Phosphorus Fertilization Strategies for Long Term Agronomic and Environmental Sustainability

John Heard, Cindy Grant, and Don Flaten

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Manitoba fertilizer phosphorus (P) guidelines have not been updated since 1992 and some troubling trends have been identified:

- In several of the past years the crop removal of P has surpassed the application rate of fertilizer P (Figure 1)
- More soil test values are declining into the LOW range in some areas of Manitoba (e.g., in the Beausejour area according to AGVISE Laboratories data in Figure 2)

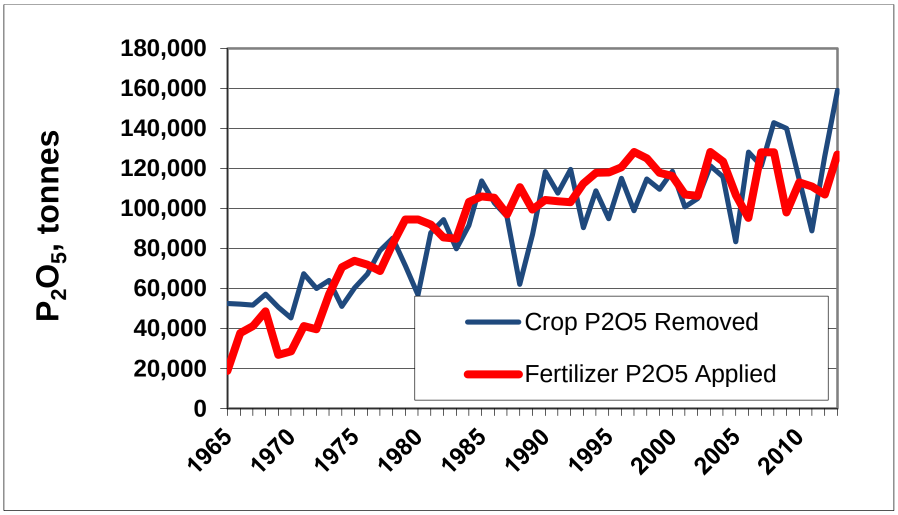

Figure 1. Annual rates of fertilizer phosphorus application and phosphorus removal removed in crop (t P_2O_5) in Manitoba. Balance does not include P supplied as manure or nutrients removed in straw. Adapted from Johnston.

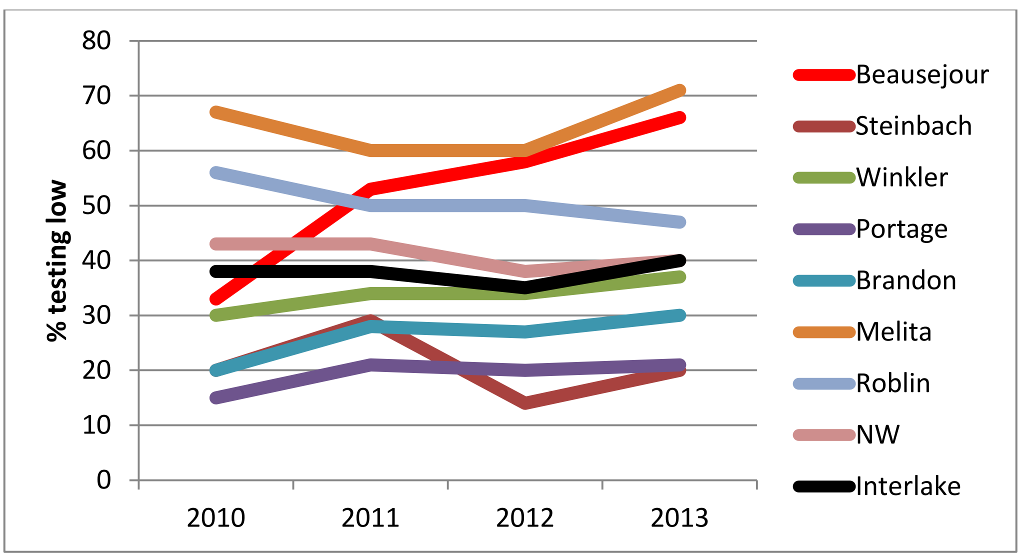

Figure 2. Trend for Manitoba fields testing low or very low (less than 10 ppm Olsen P test). AGVISE Laboratories.

