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# Long-term Dryland Crop Responses to Residual Phosphorus Fertilizer

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# Long-term Dryland Crop Responses to Residual Phosphorus Fertilizer[1]

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## ABSTRACT

**Little information is available on the long-term effects of a single P fertilizer application on grain yields of crops grown on dryland soils deficient in plant-available P. Therefore, duplicate plots were established in 1967 and 1968 on a Williams loam (fine-loamy mixed, Typic Argiborolls) with a $NaHCO_3$–extractable P of 6 mg P/kg soil. A split-plot, randomized complete block design was used with three levels of available N (generally 0, 45, and 90 kg N/ha each crop year) as main plots and a one time application of P fertilizer at rates of 0, 22, 45, 90, and 180 kg P/ha as subplots. During the first crop year, application of 22, 45, 90, and 180 kg P/ha raised the average soil test P levels to 9, 12, 26, and 40 mg P/kg soil, respectively. Soil test P levels 16 yr after P fertilization and 10 or 11 crops harvested avg 5, 6, 7, 9, and 13 mg P/kg soil in 1983 for these same respective P treatments. Soil test P levels declined progressively with each additional crop year until the eighth crop or 13 yr after P application, at which time a new soil P equilibrium level appeared to be developing. Grain yields generally increased with increasing residual soil P level when adequate levels of N, either residual or applied, were present. However, no response to increasing residual soil P level was observed under annual cropping without adequate N. Accumulated grain yields after 10 or 11 crops were about three times greater with both N and P fertilization than with P fertilization alone. The study verifies that adequate available N is required to derive benefit from residual P fertilizer. The long-term (16 yr) residual benefits from P fertilization suggest a method for possibly satisfying the P needs for several crop years in reduced and no-tillage systems, if the P is applied and incorporated before initiation of these tillage systems.**

***Additional Index Words:*** **spring wheat, winter wheat, barley, safflower, N fertilization, residual N, bicarbonate-extractable P, annual cropping, grain yield.**

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CROP YIELDS are generally increased by phosphorus (P) fertilization in the northern Great Plains on glacial till soils inherently low in plant-available P (Alessi and Power, 1980; Black, 1970 and 1982; Snider et al., 1968). Increases in grain yields and P uptake due to residual P fertilizer have been reported to last for six to eight crops in the northern Great Plains (Alessi and Power, 1980; Bailey et al., 1977; Black, 1982; Read et al., 1973 and 1977; Sadler and Stewart, 1974). However, information from residual P fertilizer studies conducted for more than eight crop years is limited.

This study is a 6-yr continuation of a residual P fertilizer study initiated in 1967 by Black (1982) using a crop-fallow system and continued using an annual cropping system. The purposes of this paper are to report (i) the changes in $NaHCO_3$–extractable soil P from 1967 to 1983; (ii) the effects of residual fertilizer P levels on grain yields of several crops grown annually with and without N fertilization; and (iii) the long-term influence of N and P fertilization on accumulative grain yields.

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**Table 1. Cropping sequence, seeding and harvest dates, growing season precipitation, available soil water, and total available water for the 1967 and 1968 plot series.**

| Year | Crop† | Cultivar | Seeding date | Harvest date | Growing season precip. | Soil water‡ | Total avail. water |
|---|---|---|---|---|---|---|---|
| | | | mo-d-yr | | mm | | |
| | | | 1967 Plot series | | | | |
| 1967 | Sp. wheat | Fortuna | 5-12-67 | 8-08-67 | 83 | 160 | 245 |
| 1969 | Sp. wheat | Fortuna | 4-23-69 | 8-07-69 | 173 | 193 | 366 |
| 1971 | Sp. wheat | Manitou | 4-30-71 | 8-03-71 | 140 | 171 | 311 |
| 1973 | Sp. wheat | Fortuna | 5-01-73 | 8-02-73 | 113 | 163 | 276 |
| 1975 | Sp. wheat | Olaf | 5-15-75 | 8-13-75 | 294 | 177 | 471 |
| 1977 | Sp. wheat | Olaf | 4-22-77 | 8-02-77 | 61 | 165 | 226 |
| 1978 | Safflower | S-208 | 4-20-78 | 9-22-78 | 452 | 165 | 617 |
| 1979 | Sp. barley | Hector | 5-15-79 | 8-15-79 | 88 | 153 | 241 |
| 1980 | W. wheat§ | Roughrider | 9-14-79 | destroyed | 92 | 45 | 137 |
| 1981 | W. wheat | Roughrider | 9-09-80 | 8-08-81 | 262 | 99 | 361 |
| 1982 | Sp. barley | Hector | 5-06-82 | 8-10-82 | 192 | 127 | 319 |
| 1983 | Sp. wheat | Lew | 4-28-83 | 8-10-83 | 186 | 141 | 327 |
| | | | 1968 Plot series | | | | |
| 1968 | Sp. wheat | Fortuna | 4-19-68 | 8-05-68 | 158 | 172 | 330 |
| 1970 | Sp. wheat | Era | 5-18-70 | 8-18-70 | 221 | 191 | 412 |
| 1972 | Sp. wheat | Fortuna | 4-27-72 | 8-16-72 | 289 | 164 | 453 |
| 1974 | Sp. wheat | Olaf | 4-24-72 | 8-06-74 | 200 | 160 | 360 |
| 1976 | Sp. wheat | Fortuna | 4-27-76 | 8-02-76 | 315 | 193 | 508 |
| 1978 | W. wheat | Roughrider | 9-13-77 | 7-25-78 | 363 | 165 | 528 |
| 1979 | Safflower | S-208 | 5-14-79 | 9-21-79 | 99 | 185 | 284 |
| 1980 | Fallow | – | – | – | – | 37 | – |
| 1981 | Sp. barley | Hector | 4-29-81 | 8-17-81 | 258 | 118 | 376 |
| 1982 | Sp. wheat | Len | 5-07-82 | 8-26-82 | 192 | 101 | 293 |
| 1983 | W. wheat | Norstar | 9-13-82 | 7-27-83 | 181 | 130 | 311 |

