MANAGEMENT EFFECTS ON PHOSPHORUS TRANSFORMATION AND IMPLICATIONS FOR SOIL TEST RECOMMENDATIONS

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ABSTRACT

Crop rotations and fertilizer application on long-term rotation plots at Lethbridge and Breton have dramatically affected most soil phosphorus (P) fractions. At the Lethbridge site, soil cultivation has reduced organic phosphorus (Po) levels as a result of mineralization. This has caused a significant increase in resin extractable Pi (most biologically available Pi), sodium bicarbonate extractable Pi (sorbed to soil surfaces) and sodium hydroxide extractable Pi (more strongly bound to Al and Fe compounds) levels. In non-fertilized treatments, continuous wheat (CW) resulted in greater P drawdown of all labile P fractions than in wheat-wheat-fallow (WWF) and wheat-fallow (WF) rotations. The addition of P fertilizer has significantly increased Resin-Pi, Bicarb-Pi and NaOH-Pi fractions. The addition of N fertilizer has resulted in increased Bicarb-Po and NaOH-Po levels in the CW, WF, and WWF rotations. At the Breton site, continuously cropped treatments, which had not received fertilizer, resulted in greater P drawdown of all P fractions except Residual-P. Addition of fertilizer had a significant effect on all P fractions (except NaOH-Po). The added P in the fertilizer treatments positively affected the Pi fractions and the N in the fertilizer treatment positively affected the Po fractions. Bicarb-Po levels were found to be negatively affected by soil pH. Finally, cropping without using phosphate fertilizer has resulted in a 30 to 41% decline in Total-P in the Breton plots.

A growth chamber study was conducted to compare four routine soil test P methods with plant uptake of P. Wheat and canola were each grown in eight soils from the Lethbridge and Breton plots with different pedogenic, crop rotation and fertilizer histories. Results of the study confirm that one calibration curve to predict P fertilizer requirements for a wide range of soils and crops is virtually impossible. Future soil tests will combine a chemical extractant with a computer model prediction of Po mineralization. Much more information is needed on root rhizosphere dynamics.

INTRODUCTION

In the past three decades, routine testing of soil for plant available P has been carried out in North America and a variety of soil test methods have been proposed (Olsen et al. 1982). Of these, two methods have been commonly used in western Canadian laboratories. Manitoba and Saskatchewan use a solution of 0.5 M sodium bicarbonate (Olsen et al. 1954) and Alberta uses a weak sulphuric acid and ammonium fluoride solution (Miller and Axley 1956). Recently, the Kelowna laboratory in British Columbia has proposed a third method which is a solution of ammonium acetate, ammonium fluoride and acetic acid (Van Lierop 1985 and Yee and Broersma 1987). All tests are simple to carry out (soil solution ratios 1:10 or 1:20 and have a short shaking time <30 minutes, solutions are filtered and P determined either chemically or in a plasma arc spectrometer). Most tests were originally validated with field and growth chamber studies and over the years extensive data has accumulated from P fertility studies that provide a data base to compare the effectiveness and accuracy of these tests. Recently, several reports (Innovative Acres 1988, McKenzie et al. 1987) have queried the validity of the Olsen test on stubble (continuously cropped land) while verifying its use on fallow land. Soils which have accumulated fertilizer P over the years may still test deficient in plant available P, yet crops may not respond to added P fertilizer. This has posed a serious problem for farmers trying to optimize their P fertilizer use through the interpretation of soil tests.

There are a variety of problems which complicate the accuracy of P tests. Plant roots explore less than 1% of the top 20 cm of soil and the rhizosphere is the zone where plants remove the majority of their required P. The area explored by roots can be slightly extended by vesicular-arbuscular mycorrhiza (VAM) infection. Not all plants are infected by VAM (i.e. canola). Therefore, soil analysis of bulk soil samples must be representative of and correlated with the processes than occur in the root rhizosphere. Secondly, the P cycle is essentially ignored in soil testing. Soil analysis is designed to be rapid and provide quick answers on P fertilizer requirements. As a result, the dynamics of the soil P cycle are not taken into account, which leads to difficulty in providing P fertilizer recommendations. Of course with any test spatial variability of soil properties may result in widely different nutrient levels within a field. Even obtaining a representative composite soil sample for analysis from a field can be a challenge.

QUESTIONS

Can rapid soil tests can be used to predict P fertilizer requirements? Before we can recommend any particular method, two basic questions have to be answered:

1) Does the labile P truly reflect available P status over a range of management practices, or should other soil P forms be considered, and

2) Do all crops use the same form of soil phosphorus?

Answers to the first question may be found by investigating the soil P transformations that have occurred on two long-term crop rotation plots in Alberta. The plots are located at the Agriculture Canada Research Station, at Lethbridge and the University of Alberta plots, near Breton. The first objective of this study was to characterize the changes in soil P form and availability as affected by crop rotation and fertilizer practices. These changes will be discussed in relation to concepts of P cycling (Figure 1) (Stewart and Tiessen 1987).

The second objective will be to determine the ability of two different crops (wheat and canola) to utilize the various P forms in the long-term plots. Plant uptake will be compared to results of four soil test extractants.

MATERIALS AND METHODS

Site Description and Soil Sampling

The study was conducted using surface soil samples taken from specific treatments in long-term crop rotation experiments. The Lethbridge site was initiated in 1912 on a sandy clay loam, Calcareous Dark Brown Chernozem (Peters et al. 1978) at the Agriculture Canada Research Station, east of Lethbridge, Alberta. The soils in this area belong to the Lethbridge soil series and were developed on lacustrine parent material under short prairie grass vegetation.

