Phosphorus Status of a Soil in a Long-Term Experiment

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Abstract

An experiment that was established in 1982 to assess placement of P fertilizer on the yield of continuous barley was terminated in 2004, after annual application of P (30 kg ha^{-1}) was discontinued in all but one treatment in 2001. Total removal of P during the first 20 years of the experiment (615 kg P_2O_5 ha^{-1}) was virtually equal to total P application (600 kg P_2O_5 ha^{-1}); however, when removal by the control that was fertilized with N only was subtracted from the total removal, a residual P component of 474 kg P_2O_5 ha^{-1} was obtained as a result. In spite of this, discontinuing P fertilization after 20 years of annual application of 30 kg P_2O_5 ha^{-1} resulted in significant reduction in barley grain yield that was greater in the treatments that P was seedrow placed (21%) than either banded (12%) or 1/3 seedrow placed and 2/3 banded (15%). Four week burial of PRS™ probes in 2006 allowed us to ascertain the reasons for these differences that reflected management and P placement practices. The use of PRS™ probes allowed us to interpret over 90% of variations both in P removal and yield of barley over the duration of the experiment.

Introduction

Evaluation of residual effects from phosphorus (P) fertilization has been the subject of numerous studies in western Canada, which were summarized by Roberts and Stewart (1987). Residual P is expected to build in soil when removal of P by crops is lower than the P applied in the form of fertilizer or other sources, e.g., manure. However, numerous studies have demonstrated that recovery of P by crops in the year of application is very low. A number of techniques have been utilized to assess fertilizer P use efficiency (FPUE); most commonly FPUE is estimated by comparing uptake of P by plants grown in a fertilized soil to that of an unfertilized control, also known as 'apparent recovery'. Labeling fertilizer sources with a radioactive isotope (^{32}P or ^{33}P) has been used to overcome a "priming" effect that results in accelerated P uptake by plants when fertilized with P and creates false positive recovery results. Independently of technique, fertilizer P recovery remains poor and can range up to 30% depending on soils, crop and management factors, however, most commonly is reported to be <10% on soils that were supplied with P (Withers et al., 2005). Higgs et al. (2000) argued that determining the percentage recovery of P as an estimate of FPUE may be inappropriate; rather a budget of inputs and outputs should be drawn and relate the balance to changes in soil P status. Obviously, that latter approach would lead to efficiencies close to 100%, since P losses from soil are minimal.

Although Sadler and Stewart (1974) gathered considerable evidence in support of their finding that up to 75% of P fertilizer not use by a crop in the year of application remains in potentially available forms, long-term studies yielded recoveries of almost half that estimate (Campbell, 1965). Bailey et al. (1977) reported a 30% of P recovery from a single P application of 100 kg P ha^{-1} after eight consecutive crops.

The objective of this study was to assess residual effects from twenty annual applications of P to a Black Chernozemic soil in Alberta and the impact on succeeding crops that received no fertilizer P.

Materials and Methods

A trial was established in the fall of 1981 at the University of Alberta Ellerslie experimental farm to assess methods of phosphorus (P) placement. The experimental site was divided into two parts, A and B (Fig. 1). Part A received a blanket application 450 kg P_2O_5 ha^{-1} in the fall of 1981 as triple super phosphate (0-45-0), which was incorporated in the surface 1.2-cm of the soil, whereas Part B received no blanket P application. A number of treatments were initiated in both Parts A and B commencing in the fall of 1981 and spring of 1982 and were repeated annually until the spring of 2001.

