BROADCAST AND RESIDUAL P VERSUS ANNUAL SEED PLACED P
(an update on the Kernen plots)

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ABSTRACT

The yield and nutrient uptake effects of single broadcast P treatments, annual seed placed P treatments and their combination, were studied over 5 years. Maximum yield was attained from a combination of moderate levels of seed placed and broadcast P applications. Moderate broadcast treatments (40 kg P/ha) alone produced a 5 year average yield which closely approached the yield from large annual seed placed treatments (20 kg P/ha/year), while larger residual treatments exceeded it. The Zn concentration in plants on plots receiving 160 kg P/ha was significantly reduced and approached levels considered deficient. After the production of five wheat crops on plots which received the broadcast application of 160 kg P/ha, the distribution of the remaining fertilizer residues among various soil P fractions was: resin-P, 35%; NaOH-P, 30-40%; $NaHCO_3$-P, 15%; HCl-P, 0-5%; H_2SO_4-P, 5%; aggregate protected P, 5%. Half the fertilizer residues remained in plant available forms (resin-P, $NaHCO_3$-P).

INTRODUCTION

Previous studies on the effect of single large broadcast applications of fertilizer phosphorus (P) to Chernozemic soils (Read et al. 1973, 1977; Bailey et al. 1977) indicated the P was available to crops in succeeding years. The formation of labile inorganic P compounds such as octocalcium phosphate and dicalcium phosphate dihydrate (Bell and Black 1970; Racz and Soper 1967; Sadler and Stewart 1977), which can persist in soils and mineralizable organic P forms capable of contributing to crop production (Chauhan et al. 1981; Halm 1972), produce this residual response.

This experiment was carried out to fully assess the effectiveness of residual P. Yield and P uptake from single broadcast P treatments were compared to annual seed placed treatments over 5 years. The fate of the broadcast P and transformations occurring throughout the period of the study were examined.

MATERIALS AND METHODS

A 5x5 latin square field layout was established on a dark brown clay Chernozem (Sutherland Association) at the University of Saskatchewan, Kernen Farm in 1979. This soil (pH 7.3, % organic C 3.43, % total N 0.31) contained low amounts of available P (<3 µg P/g soil of Olsen $NaHCO_3$-P_i). A single application of 0, 20, 40, 80 and 160 kg P/ha of triple superphosphate was broadcast on the major plots and incorporated in the spring of 1979 prior to the first seeding of the continuous wheat crops (Fig. 1). With seeding each major plot had seed placed treatments of 0, 2.5, 5, 10 and 20 kg P/ha established within it, utilizing the split plot technique (Fig. 2). In each year another set of seed placed plots was created while existing seed placed plots had the treatments repeated. Five sets of seed placed plots were created over the 5 year study, with the first set created in 1979 receiving five consecutive applications of seed placed P (Fig. 2). In the 6th year of the study the seed placed treatments were discontinued and only the broadcast P treatments were considered.

Prior to seeding each year, soil samples were analyzed for available N, K and S. Only N was required and applications were made in accordance with the Saskatchewan Soil Testing Laboratory recommendations.

Plant Analysis

Above ground plant material was sampled at tillering, flag leaf and maturity. At the tillering and flag leaf stages a sample 1 meter long was taken from a single row with a 0.18 m row spacing. At maturity a sample 3.05 m long and 3 rows wide was harvested. Plant samples were oven-dried and ground, then a 0.25 g sample was digested (Thomas et al. 1967) and P and Zn content determined.

Analysis of variance of yield and nutrient uptake was determined using a 5x5 latin square split plot analysis (Steel and Torrie 1960). The LSD was used for further comparison of broadcast and seed placed means.

Soil Analysis

Soil samples were taken 1, 2, 3, 4 and 5 years after P application. The samples were air-dried, bulked, ground to pass through a 0.9 mm sieve and analyzed in triplicate. The single exception was the year 5 sample where each field replicate was determined individually then averaged.

