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PHOSPHORUS REQUIREMENTS FOR HIGH YIELD WHEAT MANAGEMENT[1]

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ABSTRACT

Phosphorus (P) fertility management is a critical component of profitable winter wheat production. Soil tests for P have been shown to be extremely reliable in accurately predicting fertilizer P requirements for optimum yields, provided the soil tests are carefully calibrated. Adequate P fertility can strongly influence nitrogen (N) requirements and greatly increase N use efficiency. Phosphorus placement also can influence P and N use efficiency. The optimum placement method for a given soil and location will depend on many factors; however, extractable P may be used as a guide to P placement decisions. Depending on availability of capital, large one time broadcast P applications may be profitable over the long-term. Additional research is needed to quantify the residual availability of broadcast and band applied P and to incorporate these values into P fertilizer recommendation models.

INTRODUCTION

The primary limiting factors to winter wheat yields in the United States are water, N, and P. In regions where water is limiting, efficient use of available soil water depends on careful management of fertilizer inputs. Winter wheat is a phosphorus responsive crop, where yield increases of 80% or more are often observed at low soil test P levels (Havlin et al., 1988a). Soil testing is the best method available to accurately determine soil P availability and fertilizer P requirements. Therefore, obtaining profitable wheat yields, maximizing water- and fertilizer-use efficiency, and minimizing environmental impacts of fertilizer use necessitates a regular soil testing program and precise fertilizer management. This paper examines: a) soil test P and wheat yield relationships; b) N and P fertilizer interactions; and c) fertilizer P placement.

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SOIL TEST P - WHEAT YIELD RELATIONSHIPS

While soil tests do not directly establish the quantity of fertilizer P required for profitable wheat production, proper interpretation of the analytical results will provide a guideline for economic optimum P fertilization. Concerns about the validity of soil tests to predict fertilizer requirements have always been raised, and the debate eventually focuses on interpretation of the analytical results and not the laboratory methods used to obtain the results. Interpreting soil test results and developing fertilizer P recommendations should be based on calibration data obtained from field research. Fertilizer recommendations may need to be refined locally for each situation in order to obtain maximum benefit from the soil testing/fertilizer recommendation process. Growers and fertilizer dealers may want to periodically verify the accuracy of fertilizer recommendations by establishing field strip test/demonstration plots as is frequently done with crop varieties/hybrids.

Numerous soils tests are used to estimate P availability in soils; however, the most common are the Bray-1 (Bray and Kurtz, 1945), Olsen (Olsen et al., 1954), and Mehlich (Mehlich, 1984) extractable P tests. In calcareous soils the Olsen P test is the most widely used, although some laboratories use the Mehlich or Bray tests. In acid soils both the Bray and Mehlich tests are used. Use of a particular test will depend on the availability of correlation and calibration data for that test in the region of intended use.

