Diagnostic of Soil Phosphorus Availability for Crops and Concepts of Fertilizer Recommendations

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Introduction

Careful phosphorus (P) management planning is very important these days because of volatile grain/fertilizer price ratios and increasing public concerns about water quality impairment due to excess P loss from fields. Higher fertilizer prices may not be a major issue as long as the crop prices also increase. Largely unpredictable price fluctuations complicate fertilization decisions, however, and encourage producers to cut fertilization rates. Reducing P fertilization rates sometimes also is seen as an effective way of reducing P loss from fields and improving water quality, especially when manure is applied. Reducing P application rates across all conditions is not a good management decision, however, and may not increase producers' returns to crop production or reduce P loss from fields significantly. Therefore, producers and crop consultants must understand basic concepts of P management and that there is no single best philosophy for interpreting soil-test values and deciding fertilizer application rates.

Soil Phosphorus Testing

Soil P testing is not free of error, but is a useful diagnostic tool on which P fertilization should be based. Also, compared to recent grain and fertilizer prices, soil sampling and testing have become less expensive. Different tests for one nutrient often provide different results that can be expressed in a variety of ways. Soil-test methods attempt to measure an amount of nutrient that is proportional to nutrient availability for crops; however, the amount measured even by the same test may change across soils with contrasting properties. Therefore, soil-test methods need to be calibrated in order to be used in a specific region. The calibration process includes determining the soil-test level or range that separates responsive from not responsive soils (the critical level or range) and the fertilization rate appropriate for each soil-test value or range (Dahnke and Olson, 1990).

Most states establish soil-test interpretation categories that encompass very low to very high nutrient levels. Determining the critical level or range is not a clear-cut process and there is no single way of doing it. Several mathematical equations can be used to determine critical levels, but all include some bias and a significant level of uncertainty. Furthermore, calculations may involve or target maximum yield or maximum economic yield. Research has shown that widely different critical levels can be established depending on many assumptions and considerations (Mallarino and Blackmer, 1992). Also, whether it is explicitly recognized or not, scientists who develop soil-test interpretations and fertilizer recommendations introduce their own bias concerning what should be the most important considerations and most appropriate management philosophy.

Philosophies for Soil-Test Interpretation and Fertilizer Recommendations

Philosophies for soil-test interpretations and fertilizer recommendations vary across states of the United States. Another presentation will specifically address sufficiency level and build-up and maintenance philosophies, so these will not be described in detail here. A strict sufficiency level philosophy emphasizes short-term profitability from fertilization, high returns per pound of fertilizer applied, and reduced risk of fertilizer over-application by accepting a moderate risk of yield loss. It requires precise and frequent use of soil-testing and, in general, is more suitable for soils with large capacity to retain applied P in forms that are not available to crops (high "fixing" capacity). Philosophies based on build-up and maintenance concepts emphasize reduced risk of yield loss due to insufficient fertility, long-term profitability from fertilization, and maintenance of optimum or slightly higher than optimum soil-test levels. It may not require frequent soil testing, in general is suitable for soils that retain but do not necessarily "fix" much of the applied P, and requires knowledge of fertilizer rates needed to maintain soil-test values, which usually is based on P removal with or without adjustments based on empirical data.

The philosophy behind soil-test P interpretations and fertilizer recommendations in Iowa (as in most states of the North-Central Region) combines aspects of both philosophies. Interpretations and recommendations vary among states of the region in part because soil properties and other production conditions differ across states. The recommendations differ even with approximately similar crop response and soil-test calibration data, however, because the philosophy and assumptions of those making the recommendations also differ across states. The P application rates for low-testing soils recommended in Iowa (Table 1) are designed to be profitable, to minimize risk of yield loss for a soil-test range where the probability of a large crop response is very high, and to gradually increase soil-test values to the Optimum category over a certain period of time. Moderate soil-test P buildup happens even with economically optimum rates applied to low-testing soils. This is explained by partial plant uptake, recycling to the soil with residues, and soil properties that keep applied P in crop-available forms over time. Most Iowa soils have no chemical and mineralogical properties that result in significant transformation of applied P into unavailable forms as can happen in other regions (Dodd and Mallarino, 2005). Therefore, much of the P applied can be "banked" in the soil.

