

PHOSPHORUS MANAGEMENT FOR WHEAT PRODUCTION¹

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INTRODUCTION

Profitable wheat production depends on many factors, including a sound phosphorus (P) management program. Except for sunlight and water, soil fertility generally represents the most limiting factor in crop yields. Even with perfect weather and climatic conditions, a farmer that does everything right except to meet the nutrient needs of the crop will never reach optimum yield potential. Water, N, and P are generally the dominant yield limiting factors for wheat in the United States. Potassium, S, and micronutrients are generally not as limiting for wheat production and their needs can be assessed by soil testing (Halvorson, 1987; Halvorson et al., 1987). Wheat is sensitive to soil P deficiency. Approximately 0.6 lb P₂O₅ is removed with each bushel of wheat when adequately fertilized. P management will vary with location and site specific conditions, such as initial soil test P level, soil type, soil pH, application equipment available, crop rotation, tillage system, etc.

Soil testing is the best tool available to assess the need for fertilizer P. Soil test summaries for 1984 show that on an average, 54% of the soils in the north-central Region tested medium or less in available P (Table 1). In 1986, the number had dropped to 48% indicating that some progress has occurred in reducing P deficiency. These data indicate that there are a large number of soils, that if fertilized with P, would probably result in significant increases in wheat yields. Accurately assessing soil P availability and the quantity of P fertilizer required to alleviate any P deficiency becomes very important if maximum economic yields (MEY) are to be obtained. The current emphasis on the need for higher fertilizer rates to optimize grain yields necessitates that the short- and long-term economic and environmental impact of P fertilizer applications be evaluated.

This paper examines: a) the relationship between soil test P level and wheat yield potential; b) the importance of N in optimizing P fertilization responses by wheat; c) placement of P fertilizer; and d) the economics of P fertilization. Much of the information used herein comes from data collected from the Great Plains. However, many of the concepts will have implications for the more humid north-central Region, where soils tend to be more acidic.

FACTORS AFFECTING P UPTAKE

Several environmental factors affect P uptake by wheat from any source, soil or fertilizer (Munson and Murphy, 1986). These include temperature, soil compaction, soil moisture, soil aeration, soil pH, type and amount of clay content, P status of soil, and status of other nutrients in soil. When soil temperatures are low during early plant growth, P uptake is reduced. Soil compaction reduces pore space which reduces water and oxygen which reduces P uptake. Soil pH greatly affects the availability of P to plants, with P being tied up by Ca at high pH and by Fe and Al at low pH. Soils with high clay

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content tend to fix more P than low clay soils. Thus more P needs to be added to raise the soil test level of clay soils than loam and sandy soils. The presence of ammonium enhances P uptake by creating an acid environment around the root when ammonium ions are absorbed. High concentrations of ammonium-N in the soil with fertilizer P may interfere with and delay normal P fixation reactions, prolonging the availability of fertilizer P (Murphy, 1988). Thus, many factors can affect P availability to wheat plants.

Table 1. Percent of soils testing medium or less in available P in north-central States (PPI Staff, 1985 and 1987).

State	1984	1986
Illinois	59/70	38/50
Indiana	31	22
Iowa	66	44
Kansas	61	54
Kentucky	75	58
Michigan	31	28
Minnesota	33	33
Missouri	55	55
Nebraska	69	69
North Dakota	72	75
Ohio	42	38
South Dakota	76	76
Wisconsin	38	34

Average	54	48

SOIL TESTING

Soil testing is essential if accurate, profitable-fertilizer recommendations are to be made. While soil testing doesn't directly tell us how much fertilizer P will be required for profitable wheat production, proper interpretation of the analytical results will guide producers as to the amount of P required. While questions about the validity of soil testing in predicting fertilizer needs have been raised, the basic problem probably stems not from the analytical results but from the interpretation of the analytical results for making P recommendations (Leikam, 1987). Interpretation of the analytical results and the development of recommended rates of P application should be based on research data (public and private), but the recommendations may need to be refined locally for each situation in order to obtain maximum benefit from the soil testing/recommendation process.