† Spring wheat—*Triticum aestivum* L., Winter wheat—*Triticum aestivum* L., Spring barley—*Hordeum vulgare* L., Safflower—*Carthamus tinctorius* L.
‡ Available soil water (0- to 150-cm depth) measured in April or May.
§ Winter wheat growing season precipitation from April 1 to harvest.

## MATERIALS AND METHODS

The study was conducted near Culbertson, MT on a glacial till Williams loam (fine-loamy mixed, Typic Argiborolls) on identical sets of plots located about 10-m apart, one established in 1967 and one in 1968, on fallow. After the sixth crop in a crop-fallow sequence (1967–68 to 1977–78) reported by Black (1982), the plots were annually cropped. Table 1 reports the cropping sequence, crop cultivar, growing season precipitation, soil water level for each year, and planting and harvest dates for the entire sequence.

The experimental design was a split-plot, randomized complete block, with three replications. The N fertilizer (ammonium nitrate) treatments of 0, 45, and 90 kg N/ha (N0, N1, and N2, respectively) were main plots with P rates of 0, 22, 45, 90, and 180 kg P/ha, as subplots. Fertilizer P (concentrated superphosphate) was applied only once to each P treatment at initiation of each plot series in 1967 or 1968. The fertilizer P was broadcast and incorporated into the soil with a disk. The N treatments were applied each crop year during the crop-fallow cropping sequence. Due to an accumulation of residual N in the soil profile in the N1 and N2 treatments after the first six crops (Halvorson and Black, 1985a), N fertilizer was not applied in 1978 or 1979 to the seventh crop. Residual soil $NO_3^-$–N levels for several sampling dates are reported for the N0, N1, and N2 treatments of the 1967 and 1968 series in Table 2. All plots of the 1967 series received 34 kg N/ha in the spring of 1979 and 1980

**Table 2. Average soil $NO_3^-$-N levels at several sampling dates for the N0, N1, and N2 treatments of the 1967 and 1968 plot series.**

| Date | Plot series | Soil $NO_3^-$-N (0 to 120-cm depth) | | |
|---|---|---|---|---|
| | | N0 | N1 | N2 |
| | | kg N/ha | | |
| 6 Sep. 1977 | 1967 | 51 | 89 | 188 |
| 6 Oct. 1978 | 1967 | 11 | 16 | 79 |
| 21 Apr. 1981 | 1967 | 97 | 116 | 172 |
| 4 May 1982 | 1967 | 25 | 34 | 76 |
| 8 Apr. 1983 | 1967 | 16 | 35 | 96 |
| 6 Oct. 1978 | 1968 | 18 | 57 | 185 |
| 21 Apr. 1981 | 1968 | 177 | 187 | 263 |
| 4 May 1982 | 1968 | 28 | 62 | 128 |
| 8 Apr. 1983 | 1968 | 17 | 68 | 172 |

(Table 3). No fertilizer N was applied in 1981 because the 1980 crop was not harvested due to drought and a considerable amount of soil $NO_3^-$-N was present at seeding (Table 2). Nitrogen fertilizer was not applied to crop on the 1968 plot series because the plots were fallowed in 1980 due to drought. Fertilizer N was applied at the indicated rates for N1 and N2 to the last two crops in both series. When applied, the fertilizer N was broadcast and incorporated into the 0- to 8-cm soil depth with a tandem disk prior to seeding.