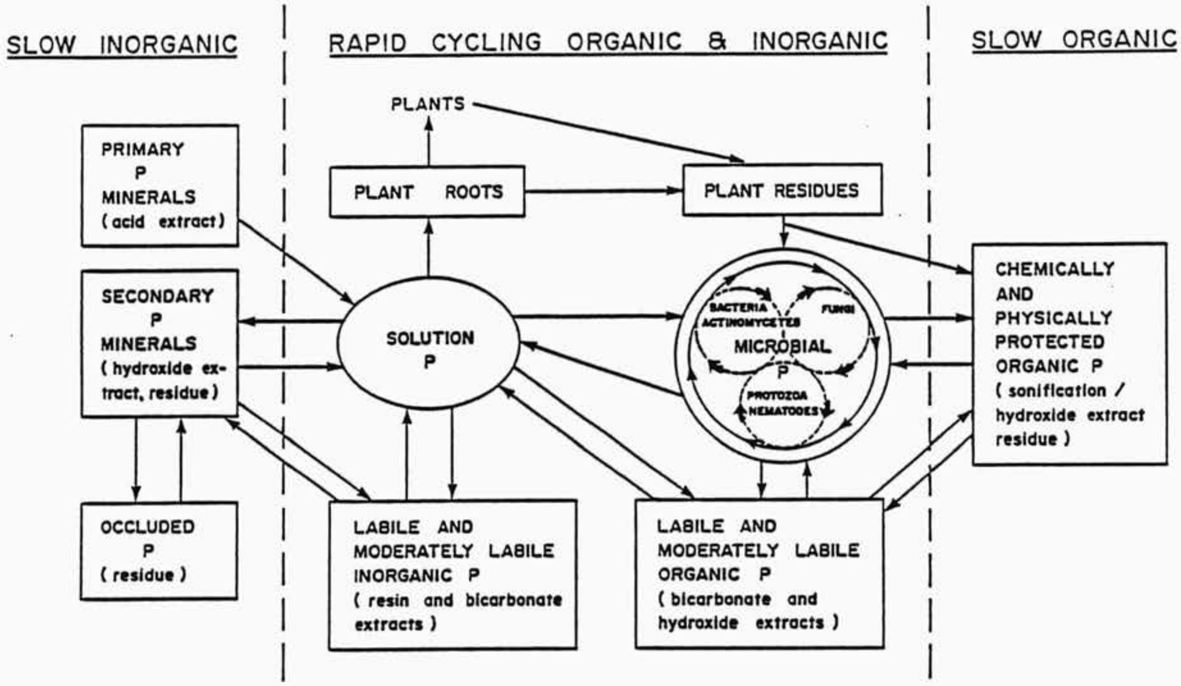

Figure 1. The soil phosphorus cycle.

The site has three dryland grain rotations: A: continuous wheat (CW), B: wheat-fallow (WF) and C: wheat-wheat-fallow (WWF) (Janzen 1987). In 1967 the plots were altered to include an annual application of 45 kg N ha^{-1}, in the ammonium nitrate form, broadcast and incorporated on a portion of each field every year, including fallow years. In 1972, phosphorus fertilizer treatments were superimposed to produce a factorial of two N rates (0 and 45 kg N ha^{-1}) by two P rates (0 and 20 kg P ha^{-1}) in each rotation.

The Breton site was initiated in 1930 by the University of Alberta Soil Science Dept. The plots are located south east of the town of Breton, Alberta. Soil at the site is loam textured and classified as an Orthic Gray Luvisol. The soils in this area belong to the Breton soil series and were developed on glacial till parent material, under boreal forest vegetation.

The Breton plots consist of two crop rotations: a five year grain-forage rotation (Series A, B, C, D and F) and a wheat-fallow rotation (Series E). The WF rotation consists of 11 treatments, which receive a variety of fertilizers and each treatment is split, with half in grain and half in fallow each year. All plots in Series E have been limed. The continuously cropped (CC) grain-forage rotation includes wheat, oats, barley under seeded to forage, forage 1 and forage 2, with each having the same 11 different management treatments. The crops are rotated on Series A, B, C, D and F. Lime was applied on the east half of all the treatments in 1972. The treatments selected for study were: numbers 1 (control) and 3 (NPKS) of Series E and numbers 5 (control) and 3 (NPKS) of Series A. Both the limed and unlimed sides of each treatment were investigated. The controls have not received any fertilizer since establishment in 1930. The NPKS treatments received 11, 6, 16 and 9 kg ha^{-1} yr^{-1} of N, P, K and S respectively from 1930 to 1979. Since 1980, the N rates have varied depending on crop and the P, K and S rates were adjusted to 22, 46 and 5.5 kg ha^{-1} yr^{-1} respectively (J.R. Robertson, personal communication). Tables 1 and 2 provide a description of the treatments sampled at each site.

Table 1. Abbreviations and descriptions of the rotation treatments sampled at the Lethbridge plots

Treatment	Treatment description (since 1972)
CWCH	A Continuous Wheat, Check
CWNO	A Continuous Wheat, Nitrogen (45 kg N ha^{-1})
CWNP	A Continuous Wheat, Nitrogen and Phosphorus (45 kg N + 20 kg P ha^{-1})
CWPO	A Continuous Wheat, Phosphorus (20 kg ha^{-1})
WFCH	B Wheat-Fallow, Check
WFNO	B Wheat-Fallow, Nitrogen Only
WFNP	B Wheat-Fallow, Nitrogen and Phosphorus
WFPO	B Wheat-Fallow, Phosphorus Only
WWFCH	C Wheat-Wheat-Fallow, Check
WWFNO	C Wheat-Wheat-Fallow, Nitrogen Only
WWFNP	C Wheat-Wheat-Fallow, Nitrogen and Phosphorus
WWFPO	C Wheat-Wheat-Fallow, Phosphorus Only
NATIVE	Undisturbed Native Soil

Table 2. Abbreviations and descriptions of the series treatments which were sampled at the Breton plots

Treatment	Series	Crop in 1986	Treatment
Bush	Native Soil		
CCCL	Series A	Oats	Control + Lime
CCCO	Series A	Oats	Control + No Lime
CCFL	Series A	Oats	Fertilized + Lime
CCFO	Series A	Oats	Fertilized + No Lime
WFCF	Series E	Fallow	Control
WFCS	Series E	Wheat	Control
WFFF	Series E	Fallow	Fertilized
WFFS	Series E	Wheat	Fertilized

Soil Analysis

Sample preparation -- Soil samples were ground to pass a 40-mesh sieve for specialized P analysis and were analyzed using the Hedley procedure (Hedley et al. 1982).

RESULTS

The results of fractionation at the Lethbridge and Breton sites are provided in Tables 3 and 4 respectively.

Table 3. Geometric means of soil P fractions from rotation plots at Lethbridge using the Hedley extraction procedure (µg P/g soil)

Treatment	Resin-Pi	BIC-Pi	BIC-Po	NaOH-PI	NaOH-Po	HCL-Pi	RESID-P	SUM-P
CWCH	18.9	7.4	4.4	19.8	51.1	201	219	529
CWNO	14.6	7.5	8.9	21.6	64.8	195	215	529
CWNP	78.1	25.4	9.3	44.1	65.6	214	220	658
CWPO	72.6	18.8	5.9	35.6	61.1	212	223	632
WFCH	42.8	14.3	7.8	35.3	58.9	217	209	585
WFNO	36.0	13.3	8.3	32.3	60.5	212	213	577
WFNP	59.3	17.9	8.9	37.6	62.9	221	213	622
WFPO	67.5	17.8	6.8	38.5	56.0	226	215	629
WWFCH	19.2	8.0	4.9	22.2	52.2	199	214	521
WWFNO	15.0	7.1	5.0	20.3	58.6	203	218	529
WWFNP	50.7	16.1	4.8	32.2	58.6	215	222	603
WWFPO	60.6	15.4	4.4	30.9	49.4	213	220	596
NATIVE[1]	8.8	5.7	7.4	11.4	72.0	218	254	577
SEi[2]	Xi(.0555)	Xi(.0455)	Xi(.0671)	Xi(.0372)	Xi(.0310)	Xi(.0166)	Xi(.0105)	Xi(.0122)

[1] Soil fractions from native grassland were not included in statistical analysis and are provided for simple comparison only.