This decline in soil test P levels (STP) may arise for a number of reasons:

- Changing crop acreages– from relatively low P removal crops of cereals and flax to canola, soybeans and corn (Table 1 and Appendix 1)
- Move to low disturbance seeders and planters with narrow openers and wide row spacings (low seedbed utilization (low SBU) which limit the safe rate of seed row applied fertilizer, especially with sensitive crops such as canola and soybeans (Table 2)
- Promotion and adoption of low P rate starter fertilizers that do not replace P that is removed by crops
- Increase in grain yields since development of original MAFRD recommendations in the early 1990s due to breeding (ie introduction of hybrid canola, semi-dwarf and general purpose spring wheats, winter wheat) and technology (ie fungicide use).
- Provincial recommendation tables do not include yield adjustment factors, so rates have been inadequate to meet current yield levels, let alone match rates of P removal

Table 1. Production of various field crops (000 acres) in Manitoba between 2001 and 2013. (Grant, 2012 and Flaten, 2014)

Crop	2001	2006	2013
Wheat	3922	3280	3485
Canola	1872	2279	3155
Soybeans	50	350	1050
Barley	1165	838	450
Peas	148	91	60
Flax	436	384	85
Oats	905	946	450
Corn (grain)	110	150	380

Table 2. Balance between phosphate removal and recommended safe limits for seed-placed monoammonium phosphate for common Manitoba crops. (Grant, 2012).

Crop	Yield	Removal	Seedrow limit	Balance
	bu/ac	lb P_2O_5/ac	lb P_2O_5/ac	lb P_2O_5/ac
Wheat	40	29	50	21
Canola	40	40	20	**-20**
Soybeans	40	32	10	**-22**
Barley	80	38	50	12
Peas	50	38	20	**-18**
Flax	32	20	20	0
Oats	100	29	50	21

Why is declining P fertility a concern?

Phosphorus is essential for many critical plant functions including photosynthesis and respiration, energy transfer, cell division and enlargement, transfer of heredity traits (DNA), seed formation, early root growth and expansion, and winter hardiness. Therefore, crop productivity declines when P supplies to the crop are inadequate. Furthermore, supplying adequate P for optimum crop yield requires a combination of sufficient overall P fertility in soil as well as sufficient amounts of P fertilizer. For example, research in Saskatchewan showed that wheat yields with P fertilizer, alone, could not match those with a combination of good overall P fertility in soil as well as P fertilizer applied annually in the seed row (Figure 3)

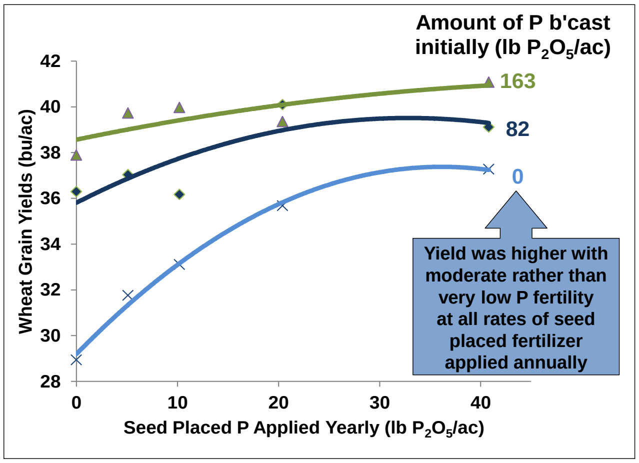

Figure 3. Crops respond to P fertilizer and P fertility, so depleted soil P can decrease crop yield potential (Wager, B.I., J.W.B. Stewart, and J.L. Henry. 1986. Comparison of single large broadcast and small annual seed-placed phosphorus treatments on yield and phosphorus and zinc contents of wheat on Chernozemic soils. Can J. Soil Sci. 66:237-248.