Soil water was measured gravimetrically in 30-cm increments to a depth of 1.5 m in April or May each crop year. Soil samples were collected in April or May each crop year from the 0- to 15-cm depth for determination of $NaHCO_3$-extractable P (Olsen et. al., 1954) using the ascorbic acid colorimetric technique (Watanabe and Olsen, 1965). Soil samples were collected in 30-cm increments to 120-cm depth at several dates from both series for measurement of $NO_3^-$-N (Table 2).

A plot combine was used to harvest a 1.5- by 5-m area from each plot at maturity for determination of grain yield in the annual cropping systems. Two or three 2.4-m segments of row were harvested at maturity from each plot for estimating straw yield.

All differences stated as significant were evaluated at the 95% confidence level unless otherwise indicated. A split-split plot analysis of variance was used to evaluate the effects of years (Little and Hill, 1978).

## RESULTS AND DISCUSSION

### Changes in Soil Test P Levels

Initial rates of P fertilizer application were directly correlated with measured soil test P levels at the 0- to 15-cm soil depth on both plot series (Fig. 1). The decline in soil test P with cropping was very similar for both series, but the soil P concentration in the 1968 series tended to be lower than for the 1967 series. Grain yields tended to be higher on the 1968 than on the 1967 plot series during the first six crops because of more favorable water conditions during those years the plots were cropped (Black, 1982). Crop removal of P was also greater for the 1968 plot series (Halvorson and Black, 1985b), consequently contributing to a lower soil test P level.

Decline in soil test P level with each additional crop was greatest for the 180 kg P/ha rate and least for the zero P treatment (Fig. 1). A new soil P equilibrium level appeared to be developing after the seventh crop as evidenced by the stability of the soil test P levels with each additional crop thereafter. The soil test P level of the 180 P/ha treatment after the seventh crop was near 15 mg P/kg soil, the level suggested by Black (1982) as the critical threshold for maximum grain

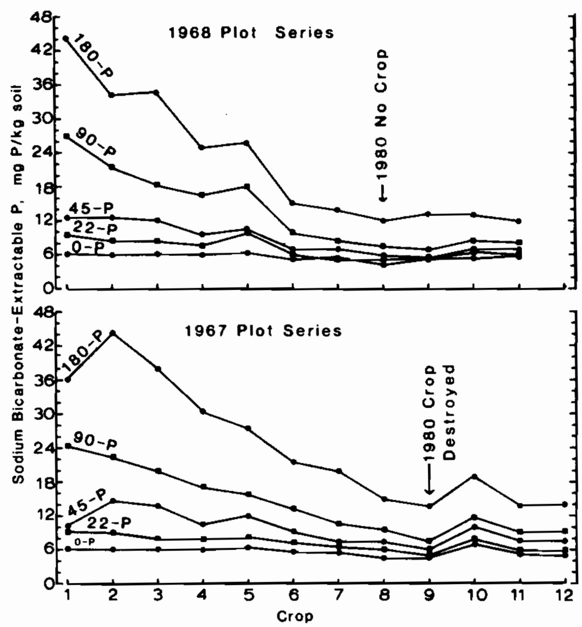


**Fig. 1. Sodium bicarbonate-extractable soil P in the 0- to 15-cm soil depth in the spring of each crop year for the 0, 22, 45, 90, and 180 kg P/ha treatments for the 1967 and 1968 plot series.**

yield production on fallow in the northern Great Plains. All other P treatments had soil test P levels less than 11 mg P/kg soil at this time (Fig. 1). The 1981 increase (Crop 10) in soil test P levels in the 1967 series probably resulted partially from the release of P from the winter wheat tissue that was soil incorporated on 20 June 1980 and from fallowing the plots from 20 June until 9 Sep 1980 (Campbell et al., 1984).

A significant linear relationship existed between soil test P level and the initial P fertilizer rate at each of the sampling dates for both plot series. The slope of the regression equation tended to decrease in value with each additional crop year (equations not reported), but with only slight changes in slope after the eighth crop.

### Grain Yields

For all nine annual crops, average grain yields generally increased (but not always significantly) with increasing residual P fertilizer levels when residual or applied N was adequate (Tables 3 and 4). Grain yields with annual cropping generally did not increase with increasing residual P levels when no fertilizer N was applied or residual $NO_3^-$-N levels were low (NO treatment in Fig. 2). In contrast, grain yields for the first six crops, each grown after summer fallow (Black, 1982), increased significantly with increasing residual P level with or without N fertilization.