Considering Uncertainty and Crop/Fertilizer Price Ratios

There is always uncertainty concerning relationships between soil-test values and nutrient sufficiency for crops and response to fertilization. Uncertainty arises from errors in soil sampling and testing but mainly by difficulty in accurately predicting conditions that limit response to fertilization or induce a higher-than-expected response. Therefore, it is very important that recommendations provide an idea of the probability of response for the different soil-test categories. As the soil-test levels increase, the probability of a yield increase from fertilization and the size of the expected increase in yield decrease. Iowa field research has shown that the percentage of P applications expected on average to produce a yield response within each soil-test category is approximately 80% for Very Low, 65% for Low, 25% for Optimum, 5% for High, and < 1% for Very High. Obviously, price ratios influence the fertilizer rate that should be applied in order to optimize the profitability of fertilizer application and crop production. No matter the philosophy supporting interpretations, the net returns to investment in fertilizer are high in low-testing soils, decrease as soil-test levels increase, and usually become negative for the High and Very High test categories (Fig. 1). Fertilization of low-testing soils usually results in significant returns because the probability of a large yield increase is high.

Fertilization rates for low-testing soils lower than needed to achieve the maximum net return increase the return per pound of nutrient applied. This is because of the usual curvilinear toward a plateau shape of the crop response to fertilization. Figure 2 shows an example of grain yield increases and net returns from P fertilization in a low-testing soil. Maximum total return often is achieved at a rate lower than the rate that maximizes yield (how much lower depends on price ratios), higher rates decrease total return, while excessively high rates may even result in negative returns. Therefore, producers should carefully study if and when application rates to low-testing soils can be reduced. A sound decision requires consideration of many factors, which include the producer business management philosophy. A low application rate may increase the return per pound of fertilizer applied, but may limit yield, total return to investment in fertilizer, and total return to the production system. In some regions, similar yield levels can be achieved in low-testing soils by using reduced planter-band P fertilizer rates compared with broadcast fertilization. Research in many fields has shown that this is seldom the case for Iowa soils, however (Bordoli and Mallarino, 1998; Borges and Mallarino, 2000; Kaiser et al., 2005).

In high-testing soils, the likelihood of a loss to investment in fertilization for one crop is high, because the probability of a yield response is low and any response usually is small. Allowing a soil-test decline to occur in high-testing soils also may reduce the risk of water-quality impairment. Therefore, avoiding unnecessary fertilization of high-testing soils is the most profitable change a producer can use in times of high or uncertain prices. Some believe that allowing high-testing values to decline may not be a good business decision, because fertilizer prices may be even higher in the future. This is an issue that each producer should consider, but this may not be a good nutrient management decision. Making decisions for intermediate soil-test values is not simple, however, and there is no single best answer valid for all conditions.

What Soil-Test Level Should be Maintained?

Fertilizer or manure application and P removal with crop harvest are the most important factors determining change in soil-test P over time in many soils of the region. Yield levels vary significantly within and across fields and, therefore, impact P removal greatly (Table 1). Figure 3 shows an example of soil-test P trends for one Iowa long-term experiment. Research in other states also has demonstrated a large effect of the P application and P removal on soil-test P trends over time. This figure also shows that although applied P can be "banked" in Iowa soils, the rate of soil P decline without fertilization becomes steeper as the soil-test level increases, probably due to greater P loss with surface runoff and increased removal due to luxury P uptake. Research has shown that an Optimum soil-test P level can be approximately maintained by applying a P rate equivalent to crop P removal, as long as assumed yield levels and nutrient concentrations of harvested products are appropriate (Mallarino and Prater, 2007). However, this research also showed that the relationship between P removal and soil-test P is clear and consistent over a period of years, but can be very variable from year to year.

