Reprinted from the *Soil Science Society of* [illegible]
Volume 49, no. 4, July–August 1985
677 South Segoe Rd., Madison, WI 53711 USA

Fertilizer Phosphorus Recovery After Seventeen Years of Dryland Cropping[1]

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ABSTRACT

Information on long-term fertilizer P recovery by grain crops from a single broadcast application in the northern Great Plains is limited. Uptake of P by grain and straw was measured in 10 or 11 crops (1967 or 1968 to 1983) grown on a Williams loam (fine-loamy, Typic Argiborolls) in a split-plot, randomized complete block experiment. Fertilizer N, as main plots, was applied each crop year, except two, at rates of 0, 45, and 90 kg N/ha. Concentrated superphosphate P fertilizer (subplots) was applied only once, at study initiation, at rates of 0, 22, 45, 90, and 180 kg P/ha. The first six wheat crops (*Triticum aestivum*) were grown in a crop-fallow system and the last four or five crops, including wheat, barley (*Hordeum vulgare*), and safflower (*Carthamus tinctorius* L.), in an annual cropping system. Average P uptake in the grain (21 crops) was 6.4, 7.2, 8.0, 9.1, and 10.0 kg P/ha per crop for the 0, 22, 45, 90, and 180 kg P/ha treatments, respectively, over all N levels. Average P uptake in straw (21 crops) was 0.6, 0.7, 0.9, 1.0, and 1.2 kg P/ha per crop for the same respective P rates. Nitrogen fertilization generally decreased P uptake at low P rates (0 and 22 kg P/ha) but increased P uptake at high P rates (90 and 180 kg P/ha). Average P uptake in grain (21 crops) was 7.6, 8.4, and 8.4 kg P/ha per crop for the 0, 45, and 90 kg N/ha treatments, respectively, over all P rates. Fertilizer P recovery in the grain for the 22, 45, 90, and 180 kg P/ha treatments averaged 32, 25, 23, and 13%, respectively, without N fertilization and 45, 38, 37, and 24% with 45 kg N/ha. The results of this study suggest that a one-time broadcast application of P fertilizer at rates as high as 90 kg P/ha is an efficient way to meet crop needs and utilize P fertilizer resources.

Additional Index Words: **N fertilization, spring wheat, winter wheat, barley, safflower, P uptake, grain, straw, residual P.**

Halvorson, A.D., and A.L. Black. 1985. Fertilizer phosphorus recovery after seventeen years of dryland cropping. Soil Sci. Soc. Am. J. 49:933–937.

FEW P FERTILITY STUDIES have evaluated the long-term effects of a single, broadcast application of P fertilizer in the northern Great Plains. Sadler and Stewart (1974) provide a review of residual P research up to 1974. One and two year studies generally show relatively low recovery, < 25%, of P fertilizer applied. Longer-term P studies, 5 to 8 yr, such as those conducted by Campbell (1965), Read et al. (1977), Bailey et al. (1977), and Read et al. (1973) show improved recoveries with time. Bailey et al. (1977) obtained P fertilizer recoveries after eight crops of 30, 22, and 14% from one-time applications of 100, 200, and 400 kg P/ha, respectively. Alessi and Power (1980) showed recoveries of P fertilizer as high as 30% with broadcast applications of 20 kg P/ha and about 5% for 160 kg P/ha after six spring wheat crops.

Sadler and Stewart (1974) concluded that about 75% of the fertilizer P not used by the first crop remains in a chemical form available to succeeding crops. They projected that > 3 yr are needed for fertilizer P to be transformed to forms similar to native P minerals. Information on the long-term residual contribution to crop yields and P uptake from fertilizer P is needed to develop management systems for most efficient use of P fertilizer.

The objective of this study was to measure the recovery of P fertilizer in 10 or 11 crops grown over a period of 17 yr following a single, broadcast fertilizer P application under varying levels of available N.

Table 1. Cropping sequence followed from 1967 to 1983 on the plots receiving fertilizer P in 1967 or 1968.