[2] The standard error (SE) for each treatment can be calculated by multiplying the geometric mean of the treatment by the value in parentheses at the bottom of the column.

Table 4. Geometric means of soil P fractions from the Breton plots using the Hedley extraction procedure (µg P/g soil)

Treatment	Resin-Pi	BIC-Pi	BIC-Po	NaOH-PI	NaOH-Po	HCL-Pi	RESID-P	SUM-P
BUSH	57.7	55.8	31.3	154.8	100.9	241	169	815
CCCL	10.8	12.9	20.7	56.9	64.1	226	176	568
CCCO	9.2	11.8	21.3	56.4	63.1	209	173	545
CCFL	45.5	38.4	23.4	120.1	63.7	246	194	732
CCFO	40.9	40.0	29.3	124.1	65.9	228	185	714
WFCF	23.5	20.4	13.8	63.6	43.6	246	159	570
WFCS	18.6	15.2	11.7	50.4	38.7	187	156	478
WFFF	57.9	37.9	18.6	98.7	54.4	282	161	712
WFFS	47.5	39.5	18.1	104.7	54.6	266	155	688
SEi[1]	Xi(.0756)	Xi(.0621)	Xi(.0339)	Xi(0.380)	Xi(.0324)	Xi(.0282)	Xi(.0157)	Xi(.0231)

[1]The standard error (SE) for each treatment can be calculated by multiplying the geometric mean of the treatment by the value in parentheses at the bottom of the column.

DISCUSSION

Lethbridge Study

The yields obtained over the initial period (1912-1986) when fertilizer was not applied is shown in Figure 2. Yield responses to fertilization (1972-1986) are shown in Figure 3.

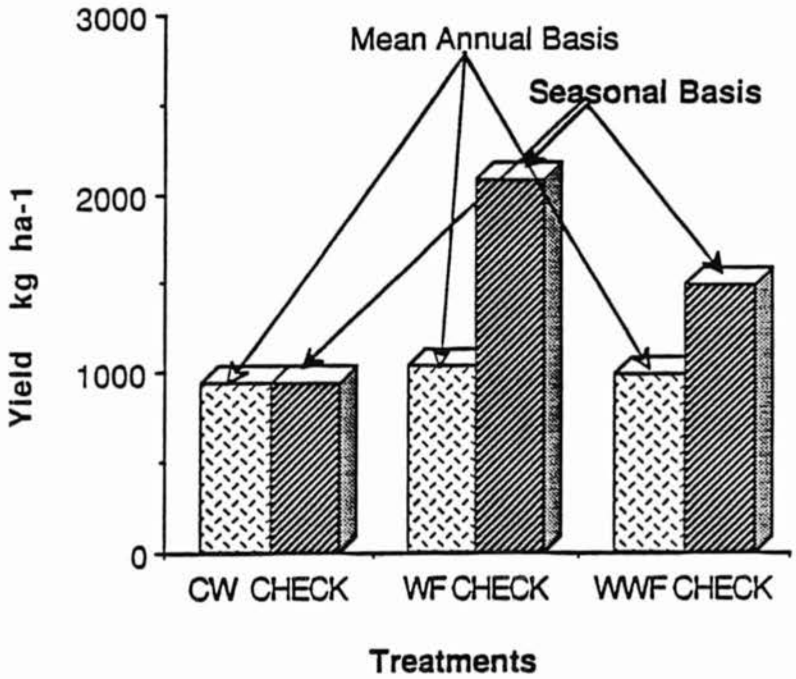

Figure 2. Yield of grain 1912-1986, long-term plots Lethbridge.

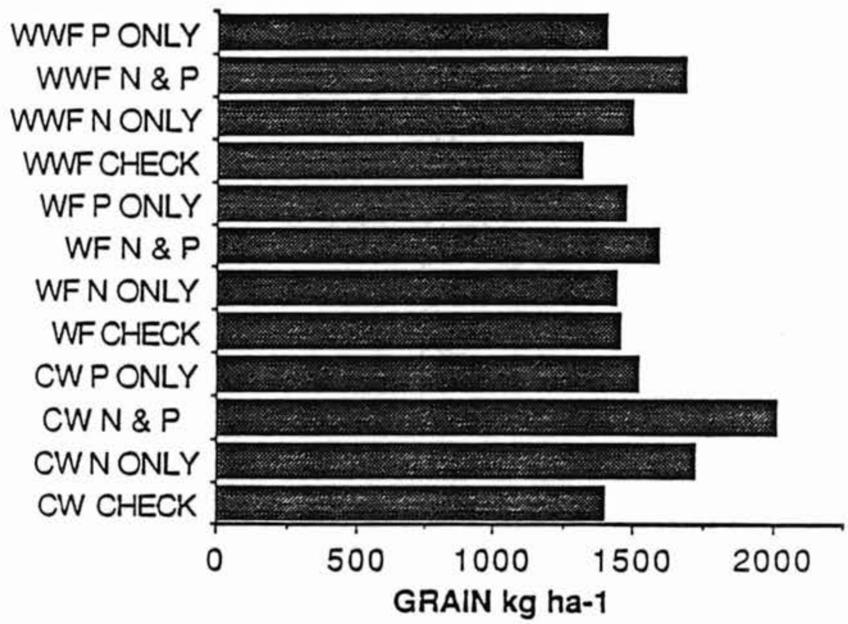

Figure 3. Yield of Lethbridge long-term plots 1972-1986.

Effect of Rotation -- Comparison of the CW, WWF and WF Rotations indicates the changes in soil P that resulted from the three different cropping systems.

Rotations which include a fallow period generally have greater losses of organic matter (Ridley and Hedlin 1968, Dormaar and Pittman 1980) than continuously cropped fields. At Lethbridge, Janzen (1987) found organic C contents in the unfertilized treatments to be approximately 12% higher in the CW rotation than in the WWF rotation.

