CROP NUTRIENTS FOR EVER-INCREASING YIELDS – ARE CURRENT FERTILIZER RECOMMENDATIONS ADEQUATE?

Gyles Randall
Southern Research and Outreach Center
University of Minnesota, Waseca, MN

Crop yields, especially corn, have been trending upward for many years. Between the early 70's and 2000, U.S. average corn yields increased about 1.9 bu/A/yr or 1.24%/year from 80 bu/A to about 140 bu/A (R. Elmore, 2009). Yield increases within the last decade have been closer to 3 bu/A/yr. Moreover with greater genetic yield potential being obtained through advances in corn breeding and biotechnology, yield goals in the next 20 years are targeted at 250 to 300 bu/A by some in the seed industry.

The purpose of this paper is to discuss challenges facing the fertilizer and nutrient management/research industry as crop yields and potential nutrient demand escalate. Are today's nutrient recommendations appropriate for the future? Will they enable these ever-increasing yields to be realized or will they become yield-limiting? Do we have the research in place to develop nutrient best management guidelines for these very high yields? If not, where do we start and what are the nutrient/crop priorities? What are the economic and environmental consequences of this extra-ordinary high-yield production system. Will time of application and placement method guidelines need to be re-evaluated? How will the logistics and capabilities of the farmer and the dealer fit into these "new" nutrient management guidelines? The intent of this paper is to shed some light on these questions and concerns.

RECENT RESEARCH
"PRODUCING HIGH CORN YIELDS ON LOW VS. V. HIGH P-TESTING SOILS"

With elevated input costs to corn production, namely land rent and fertilizer, farmers are often tempted to mine soil P and K by either not applying P and K fertilizers or by applying reduced rates. These reduced rates are often applied in a band to potentially achieve reduced fixation and greater efficiency. Mining of P and K has some downsides and can be costly, depending on the soil test level. At very high soil test levels, mining the soil for a couple of years is often a good decision without negative consequences. However, as soil tests decline from high to medium to low levels, the risk of yield loss and reduced profit escalates quickly. Thus, with a large amount of land being rented, it is important for producers to accurately know the soil test level when developing a fertilizer game plan to maximize profitability of their fertilizer dollar.

A study was conducted on both low (L) P and very high (VH) P-testing Webster clay loam soils at the Southern Research and Outreach Center at Waseca, MN to evaluate optimum P placement methods [pop-up (in seed furrow), deep-band (6-7" below soil surface under the seed), and broadcast]. Phosphorus was applied for corn at rates of 0, 25, and 50 lb P_2O_5/A on the low P-testing sites and at rates of 0, 20, and 40 lb P_2O_5/A on the VH P-testing sites. The University of Minnesota currently recommends 40 lb band-applied P_2O_5/acre and 75 lb broadcast-applied P_2O_5/acre for 175-199 bu/acre corn yields (Rehm et al., 2006). Potassium was deep-banded in the fall to all low P-testing plots at 120 lb K_2O/A in 2004 and 200 lb K_2O/A in 2005 and 2006. Corn was grown on both L and VH P-testing soils in 2005, 2006, and 2007. Soybeans were planted the following year at each site to determine residual effects of P applied for corn; no additional P was applied for soybean. Soil test P averaged 7 ppm (L) Bray P_1 at the three low P-testing sites that had been mined for six years and 25 ppm (VH) for the three higher-testing sites. The low-testing sites were always located within 600 to 1500' of the higher-testing sites. Tile drainage with a 75' spacing was similar for all sites. Corn hybrids, soybean varieties, planting dates, planting rates, N rates, and pesticides used were similar for the low and higher-testing sites each year. Soil pH averaged 5.9. Corn was planted following fall strip tillage, and soybeans were no-till planted.

Corn

Three-year corn yields shown in Table 1 averaged 193 bu/A on the VH P-testing soils with no yield response to added fertilizer P. Yields were maximized at only 168 bu/acre with the 50-lb P_2O_5/A rate on the low P-testing sites even though only 40 lb of band-applied P_2O_5/A is recommended by the University of Minnesota. (Table 2).

Broadcast application yielded 8 bu/A more (166 bu/A) than deep-band or pop-up placement (158 bu/A) when the 25-lb P_2O_5 rate was used. At the 50-lb P_2O_5/A rate, corn yields averaged 166, 166, and 167 bu/A for the deep-band, pop-up, and broadcast treatments, respectively. Thus, there was no advantage for band placement over broadcast application.