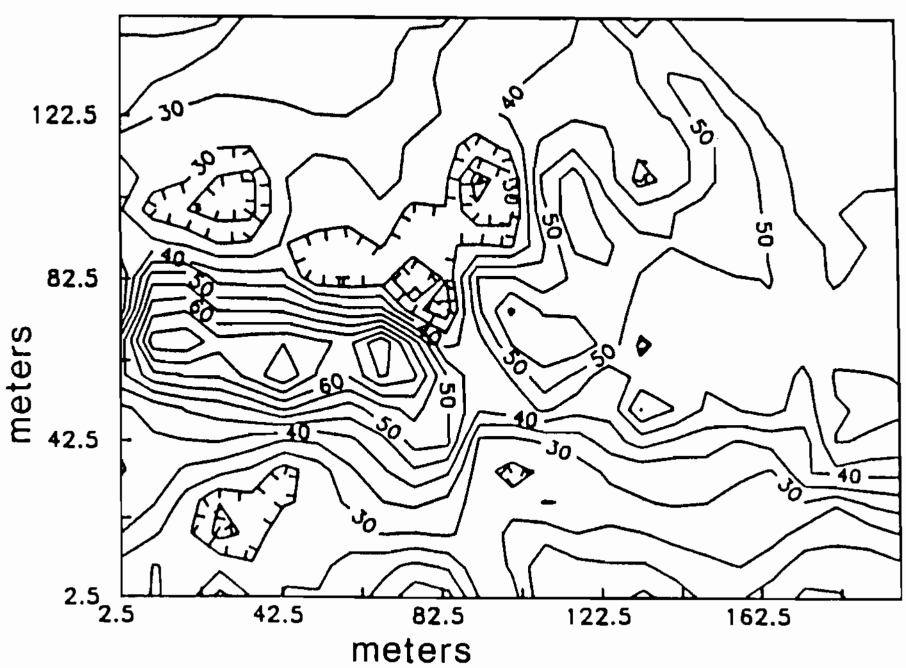

Fig 1. Spatial variability of Bray-1 extractable P. Numbers on the contour lines are ppm Bray-1 P.

Regardless of the soil test method, obtaining a representative soil sample from a field has always been difficult because extractable P can vary widely over a given field. A subsample from 10 to 20 soil cores composited from each 20 to 40 acre area is commonly recommended. This sample may or may not represent the 'true' mean value for extractable P. Recent studies in Kansas quantified the spatial variability of Bray-1 extractable P (Sisson and Havlin, 1990). The field shown in Fig. 1 is an alluvial, acid soil (Pachic Argiustoll) in eastern Kansas and shows a 4-fold range in Bray-1 extractable P. Similar data from an aeolian soil (Aridic Argiustoll) in western Kansas showed only a 2-fold range in Bray-1 P (Sun, 1990). Understanding and quantifying the spatial variability in soil test P in farm fields will facilitate variable fertilizer application which could increase fertilizer efficiency and profitability by reducing over- and under-fertilization errors.

Soil test calibration studies accomplish two objectives: 1) quantifying the relative responsiveness of soils of different extractable P levels and 2) establishing fertilizer P recommendations. The relationship between Olsen extractable P and relative yield of spring wheat grown in a dryland wheat-fallow system is shown in Fig. 2 (Halvorson, 1986). These data indicate that 26 ppm P in the surface 6 inches of soil is needed to achieve 100% of the wheat yield potential. Studies in Nebraska indicate that 21 ppm Olsen P was needed to achieve 100% yield potential of winter wheat (Fiedler et al., 1987). Similar studies with winter wheat were recently conducted in calcareous soils of western Kansas (Havlin et al., 1989). These data showed that 95% relative yield occurred at 23 ppm Bray-1 P (Fig. 3). Critical values of 13 ppm Olsen P and 25 ppm Mehlich III P also were established (data not shown). The critical value for Bray-1 extractable P is similar to that currently used by the Kansas State University Soil Testing

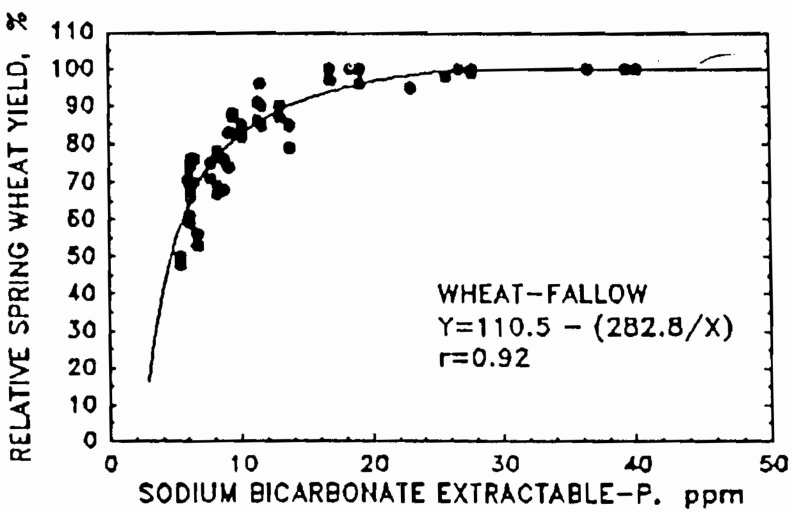

Fig. 2. Relative spring wheat yield as a function of sodium bicarbonate extractable P.

