Withholding Phosphorus after Long-Term Additions – Soil and Crop Responses

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Soil P change was directly related to the balance between input as fertilizer and output as grain removal in semiarid southwestern Saskatchewan. A change of 6 lb P/A in P balance produced a change of 1 lb P/A in Olsen P. In the absence of P fertilizer additions, Olsen P remained at approximately 15 lb P/A in the surface 6 in. of soil. While fallow-grown wheat responded positively to P applied annually, withholding fertilizer P after soil P buildup did not affect yields. Both N and P were required to optimize the yield of stubble-grown wheat.

In the semiarid prairies of western Canada, N and P are the two main nutrients limiting crop yield and quality. In this region, where summerfallow and spring wheat predominate the cropping mix (Campbell et al., 2002), rates of N applied to crops grown on summerfallow are low because much N mineralization occurs during the 21 month summerfallow period. However, P is usually applied. For crops grown on stubble, N is generally required for optimum yield, and P may also be applied. When difficult economic situations arise, producers often consider ways to reduce input costs and usually choose between reducing pesticide or fertilizer inputs, mainly P.

Most prairie soils are high in total P, but low in available P (Doyle and Cowell, 1993). Low soil water and low temperatures in early spring further act to reduce P availability (Stewart and Karamanos, 1986). In these soils, 75 to 90% of P fertilizer is left unused by the first crop after application. However, the residual P remains in forms available to subsequent crops (Spratt and Read, 1980; Roberts, 1992). Thus, there can be a build up of large amounts of residual P from the addition of regular small amounts of P fertilizer over extended periods (Spratt and McCurdy, 1966; McKenzie and Roberts, 1990; Campbell et al., 2005).

On the Canadian prairies, low P soils are those with less than 9 to 13 lb Olsen-P/A in the top 6 in. With these soils, economic yield response to P fertilization can be obtained each year (Stewart and Karamanos, 1986). But even soils high in Olsen-P (e.g., 40 lb/A) can respond to applied P about 25% of the time, especially if applied in the seed-row when soil is cool in early spring (Stewart and Karamanos, 1986; Roberts, 1992). Under cool conditions, root growth and P movement are restricted. This limits P availability to plants unless some P, preferably NH_4-P, is placed near the seed (Rennie and Mitchell, 1954). In Saskatchewan and Manitoba, the recommended rates of P fertilizer when Olsen-P in the top 6 in. are 0 to 9, 10 to13, 14 to 17, 18 to 53, and >53 lb/A are 30, 25, 20, 15, and 0 lb P_2O_5/A, respectively (Saskatchewan Agriculture, 1985).

In 1967, a field study was initiated at Swift Current, Saskatchewan, on an Orthic Brown Chernozem (Aridic Boroll) to determine the extent to which grain yield, P uptake, and soil-available P would be influenced in various crop rotations by stopping P fertilization after 27 years, and also by the continued addition or withdrawal of N fertilizer for a further 12 years. The loam soil has a pH of 6.5.

In this study, five of the initial treatments were: fallow-spring wheat-spring wheat (F-W-W) receiving (i) N and P fertilizer (N+P), (ii) P only (+P), and (iii) N only (+N), and continuous wheat (Cont W) receiving (i) N and P (N+P), and (ii) P only (+P). In 1993, we split these five treatments to provide subplots in which P was withheld from treatments that were receiving P, and N withheld

Table 1. Comparison of average grain yields, P concentration, P uptake in grain, P balances, and changes in soil Olsen P during the 1967-1993 period vs. the 1994-2005 period[1]. (Values pertain to rotation phases in parentheses, except for gain or loss, which is for the rotation).

