Long-Term Phosphorus Fertilization Effects on Crop Yields and Soil Phosphorus

By R.E. Karamanos, J.T. Harapiak, and G.A. Kruger

Discontinuing P fertilization after 20 years of annual application of 27 lb P_2O_5/A resulted in significant reduction in barley grain yield, with losses of 21% where P had been applied in the seedrow, 12% where P had been banded with N, and 15% where P had been applied one-third in the seed row and two-thirds banded. While minor benefits to residual soil P were measured from annual application, continued fertilizer P use was required to achieve optimum yields.

Evaluation of the residual effects from P fertilization has been the subject of numerous studies in western Canada (Roberts and Stewart, 1987). Residual P is expected to build in the soil when the removal of P by crops is lower than the fertilizer or manure P applied. However, numerous studies have demonstrated that recovery of P by crops in the year of application is very low (Hedley and McLaughlin, 2005). Fertilizer P recovery remains low and can range from less than 10% up to 30% depending on soil, crop, and management factors (Withers et al., 2005).

However, it has been argued that determining the percentage recovery of P as an estimate of fertilizer P recovery may be inappropriate, and some suggest a budget of inputs and outputs should be developed and related to changes in soil P status (Higgs et al., 2000). Obviously, that latter approach would lead to efficiencies close to 100%, since P losses from soil are minimal.

The objective of this study was to assess the residual effects from 20 annual applications of fertilizer P to a Black Chernozemic soil (Udic Boroll) in Alberta, and measure the impact on succeeding crops that received no fertilizer P. The trial was established in the fall of 1981 at the University of Alberta – Ellerslie Experimental Farm – to assess methods of P placement. The experimental site was divided into two parts. Part A received a blanket application 400 lb P_2O_5/A in the fall of 1981 as triple superphosphate (0-45-0), and Part B received no P fertilizer. A number of treatments were initiated in both parts on an annual basis, including (i) an unfertilized control, (ii) N only treatment that received 72 lb banded N/A, (iii) a treatment that received 72 lb banded N/A and 27 lb seed row-applied P_2O_5/A, (iv) a treatment that received 72 lb broadcast N/A and 27 lb seed row-applied P_2O_5/A, (v) a treatment in which both 72 lb N/A and 27 lb P_2O_5/A were banded (dual banding), and, (vi) a treatment that received 72 lb banded N/A and 27 lb P_2O_5/A split one-third in the seedrow and two-thirds in the band. Banded N and P (at a depth of 5 in.) 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 superphosphate (0-45-0), whereas N was in urea (46-0-0) form. Fertilization in all treatments of both parts of the study was discontinued in the fall of 2001 and the experiment was terminated after the 2004 growing season. Barley was grown in all except one year (1995, canola). Commencing in 2002, only treatment (vi) was fertilized with P at a rate of 27 lb P_2O_5/A, however seedrow-applied. All treatments other than the control still received 72 lb banded N/A according to the original schedule. Composite soil samples from 0 to 6 in. 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 27 lb P_2O_5/A in 2002-2004) was carried out in the fall of 2005 after a chemical fallow year. Samples were taken from 0 to 4 in. and 4 to 8 in. depth along a 16.4-foot 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 in. 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. Four anion PRS™ probes were buried per plot at each of two depths (0 to 4 in. and 4 to 8 in.). After 28 days, the PRS™ probes from each plot depth and treatment were retrieved, washed with deionized water, and analyzed for P as described by Hangs et al., 2004.

After the first 10 years of growing barley on both sites, no difference in the yields was observed between the two parts of the study where one part received the residual P fertilizer. However, the residual effects from the original 400 lb P_2O_5/A had been exhausted after 10 years of barley production (**Figure 1**). This is corroborated by comparing the grain yields and soil test levels of the control treatments of Parts A and B.

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'. Total uptake of P during the first 20 years of the experiment ranged from 682 to 736 lb P_2O_5/A for the P treatments compared to 568 lb P_2O_5/A for the treatment that had received N only. Hence, net uptake (uptake in any P treatment-uptake in control) ranged from 114 to 168 lb P_2O_5/A (**Figure 2**). Since a total of 532 lb P_2O_5/A was applied, it resulted in an apparent P recovery (FPUE) of between 21.2 and 31.4% for the 20-year period from 1982 to 2001. 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

Abbreviations and notes for this article: P = phosphorus; N = nitrogen; ppm = parts per million; PRS = Plant Root Simulator