No significant differences were measured in average crop yields between the N1 and N2 treatments in either the crop-fallow or annual cropping systems (Fig. 2). Significant N × P interactions were present for both cropping systems. Average grain yields increased with increasing P levels, with or without N fertilization, but responses to residual P fertilizer were greatest with N fertilization for the crop-fallow sequence. These data point out that P fertilization can result in larger yield increases than N fertilization with crop-fallow systems

**Table 3. Grain yield for the 1978, 1979, 1981, 1982, and 1983 crops of the 1967 plot series.**

| Crop | N treat. | Fert. N added | Initial P application, kg P/ha 0 | 22 | 45 | 90 | 180 | Avg. |
|---|---|---|---|---|---|---|---|---|
| | | kg/ha | Grain yield, kg/ha | | | | | |
| | | | | 1978 | | | | |
| Safflower | N0 | 0 | 1126 | 1229 | 1702 | 1654 | 1779 | 1498 |
| | N1 | 0 | 1661 | 2130 | 1934 | 2008 | 1917 | 1930 |
| | N2 | 0 | 2032 | 2234 | 2036 | 1763 | 1954 | 2004 |
| | | Avg | 1606 | 1864 | 1891 | 1808 | 1881 | |
| LSD (0.10): N rate = 359, P rate = NS, N × P interaction = 384 | | | | | | | | |
| | | | | 1979 | | | | |
| Spring barley | N0 | 34 | 1659 | 1707 | 1745 | 1528 | 1791 | 1686 |
| | N1 | 34 | 1603 | 1644 | 1674 | 1914 | 1738 | 1715 |
| | N2 | 34 | 1665 | 1786 | 1793 | 1919 | 1988 | 1830 |
| | | Avg | 1642 | 1712 | 1738 | 1787 | 1839 | |
| LSD (0.05): N rate = NS, P rate = NS, N × P interaction = NS | | | | | | | | |
| | | | | 1980 | | | | |
| Winter wheat | N0 | 34 | No yield due to drought. Crop destroyed on 20 June 1980. | | | | | |
| | N1 | 34 | | | | | | |
| | N2 | 34 | | | | | | |
| | | | | 1981 | | | | |
| Winter wheat | N0 | 0 | 2006 | 2065 | 2237 | 2351 | 2500 | 2232 |
| | N1 | 0 | 2102 | 2144 | 2070 | 2334 | 2552 | 2240 |
| | N2 | 0 | 1914 | 1927 | 1984 | 2309 | 2529 | 2132 |
| | | Avg | 2007 | 2045 | 2097 | 2331 | 2527 | |
| LSD (0.05): N rate = NS, P rate = 143, N × P interaction = NS | | | | | | | | |
| | | | | 1982 | | | | |
| Spring barley | N0 | 0 | 1514 | 1440 | 1526 | 1320 | 1216 | 1403 |
| | N1 | 45 | 2542 | 2484 | 2629 | 2779 | 2695 | 2626 |
| | N2 | 90 | 2507 | 2573 | 2707 | 2907 | 2992 | 2737 |
| | | Avg | 2188 | 2166 | 2287 | 2335 | 2301 | |
| LSD (0.05): N rate = 126, P rate = 112, N × P interaction = 194 | | | | | | | | |
| | | | | 1983 | | | | |
| Spring wheat | N0 | 0 | 997 | 904 | 925 | 937 | 1030 | 959 |
| | N1 | 45 | 1337 | 1219 | 1503 | 1484 | 1514 | 1411 |
| | N2 | 90 | 1599 | 1456 | 1638 | 1619 | 1694 | 1601 |
| | | Avg | 1311 | 1193 | 1356 | 1347 | 1413 | |
| LSD (0.05): N rate = 259, P rate = NS, N × P interaction = NS | | | | | | | | |

in the northern Great Plains. In addition, fertilization of wheat with both N and P may result in further yield increases due to a positive N × P interaction. With annual cropping systems, N is often more limiting than P. No yield response to P fertilization would be ex-

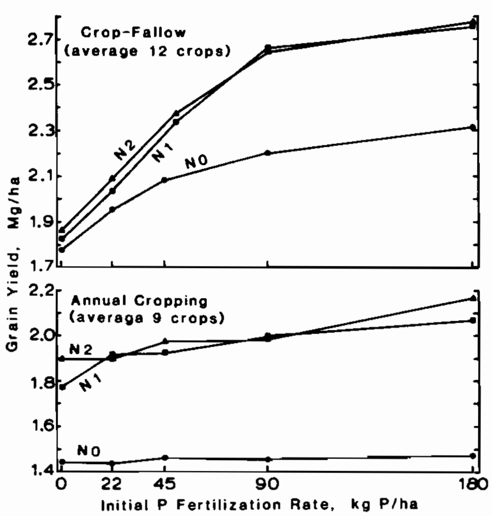


Fig. 2. Average grain yields of the crops grown under crop-fallow and annual cropping systems as a function of N and P fertilizer treatment.