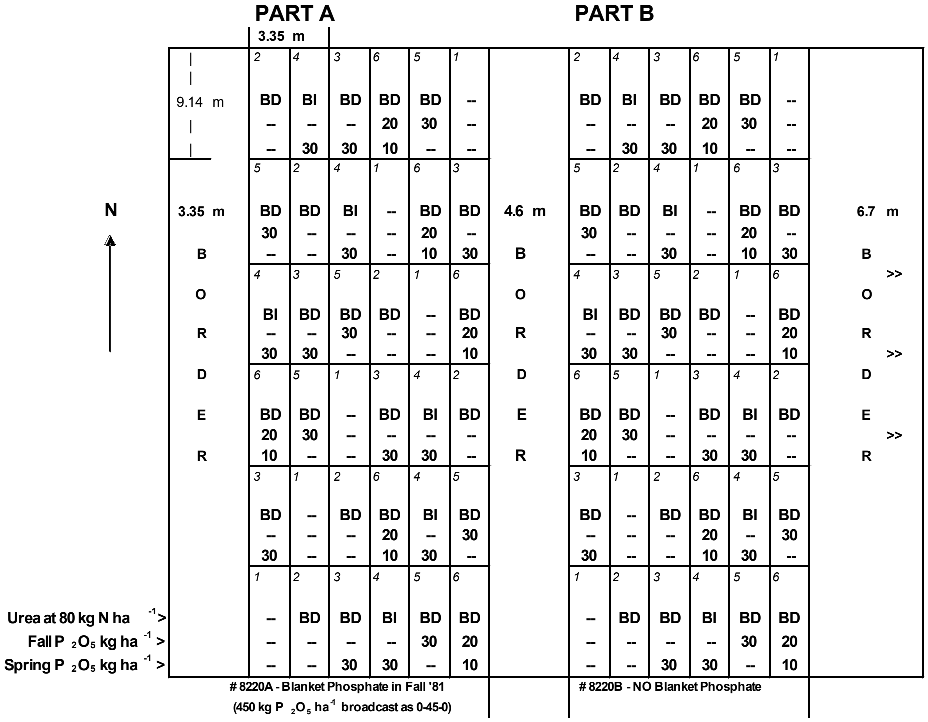

Figure 1. Experimental layout of long-term P plots at Ellerslie experimental farm.

These treatments were arranged in a randomized complete block design (RCBD) with six replications and included: (i) an unfertilized control, (ii) a nitrogen (N) only treatment that received 80 kg banded N ha^{-1}, (iii) a treatment that received 80 kg banded N ha^{-1} and 30 kg seedrow applied P_2O_5 ha^{-1}, (iv) a treatment that received 80 kg broadcast N ha^{-1} and 30 kg seedrow applied P_2O_5 ha^{-1}, (v) a treatment in which both 80 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} were banded (dual banding), and, (vi) a treatment that received 80 kg banded N ha^{-1} and 30 kg P_2O_5 ha^{-1} split 1/3 in the seedrow and 2/3 in the band. Banded N and P (at a depth of 12.7 cm) and broadcast and incorporated N fertilizer treatments were applied in the fall of the previous year; seedrow placed P was applied at seeding time. Phosphorus in all treatments was applied as triple super phosphate (0-45-0), whereas N was in urea (46-0-0) form. Fertilization in all treatments of Part B and all but one (1/3 in the seedrow and 2/3 in the band split) of Part A was discontinued starting in the fall of 2001 and the experiment was terminated after the 2004 growing season. Barley was grown in all but one year (1995 – canola). Every spring, both parts were tilled to a depth of 5 cm and then sown to a depth of approximately 2.5 cm using a six-row double disk seeder with 17.8 cm spacing. Seeding rates varied from 263-354 seeds m^{-2} depending on thousand kernel weights of the seed lots used and averaged 314 seeds m^{-2}. Crops were harvested at early maturity using a Wintersteiger Nurserymaster Elite experimental plot combine. The seed weight per plot was measured immediately following harvest and again after being dried by forced air at 60°C to constant weight and was assayed for total P. The seed yield per plot was calculated with moisture content corrected to 13.5 and 10 % for cereals and canola, respectively. Grain yield and P removal data were subject to ANOVA for a randomized complete block design using SYSTAT 8.0 (SPSS 1998) and effects were separated via least significant differences ($LSD_{0.05}$).

Commencing in 2002, only treatment (vi) of Part A (30 kg P_2O_5 ha^{-1} split 1/3 in the seedrow and 2/3 in the band) was fertilized with P at rate of 30 kg P_2O_5 ha^{-1}, however seedrow applied, whereas P fertilization in all other treatments was discontinued; all treatments other than the control still received 80 kg banded N ha^{-1} according to the original schedule. Composite soil samples from 0-15 cm depth of the control treatments were collected on an annual basis either in the fall after harvest and/or spring prior to sowing each year. Soil samples were analyzed for "available" P using the bicarbonate (Olsen et al. 1954) method.

Detailed sampling of all plots of Part B and treatment (vi) of Part A (the one receiving 30 kg P_2O_5 ha^{-1} in 2002-2004) was carried out in the fall of 2005 according to the protocol depicted in Fig. 2. Samples were taken from 0-4 inch (10.16-cm) and 4-8 (10.16 to 20.32-cm) depth along a 15-foot (4.57-m) transect crossing two rows in each plot. The transect was drawn at an angle, so that when projected on a line vertical to the direction of the seeding rows, the distance between sampling points was 1 inch (2.54-cm). Fourteen such sampling points were duplicated in each plot and the two corresponding sub-samples for each point were composited into one, thus resulting in 14 samples per plot per sampling depth. All sub-samples were analyzed for "available" P using the bicarbonate method (Olsen et al. 1954). In the summer of 2006, PRS™ probes (Hangs et al. 2004) were inserted on the row and in the middle of the inter row spaces of the same plots where soil samples were taken in the previous fall (Fig. 3). Four anion PRS™ probes were buried per plot at each of two depths (0-10 cm and 10 – 20 cm). After 28 days, the PRS™ probes from each plot depth and treatment were retrieved, washed with deionized water and analyzed as described by Hangs et al., 2004 PRS™ probe burial schedule and rainfall amounts during burial of the probes are shown in Fig. 4.