Period and period difference	Wheat on fallow			Wheat on stubble				
	F-(W)-W			F-W-(W)			Cont W	
	Rot 1 (+P)	Rot 2 (N+P)	Rot 5 (+N)	Rot 1 (+P)	Rot 2 (N+P)	Rot 5 (+N)	Rot 8 (N+P)	Rot 12 (+P)
	Grain yield, bu/A							
1967-1993	29.3	30.5	27.0	19.4	21.7	19.4	21.1	17.3
1994-2005	45.5	46.1	36.6	21.9	33.0	31.0	36.5	24.9
Difference, %	55	51	35	13	52	59	73	44
	P concentration in grain, %							
1967-1993	0.34	0.34	0.34	0.40	0.39	0.35	0.38	0.40
1994-2005	0.40	0.39	0.32	0.46	0.43	0.36	0.43	0.47
Difference, %	18	15	-6	15	10	3	13	18
	P uptake in grain, lb/A							
1967-1993	6.0	6.2	5.4	4.5	4.9	4.1	4.9	4.2
1994-2005	10.8	10.6	6.9	5.8	8.1	6.1	9.0	6.9
Difference, %	81	70	28	27	65	50	84	64
P balance, gain (+) or loss (-), lb/A								
1967-1993	+67	+60	-86				+108	+127
1994-2005	+7	-4	-53				0	+27
Change in soil Olsen-P, lb/A								
1967-1993	26.6	18.2	-1.3				19.9	30.1
1994–2005	16.6	5.0	-4.6				-4.5	32.6

[1] Average growing season precipitation in 1967-1993 = 7.4 in. and in 1994-2005 = 9.3 in.; the 104-yr mean = 8.3 in.

Abbreviations and notes for this article: P = phosphorus; N = nitrogen; NO_3 = nitrate; MAP = monoammonium phosphate; NH_4^+ = ammonium.

from the F-W-W (+N) treatment.

Ammonium nitrate was broadcast in the spring and incorporated with a pre-seeding tillage, based on levels of soil NO_3 (0 to 24 in.) measured in individual plots in the previous fall. From 1967 to 1989, we used N rates (soil test + fertilizer N) of 58 lb/A, which increased to 80 lb/A on fallow and 65 lb/A on stubble in 1990 in accordance with changes in soil test recommendations. Phosphorus fertilizer (MAP) was applied with the seed at an average rate of 20 lb P_2O_5/A using a hoe drill. Soil samples from the surface 6 in. were collected annually and bicarbonate-extractable (Olsen) P determined (Hamm et al., 1970). We monitored grain yield, P concentrations, and P uptake in grain annually. During the 1967 to 1993 period, growing season precipitation (GSP) averaged 7.4 in. (i.e., 10% below the 8.3 in. long-term average), but during the period 1994 to 2005, GSP averaged 9.25 in. (12% above average).

Under the original fertilization protocol, grain yield of wheat grown on fallow was increased by P fertilization in 1967 to 1993 and even more so in the wetter 1994-2005 period (Rot 2 vs Rot 5, **Table 1**). However, there was no response to N (Rot 1 vs Rot 2) because N was being adequately supplied by mineralization. Yield of wheat grown on stubble was increased by N (Rot 1 vs Rot 2 and Rot 8 vs Rot 12) especially in the wetter 1994-2005 period, but response to P was minimal (**Table 1**).

A P balance (fertilizer P minus P removed in the grain) calculation (**Table 1**) indicated that systems receiving P had accumulated Olsen-P (**Figures 1 and 2**) to levels two to three times the initial quantities by 1993. However, in the F-W-W (+N) system Olsen-P levels had remained constant until about 1990, likely because P uptake (**Table 1**) was restricted by the below average precipitation conditions prevalent in the 1967 to 1993 period. During the 1994 to 2005 period, growing season precipitation was above average and yield and P uptake were much greater (**Table 1**), thus resulting in a reduction in Olsen-P in the F-W-W (+N) system (**Figure 1**). During this latter period, Olsen-P in systems receiving P tended to remain constant when N was also being applied, but tended to increase when only P was applied (**Figures 1 and 2**) and P uptake

