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DIVISION S-8—FERTILIZER MANAGEMENT & TECHNOLOGY

No-Till Winter Wheat Response to Phosphorus Placement and Rate

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ABSTRACT

Phosphorus deficiency of winter wheat (*Triticum aestivum* L.) is common in the central Great Plains. Acceptance of reduced and no-till systems for wheat production has made soil incorporation of broadcast P fertilizer more difficult. This field study evaluated the effectiveness of P placement methods (surface broadcast with and without incorporation and banded below the seed zone) for no-till winter wheat production at rates of 0, 34, 67, 101, and 134 kg P ha^{-1} in 1986 and 1987. Subplots of 0 and 56 kg N ha^{-1} were included with each P rate. A Rosebud–Escabosa loam soil (fine-loamy, mixed, mesic Aridic Argiustoll–Calciustoll) with a $NaHCO_3$-extractable P level of 10 mg P kg^{-1} soil (medium soil test level) and a pH of 7.8 was used. Phosphorus placement had no significant effect on grain yield. Grain yields increased curvilinearly with increasing P rate up to 101 kg P ha^{-1} for both broadcast and banded treatments. Straw yields also increased curvilinearly with increasing P rate. Nitrogen fertilization enhanced grain protein by 6% and also grain P uptake. Total P uptake by grain increased with increasing rate of P application. Broadcast applications of P without incorporation under no-till conditions effectively increased winter wheat yields on a soil testing medium in available P. When sufficient P was applied to correct P deficiency in winter wheat, method of placement had little effect.

PHOSPHORUS DEFICIENCY in winter wheat is a common problem in the central Great Plains (Fiedler et al., 1987; Follett et al., 1987; Westfall et al., 1986). Stecker et al. (1988) pointed out that there is limited information available on P fertilizer placement and rate effects on winter wheat produced within no-till systems in the Great Plains. Banding of low rates of P fertilizer near the seed on soils testing low in available P has been shown to be more effective than broadcast applications of P fertilizer at the same rate during the first year of application (Leikam et al., 1983; Westfall et al., 1987). The difference in yields resulting from banding and broadcast applications is expected to decrease, as the soil test P level increases from low to high (Peterson et al., 1981). Stecker et al. (1988) found no significant interaction of tillage system (no-till, stubble-mulch, and plow) and P placement method (knifed, seed placed, and broadcast without incorporation) on winter wheat response to P application rates at three locations in western Nebraska. Grain yields, however, were increased as P rate increased. Their study showed that dryland winter wheat yields were not maximized at their highest P rate, 16.8 kg P ha^{-1}, which is typically a higher than normal P rate for dryland wheat in this area.

For wheat production on a long-term basis, a broadcast application of P fertilizer may be equally as effective as a band application at equal rates (Roberts and Stewart, 1987; Sleight et al., 1984). Phosphorus studies conducted by Black (1982) and Halvorson and Black (1985a,b) in the northern Great Plains indicated that high rates of P (>90 kg P ha^{-1}) were needed to minimize P deficiency in crops grown on a Williams loam soil (fine-loamy, mixed Typic Argiboroll). Halvorson and Black (1985a) suggested that a one-time, high-rate application of P fertilizer may be one way to satisfy the P needs of crops grown with reduced and no-till systems. Halvorson (1989) found that application of 67 kg P ha^{-1} to no-till, irrigated winter wheat resulted in greater grain yields than where 34 kg P ha^{-1} had been applied to a P-deficient Weld silt loam (fine, montmorillonitic, mesic Aridic Paleustoll) at Akron, CO. The objectives of this study were to determine the effects of high P rates and P placement methods on dryland winter wheat production within no-till system and determine the level of P fertilizer needed to maximize winter wheat yields with and without N fertilization.