The phosphorus fractionation procedure used to analyze the soil

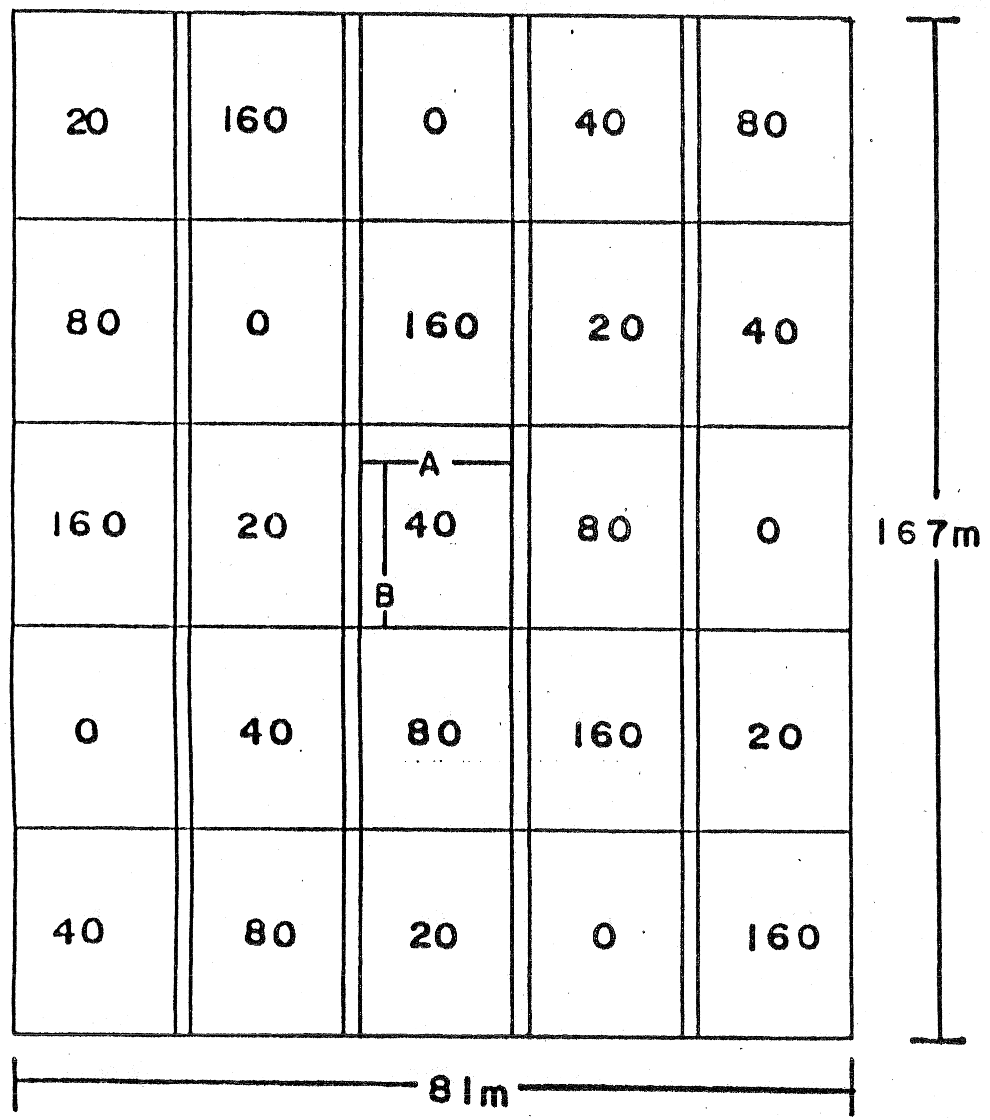


Fig. 1 Layout of the field plots receiving broadcast P treatments of 0, 20, 40, 80 and 160 kg P/ha, applied as triple superphosphate in the spring of 1979.

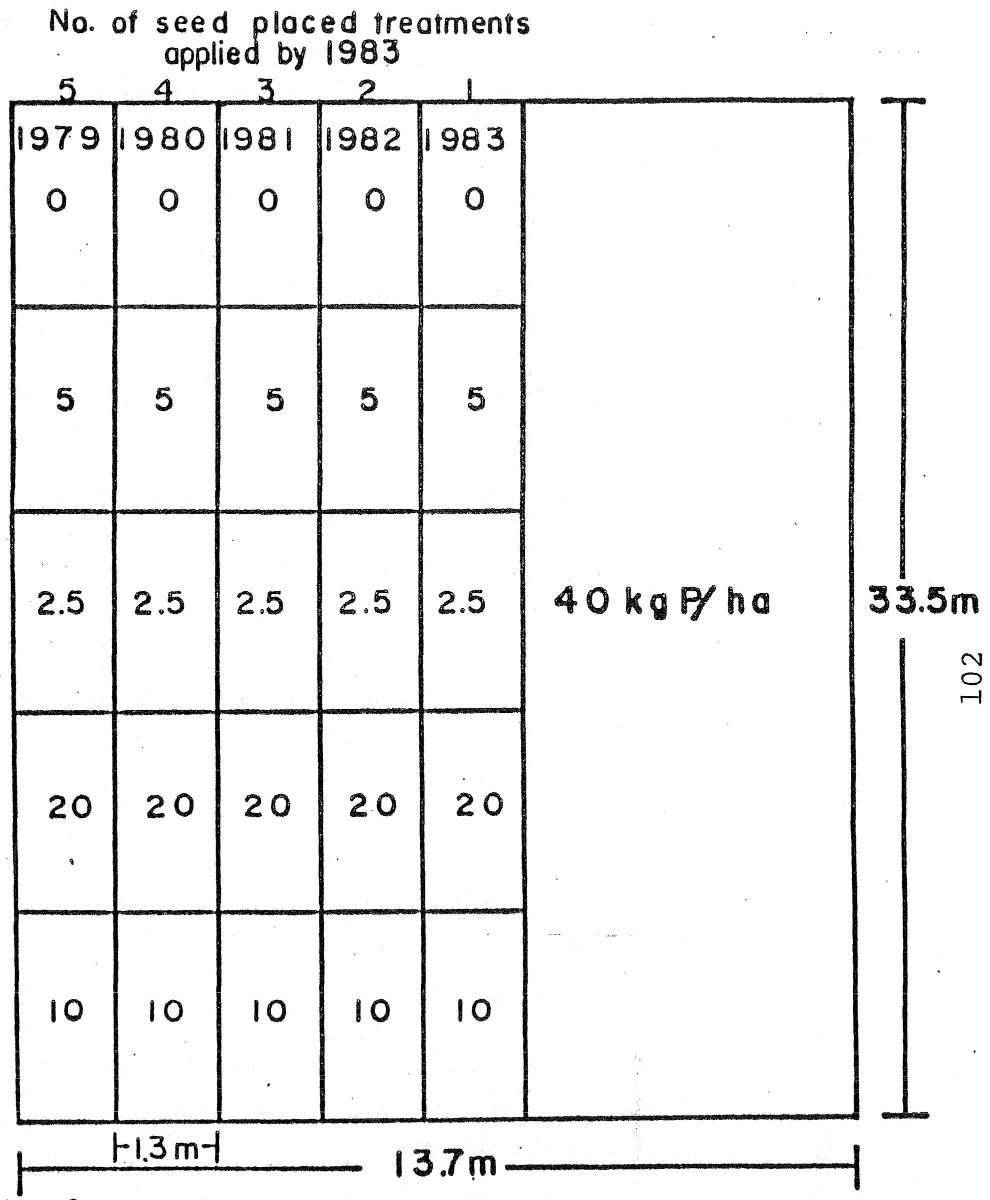


Fig. 2 Details of a single broadcast plot (area AB in Fig. 1) illustrating the seed placed treatments of 0, 2.5, 5, 10 and 20 kg P/ha. In 1979 one set of seed placed treatments was applied. With each year up to 1983 another set of treatments was initiated and previous

0.4 g soil samples in 50 ml screw cap centrifuge tubes

Add 30 ml deionized water plus 0.4 g resin in nylon bag (1 x 8-50 anion exchange resin, $NaHCO_3$ form). Shake 16 h, remove resin bag[1], centrifuge[2], discard supernatant

→ Resin P (P_i)

Soil

Add 30 ml 0.5 M $NaHCO_3$ (pH 8.5), shake 16 h, centrifuge[2] and collect supernatant[3]

→ Bicarbonate P (P_i and P_o)

Soil

Add 30 ml 0.5 M NaOH, shake 16 h, centrifuge, collect supernatant

→ Hydroxide P (P_i and P_o)

Soil

Add 20 ml 0.1 M NaOH and sonicate in an ice bath at 75 W (Braunsonic 1510) for 2 min, make to 30 ml volume, shake 16 h, centrifuge, collect supernatant

→ Sonicate/hydroxide P (P_i and P_o)

Soil

Add 30 ml 1.0 M HCl, shake 16 h, centrifuge, collect supernatant

→ Acid P (P_i)

Residual Soil

Digest with 5 ml H_2SO_4 and H_2O_2

→ Residue P (total P only)

[1] Resin bag desorbed in 50 ml centrifuge tube with 20 ml 0.5 M HCl; shake 16 h

[2] Centrifuge at 10,000 rpm for 10 min at $0^{o}C$

[3] Supernatant collected after millipore filtering, so escaping soil particles can be returned to soil residue

Figure 3. Sequential extraction procedure for soil phosphorus.

samples removed labile inorganic P (P_i) and organic P (P_o) first, followed by stable P forms removed with stronger extraction agents (Hedley et al. 1982). Details of the procedure are given in Figure 3.

