Reprinted from the *Soil Science Society of A*
Volume 53, no. 6, November-Decemb
677 South Segoe Rd., Madison, WI 53

Multiple-Year Response of Winter Wheat to a Single Application of Phosphorus Fertilizer

A. D. Halvorson

Multiple-Year Response of Winter Wheat to a Single Application of Phosphorus Fertilizer

A. D. Halvorson*

ABSTRACT

Information on multiple-year responses of irrigated winter wheat (*Triticum aestivum* L.) to a single application of P fertilizer in the central Great Plains is limited. The effects of one-time P applications (0, 34, 67 kg ha^{-1}), with 5 N rates applied annually as subplots, on winter wheat grain yield and protein were studied. Winter wheat was grown on the same plots for three consecutive years under limited irrigation on a Weld silt loam (fine, montmorillonitic, mesic Aridic Paleustoll). Single P applications in the fall of 1983 significantly increased grain yields each of three consecutive years. Applying N to P-fertilized plots resulted in greater yields than when N or P was applied alone. The 67 kg P plus 134 kg N ha^{-1} treatment produced 5405 kg/ha more grain in three crops than without P and N applied. Grain protein was reduced by P fertilization at low N rates, but increased by N fertilization. Soil-test P and residual NO_3–N levels were significantly increased by P and N fertilizer additions, respectively. Soil NO_3–N in the 0 to 180-cm depth for the highest N rate (336 kg N ha^{-1} in 1984 and 268 kg N ha^{-1} in 1985–86) was 764 kg N ha^{-1} without P and 458 kg N ha^{-1} with 67 kg P ha^{-1} applied. Downy brome (*Bromus tectorum*) infestations responded positively to N and P fertilization and tended to increase in severity each year in this monoculture winter wheat system. The results indicate that an adequate level of P and optimum level of N are needed to achieve efficient use of these nutrients by winter wheat and to reduce the amount of potentially leachable NO_3–N in the soil profile.

USDA-ARS, P.O. Box 400, Akron, CO 80720. Contribution from USDA-ARS. Received 25 Mar. 1988. *Corresponding author.

Published in Soil Sci. Soc. Am. J. 53:1862–1868 (1989).

SOIL P DEFICIENCY for winter wheat and other crops is common in the central Great Plains area (Follett et al., 1987; Westfall et al., 1986). With continued years of cropping and with very little fertilizer P (about 1.5 kg P ha^{-1}) being applied to winter wheat in Colorado each crop year, one might expect P deficiencies to become more prevalent with time (Berry and Hargett, 1987). Most P soil-fertility work in the central Great Plains has concentrated on evaluating winter wheat response to P fertilizer application for only one crop harvest (Fiedler et al., 1987; Follett et al., 1987; Leikam et al., 1983; Peterson et al., 1981).

Phosphorus fertility work in the northern Great Plains has shown the residual effects of P fertilization on increasing small-grain yields (Black, 1982; Halvorson and Black, 1985; Read et al., 1977; Roberts and Stewart, 1987; Wagar et al., 1986) as well as the economic benefits in increasing farm profit potential (Halvorson et al., 1986; Jose, 1981; Roberts and Stewart, 1987). Many of these studies were conducted using conventional dryland tillage systems and a crop-fallow cropping sequence.

Multiple-year responses of alfalfa (*Medicago sativa* L.) and grain sorghum [*Sorghum bicolor* (L.) Moench] to single applications of P fertilizer have been investigated in the central Great Plains (Havlin et al., 1984; Janssen et al., 1985; Schlegel et al., 1986). The effects of P fertilization on increasing soil-test P levels of several central Great Plains soils for several years was shown by Hooker et al. (1980); however, wheat yields were not included. Thus, only limited information is available on residual P-fertilizer effects on winter wheat yields in the central Great Plains. This study was conducted to evaluate short-term residual P-fertilizer effects on irrigated winter wheat grain yields and protein content, N-fertilizer utilization, and residual soil N and P levels using a no-till, annual winter wheat (monoculture) cropping system.

MATERIALS AND METHODS

The study was conducted from 1984 through 1986 near Akron, CO on an irrigated Weld silt loam soil with an initial $NaCO_3$-extractable P level of 5.7 mg P kg^{-1} soil (low rating), a pH of 7.1 and 14 g organic matter kg^{-1}. The plot area was summer fallowed in 1980 and then planted annually with winter wheat from 1981 to 1986. Conventional tillage operations (disked 4–5 times) had been used to control weeds between crops and for seedbed preparation from 1981 to 1983. A reduced tillage system (disked twice to incorporate fertilizer) was used for the 1984 crop and no-tillage for the 1985 and 1986 crops.