	Crop†			Crop†	
Year	1967 Plot series	1968 Plot series	Year	1967 Plot series	1968 Plot series
1967	Spring wheat	Summerfallow	1976	Summerfallow	Spring wheat
1968	Summerfallow	Spring wheat	1977	Spring wheat	Summerfallow
1969	Spring wheat	Summerfallow	1978	Safflower	Winter wheat
1970	Summerfallow	Spring wheat	1979	Spring barley	Safflower
1971	Spring wheat	Summerfallow	1980	Winter wheat‡	Summerfallow§
1972	Summerfallow	Spring wheat	1981	Winter wheat	Spring barley
1973	Spring wheat	Summerfallow	1982	Spring barley	Spring wheat
1974	Summerfallow	Spring wheat	1983	Spring wheat	Winter wheat
1975	Spring wheat	Summerfallow			

† Spring wheat—*Triticum aestivum* L., Winter wheat—*Triticum aestivum* L., Spring barley—*Hordeum vulgare* L., Safflower—*Carthamus tinctorius* L.
‡ Winter wheat planted in September 1979, destroyed 20 June 1980 because of drought.
§ Chemically fallowed because of drought.

Table 2. Amount of fertilizer N applied each crop year.

1967 Plot series				1968 Plot series			
	Fertilizer N treatments				Fertilizer N treatments		
Crop year	N0	N1	N2	Crop year	N0	N1	N2
	kg N/ha				kg N/ha		
1967	0	45	90	1968	0	45	90
1969	0	45	90	1970	0	45	90
1971	0	45	90	1972	0	45	90
1973	0	45	90	1974	0	45	90
1975	0	45	90	1976	0	45	90
1977	0	45	90	1978	0	45	90
1978	0	0	0	1979	0	0	0
1979	34	34	34	1980‡	0	0	0
1980†	34	34	34	1981	0	0	0
1981	0	0	0	1982	0	45	90
1982	0	45	90	1983	0	45	90
1983	0	45	90				
Total	68	428	788	Total	0	360	720

† Crop destroyed on 20 June 1980 due to drought. Residue was soil incorporated.
‡ Crop not planted due to drought. Plots chemically fallowed.

[1] Contribution from USDA-ARS. Received 29 Oct. 1984. Approved 26 Feb. 1985.

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Table 3. Phosphorus uptake in grain each crop year as affected by available N level and by a single P fertilizer application in 1967.

P added	Crop year 1967	1969	1971	1973	1975	1977	1978	1979	1981	1982	1983	Avg
kg/ha	kg P/ha											
	Nitrogen†, N0											
0	6.1	5.0	9.5	4.1	10.4	4.0	4.7	4.3	8.4	5.9	5.2	6.1
22	6.5	4.7	10.6	4.7	12.3	4.5	6.0	4.5	9.5	5.4	4.6	6.7
45	7.3	7.0	12.5	4.4	12.0	4.3	7.5	5.2	9.8	5.7	4.7	7.3
90	8.0	7.1	13.6	4.9	14.9	5.6	8.8	4.7	11.3	5.5	5.4	8.2
180	8.5	6.6	14.4	5.3	13.2	5.5	9.7	6.3	12.0	5.2	6.1	8.4
Avg	7.3	6.1	12.1	4.7	12.6	4.8	7.3	5.0	10.2	5.5	5.2	7.3
	Nitrogen, N1											
0	6.2	5.6	8.8	4.2	11.4	3.2	7.3	3.4	8.2	7.1	5.6	6.5
22	6.9	6.6	10.0	3.8	11.7	3.0	9.6	4.5	8.4	7.4	5.1	7.0
45	7.5	7.9	11.1	4.0	11.9	3.8	8.1	4.8	8.9	7.4	6.3	7.4
90	8.5	9.4	12.5	5.5	15.8	4.8	9.9	6.0	10.0	8.8	6.8	8.9
180	9.5	8.9	15.6	6.0	16.9	4.4	9.8	5.2	11.4	9.6	7.0	9.5
Avg	7.7	7.7	11.6	4.7	13.5	3.8	8.9	4.8	9.4	8.1	6.2	7.9
	Nitrogen, N2											
0	5.6	6.3	8.8	4.1	8.4	2.9	8.6	3.7	8.1	6.8	7.4	6.4
22	7.0	6.8	10.8	3.8	11.5	3.3	9.1	4.8	8.0	7.0	6.5	7.1
45	7.7	8.8	14.1	4.4	13.0	3.5	8.7	4.5	8.9	7.4	7.0	8.0
90	8.7	9.5	12.9	5.1	16.2	4.4	8.7	6.4	10.5	9.3	6.6	8.9
180	9.3	10.6	15.4	5.6	16.0	4.3	10.0	6.1	12.2	10.5	7.8	9.8
Avg	7.7	8.4	12.4	4.6	13.0	3.7	9.0	5.1	9.5	8.2	7.1	8.1
LSD (0.05)												
Avg N rates	NS	1.1	NS	NS	0.5	0.3	NS	NS	NS	0.7	1.5	0.3
Avg P rates	0.5	1.1	1.4	0.3	0.6	0.3	1.1	0.5	1.0	0.6	NS	0.2
N × P	NS	NS	NS	0.5	1.1	NS	1.9	0.8	NS	1.1	NS	0.6