MATERIALS AND METHODS

The study was located near Peetz, CO, on a Rosebud–Escabosa loam soil with a pH of 7.8 and organic matter level of 24 g kg^{-1}. The initial $NaHCO_3$-extractable soil P level (0–15-cm depth) was 10 mg P kg^{-1} soil, a medium soil test P level in Colorado. A randomized block design with a split-split-plot treatment arrangement was used with P placement method as main plots (12.2 by 24.4 m area), P fertilizer rates as subplots (4.9 by 12.2 m), and N fertilizer rates as sub-subplots (4.9 by 6.1 m) with four replicates. Fertilizer P placement methods were: (i) broadcast prior to planting with no incorporation (BC W/O INC); (ii) broadcast prior to planting with shallow incorporation (7.5-cm depth) using a disk (BC INC); and (iii) banded 3.8 cm to the side and 3.8 cm below seed during planting (BD) or about 7.5 cm below the soil surface. Fertilizer P (concentrated superphosphate) rates were 0, 34, 67, 101, and 134 kg P ha^{-1} (elemental P). Fertilizer N was either not added or broadcast applied without incorporation prior to planting at 56 kg N ha^{-1} as $(NH_4)_2NO_3$.

Duplicate sets of treatments were established in adjacent plot areas to accommodate the wheat–fallow system and to allow harvest of winter wheat crops each year. One set was begun in the fall of 1985 (BC treatments established 6 Aug. 1985; BD treatments at planting, 17 Sept. 1985) and the

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Abbreviations: BC W/O INC, broadcast prior to planting with no incorporation; BC INC, broadcast prior to planting with shallow incorporation (7.5-cm depth) using a disk; BD, banded 3.8 cm to the side and 3.8 cm below seed during planting.

other in the fall of 1986 (BC treatments established 4 Sept. 1986; BD treatments at planting, 9 Sept. 1986). The wheat was planted each year into no-till fallow, at a seeding rate of ≈62 kg ha^{-1}. A no-till hoe-type drill (Haybuster Model 8000, Haybuster Manufacturing, Jamestown, ND)[1] with dual seed-placement row openers on each shank (two rows, 7.5 cm apart) and 30.5 cm between shanks was used. 'Tam 105' winter wheat was grown in 1986 and 'Tam 107' (similar yield potential to Tam 105, but better disease resistance) in 1987. A plot combine was used to harvest a 14-m^2 area from each plot on 11 July 1986 and 14 July 1987. Straw yields were determined at harvest by determining the total biomass yield of a 1- to 2-m^2 area from each plot and then subtracting the combine grain yield. Herbicides were used to control broadleaf weeds in the growing crop and during the fallow period. Phosphorus fertilizer incorporation was the only tillage operation and occurred only in the BC INC treatments. Soil samples from the 0- to 15-cm depth were collected from four locations within each replication before fertilizer P application. Each sample was analyzed for $NaHCO_3$-extractable soil P (Olsen et al., 1954; Watanabe and Olsen, 1965).

Soil samples to a depth of 120 cm in 30-cm increments were collected for determination of gravimetric soil water content and residual NO_3–N (Technicon Industrial Systems, 1973a). Volumetric soil water content was calculated using an average soil bulk density of 1.34 g cm^{-3}. Soil water content was determined at planting and after wheat harvest in the 0, 67, and 134 kg P ha^{-1} plots of BC INC and BD placement methods. Soil samples from the 0- to 120-cm depth collected before N application in the fall had average initial soil NO_3–N levels of 72 kg N ha^{-1} in 1985 and 109 kg N ha^{-1} in 1986 from the second site.

Grain samples were cleaned before weighing for yield determination and laboratory analyses. Subsamples of harvested grain were ground to pass a 0.425-mm screen. Nitrogen and P concentrations of grain were determined using a modified wet-acid digestion procedure (Isaac and Johnson, 1976; Thomas et al., 1967) and colorimetric analysis with an autoanalyzer (Technicon Industrial Systems, 1973b,c).

All statistical comparisons are at the 0.05 probability level unless otherwise stated. Analysis of variance was performed using the MSTAT-C computer program from Michigan State University (Freed et al., 1989). If the analysis of variance indicated a significant *F* value at the 0.05 probability level, regression analyses were used to evaluate rate response data.

