Optimum Phosphorus Management for Small Grain Production

By Paul E. Fixen and Ardell D. Halvorson

In many respects, economic evaluation of phosphorus (P) management is more complex than nitrogen (N) management. This is due to the substantial residual value of P fertilizer applications. Also, P soil tests are indices which reflect the average relative yield or probability of response at a given level. They frequently do not accurately predict the precise rate of P necessary to give a certain yield in any given season. This uncertainty has led to debates by agronomists on how to best use P soil tests. Typically these debates go unresolved with differences attributed to the "philosophical" positions of the individuals.

PART OF THE CHALLENGE in economic evaluation of P management is dealing with variable responses. **Figure 1** summarizes several long-term spring wheat studies from the northern Great Plains and is typical of P calibration data. At a 20 lb/A P soil test, relative yield varies from 70 percent to 100 percent (100 percent is defined as the estimated yield with P non-limiting). At a 10 lb/A soil test (**Table 1**), a grower who does not apply P could expect to lose from 7 to 15 bu/A, depending on average yield potential, due to inadequate P availability. However, the actual P response varies widely from year to year.

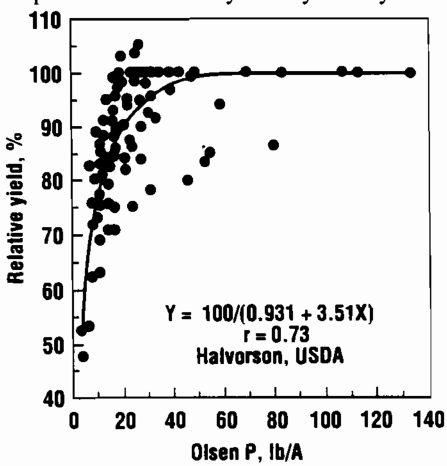

Figure 1. Spring wheat response to soil test P level in the northern Great Plains.

Table 1. Estimated spring wheat yield loss from P deficiency at various soil test levels.

Olsen P, lb/A	Relative yield, %	Average yield potential, bu/A: 30	50	70
		bu/A lost		
10	78.0	6.6	11.0	15.4
20	90.4	2.9	4.8	6.7
30	95.4	1.4	2.3	3.2
40	98.2	0.5	0.9	1.3
50	99.9	0.0	0.1	0.1

Based on data from Figure 1. Halvorson, USDA

Response variability to fertilization at a given soil test P level should not be surprising. Numerous factors other than soil test level influence supplemental P needs in a given growing season on a given soil type. Variability in P response among years and the nature of P soil tests suggest that response economics should be viewed in the long term.

Economic Evaluation of P Management

Nearly all P fertilizer recommendation systems maintain soil tests at some level either intentionally or incidentally from rates recommended for various yield goals. However, systems vary in the rate and extent of build-up. A critical question is: At what level should P soil tests be maintained? This question can be addressed

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economically. It can be viewed as independent of maintenance costs as long as the costs of the maintenance nutrients are subtracted from the value of the crop grown. A bushel of wheat grain contains about 0.5 lb of P_2O_5 at a value of approximately 11 cents.

Only a fraction of the P_2O_5 applied in any one year is used by the crop in that year. In most soils, the majority of P_2O_5 applied remains in the soil in forms that are available for future uptake. Just as costs of installing tile drainage or irrigation are not recovered in one year, the cost of build-up P does not need to be recovered in one year, even though this can happen.

The cost of build-up applications should be amortized over several years ... the expected lifetime of the investment or the expected time of ownership. Since build-up P should never wear out if removed nutrients are replaced, expected time of ownership or operation would normally be the controlling factor. Therefore, land tenure becomes an important factor in determining the target soil test level.

Amortization requires use of an interest rate. This could be the interest associated with borrowed capital or viewed as an opportunity cost for alternative investments if no money is borrowed.

Long-term crop and fertilizer prices will influence selection of a target soil test level. Also, the amount of P_2O_5 required to change the soil test level a given amount impacts the cost of soil P build-up.

Since soil tests are usually related to relative yield in percent, the average yield potential of the field is another factor to consider. The higher the absolute yield, the greater dollar value each percent increase in relative yield will have.

Obviously, a number of factors influence the optimum soil test level for a given field. One must decide the importance of each of these factors and how they interact with each other. The best way to discuss these factors is to select an appropriate data set and evaluate the effect of various conditions on the optimum soil test P level.

Factors Influencing Optimum Soil Test Levels

The percent yields in **Figure 1** were converted to bushels per acre (**Table 1**) since economic evaluation requires absolute rather than relative yields. A relative yield of 95 percent has commonly been viewed as essentially the same as maximum yield. However, an **actual** long-term average yield reduction of 5 percent can be of substantial economic importance to a farmer ... and important when considering P because of the relatively inexpensive nature of P build-up.