† See Table 2 for N amount applied each crop year.

Table 4. Phosphorus uptake in grain each crop year as affected by available N level and by a single P fertilizer application in 1968.

P added	Crop year 1968	1970	1972	1974	1976	1978	1979	1981	1982	1983	Avg
kg/ha	kg P/ha										
	Nitrogen†, N0										
0	7.3	5.7	10.1	6.0	8.2	6.4	4.7	8.0	6.1	5.0	6.7
22	10.5	6.2	9.4	7.7	10.1	7.6	5.0	7.4	6.2	5.1	7.5
45	10.9	7.3	10.4	7.2	11.2	8.8	5.1	8.1	5.3	2.8	7.7
90	12.0	7.7	11.5	8.4	11.5	11.6	5.1	7.6	5.5	4.8	8.6
180	12.4	9.4	13.5	7.8	11.9	11.8	4.9	8.1	5.3	3.2	8.8
Avg	10.6	7.2	11.0	7.4	10.6	9.3	5.0	7.8	5.7	4.2	7.9
	Nitrogen, N1										
0	5.8	4.9	8.3	5.8	9.8	5.3	3.9	6.8	7.3	4.5	6.2
22	9.0	7.1	9.3	6.5	10.0	6.6	5.3	8.0	8.7	5.5	7.6
45	11.9	8.0	9.3	8.5	12.4	9.4	5.1	7.9	8.5	5.0	8.6
90	13.4	9.5	13.1	9.5	15.1	13.1	5.3	8.2	8.7	5.8	10.2
180	15.1	10.9	14.5	10.2	17.5	15.3	5.9	10.1	9.7	7.4	11.7
Avg	11.0	8.1	10.9	8.1	13.0	9.9	5.1	8.2	8.6	5.6	8.9
	Nitrogen, N2										
0	6.1	4.5	8.5	5.4	11.5	5.9	4.3	7.0	7.6	4.6	6.5
22	9.0	6.3	8.5	6.1	11.9	7.1	3.9	7.3	7.6	4.5	7.2
45	10.9	7.6	11.6	8.2	13.1	9.5	4.6	7.7	7.9	5.0	8.6
90	12.4	11.2	12.3	9.5	14.1	12.2	5.1	6.7	7.9	4.5	9.6
180	14.4	11.1	15.5	9.2	16.5	17.2	6.4	8.4	10.3	5.8	11.5
Avg	10.6	8.1	11.3	7.7	13.4	10.4	4.9	7.4	8.2	4.9	8.7
LSD (0.05)											
Avg. N Rates	0.2	0.8	NS	0.4	0.7	NS	NS	0.4	1.6	0.7	0.3
Avg P Rates	0.9	1.5	1.2	0.5	1.1	0.9	0.6	0.9	0.8	NS	0.3
N × P	1.6	NS	NS	0.8	1.8	1.6	1.1	1.7	1.4	NS	0.7

† See Table 2 for N amount applied each crop year.