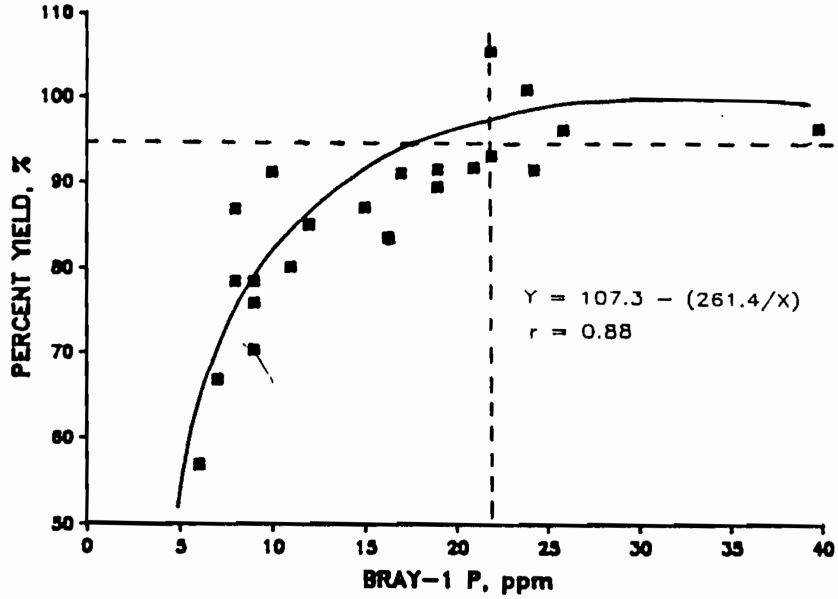

Fig. 3. Relative winter wheat yield as a function of Bray-1 extractable P.

Laboratory (Whitney, 1983). The Bray soil test is widely used for acid soils with critical levels ranging from 25 to 50 ppm (usually about 30 ppm) required to achieve maximum wheat yield potentials in the midwest and eastern Great Plains regions (Agronomy Staff, 1989; Fiedler et al., 1987; Oplinger et al., 1985). This test has had extensive field calibration with measured crop response to P fertilization.

The relationships shown in Figs. 2 and 3 are useful in estimating yield reductions by inadequate P soil test levels. Soil testing of P fertilized fields can verify the influence of fertilizer P additions on extractable P levels. Once soil test P reaches the 'critical level', then only P rates required to maintain the soil test at the critical level would be necessary. Halvorson and Kresge (1982) estimated that 8 to 10 lb P_2O_5/a was needed to raise the Olsen extractable P level 1 ppm.

FERTILIZER NITROGEN - PHOSPHORUS INTERACTIONS

Adequate levels of N are essential to get full benefit from P fertilization, regardless of the P application method. The data in Fig. 4 shows that the addition of 40 lb N/a increased the response of winter wheat to applied P (unpublished data - A.D. Halvorson and J.L. Havlin). Long-term data from Montana also showed that N fertilization was needed for optimum response of spring wheat to P fertilization (Black, 1982; Halvorson and Black, 1985).