Resin-Pi levels were significantly affected by crop rotation. Levels in the check and N only treatments in the WF rotation were 226 and 247% higher than the respective treatments in the CW rotation. One hypothesis is that the WF rotation treatments were in a fallow condition every second year, resulting in reduced P uptake by plants. The Total-P levels in soil confirm that less P has been removed from the WF than CW or WWF rotations. A second reason for higher Resin-Pi levels in the WF rotation is increased mineralization of Po from soil organic matter during fallow periods. Results show that more frequent fallow periods resulted in greater decline in Residual-P levels (Table 3). With up to 60% of the Residual-P in organic form, this fraction has made a direct contribution to replenishing the supply of labile Po fractions via oxidation and breakdown reactions (Schoenau et al. 1989). Therefore, higher levels of Resin-Pi have resulted in the WF rotation than in the other rotations. The Bicarb-Pi and NaOH-Pi levels of the check and N only fertilizer treatments in the WF rotation were also significantly higher than in either the CW or WWF rotations for the same reasons.

The Bicarb-Po and NaOH-Po levels in the CW and WWF rotations measured in this study were not significantly different. Further, the WF rotation was not as detrimental to labile and moderately labile Po pool size as it was to soil organic matter content in general. The detrimental effect was primarily on the Po from the residual-P fraction (discussed later in this section). Further, the CW and WWF rotation treatments without added fertilizer placed an added drain on the labile and moderately labile Po fractions. More frequent C additions to soil in the CW and WWF rotations, would provide additional energy for microbial activity and hasten breakdown of Po compounds.

Without N and P fertilizer additions, the Bicarb-Po and the more stable NaOH-Po, HCl-Pi and Residual-P fractions have suffered a significant decline in the cultivated soils in all three rotations (except Bicarb-Po in the WF rotation). However, the CWNP treatment has resulted in establishing a higher level of Po in the Bicarb and NaOH fractions as a direct result of increased crop residue return to the soil. Similar observations have been made by O'Halloran (1986) and Wagar et al. (1986). Further support comes from Janzen (1987) on the Lethbridge plots, where the N-fertilized CW treatment increased organic C content by 14%, organic N by 15%, and relative N mineralization potential by 22%. The combined effect of N fertilizer and continuous cropping has significantly enhanced both the labile N pool (Janzen 1987), and the labile Po levels (as estimated by Bicarb Po and NaOH Po level).

Although true statistical comparison of the rotation plots to the nearby Native soil was not possible, it was interesting to note that Resin-Pi, Bicarb-Pi, and NaOH-Pi levels in the cultivated soils were all higher than the levels in the undisturbed Native soil. The Bicarb-Po level in the WFCH treatment was not much different from the Native soil level. However, in the CW and WWF unfertilized treatments, the Bicarb-Po levels were 41 and 33% lower, respectively, than the Native soil level. Further, the NaOH-Po fraction in the Native soil ranged from 1.2 to 1.4 times higher than levels in the unfertilized rotation plots. The decline was the result of 74 years of cultivation and cropping, resulting in increased mineralization of Po compounds. The decline in Po has contributed to large increases in the Resin-Pi, Bicarb-Pi and NaOH-Pi fractions in all three rotations. Also, an 11.9 to 17.5% decline in Residual-P between the Native soil and the cultivated soils represents a significant loss of Po.

Influence of Phosphorus Fertilizer -- Without added P fertilizer, calculations estimate 283 to 308 kg ha^{-1} of P have been exported from the plots, with virtually every pool of P being affected. However, with annual P additions of 20 kg ha^{-1} in the past 14 years, there has been a dramatic change in P transformations. With P additions now exceeding P removal rates, a net increase in all soil Pi pools is clearly emerging.

The differences in measured Total-P between the control and N&P treatments of the CW, WWF and WF rotations were 258, 152 and 88 kg ha^{-1} respectively (Table 3) in the 0-15 cm depth of soil, while the calculated P removal (from harvested grain) values were 260, 155 and 109 kg ha^{-1} respectively. This suggests that virtually all the P taken up by plants has come from the top 15-cm of soil in the CW and WWF rotations.

Resin-Pi levels were 5.7 to 8.9 times higher, Bicarb-Pi levels were 2.7 to 4.5 times higher and NaOH-Pi levels were 2.7 to 3.9 times higher in P-fertilized treatments than in the Native soil. O'Halloran (1986), studying P transformations in a Brown Chernozem at Swift Current, Saskatchewan, observed increased Resin-Pi, Bicarb-Pi, and NaOH-Pi levels, similar to this study.

The addition of P fertilizer without N had no significant effect on the Bicarb-Po and NaOH-Po fractions. This is in agreement with O'Halloran results (1986) who further proposed that the addition of P fertilizer with continuous cropping has reduced the losses of Po from the soil in the more resistant Po fractions. The NaOH-Po levels in the P fertilized treatments of the CW rotation were significantly higher than the NaOH-Po levels in the same treatments in the WWF and WF rotations (Table 3). Observations in this study therefore support O'Halloran's findings.

Influence of Nitrogen Fertilizer -- There was a highly significant N effect on the CW, WF and WWF rotations. The additional N and P fertilizer in the CW rotation increased yields by 44% in the past 15 years. Nitrogen and P fertilizer have also increased C return to the soil by approximately the same proportion.

In all three rotations, the N only fertilizer treatments had lower Resin-Pi levels than their respective check treatments. In the WF and WWF rotations, the N & P fertilizers treatment also had lower Resin-Pi levels compared with the respective P only fertilizer treatment. This was due to increased crop growth from N fertilizer application resulting in a greater drawdown of P fertilizer.

Fertilizer treatments had a much different effect on Bicarb-Po versus the Bicarb-Pi fraction. The fundamental difference was that P fertilizer had no overall effect on Bicarb-Po levels whereas N fertilizer overall had highly significant effects. Nitrogen fertilizer promoted crop growth and therefore C return to soil, which resulted in increased soil organic matter content as well as increased Bicarb-Po and NaOH-Po levels.

Overall, N fertilizer had two primary effects. The first was to significantly increase the Bicarb-Po and NaOH-Po fractions. Increases were most dramatic in the NaOH-Po fraction in all three rotations. Fertilizer N additions promoted increased root growth, root exudation and above ground biomass being returned to the soil, resulting in increased soil Po levels. Secondly, N had a significant interaction effect with P fertilizer. In the CW rotation, the positive interaction effect resulted in the highest levels of Resin-Pi, Bicarb-Pi and Po, NaOH-Pi and Po, and HCl-Pi levels compared with all other treatments. The negative interaction effect in the WF and WWF treatments resulted from additions of N and P causing increased crop growth and therefore significantly greater drawdown of Resin-Pi. The increased available moisture from fallow periods was partly responsible for the different interaction effects of the CW rotation versus the other rotations.

Breton Study

Influence of Rotation -- The comparison of the two-year WF and the five-year CC rotations in the Breton plots has revealed dramatic differences in soil P cycling. Although the WF cropping system is no longer widely used in the Luvisolic soil area, the changes observed provide a useful comparison with the more frequently utilized continuous cropping system.