On the VH P-testing soils, grain moisture at harvest, grain P concentration, and grain P uptake were not affected by any of the P placement and rate treatments (Table 1). On the low P-testing soils, grain moisture at harvest was highest for the no P control treatment and was significantly less (0.4 to 0.5 percentage points) for in-furrow, pop-up placement than for deep-band and broadcast placement (Table 2). Grain P concentration was affected very slightly by the P treatments with a trend toward lowest P for the deep-band treatment. The significant P Placement x Year interaction was due no affect of P placement in 2005 but significant affects of P placement on grain P in 2006 and 2007. Uptake of P in the grain was increased significantly over the no P control by 6 of the 7 P treatments. Greatest P uptake occurred with the dual placed deep-band + pop-up treatment; however, P placement did not affect grain P uptake when averaged across the two P rates. Annual phosphorus uptake averaged 10 lb P/A greater for the VH P-testing sites with no fertilizer P (27 lb P/A) than for the low P-testing sites receiving 50 lb P_2O_5/A (17 lb P/A).

Soybean

Soybean yields in the following year averaged 49 bu/A on the VH P-testing soils without added fertilizer P and 39 bu/A on the low P-testing soils that received 50 lb P_2O_5/A for corn the previous year (Tables 3 and 4). Soybean yields were not affected by any of the P treatments on the VH P-testing soils but were increased by as much as 6 bu/A by the residual effect of the P placement and rate treatments applied the previous year for corn on the low P-testing sites. Similar to the corn results, there was no yield advantage for deep-band placement compared to broadcast. Annual P uptake in the soybean seed averaged 15 lb P/A for the VH P-testing soils and only 8 lb P/A on the low P-testing soils receiving a 50-lb P_2O_5 rate applied for the previous corn crop.

Corn-Soybean Rotation Summary

Results from this 3-yr corn-soybean rotation (6 site-years) confirm that very high P-testing soils produce greater and more profitable corn and soybean yields without additional fertilizer P than mined, low P-testing soils where recommended rates of fertilizer P are applied. The corn and soybean yield advantage of 25 and 10 bu/A, respectively, for the VH P-testing sites points out the economic penalty associated with low P-testing soils even when P fertilizer is applied. At corn and soybean prices of $3.50 and $10.00/bu, respectively, economic return was reduced by $88/A for corn and $100/A for soybean on these low P-testing soils.

The above data coupled with the greatly increased P concentrations in the corn grain (46%) and soybean seed (43%) from the VH P-testing sites strongly suggests that maintaining soil test P at or above 20 ppm Bray P_1 optimizes yields, reduces the need for supplemental P for soybeans, improves profitability, and reduces economic risk compared to growing a corn-soybean rotation on low P-testing soils. Furthermore, the results clearly indicate: (1) the importance of knowing the soil test P status of fields planted to corn and soybeans, especially those recently rented or acquired, (2) mining of soil P may pay in the short term, but over time yields and profits will be reduced substantially, (3) deep-banding P at a half-rate led to decreased yields and economic return compared to full-rate of fertilizer P on soils that have been mined to low soil tests and (4) a high fertilizer rate does not equate to high soil fertility.

STATUS OF CURRENT FERTILIZER RECOMMENDATIONS AND FUTURE CONSIDERATIONS

- Many Are Old

Many of the current recommendations, if not following a crop removal philosophy, are based on research conducted in the 80’s, 70’s, and even earlier. At that time U.S. average yields ranged from 80 to 120 bu/A, and it is likely that yields in many of the calibration research trials seldom exceeded 175 bu/A. Yield response probabilities and critical levels were based on the calibration studies of the time. In some states, little P and K calibration research has been conducted since. In other states, notably Iowa, scientists with extended vision started long-term P and K response trials at that time, which have been most helpful for updating nutrient rate recommendations. Recently, the University of Nebraska changed their long-time STP critical level of 15 ppm to 25 ppm for corn after corn based on current high-yield data (Richard Ferguson, personal communication, 2009).

- Logistical Concerns

Soil Testing is critical to the implementation of sound nutrient rate recommendations. But, soil testing has its share of uncertainties (A. Mallarino, 2009) and a vigorous research and extension effort is needed to complement new fertilizer recommendations.

Variable Rate Application has come a long way since its inception. With improved technology and information, it will be desirable to apply variable rates of P and K to the soil to obtain very high and profitable yields with reduced risk of insufficient P or K.