The research plots were established in September 1983, with concentrated superphosphate and NH_4NO_3 incorporated into the surface 7 cm of soil with a disk at rates of 0, 34, and 67 kg P ha^{-1} and 0 (N1), 56 (N2), 112 (N3), 224 (N4), and 336 (N5) kg N ha^{-1}. Nitrogen fertilizer was applied as subplots to each main P treatment in a randomized complete block, split plot design with 3- by 18-m subplots and three replications. Because the anticipated yield goal of 6700 kg/ha was not achieved in 1984 and there was a buildup of residual soil NO_3–N with the higher N treatments, all rates of N applied in 1985 and 1986 were reduced to maintain a doubling effect of rates and to bracket the N needs of the crop more closely. The N rates were reduced to 34 (N2), 67 (N3), 134 (N4), and 268 (N5) kg ha^{-1} for the 1985 and 1986 winter wheat crops. Phosphorus fertilizer was applied only once, at study initiation in September 1983. Fertilizer N was applied surface broadcast with no incorporation before planting for the 1985 and 1986 crops. Broadleaf weeds were chemically controlled with 2,4-dichlorophenoxyacetic acid.

'Vona' winter wheat was grown in 1984 and 1985. 'Tam 105' winter wheat was grown in 1986 to allow application of terbutryn (2-*tert*-butylamino-4-ethylamino-6-methylthio-s-triazine) and metribuzin (4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one) to suppress downy brome, which had become more of a problem with each additional crop year. Winter wheat was planted with a no-till grain drill (30.5-cm row spacing) at a seeding rate of 67 kg ha^{-1} on 22 Sept. 1983, on 10 Sept. 1984, and on 18 Sept. 1985. The wheat was harvested in early to mid-July from an area of at least 14 m^2 in each plot in 1984 and 1985 and threshed with a bundle thresher. In 1986, a 30-m^2 area from the center of each plot was harvested using a plot combine. Grain samples were cleaned before weighing for yield determination and laboratory analyses.

Soil samples from the 0- to 15-cm soil depth were collected from 6 to 8 locations within each plot and composited on 17 May 1984, 3 Apr. 1985, and 23 Apr. 1986. Each sample was analyzed for $NaCO_3$-extractable soil P (Olsen et al., 1954; Watanabe et al., 1965).

Soil samples from the 0- to 30-, 30- to 60-, 60- to 90-, 90- to 120-, 120- to 150-, and 150- to 180-cm soil depths were collected at one location within each plot in early spring (shortly after winter wheat broke dormancy) and after grain harvest for determination of gravimetric soil water content and residual NO_3–N (after-harvest samples only) (Technicon, 1973a). Soil water content was calculated using an average soil bulk density of 1.34 g cm^{-3}. Soil samples collected on 16 Nov. 1983 from areas receiving no N fertilizer had an average initial soil NO_3–N level of 11.7, 25.3, 18.3, 16.0, 21.6, and 14.1 kg ha^{-1} in the 0- to 30-, 30- to 60-, 60- to 90-, 90- to 120-, 120- to 150-, and 150- to 180-cm soil depths, respectively.

Table 1. Estimated total crop water use (evapotranspiration) each year as a function of growing-season precipitation, estimated soil water use, and irrigation water applied.

Year	Growing-season precipitation	Estimated soil water used†	Growing-season irrigation water applied	Estimated crop water use
	mm			
1984	174	197	38	409
1985	178	11	150	339
1986	212	70	35	317

† 0- to 180-cm soil depth.

Estimated crop water use (evapotranspiration) was determined by totaling: (i) growing season precipitation received between spring and harvest soil-sampling periods: (ii) estimated soil water used by the crop in the 0- to 180-cm soil depth (spring minus harvest soil water); and (iii) irrigation water applied during the growing season. Irrigation water was applied on 12 June (18.2 mm) and 2 July (19.5 mm) in 1984; on 17 April (47.2 mm), 2 May (40.6 mm), 6 June (32.5 mm) and 15 June (29.9 mm) in 1985; and on 23 May (34.8 mm) in 1986. The entire plot area was irrigated with about 100 mm of water after harvest and before winter wheat planting each year to partially recharge the soil profile. Estimated crop water use is reported in Table 1. Because of a declining water table (Powers, 1987) and increasing pumping costs, a limited irrigation management program was followed. Irrigations were scheduled based on weekly soil water removal (by neutron moisture probe) in an adjacent irrigation water management study with winter wheat. Irrigation water was applied when more than 30 mm of soil water had been removed from the soil profile. Irrigation continued as needed until the soft dough stage.

Subsamples of harvested grain were ground to pass a 0.425-mm screen. Nitrogen and P content of grain were determined using a modified wet-acid digestion procedure (Isaac and Johnson, 1976; Thomas et al., 1967) and colorimetric determination with an autoanalyzer (Technicon, 1973b,c). Fertilizer-N recovery was estimated using the following equation

$$\text{Fertilizer-N Recovery (\%)} = [(N_f - N_0)/N_t] \times 100$$

where N_f equals N uptake in grain of fertilized N treatment at each P level; N_0 equals N uptake in grain of zero-N treatment at each P level, and N_t equals total fertilizer N added at each N level. Fertilizer P recovery was calculated similarly to that of N.

All statistical comparisons are at the 0.05 probability level unless otherwise stated. Analysis of variance and regression were used to statistically analyze data. Because residual soil NO_3–N levels changed each year, the response data were plotted as a function of soil NO_3–N plus fertilizer N applied when the P × N interaction was significant, as indicated by analysis of variance. Most response surfaces were best described by either a linear, quadratic, or hyperbolic equation. The best-fit equation was used to describe each response curve.