The control and NPKS treatments in the CC rotation returned 240% and 400% more C to the soil than the respective treatments in the WF rotation resulting in substantially higher % C in the CC rotation soils than in the WF rotation (McGill et al. 1986).

Phosphorus transformations were highly influenced by crop rotation. Overall, Resin-Pi levels in the unfertilized treatments in WF were significantly higher than in CC. The comparison of unfertilized, limed CCCL treatment with the WFCS unfertilized treatment revealed some interesting transformations. The Resin-Pi and Bicarb-Pi levels in the unfertilized CC treatments were significantly lower than in the WF treatments, because of greater drawdown of Pi by annual cropping versus treatments in fallow every second year. Resin-Pi and Bicarb-Pi levels in CC treatments have declined approximately 80 to 82%, in comparison to the Native soil levels. In WF treatments the levels declined by only 59 and 64%. The Resin-Pi levels in the Native soil were much higher than expected. The bush and grass growth were reasonably dense, and one would have expected a greater drawdown of the Resin-Pi. The Native soil Bicarb-Pi levels were significantly higher than all the sampled Breton plot treatments. The NaOH-Pi levels in CC and WF declined by 63 and 59%, respectively, compared with the Native soil, indicating a very dramatic reduction in NaOH-Pi levels. This demonstrates that cropping without added fertilizer has greatly reduced plant available Pi levels in Luvisolic soils. Even a decline in HCl-Pi levels occurred in under continuous cropping.

There was approximately a 35 to 36% decline in Bicarb-Po, a 36 to 42% decline in NaOH-Po and a 4 to 9% increase in Residual-P in the unfertilized CC rotation compared with the Native soil levels. The Bicarb-Po, NaOH-Po, and Residual-P levels in the unfertilized CC treatments were significantly higher than in the WF treatments. This indicated that higher C return to the soil by continuous cropping has slowed down the decline of Po fractions in comparison with the WF rotation.

The cropping effect had several major influences. The more biologically available Pi suffered greater drawdown in unfertilized CC rotation than in the WF rotation. Continuous cropping has slowed the breakdown and decline of Bicarb-Po and NaOH-Po fractions, and aided in a slight increase of Residual-P. Finally, cropping without fertilization has resulted in a 30 to 41% decline in Total-P in the Breton plots.

Influence of Fertilizer -- Estimates indicate that 129 and 258 kg ha^{-1} of P have been removed from the control treatments of the WF and CC rotations respectively. Virtually every soil P fraction has been affected. However, in the NPKS treatments, 6 kg ha^{-1} of P were added to each crop until 1979 when the rate was increased to 22 kg ha^{-1} yr^{-1}. The added P clearly changed the pathways of P cycling in the fertilized versus unfertilized treatments. The recent increase in the P application rate has imposed a greater effect on P transformations with additions of P exceeding exports of P from the soil.

Even with the modest P application of 6 kg ha^{-1} yr^{-1}, all P fractions were affected by fertilizer, which resulted in reduced P drawdown and contributed to increases in some P fractions. The P in the fertilized treatments significantly contributed to Resin-Pi, Bicarb-Pi, NaOH-Pi and possibly HCl-Pi levels. Higher Resin-Pi and Bicarb-Pi levels were expected. However, Bicarb-Pi levels in fertilized treatments of Series A and C were still 28 to 51% lower than Native soil levels. The NaOH-Pi level in the Native soil was 127 to 298% higher than the Breton plot treatments, indicating a very dramatic reduction in NaOH-Pi levels, even with fertilizer use, over the 57 year cropping period.

The Native soil Bicarb-Po level was very high. Only the fertilized, unlimed treatments under CC had comparably high levels. The higher Bicarb-Po levels were the result of N in the fertilizer treatment. Fertilizer had no effect on the NaOH-Po levels in CC and a significant effect in WF.

Influence of Lime -- Liming acid soils to improve soil conditions for crop production is a widely accepted practice. The purpose of adding lime is to reduce the Fe and Al activity, and to increase the level of plant available P. Soil pH levels have been affected by both fertilizer application (McCoy and Webster 1977) and liming. Treatments such as CCCO which have not been limed had lower pH levels than their respective limed treatments. Further, the unlimed and fertilized treatments, CCFO, have significantly lower pH levels than their respective limed treatments, indicating a drop in soil pH as a result of fertilizer use. Therefore, the pH and lime effects in soil P transformations were considered in the analysis of the Breton data.

The Resin-Pi levels in CC unlimed treatments tended to be slightly lower than in the limed treatments. Lime application on the Breton plots had a significant negative effect on organic P levels (Bicarb-Po and NaOH-Po). Bicarb-Po and NaOH-Po levels were 20 to 30% higher in unlimed fertilized treatments than in the respective treatments that received lime. The pH levels were 1.1 to 1.5 units lower in the unlimed treatments. Therefore, the amount of labile Po mineralized was greater at higher pH levels.

Lime interacted with fertilizer to cause a slight but significant increase in Residual-P. The interaction of lime and fertilizer on the HCl-Pi fraction in CC increased HCl-Pi levels. This explains why NaOH-Pi levels in limed treatments in CC were lower than in unlimed treatments.

SUMMARY OF LONG-TERM PLOT DATA

Without fertilizer additions, the dominant movement of P at both the Lethbridge and Breton sites was in one direction from stable to labile pools for plant removal. Even though the initial sizes of the various P pools were quite different, cropping without fertilizer inputs resulted in a continuous drain on almost all of the soil P pools. Leaving the soil in fallow every second year accentuated the drain on Po pools. The addition of fertilizer inputs at both sites resulted in a much more dynamic P cycle. The size of virtually all P pools was increased at both sites by fertilization. The CC treatments that received N and P fertilizer inputs had the highest Total-P levels of all treatments at both locations.