RESULTS AND DISCUSSION

Winter wheat grain yields averaged across the 1986 and 1987 growing seasons were significantly increased from 3710 to 4120 kg ha^{-1} with the application of 56 kg N ha^{-1}. Method of P placement had no significant effect on grain yield, with 2-yr average yields of 3990, 3810, and 3950 kg ha^{-1} for the BC INC, BC W/O INC, and BD treatments, respectively. The interactions of N with P application rate or placement method were not significant for grain yield.

Grain yields increased significantly with increasing rates of P fertilization for all placement methods. Grain yields, when averaged across placement methods, were significantly increased by P application, with 2-yr averages of 3390, 3860, 4060, 4110, and 4170 kg ha^{-1} for the 0, 34, 67, 101, and 134 kg P ha^{-1} treatments, respectively. Grain yields were near or at maximum with the application of 101 kg P ha^{-1}. Analysis of the grain yield data indicated a significant year × P placement × P rate interaction. This interaction occurred as a result of the BC INC treatment giving lower grain yields than the BC W/O INC and BD treatments in 1986, whereas the BC INC treatments gave higher grain yields than the BC W/O INC and BD treatments with increasing P rate in 1987 (Fig. 1). A possible explanation for the difference between years in grain yield response for the BC INC treatment is that climatic conditions after incorporation of the broadcast P were dry in 1986 and moist in 1987 (Table 1). Thus, the loss in soil water from the seedbed with tillage in 1986 resulted in slightly reduced plant stands and drought-stressed plants. These produced lower grain yields than the other placement treatments, which were strictly no-till and had good surface soil water conditions for plant establishment and early plant growth. Phosphorus placement had little influence on winter wheat grain yields in this study, indicating that P applied BC W/O INC will effectively stimulate winter wheat yields under no-till conditions. The results also indicate that, when sufficient P is applied to correct

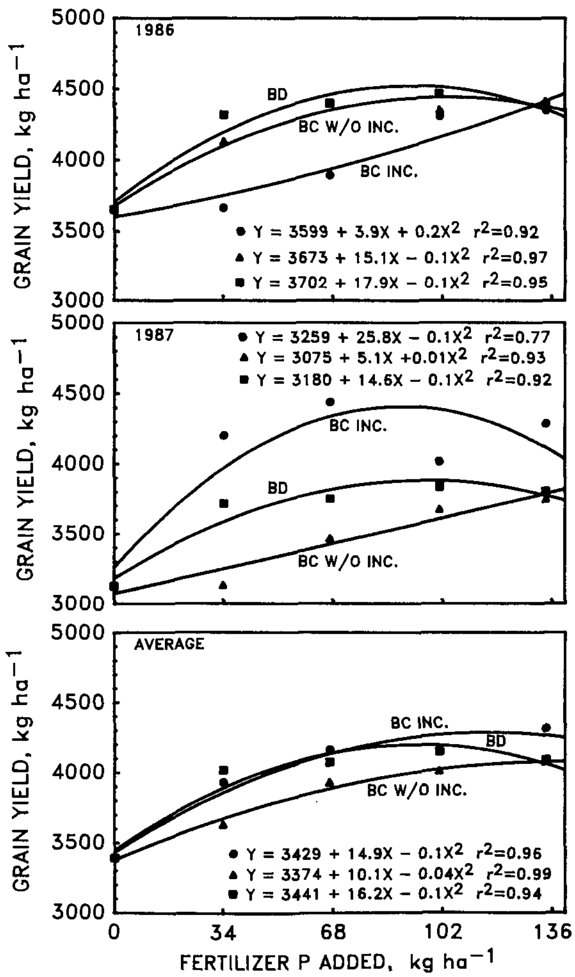

Fig. 1. Grain yield as a function of fertilizer P placement and application rate in 1986, 1987, and average of both years. Note: year × P placement × P rate interaction was significant (P = 0.05).