RESULTS AND DISCUSSION

During the field study growing conditions varied considerably, reflecting normal dryland farming conditions. Variation in the production capabilities between years was largely a result of the precipitation falling on the plots in June, July and August (Table 1). Production was very good in 1979 in response to summerfallowing the previous year, and in 1983 due to abundant precipitation. Production was above average in 1982, near average in 1980, below average in 1984 and poor in 1981.

Residual Phosphorus Yield Effects

The single broadcast applications of P produced consistent yield increases over 6 years of cropping (Table 2). The 6-year average yield increases over the control for the broadcast 160 (B160), B80, B40 and B20 treatments were 35, 33, 24 and 9%, respectively. Only the B20 treatment did not produce a statistically significant yield increase. The B40 treatment produced significant yield increases up till the fifth year, while the B80 and B160 treatments produced significant increases over the 6 years of cropping and may continue to do so. Although maximum average yield occurred with the B160 treatment, its increase over the B80 treatment was insignificant over a 6 year time span.

Seed Placed Phosphorus Yield Effects

Yearly, consecutive seed placed applications of 20, 10, 5 and 2.5 kg P/ha, without broadcast P, produced 5 year average yield increases which exceeded the control by 29, 24, 15 and 10%, respectively. The increases from the seed placed treatments of 20 kg P/ha (S20), S10 and S5 are statistically significant. Although maximum yield was attained by the S20 treatment there was no significant yield increase over the S10 treatment (Table 3).

Comparison of Single Versus Multiple Seed Placed Phosphorus Treatments

Yields obtained on plots receiving yearly consecutive seed placed P treatments were compared to yields obtained where seed placed P was applied only on the current year of production. In 1982 and 1983, when adequate moisture prevailed, the yields on plots which received multiple seed placed

Table 1. Precipitation received by the Kernen plots during the six growing seasons from 1979 to 1984

	Year					
	1979	1980	1981	1982	1983	1984
	mm of precipitation					
May	23.6	18.0	13.7	76.2	21.0	24.1
June	62.2	51.1	59.0	32.8	127.5	61.2
July	48.3	19.6	35.8	76.7	70.3	14.5
August	19.6	56.6	9.7	105.7	44.9	6.9
Total June, July, August	130.1	127.3	104.5	215.2	242.7	82.6
Total Annual	305.7	350.6	280.3	436.2	471.6	297.5

Information courtesy of D. Bayne, Dept. of Hydrology, University of Saskatchewan and from Saskatchewan Research Council Technical Reports.

Table 2. Average wheat yield in kg/ha from Kernen residual P plots receiving residual P treatments of 0, 20, 40, 80 and 160 kg P/ha, over a six year period, where no seed placed P was applied

	Residual treatments (kg P/ha)					
	0	20	40	80	160	LSD
Year	kg grain/ha					
1979	2841^{ABC}	2906^{D}	3295^{A}	3458^{BD}	3287^{C}	445
1980	1572	1474	1767	2159	2086	760
1981	1070	995	1244	1255	1257	346
1982	1981^{ABC}	2421	2838^{A}	2507^{B}	2868^{C}	449
1983	2253^{ABCD}	2833^{AE}	3069^{B}	3379^{C}	3571^{DE}	569
1984	1448^{AB}	1532^{C}	1635	2044^{AC}	1979^{B}	481
6 Year Mean	1861^{ABC}	2027^{DEF}	2308^{AD}	2467^{BE}	2508^{CF}	223

Similar letters superscript after yields indicate significant differences (5% level) occurring between P treatments of a particular year or mean.

Table 3. Wheat yields in kg/ha from Kernen plots receiving single and multiple applications of 0, 2.5, 5, 10 and 20 kg P/ha as seed placed P, where no residual P has been utilized

Year	Cummulative no. of seed placed P treatments	Seed placed P treatments (kg P/ha)					LSD
		0	2.5	5	10	20	
		----------------kg grain/ha---------------					
(Plots receiving multiple seed placed P treatments over 5 yr. of production)							
1979	1	2841	2911	2842	3028	3201	383
1980	2	1572	1683	1660	1736	1716	474
1981	3	1070	1157	1182	1157	1210	278
1982	4	1981^{ABC}	2356^{DE}	2433^{AF}	2779^{BD}	2925^{CEF}	405
1983	5	2253^{ABC}	2602^{DE}	3041^{AF}	3327^{BD}	3510^{CEF}	580
5 Yr. Mean		1943^{ABC}	2142^{DE}	2232^{AF}	2405^{BD}	2512^{CEF}	236
(Plots receiving a single seed placed P treatment on the current year of production)							
1979	1	2841	2911	2842	3028	3201	383
1980	1	1685	1662	1609	1498	1675	547
1981	1	1233	1163^{A}	1202	1145^{B}	1400^{AB}	235
1982	1	1968^{ABC}	2104^{C}	2180^{D}	2408^{A}	2630^{BCD}	319
1983	1	1650^{A}	1659^{B}	1976	1862	2371^{AB}	512
5 Yr. Mean		1875^{A}	1900^{B}	1962^{C}	1988^{D}	2255^{ABCD}	189

Similar letters superscript after yields indicate significant differences (5% level) occurring between P treatments of a particular year or mean.

treatments greatly exceeded the yield from plots receiving a single treatment (Table 3). Average yields from the last 4 years of seed placed P application, where multiple versus single seed placed treatments can be statistically compared, indicate plots receiving multiple applications produced significantly greater yields (Table 4). Even the smallest consecutive seed placed treatment experienced enhanced yield, demonstrating a significant residual response from prior seed placed P treatments.