Soil testing success depends on collection of a representative soil sample and an accurate laboratory analysis. Numerous soil samples, from the appropriate soil depth, need to be collected from representative areas of the field. Divide the field, avoiding odd or problem areas, into about 20 to 40 acre lots (100 acre lots may be more practical but less desirable) and collect 10 to 15 subsamples from each lot for a good composite sample. Sample different or special problem areas separately and have these samples analyzed separately. Soil samples for P analysis should be collected from approximately the surface 6 inches of soil. Most laboratories in the spring wheat region of the U.S. and Canada utilize a

sodium bicarbonate extraction procedure to estimate P availability on calcareous soils (Halvorson et al, 1987; Murphy, 1988). On moderately acid soils, a weak acid extract (Bray-Krutz) is used. Repeated sampling and P determination over a period of years may help improve the reliability of the test. Soil test results for P may be variable where fertilizer P has been applied in preplant bands or banded at seeding because the bands may or may not be included in the sampling process. Collection of a larger number of samples per unit area may reduce the variability. A non-representative sample can be misleading and may be worse than no sample at all.

SOIL TEST vs WHEAT YIELD RELATIONSHIPS

When P fertilizer is added to most soils in the Great Plains, an increase can be expected in soil test P levels. The amount of increase will depend upon soil texture and other soil characteristics (Dahnke, 1985). Halvorson and Kresge (1982) used this approach to estimate the amount of broadcast-incorporated P fertilizer needed to optimize yields. If less P fertilizer is applied than recommended, wheat yield potentials need to be reduced along with N fertilizer recommendations. They estimated that 8 to 10 lb P₂O₅/acre was needed to raise the soil test P level 1 ppm. In Illinois, application of 9 lb P₂O₅/acre is estimated to increase the soil test P level 1 lb/acre (Agronomy Staff, 1989).

The relationship between the sodium bicarbonate P test and relative yield potential of wheat grown in a dryland wheat-fallow system is shown in Fig. 1 (Halvorson, 1986). These data indicate that a 26 ppm P level in the surface 6 inches of soil is needed to achieve 100% of the wheat yield potential. The Bray-Kurtz P soil test is widely used for acid soils (pH <6.5) with similar soil test P levels (about 30 ppm) required to achieve maximum wheat yield potentials in the north-central Region (Agronomy Staff, 1989; Fiedler et al., 1987; Oplinger et al., 1985; personal communications, Dr. Paul Fixen, SDSU, Brookings, 1986). Bray-Kurtz soil test values considered adequate for wheat on acid soils range from about 25 ppm to as high as 50 ppm, depending on yield goal and location. Usually, higher soil test values are desirable in northern areas (Murphy, 1988).

These tests have had extensive field calibration with measured crop response to P applications.

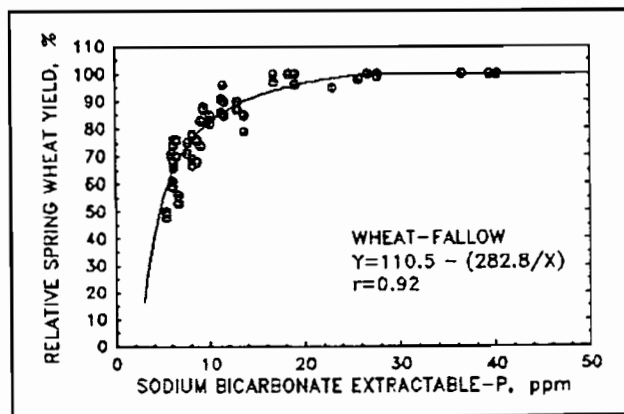


Fig. 1. Relative spring wheat yield as a function of soil test P.

The type of relationship shown in Fig. 1 is useful in estimating yield reductions caused by inadequate available P levels, thereby allowing a more accurate estimate of N fertilizer needs. In general, sufficient fertilizer P should be applied to bring the soil test level to approximately 21 ppm on calcareous soils or near 30 ppm on acid soils to optimize wheat yields and response to N fertilization. Halvorson and Black (1985) found adequate levels of P were needed to obtain optimum response to N fertilization. As more intensive wheat management systems are adapted, higher soil test P levels may be required to optimize yields.

