Multiple Year Response of Irrigated Winter Wheat to a Single Application of Phosphorus

By Ardell D. Halvorson and Curtis A. Reule

Soil P deficiency for winter wheat and other crops is common in the central Great Plains. Continued years of cropping with very little fertilizer P being applied to crops have increased the frequency and severity of P deficiencies. Most P fertility research in the region has concentrated on evaluating crop response to P application only during the first crop year after fertilizer P application. Multiple year observations of crop response to fertilizer P application are limited, especially for irrigated winter wheat. In this study, we evaluated the response of continuous winter wheat to P and N fertilization within reduced-till and no-till production systems under limited irrigation.

Findings of a multi-year study with a continuous wheat system in the Great Plains indicate that a single phosphorus (P) fertilization can influence grain yields for several years. Therefore, the cost of fertilizer P applications should probably be amortized over several years. The results show that a balanced nitrogen (N) and P fertilization program is needed to optimize yields and economic returns and reduce the potential for nitrate-N (NO_3-N) contamination of groundwater.

The plot area was located on a Weld silt loam soil near Akron, Colorado, with a pH of 7.1 and 1.4 percent soil organic matter. The plot area had been summer fallowed using conventional tillage the year prior to the first crop of winter wheat, then continuously cropped to winter wheat for two more years prior to establishing this P x N fertility study. Three winter wheat crops were produced following P application. Three rates of fertilizer P (0, 69, and 137 lb P_2O_5/A) were applied at planting time of the fourth winter wheat crop. The soil had an initial Olsen soil test P level of 5.7 parts per million (ppm), a low soil test rating in Colorado. Fertilizer N rates of 0, 50, 100, 200, and 300 lb N/A were also established with the fourth crop, anticipating a yield potential of more than 100 bu/A. Since this yield potential was not achieved with the fourth crop, fertilizer N rates were reduced for the fifth and sixth crops to 0, 30, 60, 120, and 240 lb N/A. Fertilizer P was applied only once in the study.

Fertilizer P (0-45-0) and fertilizer N (34-0-0) were broadcast applied and incorporated into the top 3 inches of soil with one pass with a tandem disk and one pass with a mulch treader just prior to planting the fourth wheat crop. No other tillage was performed following harvest of the third wheat crop. A no-till environment was used for the fifth and sixth crops. A randomized complete block split-plot design with three replications was used with P_2O_5 rates as main plots and N rates as subplots. High yielding winter wheat cultivars were grown during the study. A limited irrigation management program was used. Irrigation water was applied when more than 1.2 inches of soil water had been depleted from the soil profile. Irrigation was continued as needed until the soft dough kernel stage. **Table 1** summarizes the amount of growing season precipitation received, irrigation water applied, soil water use, and estimated crop water use.

Grain yields were increased each year by N and P fertilization (**Table 2**). The largest increase came with the addition of the first increment of fertilizer N (either 30 or 50 lb N/A) with both P_2O_5 rates. Grain yields were near optimum with the application of 100 lb N/A the first crop after P fertilization and 60 lb N/A the second and third crop after P fertilization. Grain yields were greater with 69 lb P_2O_5/A than with 137 lb P_2O_5/A the first crop after P fertilization at all N rates. Analysis of the grain for zinc (Zn) concentration indicated that at the 137 lb/A P_2O_5 rate, Zn deficiency may have been a factor limiting yield with the first crop after P fertilization. With the second and third crops after P fertilization, grain yields were maximized with the 137 lb/A P_2O_5 rate.

TABLE 1. Estimated crop water use (evapotranspiration) each crop year (crops 4, 5, and 6) as a function of growing season precipitation, estimated soil water use, and irrigation water applied.

Wheat crop	Growing-season precipitation	Estimated soil water used	Growing-season irrigation water	Estimated crop water use
	....	.... inches	....	....
Crop 4	6.85	7.76	1.50	16.10
Crop 5	7.01	0.04	5.91	12.96
Crop 6	8.35	2.76	1.38	12.49

The total three-year increase in grain yield above that of the check treatment (no P or N applied) for the N and P_2O_5 treatments is shown in **Figure 1** as a function of the total amount of N applied in three crop years (significant P x N interaction). Grain yields were increased a small amount by P application without N. Likewise, grain yield response to N application without P did not result in maximum grain yields. Both N and P fertilization were needed to optimize grain yield. **Figure 1** shows that for the three-year period, the 69 lb/A P_2O_5 rate resulted in a greater three-year yield increase than with the 137 lb/A P_2O_5 rate for the 110 lb/A total three-year N application. As the total N applied increased, the 137 lb/A P_2O_5 rate was needed to maximize yield potential. The three-year grain yields were near maximum with the total application of 220 lb N/A and 137 lb P_2O_5/A.