Developing a long term sustainability strategy to address declining P fertility

To address this decline in soil fertility and potential productivity in Manitoba, an alternative strategy for long-term phosphorus management is proposed.

Current recommendations for P are based on the "short term sufficiency" approach, which aims to supply just enough P to produce good yield of the current crop. Another approach is to consider the longer term productivity of the soil, which is referred to here as the "long-term sustainability" approach. This approach uses buildup, maintenance and drawdown strategies to move soil test levels into a medium range. The characteristics of each approach are contrasted in Table 3.

Table 3. Assumptions, strengths and weaknesses for sufficiency versus sustainability approaches to developing fertilizer recommendations (based on Ontario Soil Fertility Handbook)

	Short term sufficiency approach	Long term sustainability approach
Assumptions	Cost of P is paid for by yield increase in the current crop	Nutrient applied has residual benefit to following crops
	No economic value is given to residual effect of fertilizer	Nutrient is not subject to high losses via leaching, runoff or gaseous loss
	Yields achieved at low soil test levels with added fertilizer are similar to yields at high soil tests with less fertilizer	
Strengths	in a single year provides the greatest economic return to fertilizer	Accounts for residual benefit of fertilizer
		Reduces risk that yields will be limited by nutrients
		Soil test levels tend to stabilize in the medium soil test range
		Provides flexibility in rotational fertilization timing and rates. For example, may use starter rates only when crop prices are low and P fertilizer is expensive. Replenish soil when prices are more favourable.
Weaknesses	Dependent upon current research to predict rate	Requires spreading costs of application over several years to obtain full economic return
	Soil test levels tend to stabilize in the low soil test range	

The suitability of these systems may also vary depending upon objectives and circumstances of the individual farmer (Table 4).

Table 4. Suitability of sufficiency vs. sustainability approaches for different farming situations.

Short term sufficiency approach	Long term sustainability approach
• Short term land tenure, such as annual land rental • Wish to spend as little as possible • Low crop and high fertilizer prices • Limitations to yield other than fertility • Requires band placement to ensure greatest effectiveness of low rates	• Long-term land tenure • Not wanting fertility to be a yield limiting factor • High value, high yielding crops • Low cost source of nutrients ,such as manure • Rotational crops needing high level of nutrients • Limited risk of off-site losses of nutrient?

A chart of the existing P recommendation rates based on the short term sufficiency approach is shown in Appendix 2.

The phosphorus rates for the long-term sustainability approach are based on meeting the minimal sufficiency rate, with additional phosphorus related to soil test level and anticipated crop removal of P.

A visual presentation of the long term sustainability approach is shown in Figure 4. Note, that exact fertilizer rates are not specified. They are based upon projection of crop removal amounts over the length of the crop rotation. This allows rates to be increased in those crops with greater seed-placed tolerance or when applications of livestock manure are available. In the drawdown range, phosphorus levels decline to modest rates of seedrow P that provide a starter effect, a benefit of P fertilization that is especially important in areas with cold soils and/or short growing seasons.