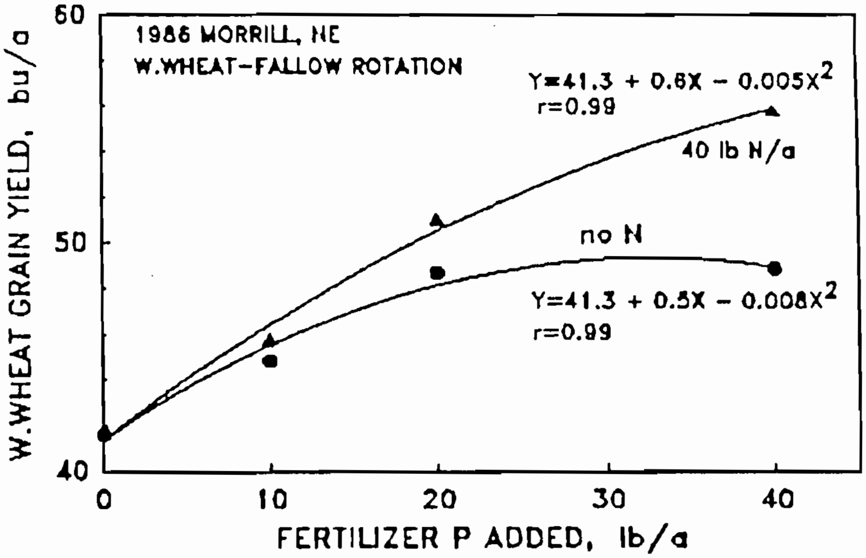

Fig. 4. Typical increase in fertilizer P response by winter wheat with and without N fertilizer.

Similarly, adequate levels of P are required for maximum economic yield response to N fertilization. Results from long-term studies in western Kansas with irrigated winter wheat showed that the economic optimum N rate was only 95 lb N/a without P fertilization, compared to 120 lb N/a with 40 lb P_2O_5/a (Fig. 5; Schlegel et al., 1986). Net returns increased 56% with adequate P fertility. Thus, by having adequate P present and balancing the N requirement of the crop, optimum yield and profit potentials can be obtained. Halvorson (1989) found that adequate P fertility also improved N use efficiency

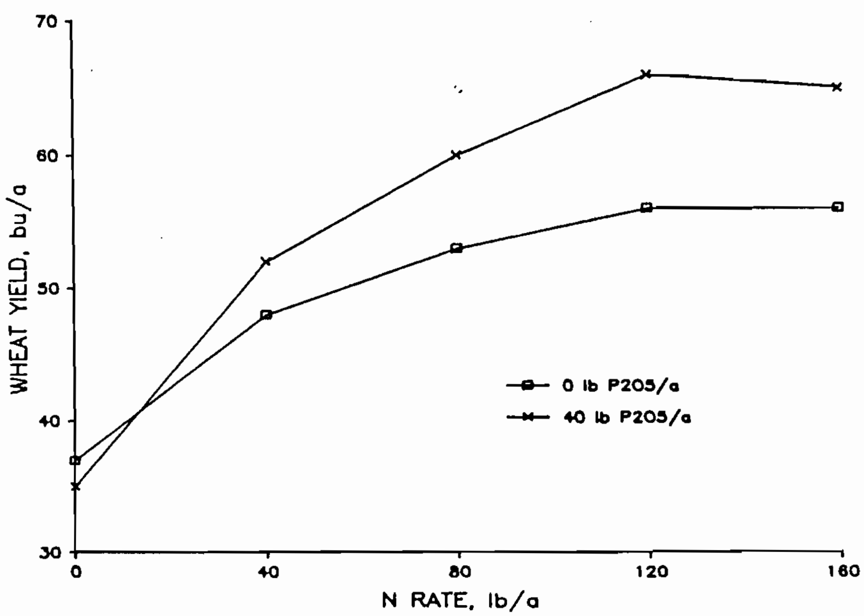

Fig. 5. Effect of long-term P fertilization on irrigated winter wheat response to N at Tribune Exp. Sta. (1974-1986).

by irrigated winter wheat. Residual soil profile NO_3-N levels were significantly less where sufficient P was applied, thereby reducing the potential for NO_3 contamination of groundwater. In the studies of Leikam et al. (1983) 75 lb N/a was band applied with each P rate shown in Fig. 6. Increasing P rate from 20 to 40 lb P_2O_5/a increased N use efficiency from 28 to 59%, respectively. In other words, applying the correct P rate reduced the fertilizer N remaining after harvest (or potentially leachable N) from 55 to 30 lbs N/a with the 20 and 40 lb P_2O_5/a rates, respectively.