Yield Comparison From Different Methods of Phosphorus Application

Average yields on plots receiving only broadcast P or only seed placed P can be compared over the first 5 years of the study (Table 5). Maximum average yield from seed placed P occurred on the S20 plots (2512 kg/ha). However, this was exceeded by yields from the single broadcast application of 160 and 80 kg P/ha, while the broadcast application of 40 kg P/ha produced an average yield which exceeded the annual S10 treatment. Over 5 years a single broadcast application of 40 kg P/ha produced yields comparable with those produced by large seed placed treatments (20 kg P/ha/year) while requiring much reduced fertilizer inputs. The broadcast application of 20 kg P/ha produced minimal yield increases which were exceeded by the yearly seed placed applications of 2.5 and 5 kg P/ha. Thus moderate and large broadcast P applications can be as effective in increasing yields as annual seed placed P, but small broadcast P applications are less effective than seed placed treatments.

Yields From the Combination of Broadcast and Seed Placed Phosphorus

Escalating applications of seed placed P applied to the B0 and B20 plots produced increasing yields (Fig. 4). On the B40 plots only the seed placed application of 10 and 20 kg P/ha produced substantial yield increases. Significant yield increases did not occur when seed placed P was applied to the B80 and B160 plots.

The B80-S20 combination of fertilizer treatments produced the overall maximum yield, requiring a total fertilizer input of 180 kg P/ha, over 5 years. Many combinations of broadcast and seed placed P produced near maximum yields (Fig. 4). However, only two combinations attained greater than 95% of maximum yield while requiring a total application of less than 100 kg P/ha. The B40-S10 combination produced 98.3% of the maximum yield with a total application of 90 kg P/ha and the B80-S2.5 treatment produced

Table 4. Average grain yield from Kernen plots which received only seed placed P applied a) consecutively each year and b) on the current year of production alone (only data from the last four years of the experiment is used where the effects of single versus multiple applications of seed placed P can be contrasted)

Seed placed treatment kg P/ha	Means of plots receiving multiple consecutive seed placed P treatments	Means of plots receiving single seed placed treatments on current year only	LSD
	------------------kg grain/ha---------------------		
0	1719	1634	175
2.5	1964*	1647	248
5	2087*	1742	267
10	2253*	1728	297
20	2348*	2019	265

*Yield significantly greater (5% level) than yield obtained with single seed placed P treatments.

Table 5. Five year average wheat production in kg/ha from Kernen plots receiving a) a single residual P application of 0, 20, 40, 80 and 160 kg P/ha and b) plots receiving consecutive yearly seed placed treatments of 0, 2.5, 5, 10 and 20 kg P/ha

	Residual P treatment (kg P/ha)				
	0	20	40	80	160
	-----------------kg grain/ha-----------------				
Average yield from plots receiving only residual P	1943	2126	2442	2552	2614
	LSD (5% level) = 262 kg grain/ha				

	Yearly seed placed P treatments (kg P/ha)				
	0	2.5	5	10	20
	-----------------kg grain/ha-----------------				
Average yield from plots receiving only seed placed P	1943	2142	2232	2405	2512
	LSD (5% level) = 236 kg grain/ha				

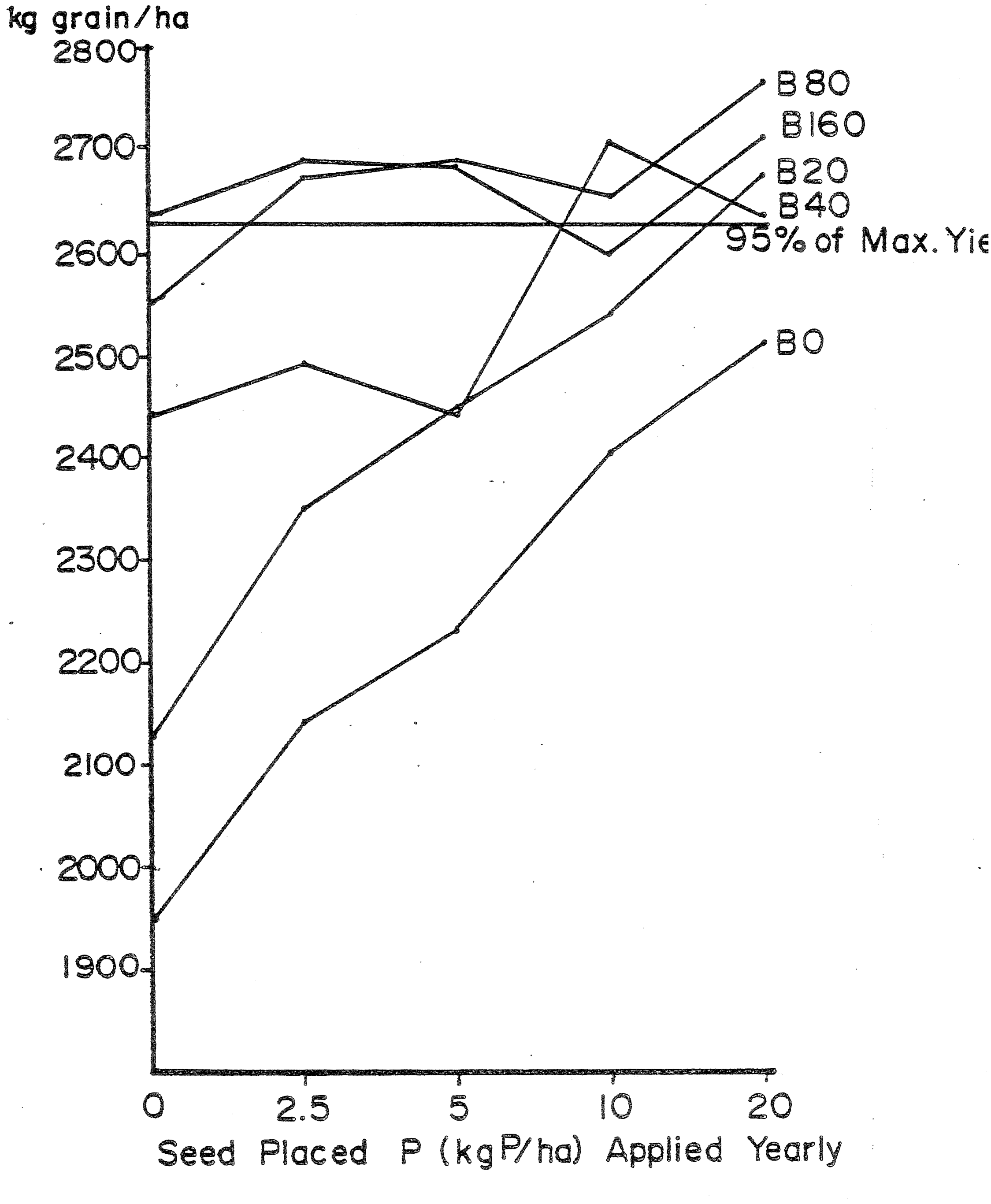


Figure 4. Grain yields (5 year means) from Kernen plots receiving initial broadcast P treatments of 0, 20, 40, 80 and 160 kg P/ha and annual seed placed treatments of 0, 2.5, 5, 10 and 20 kg P/ha.