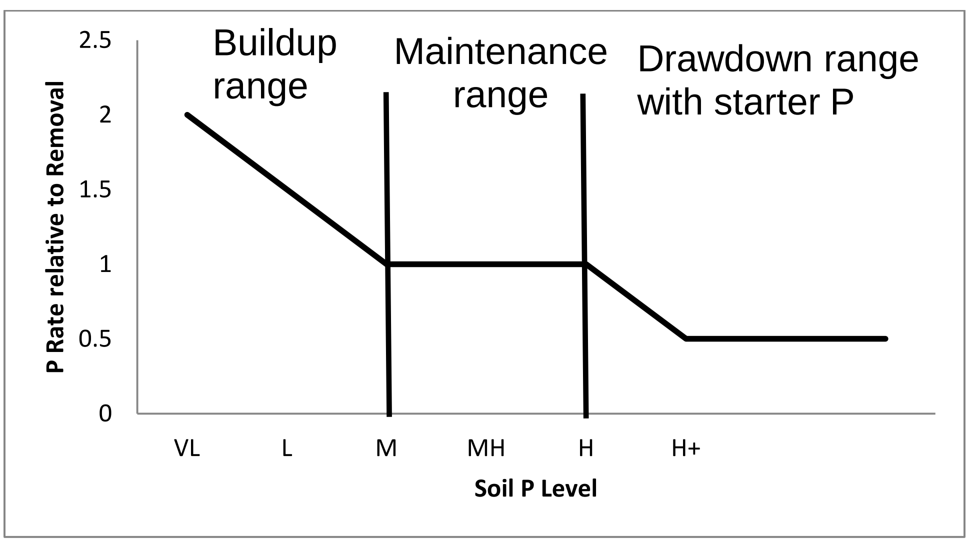

Figure 4. Long-term sustainability fertilization approach. Adapted from Ontario Soil Fertility Handbook

Olsen P test values have not been noted for the above chart, but general ranges for Manitoba are:

0-5 ppm = very low (VL), 6-10 = low (L), 11-15 = medium (M), 16-20 = high (H), 21+ = very high

The anticipated crop removal rate can be calculated by crop by using published crop removal amounts. To aid the determination of nutrient removal and balance through the rotation a spreadsheet-based calculator such as that in Table 5 could be used.

Table 5. A spreadsheet to aid calculation of the P balance through the rotation. (Flaten and Heard, 2014)

Crop	Typical Yield	P Applied	P Removed per bu	P Removed per acre	Annual Balance
	(bu/ac)	------------ (lb P_2O_5/ac) ------------			
HR Spring wheat	60	30	0.59	35	-5
Winter wheat	75	30	0.51	38	-8
Barley			0.43	0	0
Oats			0.26	0	0
Canola	40	20	1.00	40	-20
Soybeans	40	10	0.85	34	-24
Peas			0.68	0	0
Flax			0.65	0	0
Corn (grain)			0.44	0	0
Total for Rotation		90		148	-58

Blue cells are filled in by the individual for their typical rotation, yields and P application. This does not account for nutrients removed when straw or chaff is removed or burned.

Options for implementing a long term sustainability strategy for P fertilization

1. Broadcasting fertilizer P is agronomically inefficient and environmentally risky.

Banded P is generally more agronomically efficient than broadcast P because banding reduces the contact between P fertilizer and soil, reducing P retention and improving the chemical availability of P to most crops. Even more important, the poor mobility of P fertilizer means that the subsurface placement puts the P fertilizer in a better position for root uptake. This positional advantage for banded P is greatest when the P is placed in or near the seedrow of crops (starter P), especially in soils that are cold and/or low in P fertility.

From an environmental perspective, banded P is much less likely than broadcast P to be lost to surface runoff. Phosphorus losses are especially unlikely if the P is banded during spring planting, after the snowmelt runoff period. By comparison, fall broadcasting water soluble fertilizer P (eg. 11-52-0 or 10-34-0) is much more likely to cause substantial losses of P to surface water, especially during the snowmelt runoff period, when most runoff occurs in Manitoba.

If there are no practical options for subsurface banding of P (eg. in perennial forages), early spring or midsummer applications are less susceptible to runoff losses than late fall applications.

2. Sidebanding at planting can match P rate to crop removal without risk of seedling injury.

Generally, seedrow placement is the optimum method for applying P fertilizer to small seeded and solid seeded crops in Manitoba. However, as mentioned earlier, sensitive crops such as canola, will not tolerate rates of seedrow placed P that are high enough to match crop removal. Furthermore, the wide row spacings and narrow row spreading widths for row crops such as corn and soybeans creates low thresholds for seedling injury. However, seeding equipment that has the capability to band fertilizer P beside and/or below the seed can alleviate these limitations and enable applying enough fertilizer P at planting to match crop removal without the risk of injuring seedlings (Table 6).

Solid seeded crops – side banded fertilizer for narrow row crops is usually placed between 1”-2” to the side and below the seedrow. Full removal rates of P can safely be placed in this sideband. When high rates of nitrogen are dual banded with this P, greater separation distances may be required for seed safety and N may delay P uptake from this band.

Mid-row banding at seeding allows full removal rates of P, but will not provide the pop-up benefit of starter P when soils are cold and/or very deficient.