A computer program was developed, based on the equation in **Figure 1**. It will calculate the P soil test level at which the amortized cost of an additional unit of soil test build up is equal to the average value of the additional yield increase. The following discussion is based on that program.

Average yield potential and land tenure have dramatic effects on optimum soil test level (STL) (**Figure 2**). The three curves represent 30, 50 and 70 bu/A average yield potentials. As land tenure increases, optimum soil test level increases. Land operated on a short-term lease has a lower optimum level than land that is owned and likely to stay in the family for decades.

Fertilizer price, crop value, and interest rates also influence optimum soil test levels, but not as much as yield potential and land tenure. For example, increasing net wheat price from $2.50 to $3.50/bu increases optimum soil test level by only 5 to 8 lb/A.

Soils differ in the amount of P required

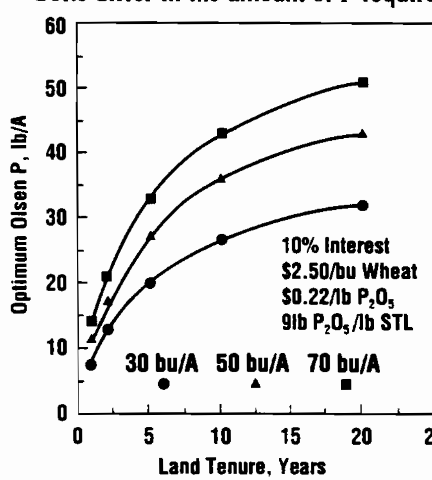

Figure 2. Land tenure affects optimum Olsen P level for wheat.

to change soil test levels (P buffer capacity). Some low pH and some high pH soils fix applied P_2O_5 readily and build-up is more costly, decreasing the optimum soil test level. Many soils require from 8 to 12 lb P_2O_5 to change the soil test P level one lb/A.

Determining Optimum P Rates

When a long-term basis is used in making P rate decisions, the focus must be on soil test P level. Therefore, the first step in determining optimum rate must be determination of optimum soil test level considering the factors discussed earlier. Then, a rate-soil test level relationship needs to be used that maintains soil test levels at the optimum point. In other words, if the current soil test level is less than the optimum, the rate should be greater than the quantity of P removed by the crop to allow soil test levels to build. If the current level exceeds the optimum, the rate should be less than removal which will allow soil test levels to decline to the optimum point.

A critical question is: How fast should a low testing soil be built to the optimum level? In most cases it makes little economic sense to apply P at a rate that exceeds the rate required for maximum yield during the year of application. The following example illustrates how that rate can be estimated.

Given:	
Current P soil test level:	5 lb/A
Relative yield (Figure 1):	61.2%
Yield with P nonlimiting:	50 bu/A
P (P_2O_5) uptake by plants:	
Total: 0.68 lb P_2O_5/bu × 50 bu = 34 lb P_2O_5	
From soil:	21 lb (61.3%)
From fertilizer:	13 lb (34-21)

In this example, 13 lb P_2O_5 must come from the fertilizer for the crop to yield its full potential of 50 bu/A. In order to know how much fertilizer to apply, the first year recovery of fertilizer P by the crop must be known or assumed. Recovery the year of application at low soil test levels can vary from less than 10 percent to as high as 30 percent. As soil test P levels increase, response to P fertilization decreases and recovery declines.

The best we can do in our general example is to illustrate rate requirements at high and low first year recoveries as follows:

30% recovery: 13 lb P_2O_5 needed/0.30 = 43 lb P_2O_5 to apply

15% recovery: 13 lb P_2O_5 needed/0.15 = 86 lb P_2O_5 to apply

Fertilizer placement and growing season weather conditions are major factors determining P recovery. Recovery at low soil test levels and modest application rates will usually be higher for band than for broadcast applications. Above Olsen P levels of 25 to 30 lb/A, band and broadcast applications generally have similar effectiveness. However, environmental conditions can cause enhancement of early growth and development by seed-placed P_2O_5 even at high soil test P levels.

Recommended rate of applied P would decrease as soil test level increases above 5 lb/A until application equals removal at the grower's optimum soil test level. If the grower in the example had an optimum soil test P level of 25 lb/A (10 percent interest, 4-year tenure, 9 buffer potential, \$0.22/lb P_2O_5, \$2.50/bu), crop removal or 25 lb P_2O_5/A (0.5 lb P_2O_5 removed/bu) would be applied at that level.

A single application of 86 lb P_2O_5/A, indicated for the lower first year recovery in the example, will normally increase soil test levels by 6 to 9 lb/A. That will result in a reduction in future P_2O_5 needs and greater placement flexibility.