96.6% of the maximum yield and required 92.5 kg P/ha. Therefore in attempting to produce maximum yield the combination of moderate amounts of residual and seed placed P can accomplish this with a smaller fertilizer input than required of either applied alone.

Phosphorus Uptake

The application of broadcast P alone stimulated increased P uptake by grain with each increment in P application (Fig. 5). The five year total uptake on the control was 30.7 kg P/ha, which increased to 53.2 kg P/ha on the B160 plots. The B160 and B80 plots displayed significantly greater P uptake in each year. The B40 treatment consistently exceeded the control, but in the drier years (1980, 1981) the increase was not statistically significant. Luxury consumption of P occurred on the B160 plots in the first 3 years of the experiment as P concentration in the grain increased without corresponding yield increases over the B80 plots.

Seed placed P influenced P uptake to a lesser degree than the broadcast treatments. The importance of seed placed P in influencing P uptake increased as the experiment progressed. The correlation coefficients for P uptake in response to seed placed P went from 0.101 in year 1 to 0.572 in year 5, as residues from successive applications accumulated in the soil (Fig. 6). Where no residual P was applied, five year total P uptake went from 30.7 kg P/ha on the control to 45.6 kg P/ha on the S20 plots. This uptake was exceeded by the B160 and B80 treatments, and closely approached by the B40 treatment, where 44.1 kg P/ha was taken up over the 5 years (Fig. 5).

The combination of broadcast and seed placed treatments enhanced P uptake. The effect of seed placed P was most pronounced on the B0 and B20 plots and produced significant increases in P uptake. On the B40 plots the seed placed application of 10 and 20 kg P/ha significantly increased P uptake. The only significant increase in P uptake on the B80 plots occurred with the seed placed application of 20 kg P/ha. The P uptake on B160 plots did not significantly respond to seed placed P.

Phosphorus-Zinc Interaction

Zinc concentration in plant matter and zinc uptake by grain were both significantly reduced by broadcast P applications. The decreased Zn content of plant matter was most apparent on the B160 plots where it was significantly reduced in 4 out of 5 years of crop production. Similar but smaller

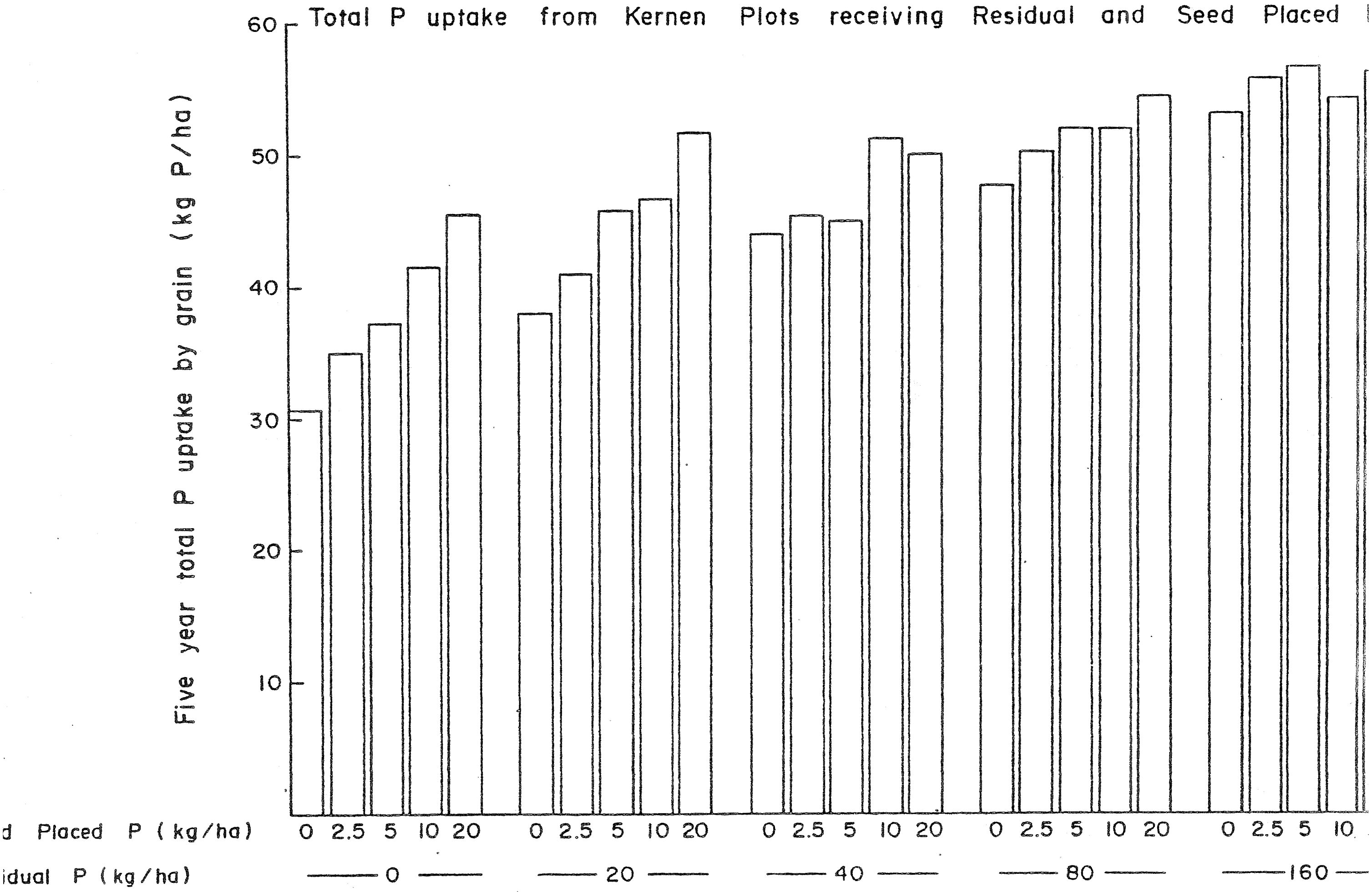
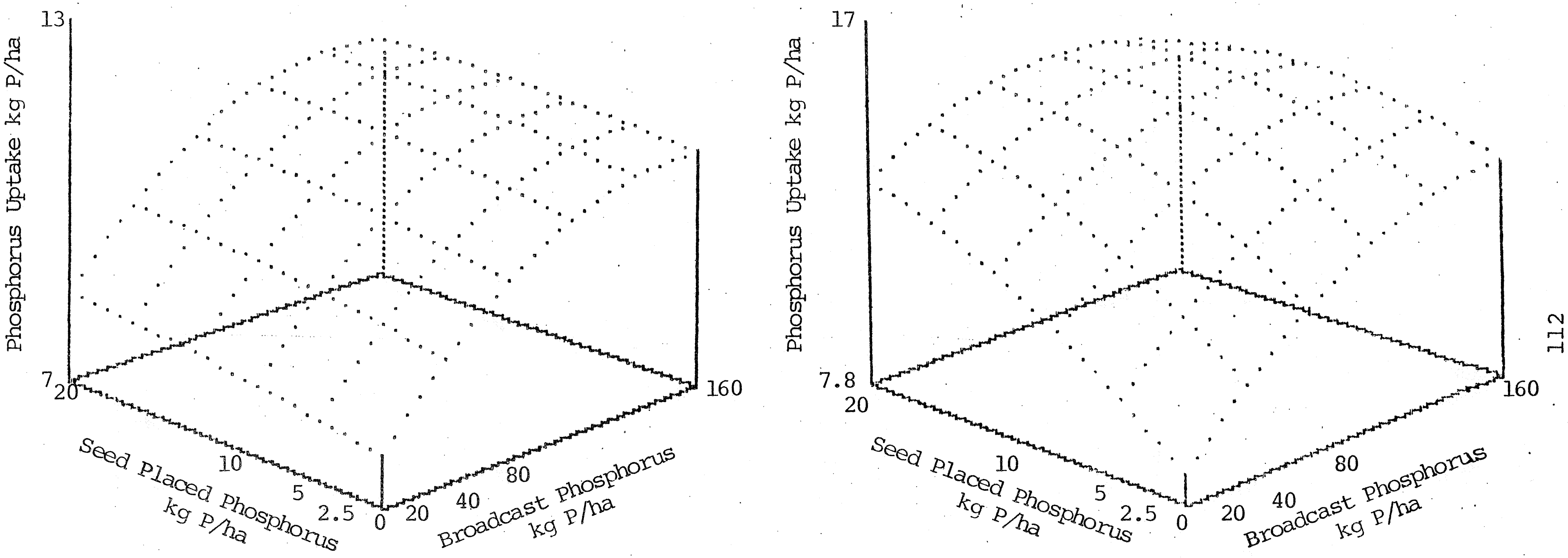