Results and Discussion

After the first 10 years of growing barley on both sites no differences in the yields between the corresponding treatments of A and B could be observed (Figure 5), thus suggesting that residual effects from the original 450 kg P_2O_5 ha^{-1} had been exhausted. This is corroborated by comparing the grain yields and soil test levels of the control treatments of Parts A and B (Fig. 6).

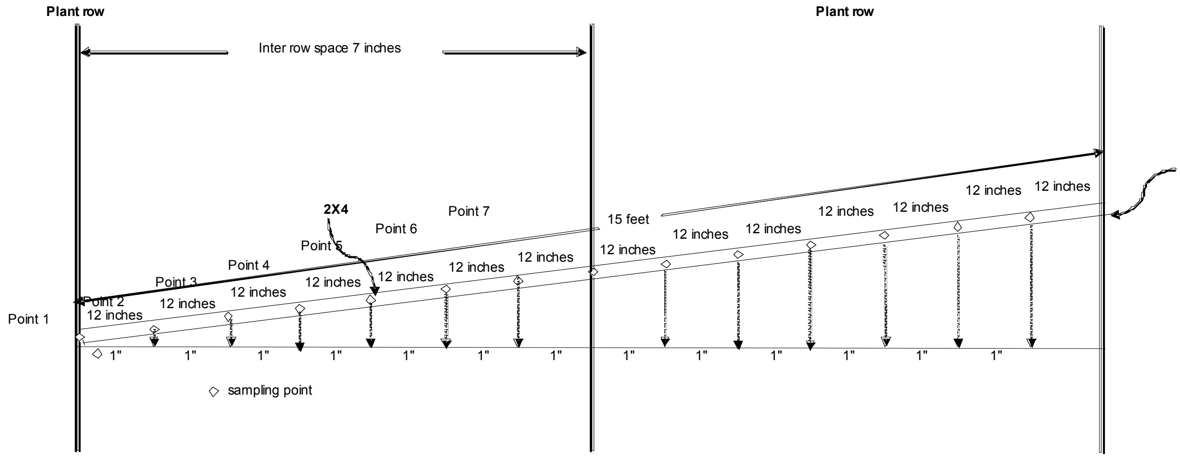

Figure 2. Soil sampling protocol for detailed site sampling in the fall of 2005.

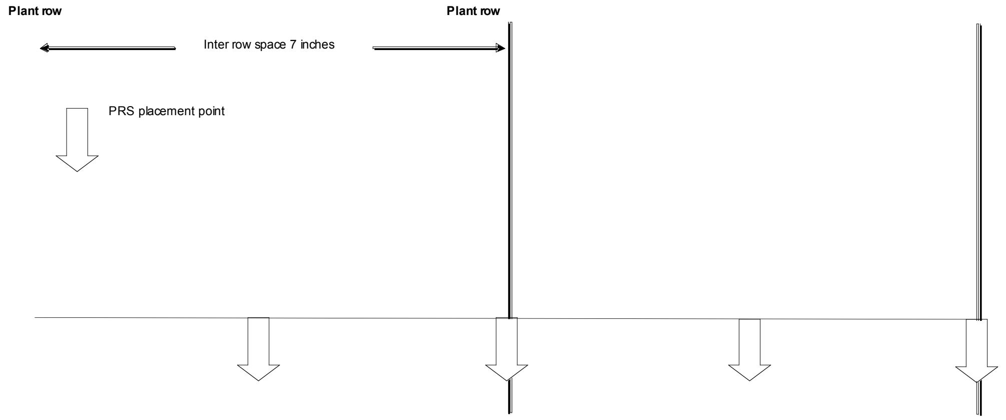

Figure 3. Placement points of PRS$^{\text{TM}}$ probes within each plot in the summer of 2006.