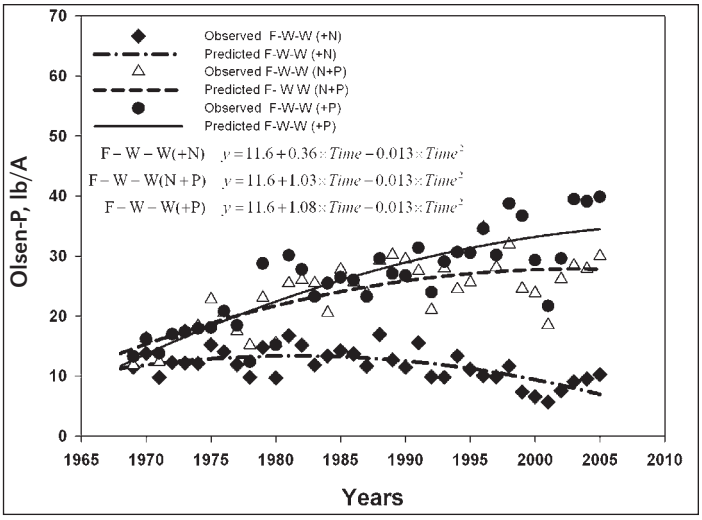

Figure 1. Long-term effect (1968 to 2005) of fertility regimes on Olsen-P content of the soil (0 to 6 in.) under F-W-W rotation. Equations shown were obtained from a quadratic model fitted to all rotations, with rotations as an indicator variable.

was lower for wheat grown on stubble than when both N and P were applied (**Table 1**).

Since the change in the P fertilization protocol in 1994, wheat grown on fallow did not respond to P fertilizer (Rot 1 vs Rot 2, **Table 2**), but wheat grown on stubble did in most cases (Rot 1, Rot 8 and Rot 12, **Table 2**). This suggests that after P was built up in the soils, mineralization and/or solubilization during the fallow period released adequate available P amounts to satisfy the crop needs. Further, because in stubble cropping N is more limiting than P after 27 years of buildup of available P in soil, withholding P in F-W-(W)(N+P) did not influence yield. However, withholding P in F-W-(W)(+P) reduced yield, suggesting that extended cropping without N fertilization in this last system has reduced the ability of the crop to use the built up P stores, possibly due to reduced root growth. Phosphorus uptake by the plant is proportional to the concentration of P in the soil and the volume of soil explored by roots.

Table 2. Effect[1] of N and P and withholding of N or P after 27 years on grain yield, P concentration, and P uptake of wheat grown on fallow or stubble from 1994-2005. (Values are for rotation phases in parentheses).

	Fallow crop [F-(W)-W]						
Grain	Rot 1		Rot 2		Rot 5		LSD[3](p<0.05)
characteristic[1]	(+P)	(no N or P)	(N+P)	(+N)	(+N)	(no N or P)	treat**
Yield, bu/A	45.5	44.0	46.1	45.9	36.6	37.5	2.4
P conc., %	0.40	0.38	0.39	0.37	0.32	0.34	0.01
P uptake, lb/A	10.8	10.0	10.6	10.0	6.9	7.6	0.7

	Stubble Crop										
	F-W-(W)						Cont W				
	Rot 1		Rot 2		Rot 5		Rot 8		Rot 12		
	(+P)	(no N or P)	(N+P)	(+N)	(+N)	(no N or P)	(N+P)	(+N)	(+P)	(no N or P)	
Yield, bu/A	21.9	19.2	33.0	34.1	30.9	23.4	36.5	32.9	24.9	22.4	2.6
P conc., %	0.46	0.47	0.43	0.41	0.36	0.42	0.43	0.41	0.47	0.47	0.01
P uptake, lb/A	5.8	5.2	8.1	8.1	6.1	5.7	9.0	7.8	6.9	6.8	0.7

[1] Values are averaged over years. The year × treatment interactions were significant (p<0.01) but are not shown to simplify interpretation.

[2] Grain yields and P uptake were converted from g/m² to kg/ha by multiplying by 10, and to lb/A by multiplying by 0.89.

[3] The treatment and year LSDs were all significant (p<0.01) in the full split plot analysis, but we show only the treatment means here for simplicity of interpretation.