RESULTS AND DISCUSSION

Application of fertilizer P in the fall of 1983 significantly increased the soil-test P level (Fig. 1). Soil-test P levels in 1984 increased linearly with increasing rate of P application in 1983 (soil test P = 4.92 + 0.23 P

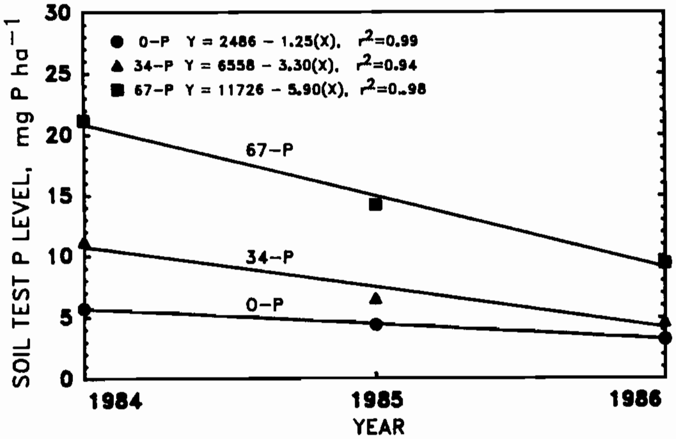

Fig. 1. Sodium bicarbonate-extractable soil P level in the spring of 1984, 1985, and 1986 as a function of P-fertilizer rate applied in September 1983.

added; $r^2 = 0.98$). Soil-test P levels maintained a significant linear relationship with rate of initial P application in 1985 (soil test P = 3.46 + 0.146 P added; $r^2 = 0.90$) and 1986 (soil test P = 2.63 + 0.092 P added; $r^2 = 0.90$). Soil-test P levels, however, declined each year for each P rate as shown in Fig. 1. The decline in soil-test P probably reflects the conversion of applied fertilizer P to nonextractable forms in the soil and P removal by the wheat crop.

Application of 34 and 67 kg P ha^{-1} significantly increased winter wheat grain yields each crop year (Fig. 2). Grain yields increased significantly with increasing levels of available N (soil NO_3–N plus fertilizer N) each year, with the highest grain yield (4712 kg ha^{-1}) resulting from fertilization with 34 kg P plus 336 kg N ha^{-1} in 1984. The fact that the 67 kg P ha^{-1} treatments tended to yield less than the 34 kg P ha^{-1} treatments in 1984 probably resulted from a P-induced Zn deficiency at this P rate. A soil test taken for Zn after harvest in 1986 indicated that the AB-DTPA extractable Zn level was 0.3 mg Zn kg^{-1} soil, a deficient rating by Colorado State University Soil Testing Laboratory standards. In 1984, the grain was analyzed for Zn by atomic absorption and found to have Zn concentrations of 35.6, 28.8, and 26.2 mg Zn kg^{-1} grain for the 0, 34, and 67 kg P ha^{-1} treatments, respectively. Singh et al. (1986) reported Zn deficiency in wheat following a high rate of P application, with grain Zn concentrations from the Zn-responsive plots about equal to those found in this study for the zero-P treatment.

In 1985 and 1986, grain yields (Fig. 2) increased significantly in response to residual P fertilizer availability and increasing N availability (soil NO_3–N plus fertilizer N) up to about 150 kg N ha^{-1}. Yields from the 67 kg P ha^{-1} residual treatment were slightly higher than the 34 kg P ha^{-1} treatment up to about 200 kg N ha^{-1}. Both P-fertilizer rates had significantly greater yields than the zero-P treatment at all N levels. Maximum yields in 1985 occurred with the 67 kg P plus 67 kg N ha^{-1} treatment (soil NO_3–N plus fertilizer N = 212 kg ha^{-1}) and in 1986 with the 67 kg P plus 134 kg N ha^{-1} treatment (soil NO_3–N plus fertilizer N = 278 kg N ha^{-1}). In 1985 and 1986, significant increases in grain yield were observed as a result of the initial