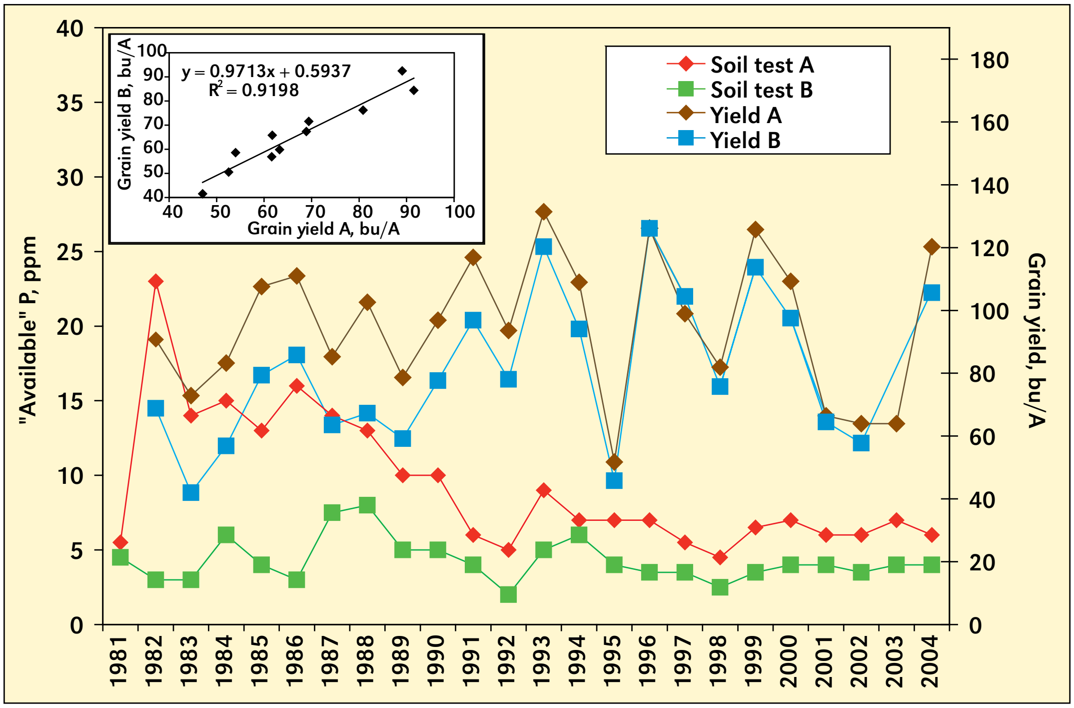

Figure 1. Comparison of barley grain yields between control treatments of Parts A and B from 1982 to 2001 (enclosed regression between 1993 and 2001 excludes canola in 1995).

and redistributed every year prior to seeding. Further, there was a difference of up to 4 ppm on the row, and 3 ppm in the inter-row spaces, of the 0 to 4 in. layer between the P fertilized treatments and the unfertilized controls (**Table 1**). These "available" P levels in the 0 to 4 in. 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.

demonstrated that N fertilization results in increased P uptake and, consequently, higher P recovery in crops (Halvorson and Black, 1985). In spite of this, interruption of P fertilization in 2002 led to significant yield decreases with average losses over a 3-year period (2002-2004), being greater (21%) when 27 lb P_2O_5/A was being seed-placed for the first 20 years, and lesser with one-third seed-placed and two-thirds banded (15%) and banded with N (12%) (**Figure 3**).

Soil P levels showed virtually no differences between "available" P levels on the row (where P placed) and in the inter-row spaces (**Table 1**). The exception was at the 4 to 8 in. depth of N+P banded treatment, in which P levels on the row were 2 ppm 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

Four-week (28 day) 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 **Figure 4**. Although distribution of bicarbonate-extractable P in the seed-placed P treatment was fairly equal over the 14 sampling points, supply rates were distinctly different between on-row and inter-row spaces (**Figure 4a**). Supply rates on the row averaged 3.3 µg/10 cm²/28 days and those in the inter-row spaces were 24% greater at 4.1 µg/10 cm²/28 days. 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