[1] Mention of trade names or manufacturer within the context of this article is solely to provide specific information and does not constitute a guarantee or endorsement by the USDA or Kansas State Univ.

Table 1. Monthly precipitation measured or estimated at the Peetz, CO, field site during the study period.

Month	1985	1986	1987	82-yr average†
		mm		
Jan.	—	1†	5†	8
Feb.	—	27†	30†	5
Mar.	—	29	23†	18
Apr.	—	31	3	32
May	—	69	139	77
June	—	125	78	66
July	—	30	81	64
Aug.	2	26	88	44
Sept.	6	47	26	26
Oct.	13	32	12	21
Nov.	17	7	12	12
Dec.	20†	15	22	8

† Precipitation estimated from nearest weather recording station, Sterling, CO.

soil P deficiency for winter wheat, the method of application may have little influence on grain yield. These data also suggest that P rates greater than those generally recommended (Whitney, 1983; Soltanpour et al., 1985) may be needed to correct P deficiency in winter wheat in the central Great Plains. With an average 722 kg ha^{-1} increase in grain yield with application of 101 kg P ha^{-1}, however, this rate may not be economical in the first year of application. Therefore, the residual value of the applied P over several years will need to be considered (Wagar et al., 1986; Halvorson and Black, 1985a; Halvorson et al., 1986).

Water supply during the growing season was adequate both years, with 244 and 297 mm of growing season precipitation from April until harvest for 1986 and 1987, respectively. Soil water measurements indicated very little soil water use in 1986, with only 15 mm depleted from the 0- to 120-cm soil depth at harvest and 56 mm in 1987. This resulted in an average, estimated, total water use (evapotranspiration) by the winter wheat crops in 1986 and 1987 of ≈307 mm. Because estimated soil water use did not change with fertility level, the water-use efficiency of winter wheat increased significantly as P fertility level increased.

Application of 56 kg N ha^{-1} significantly increased straw yields from 4300 to 4700 kg ha^{-1} when averaged across both years. The year × P placement × P rate interaction was also significant for straw yield. Both years, straw yields increased with increasing P rate for all methods of application (Fig. 2). The year × P placement × P rate interaction was significant because of the BC INC straw yields being lower than those of the other placement methods in 1986 and higher in 1987 at most P rates. Both years, straw yields were similar with increasing P rate for the BD and BC W/O INC treatments. Because of the increased straw production with N and P fertilization, one might expect improved soil water relations and better protection from wind and water erosion with time. This increased level of crop residue will be beneficial to farmers using residue management to meet the conservation tillage needs of the 1985 Food Security Act. Thus, the beneficial effects of N and P fertilization include more than just increased grain yield in a given year.

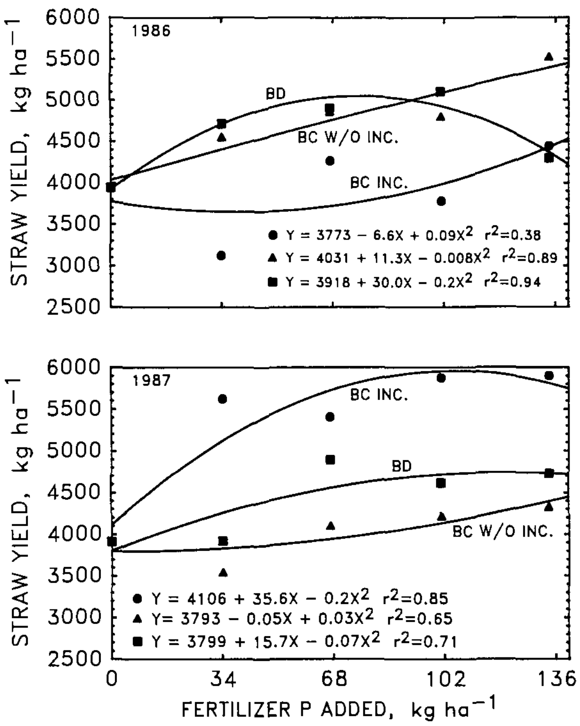

Fig. 2. Straw yield as a function of fertilizer P placement and application rate for 1986 and 1987. Note: year × P placement × P rate interaction was significant (P = 0.05).