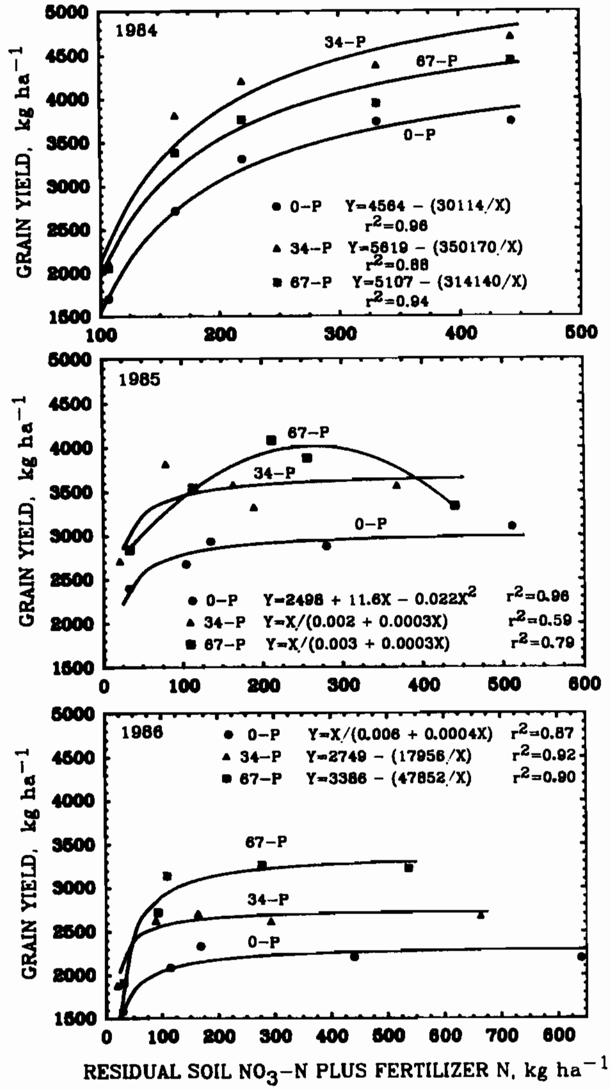

Fig. 2. Grain yield of the fertilizer-P treatments as a function of residual soil NO_3–N plus fertilizer N applied for 1984, 1985, and 1986.

1983 fertilizer-P application with relative treatment yields being 67 > 34 > 0 kg P ha^{-1}. Significant increases in grain yield to increasing rates of fertilizer N were not observed above 67 kg N ha^{-1} (N3 treatment) in 1985 or 1986 for any of the P treatments.

Infestations of downy brome were visually more severe in plots receiving P, and increased with increasing N rate. This may partially explain why higher grain yields were not obtained with N rates >67 kg ha^{-1}. In 1986, the downy brome infestation was reduced considerably (visual estimate, about 90%) by the application of grass herbicides; however, the herbicides appeared to stunt the wheat slightly in early spring. The occurrence of a severe downy brome problem is very typical of a monoculture winter wheat cropping system (Wicks, 1984). Examination of grain-yield data obtained from the experimental area from 1981 to 1986 reveals a decline in grain yield of about 690 kg ha^{-1} with each additional wheat crop. Increasing severity of downy brome infestation probably contributed to the decline in yield with time. In addition,

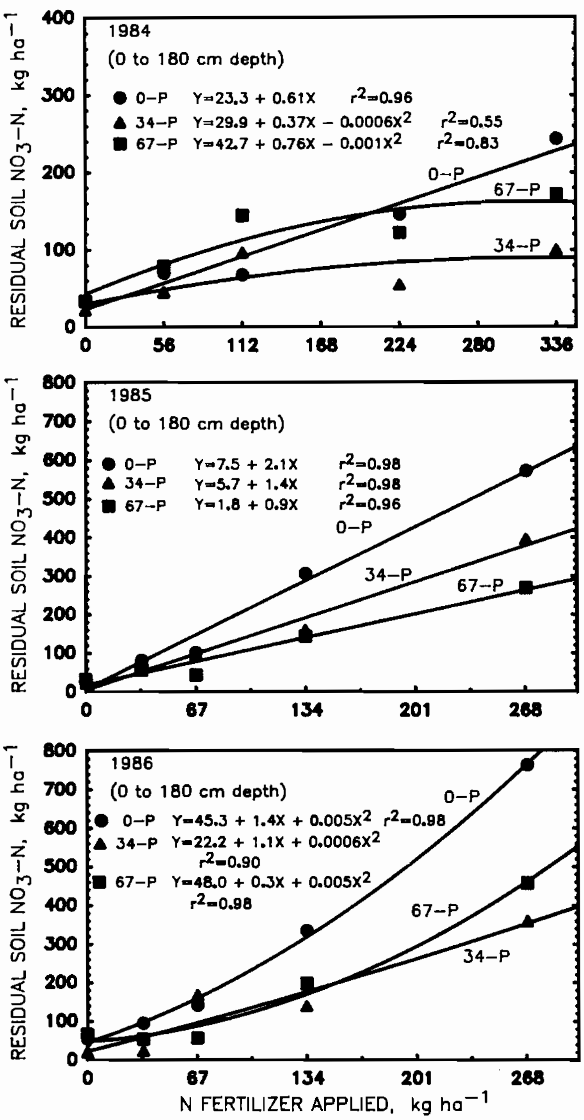

Fig. 3. Residual soil NO_3–N level after wheat harvest for each fertilizer-P treatment as a function of fertilizer N added each year for 1984, 1985, and 1986.