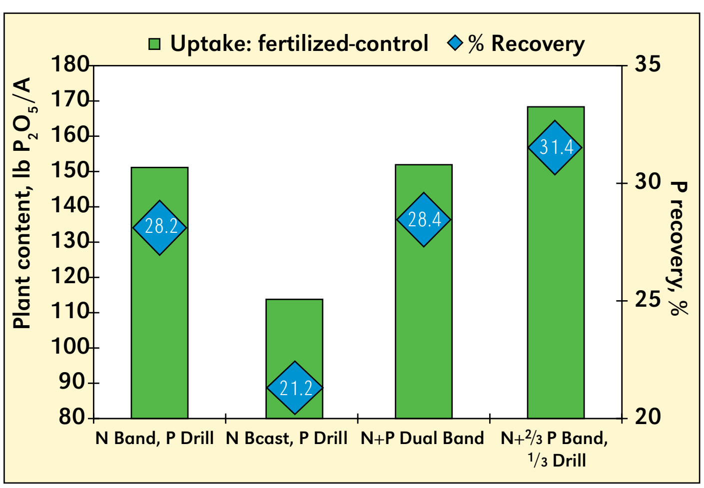

Figure 2. Total net uptake and 'apparent' P recovery after 20 annual applications of 27 lb P_2O_5/A in the form of triple superphosphate (0-45-0).

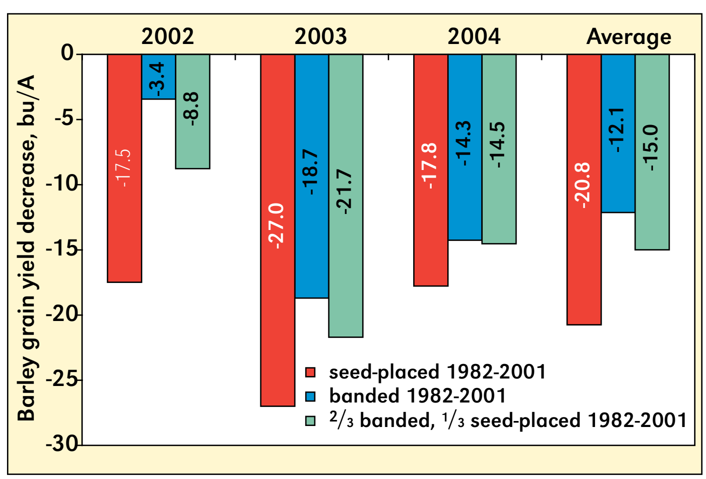

Figure 3. Barley grain yield loss resulting from discontinuing P application after 20 years of annual application of 27 lb P_2O_5/A as 0-45-0.

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

	Depth, in	Min.	Max.	Mean	On row, A	Between rows, B	Delta A-B
		lb/A					
No fertilizer	0-4	9.1	10.7	10.0	9.6	10.0	-0.4
	4-8	5.4	7.3	6.4	6.2	6.5	-0.4
N banded, no P	0-4	9.3	11.3	10.2	9.9	10.3	-0.4
	4-8	5.0	7.3	6.3	5.4	6.3	-0.9
N banded, P seed-placed	0-4	10.4	12.5	11.4	11.6	11.4	0.2
	4-8	6.2	8.1	6.8	6.4	6.9	-0.4
N B&I[1], P seed-placed	0-4	11.1	13.1	12.1	12.3	12.1	0.3
	4-8	5.4	7.1	6.2	5.9	6.2	-0.4
N+P banded	0-4	11.5	14.5	12.8	13.7	12.6	1.1
	4-8	6.8	10.9	8.3	10.0	8.0	2.0
N+2/3 P banded+ 1/3 P seed-placed	0-4	10.1	13.5	11.4	11.1	11.4	-0.4
	4-8	5.5	7.1	6.5	6.4	6.5	0

[1]Broadcast and incorporated.

treatments were significantly higher on the row (4.2 µg/10 cm²/28 days) compared to the middle of the inter-row spaces (3.3 µg/10 cm²/28 days) and reflected both higher accumulation of P in the band as well as possible translocation to shallower depths via biocycling (**Figure 4b**). Supply rates greater than 3.5 µg/10 cm²/28 days are considered as an indicator of sufficient P supply in the soil (Hangs et al., 2002).

Barley grain yields obtained in the last year of the study were significantly correlated with supply rates for on row (r^2 = 0.936), in the middle of the row spaces (r^2 = 0.678) and when supply rates were combined into one per plot (r^2 = 0.891) (data not shown). Corresponding correlations of barley yields with bicarbonate extractable-P levels were also statistically significant, but lower (0.685, 0.670, and 0.684). Similar trends were obtained when the average 23-year yields were correlated with supply rates and bicarbonate extractable-P levels (data not shown).

Residual P from long-term P fertilization was not sufficient alone to provide all the P requirements of barley grown in a monoculture system when P fertilization was discontinued after 20 years of application. 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 93% of variations in P removal by barley over the duration of the experiment. BC

Dr. Karamanos (email: r.karamanos@westcoag.com) is Manager of Agronomy and Mr. Harapiak is a retired Agronomist with Western Co-operative Fertilizers Limited in Calgary, Alberta. Mr. Kruger is with Western Ag Innovations, Saskatoon, Saskatchewan.

