YIELD AND NUTRIENT ANALYSIS OF THE KERNEN RESIDUAL PHOSPHORUS STUDY

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Previous studies on the effect of large applications of fertilizer phosphorus to Chernozemic soils (Read et al., 1973, 1977; Bailey et al., 1977; Sadler and Stewart, 1974, 1975, 1977) have shown that applied P will be available to crops in succeeding years. These results have caused farm operators to seriously consider the possibility of applying one large quantity of fertilizer P to supply many successive crops. Advantagesfrom this procedure are: time saving in spring resulting in maximum utility of the frost free period; decreased fertilizer damage to susceptible seeds such as flax and rapeseed; the increased level of plant available phosphate in the complete rooting zone would ensure maximum P uptake; and a possible economic advantage because of the escalating cost of fertilizer.

To fully assess the effectiveness of residual phosphorus an experiment was initiated by Stewart et al. (1980) at the University of Saskatchewan, Kernen Farm. The experiment consists of two 3.5 acre latin square field layouts. One latin square received a continuous wheat rotation while the other is seeded to a flax, wheat, rapeseed rotation. This paper describes the results from the continuous wheat plots.

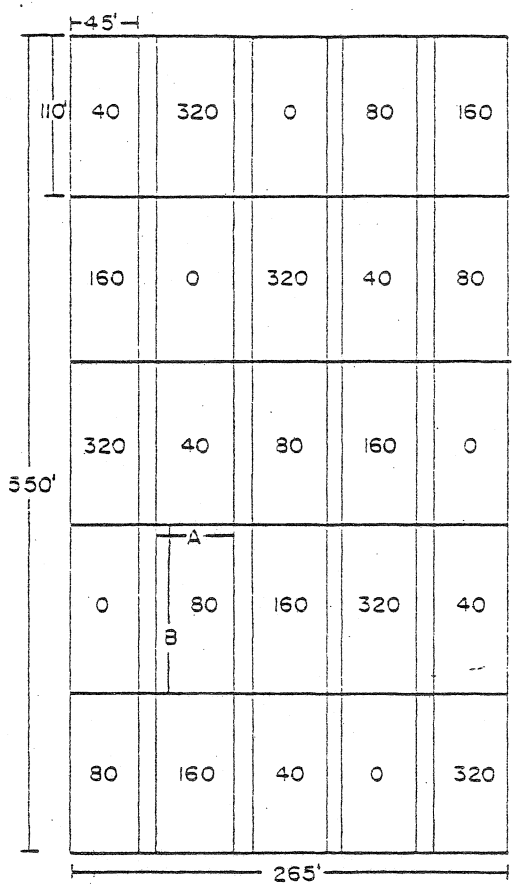
Residual phosphorus treatments of 0, 40, 80, 160 and 320 kg P/ha were applied to the major plots in the spring of 1979 preceeding the sowing of the first crop. Each major plot also had minor seed placed phosphorus treatments of 0, 5, 10, 20 and 40 kg P/ha applied to subplots within it. Each year initiates the creation of another set of seed placed treatments applied to the major plots, while existing seed placed treatments are repeated. Thus in 1981 three sets of seed placed treatments have been applied to each major or residual plot. Seed placed treatments applied in the first year of the experiment, Year 1 Plots, have received three consecutive applications of seed placed phosphorus, while Year 2 Plots received seed placed treatments in 1980 and 1981 only. Thus Year 3 Plots only received seed placed treatments in 1981.

Yield Analysis of Residual Phosphorus Plots

Residual phosphorus yield effects

Table 1 clearly indicates that maximum grain yield on plots receiving residual P treatments alone, occurs on the residual 160 kg P/ha plots (Res. 160). In 1979 and 1980 the Res. 160 treatment resulted in statistically significant yield increases over the control. The Res. 320 treatment results in no additional yield benefit over the Res. 160 treatment and appears to depress grain yield in 1979 and 1980. Res. 80 plots closely approach yields obtained by the Res. 160 plots and no statistically significant yield differences occur between them.

Figure 1



Field plot layout at Kernen Farm. P applied at designated rates as triple superphosphate (0-45-0) in the spring of 1979 to two blocks, one of which was seeded to wheat and the other to flax.