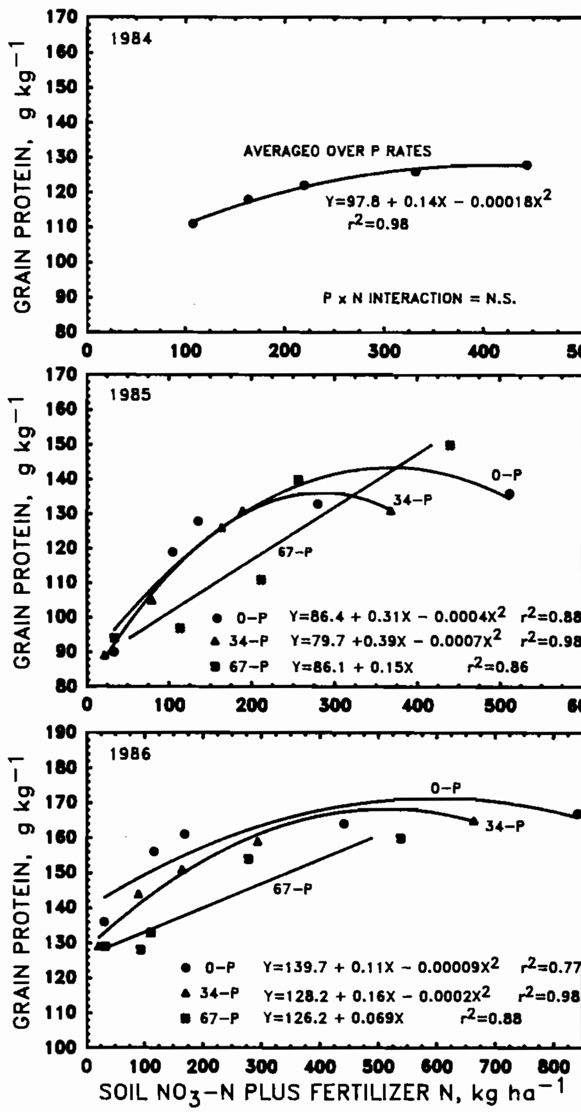

Fig. 4. Grain protein for each fertilizer P treatment as a function of available N (soil NO_3–N plus fertilizer N) for 1984, 1985, and 1986.

phytotoxic or allelopathic effects of wheat residues on following wheat crops may have contributed to the yield decline, because N and P fertility and water were probably not the yield-limiting factors. The decline in crop water use (Table 1) from 1984 to 1986 reflects the decline in grain yield. The need for rotating crops within an irrigated winter wheat cropping system is suggested.

Residual soil NO_3–N levels remaining after harvest continued to increase each crop year for the N4 and N5 treatments (Fig. 3). Residual soil NO_3–N levels in the 0- to 180-cm soil depth were significantly less at the two highest N rates (N4 and N5) in 1986 where P had been applied. In 1985 and 1986, a curvilinear increase in residual soil NO_3–N is evident at N-fertilizer rates from 67 to 269 kg N ha^{-1}. The N needs of the winter wheat crop were exceeded at the two highest N rates (N4 and N5) in this study.

Grain protein concentration was significantly increased each crop year by the application of N fertilizer (Fig. 4). Rate of P fertilization had no effect on grain protein in 1984 or 1985; however, a significant decline in grain protein was observed in 1986 as the level of available P increased. When averaged over years, application of P caused a significant decline in grain protein concentrations with levels of 133, 129, and 127 g kg^{-1} for the 0, 34, and 67 kg P ha^{-1} treatments, respectively. In 1985 and 1986, a significant P × N interaction indicates that P application caused a reduction in grain protein concentration at the lower N levels (N1, N2, N3), but no reduction at the higher N levels (N4 and N5). This is consistent with the observations reported by Halvorson et al. (1986) that application of P reduced grain protein level.

Nitrogen uptake in grain was significantly increased each crop year by P and N fertilization (Fig. 5). Recovery of total fertilizer N applied in the grain was highest for the 34 kg P plus 34 kg N ha^{-1} (N2) treatment (72%) when totaled over the three crops. Total fertilizer-N recoveries (3 crops) for the respective N1,