Crop water use (**Table 1**) was not influenced by the N or P treatments. Therefore, water use efficiency (bushels of grain produced per inch of water) was increased by the application of both N and P fertilizer since more grain was produced with the same amount of water.

The grain yield responses shown in **Table 2** and **Figure 1** indicate that response to fertilizer P application will occur more than one year. Phosphorus is relatively immobile in the soil and not subject to leaching like fertilizer N. The Olsen soil test P data in **Figure 2** show that the single applications of P increased soil test P levels throughout the duration of this study and probably for

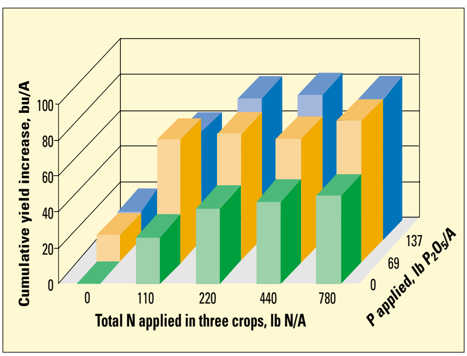

Figure 1. Cumulative yield above check treatment (no N or P added) of three irrigated winter wheat crops as a function of P and N fertilization.

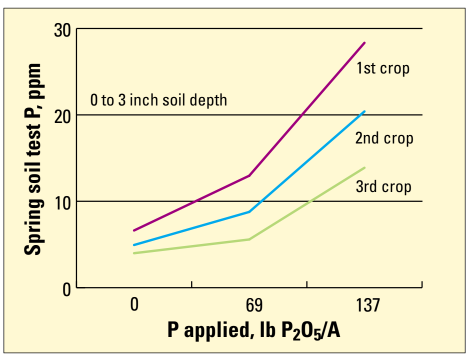

Figure 2. Spring soil test P (Olsen) levels each crop year following a single P fertilizer application.

several more crop years.

The higher rate of P was needed to optimize wheat yields the second and third crops after application. Thus, application of P fertilizer to a P deficient soil can have long-term impacts on crop yields. In the northern Great Plains, Halvorson and Black (*Soil Science Soc. Am. J.*, 1985) reported responses to a single P fertilizer application for 17 years in a Montana, dryland cropping system. Economic returns to P application continued to increase with each additional year of cropping. Roberts and Stewart (*Better Crops*, 1988) reported similar results in Canada.

The economic returns to N and P fertilization were estimated for this study assuming that P_2O_5 was worth \$.25/lb, N was \$.20/lb, and winter wheat \$2.50/bu. **Table 2** shows that P fertilization increased grain yields and net return to N fertilization. Although the P rates applied in this study were higher than those normally applied by Great Plains farmers, the economic data in **Table 2** show that the increased yields due to P fertilization were profitable the first crop year with N fertilization. Without N fertilization, the P applications were not profitable in the first crop year. With the first crop year after P fertilization, the highest profit potential was with the application of 69 lb P_2O_5/A and 100 lb N/A. With the second and third crops after P fertilization, the

TABLE 2. Winter wheat grain yields and net return to fertilizer application as a function of P_2O_5 and N fertilization treatments for three crop years (i.e., crops 4, 5, and 6).

Fertilizer treatment, lb/A		Grain yield, bu/A				Net return to fertilizer application, \$/A			
P_2O_5	N rate[1]	Crop 4	Crop 5	Crop 6	Total	Crop 4	Crop 5	Crop 6	Total
0	1	25.4	35.6	23.6	84.6	0	0	0	0
0	2	40.4	39.8	31.0	111.2	28	5	13	45
0	3	49.2	43.6	34.7	127.5	40	8	16	63
0	4	55.5	42.8	32.7	131.0	35	-6	-1	28
0	5	55.6	46.1	32.6	134.3	15	-22	-26	-32
69	1	31.5	40.3	27.9	99.7	-2	12	11	21
69	2	56.8	56.8	39.1	152.7	51	47	33	131
69	3	62.5	53.2	40.3	156.0	56	32	30	117
69	4	65.2	49.4	38.8	153.4	42	11	14	67
69	5	70.1	53.1	39.8	163.0	35	-4	-8	23
137	1	30.6	42.2	28.4	101.2	-21	17	12	7
137	2	50.4	52.7	40.5	143.6	18	37	36	91
137	3	56.0	60.7	46.7	163.4	22	51	46	119
137	4	58.7	57.7	48.6	165.0	9	31	39	79
137	5	66.0	49.6	47.9	163.5	7	-13	13	7

[1] N rates for crop 4 were: 1 = 0; 2 = 50; 3 = 100; 4 = 200; 5 = 300 lb N/A; for crops 5 and 6: 1 = 0; 2 = 30; 3 = 60; 4 = 120; 5 = 240 lb N/A.