Details of a 80 kg ha^{-1} treatment (designated area AB in Fig. 1). P was seed-placed with wheat (side-banded with flax) at rates 0, 5, 10, 20 and 40 kg ha^{-1} in one strip 5 feet wide in 1979. In 1980, the seed-placed P was applied to a 10 foot strip that included the 1979 5 foot strip. In 1981 a 15 foot strip will be used.

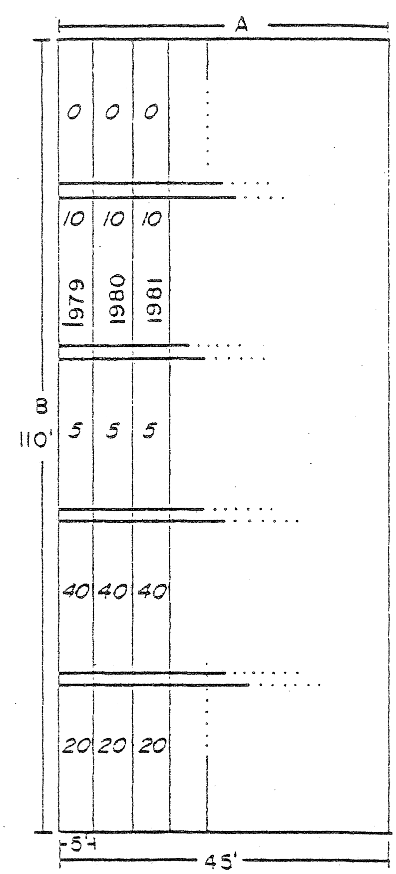


Table 1. Mean grain yields in kg/ha from residual treatments receiving no seed placed P.

	Residual treatments (kg P/ha)				
	0	40	80	160	320
1979 Year 1	2841	2906	3295^A	3458^A	3287^A
1980 Year 1	1572	1474	1767	2159^A	2086
1981 Year 1	1070	995	1244	1255	1257
1979 Year 1	2841	2906	3295^A	3458^A	3287^A
1980 Year 2	1685	1517	2168	2188	2033
1981 Year 3	1233	1279	1334	1373	1372

A - yield significantly larger than control

Seed placed phosphorus yield effects

Seed placed P treatments applied to the residual plots resulted in yield increases (Table 2). In two of the three years, the seed placed treatment of 40 kg P/ha (S.P. 40) resulted in a yield statistically significantly greater than the control. Although maximum yield is attained by the S.P. 40 treatment in all but one instance, the S.P. 40 yield is never significantly larger than the S.P. 20 treatment.

Table 2. Mean grain yields in kg/ha of seed placed treatments applied to all residual plots.

	Seed placed treatments (kg P/ha)				
	0	5	10	20	40
1979 Year 1	3157	3251	3254	3231	3330^A
1980 Year 1	1811	1908	1944	1996	1959
1981 Year 1	1164	1293^A	1200	1270	1315^A
1979 Year 1	3157	3251	3254	3231	3330
1980 Year 2	1918	1938	1892	1820	1950
1981 Year 3	1318	1318	1276	1365	1425^A

A - yield significantly larger than control

Comparison of Single Versus Multiple Seed Placed Treatments

In 1980, plots receiving the seed placed upon seed placed treatment (Year 1 Plots) did benefit from the seed placed treatment of the previous year (Table 3). This was reflected in increased yield and better consistency of response toward seed placed treatments. In 1981 this does not reoccur. The 1981 Year 1 plots have received three seed placed P applications to date. They did not respond with increased yield over the 1981 Year 3 plots where seed placed P had been applied on the current year only. However in 1981 moisture stress rather than nutrient deficiency exerted a major force on yields.

Table 3. Comparison of grain yields in kg/ha on plots receiving single and multiple applications of seed placed P, where no residual P has been applied.