METHODS AND MATERIALS

The study was conducted near Culbertson, MT on a glacial till Williams loam (fine-loamy mixed, Typic Argiborolls) with a 2 to 4% slope. Alternate spring wheat-fallow plots were established on fallow in 1967 and 1968, with one set of plots being fallowed and the other cropped each year through 1978. The two plot series were about 10-m apart. After the sixth crop, the plots were annually cropped. The cropping sequence followed is shown in Table 1.

The experimental design was a split-plot, randomized complete block with three replications. The main plots were ammonium nitrate broadcast at rates of 0, 45, and 90 kg N/ha (N0, N1, N2, respectively) each crop year, except two (Table 2). Nitrogen fertilizer was not applied these two years because of a build up of residual NO_3–N in the soil profile of the 45 and 90 kg N/ha treatments (Halvorson and Black, 1985a). The subplots were concentrated superphosphate broadcast once at study initiation at rates of 0, 22, 45, 90, and 180 kg P/ha. Both the N and P fertilizers were incorporated in the 0- to 8-cm soil depth with a tandem disk prior to planting. All tillage operations in either cropping system were performed at a relatively shallow depth of 8 to 10 cm. No N or P fertilzer had been applied to the plot area prior to 1967. The soil had a sodium bicarbonate-extractable P level (Olsen et al., 1954) of 6 mg P/kg soil at study initiation.

Grain and straw samples were collected at maturity for plant P analysis. The samples were dried at 70°C for 36 h, ground to pass through a 0.425-mm screen and digested with a 3:1 mixtue of perchloric/sulfuric acids. Prior to 1973, P concentration was determined by a manual colorimetric method (Chapman and Pratt, 1961) and after 1973 by an autoanalyzer method (Technicon, 1973). Yield data used to calculate P uptake has been reported by Black (1982) and Halvorson and Black (1985b). All differences discussed as significant were evaluated at the 95% confidence level unless otherwise stated.

Phosphorus fertilizer recovery in grain was calculated using the following equation:

$$\% \text{ P recovery} = [(TP_f - TP_c)/P] \times 100$$

where TP_f and TP_c = total P uptake in grain from fertilized and corresponding control (no P fertilizer) plots, respectively, and P = total fertilizer P applied.

RESULTS AND DISCUSSION

Phosphorus uptake by grain each crop year, except 1983, was significantly increased by the one-time fertilizer P applications made in 1967 or 1968 (Tables 3 and 4). The average P uptake in grain per crop was 6.3, 6.9, 7.6, 8.7, and 9.2 kg P/ha for the 1967 plot series and 6.5, 7.5, 8.3, 9.4, and 10.7 kg P/ha for the 1968 plot series for the 0, 22, 45, 90, and 180 kg P/ha fertilizer treatments, respectively. The lack of a significant difference in P uptake in 1983 from residual P fertilizer was attributed to a severe drought in late 1982, extending through 1983, which reduced grain yields (Halvorson and Black, 1985b).

Nitrogen fertilization (N1 or N2 treatments) significantly increased P uptake by grain over the no fertilizer N treatment, when averaged over the duration of the study. Even though the effect of N fertilization was not significant every crop year, the general trend in those years was for N fertilization to increase P uptake. Nitrogen fertilization had a positive effect on P uptake by grain 45 and 70% of the time for the 1967 and 1968 plot series, respectively (Tables 3 and 4). At low P rates (0 and 22 kg P/ha), P uptake usually was reduced with N fertilization because the P deficiency

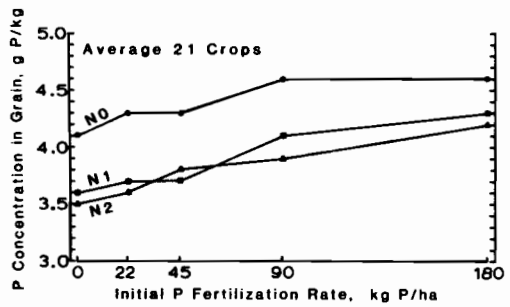

Fig. 1. Average P concentration in grain (21 crops) as a function of N and P fertilization.