Plant Uptake

Eight soils from long-term rotation plots at Lethbridge and Breton were utilized in a growth chamber experiment. Both wheat and canola were grown in each of the eight different soil types. The soils used are shown below:

CWCH	-	Continuous Wheat	Check Plots	Lethbridge
CWNP	-	Continuous Wheat	N & P applied	Lethbridge
WFCH	-	Wheat-Fallow	Check plots	Lethbridge
WFNP	-	Wheat-Fallow	No P applied	Lethbridge
CCCO	-	Continuous Cropped	Control + No Lime	Breton
CCFO	-	Continuous Cropped	NPKS + No Lime	Breton
WFCS	-	Wheat-Fallow	Control	Breton
WFFS	-	Wheat-Fallow	NPKS	Breton

The air dried samples from the rhizosphere of all soils were analyzed using routine P soil testing methods including: Bray (Bray and Kurtz 1945), Olsen (Olsen et al. 1954), and Miller and Axley (Miller and Axley 1956). The new Kelowna method (Van Lierop 1985 and Yee and Broersma 1987) was also included. Various P fractions (Hedley et al. 1982) were determined to statistically compare the P soil test methods. The Bray P1 (weak Bray) extraction solution used was 0.03 N NH_4F and 0.025 N HCl with a soil to solution ratio of 1:10, with a 1-minute shake time. The Miller and Axley extraction solution (utilized by the Alberta Agricultural Soil and Animal Nutrition Laboratory) used was 0.03 N H_2SO_4 and 0.03 N NH_4F with two soil to extraction solution ratios of 1:5 and 1:10, with a 5-minute shake time. The Olsen method (utilized by the University of Saskatchewan Soil Testing Laboratory) used 0.5 M $NaCO_3$, adjusted to a pH of 8.5, using a solution ratio of 1:20, with a 30-minute shake time. Both inorganic and total P were determined so that organic P could be considered in the correlations. The modified Kelowna extraction solution (utilized by Norwest Labs Ltd.) used was 0.5 N HOAc and 0.015 N NH_4F with the addition of 1.0 N NH_4Ac with a soil solution ratio of 1:10, with a 30-minute shake time; P in plant material was determined following digestion.

RESULTS

Scattergrams of the relationship between rhizosphere Resin-Pi (all soils and both crops) and each routine soil P method were prepared, and regression equations (Figure 4) and r^2 values were calculated. In all comparisons, there was a strong relationship between Resin-Pi and the amount of P extracted by each method. Each relationship was highly significant.

To further test the observed positive correlations between Resin-Pi and each routine P method, regression analysis was conducted for both wheat and canola separately when grown in each soil (Table 5). Correlation of all the methods to Resin-Pi were exceptionally good for the Chernozemic soils, and the Olsen-Pi method overall gave slightly better correlations than the other methods. In the Luvisolic soils, the correlations were not as good as in the Chernozemic soils. The Kelowna, M & A and Bray methods all performed reasonably well and better than the Olsen method. However, no one method consistently gave higher correlations than other methods.

The relationship of measured P in plant material (P uptake) with Hedley P fractions and routine P analysis was conducted to relate soil values to P content in the plant. Figure 5 shows the relationship between Resin-Pi levels and plant uptake of P from all soils. With all soil and crop data combined, the r^2 value of 0.468 was poor. Separation of P uptake data on the basis of crop (wheat and canola) and soil type (Chernozem and Luvisol) revealed that each of the four groups was clearly different (Figure 6). Figure 7 provides scattergrams, regression equations and r^2 value for the relationship of P uptake by the two crops in the two soil types. The r^2 values are significant at the 1% level for all the correlations except wheat grown in the Luvisol soil.

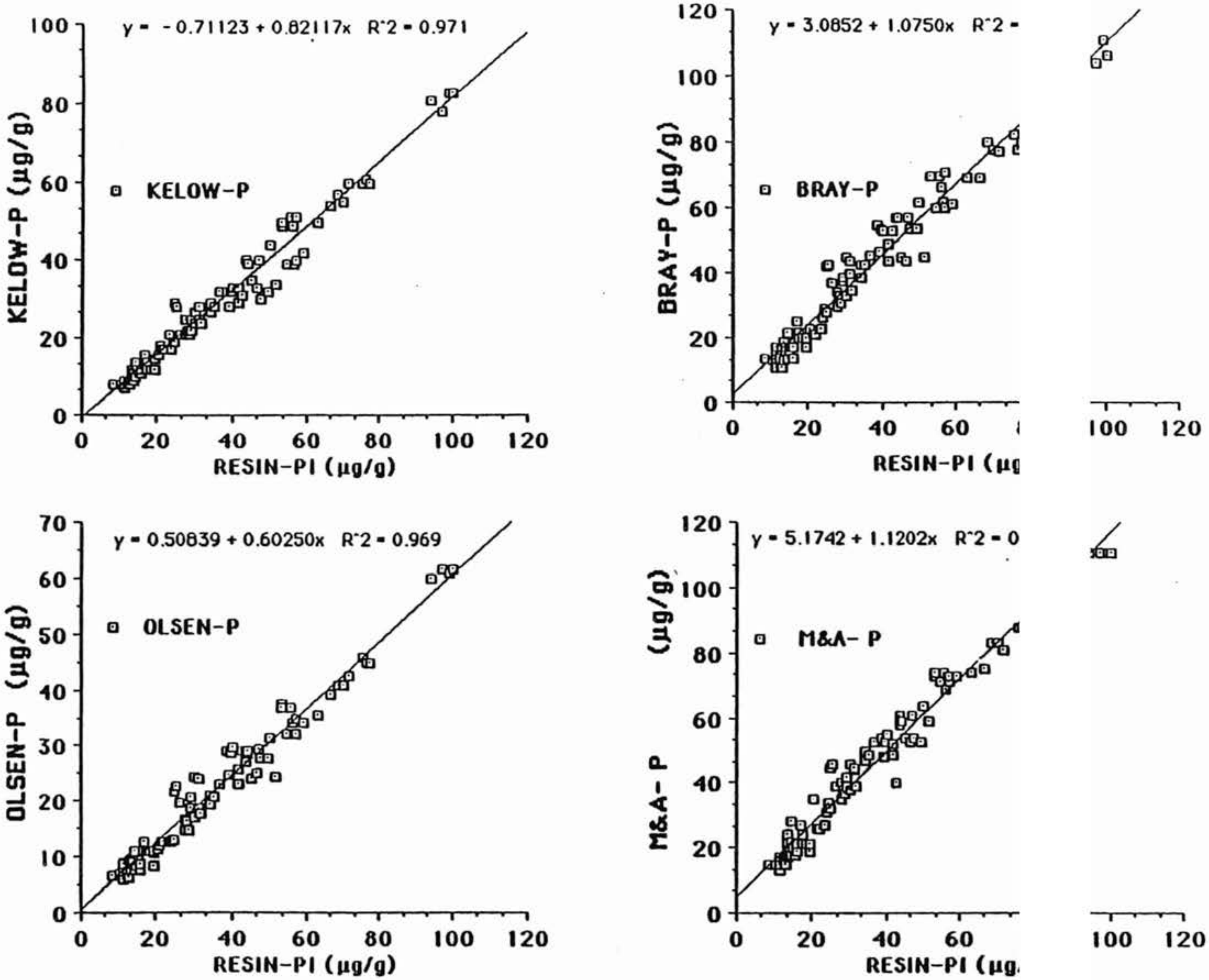

Figure 4. Scattergrams of the relationship between rhizosphere Resin-Pi a[illegible]ach routine soil P method.