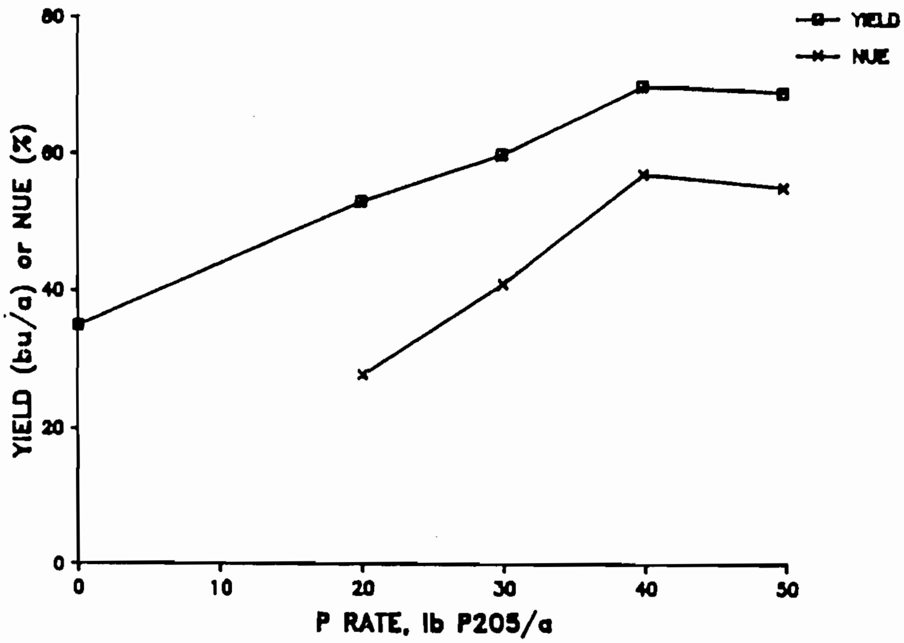

Fig. 6. Effect of P fertilization on winter wheat grain yield and N use efficiency.

FERTILIZER PHOSPHORUS PLACEMENT

Over the last several decades extensive P placement research has been conducted with often contrasting results. Fixen and Leikam (1989) discussed numerous factors affecting crop response to P and P placement methods. These included: a) soil test P level; b) root contact with fertilized soil; c) P concentration in the fertilized soil solution; and d) environmental factors. 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. In addition to agronomics, the availability of equipment, labor, fertilizer source, and operating capital are other common factors affecting P application decisions.

Numerous placement options are available which place the fertilizer in various locations relative to the seed. Deep placement of N and P under both conventional and reduced tillage systems has frequently been more effective for wheat grown on low P soils than methods where N and P are placed separately in the soil (Leikam et al., 1983; Harapiak and Flore, 1984; Dahnke, 1985). Generally, yield differences between deep banding or P placement near or with the seed have been relatively small and as a result P recommendations generally do not differentiate between these methods (Havlin et al., 1988a). In most years P 'dribbled over the row' with a hoe drill also has been shown to be equivalent to subsurface P applications (Westfall et al., 1987; Havlin et al., 1988b). Recent data from Kansas showed that in dry fall and spring conditions dribble P application may not be equivalent to seed placed or below the seed methods.

If low rates of fertilizer P are applied to low P soils, then banding P below or with the seed is generally more efficient than broadcast P applications (Peterson et al., 1981; Sleight et al., 1984; Murphy and Dibb, 1986). On soils testing medium to high in available P, few differences between broadcast and band applications are observed (Peterson et al., 1981; Halvorson and Havlin, 1990). The influence of P soil test level on relative yield response to P placement is shown in Fig. 7 (Havlin et al., 1989). The yield data, from six locations in western Kansas, are expressed as the ratio of wheat yield with broadcast P to banded P at the three P rates.