PLACEMENT METHOD

Not everyone agrees on the best method of P application. Fixen and Leikam (1989) stated that "contradictory recommendations for method and placement of phosphorus (P) often are due to the fact that conditions influencing P fertilizer response vary among studies." They discussed many factors affecting the effectiveness of P placement methods and addressed the following questions: a) Which is better, band or broadcast P applications?; b) Are all band P applications methods equal in effectiveness?; and c) How much can P recommendations be reduced if P is banded instead of broadcast? They list the following factors as influencing crop response to fertilizer P: a) soil test levels; b) root contact with the fertilized soil; and c) P concentration of the fertilized soil solution. Root contact with the fertilized soil is influenced by total root length, volume of soil fertilized (varies with placement method), and location of the fertilized soil in relation to plant roots. Depending on soil and environmental factors, band applications of P may or may not be better than broadcast incorporated applications of P. In general, if there is a difference in crop response due to P application method, band applications will perform equal to or better than broadcast applications. In addition to agronomics, other factors are equally important in selecting the best P application method. Equipment availability, labor requirements, product availability, and availability of operating capital all affect this decision.

Long-term studies in the northern Great Plains have shown that high rates of broadcast P (183 lb P_2O_5 /acre) can have long-term effects (17 years) on soil test P, wheat yields, (Bailey et al., 1977; Halvorson and Black, 1985; Roberts and Stewart, 1987) and profitability (Jose, 1981; Halvorson et al., 1986). Similar results have been reported from Saskatchewan (Wagar et al., 1986) where a single broadcast application of 160 lb P_2O_5 /a resulted in a higher 5 year average yield than 40 lb P_2O_5 /a annually banded with the seed.

Deep placement of N and P (pre-plant banding) has grown in popularity recently in the Great Plains of the U.S. and in the Canadian Prairie Provinces (Murphy, 1988). Deep placement of N and P under both conventional and reduced tillage systems has frequently been more effective for wheat than application methods which placed most of the N and P at different positions in the soil (Leikam et al., 1983; Harapiak and Flore, 1984; Dahnke et al., 1985), particularly at low P soil test levels. Generally, yield differences between deep banding or P placement near the seed have been relatively small. Consequently, fertilizer recommendations frequently do not differentiate between seed placement and deep banding in terms of P efficiency. Alessi and Power (1980) reported wheat yield increases resulting from banding P with the seed even when soil test levels were high. Environmental conditions should be considered in addition to soil test results as a part of the management decisions which go into higher wheat yields. Cold, wet soil conditions compounded by heavy surface residue may be conducive to P responses, particularly from starter applications, even when P soil tests are high (Murphy, 1988).

Method and rate of application can affect the response of wheat to P fertilization. If low rates of fertilizer P are to be applied to soils testing "low" in plant-available P, then banding the fertilizer P below or with the seed is generally more efficient and results in greater yield increases than broadcast P applications (Murphy and Dibb, 1986; Peterson et al., 1981; Sleight et al., 1984). However, if sufficient fertilizer P was to be added to attain maximum wheat yields on a soil testing "low" in P, then method of placement may not be

as critical. On soil testing medium to high in available P, the difference in effectiveness between broadcast and band applications of any type is lessened (Peterson et al., 1981; Halvorson and Havlin, 1990). The recent work of Wagar et al. (1986) supports this theory. They found that a single, broadcast P application of 163 lb P₂O₅/a had a greater cumulative yield after 5 years than 41 lb P₂O₅/a applied each crop year with the seed. Thus the broadcast treatment produced at or near optimum yields each year whereas the seed placed P treatment produced at less than optimum yield potential during the first several years. They also found that a combination of a residual 82 lb P₂O₅/a broadcast one time plus 20 lb P₂O₅/a applied each crop year with the seed produced near maximum wheat yields. The latter treatment would be desirable from the stand point of spreading the P fertilizer costs out over a longer time frame and still being able to maintain near maximum yield potential. In the final analysis, phosphorus placement may enhance P availability and increase yields and should be at least considered in formulating a plan for higher wheat yields. Growers attempting to improve wheat yields and profitability should maintain recommended rates of P even if more efficient methods of application are utilized. Cutting back on P rates to cut production inputs may result in lost profits (Murphy, 1988).