	Seed placed P treatments (kg P/ha)					Total of plots receiving S.P. P
	0	5	10	20	40	
1980 Year 1 S.P. on S.P.	1572.1	1682.8	1659.9	1736.2	1715.6	6794.5
1980 Year 2 S.P.	1685.3	1662.3	1609.0	1497.5	1674.6	6443.4
1981 Year 1 S.P. on S.P. on S.P.	1070.3	1157.4	1182.0	1157.4	1209.7	4706.5
1981 Year 3 S.P.	1232.7	1162.5	1201.9	1145.3	1400.0	4909.7

Yield Comparison of the Modes of Fertilizer Application

Over the three years of the experiment, plots receiving only residual P had a maximum cumulative yield occurring on the Res. 160 plots (Table 4). The Res. 160 plots yielded 566 kg/ha (8.4 bu/acre) greater than the Res. 80 plots and 240 kg/ha (3.6 bu/acre) greater than the Res. 320 plots, over the three years.

Plots receiving only seed placed P treatments had maximum cumulative yield occurring on S.P. 40 plots. The S.P. 40 treatment exceeded the S.P. 20 treatment by 206 kg/ha (3.1 bu/acre), over the three year period (Table 5).

Table 4. Three year cumulative yield totals in kg/ha from residual plots receiving no seed placed P.

Residual P treatments (kg P/ha)				
0	40	80	160	320
5483	5374	6305	6871	6631

Table 5. Three year cumulative yield totals in kg grain/ha from seed placed treatments applied successively each year to Year 1 plots receiving no residual P.

Seed placed P treatments (kg P/ha)				
0	5	10	20	40
5483	5751	5684	5921	6127

Viewing Tables 4 and 5 together, a comparison of the effectiveness of residual versus seed placed phosphorus treatments can be made. For the first three years the Res. 80, 160 and 320 treatments all outyielded the S.P. 40 treatment. It is concluded that for the first three years the Res. 80 treatment applied initially is as yield effective as the S.P. 40 treatment applied annually.

Overall maximum cumulative yield was obtained by the Res. 80-S.P. 20 combination. This treatment obtained a cumulative yield of 7102 kg grain/ha which is 231 kg/ha (3.4 bu/acre) greater than the Res. 160-S.P. 0 treatment (Table 6) and 967 kg/ha (14.5 bu/acre) greater than the Res. 0-S.P. 40 treatment.

Table 6. Three year cumulative yield in kg grain/ha from various modes of phosphorus application.

Phosphorus treatment		Yield		Total P applied
Residual	S.P. Yearly	kg/ha	bu/acre	kg P/ha
0	0	5483	81.6	0
0	40	6126	91.2	120
40	40	6488	96.5	160
160	0	6871	102.2	160
80	20	7102	105.7	140

Analysis of yield data leads one to conclude that maximum yields are obtained from moderate residual P treatments combined with intermediate levels of seed placed P. Yield analysis of the first three years also leads to the conclusion that moderate residual P applications (80 kg P/ha) can be more effective or at least as effective as large seed placed treatments.

Phosphorus Uptake Analysis

Residual phosphorus treatments and phosphorus uptake

Statistical analysis of phosphorus uptake shows that each year the Res. 160 and 320 treatments resulted in statistically significant increases in P uptake. Phosphorus uptake increased with each increment in residual P application such that maximum uptake occurred on the Res. 320 treatment. However, maximum yield from plots receiving residual P occurred on Res. 160 plots. This fact combined with the increased concentration of P in the grain from Res. 320 plots (Table 7), indicates that luxury consumption of phosphorus has occurred.

Table 7. P uptake by wheat plant and % P in the grain from Year 1 plots receiving residual P treatments only.

Residual treatment kg P/ha	1979		1980		1981		3 Year Total P uptake kg P/ha
	kg/ha	% in grain	kg P/ha	% in grain	kg P/ha	% in grain	
0	8.73	0.28	4.21	0.27	3.22	0.27	16.16
40	10.07	0.32	4.48	0.29	3.61	0.32	18.16
80	11.70	0.32	5.49	0.29	4.67	0.34	21.86
160	12.64	0.33	7.03	0.31	5.04	0.36	24.71
320	13.00	0.37	7.41	0.34	6.45	0.44	26.86

Seed placed phosphorus and phosphorus uptake

Statistical analysis of P uptake by grain on Year 1 plots indicated that in 1979 and 1981 the S.P. 40 treatment significantly increased P uptake. In 1981 the S.P. 40 treatment resulted in P uptake statistically significantly greater than S.P. 0, 5, and 10 treatments. This indicates that repeated application of the S.P. 40 treatment is increasing P uptake. This is also shown by the increased concentration of P in the grain of the 1981 S.P. 40 treatment (Table 8).