Time and Labor are substantial issues facing farmers and fertilizer suppliers, especially as farm operations get larger and the territory served by fertilizer dealers expands. Fertilizer applications that require more time, management, and specific placement equipment often are passed over in favor of broadcast application as a farmer's acreage grows. With increased emphasis on early and timely planting, larger farm operations often pass on application methods that slow or delay planting. Storage space also becomes an issue for the dealer if non-traditional N and P products are desired. Some of these products may have increased-efficiency attributes desired by the grower, but extra storage needs for these products can be a negative issue for the dealer. Regardless, timing and fertilizer placement choices are influenced by the dealer's and grower's needs, and they require consideration by the nutrient research community as research is developed and prioritized.

Risk of yield loss is a concern that faces both dealers and farmers. The possibility that yield is left in the field due to inadequate nutrient availability or supply is unthinkable for growers attempting to maximize return on their fertilizer dollar. As farmers work with their dealers and/or agricultural advisors to arrive at a nutrient application game plan, risk plays a key role in arriving at the final decision. Researchers, working to provide adequate nutrient supply for high and very-high yield conditions, need to keep economic and environmental risks in mind.

- Land Tenure

Whether the land to be fertilized is owned or is rented can and perhaps should play an important role in decisions on fertilizer rate and placement. To date this factor has not been included in fertilizer guidelines provided by most Universities. Kansas State University has led the way in developing P recommendations based in part on land tenure. Farmers who own land to be fertilized generally have a long-term vision for that land that involves keeping the soil test values at somewhat higher levels to minimize risk of yield loss and to enhance the value of their enterprise. On the other hand, when land is rented and the tenure is not secure for more than 2 or 3 years, farmers often choose a short-term plan of using lower rates of fertilizer to maximize economic return for the current year or two. This approach annually requires a different nutrient rate recommendation than does the long-term approach suitable for land owners.

- Financial position

Similar to land tenure, those farmers who are in a strong financial position can afford and do value keeping their soil tests at higher levels. Also, this is often true for those farmers who have purchased low-testing land and now want to build the soil test up to a higher level where they will maintain it at that level in the future. On the other hand, farmers with limited cash resources will lean toward applying just enough fertilizer to optimize profit for the present year.

- Environmental concerns

Environmental concerns will continue to escalate as public perceptions mount, relating decreased water quality to agriculture in general and fertilizer in particular. Nutrient regulations will likely become more prevalent and enforcement more strict. Thus, in addition to agronomic and economic factors, environmental concerns must be a part of the planning process when developing a nutrient game plan.

- Uptake Amounts Will Be Greater

Based on the P uptake shown for the P treatments in Tables 1 and 2 for corn and Tables 3 and 4 for soybean, P uptake was 70% greater for 192 bu/A corn grown in a high STP environment compared to 164 bu/A corn with fertilizer P in a low STP environment. Similarly, P uptake by 49 bu/A soybeans in a high STP environment was 90% greater than for 37 bu/A soybeans in a low STP environment. Furthermore, based on these high STP soils, it is estimated that P uptake will be increased 56% (13.2 lb/A) by 250 bu/A corn compared to 160 bu/A corn and by 66% (9.0 lb P/A) when increasing soybean yields from 45 to 75 bu/A. Over a 2-yr C-S rotation, this is an increase of more than 22 lb P/A taken up from the soil by these higher yields.

- Soil Test Decline Rates Will Be Greater

With increasing amounts of P taken up annually by higher yielding corn and soybean, we can expect STP to decline at faster rates. Research conducted on a Webster soil in southern Minnesota from 1974-1993 showed annual STP decline rates of 2 ppm Bray P/year when initial Bray P was about 20 ppm (until STP declined to 10 ppm) and 2.5 ppm Bray P/yr when the initial test was about 40 ppm when no fertilizer P was added (Randall et al., 1997). Corn and soybean yields averaged 150 and 49 bu/A, respectively in this study. The University of Minnesota has no STP decline rate data for higher yielding situations, but it is fair to assume that STP decline rates will be much greater as P uptake is increased by 50% per year.

NUTRIENT MANAGEMENT RESEARCH TO MEET FUTURE NEEDS

Presently, there appears to be very little P and K management research to develop critical levels, calibration data, and application rate, timing, and placement guidelines to meet the needs of very-high-yield corn production. Three factors contribute to this situation. First, nitrogen has been a priority because of heightened water and air quality concerns. Second, funding to support P, K, S, and micronutrient research has been limited, especially with respect to high-yield conditions. Third, due to funding issues and shifts in research priorities within universities, the number of applied scientists within soils and agronomy departments, who are available to conduct this research, is limited.