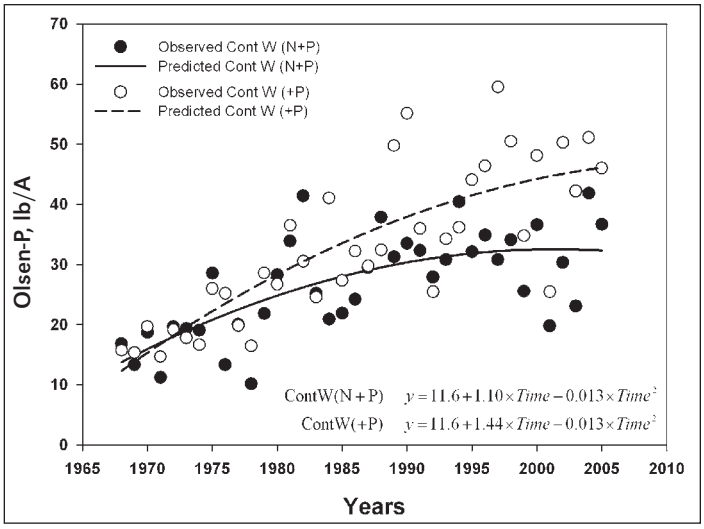

Figure 2. Long-term effect (1968 to 2005) of fertility regimes on Olsen-P content of the soil (0 to 6 in.) under Cont W rotation. Equations shown were obtained from a quadratic model fitted to all rotations, with rotations as an indicator variable.

The 27 years of withholding P from the F-W-W(+N) system did not influence Olsen-P (**Figure 1**), and reduced yields only slightly (**Table 1**). However, withholding N thereafter (**Table 2**), though reducing substantially the yields of wheat grown on stubble, did not influence yield of wheat grown on fallow mainly because sufficient N was mineralized during the fallow period.

Olsen-P in F-W-W(N+P) remained generally constant between 1994 and 2005. The relationship between Olsen-P in the 0 to 6 in. depth (y), in lb/A, and *Time* (years) for this system was : $y = 27.3 - 2.41 \times Time + 0.20 \times Time^2$. Withholding P from this system during this period decreased Olsen-P before leveling at about 15 lb/A 8 years after suspending fertilization. The relationship between y and *Time* in this case was: $y = 27.3 - 3.23 \times Time + 0.20 \times Time^2$. There was a concomitant negative P balance (-67 lb P/A) and Olsen-P decreased at an average annual rate of 0.61 lb/A. The P balance during 1994 to 2005 for Cont W (N+P) was zero (**Table 1**) and the calculated rate of change in Olsen-P was also zero (data not shown). Withholding P from this treatment resulted in a sharp initial decrease in Olsen-P that leveled off at 15 lb/A (data not shown).

The rates of change in Olsen-P in the surface 6 in. of soil over the study period was greater for Cont W (N+P) than for F-W-W (N+P) (0.57 vs 0.41 lb/A/yr), and greater for Cont W (+P) than for F-W-W (+P) (0.92 vs 0.55 lb/A/yr), because of the greater amount of P applied to Cont W. Further, the rates of increase in Olsen-P over the study period were higher when only P was applied compared to when N+P were applied because with the better nutrient supply (N + P) increased P uptake, thereby reducing residual P in soil. The rates of Olsen-P increase were greater in the 1967-1993 period when conditions were drier, because of lower P uptake than in the wetter 1994-2005 period (e.g., F-W-W(N+P) = 0.57 vs 0.06 and Cont W(N+P) = 0.73 vs 0.22 lb/A per year). The results obtained with the P balance calculation agreed with those calculated from the rates of Olsen-P change over time (**Table 1**). Changes in Olsen-P in the soil in this long-term study were directly proportional to the P balances of the different treatments; thus Olsen-P change = 9.6 + 0.17 x P balance, R^2=0.7 indicating that a change in P balance of 6 lb P/A produces a change of 1 lb P/A in Olsen-P.

In conclusion, fallow-grown wheat yield was increased by P fertilization under the original fertilization protocol, especially in the wetter than average 1994-2005 period, while there was no response to N on fallow. For stubble-grown wheat, the converse was true – it responded to N but not to P. After a build-up in available soil P, and the change in fertilization protocol in 1994, fallow grown wheat did not respond to the withholding of P. However, both N and P were required to optimize yields of stubble grown wheat. Soil P change was related to the balance between fertilizer input and P removal in grain. BC

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