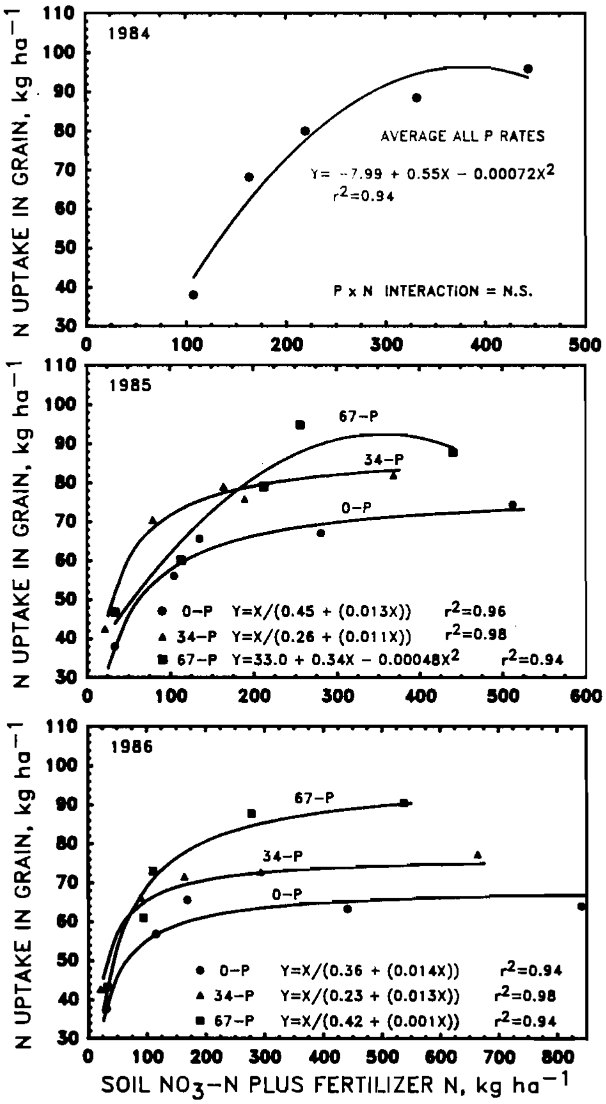

Fig. 5. Nitrogen uptake in grain for each fertilizer-P treatment as a function of residual soil NO_3-N plus fertilizer N applied for 1984, 1985, and 1986.

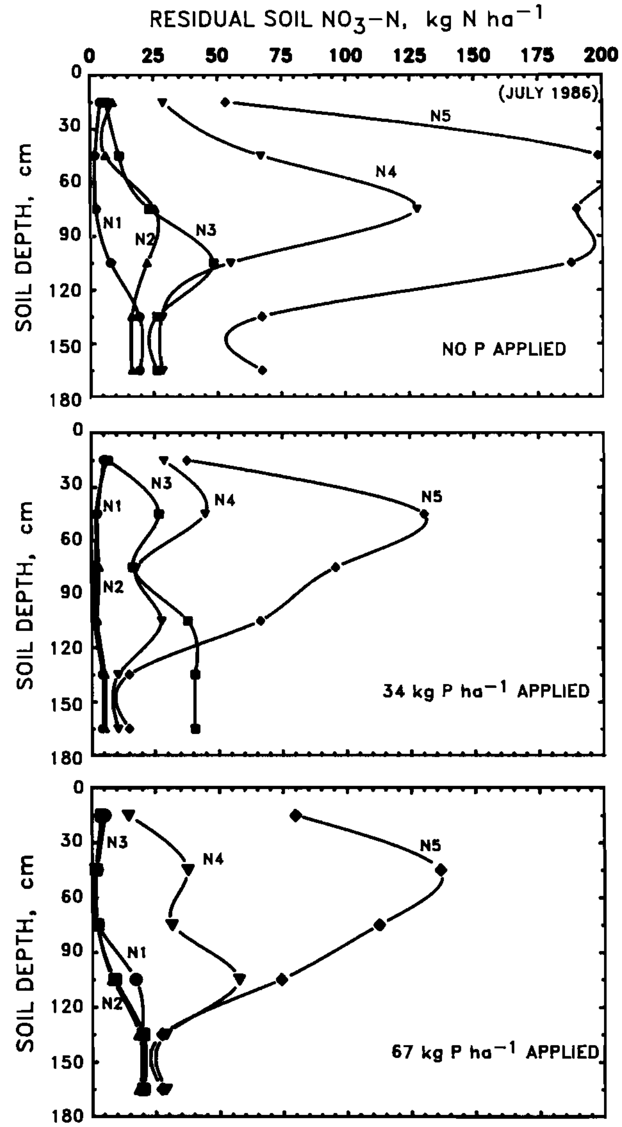

Fig. 6. Distribution of NO_3-N in the soil profile as a function of annual N rate and initial rate of P application.

N2, N3, N4, and N5 treatments were 50, 38, 21, and 13% with no P applied; 72, 46, 24, and 16% with 34 kg P ha^{-1} applied; and 47, 42, 28, and 17% with 67 kg P ha^{-1} applied. Efficiency of N-fertilizer use decreased, as shown by estimates of fertilizer-N recovery with increasing N rates. Although residual soil NO_3-N levels increased significantly with N rates >67 kg ha^{-1} (N3) where N-fertilizer requirements for optimum yield were exceeded, much of the residual soil NO_3-N remained in the 0- to 120-cm soil depth (Fig. 6).

As the soil NO_3-N plus fertilizer-N level increased, grain P concentration decreased (Fig. 7). However, as the rate of P fertilization increased, the decline in grain P concentration with increasing levels of available N was less than without P fertilization, as indicated by significant P $\times$ N interactions each crop year.

Phosphorus uptake and removal with the harvested grain generally increased as the soil NO_3-N plus fertilizer N level increased in 1984 for all P rates but only for the 67 kg P ha^{-1} treatment in 1985 and 1986 (Fig. 8). Estimated fertilizer-P recovery in the harvested grain of three winter wheat crops for the 34 kg P ha^{-1} applied was 9.7, 42.4, 26.5, 22.9, and 24.7% for the N1, N2, N3, N4, and N5 treatments, respectively. Estimated fertilizer-P recovery in the harvested grain of three winter wheat crops for the 67 kg P ha^{-1} applied in 1983 was 7.2, 22.4, 27.3, 26.0, and 23.3% for the same respective N treatments. Thus, N fertilization significantly improved the recovery of fertilizer P in the harvested grain.