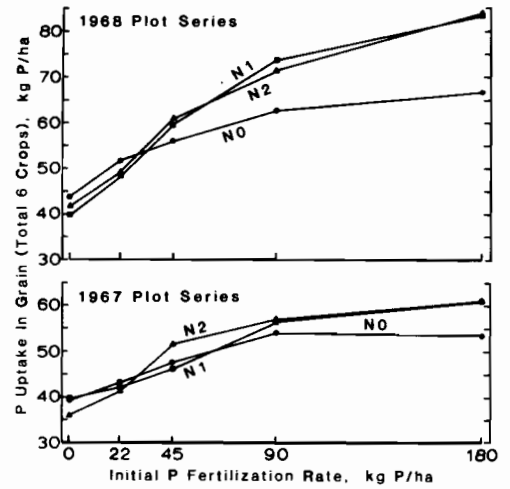

Fig. 2. Total accumulated P uptake in grain by the first six crops of the 1967 and 1968 plots series as a function of N and P fertilizer treatment in a crop-fallow system.

was accentuated, while at higher rates (90 and 180 kg P/ha) where P was adequate or near adequate, N fertilization increased P uptake. This accounts for the N × P interactions.

Phosphorus uptake varied significantly among years (Tables 3 and 4) and yr × N and yr × P interactions were significant. The magnitude of P uptake, as affected by N and P fertilization, reflect the variable yields obtained from year to year due to varying climatic conditions (Black, 1982; Halvorson and Black, 1985b).

The influence of N and P fertilization on average P concentration in the grain (21 crops) is shown in Fig. 1. The P concentration in the grain varied significantly from year to year, but generally increased as P rates increased, and decreased as N rates increased. The average P concentration in the grain over all years and fertility treatments was 4.0 g P/kg for both plot series and for both the crop-fallow and annual cropping systems.

Total P uptake in grain by the first six crops (crop-fallow sequence) was significantly increased as P fertilization rate increased (Fig. 2). Nitrogen fertilization significantly increased total P uptake at P fertilization rates > 45 kg P/ha on the 1968 plot series but not on the 1967 plot series, although, the N × P interaction was significant for both plot series. The interaction occurred because N fertilization generally reduced P uptake at the 0 and 22 kg P/ha fertilizer levels and increased P uptake at the 90 and 180 kg P/ha levels.

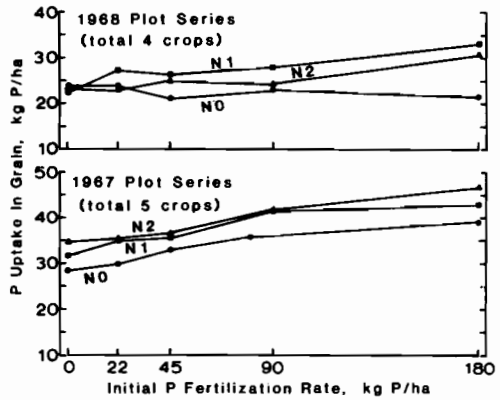

Fig. 3. Total accumulated P uptake in grain by the last five crops (1967 plot series) and four crops (1968 plot series) as a function of N and P fertilizer treatment with annual cropping.

Although N fertilization decreased the concentration of P in the grain, the increase in grain yields at the higher P rates with N fertilization more than offset the decrease in P concentration in the grain; consequently, increased P uptake with N fertilization at high P levels.

Total P uptake in grain of the last four or five crops (annual cropping sequence) increased with increasing levels of residual P fertilizer, with and without N fertilization, for the 1967 plot series, but only with N fertilization for the 1968 plot series (Fig. 3). Grain yields without N fertilization tended to decline with increasing level of P fertilization for the last four crops on the 1968 plot series (Halvorson and Black, 1985b). Consequently, P uptake decreased slightly with increasing P level without N fertilization for the 1968 plot series (Fig. 3.).

General trends for P uptake in straw were similar to those observed for grain (Tables 5 and 6). The one-time applications of P fertilizer had a positive effect on P uptake in straw each year except 1981 and 1982 for the 1967 plot series and 1979 for the 1968 plot series. Over all N rates, P uptake averaged 0.6, 0.7, 0.9, 1.0, and 1.2 kg P/ha per crop for the 1967 plot series and 0.5, 0.7, 0.8, 1.0, and 1.2 kg P/ha per crop for the 1968 plot series for the 0, 22, 45, 90, and 180 kg P/ha fertilizer treatments, respectively.