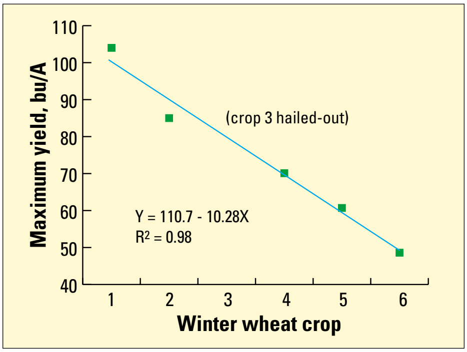

Figure 3. Change in maximum wheat yield with each additional crop of winter wheat.

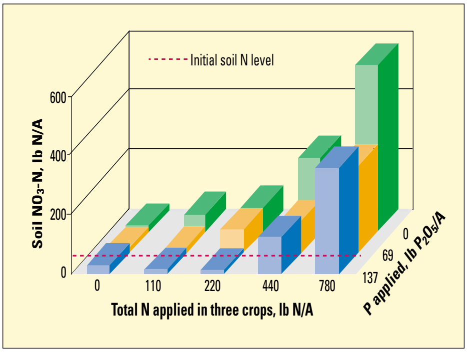

Figure 4. Residual soil NO_3-N level (0- to 4-ft. depth) after harvest of sixth wheat crop.

estimated net return to fertilization was greatest with the application of 60 lb N/A and the 137 lb/A P_2O_5 rate. Over the three-year period, cumulative net profits were greatest with the total application of 110 lb N/A and 69 lb P_2O_5/A. At the 137 lb/A P_2O_5 rate, the highest net return was with the total application of 220 lb N/A in three years. Continued cropping of the plots for several more years would more than likely have resulted in the greatest net return being with the 137 lb/A P_2O_5 rate. **Figure 2** shows that the one time application of P fertilizer improved soil test P levels for several years, with the 137 lb/A P_2O_5 rate still testing in the medium range the third crop year after P fertilization.

Maximum grain yields declined with each additional year of continuous winter wheat production on the plot area used in this study. **Figure 3** shows the decline in maximum grain yield attained each crop year. Downy brome grass competition increased with each additional year of winter wheat and with N and P fertilization. However, the downy brome was chemically controlled the last crop year, so competition with the wheat was minimized. In addition to the downy brome problem, other factors such as phytotoxic or allelopathic effects of the wheat residues on the next wheat crop may have contributed to the declining wheat yields. These observations show the importance of crop rotation as well as a good fertility program in maintaining optimum crop yields.

Application of P not only improved grain yields, but also improved N use efficiency. The residual soil NO_3-N levels in the 0- to 4-ft. profile after harvest of the last crop were lower with than without P fertilization (**Figure 4**). Note the large increase in residual soil NO_3-N when N application rates exceeded those needed for optimum grain yield (application of 440 and 780 lb N/A in three crops). Soil testing to determine N and P fertilization needs before nutrient application is important to optimizing yields and nutrient use efficiency and for protecting the environment from excess nutrient application. BC

Dr. Halvorson and Mr. Reule are with USDA-ARS, P.O. Box E, Fort Collins, CO 80522. E-mail: adhalvor@lamar.colostate.edu Ph: 970-490-8230.

The U.S. Department of Agriculture offers its programs to all eligible persons regardless of race, color, age, sex, or national origin and is an equal opportunity employer.

Site-Specific Nutrient Management... *(continued from page 13)*

for no supplemental P or K. However, with more intensive sampling and yield goal assessment, approximately 73 acres (46 percent) were identified as needing additional P, and 76 acres (48 percent) required additional K. The recommended rates per acre for each management zone are shown in **Figure 4**.

Total field requirements of 4,740 lb of P_2O_5 and 4,895 lb of K_2O were identified by the zone management plan, but were missed by whole field sampling and yield goal determination.

These two examples demonstrate the possibilities of precision agriculture in refining nutrient management. How often such disparities exist between whole-field and site-specific nutrient management has not been well assessed in many regions. Fields with known "hotspots" or areas with very high soil test levels are currently considered good candidates. The range in soil test levels is also important. Variability occurring at levels higher than those requiring additional nutrients is not cost-effective for site-specific nutrient management. However, wide ranges that include soil test levels requiring additional nutrients are thought to benefit from more refined approaches. BC

Dr. H.F. Reetz, Jr. is PPI Midwest Director, located at Monticello, Illinois; e-mail hreetz@ppi-far.org. Dr. T.S. Murrell is PPI Northcentral Director, located at Woodbury, Minnesota; e-mail smurrell@ppi-far.org. Mr. L.J. Murrell is Agronomist for The Andersons, located at Walton, Indiana.