Figure 5. P uptake (five year cumulative) from the Kernen plots receiving residual P treatments of 0, 20, 40, 80 and 160 kg P/ha and annual seed placed treatments of 0, 2.5, 5, 10 and 20 kg P/ha.



Year 1 Phosphorus Uptake
(1 seed placed treatment)

Year 5 Phosphorus Uptake
(5 seed placed treatments)

Figure 6. Phosphorus uptake by grain in the 1st and 5th year of wheat production on plots which received a single broadcast treatment of 0, 20, 40, 80 and 160 kg P/ha and consecutive annual seed placed applications of 0, 2.5, 5, 10 and 20 kg P/ha.

Table 6. Average zinc concentration in μg Zn/g plant matter from tissue samples taken at the flag leaf stage from Kernen plots receiving residual P treatments of 0, 20, 40, 80 and 160 kg P/ha, where no seed placed P was applied

Residual treatment kg P/ha	Year				
	1979	1980*	1981	1982	1983
	μg Zn/g				
0	31.8^{AB}	47.4^{AB}	54.0^{ABCD}	34.6^{ABC}	40.0^{A}
20	22.2	48.0^{CD}	38.4^{AE}	29.2^{DE}	35.6
40	19.2^{A}	37.8	38.4^{BF}	28.2^{AFG}	30.4
80	25.0	32.4^{AC}	33.6^{CG}	20.6^{BDF}	25.2^{A}
160	14.0^{B}	32.0^{BD}	24.0^{DEFG}	15.0^{CEG}	31.8
LSD (5% level)	12.1	14.5	8.2	6.2	12.6

Similar letters superscripted behind data in individual years indicates a significant difference (5% level).

*1980 data taken at tillering, as flag leaf sampling was not done because of uneven growth stages present.

reductions in the Zn concentration of plant matter occurred with seed placed P. Present recommended Zn concentrations for plant matter (Chapman 1966; Radjagukguk et al. 1980) suggest that concentrations found in plants from the B160 plots are borderline to deficient. This may explain why maximum yields were not found on the B160 plots during the initial years of the experiment.

Soil Transformations of Applied Phosphorus With Time

The summary of the sequential P extraction of the Sutherland soil, taken from the residual P plots where 0 and 160 kg P/ha was applied, is illustrated in Figure 7. Detailed results including P_i and P_o content of fractions are given in Table 7.

One year following P application, total P recovered on the soil which received 160 kg P/ha (Sutherland 160) exceeded the control by 94 µg P/g soil. This represented approximately 106% of the theoretical value.

Resin Extractable Phosphorus

Resin P contained 47.6% of the recoverable fertilizer P on the Sutherland 160 soil in year 1. During the first four years resin P remained high, dropping only 3.5 µg P/g soil (Fig. 7). Although a large drop occurred in year 5, a probable result of spring flooding, resin P still represented 34.8% of the fertilizer P recovered in the top 15 cm of soil. Resin P is the most plant available P consisting of P_i adsorbed on surfaces of more crystalline P compounds, sesquioxides or carbonates (Mattingly 1975) and soluble Ca phosphates such as DCPD and OCP. The persistence of greater than 30% of the applied P in this form will largely be responsible for the increase in P uptake and yield.

Bicarbonate Extractable Phosphorus

Total bicarbonate extractable P ($NaHCO_3$-P_T) of the year 1 Sutherland 160 soil exceeded the control by 15.1 µg P/g soil and represented 16.1% of the recoverable fertilizer P. This level declined gradually with cropping (Fig. 7). In year 5 this soil exceeded the control by 8.6 µg P/g soil, representing 15.2% of the recoverable P. The increase in bicarbonate extractable P was due almost entirely to the increase in the P_i component (Table 7).