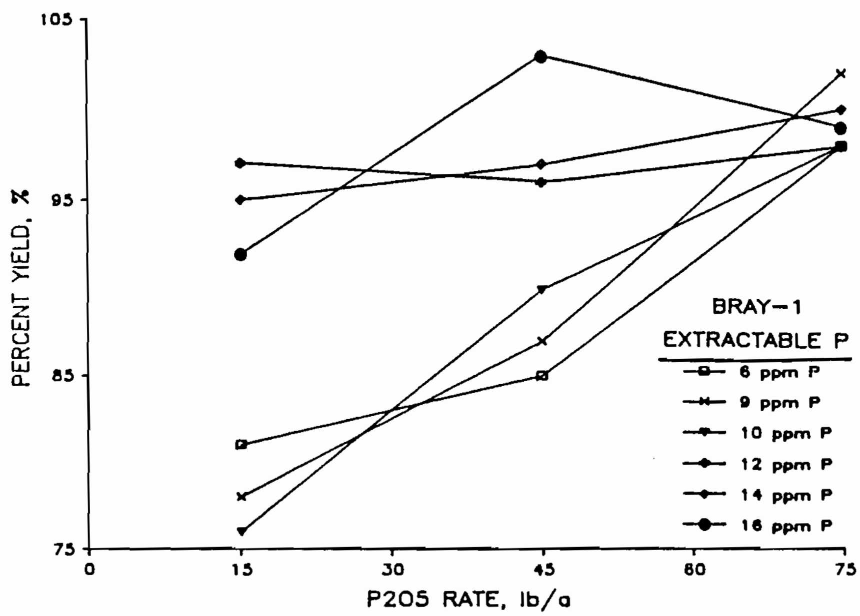

Fig. 7. Interaction of P rate and placement on relative winter wheat yield at 6 locationsin western Kansas. Percent yield represents the ratio of grain yield with banded P to yield with broadcast P.

These data show that in soils testing below 12 ppm Bray-1 extractable P wheat yields with broadcast P are about 78, 88, and 100 % of the yields obtained with band applied P at the 15, 45, and 75 lb P_2O_5/a rates, respectively. No yield differences were observed between placement methods on soils testing above 12 ppm Bray-1 extractable P. These results indicate that extractable P may be used as a guide to P placement decisions. In some cases, however, wheat yield responses to fertilizer P have been observed on high P soils (Alessi and Power, 1980). Environmental conditions should be considered in addition to soil test results. Cold, wet soil conditions compounded by heavy surface residue may be conducive to P responses even in high P soils (Murphy, 1988).

Long-term studies in the northern Great Plains have shown that high rates of broadcast P (183 lb P_2O_5/a) can have lasting effects on extractable P and wheat yields (Bailey et al., 1977; Halvorson and Black, 1985; Roberts and Stewart, 1987). Similar data were reported by Wagar et al (1986) where a single broadcast application of 160 lb P_2O_5/a resulted in a greater cumulative wheat yield after 5 years than 40 lb P_2O_5/a applied annually with the seed (Wager et al., 1986). Thus, the broadcast treatment produced at or near optimum yields each year whereas the seed placed P treatment produced below the optimum yield potential during the first several years. The long-term economics of a large one time P application can be profitable; however, the short-term profitability may be marginal (Jose, 1981; Halvorson et al., 1986). Wager et al. (1986) also found that a combination of residual 82 lb P_2O_5/a broadcast one time plus 20 lb P_2O_5/a annually applied with the seed produced near maximum wheat yields. This treatment allows the grower to distribute P fertilizer costs over a longer period while still maintaining maximum yield potential.

The difference in residual P availability between broadcast and band applied P needs further research. Data from western Kansas showed that no residual fertilizer P was detected by the Bray-1 soil test 14 months after application of 15 lb P_2O_5/a broadcast and banded P (data not shown) and 45 lb P_2O_5/a broadcast P (Fig. 8; Havlin et al., 1989). Residual available P was detected for the 45 lb P_2O_5/a band treatment and for both the broadcast and band treatments applied at 75 lb P_2O_5/a. These data generate several questions. First, how responsive is a wheat crop to residual fertilizer P bands; second, what soil sampling scheme should be used for obtaining a soil test value that accurately reflects plant available P; and third, how can this soil test value be used to adjust future fertilizer P recommendations? Unfortunately,the answers to these questions are not available at this time but research is currently being conducted (Kitchen et al., 1990).