The fit of the approach outlined can best be evaluated by using data shown in **Figure 3**. It indicates the average wheat

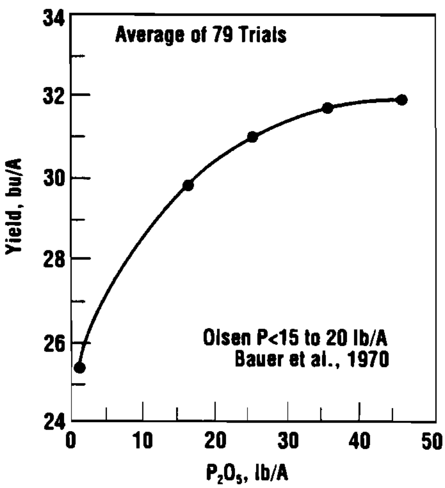

Figure 3. Wheat response to banded P (North Dakota, 1949-1961).

response to rates of banded P from 79 trials conducted in North Dakota from 1949 to 1961 where soil P tests were less than 20 lb/A. These historical data show some yield response up to 45 lb banded P_2O_5 and are supportive of the rates calculated where high first year recovery is assumed. Rate requirements today are likely to be at least as high at a given soil test level as they were in the 1950s.

A Long-Term Look at P Rates, Placement, and Yields

To maximize profitability, long-term effects cannot be ignored in P fertilizer management. Researchers in Saskatchewan have compared one-time broadcast P applications to annual seed-placed P and to various combinations of broadcast and seed-placed P over a 5-year period (**Figure 4**). At low P rates, seed placement appeared to have a slight advantage over broadcast application; however, at optimum rates, broadcast application produced higher yields over the 5-year period even though the initial soil test P level was very low.

Highest yields occurred where an initial heavy broadcast P application elevated soil test levels followed by small annual rates applied with the seed. These data suggest that regardless of placement method(s), it is important to maintain an optimum soil test level to experience the full yield potential of the system.

Similar effects are being measured in an ongoing Colorado study on no-till winter wheat (**Figure 5**). Cumulative response to seed-placed P leveled off at about 100 lb P_2O_5/A and produced a total response of 14 bu/A. The broadcast treatments continued to increase yield to rates exceeding 200 lb P_2O_5/A and produced a total response of about 28 bu/A, twice that of the seed-placed treatments. Like the Saskatchewan study, there was a decided advantage to increasing soil test levels quickly. These studies and others indicate that a soil testing at its optimum level will often have a higher yield potential than one testing low, even when P fertilizer is applied to the low soil.

Summary

Many of the differences in P recommendations attributed to "philosophical" positions appear to be due to the assumptions made about the situation of the individual grower. Small grain profitability could be increased through site specific P recommendations that replace general assumptions with specific soil and grower data and that consider both long-term and short-term effects. ■

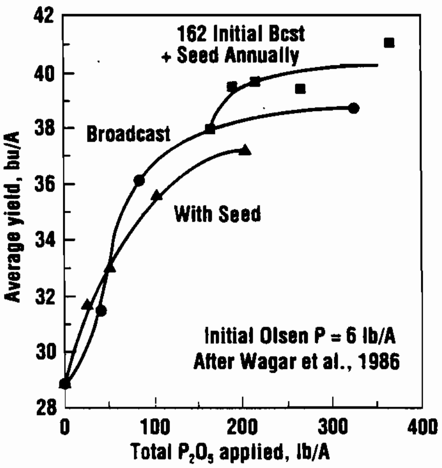

Figure 4. Spring wheat response to P in Saskatoon, 5-year average.

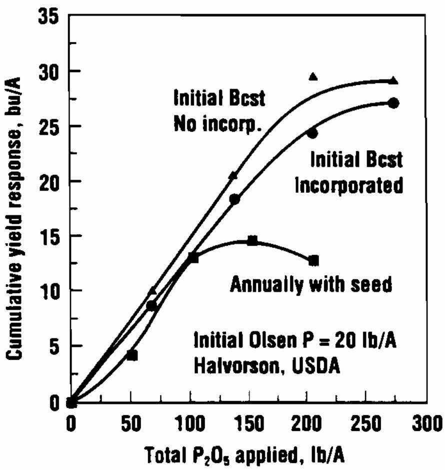

Figure 5. Cumulative winter wheat response to P at Peetz, CO, 3-year totals.

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Our Cover: Wheat with 60 lb/A of P_2O_5 band applied showed dramatic response compared t plots with no P_2O_5 applied. Oklahoma State Uni versity research at Carrier, OK.
Photo by Dr. Larry S. Murphy.