Although the concept of maintenance fertilization is well established in the North-Central

Region, it still is poorly understood by some producers and crop consultants. Use of this concept reflects the fertility management philosophy underlying fertility management. Soil-test maintenance should not be considered by a strict sufficiency-level philosophy, for example. Moreover, recommendations often fail to specify the criterion used to establish the soil-test range for which maintenance fertilization is recommended and the expected return to maintenance fertilization. Application of P (and also K) based on crop removal is recommended for the Optimum soil-test class in Iowa, and the provided default rates should be adjusted for actual yield levels (Table 1). The recommendations clearly establish that the objective of fertilization based on removal is to maintain a soil-test range that results in a 25% probability of a yield response, and that the expected yield response is small. Therefore, such application rates are designed to maintain soil-test values and eliminate nutrient deficiency, not necessarily to maximize profit from fertilization of one crop.

Withholding fertilization of soils in the Optimum Iowa soil-test category may result in a yield loss and a soil-test decline that will further increase the probability of yield loss in the future. Moreover, any profit increase would be temporary, because higher P application rates will be needed in the future. Soil-test decline without sufficient P application is small in one year and gradual over time, but does occur. A producer could reduce or withhold fertilizer application for this soil-test category, however, depending on various factors. For example, some may decide not to apply fertilizer when the probability of a yield response (and a small one) is only 25%. Applying a lower rate may be reasonable when the fertilizer/grain price ratio is higher than usual, fertilizer or manure supply is scarce, or limited funds are needed for more critical production inputs. A partial crop removal rate or even a common starter fertilizer rate may provide adequate fertilization for one year and perhaps greater profits from that crop, but will not avoid a soil-test decline over time. On the other hand, some producers may believe that a 25% probability of a yield loss, even when small, is not acceptable, given high costs of other production inputs or fixed costs. Furthermore, perceptions about next year's crop and fertilizer prices may encourage producers to maintain soil-test values by applying a removal-based fertilizer, apply even more, or apply less or none.

Land tenure and the producer business management approach should affect the P and K fertilizer rate to be applied, mainly with soil-test values near optimum. Many years ago Fixen (1992) demonstrated that interest rates and land tenure may have a large impact on the optimum soil-test level in addition to crop/fertilizer prices. There are many different types of landowner/tenant or cropping contracts, some requiring maintenance of certain soil-test levels. Reducing the fertilizer rate in low-testing soils seldom is a good business decision even with uncertain land tenure because there is a high probability of a large crop response and lower rates increase the risk of yield loss and may limit returns to the production system. With uncertain land tenure for the next year, however, even with good prices P fertilization can be reduced or withheld when soil test results indicate a low probability of crop response.

Summary

Soil testing and P removal information should be used together with fertilizer/crop price ratios when deciding P application rates. Other considerations also are important, however. Applied P (and also K) reactions in most soils of the Corn Belt allow for managing soil-test values and fertilizer application over time. This is a major advantage compared to P management in soils of other regions or to other nutrients (such as nitrogen). The possibility for long-term management and consideration of probabilities result in several effective P management philosophies. Consideration of producers' attitudes concerning risk when investing in fertilizer or other production inputs and land tenure further expand the realm of alternatives, many of which are effective "best management practices." However, volatile fertilizer and crop prices, and public perceptions of P-induced water quality impairment make P management more challenging than in the past. Producers and crop consultants should consider factors other than the usually simple published recommendations and crop/fertilizer ratios, such as fertilizer and manure supply, producers' economic conditions in relation to the purchase of all production inputs, land tenure, and business management philosophy. Simply reducing P fertilizer rates across all conditions during times of unfavorable crop/fertilizer prices or applying high rates when prices are good often are not good nutrient or business-management decisions.

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Table 1. Iowa soil-test P interpretations and fertilization rates for corn and soybean. †

Subsoil P	Soil-Test Category	Soil-Test range ‡	Corn Yield 150 bu	Corn Yield 200 bu	Soybean Yield 50 bu	Soybean Yield 60 bu
		ppm	lb P_2O_5			
Low	Very low	0-8	100	100	80	80
	Low	9-15	75	75	60	60
	Optimum	16-20	55	75	40	48
	High	21-30	§	§	0	0
	Very High	31+	0	0	0	0
High	Very low	0-5	100	100	80	80
	Low	6-10	75	75	60	60
	Optimum	11-15	55	75	40	48
	High	16-20	§	§	0	0
	Very High	21+	0	0	0	0

† Adapted from publication Pm-1688 (Sawyer et al., 2002). Only rates for the Optimum category are adjusted for yield level.