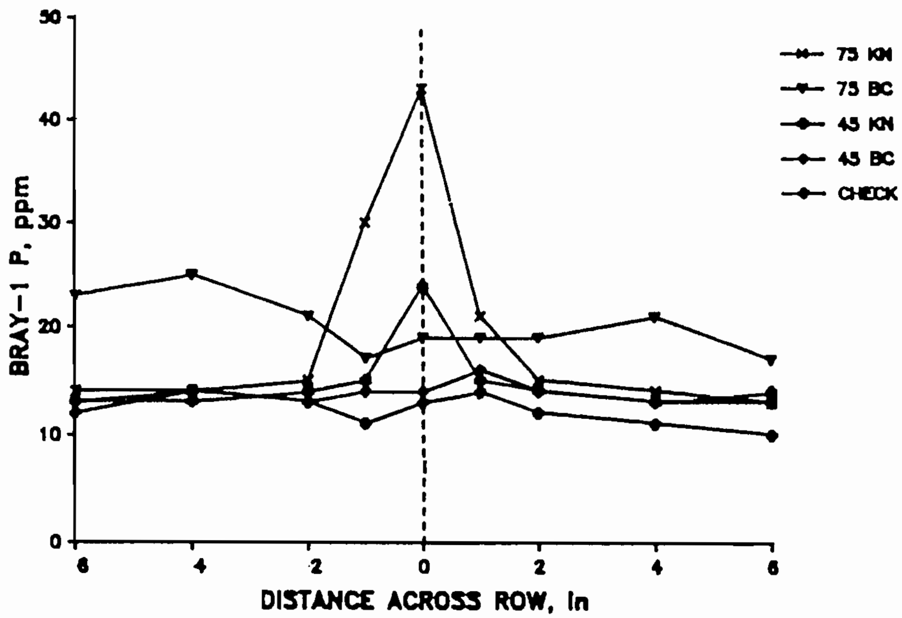

Fig. 8. Fertilizer P rate and placement effects on Bray-1 extractable P levels across a wheat row. Fertilizer applied on 9-25-86 and soils sampled on 8-12-88. (KN = band below seed; BC = broadcast; numbers in key are lb P_2O_5/a)

In addition to increased P use efficiency, P placement also can increase apparent N use efficiency. Phosphorus placement studies with winter wheat in central Kansas showed significant yield responses to starter P compared to broadcast P (Fig. 9a; Whitney and Lamond, 1985). Similar differences in fertilizer P use efficiency between placement methods at equivalent P rates also was observed (Fig. 9b). In this study 100 lb N/a was broadcast applied to all P rate and placement treatments. At the 16 and 32 lb P_2O_5/a rates apparent N use efficiency with seed applied P was more than double that obtained with broadcast P (Fig. 9c). These data demonstrate the importance of P management on potential environmental effects of fertilizer N use.

SUMMARY

Increasing input efficiency, protecting the environment, and sustaining the productive capacity of our soils are critical components of successful farm management. Soil testing provides the best available method for accurately determining fertilizer recommendations and attaining a good balance of plant nutrients, which is essential for achieving optimum economic crop yields. Reducing the frequency of overapplying or underapplying fertilizers also will improve input efficiency, reduce environmental impacts, and increase