The positive benefits of residual P-fertilizer availability on irrigated winter wheat yields in the central Great Plains were demonstrated. These data demonstrate that P-fertilizer use efficiency needs to be evaluated over a longer period than just one crop year. Phosphorus fertilization costs may need to be amortized over several years, in order to apply enough P to optimize yield potential and make efficient use of

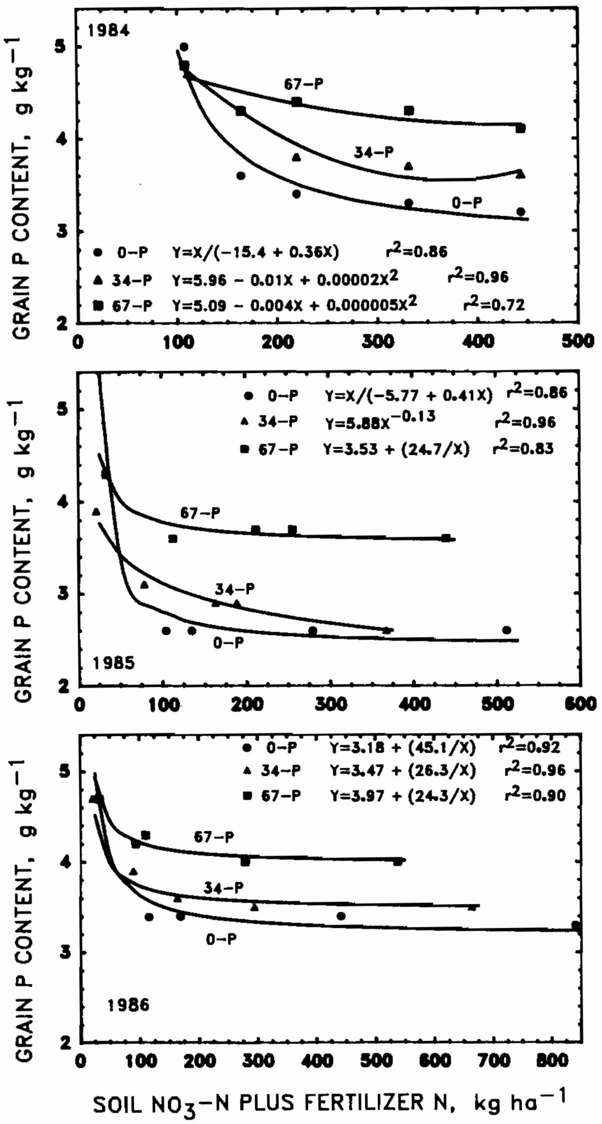

Fig. 7. Grain P content for each fertilizer P treatment as a function of residual soil NO_3-N plus fertilizer N applied for 1984, 1985, and 1986.

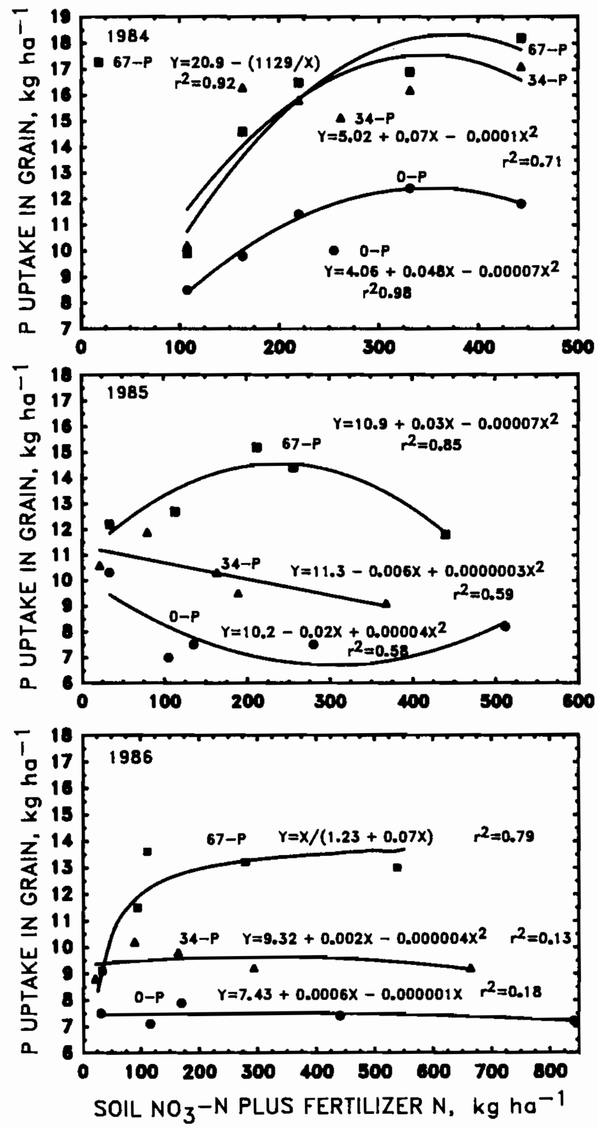

Fig. 8. Phosphorus uptake in grain for each fertilizer P treatment as a function of residual soil NO_3-N plus fertilizer N applied for 1984, 1985, and 1986.

other plant nutrients, such as N. Adequate P fertilization for optimum growth improved N uptake by winter wheat and left less residual NO_3-N in the soil profile, reducing the quantity of NO_3-N that could potentially be leached below the root zone and into the groundwater under irrigated conditions.