It appears that the following are needed if the scientific community is going to meet the needs of very-high-yield corn production:

- Calibration research

Present-day critical levels, yield response probabilities, and relative soil test interpretation ranges (L, M., Opt. H, and VH) will need to be re-examined under very-high-yield levels. To minimize the effect of other non-controllable yield-limiting factors, i.e., water, more of this research will need to be conducted under irrigated conditions or at least where supplemental water can be added at critical growth stages or during extensive dry periods. A combination of small and large scale research (small plots and field-size plots) would be beneficial for obtaining this new calibration information.

- Multiple recommendations

Rather than the single prescriptive nutrient rate recommendations that are often given now (tending toward one size fits all), we need to provide a suite of recommendations that meets the needs of our customers. Land tenure, financial position, and fertilization philosophies differ among the clientele using nutrient guidelines. We must provide nutrient management options if we are going to meet their “tailor-made” needs. By doing so, these nutrient guidelines will facilitate communication between the grower and their fertilizer supplier, ag advisor, and/or lender. Fertilizer response-based recommendations should be available for short-term land rental and financially limited positions, whereas build and maintenance recommendations should be available for land owners with a long-term nutrient management vision.

- Sulfur and micronutrients

Traditionally, sulfur and micronutrients have received little attention on most highly productive Corn Belt soils. Yield responses by corn to these nutrients were almost non-existent in the 20th century on higher organic matter and medium and fine-textured soils. This is changing as many responses to S and some to Zn have been reported in the last few years. This trend is expected to continue, especially as a greater nutrient demand exists with very-high-yield production.

- Priorities

Priorities with respect to crop and nutrient studied will need to be made for each state. Bringing the highest priorities to potential funding sources (fertilizer industry, commodity groups, bio-fuel industry, and other agencies) should produce the kind of research that will lead to improved nutrient recommendations for all growers – not just those capable of very high yields. From my perspective, a well coordinated Midwest regional approach to new P recommendations would be a good place to start.

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Table 1. Three-yr average corn grain yield, moisture, P concentration, and P uptake as affected by placement and rate of P in a strip-till system on HIGH and VERY HIGH P-testing soils at Waseca, 2005-2007.

P Treatments			Grain	Grain	Grain	Grain
No.	Placement	Rate	Yield	H_2O	[P]	P Uptake
		lb P_2O_5/A	bu/A	%	%	lb/A
Stats for RCB Design analyzed across years (Split-plot, year is main plot)						
Treatment						
1	None	0	193	19.0	0.296	26.9
2	Pop-up starter	20	192	18.6	0.307	27.7
3	Deep band	20	196	18.7	0.313	28.9
4	Broadcast	20	196	18.9	0.314	29.0
5	Deep band + pop-up	20 + 20	189	19.2	0.313	27.8
6	Pop-up starter	40	194	18.4	0.305	27.9
7	Deep band	40	186	18.7	0.309	27.2
8	Broadcast	40	190	18.8	0.315	28.1
P > F:			0.392	0.086	0.850	0.718
LSD (0.05):			NS	NS	NS	NS
Interaction (Year*Treatment)						
P > F:			0.994	0.486	0.413	0.519
CV (%):			6.1	3.2	10.1	11.4
Stats for RCB Design with 2-Factor Factorial Arrangement (treatments 2-4 and 6-8)						
P Placement						
Pop-up			193	18.5	0.306	27.8
Deep band			191	18.7	0.311	28.0
Broadcast			193	18.9	0.314	28.5
P > F:			0.826	0.137	0.660	0.720
LSD (0.05):			NS	NS	NS	NS
P Rate (lb P_2O_5/A)						
20			195	18.8	0.311	28.5
40			190	18.6	0.309	27.7
P > F:			0.102	0.382	0.828	0.313
Interactions (P > F)						
P Placement x rate			0.133	0.843	0.968	0.614
P place x year			0.971	0.628	0.249	0.331

Table 2. Three-yr average corn grain yield, moisture, P concentration, and P uptake as affected by placement and rate of P in a strip-till system on a LOW P-testing soil at Waseca, 2005-2007.