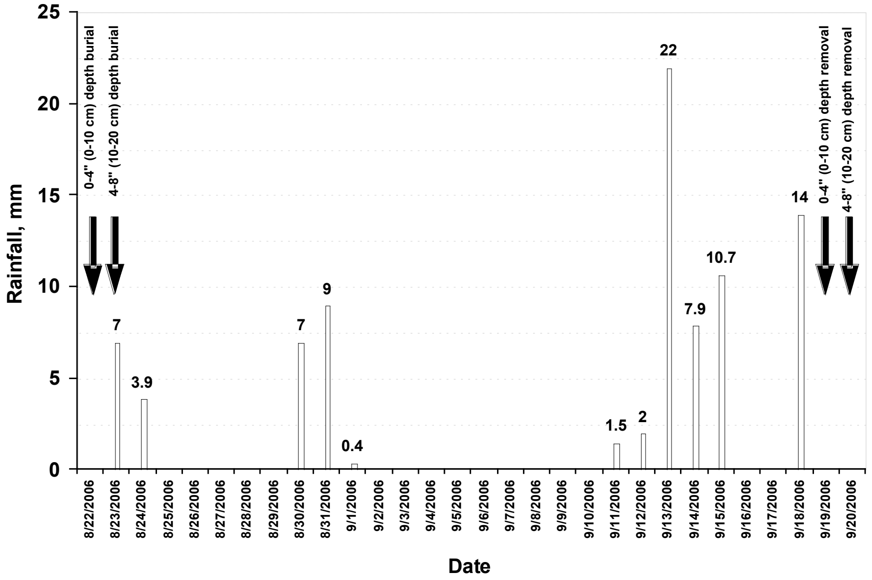

Figure 4. Burial schedule for PRS™ probes and daily precipitation during burial.

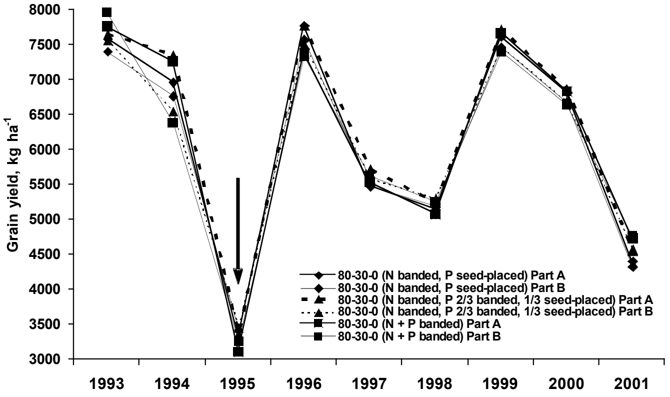

Figure 5. Comparison of barley grain yields (→ Canola in 1995) between treatments during the last decade that treatments received both N and P applications.

Total removal of P during the first 20 years of the experiment (615 kg P_2O_5 ha^{-1}) was virtually equal to total P application (600 kg P_2O_5 ha^{-1}); however, when the P_2O_5 removed in the control treatments (412 in the unfertilized control and 489 when only N was applied) was accounted for in the removal a large "residual" P_2O_5 pool was calculated (474 kg ha^{-1}). As a result an 'apparent P recovery (FPUE) of between 21.2 and 31.4% for the 20-year period from 1982 to 2001 was obtained (Figure 7). The lowest recovery rate was obtained when N was broadcast and incorporated and P was seedrow placed. This reflects the lower fertilizer N use efficiency (FNUE), as it has been already demonstrated that N fertilization results in increased P uptake and, consequently, higher P recovery in crops (Halvorson and Black 1985).

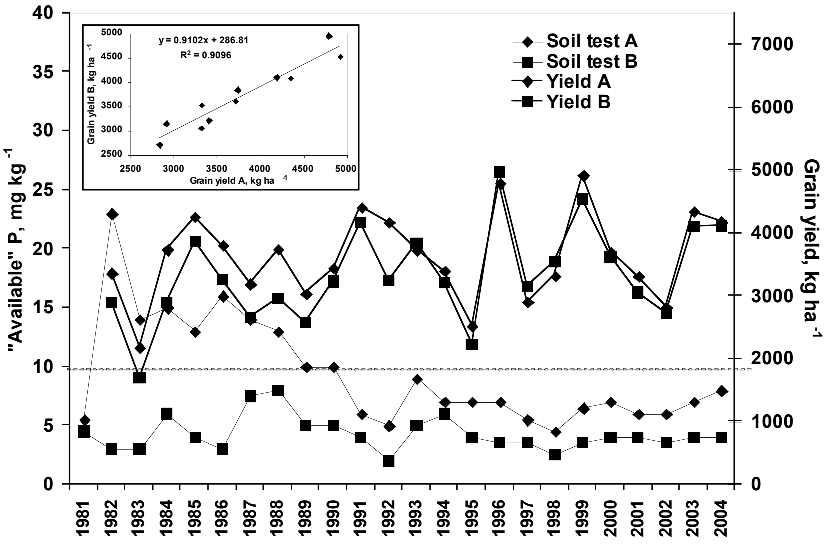

Figure 6. Comparison of barley grain yields between control treatments of Parts A and B from 1982 to 2001 (enclosed regression between 1993 and 2001 excludes canola in 1995).