**Table 4. Grain yield of the 1979, 1981, 1982, and 1983 crops of the 1968 plot series.**

| Crop | N treat. | Fert. N added | Initial P application, kg P/ha 0 | 22 | 45 | 90 | 180 | Avg |
|---|---|---|---|---|---|---|---|---|
| | | kg/ha | Grain yield, kg/ha | | | | | |
| | | | | 1979 | | | | |
| Safflower | N0 | 0 | 1169 | 1202 | 1125 | 1146 | 1062 | 1141 |
| | N1 | 0 | 1461 | 1563 | 1496 | 1477 | 1475 | 1494 |
| | N2 | 0 | 1532 | 1423 | 1593 | 1661 | 1763 | 1595 |
| | | Avg | 1388 | 1396 | 1405 | 1428 | 1433 | |
| LSD (0.05): N rate = 258, P rate = NS, N × P interaction = 184 | | | | | | | | |
| | | | | 1981 | | | | |
| Spring barley | N0 | 0 | 2575 | 2472 | 2397 | 2500 | 2310 | 2451 |
| | N1 | 0 | 2239 | 2730 | 2674 | 2733 | 3058 | 2687 |
| | N2 | 0 | 2546 | 2507 | 2687 | 2385 | 2753 | 2576 |
| | | Avg | 2453 | 2570 | 2586 | 2539 | 2707 | |
| LSD (0.10): N rate = 168, P rate = NS, N × P interaction = 343 | | | | | | | | |
| | | | | 1982 | | | | |
| Spring wheat | N0 | 0 | 1151 | 1129 | 914 | 914 | 921 | 1006 |
| | N1 | 45 | 1607 | 1850 | 1899 | 1815 | 1921 | 1818 |
| | N2 | 90 | 1757 | 1801 | 1819 | 1780 | 2092 | 1850 |
| | | Avg | 1505 | 1593 | 1544 | 1503 | 1645 | |
| LSD (0.05): N rate = 347, P rate = NS, N × P interaction = 208 | | | | | | | | |
| | | | | 1983 | | | | |
| Winter wheat | N0 | 0 | 833 | 804 | 603 | 771 | 667 | 736 |
| | N1 | 45 | 1399 | 1460 | 1437 | 1466 | 1755 | 1503 |
| | N2 | 90 | 1523 | 1387 | 1539 | 1527 | 1737 | 1543 |
| | | Avg | 1252 | 1217 | 1193 | 1255 | 1387 | |
| LSD (0.05): N rate = 95, P rate = NS, N × P interaction = NS | | | | | | | | |

pected without first establishing adequate levels of available N in annual cropping systems.

With N fertilization (average of N1 and N2 treatments), grain yields of the nine crops grown annually on the 0, 22, 45, 90, and 180 kg P/ha treatments, avg 99, 92, 83, 75, and 77%, respectively, of those obtained for the 12 crops grown in a crop-fallow sequence. For the same comparison made without N fertilization, annual cropping averaged 81, 74, 70, 66, and 64% of the grain yields obtained with crop-fallow for the same respective P treatments. Annual cropping with N fertilization averaged 103, 98, 94, 91, and 91% of the grain yields obtained with crop-fallow without N fertilization for the same respective P treatments. Growing season precipitation (Table 1) was generally below normal during the annual cropping period of this study, making yield comparisons less favorable between annual crop and crop-fallow systems. Although grain yields under annual cropping were not 100% of those on fallow, a crop was harvested every year, except for the extreme drought year of 1980. These data point out that annual cropping in the northern Great Plains may be profitable with proper N and P fertilization and a flexible cropping system (Halvorson and Kresge, 1982). Annual cropping could be economically sound if a producer would base the cropping decision on available stored soil water supply at seeding (Halvorson and Kresge, 1982).

The 1968 plot series (10 crops) had a greater accumulated grain yield (Table 5) than the 1967 series with 11 crops (Table 6). The major differences in yields occurred during the first six crops grown following fallow. The 1968 series tended to be cropped during years of more favorable water supply, consequently, producing higher grain yields. The accumulative grain yield response to N and P fertilization was significant