Bicarbonate extractable P_i is readily plant available while the P_o component is easily mineralizable and contributes to plant available P (Bowman and Cole 1978). Plant available P is the sum of the resin and $NaHCO_3$

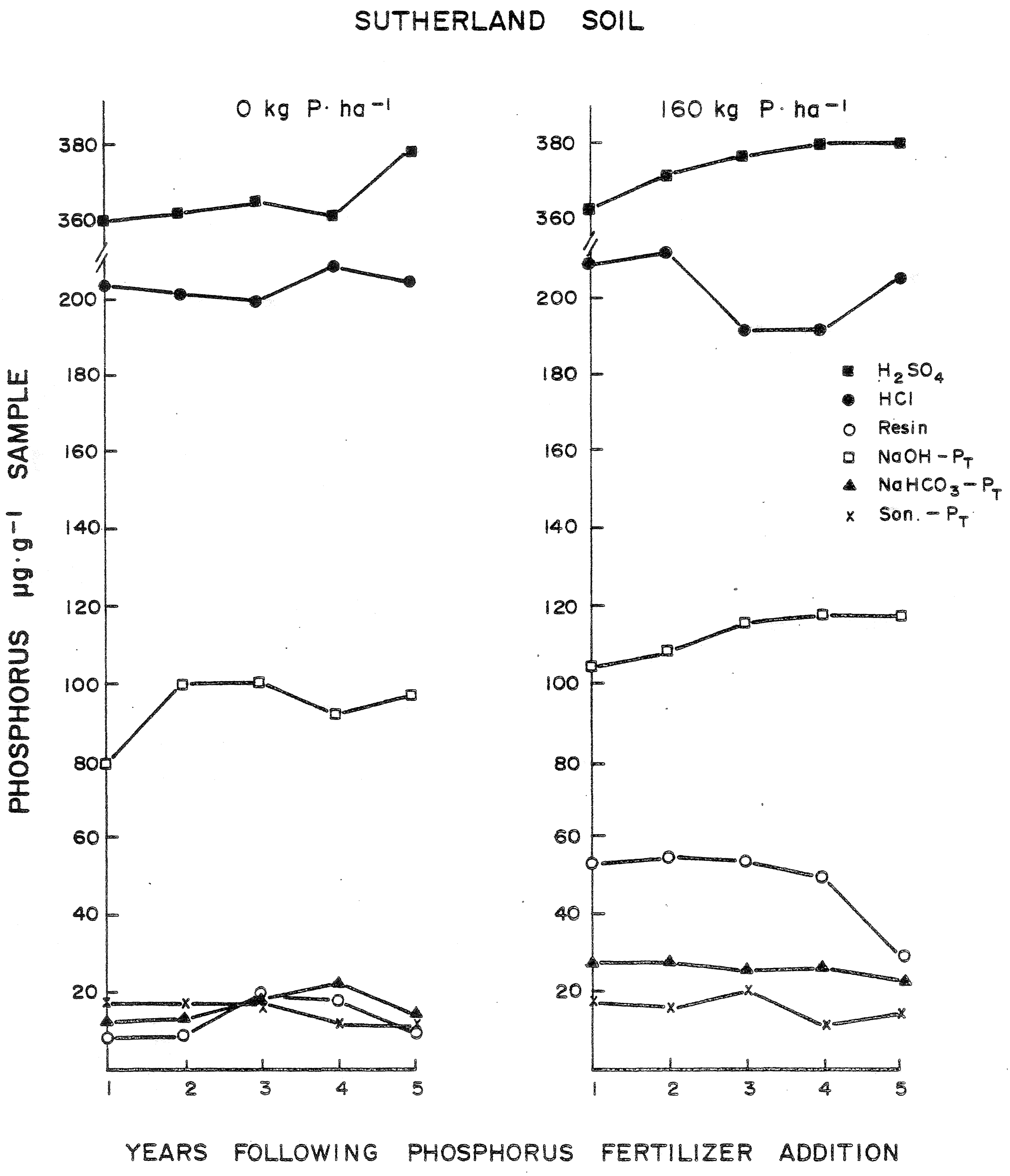


Figure 7. The phosphorus content of soil phosphorus fractions extracted from the Sutherland soil receiving 0 and 160 kg P/ha, sampled 1, 2, 3, 4 and 5 years following fertilizer application.

Table 7. Average P content and standard error in ug P/g sample for the P fractions of the Sutherland soil sampled 1, 2, 3, 4 and 5 years after P addition of 0 and 160 kg P/ha

Year	Resin P	$NaHCO_3$-P P_i	$NaHCO_3$-P P_o	NaOH-P P_i	NaOH-P P_o	Son. + NaOH-P P_i	Son. + NaOH-P P_o	HCl P	Residue P	Total P
					0 kg P/ha					
1	8.0±0.0	5.1±0.4	7.0±0.9	13.5±0.1	65.8±1.1	3.1±0.1	13.7±0.5	203.8±1.2	359.5±2.4	679.6
2	8.5±0.1	5.3±0.3	7.6±0.5	14.5±0.1	85.1±0.5	3.4±0.3	13.6±0.9	201.2±1.7	361.9±1.6	701.1
3	19.1±0.2	9.3±0.1	8.7±0.3	19.6±0.2	80.4±0.4	3.6±0.2	13.3±0.7	199.1±0.5	364.9±0.6	718.1
4	17.6±0.5	9.3±0.4	12.9±2.5	16.5±1.0	74.9±0.5	3.1±0.4	8.6±1.8	208.4±1.3	361.0±5.9	712.4
5	9.3±1.4	5.9±0.7	8.0±1.3	12.8±0.3	83.8±10.5	2.4±0.3	7.4±1.1	204.3±13.5	377.7±6.2	711.7
					160 kg P/ha					
1	52.7±0.9	18.5±0.2	8.4±0.1	23.6±0.3	80.6±0.9	4.0±0.1	13.0±1.2	209.1±2.1	363.1±1.2	773.5
2	54.5±0.4	18.8±0.1	8.6±0.2	26.0±0.2	82.1±2.7	4.6±0.0	11.1±0.9	212.1±0.7	372.0±0.6	789.9
3	53.3±0.3	16.6±0.3	8.6±0.1	28.7±0.0	86.7±0.5	4.9±0.2	15.0±0.8	191.4±1.4	376.8±2.1	782.2
4	49.2±0.2	16.3±0.7	9.7±0.5	26.8±0.6	90.8±1.4	3.8±0.2	7.2±0.3	191.6±3.3	380.0±0.0	775.4
5	29.0±3.2	13.4±1.1	9.1±0.8	22.7±1.9	94.4±3.7	4.1±0.3	10.3±0.8	205.2±13.9	380.0±8.6	768.2

extractable P. Thus, after 5 years of cropping, 50% of the fertilizer P recovered on the Sutherland 160 soil remained in plant available forms.