Table 8. Phosphorus uptake by wheat plant and % P in grain from Year 1 plots which received yearly applications of seed placed P, and no residual P.

Seed placed treatment kg/ha	1979		1980		1981		Total P uptake kg P/ha
	kg P/ha	% in grain	kg P/ha	% in grain	kg P/ha	% in grain	
0	8.73	0.28	4.21	0.27	3.22	0.27	16.16
5	9.04	0.29	4.54	0.26	3.87	0.31	17.45
10	9.03	0.29	4.82	0.28	3.82	0.29	17.67
20	9.25	0.28	4.89	0.27	4.19	0.32	18.33
40	10.12	0.29	5.19	0.29	4.88	0.36	20.19

Comparison of P Uptake From Different Modes of Phosphorus Application

Maximum cumulative P uptake from plots receiving only seed placed P occurs on the S.P. 40 treatment where 20.19 kg P/ha was taken up (Table 8). This uptake is exceeded by plots receiving only residual P, by the Res. 80, 160, and 320 treatments (Table 7). Thus the moderate residual P treatment of 80 kg P/ha has to this point exceeded both the yield and P uptake of the large seed placed treatment (S.P. 40).

Where the residual and seed placed treatments were combined, the Res. 0 and Res. 40 plots responded to seed placed treatments with increased P uptake. However the S.P. 40 treatment appeared excessive on the Res. 80 plots and a decrease in yield and P uptake was noted. Seed placed treatments exceeding 10 kg P/ha on the Res. 160 and 320 plots had no consistent effect on increasing P uptake. Depressions in both uptake and yield were often noted.

The three modes of P application being studied are residual treatments alone, seed placed treatments alone and the combination of residual and seed placed treatments. The treatments resulting in maximum yield for these methods of P application have their P uptake data shown in Table 9. The Res. 80-S.P. 20 treatment which results in maximum yield also incurs increased P uptake. This is a result of both increased yield of plant material and increased concentration of P in the plant.

Overall maximum P uptake occurred on the Res. 320-S.P. 10 plots where 28.88 kg P/ha was taken up over the three years. This again indicates luxury consumption of P.

Table 9. Concentration of P in plant material and total cumulative P uptake, from the control and various modes of P application giving maximum yields.

Residual P treatment	Seed placed treatment	1979 % P		1980 % P		1981 % P		Cumulative P uptake kg P/ha	P applied kg P/ha
		grain	straw	grain	straw	grain	straw		
0	0	0.28	0.02	0.27	0.01	0.21	0.02	16.16	0
0	40	0.29	0.02	0.29	0.02	0.36	0.03	20.19	120
80	20	0.33	0.02	0.31	0.02	0.38	0.04	25.74	140
160	0	0.33	0.02	0.31	0.01	0.36	0.03	24.71	160

Fertilizer Phosphorus Transformations

The Kernen experiment is in a stage where it is still too early to determine what kind of changes the fertilizer is undergoing in the soil. However a laboratory study was carried out on soils obtained from a similar experiment which may give some insight into the kind of changes in P forms that may be expected. Read et al. (1977) carried out a study where 0, 100, 200, and 400 kg P/ha was added to Sceptre clay Chernozemic soil preceeding an eight-year fallow-wheat rotation.

Hedley and Stewart (1982) used a sequential extraction procedure to examine the distribution of labile, moderately labile, and more stable inorganic and organic P in soils (Table 10). When this phosphorus extraction technique was applied to the soil of the Read study, only two of the six major soil P fractions delineated by the procedure showed substantial change after addition of fertilizer P (Figure 2).

Table 10. Details of the Hedley sequential extraction: the extractants and types of soil phosphorus removed by them.