**Table 5. Accumulated grain yield above check (zero N and P) with each additional crop year for the 1968 plot series.**

| Total P added | Crop year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1968 | 1970 | 1972 | 1974 | 1976 | 1978 | 1979 | 1981 | 1982 | 1983 |
| | kg/ha | | | | | | | | | |
| | Nitrogen treatment, N0 | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 664 | 797 | 692 | 775 | 1099 | 1304 | 1338 | 1235 | 1212 | 1184 |
| 45 | 722 | 1023 | 1109 | 1136 | 1743 | 1878 | 1834 | 1656 | 1419 | 1188 |
| 90 | 756 | 1042 | 1426 | 1608 | 2384 | 2711 | 2688 | 2612 | 2375 | 2314 |
| 180 | 970 | 1786 | 2451 | 2643 | 3379 | 3890 | 3783 | 3518 | 3287 | 3122 |
| | Nitrogen treatment, N1 | | | | | | | | | |
| 0 | −275 | −284 | −254 | −315 | 262 | 79 | 372 | 36 | 491 | 1058 |
| 22 | 859 | 1315 | 1418 | 1461 | 2148 | 2190 | 2584 | 2739 | 3438 | 4065 |
| 45 | 1322 | 1880 | 2299 | 2619 | 3790 | 4591 | 4918 | 5017 | 5766 | 6369 |
| 90 | 1321 | 2086 | 3272 | 3865 | 5537 | 7123 | 7432 | 7589 | 8253 | 8886 |
| 180 | 1402 | 2529 | 3564 | 4220 | 6005 | 7968 | 8274 | 8757 | 9527 | 10450 |
| | Nitrogen treatment, N2 | | | | | | | | | |
| 0 | −220 | −297 | −228 | −369 | 388 | 412 | 775 | 746 | 1352 | 2041 |
| 22 | 644 | 935 | 1134 | 1127 | 2172 | 2517 | 2771 | 2703 | 3353 | 3907 |
| 45 | 1065 | 1478 | 2259 | 2540 | 3854 | 4628 | 5052 | 5164 | 5832 | 6537 |
| 90 | 1243 | 2261 | 3537 | 4119 | 5670 | 7283 | 7775 | 7585 | 8214 | 8908 |
| 180 | 1348 | 2508 | 3772 | 4325 | 6013 | 8371 | 8965 | 9143 | 10084 | 10988 |

**Table 6. Accumulated grain yield above check (zero N and P) with each additional crop year for the 1967 plot series.**

| Total P added | Crop year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1967 | 1969 | 1971 | 1973 | 1975 | 1977 | 1978 | 1979 | 1981 | 1982 | 1983 |
| | kg/ha | | | | | | | | | | |
| | Nitrogen treatment, N0 | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | 137 | 94 | 314 | 472 | 753 | 806 | 910 | 957 | 1017 | 943 | 850 |
| 45 | 215 | 600 | 1098 | 1221 | 1656 | 1763 | 2338 | 2425 | 2657 | 2669 | 2597 |
| 90 | 285 | 652 | 1144 | 1336 | 1898 | 2364 | 2892 | 2762 | 3108 | 2914 | 2854 |
| 180 | 332 | 622 | 1199 | 1483 | 2078 | 2537 | 3190 | 3322 | 3817 | 3518 | 3552 |
| | Nitrogen treatment, N1 | | | | | | | | | | |
| 0 | 44 | 220 | 325 | 379 | 566 | 480 | 1015 | 959 | 1056 | 2084 | 2424 |
| 22 | 160 | 493 | 641 | 613 | 973 | 887 | 1891 | 1876 | 2015 | 2984 | 3206 |
| 45 | 246 | 847 | 1233 | 1415 | 2140 | 2130 | 2938 | 2953 | 3018 | 4132 | 4639 |
| 90 | 322 | 1158 | 1620 | 2162 | 3185 | 3463 | 4345 | 4600 | 4929 | 6194 | 6681 |
| 180 | 389 | 1073 | 1657 | 2267 | 3381 | 3775 | 4565 | 4644 | 5191 | 6372 | 6889 |
| | Nitrogen treatment, N2 | | | | | | | | | | |
| 0 | −63 | 257 | 392 | 391 | 651 | 579 | 1484 | 1490 | 1399 | 2393 | 2994 |
| 22 | 224 | 571 | 811 | 854 | 1268 | 1206 | 2313 | 2440 | 2362 | 3421 | 3880 |
| 45 | 264 | 981 | 1462 | 1632 | 2388 | 2486 | 3397 | 3531 | 3510 | 4703 | 5344 |
| 90 | 200 | 1054 | 1505 | 1962 | 2867 | 3106 | 3743 | 4003 | 4306 | 5699 | 6321 |
| 180 | 224 | 1166 | 1865 | 2327 | 3298 | 3593 | 4422 | 4750 | 5274 | 6752 | 7449 |

for both plot series, but, the N × P interaction was significant only in the 1968 series. The N1 plus 180 kg P/ha treatment had accumulated 9392 and 4465 kg/ha more grain in 10 (1968 series) and 11 (1967 series) crops, respectively, than the N1 without P (check) treatment. The average increase in grain yield for 21 crops is 660 kg/ha per crop due to a single application of 180 kg P/ha with adequate N fertilization. In contrast, the average increase in grain yield each crop year due to a single application of 180 kg P/ha without N fertilization was 318 kg/ha. The higher accumulated yields for the 1968 versus the 1967 series correlates with the lower soil test P levels measured in the soil for the 1968 vs. the 1967 plot series (Fig. 1). Also of interest is the fact that for the N0 treatments, yield increases peaked out in about 1978 for the 1968 series (Table 5) and in about 1981 for the 1967 series (Table 6) and declined thereafter, suggesting that residual P without N fertilization initially enhanced crop growth until available N became limiting. Thereafter, yields of the N0 treatments with P were less than yields without P.