Table 5. Correlation coefficients between Resin-Pi and the various routine soil P extractants for each crop grown in each soil

Soil	Crop	Olsen Pi	Kelowna	M&A	Bray
CWNP	Wheat	.9964	.9804	.9928	.9608
	Canola	.9978	.9924	.9979	.9893
CWCH	Wheat	.9933	.9870	.9869	.9808
	Canola	.9872	.9965	.9953	.9890
CCCO	Wheat	.4517**	.8511*	.3520**	.4151**
	Canola	.8592*	.9273	.9410	.9083*
CCFO	Wheat	.6979**	.7283**	.8276*	.8923*
	Canola	.8918*	.9244	.5597**	.8970*
WFCS	Wheat	.9779	.8054**	.9492	.9676
	Canola	.9523	.9833	.9666	.9800
WFFS	Wheat	.8682*	.9734	.9109*	.9048
	Canola	.9515	.9917	.9826	.9916
WFCH	Wheat	.9906	.9631	.9748	.9737
	Canola	.9878	.9778	.9756	.9840
WFNP	Wheat	.9962	.9833	.9933	.9966
	Canola	.9991	.9942	.9901	.9893

** - Correlation Not Significant; * - Significant @ 0.05; No Asterisk - Significant @ 0.01

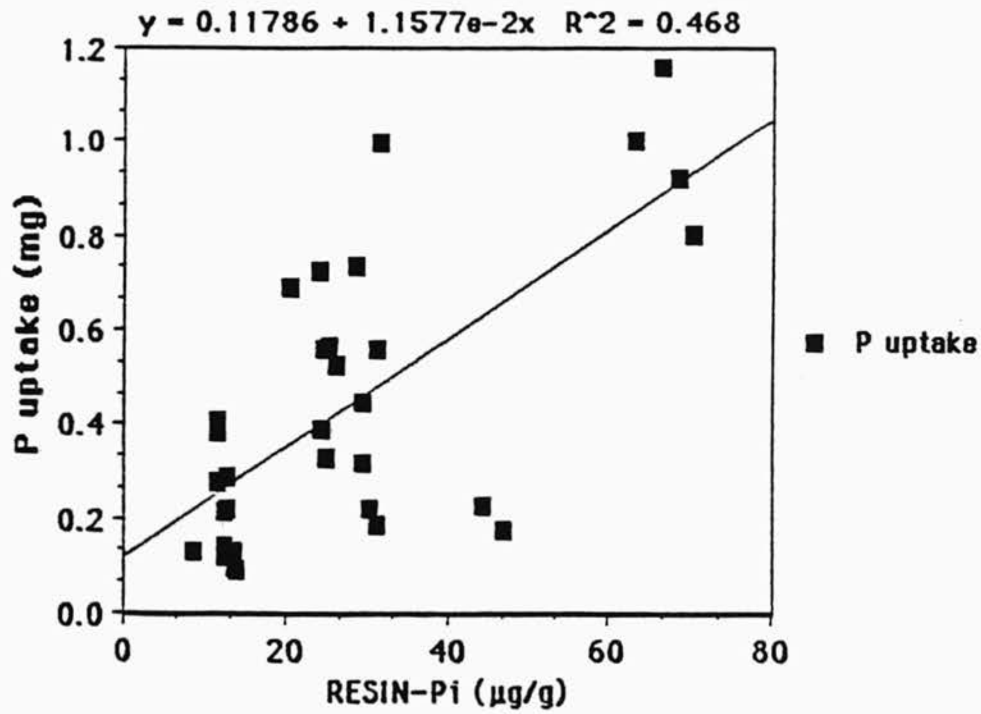

Figure 5. Scattergram, regression equation and r^2 value for the relationship between Resin-Pi and plant uptake of P for both crops grown in all soils.

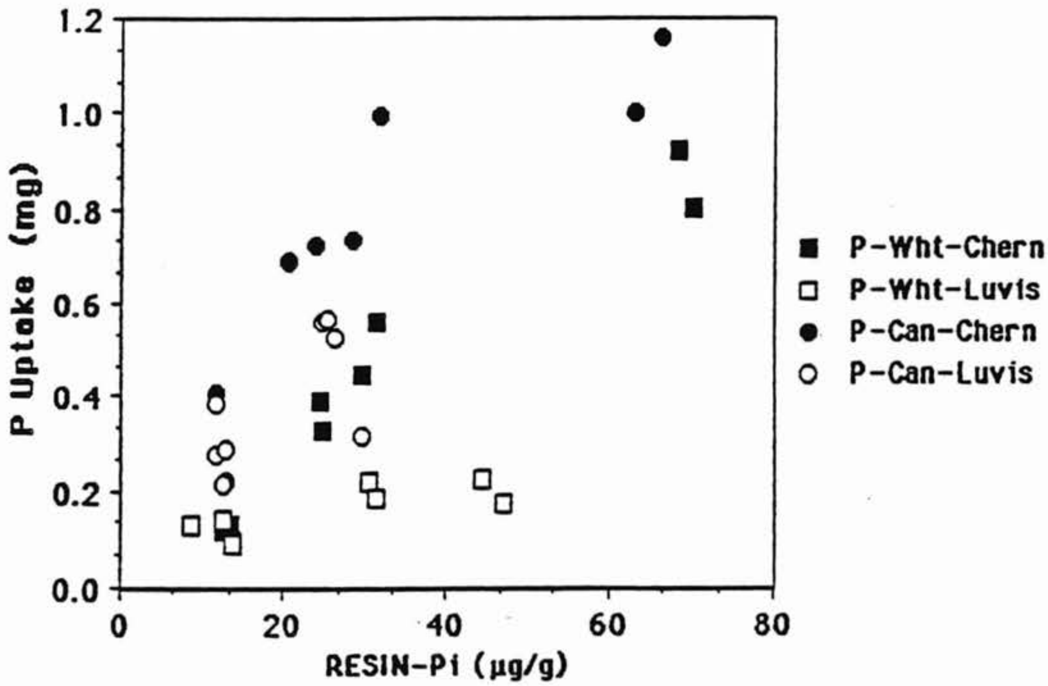

Figure 6. Scattergram showing the relationship between Resin-Pi and plant uptake of P. Data points are separated by crop (wheat or canola) and soil type (Chernozem or Luvisol).

DISCUSSION

Results of the present study confirm that use of one calibration curve to predict P fertilizer requirements for a wide range of soils and crops is not feasible. Separate calibration curves for each soil and crop combination would be required. For example, Figure 5 demonstrated when plant uptake of P by both crops from all eight soils were correlated, the results were poor. However, when P uptake by one crop was correlated with soil P from specific soil, the results were frequently highly correlated (Figure 7). The fundamental problem then is to determine why P soil tests are unable to predict crop response to P fertilizer under field conditions.