Extractant	
Resin	Labile Pi
0.5 M $NaHCO_3$	Labile Pi and labile Po
0.1 M NaOH	Moderately labile clay adsorbed Pi and Po
Ultrasonification and 0.1 M NaOH	Aggregate protected Pi and Po
1.0 M HCl	Stabile inorganic cpds, i.e. HA, OCP
H_2SO_4 digestion	Resistant P, mainly Po

Ref: Stewart et al., 1980.

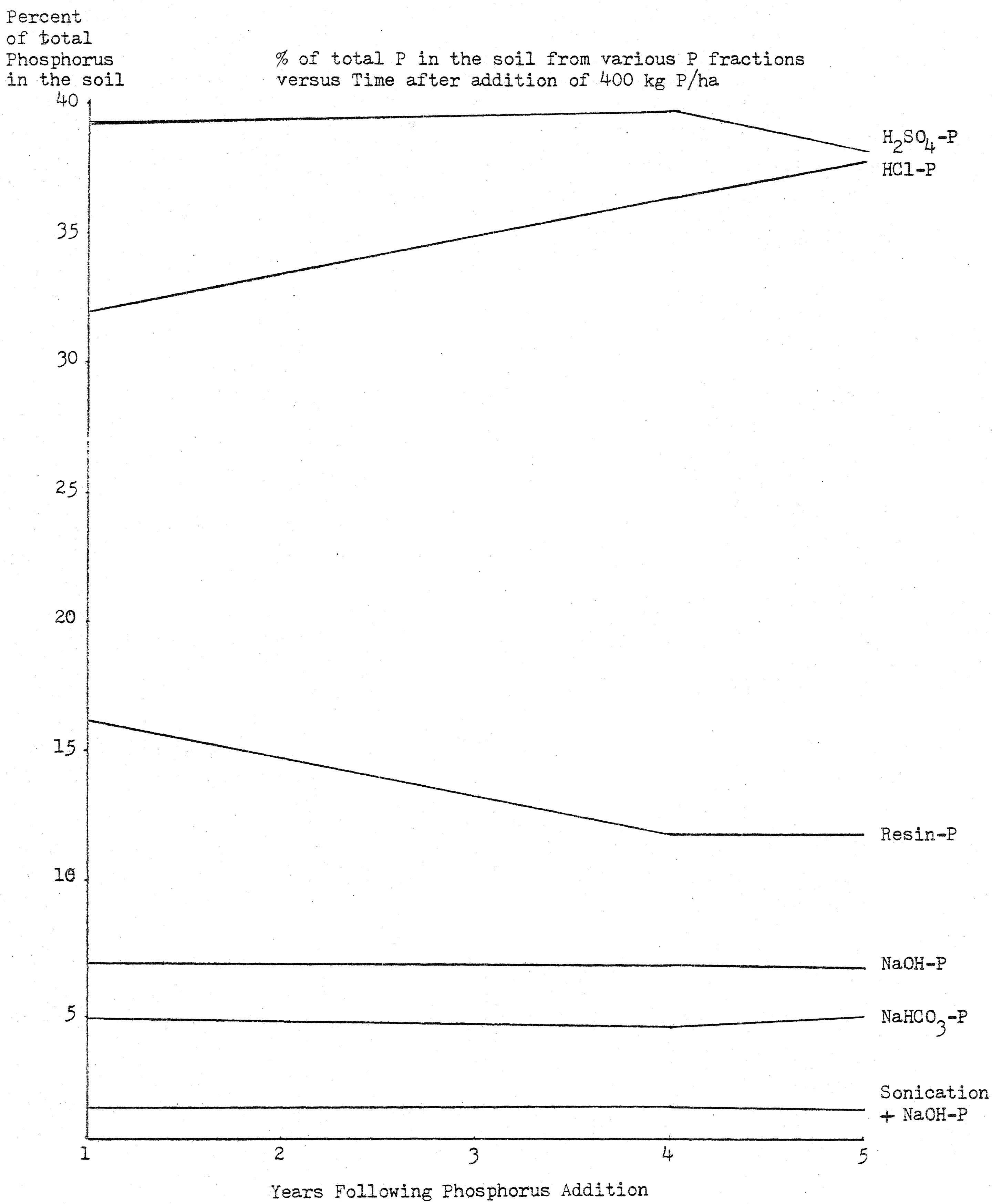
Resin-P is highly plant available inorganic phosphorus. Bowman et al. (1978) found resin extracted an average 89 percent of total plant available P. Figure 2 shows how the level of resin-P in the soil drops with time after addition of 400 kg P/ha. One year after fertilizer addition, resin-P contains 16.1% (138 ppm) of total soil P. Five years after fertilizer addition resin-P drops to 11.8% (100 ppm) of total soil P. Even so, this level of resin-P remaining in the soil five years after fertilizer phosphorus addition, means 40% of the fertilizer P still remains in a highly plant available form.