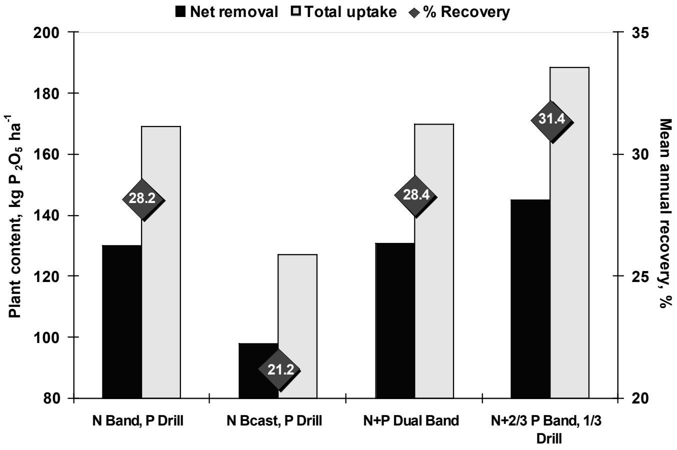

Figure 7. Total net removal, uptake and 'apparent' P recovery after 20 annual applications of 30 kg P_2O_5 ha^{-1} in the form of triple super phosphate (0-45-0).

In spite of this, interruption of P fertilization led to significant yield decreases with average losses over a three year period (2002-2004) being greater (21%) when 30 kg P ha^{-1} was being seed-placed for the first 20 years and lesser with 1/3 seed-placed and 2/3 banded (15%) and banded (12%) (Fig. 8).

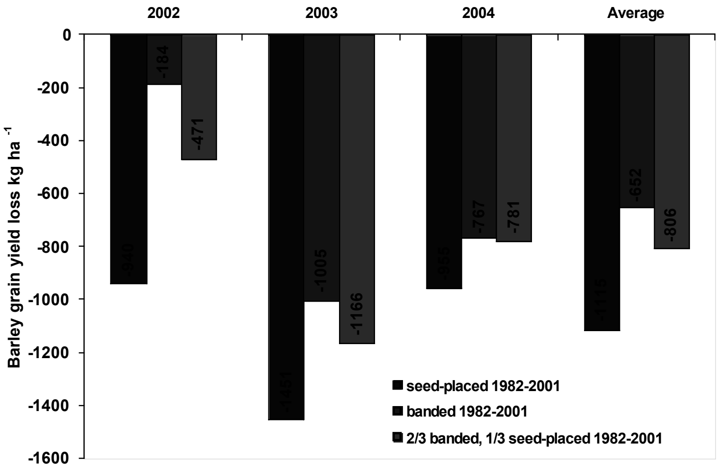

Figure. 8. Barley grain yield loss resulting from discontinuing P application after 20 years of annual application of 30 kg P_2O_5 ha^{-1} as 0-45-0.

"Available" P levels extracted with bicarbonate (Olsen et al., 1954) virtually showed no differences between "available" P levels on the row and in the inter row spaces (Table 1) with the exception of the 10-20 cm depth of N+P banded treatment, in which bicarbonate-extractable P levels on the row were 2 mg kg^{-1} greater than in the inter row spaces, reflecting accumulation of fertilizer P at that depth. Lack of differences in the remaining treatments would appear logical, since the surface soil layer above the depth of banding was being disturbed and redistributed every year prior to seeding. Further, there was a difference of up to 4 mg kg^{-1} on the row and 3 mg kg^{-1} in the inter row spaces of the 0-10 cm layer between the P fertilized treatments and the unfertilized controls (Table 1). "Available" P levels ion the 0-10 cm layer are considered very low (McKenzie et al., 2003; Saskatchewan Agriculture and Food, 2006) to low (Manitoba Agriculture, Food and Rural Initiatives, 2001). Hence, a greater than 75% probability of response to P based on the above sources should be anticipated. However, differences in the extractable P levels of previously P fertilized treatments were not sufficiently wide to fully explain the observed yield losses.

Table 1. Basic statistics for detailed sampling of two rows of every plot of Part B in 2005.