‡ Bray-1 or Mehlich-3 tests with a colorimetric determination of extracted P.

§ Starter N-P or N-P-K starter fertilizer may be used in some conditions.

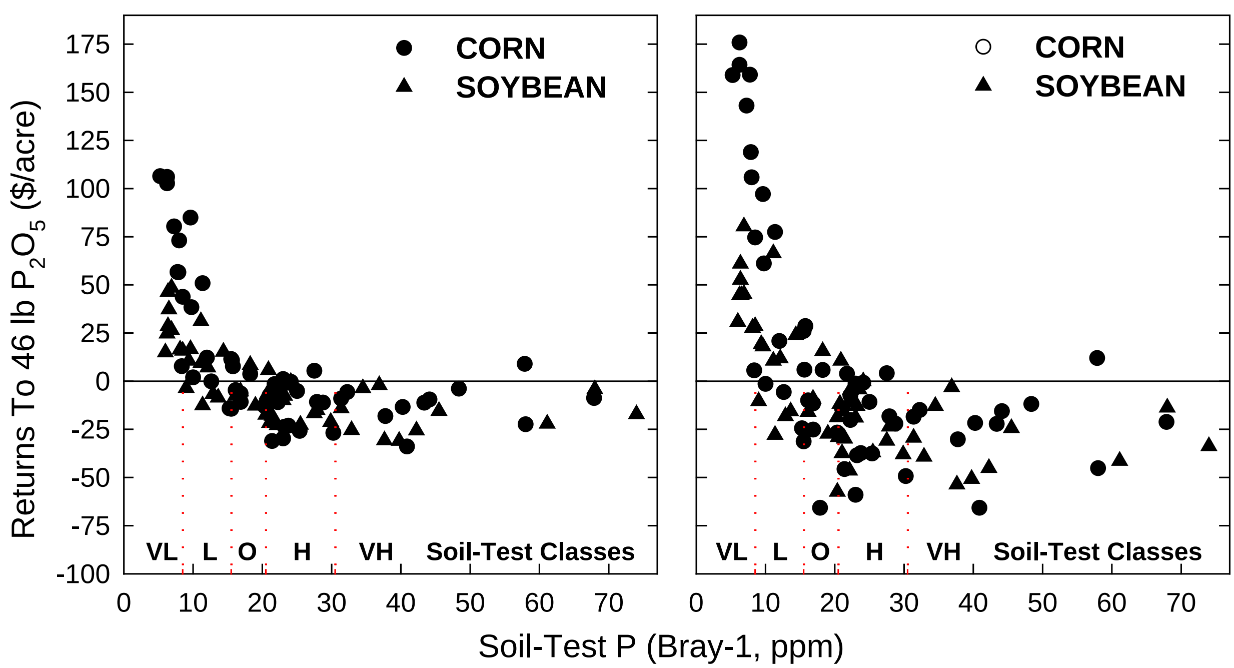

Fig. 1. Net returns to P for different soil-test P levels and prices. A: Corn and soybean grain at $2.00/bu and $5.50/bu, and P at $0.32/lb P_2O_5. B: Corn and soybean at $4.00/bu and $10.00/bu, and P at $0.40/lb. VL, very low; L, low, O, optimum; H, high; VH, very high.