The HCl-P fraction contains stable inorganic P components such as hydroxyapatite and octacalcium phosphate. This fraction is relatively stable thus has low plant availability. Figure 2 shows the increase in HCl-P with time after fertilizer addition. The HCl-P goes from 31.9% (273 ppm) of total soil phosphorus in year 1 to 37.7% (319 ppm) of total soil phosphorus five years after fertilizer addition (Table 11).

Table 11. Change in P content, with time, of various soil phosphorus fractions extracted by the Hedley sequential extraction technique following addition of 400 kg P/ha to a Sceptre soil.

	Resin-P	$NaHCO_3$-P	NaOH-P	Son. NaOH-P	HCl-P	H_2SO_4-P	Total
Year 1	137.9	40.0	57.9	10.0	272.9	335.7	854.4
Year 5	99.8	39.5	55.9	9.1	319.3	323.1	846.7

Figure 2. Changes in soil phosphorus forms following addition of fertilizer phosphorus.



From all the above evidence it is possible to postulate that the Kernen soils, where amended with P fertilizer, should experience a decrease in highly available inorganic P, with the formation of less available crystalline phosphates of an apatite-like nature. If the Kernen soils react to phosphorus additions as the Sceptre soil did, one would also expect the intermediately labile NaOH fractions made up of both organic and inorganic P to remain relatively constant. However the questions yet to be answered are: will the formation of these less available apatite-like phosphates be substantial enough to negate residual P utilization; and does the level of residual P application influence the rate of formation of these stable compounds?

Phosphorus Zinc Interaction

Effects of residual phosphorus on zinc uptake

Zinc uptake by grain on the Res. 320 plots experienced a statistically significant reduction during each year of the experiment. In 1979 maximum zinc uptake occurred on Res. 0 plots, where 124.79 g Zn/ha was removed (Table 12). Grain uptake accounted for 108.71 g Zn/ha being removed from the Res. 0 plots. The grain uptake by Res. 160 and 320 treatments was 77.06 and 76.45 g Zn/ha, respectively, both significantly reduced from the control. In 1980 maximum zinc uptake occurred on the Res. 80 plots, though the uptake by grain was not significantly increased over the Res. 0 plots. However, the Zn uptake by grain on the Res. 320 plots was significantly lower than on the Res. 80 plots. In 1981 maximum zinc uptake occurred again on the Res. 0 plots. The zinc uptake by grain on the Res. 0 plots was 51.97 g Zn/ha with the Res. 320 zinc uptake of 40.48 g Zn/ha being a statistically significant reduction.

Table 12 shows the concentration of zinc in both grain and straw to decrease with increasing residual P treatments. Res. 40 and Res. 80 treatments show minor reductions while the zinc concentrations in plant material from Res. 160 and Res. 320 treatments drop substantially. Residual P treatments have clearly reduced zinc concentration and total uptake.

Table 12. Average residual treatment values of Zn uptake in g Zn/ha and average concentration of Zn in plant material in μg/g of Year 1 plots.