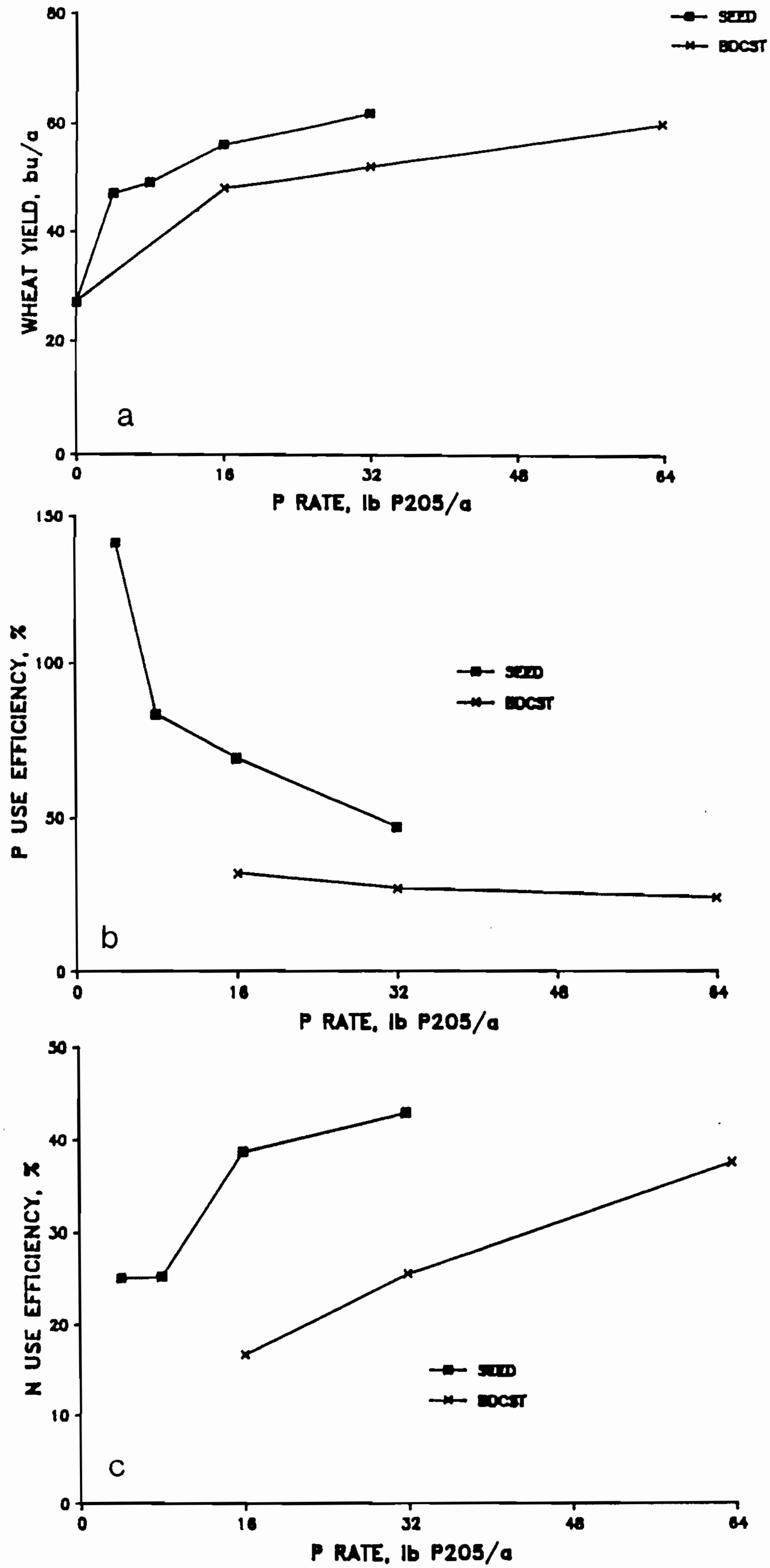

Fig. 9. Effect of P rate and placement on dryland winter wheat grain yield (a), P use efficiency (b), and N use efficiency (c).

profitability. Growers should not allow P to be a limiting factor for optimum wheat production. Although wheat price and fertilizer cost are important considerations, the soil test P level determines how much P can be profitably applied. The investment in P fertilizer may need to be amortized over several years in order to optimize wheat yields and responses to N fertilization. Application of fertilizer P to increase soil test P to the 'critical level' established for the region, and thereafter, maintaining the critical level will optimize wheat yields and short- and long-term profitability. Soil test levels also can be used to guide P placement decisions, where band applications of P are generally better than broadcast applications at low soil test levels. Depending on soil and environment factors, P placement also may be profitable on medium and high P soils. Regardless of placement method, the influence of residual fertilizer P on P availability to subsequent crops needs to be quantified and incorporated into soil testing and fertilizer recommendations programs.

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