	Depth (cm)	Min.	Max.	Mean	On row A (kg ha^{-1})	Between rows B	Delta A-B
No Fertilizer	0-10	10.2	12.0	11.2	10.8	11.2	-0.5
	10-20	6.0	8.2	7.2	6.9	7.3	-0.4
N Banded, no P	0-10	10.4	12.7	11.4	11.1	11.5	-0.4
	10-20	5.6	8.2	7.0	6.1	7.1	-1.0
N Banded, P seed-placed	0-10	11.6	14.0	12.8	13.0	12.8	0.2
	10-20	6.9	9.1	7.6	7.2	7.7	-0.5
N B&I, P seed-placed	0-10	12.4	14.7	13.5	13.8	13.5	0.3
	10-20	6.0	8.0	6.9	6.6	6.9	-0.4
N+P Banded	0-10	12.9	16.2	14.3	15.3	14.1	1.2
	10-20	7.6	12.2	9.3	11.2	9.0	2.2
N+2/3 P Banded+1/3 P Seed-placed	0-10	11.3	15.1	12.8	12.4	12.8	-0.4
	10-20	6.2	8.0	7.3	7.2	7.3	0.0
Minimum	0-10	10.2	12.0	11.2	10.8	11.2	-0.5
	10-20	5.6	8.0	6.9	6.1	6.9	-1.0
Maximum	0-10	12.9	16.2	14.3	15.3	14.1	1.2
	10-20	7.6	12.2	9.3	11.2	9.0	2.2
Mean	0-10	11.5	14.1	12.7	12.7	12.7	0.1
	10-20	6.4	9.0	7.5	7.5	7.5	0.0

Mean ‘apparent’ recovery of previously applied P from 2002-2004, i.e., after P fertilization was discontinued, ranged from 5.5 to 12.2% (Fig. 9); similarly to mean annual values, the lowest recovery rate was obtained when N was broadcast and incorporated and P was seedrow placed and the highest when it was banded. Hence, overall recovery ranged between 26.7 and 43.6% (Fig. 7 and 9).

Four week burial of PRS™ probes in 2006 measured major differences in supply rates, hence P availability, based on management and P placement practices. The supply rates and bicarbonate-extractable P levels of the N banded P seed-placed and N+P banded treatments are contrasted in Fig. 10. Although distribution of bicarbonate-extractable P in the seed-placed P treatment was fairly equal over the fourteen sampling points, supply rates were distinctly different between on row and inter row spaces (Fig. 10a). Supply rates on the row averaged 3.3 μg 10 cm^{-2} 28 d^{-1} and those in the inter row spaces were 24% greater at 4.1 μg 10 cm^{-2} 28 d^{-1}. Hence, in this treatment, PRS probes were able to isolate the depletion of P reserves on the row, since the position of the row remained fairly stable over the experiment and the inability of the roots to reach the P reserves that were stored in the middle of the inter row spaces. Conversely, supply rates in the banded treatments were significantly higher on the row (4.2 μg 10 cm^{-2} 28 d^{-1}) compared to the middle of the inter row spaces (3.3 μg 10 cm^{-2} 28 d^{-1}) and reflected both higher accumulation of P in the band as well as possible translocation to shallower depths via biocycling (Fig. 10 b).

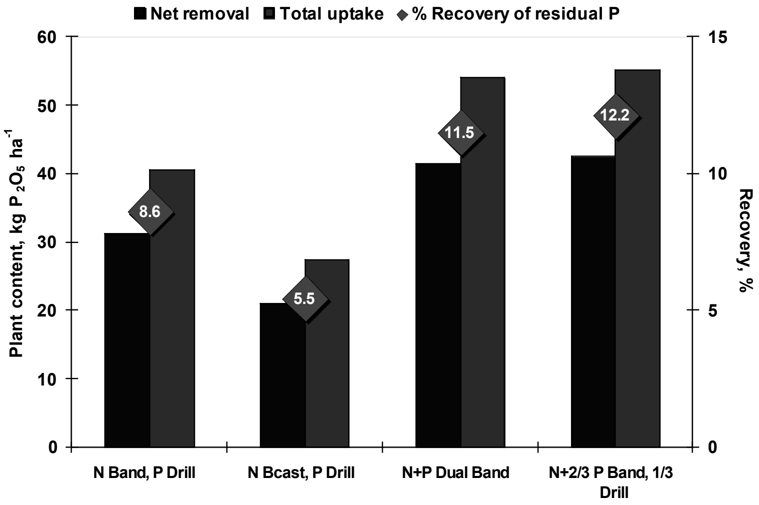

Figure 9. Total net removal, uptake and 'apparent' P recovery of residual P from 20 annual applications of 30 kg P_2O_5 ha^{-1} in the form of triple super phosphate (0-45-0) after three consecutive barley crops grown without P fertilization.