It is now quite clear that no one extractant will be capable of doing this. The results of the fractionation of phosphate under different management treatments has shown quite clearly that the quantity of labile P forms in the soil can be significantly altered by management. The initial soil test was developed to predict phosphate availability in soils that had been fallowed for one year. In the calcareous soils this still works quite well, however, in soils under continuous cropping it does not take into account the build-up of labile organic P forms which contributes substantially to the P uptake by plants during that growing season. Therefore, soils will test deficient and yet will have a reserve of labile phosphate. In more acidic soils the situation is quite complicated and will be further compounded if the soils are limed. First of all, the inorganic P forms in the soil are different and in these soils an extractant that contains an acid or a fluoride ion may adequately describe and measure the labile P forms. However, it will not measure the Po forms under continuous cropping and if the soils are limed, then the calcium level in the soil solution will be increased and the soils will behave more like Chernozemic soils.

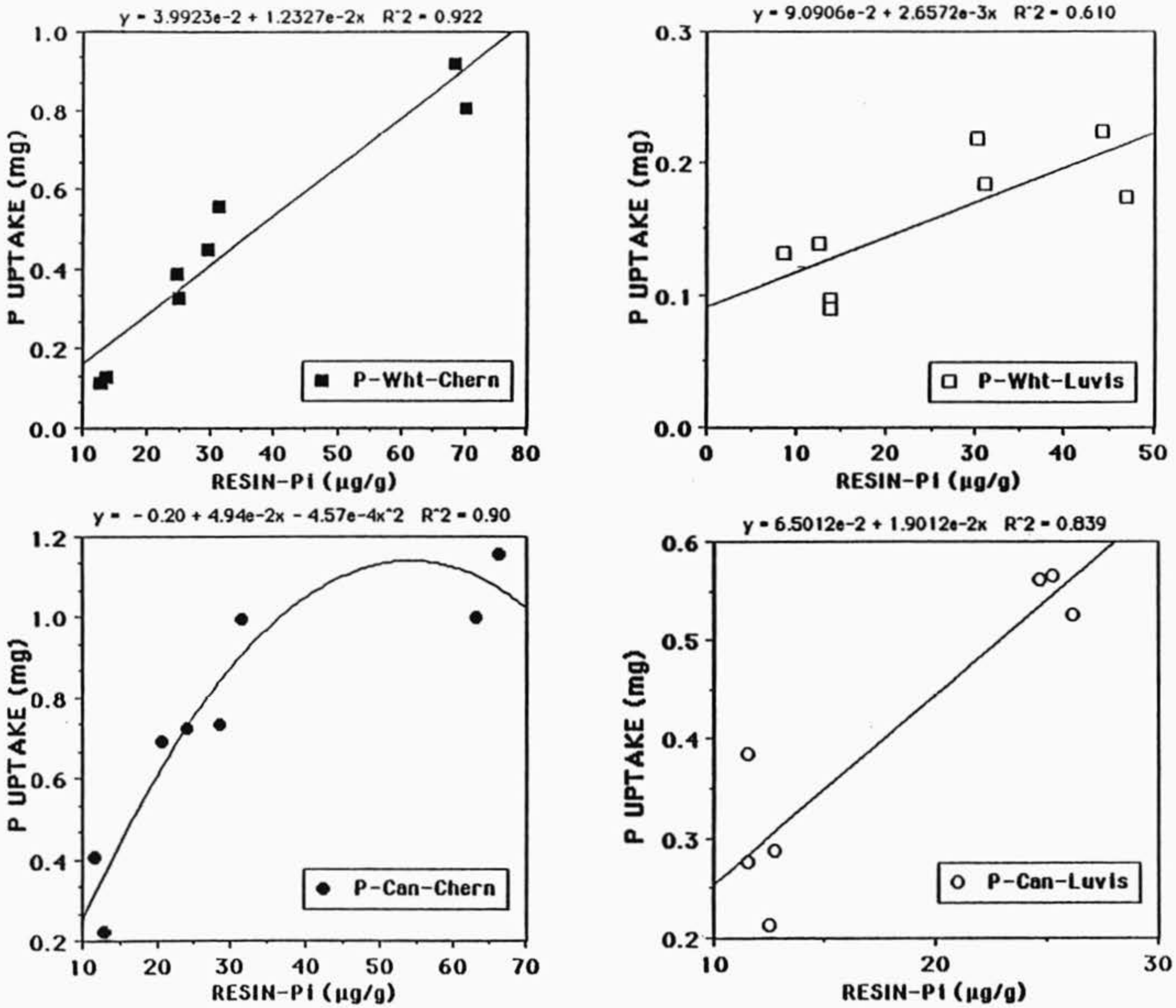

Figure 7. Scattergrams for the relationship of P uptake by both wheat and canola in each of the Chernozemic and Luvisolic soils.

Another aspect that will have to be taken into consideration is the difference in rooting characteristics of crops and the presence or absence of the VA mycorrhiza. This aspect was not specifically tested in the work underway, but it was shown that the rate of phosphorus uptake from the same soil was more rapid with wheat than with canola. However, an additional factor comes into play in that canola does create an acid environment in the vicinity of the roots which solubilizes some apatite or parent material phosphate. This does not occur with wheat.

We anticipate that improvements to the phosphate test will come from the following:

The use of the existing soil tests -- These tests have been correlated under wheat-fallow conditions in both prairie provinces and provide an adequate assessment of soil phosphate under those cropping conditions. Where continuous cropping with fertilization is the dominant practice then the availability of phosphorus will not be predicted by a soil test alone. It will, in a manner similar to nitrogen and sulphur, have to be supplemented with a knowledge of the amount of the organic form of the nutrient which is mineralized over the growing season. This can be predicted from the computer simulation models that have been developed.

Finally, we need to know more about the roots and the root rhizosphere of the common plant species that we grow in the prairies, specifically we need to know more about their rooting system, their infection or non-infection with VA mycorrhiza and the changes that occur in the root rhizosphere of these plants over the growing season. However, it will be possible to provide a much more accurate phosphate test within a year.

SUMMARY - P UPTAKE

The challenge is to conduct sufficient greenhouse trials using a number of crops and a wide range of soil types from across the prairies. The results must be correlated with various P soil test methods to develop a data base such that a number of physical and chemical variables (such as crop rotation history, P fertilizer history, soil zone, climatic zone, pH, % clay, % organic matter, $CaCO_3$ content) can be appropriately matched. Only after considerable correlation work has been completed coupled with field verification, can the best routine soil P test methods be identified that would be crop, management, soil area, and climate specific to permit accurate soil test based fertilizer P recommendations to farmers.

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