Residual treatment kg P/ha	Grain Zn conc.			Straw Zn conc.			Grain uptake g/ha			Total uptake g/ha			3 Year total Zn uptake
	1979	1980	1981	1979	1980	1981	1979	1980	1981	1979	1980	1981	
0	37	46	31	4	19	11	108.71	77.16	51.97	124.77	109.55	70.49	304.81
40	30	39	29	5	13	8	91.92	65.19	47.63	113.02	87.11	60.81	260.94
80	25	47	23	5	11	4	85.43	99.13	47.85	107.34	123.47	53.89	284.70
160	17	39	20	4	8	8	58.03	84.16	43.16	77.06	102.34	58.13	237.53
320	17	29	20	4	7	2	58.41	58.19	40.48	76.45	72.96	43.73	193.14

Effect of seed placed phosphorus on zinc uptake

Statistical analysis of seed placed means indicated that seed placed phosphorus also had an effect on reducing zinc uptake. Analysis of Year 1 plots resulted in the S.P. 40 treatments consistently showing the lowest zinc uptake. In 1979 zinc uptake by S.P. 20 and S.P. 40 treatments was significantly lower than S.P. 0 and S.P. 5 treatments. Plots in 1980 showed no statistically significant differences in zinc uptake due to seed placed treatments. However, the S.P. 40 treatment resulted in lowest zinc uptake. In 1981 the S.P. 40 treatment had zinc uptake which was significantly lower than the S.P. 5 and S.P. 10 treatments.

Table 13 illustrates the reduction in zinc concentration of plant material due to seed placed treatments. S.P. 10, S.P. 20, and S.P. 40 treatments increasingly reduce zinc concentrations within both grain and straw, which is reflected in decreased total zinc uptake. The reduction in zinc uptake due to seed placed P is less in magnitude than the larger residual treatments, however, the phenomenon still occurs.

Table 13. Zn uptake on Year 1 plots receiving seed placed phosphorus alone.

Seed placed treatments kg P/ha	Concentration of Zn in grain (μg/g)			Concentration of Zn in straw (μg/g)			3-Year total Zn uptake g Zn/ha
	1979	1980	1981	1979	1980	1981	
0	44	51	56	4	19	21	343.04
5	43	45	49	12	30	12	376.78
10	35	49	46	8	17	12	317.90
20	34	44	40	8	13	9	295.42
40	28	41	37	4	13	6	254.45

References to zinc concentrations in plant tissue necessary to avoid deficiencies in wheat plants are few. No references at all are available to indicate necessary levels for Saskatchewan conditions and wheat varieties. However, Chapman (1966) states that deficiency levels are characterized by zinc levels of less than 20-25 ppm in plant dry matter. He also states that oats experience deficiencies where the zinc concentration is less than 20 ppm when the whole above ground plant is sampled before inflorescence. Radjagukguk et al. (1980) found deficiency symptoms in wheat plants where the Zn concentration of the complete top at 7 weeks dropped to 19.6 μg/g or less. They determined the critical level of zinc concentration where 90% of maximum dry matter was attained to be 20 μg/g.

In the Kernen experiment plant tissue samples were taken at tillering and flag leaf stages of growth. Zinc concentrations in plant matter at tillering may be influenced by Zn concentrations in the seed.

Thus zinc concentrations of the entire above ground plant at the flag leaf stage may be most indicative of zinc deficiencies. This data is presented in Table 14 for 1979 and 1981. Unfortunately, uneven growth stages in 1980 made sampling of the flag leaf stage difficult.

Table 14. Average zinc concentration of μg/g of above ground plant material at the flag leaf stage from the residual treatments.

Residual treatment (kg P/ha)	1979	1981
0	26.8	39.0
40	22.1	32.0
80	18.7	30.0
160	18.4	30.2
320	15.3	22.8

Data in Table 14 combined with present recommended zinc concentrations in plant matter would suggest that in 1981 only marginal levels of zinc were found in plants from the Res. 320 treatments, while levels in 1979 were low. In 1980, zinc concentrations on the Res. 320 plots at tillering averaged 25.7 μg/g, compared to 32.8 μg/g and 41.0 μg/g for Res. 160 and Res. 0 plots, respectively. Thus borderline zinc levels on Res. 320 treatments may explain why yields were consistently lower than Res. 160 yields.

The most probably explanation of the Zn x P interaction is that of Lambert et al. (1979) who related decreases in Zn uptake to observed decreases in mycorrhizal infection on plants grown under high P treatments. We could not provide conclusive evidence to support or disagree with this explanation in our field observation in 1981. However, ongoing work will examine both (1) the response of high P treatment to added Zn and (2) the effect of high P on mycorrhizal infection of wheat roots.

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