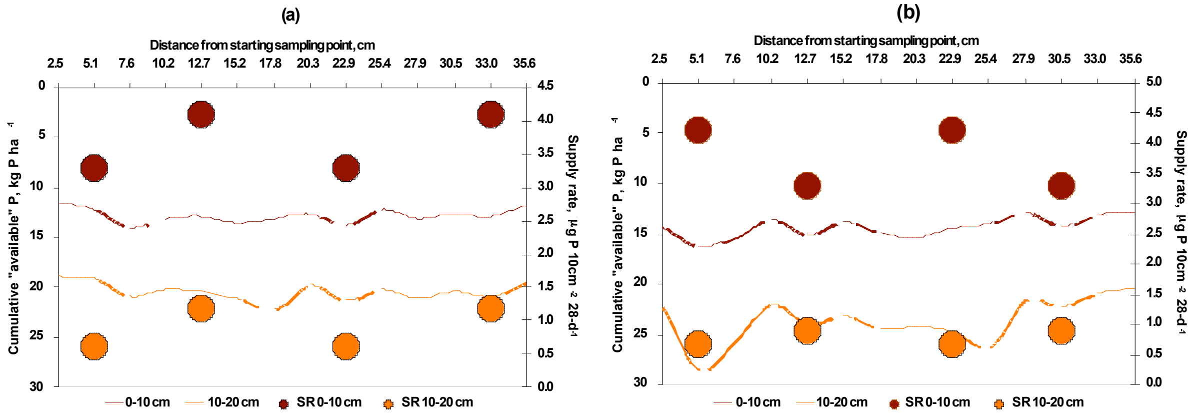

Figure 10. Distribution of bicarbonate-extractable-P and P supply rates in the 80 kg banded N ha^{-1} and 30 kg seedrow applied P_2O_5 ha^{-1} (a) and both 80 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} banded (dual banding) (b) treatments.

Supply rates greater than 3.5 μg 10 cm^{-2} d^{-1} are considered as an indictor of sufficient P supply in the soil (Hangs et al. 2002). Although supply rates after 28 d burial are expected to be higher than those after 1 d that are used for routine soil P availability there is no direct relationship between the two. However, separation of means (Cate and Nelson, 1965) would indicate that the sufficiency limit after 28 d equilibration is not that dissimilar (Fig. 11).

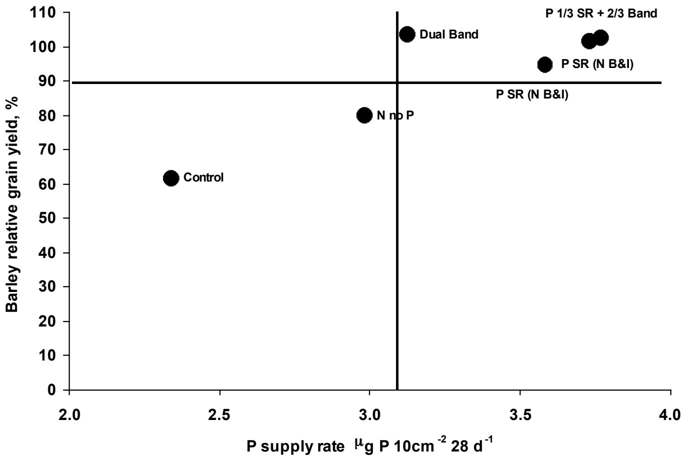

Figure 11. Cate-Nelson split of the 23-average relative grain yields of barley based on supply rates after 28 day burial of PRS™ probes.

Phosphorus removal by barley was equally well correlated with 28d supply rates (r^2=0.93) and bicarbonate-extractable P (r^2=0.87) (Fig. 12). However, average barley grain yields obtained over the total duration of the experiment (1982-2004) gave a higher statistically significant correlation with supply rates (r^2 = 0.94) than with bicarbonate-extractable P levels (r^2= 0.68) (Fig. 13). Similar trends were obtained when the last year (2004) barley grain yields were correlated with supply rates and bicarbonate-extractable P levels (Fig. 14). Hence, PRS™ probes provided a better means of identifying both long-term usage as well as placement trends than bicarbonate-extractable P.

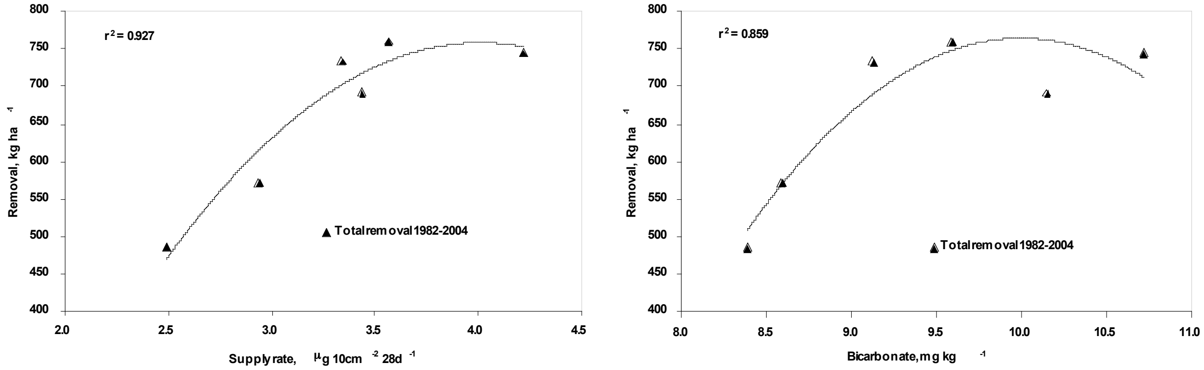

Figure 12. Correlation between total P removal by barley and supply rates (left half) or bicarbonate-extractable P levels (right half).