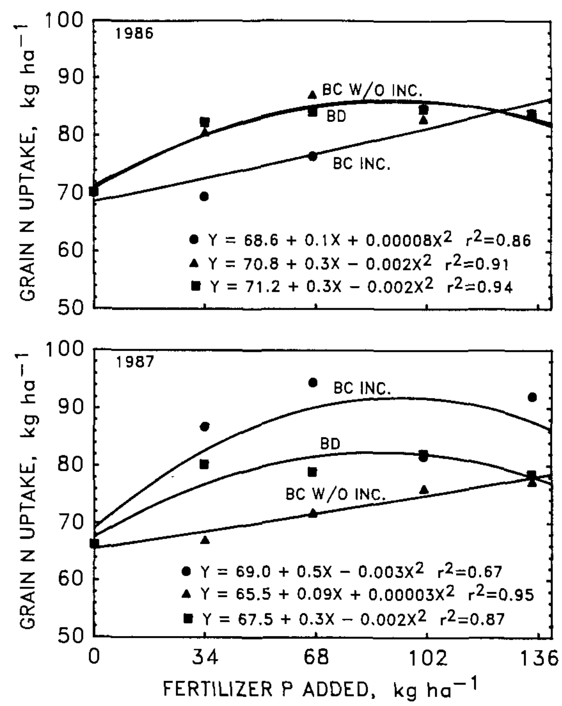

Fig. 3. Grain N uptake as a function of P placement and P rate for 1986 and 1987. Note: year × P placement × P rate interaction was significant (P = 0.05).

Nitrogen fertilization significantly increased grain protein concentration, from 126 g kg^{-1} without N to 134 g kg^{-1} with 56 kg N ha^{-1}, as well as grain P uptake. The effect of P placement on grain protein concentration was not significant. Grain protein concentration tended to decrease slightly as the rate of P application increased (data not shown). The uptake of N by grain, however, was significantly increased as the rate of P fertilization was increased (Fig. 3) because of the increase in grain yield with increasing P rate. The year × P placement × P rate interaction was significant for N uptake by grain. Nitrogen uptake by grain followed the same response patterns as grain and straw yields with increasing P rate; consequently, the significant interaction occurred. Thus, N-use efficiency was improved as P rate increased. This result has important implications for the environment as well as for improving the economics of N fertilization. Nitrogen uptake by grain was significantly increased from 72 kg N ha^{-1} without N to 85 kg N ha^{-1} with the application of 56 kg N ha^{-1} when averaged across years.

The P concentration in the grain was significantly decreased from 4.26 g P kg^{-1} without N to 4.16 g P kg^{-1} grain with the application of 56 kg N ha^{-1} when averaged across P rates, placement methods, and years. Nitrogen application tended to decrease grain P concentration at low P rates (<67 kg P ha^{-1}) but not at the two highest P rates (data not shown). Since there was a significant year × P placement × P rate interaction for grain P concentration, the data for each year are shown separately in Fig. 4. The BD placement method in 1986 produced higher grain P concentrations than the broadcast treatments, indicating a greater efficiency of fertilizer P uptake. The BC INC treatment tended to have the lowest grain P concentration. In 1987, grain P concentration was similar for all placement methods, with BC INC tending to have the highest grain P concentration. In both years, grain P concentration increased with increasing P rate.