References

Halvorson, A.D. and A.L. Black. 1985. Soil Sci. Soc. Am. J. 49: 933-937.

Hangs, R., K. Greer, C. Sulewski, and D. Hicks. 2002. p. 120-130 in Proc. Soils and Crops 2002, Extension Division, University of Saskatchewan, Saskatoon, SK.

Hedley, M. and M. McLaughlin, M. 2005. p.181-252 *In* J.T. Sims and A.N. Sharpley (eds) Phopshorus: Agriculture and the Environment. Monograph no. 46, American Society of Agronomy, Madison, WI.

Higgs, B., A.E. Johnston, J.L. Salter, and C.J. Dawson. 2000. J. Envir. Qual. 29: 80-87.

Manitoba Agriculture, Food and Rural initiatives. 2001. [Online] Available: http://gov.mb.ca/agriculture/soilwater/soilfert/fbd02s16.html#12 [12 January 2007].

McKenzie, R.H., E. Bremer, L. Kryzanowski, A.B. Middleton, E.D. Solberg, D. Heaney, G. Coy, and J. Harapiak. 2003. Can. J. Soil Sci. 83: 431-441.

Olsen, S.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. 1954. USDA Circ. 939, U.S. Gov. Print. Office, Washington, DC.

Roberts, T.L. and J.W.B. Stewart. 1987. Sask. Inst. Pedol. Publ. R523, University of Saskatchewan, Saskatoon, SK.

Saskatchewan Agriculture and Food. 2006. [Online] Available: http://www.agr.gov.sk.ca/docs/production/Phosfert.asp [12 January 2007].

Withers, P.J.A., D.M. Nash, and C.A.M. Laboski. 2005. p. 781- 827 *In* J.T. Sims and A.N. Sharpley (eds) Phopshorus: Agriculture and the Environment. Monograph no. 46, American Society of Agronomy, Madison, WI.

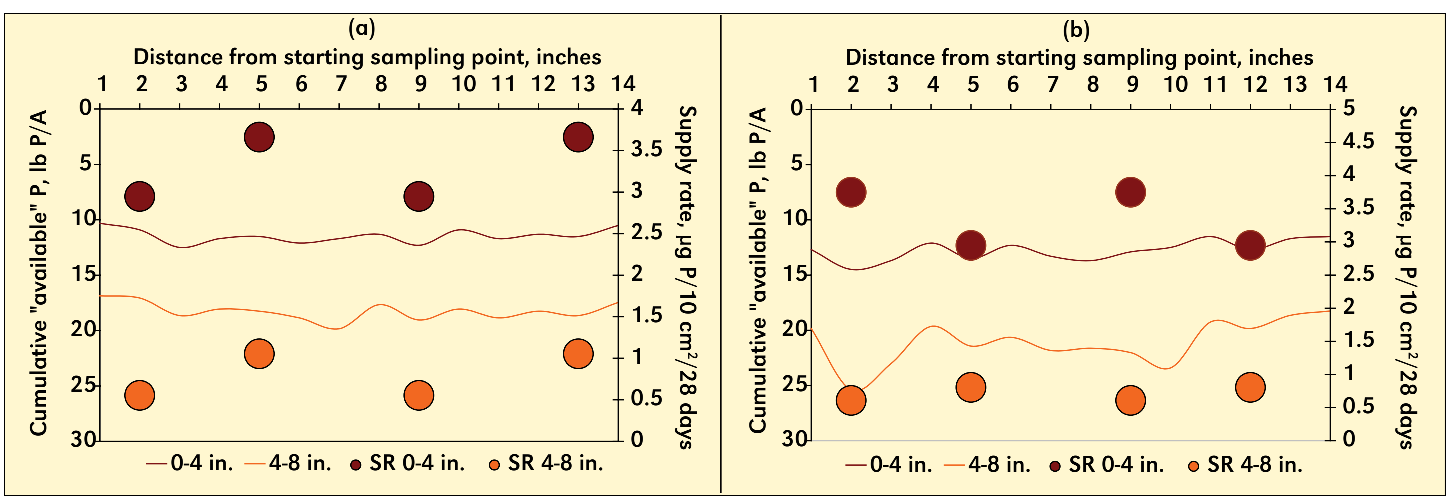

Figure 4. Distribution of bicarbonate extractable-P and P supply rates in the 72 lb banded N/A and 27 lb seedrow-applied (SR) P_2O_5/A (a) and both 72 lb N/A and 30 lb P_2O_5/A banded (dual banding) (b) treatments.