REFERENCES

Berry, J.T., and N.L. Hargett. 1987. 1986 Fertilizer summary data. Bull. Y-197, Natl. Fertilizer Devel. Center, TVA, Muscle Shoals, AL.

Black, A.L. 1982. Long-term N-P fertilizer and climate influences on morphology and yield components of spring wheat. Agron. J. 74:651–657.

Fiedler, R.J., D.H. Sander, and G.A. Peterson. 1987. Predicting winter wheat grain yield response to applied P with different soil P tests and sampling depths. J. Fert. Issues 4:19–28.

Follett, R.H., D.G. Westfall, J.W. Echols, R.L. Croissant, and J.S. Quick. 1987. Integration of soil fertility trials into on-going cultivar testing programs. J. Agron. Educ. 16:81–84.

Halvorson, A.D., and A.L. Black. 1985. Long-term dryland crop response to residual phosphorus fertilizer. Soil Sci. Soc. Am. J. 49:928–933.

Halvorson, A.D., A.L. Black, D.L. Watt, and A.G. Leholm. 1986. Economics of a one-time phosphorus application in the northern Great Plains. Appl. Agric. Res. 1:137–144.

Havlin, J.L., D.G. Westfall, and H.M. Golus. 1984. Six years of phosphorus and potassium fertilization of irrigated alfalfa on calcareous soils. Soil Sci. Soc. Am. J. 48:331–336.

Hooker, M.L., G.A. Peterson, D.H. Sander, and L.A. Daigger. 1980. Phosphate fractions in calcareous soils as altered by time and amounts of added phosphate. Soil Sci. Soc. Am. J. 44:269–277.

Isaac, R.A., and W.C. Johnson. 1976. Determination of total nitrogen in plant tissue, using a block digester. J. Assoc. Off. Anal. Chem. 59(1):98–100.

Janssen, K.A., D.A. Whitney, and D.E. Kissel. 1985. Phosphorus application frequency and sources for grain sorghum. Soil Sci. Soc. Am. J. 49:754–758.

Jose, H.D. 1981. An economic comparison of batch and annual phosphorus fertilizer application in wheat production in western Canada. Can. J. Soil Sci. 61:47–54.

Leikam, D.F., L.S. Murphy, D.E. Kissel, D.A. Whitney, and H.C. Moser. 1983. Effects of nitrogen and phosphorus application method and nitrogen source on winter wheat yield and leaf tissue phosphorus. Soil Sci. Soc. Am. J. 47:530–535.

Peterson, G.A., D.H. Sander, P.H. Grabouski, and M.L. Hooker. 1981. A new look at row and broadcast phosphate recommendations for winter wheat. Agron. J. 73:13–17.

Powers, W.L. 1987. the Ogallala's bounty evaporates. Sci. Food

Agric. 5(3):2–5.
Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. 939. U.S. Gov. Print. Office, Washington, DC.
Read, D.W.L., E.D. Spratt, L.D. Bailey, and F.G. Warder. 1977. Residual effects of phosphorus fertilizer. I. For wheat grown on four chernozemic soil types in Saskatchewan and Manitoba. Can. J. Soil Sci. 57:255–262.
Roberts, T.L., and J.W.B. Stewart. 1987. Update of residual fertilizer phosphorus in western Canadian soils. Sask. Inst. of Pedology Publ. no. R523.
Schlegel, A., R.E. Gwin, and W.A. Conrad. 1986. Effect of nitrogen, phosphorus, and potassium on irrigated corn and sorghum. p. 45–48. *In* Kans. Agric. Exp. Stn. Rep. of Progress 509. Manhattan.
Singh, J.P., R.E. Karamonos, and J.W.B. Stewart. 1986. Phosphorus-induced zinc deficiency in wheat on residual phosphorus plots. Agron. J. 78:668–675.
Technicon. 1973a. Nitrate and nitrite in water and wastewater. Industrial Method no. 100–70W, Technicon Industrial Systems, Tarrytown, NY.
Technicon. 1973b. Phosphorus/BD acid digests. Industrial Method no. 328–74A, Technicon Industrial Systems, Tarrytown, NY.
Technicon. 1973c. Ammonia/BD acid digest. Industrial Method no. 321–74A, Technicon Industrial Systems, Tarrytown, NY.
Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. Agron. J. 59:240–243.
Wagar, B.I., J.W.B. Stewart, and J.L. Henry. 1986. Comparison of single large broadcast and small annual seed-placed phosphorus treatments on yield and phosphorus and zinc content of wheat on chernozemic soils. Can. J. Soil Sci. 66:237–248.
Watanabe, F.S., and S.R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soils. Soil Sci. Soc. Am. Proc. 29:677–678.
Westfall, D.G., R.H. Follett, and J.W. Echols. 1986. Fertilization of dryland winter wheat. Colorado State Univ. Service-In-Action no. 114. Fort Collins.
Wicks, G.A. 1984. Integrated systems for control and management of downy brome (*Bromus tectorum*) in cropland. Weed Sci. 32, Suppl. 1:26–31.