State University P Correlation Data

Geographic regions. Why do different institutions/people adopt different approaches to P and K fertilization? Is it because crops respond differently in different geographic regions, making one approach better than others for a given region? Not really. Actually, soil test correlation research conducted across wide geographic areas provides very similar results if the soil sampling depth is the same. For a specific P or K soil test procedure that is appropriate for a given geographic area, similar long-term average relative yields at various soil test values have been found. Figure 1 uses P correlation data from Iowa State University and Kansas State University to illustrate this point. While there are significant differences in soils and climate between these two states, the resulting crop response research data are very similar. The general interpretation of Bray P1 soil test values in the heart of the Iowa Corn Belt is the same as that on the Great Plains of Kansas. Similar conclusions result for other comparisons across the U.S. and Canada--if the same soil test extractions/procedures are used. The science is essentially the same: it is the interpretation of the science that often varies.

Critical value. While the established P critical value for Iowa State and Kansas State has been set at 20 ppm Bray P1 (Figure 1), others have generally set the critical values anywhere between 15 and 25 ppm Bray P1. These differences may result from the specific mathematical model used to describe the relationship between soil test and relative crop yield and other subjective factors such as an allowance made recognizing that fields exhibit spatial and temporal variability in soil test values. And although not explicitly recognized, those developing soil-test-based fertilizer recommendations introduce their own bias concerning the best approach for interpreting response data and managing P and K fertility programs. It is not so much a difference in research data that causes differences in approaches to P and K fertility programs by different institutions/individuals as it is a difference in 'philosophy'-- a particular approach to risk management and/or past experience among those developing fertility recommendation programs.

Which is correct?

This is a relevant question, but there is not a simple, clear-cut answer. There are many nutrient management programs that vary between a strict sufficiency approach and a strict build-maintenance approach. The advantages of P and K management programs that are closer to a nutrient sufficiency approach include the fact that 1) P and K applications are minimized at soil test values less than the established critical value and 2) that the risk of not obtaining a profitable response to the last increment of applied P and/or K in the year of application is also minimized (not eliminated, but minimized). Situations when the sufficiency approach makes the most sense include 1) limited resources available to invest in a particular year, 2) expected short land tenure situations, and 3) the relatively few soils with a very high capacity to quickly convert relatively soluble/exchangeable forms of P and K to forms that are largely unavailable for crop uptake in a given year. Disadvantages of this approach include 1) need for frequent, precise, and accurate soil testing, 2) very good knowledge of optimum application rates each year is required, and 3) the risk of P or K limiting crop growth and long-term crop productivity and profitability is greater.

Build-maintenance. The advantages of programs closer to a strict build-maintenance approach include 1) greatly reducing risk that P or K will limit crop growth and long-term productivity/profitability, 2) reducing need for frequent soil testing, 3) allowing for timely planting and management of fertilization over time, and 4) increasing future flexibility in the overall fertility program. However, this increased flexibility and risk reduction may require a greater investment in fertilizer initially to build soil test values to the maintenance range. In the long term, however, both nutrient sufficiency and build-maintenance rates eventually 'tend to' stabilize at rates equal to the amounts of P and K removed in the harvested portions of the crop.

Individualize programs. Both of these nutrient recommendation approaches and management strategies specific to each approach are appropriate for individual farmers, individual fields, and for specific conditions in any given year. Regardless of what State a farmer operates in or consideration of an individual producer's attitude concerning risk, their viewpoint in making long-term investments in soil fertility, expected land tenure, and other farmer-specific objectives should be used to develop individualized P and K fertility management programs. In the past, the risk and benefits of various approaches generally have not been well communicated to farmers and crop advisors. Any of the discussed approaches may be 'right' for a given situation or any might be 'wrong.'

Fertilizer a substitute?

One of the assumptions that most P and/or K recommendations are based on is the premise that fresh fertilizer applications to low-testing soils will fully substitute for the fertility provided by high-testing soils. In other words, it is generally assumed that maximum yields can be obtained either by building up soil test P and K levels to 'high' values or by applying enough nutrients to soils testing 'low.' Research has shown that this may not always be the case. For example, several Canadian studies with small grains clearly demonstrated that annual applications of row-applied P to low-testing soils never did equal the yields of wheat and barley grown on high-testing soils. Long-term studies at the Rothamsted Experiment station in the United Kingdom also found that P fertilized crops on low-testing soils did not equal those on high-testing soils.

Penalty severe. Recent studies with corn and soybeans have shown similar results. Table 2 presents the summarized results of a three-year University of Minnesota research study that included both low (6-9 ppm Bray P1) and high-testing soils (20-27 ppm Bray P1). In this study, P was applied only to the corn crop in the corn/soybean rotation. On the high-testing soil, corn yields averaged 192 bu/A over the three years with no response to freshly applied P. On the low-testing soil, which had been mined by ten years of either corn for grain, corn silage or soybeans with no P added, there was a modest response to the applied P but yields only averaged 167 bu/A even at the higher 50-lb P_2O_5/A rate. For soybeans, there was a small response to residual P applications to corn measured on the low P soil with no response on the high P soil, but yields averaged 49 bu/A on the high-testing soils and only 37 bu/A on the low-testing soils. Clearly, there was an advantage to both corn and soybeans for having a high P soil test as compared to a low test. The yield advantage across all eight treatments averaged 30 bu/A (18%) for corn and 12 bu/A (32%) for soybeans. Moreover, the economic penalty associated with the low P-testing field was severe even when P was applied at nutrient sufficiency rates recommended by the University.

Interesting questions. The results from this and other studies do raise some interesting researchable questions. Under what conditions would applied fertilizer be expected to fully substitute for low soil fertility? How does subsoil P and K fertility enter into this discussion? How do soil/environmental conditions interact to affect the effectiveness of fertilizer applications vs. soil fertility (e.g., temperature, moisture, etc.)? Are current university nutrient recommendations based on data from older, lower-yielding sites appropriate for very high-yielding production systems where daily nutrient demand and annual drawdown from the rooting profile can be substantial? The previously discussed research suggests that current soil-test-based fertilizer recommendations are not always adequate for obtaining very high yields. These and other questions identify numerous and valuable opportunities for 1) additional research to continue improving crop production efficiencies, 2) achieving the very high yield potential of current high-yielding hybrids/varieties, and 3) achieving the promise of future genetic advances.

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