Averaged over all years, N fertilization significantly increased the level of P uptake in straw (Tables 5 and 6). The significant N × P interactions generally resulted because of greater increases in straw yields with increasing P levels with N fertilization than without N fertilization, consequently greater P uptake with N fertilization. Phosphorus uptake in the straw was only about 10 to 11% of that in grain. Since the straw was not removed from the plots, P in the straw was returned to the soil-plant system to be recycled. Although not measured, soil P availability may have been improved at the higher N and P fertility levels by the return of greater amounts of residue with higher P concentrations to the soil-plant system (Chauhan et al., 1979 and 1981; Hedley et al., 1982).

Estimated Recovery of P Fertilizer

Cumulative P uptake in grain by 11 crops (1967 plot series) and 10 crops (1968 plot series) increased with increasing rates of P application (Table 7). Nitrogen

Table 5. Phosphorus uptake in straw each crop year as affected by available N level and by a single P fertilizer application in 1967.

P added	Crop year 1967	1969	1971	1973	1975	1977	1978	1979	1981	1982	1983	Avg
kg/ha	kg P/ha											
	Nitrogen†, N0											
0	1.4	0.5	0.3	0.1	0.3	0.4	0.4	0.3	1.6	0.9	0.3	0.6
22	1.7	0.6	0.4	0.1	0.4	0.5	0.7	0.3	1.5	0.6	0.4	0.7
45	1.8	0.8	0.6	0.1	0.5	0.7	0.8	0.4	2.1	1.0	0.5	0.8
90	2.1	1.0	0.6	0.1	0.5	0.5	0.7	0.5	1.4	0.8	0.6	0.8
180	2.5	1.2	0.8	0.1	0.7	0.2	1.0	0.6	1.6	1.1	0.8	1.0
Avg	1.9	0.8	0.5	0.1	0.5	0.5	0.7	0.4	1.6	0.9	0.5	0.8
	Nitrogen, N1											
0	1.5	0.5	0.4	0.1	0.6	0.4	0.9	0.3	1.5	0.4	0.4	0.6
22	2.1	0.8	0.5	0.1	0.5	0.3	1.4	0.3	0.9	0.7	0.3	0.7
45	2.0	0.8	0.5	0.1	0.6	0.3	1.2	0.3	1.5	0.8	0.3	0.8
90	2.9	1.1	0.7	0.1	0.7	0.6	1.5	0.4	1.4	1.2	0.5	1.0
180	4.3	1.4	0.8	0.1	1.1	0.6	1.7	0.5	1.4	0.6	0.4	1.2
Avg	2.6	0.9	0.6	0.1	0.7	0.4	1.3	0.4	1.4	0.7	0.4	0.9
	Nitrogen, N2											
0	1.9	0.6	0.4	0.1	0.4	0.2	1.4	0.3	1.3	0.8	0.4	0.7
22	2.3	0.5	0.4	0.1	0.5	0.4	1.1	0.3	1.4	1.0	0.4	0.8
45	3.2	0.7	0.8	0.1	0.6	0.3	1.6	0.4	1.8	1.1	0.4	1.0
90	4.7	1.1	0.8	0.1	0.8	0.4	1.5	0.5	1.4	0.9	0.4	1.2
180	4.2	1.4	1.2	0.3	1.1	0.5	1.7	0.5	2.3	0.7	0.7	1.3
Avg	3.3	0.9	0.7	0.1	0.7	0.4	1.5	0.4	1.6	0.9	0.5	1.0
LSD (0.05)												
Avg N Rates	0.4	NS	NS	NS	0.2	<0.1	0.4	<0.1	NS	NS	NS	0.1
Avg P Rates	0.4	0.3	0.2	<0.1	0.1	<0.1	0.3	0.1	NS	NS	0.1	0.1
N × P	0.7	NS	NS	NS	0.1	<0.1	NS	NS	NS	NS	NS	0.2

† See Table 2 for N amount applied each crop year.