**Table 7. Average precentage increase in grain yield over check plot due to N and P fertilization in the crop-fallow and annual cropping systems.**

| P added | Crop-fallow (12 crops) | | | Annual cropping (9 crops) | | |
|---|---|---|---|---|---|---|
| | 0-N | 45-N | 90-N | 0-N | 45-N | 90-N |
| kg/ha | % | | | | | |
| 0 | 0 | 3 | 5 | 0 | 22 | 31 |
| 22 | 10 | 14 | 17 | −1 | 32 | 31 |
| 45 | 17 | 32 | 33 | 1 | 33 | 37 |
| 90 | 24 | 50 | 49 | 1 | 38 | 37 |
| 180 | 30 | 55 | 56 | 2 | 43 | 50 |

**Table 8. Straw yield for the 1978, 1979, 1981, 1982, and 1983 crops of the 1967 plot series.**

| Crop | N treat. | Fert. N added | Initial P application, kg P/ha | | | | | Avg |
|---|---|---|---|---|---|---|---|---|
| | | | 0 | 22 | 45 | 90 | 180 | |
| | | kg/ha | Straw yield, kg/ha | | | | | |
| | | | 1978 | | | | | |
| Safflower | N0 | 0 | 2433 | 3056 | 3395 | 3579 | 3371 | 3167 |
| | N1 | 0 | 4297 | 5860 | 4897 | 5183 | 5052 | 5058 |
| | N2 | 0 | 5886 | 6120 | 5634 | 5864 | 6255 | 5952 |
| | | Avg | 4205 | 5012 | 4642 | 4875 | 4893 | |
| LSD (0.10): N rate = 993, P rate = 493, N × P interaction = NS | | | | | | | | |
| | | | 1979 | | | | | |
| Spring barley | N0 | 34 | 1522 | 1572 | 1660 | 1455 | 1767 | 1595 |
| | N1 | 34 | 1459 | 1488 | 1507 | 1774 | 1598 | 1565 |
| | N2 | 34 | 1475 | 1663 | 1640 | 1782 | 1917 | 1695 |
| | | Avg | 1485 | 1574 | 1602 | 1670 | 1760 | |
| LSD (0.05): N rate = NS, P rate = 173, N × P interaction = NS | | | | | | | | |
| | | | 1981 | | | | | |
| Winter wheat | N0 | 0 | 4530 | 4954 | 5843 | 4847 | 5399 | 5115 |
| | N1 | 0 | 4647 | 4585 | 5146 | 5534 | 4520 | 4886 |
| | N2 | 0 | 5142 | 5183 | 5094 | 4408 | 5551 | 5076 |
| | | Avg | 4773 | 4907 | 5361 | 4930 | 5157 | |
| LSD (0.05): N rate = NS, P rate = NS, N × P interaction = NS | | | | | | | | |
| | | | 1982 | | | | | |
| Spring barley | N0 | 0 | 1790 | 863 | 1211 | 1192 | 1624 | 1336 |
| | N1 | 45 | 1288 | 2337 | 2243 | 2957 | 2033 | 2172 |
| | N2 | 90 | 2497 | 3150 | 3252 | 2454 | 1759 | 2622 |
| | | Avg | 1859 | 2117 | 2235 | 2201 | 1805 | |
| LSD (0.05): N rate = 739, P rate = NS, N × P interaction = 1035 | | | | | | | | |
| | | | 1983 | | | | | |
| Spring wheat | N0 | 0 | 1047 | 930 | 932 | 927 | 1100 | 987 |
| | N1 | 45 | 1634 | 1490 | 1824 | 1734 | 1740 | 1684 |
| | N2 | 90 | 1973 | 1694 | 2022 | 2069 | 2093 | 1970 |
| | | Avg | 1551 | 1371 | 1593 | 1577 | 1644 | |
| LSD (0.05): N rate = 136, P rate = NS, N × P interaction = NS | | | | | | | | |

The average percentage increase in grain yield above that of the check plot due to N and P fertilization is summarized in Table 7 for the crop-fallow and annual cropping phases of this study. Addition of N fertilizer without P resulted in only a 3 to 5% increase in grain yield under crop-fallow conditions but a 22 to 31% increase with annual cropping conditions. A significant and positive N × P interaction occurred with both cropping systems.