CONCLUSION

Residual P from long-term P fertilization was not sufficient to alone provide all the P requirements of barley grown in a monoculture system after P fertilization was discontinued. PRS™ probes afford a satisfactory means of identifying point sources as well as long-term trends of P fertilization, i.e., placement and long-term fertilization effects. The use of PRS™

probes allowed us to interpret over 90% of variations in barley grain yields as well as P removal by barley over the duration of the experiment.

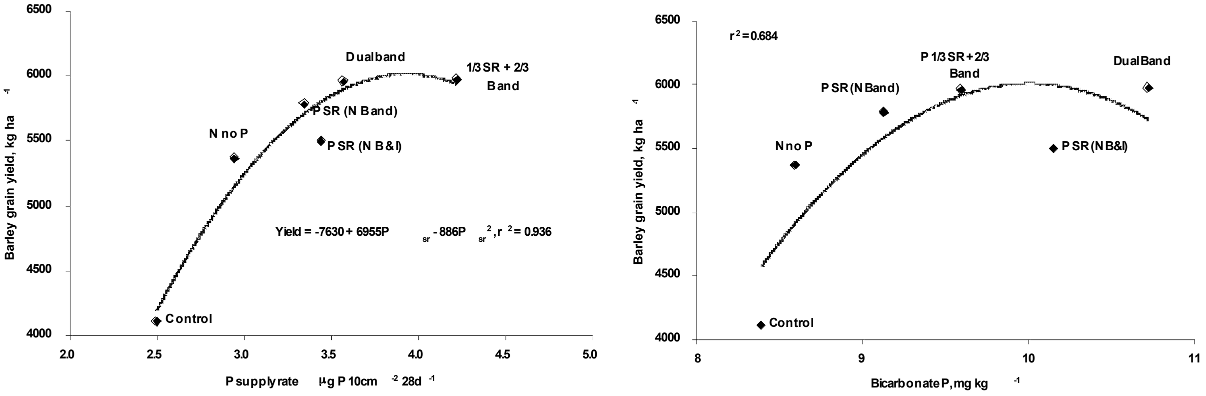

Figure 13. Correlation between average barley grain yields obtained over 23 years and supply rates (left half) or bicarbonate-extractable P levels (right half).

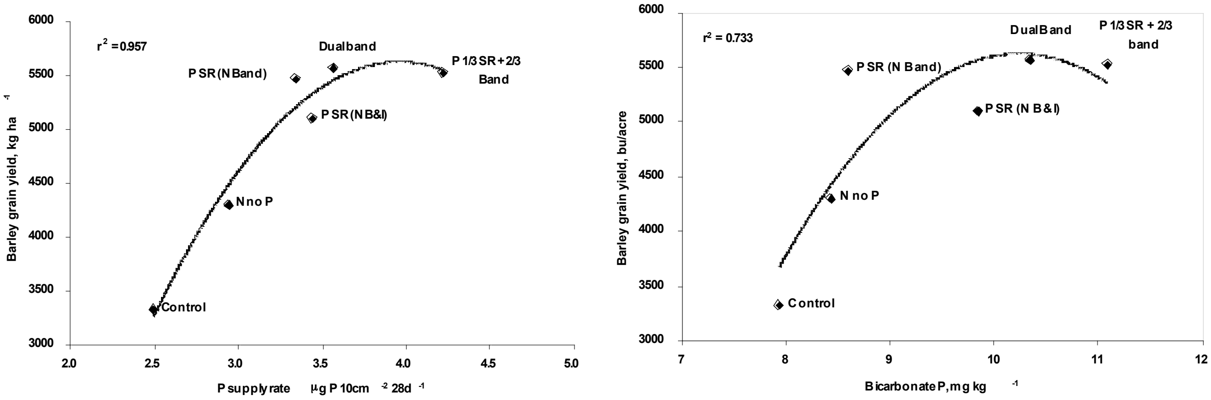

Figure 14. Correlation between 2004 barley grain yields obtained and supply rates (left half) or bicarbonate-extractable P levels (right half).

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