NITROGEN-PHOSPHORUS INTERACTIONS

Adequate levels of N are essential to get full benefit from P fertilization, regardless of the method of P application. The data in Fig. 2 (unpublished data - A.D. Halvorson and J.L. Havlin) shows that addition of 40 lb N/a increased the response of winter wheat to the application of 40 lb P/a. Long-term yield data from Montana (Black, 1982; Halvorson and Black, 1985) also shows that N

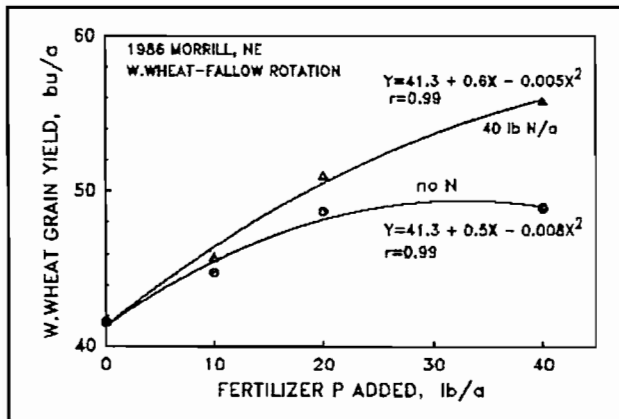


Fig. 2 - Typical increase in fertilizer P response by winter wheat with N added.

fertilization was needed to get optimum response of spring wheat to high rates of P fertilization. Thus, by having adequate P present and balancing the N needs of the crop, optimum yield and profit potentials can be realized. Halvorson (1989) found that the presence of adequate levels of P also improved the N use efficiency by irrigated winter wheat. Residual soil NO₃-N levels in the soil profile were significantly less where adequate P was applied, reducing the potential for NO₃ contamination of groundwater.

ECONOMICS

Many farmers today consider themselves economically stressed as a result of production costs rising while wheat prices have tended to remain fairly constant, when considering Federal price support programs. Current farm management emphasis is on increasing input-use efficiency. A good balance of plant nutrients is essential for obtaining optimum economic yields while protecting the environment. By soil testing, more accurate fertilizer recommendations can be made, helping farmers achieve the required nutrient balance without overinvesting or underinvesting in fertilizer.

The short- and long-term economics of P fertilization need to be considered. The long-term economics of a large one time application of P fertilizer can be profitable (Jose, 1981; Halvorson et al., 1986; Wagar et al., 1986). However, the short-term profitability may be marginal for a one-time large P application. Jose (1981) concluded there was a long-term economic advantage of a single high rate broadcast P application over annual band P applications at several dryland sites in Canada. Wheat price, fertilizer cost, and current soil test P level will govern how much P can be profitably applied in a given year. The investment in P fertilizer may need to be amortized over several years, similar to machinery, in order to optimize wheat yields and responses to N fertilization. Application of adequate fertilizer P to bring the soil test P level to about 21 ppm (Olsen P test) or about 30 ppm (Bray-Kurtz P1) followed by smaller annual P applications to maintain this soil test level may result in optimum wheat yields and optimum short- and long-term profitability. This approach to P fertilization would probably provide the potential for optimum wheat yields each crop year. In dry years, a high level of soil P will not hurt yields and in the wet years, a high level of soil P will provide that opportunity to utilize more efficiently the available water supply, providing that N is not limiting.

SUMMARY

Whenever possible, P should not be a yield limiting factor for wheat production. Phosphorus is a relatively immobile nutrient, not subject to leaching losses. The loss mechanisms are mainly through soil erosion and that removed in the harvested portion of the crop. Phosphorus fertilization is an investment that will pay dividends for several years and should be considered a capital improvement to the land. Therefore, a program to build P to an adequate level and maintain it at an adequate level will probably be the most profitable in the long-term.

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