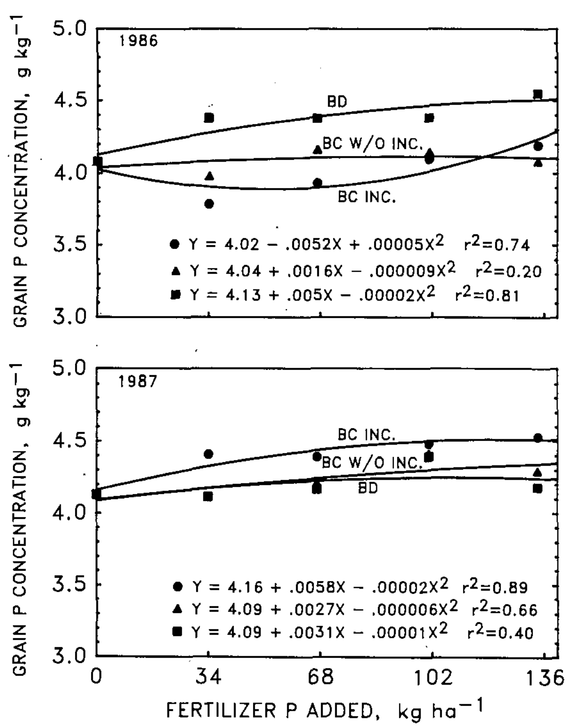

Fig. 4. Grain P concentration as a function of fertilizer P placement and application rate for 1986 and 1987. Note: year × P placement × P rate interaction was significant (P = 0.05).

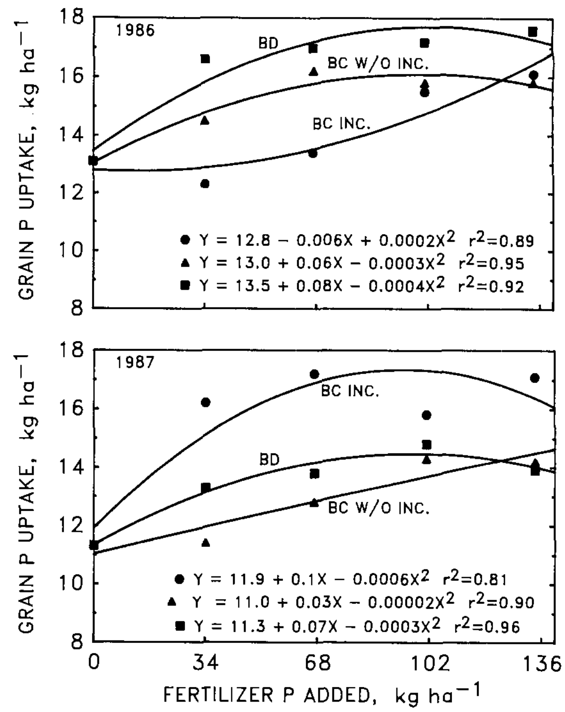

Fig. 5. Grain P uptake as a function of fertilizer P placement and application rate for 1986 and 1987. Note: year × P placement × P rate interaction was significant (P = 0.05).

Phosphorus uptake by grain followed grain yield, straw yield, and N uptake patterns, with a significant year × P placement × P rate interaction (Fig. 5). Phosphorus uptake by grain increased with increasing rate of P application. Applications of 56 kg N ha^{-1} significantly increased grain P uptake to 15 kg P ha^{-1} vs. 14 kg P ha^{-1} without N.

SUMMARY

The results of this study indicated that a nonincorporated, broadcast application of fertilizer P prior to planting under no-till conditions was effective in increasing winter wheat grain yields on a soil with a medium soil test P level. The 1986 BC INC data demonstrate the risk of losing valuable soil water in the seed zone when tillage is needed to incorporate fertilizer in a dry year. Poor plant establishment and vigor in the BC INC plots resulted in lower grain yields than those of the other P placement treatments where tillage was not used. The data also implied that, when sufficient P is applied to correct a P deficiency in winter wheat, the method of application is not critical. Higher rates of P than those normally recommended may be needed to correct P deficiency of winter wheat grown on P-deficient soils. However, the economics of higher P rates needs to be evaluated (Fixen and Halvorson, 1991; Halvorson et al., 1986; Jose, 1981). Higher P fertilizer rates may require P costs to be amortized over a longer time span than 1 yr to adequately correct P deficiency in winter wheat in the Great Plains.

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