Table 6. Phosphorus uptake in straw each crop year as affected by available N level and by a single P fertilizer application in 1968.

P added	Crop year 1968	1970	1972	1974	1976	1978	1979	1981	1982	1983	Avg
kg/ha	kg P/ha										
	Nitrogen†, N0										
0	1.3	0.3	0.3	0.2	0.5	0.8	0.7	0.5	0.5	0.2	0.5
22	2.1	0.2	0.2	0.2	0.6	0.8	0.6	0.8	0.4	0.3	0.6
45	2.3	0.2	0.3	0.2	0.7	0.7	1.2	0.8	0.5	0.3	0.7
90	2.8	0.2	0.4	0.2	0.7	0.8	1.0	0.8	0.7	0.3	0.8
180	3.3	0.3	0.4	0.3	0.8	1.0	1.2	1.2	0.7	0.4	1.0
Avg	2.3	0.3	0.3	0.2	0.6	0.8	0.9	0.8	0.6	0.3	0.7
	Nitrogen, N1										
0	1.2	0.2	0.3	0.1	0.5	0.6	0.7	0.9	0.4	0.3	0.5
22	2.6	0.2	0.3	0.2	0.5	0.8	0.7	1.0	0.5	0.4	0.7
45	3.2	0.2	0.3	0.3	0.8	1.1	0.6	0.9	0.4	0.3	0.8
90	4.3	0.2	0.4	0.3	1.1	1.2	0.7	1.3	0.6	0.3	1.0
180	5.8	0.4	0.6	0.4	2.0	1.2	0.7	1.1	0.6	0.5	1.3
Avg	3.4	0.3	0.4	0.3	1.0	1.0	0.7	1.0	0.5	0.4	0.9
	Nitrogen, N2										
0	1.3	0.1	0.3	0.2	0.6	0.8	0.7	0.5	0.4	0.4	0.5
22	2.7	0.1	0.3	0.2	0.7	0.7	0.6	0.8	0.4	0.3	0.7
45	3.7	0.2	0.5	0.2	0.7	1.3	0.6	0.8	0.6	0.4	0.9
90	5.7	0.3	0.4	0.3	1.1	1.2	0.7	0.9	0.5	0.3	1.1
180	6.0	0.2	0.6	0.4	1.8	1.5	0.7	1.7	0.9	0.5	1.4
Avg	3.9	0.2	0.4	0.3	1.0	1.1	0.7	0.9	0.5	0.4	0.9
LSD (0.05)											
Avg N Rates	0.1	NS	NS	<0.1	0.3	0.1	NS	NS	NS	NS	0.1
Avg P Rates	0.3	0.1	0.1	<0.1	0.2	0.1	NS	0.3	0.2	0.1	0.1
N × P	0.4	0.1	0.1	NS	0.3	0.2	NS	NS	NS	NS	0.1

† See Table 2 for N amount applied each crop year.

fertilization significantly increased the amount of total P uptake by crops of the 1968 plot series, but not the 1967 series, although the general trends for both the 1967 and 1968 plot series were similar. The N × P interaction was significant for the 1968 plot series, as a result of a greater amount of P uptake with increasing P fertility level with N fertilization than without N fertilization.

Phosphorus fertilizer recovery in grain ranged from a high of 38% (N1 + 45 kg P/ha treatment) to a low of 14% (N0 + 180 kg P/ha treatment) for the 1967 plot series (Table 7). When averaged over all N treatments, P fertilizer recovered in the grain was 30, 30, 29, and 18% for the 22, 45, 90, and 180 kg P/ha treatments, respectively.