## Straw Yields

Quantity of straw residue produced by a cropping system can significantly influence the amount of soil loss resulting from wind and water erosion. Thus, straw residue plays an important role in maintaining soil productivity. Straw yields with annual cropping generally increased significantly with increasing levels of

**Table 9. Straw yield of the 1979, 1981, 1982, and 1983 crops of the 1968 plot series.**

| Crop | N treat. | Fert. N added | Initial P application, kg P/ha 0 | 22 | 45 | 90 | 180 | Avg |
|---|---|---|---|---|---|---|---|---|
| | | kg/ha | Straw yield, kg/ha | | | | | |
| | | | | 1979 | | | | |
| Safflower | N0 | 0 | 1766 | 1716 | 1786 | 1599 | 1654 | 1704 |
| | N1 | 0 | 2287 | 2371 | 2176 | 2051 | 1932 | 2163 |
| | N2 | 0 | 2555 | 2245 | 2479 | 2565 | 2494 | 2467 |
| | | Avg | 2203 | 2111 | 2147 | 2072 | 2027 | |
| LSD (0.10): N rate = 452, P rate = NS, N × P interaction = NS | | | | | | | | |
| | | | | 1981 | | | | |
| Spring barley | N0 | 0 | 1629 | 2034 | 2334 | 2117 | 2260 | 2077 |
| | N1 | 0 | 2671 | 2959 | 2232 | 2956 | 2878 | 2739 |
| | N2 | 0 | 1743 | 2393 | 2533 | 2847 | 4222 | 2748 |
| | | Avg | 2014 | 2462 | 2369 | 2640 | 3120 | |
| LSD (0.05): N rate = NS, P rate = 663, N × P interaction = NS | | | | | | | | |
| | | | | 1982 | | | | |
| Spring wheat | N0 | 0 | 1374 | 1337 | 1096 | 1251 | 1302 | 1272 |
| | N1 | 45 | 1748 | 2214 | 1698 | 2672 | 1932 | 2053 |
| | N2 | 90 | 1781 | 1812 | 2515 | 2039 | 2727 | 2175 |
| | | Avg | 1634 | 1787 | 1769 | 1987 | 1987 | |
| LSD (0.05): N rate = 449, P rate = NS, N × P interaction = 661 | | | | | | | | |
| | | | | 1983 | | | | |
| Winter wheat | N0 | 0 | 972 | 1023 | 743 | 930 | 851 | 904 |
| | N1 | 45 | 1740 | 1789 | 1898 | 1765 | 2134 | 1865 |
| | N2 | 90 | 1941 | 1800 | 1857 | 1937 | 2087 | 1924 |
| | | Avg | 1551 | 1537 | 1499 | 1544 | 1691 | |
| LSD (0.05): N rate = 167, P rate = NS, N × P interaction = NS | | | | | | | | |

available N, either from residual N or applied N (Tables 8 and 9). The yield trends for straw were similar to those of grain. Straw yields were occasionally increased significantly with increasing levels of residual P fertilizer.

Average straw yields per crop were higher with the crop-fallow system than with the annual cropping system (Fig. 3). This is probably the result of less water and mineralizable N available for crop growth with annual cropping. However, the production of straw on a per year basis was greater for the annual cropping system than for the crop-fallow system. Thus, over the long term, an annual cropping system would return more residue to the soil for greater buildup of soil organic matter and soil erosion protection than with a crop-fallow system.

## SUMMARY AND CONCLUSION

The $NaHCO_3$-extractable P soil test (Olsen et al., 1954) was sensitive to levels of residual P throughout the duration of this study, as evidenced by yield responses to residual P. Grain yields generally increased with increasing levels of residual P and N fertilization over the 10 and 11 harvested crops. With annual cropping, grain yields generally were not increased by increasing residual P levels without N fertilization. However, with adequate residual soil $NO_3^-$-N or application of 45 or 90 kg N/ha, grain yields with annual cropping, generally increased with increasing residual P level. Annual cropping grain yields with N fertilization were at least 90% of those obtained on fallow without N fertilization. When adequate levels of soil water, N, and P are present or supplied before planting a crop, more intensive dryland cropping than ob-

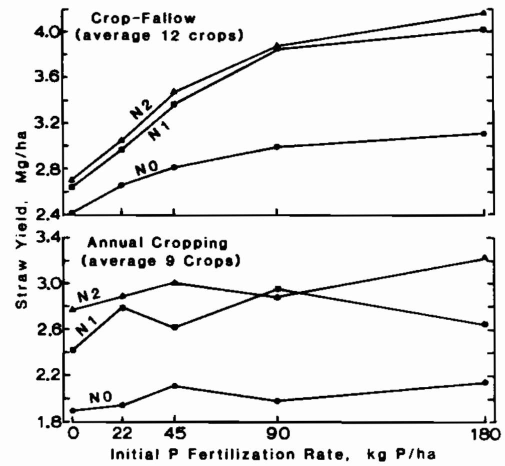


**Fig. 3. Average straw yields of the crops grown under crop-fallow and annual cropping system as a function of N an P fertilizer treatment.**

tained with a crop-fallow system may be profitable in the northern Great Plains.

The results of this study indicate the long term residual benefits of a single broadcast application of P fertilizer. Application of a high rate of P fertilizer before entering into a reduced tillage or no-till farming system may be one way of satisfying the P needs of several future crops. The P application rate, inherent soil properties, and kind of crops grown will determine how well and for how long crop needs could be satisfied.

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