Hydroxide Extractable Phosphorus

The NaOH fraction of the Sutherland 160 soil contained 26.5% of the recoverable fertilizer P in year 1. With cropping the NaOH-P_T content of the Sutherland control soil increased over the first 3 years while on the Sutherland 160 soil this fraction continued to increase through year 4. Following 5 years of cropping, the increase sustained on the control soil consisted of P_o alone. The increase on the Sutherland 160 soil, in excess of the control, resulted from increases of 9.9 and 10.6 µg P/g soil from both P_i and P_o components, respectively. After 5 years of crop production the NaOH extractable fraction of the Sutherland 160 soil contained 36.3% of the recoverable fertilizer P.

Hydroxide extraction removes P forms of lower plant availability. The P_i component is associated with amorphous and crystalline Al and Fe phosphates via chemisorption (Williams et al. 1980). The P_o compounds extracted are more stable forms involved in longer term P transformations. Thus, the rapid and large conversion of fertilizer P to NaOH extractable forms constitutes a significant decrease in P availability.

The increase of P_o on both the Sutherland control and 160 soils indicates part of the increase must result from a factor other than P application. The prior cropping history of the plots was a 2 year crop-summerfallow rotation. With this history, the soil may be responding to the change to continuous cropping. The increased crop residue incorporation resulting from continuous cropping may have established new and higher equilibrium levels of organic P. This is corroborated by the increase in residue P, with its large P_o constituent, also seen in both the Sutherland control and 160 soils (Fig. 7).

Aggregate Protected Phosphorus

Sonification followed by NaOH extraction removes unavailable P_i and P_o held within the internal surfaces of stable soil aggregates. In year 1 less than 2% of the P applied to the Sutherland 160 soil was recovered in this fraction. Little change occurred with further time and cropping which indicated aggregate protected P had little importance in this soil.

Acid Extractable Phosphorus

One M HCl extraction removes mainly stable Ca bound P characterized by hydroxyapatite (HA) (Syers et al. 1972; Williams et al. 1980). HA is thought to be the stable end product of P added to Chernozemic soils, though conversion is considered to be slow (Sadler and Stewart 1977). Results on the Sutherland 160 soil support this view, as no significant conversion of fertilizer P into HCl extractable forms occurred over 5 years of cropping (Table 7).

Residue Phosphorus

Residue P is a stable fraction extracted by H_2SO_4-H_2O_2 digestion. The large P_o content of the fraction is a constituent of humus and humic acid (Stewart et al. 1980) and the P_i consists of relatively insoluble forms. One year after P application 4% of the fertilizer P was recovered as residue P on the Sutherland 160 soil. With further cropping, residue P levels in both the Sutherland control and 160 soils increased from 18 to 20 µg P/g soil, a probable result of an increase in P_o with the shift to continuous cropping. In year 5, 4% of the applied P was recovered in the residue P fraction. As this fraction is chemically stable, fertilizer recovered in it represents a loss of available P over a farm operator's time scale. However, the small recovery of fertilizer P in this form is not a serious deterrent to the utilization of residual P applications in this soil.

Fate of Applied Phosphorus

After 5 years of cropping it was possible to account for all of the P applied to the Sutherland 160 soil (Table 8). Not all of the applied P could be accounted for in the top 15 cm of soil as a significant downward movement of P occurred. Similar downward movement of fertilizer P was reported on a Saskatchewan Haverhill Wood Mountain soil (Read and Campbell 1981). Movement of P down into the soil by plant roots in a biocycling process was suggested as a mechanism. The grumic nature of the Sutherland soil and water ponding on the site in the spring of 1983 might have contributed to this downward movement. Fertilizer P recovered below 15 cm was found largely in the NaOH and residue P fractions and therefore cannot be considered plant available in the short term. After the application of 160 kg P/ha and the production of five wheat crops, 13% of the applied P was recovered in the grain, 34% moved below the top 15 cm of soil and 60% remained in the topsoil, of which half was plant available.

Table 8. Recovery of fertilizer P 5 years following the application of 160 kg P/ha to the Sutherland soil

Source		μg P/g soil recovered in excess of control	% recovery of fertilizer P
Soil	0-15 cm	56.5	60.1
	15-30 cm	19.1	20.3
	30-60 cm	13.4	14.3
Grain		12.5	13.3
Total		101.5	108

CONCLUSIONS

The combination of moderate amounts of residual and seed placed P produced maximum yields.

Single moderate broadcast treatments (40 kg P/ha) sustained a 5 year average yield which closely approached that obtained from large annual seed placed treatments (20 kg P/ha), indicating moderate residual applications can be as yield effective as seed placed P. Larger single broadcast P treatments (80 and 160 kg P/ha) produced average yields which exceeded those from seed placed applications. Significant yield responses from the large broadcast treatments continued into the 6th year of the experiment and available P levels on these plots suggest yield increases will continue in the future.

Large broadcast P applications significantly affected micronutrient uptake. A significant P-Zn interaction occurred which was reflected in yields during the initial years of the experiment.

The approximate distribution of fertilizer residues remaining in the top 15 cm of soil where 160 kg P/ha had been applied was: resin-P, 35%; NaOH-P, 30-40%; $NaHCO_3$-P, 15%; HCl-P, 0-5%; residue-P, 5%; aggregate protected P, 5%. After 5 years of cropping, half of the fertilizer residue in the top soil was in plant available form (resin-P, $NaHCO_3$-P_T).

Significant quantities of fertilizer P were converted to NaOH extractable forms without an increase in HCl extractable P. Therefore, moderately plant available P removed by NaOH extraction may be very important in the long term availability of fertilizer P on some calcareous soils.

The ability of single large broadcast P treatments to produce significant residual yield increases and sustain elevated available P levels in this soil indicate it is a viable alternative to annual seed placed treatments.

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