P Treatments			Grain	Grain	Grain	Grain
No.	Placement	Rate	Yield	H_2O	[P]	P Uptake
		lb P_2O_5/A	bu/A	%	%	lb/A
Stats for RCB Design analyzed across years						
Treatment						
1	None	0	148	19.4	0.199	14.2
2	Pop-up starter	25	158	18.4	0.215	16.2
3	Deep band	25	158	18.9	0.200	15.1
4	Broadcast	25	166	18.7	0.212	16.7
5	Deep band + pop-up	25 + 25	172	18.8	0.229	18.6
6	Pop-up starter	50	166	18.4	0.218	17.2
7	Deep band	50	166	18.9	0.207	16.5
8	Broadcast	50	167	18.9	0.220	17.4
P > F:			<0.001	<0.001	0.031	<0.001
LSD (0.05):			10.5	0.5	0.019	1.9
Interaction (Year*Treatment)						
P > F:			0.032	0.519	0.144	0.013
CV (%):			7.9	3.0	11.0	14.0
Stats for RCB Design with 2-Factor Factorial Arrangement (treatments 2-4 and 6-8)						
P Placement						
Pop-up			162	18.4	0.216	16.7
Deep band			162	18.9	0.203	15.8
Broadcast			167	18.8	0.216	17.0
P > F:			0.256	<0.001	0.051	0.120
LSD (0.05):			NS	0.3	NS	NS
P Rate (lb P_2O_5/A)						
25			161	18.7	0.209	16.0
50			166	18.7	0.215	17.0
P > F:			0.049	0.477	0.222	0.049
Interactions (P > F)						
P Placement x rate			0.447	0.705	0.901	0.793
P Placement x year			0.044	0.268	0.005	0.001

Table 3. Three-yr average soybean seed yield, P concentration, and P uptake as affected by placement and rate of P applied for corn in the previous year in a strip-till system on HIGH and VERY HIGH P-testing soils at Waseca, 2006-2008.

P Treatments			Seed	Seed	Seed
No.	Placement	Rate	Yield	[P]	P Uptake
		lb P_2O_5/A	bu/A	%	lb/A
Stats for RCB Design analyzed across years					
Treatment					
1	None	0	49.1	0.583	15.0
2	Pop-up starter	20	49.1	0.579	14.9
3	Deep band	20	48.8	0.579	14.8
4	Broadcast	20	50.3	0.576	15.1
5	Deep band + pop-up	20 + 20	49.3	0.577	15.0
6	Pop-up starter	40	48.9	0.578	14.8
7	Deep band	40	49.1	0.563	14.5
8	Broadcast	40	48.4	0.587	14.8
P > F:			0.842	0.677	0.962
LSD (0.05):			NS	NS	NS
Interaction (Year*Treatment)					
P > F:			0.982	0.671	0.976
CV (%):			5.6	5.0	7.7
Stats for RCB Design with 2-Factor Factorial Arrangement (treatments 2-4 and 6-8)					
P Placement					
Pop-up			49.0	0.579	14.8
Deep band			48.9	0.571	14.6
Broadcast			49.4	0.581	15.0
P > F:			0.827	0.396	0.605
LSD (0.05):			NS	NS	NS
P Rate (lb P_2O_5/A)					
20			49.4	0.578	14.9
40			48.8	0.576	14.7
P > F:			0.331	0.732	0.423
Interactions (P > F)					
P Placement x rate			0.314	0.229	0.969
P place x year			0.471	0.510	0.752

Table 4. Three-yr average soybean seed yield, P concentration, and P uptake as affected by placement and rate of P applied for corn in the previous year in a strip-till system on a LOW P-testing soil at Waseca, 2006-2008.

P Treatments			Seed	Seed	Seed
No.	Placement	Rate	Yield	[P]	P Uptake
		lb P_2O_5/A	bu/A	%	lb/A
<u>Stats for RCB Design analyzed across years</u>					
Treatment					
1	None	0	34.5	0.385	7.1
2	Pop-up starter	25	36.4	0.393	7.6
3	Deep band	25	34.7	0.379	7.0
4	Broadcast	25	36.7	0.399	7.8
5	Deep band + pop-up	25 + 25	40.8	0.444	9.5
6	Pop-up starter	50	38.2	0.419	8.4
7	Deep band	50	38.5	0.406	8.2
8	Broadcast	50	37.1	0.423	8.2
P > F:			0.013	0.001	0.001
LSD (0.05):			3.5	0.025	1.1
Interaction (Year*Treatment)					
P > F:			0.167	0.119	0.227
CV (%):			11.5	7.5	16.8
<u>Stats for RCB Design with 2-Factor Factorial Arrangement (treatments 2-4 and 6-8)</u>					
P Placement					
Pop-up			37.3	0.406	8.0
Deep band			36.6	0.393	7.6
Broadcast			36.9	0.411	8.0
P > F:			0.788	0.084	0.386
LSD (0.05):			NS	NS	NS
P Rate (lb P_2O_5/A)					
25			35.9	0.391	7.4
50			37.9	0.416	8.3
P > F:			0.015	0.001	0.003
Interactions (P > F)					
P Placement x rate			0.228	0.988	0.521
P Placement x year			0.226	0.053	0.120