Although fertilizer P recovery in grain decreased with increasing P application rate, N fertilization did increase P recovery at P fertilizer rates > 22 kg P/ha for the 1968 plot series (Table 7). For the 1968 plot series, the highest level of P recovery in grain (62%) occurred with the N1 + 22 kg P/ha treatment and the lowest level with the N0 + 180 kg P/ha treatment (12%). What appears to be a higher than expected P recovery at the N1 level (62%) and lower than expected P recovery at the N2 level (30%) for the 22 kg P/ha treatments of the 1968 plot series may be the result of cumulative variations in P uptake data with time, especially at the low P rates (0 and 22 kg P/ha). When averaged over all N treatments, P fertilizer recovered in the grain was 43, 40, 33, and 23% for the 22, 45, 90, and 180 kg P/ha treatments, respectively. Recoveries of P fertilizer in grain tended to be higher for the 1968 plot series (10 crops) than for the 1967 plot series (11 crops) because grain yields for the 1968 plot series tended to be higher during the first six crops due to wetter growing seasons and larger responses to N fertilization in those years (Black, 1982; Halvorson and Black, 1985b).

Fertilizer P recoveries found in this study are in agreement with those reported by others (Alessi and Power, 1980; Bailey, et al., 1977; Read et al., 1973 and 1977; Sadler and Stewart, 1974) for northern Great Plains dryland conditions. Although this study was conducted for a longer time period than most studies, the P recoveries at the higher P rates (> 45 kg P/ha) were < 50% of that applied. Many more crops would have to be grown on these plots to recover a larger proportion of the P fertilizer applied. Recovery of fertilizer P was still increasing at the higher P rates through harvest of the last crop in 1983.

Recovery of P fertilizer in grain was less per crop in the annual cropping system (last four or five crops) than with the crop-fallow system (first six crops). Average P uptake in grain per crop year without N fertilization was 6.9, 7.9, 8.6, 9.8. and 10.0 kg P/ha for the crop-fallow and 5.9, 6.0, 6.0, 6.5, and 6.7 kg P/ha for the annual cropping systems for the 0, 22, 45, 90, and 180 kg P/ha treatments, respectively. For these same respective P treatments with N fertilization (average of N1 and N2 treatments), P uptake in grain averaged 6.6, 7.6, 9.1, 10.8, and 12.1 kg P/ha per crop for the crop-fallow and 6.2, 6.7, 6.8, 7.4, and 8.5 kg P/ha per crop for the annual cropping systems. The differences in P uptake in grain between cropping systems became greater as the level of P application increased, basically as a result of greater grain yields with increasing P levels in the crop-fallow than the

Table 7. Cumulative P uptake and fertilizer P recovery in grain from the 1967 and 1968 plot series as affected by available N level and a single application of P fertilizer.

	1967 Series (11 crops)		1968 Series (10 crops)	
P added	Uptake†	Recovery	Uptake‡	Recovery
kg/ha	kg P/ha	%	kg P/ha	%
	Nitrogen treatment, N0			
0	67.5	–	67.5	–
22	73.4	27	75.4	36
45	80.6	29	77.1	21
90	89.7	25	85.8	20
180	92.7	14	88.4	12
Avg	80.8	–	78.8	–
	Nitrogen treatment, N1			
0	71.1	–	62.3	–
22	77.1	27	76.0	62
45	81.6	23	86.0	53
90	98.0	30	101.7	44
180	104.2	18	116.7	30
Avg	86.4	–	88.5	–
	Nitrogen treatment, N2			
0	70.7	–	65.4	–
22	78.6	36	72.1	30
45	88.0	38	86.0	46
90	98.4	31	95.8	34
180	107.8	21	114.7	27
Avg	88.7	–	86.8	–
LSD (0.05)				
N rate	NS		6.3	
P rate	3.5		4.3	
N × P interaction	NS		7.5	

† Cumulative uptake 1967 to 1983.
‡ Cumulative uptake 1968 to 1983.

annual cropping system, both with and without N fertilization, and lower levels of available soil P with time (Halvorson and Black, 1985b). This is supported by the fact that the P concentration in the grain averaged the same for both cropping sequences, 4.0 g P/kg grain.

Although fertilizer P recoveries were generally < 50% after 17 yr of dryland cropping, a one-time broadcast application of P fertilizer at rates as high as 90 kg P/ha appears to be an efficient way to meet crop P needs and utilize P fertilizer resources. This is supported by the fact that the 90 and 180 kg P/ha treatment with N fertilization had the greatest accumulated grain yields above that of the check plot for the duration of this study (Halvorson and Black, 1985b).

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