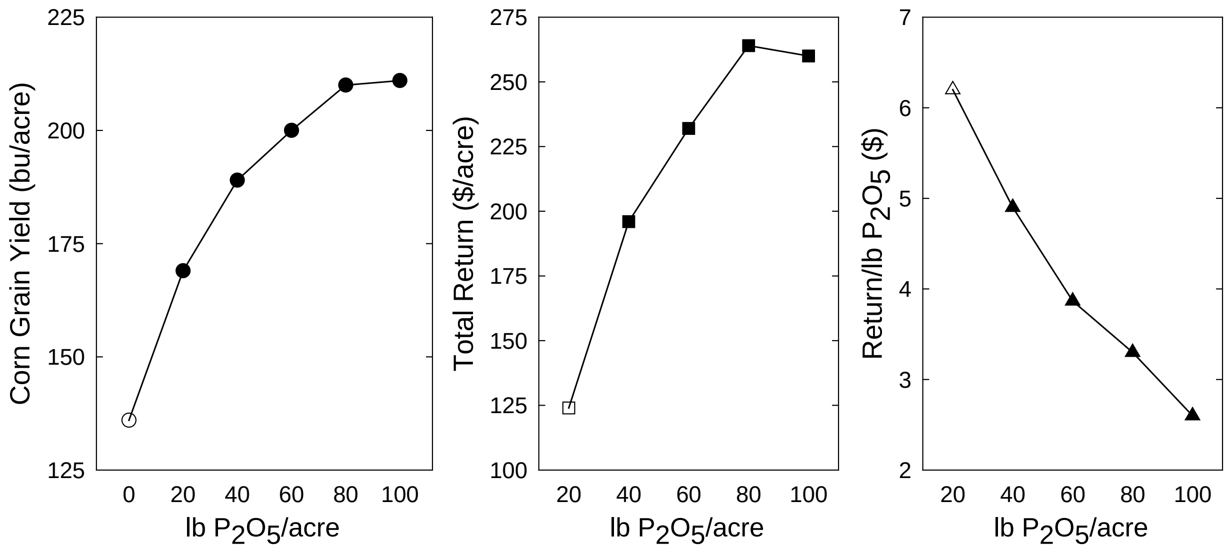

Fig. 2. Corn yield response to P fertilization in a soil testing very low in P, total net returns, and returns per lb of P_2O_5 applied. Assumed \$4.00/bu of corn and \$0.40/lb P_2O_5.

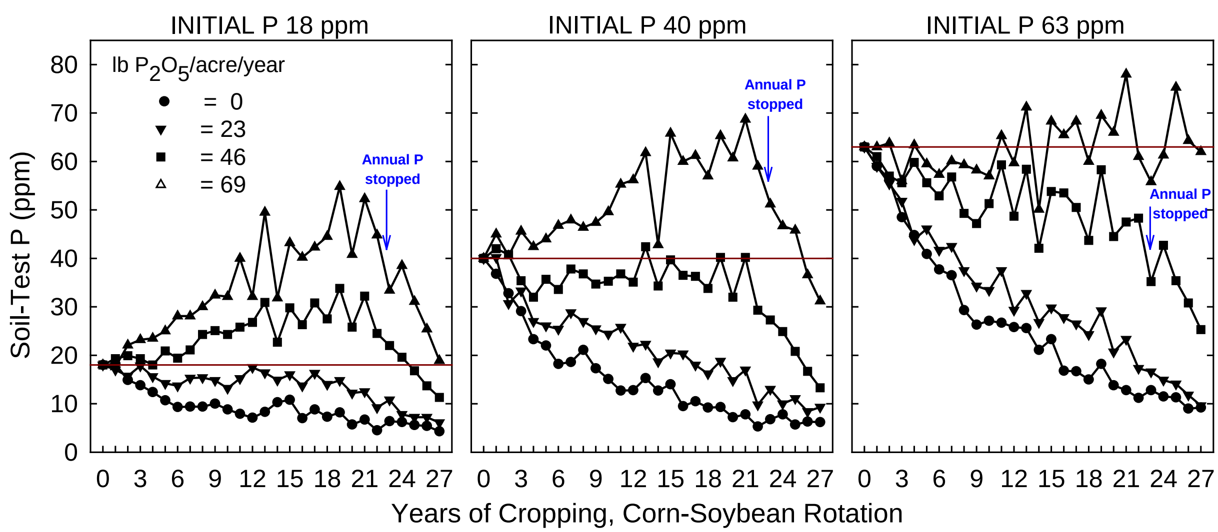

Fig. 3. Change in soil-test P (Bray-1) over time with different initial soil-test levels and P fertilizer rates for corn-soybean rotations.