Row crops – sideband placement is routinely 2” to the side and 2” below the seed. This places P in a high concentration band where seedlings will contact it. Co-application of high rates of other fertilizers (especially urea and potash) in this band increases the risk of fertilizer burn, so total material rate should not exceed 300 lb/ac. Another option is preplant banding (even in the fall) followed by precision guided planting. When very high or buildup rates of P are applied in such wide row spacings, typically 30”, following crops on low P soils may exhibit alternating deficient striping if phosphorus is not applied.

Table 6. Banding P away from seed enables maintenance of P balance for every crop, every year, without the risk of seedling injury.

P balance for 4 year rotation with some P sidebanded				
Crop	**Yield**	**P Applied**	**P Removed***	**Annual Balance**
	(bu/ac)	**----------**	**(lb P_2O_5/ac)**	**----------**
GP spring wheat	**60**	**35**	**35**	**0**
Canola	**40**	**40**	**40**	**0**
Winter wheat	**75**	**40**	**38**	**2**
Soybeans	**35**	**30**	**30**	**0**
4 Year Total		**145**	**143**	**2**

* Using 0.59, 1.0, 0.51, 0.85 lb P_2O_5/bu respectively for grain only

3. Maximizing seedrow P in crops such as cereals that tolerate more than their removal

For farmers that do not have access to sidebanding fertilization equipment, applying a rate of P fertilizer to that is larger than the amount of P removed by a small-seeded cereal crop can help to compensate for crops in the rotation that remove more P than can be safely applied with the seed. In other words, applying a surplus of P to one crop can help make up for the deficit for another crop in the rotation (Table 7).

For example, crops such as wheat, barley and oats can tolerate seedrow placed P at rates up to 50 lbs P_2O_5/acre; however, these crops rarely remove this much P. Therefore this short term surplus of P can be used to maintain P fertility during other phases of the rotation (eg. canola, soybeans or corn). Furthermore, the crops that tolerate high rates of seedrow P can also make relatively good use of that surplus P and the residual P is left in a good position, safely underneath the soil surface, for efficient use by subsequent crops and for low risk of runoff losses.

Table 7 Maximizing seed-row P for cereal phase of rotation reduces P deficits

P balance for 4 year rotation with max P in cereal phase				
Crop	**Yield**	**P Applied**	**P Removed***	**Annual Balance**
	(bu/ac)	**----------**	**(lb P_2O_5/ac)**	**----------**
GP spring wheat	**60**	**50**	**35**	**15**
Canola	**40**	**20**	**40**	**-20**
Winter wheat	**75**	**50**	**38**	**12**
Soybeans	**35**	**10**	**30**	**-20**
4 Year Total		**130**	**143**	**-13**
* Using 0.59, 1.0, 0.51, 0.85 lb P_2O_5/bu respectively for grain only				

4. Manure application to meet crop N requirements supplies P for several years

The ratio of available N:P_2O_5 in most manures is less than 1:1, but the ratio of N required:P_2O_5 removed by most crops greater than 2:1. Therefore, application of manure to meet the crop's N requirements results in application of enough P for several years of crop production (Table 8).

Similar to the recommendations for synthetic fertilizer, subsurface injection or incorporation is highly recommended for manure wherever possible, to maximize agronomic efficiency and minimize the risk of runoff losses. In the years between manure applications, modest rates of seedrow-placed "starter P" may be helpful to ensure that seedlings have access to supplemental P during early spring, when cold soils and slow root growth limit the ability of crops to use residual P in soil.

Table 8. Manure application to meet crop N requirements supplies enough P for several crop years

P balance for 4 year rotation with pig manure, including 15 lb/ac starter P in small seeded crops				
Crop	**Yield**	**P Applied**	**P Removed***	**Annual Balance**
	(bu/ac)	----------	**(lb P_2O_5/ac)**	----------
GP spring wheat	**60**	**123**	**35**	**88**
Canola	**40**	**15**	**40**	**-25**
Winter wheat	**75**	**15**	**38**	**-23**
Soybeans	**35**	**0**	**30**	**-30**
4 Year Total		**153**	**143**	**10**
* Using 0.59, 1.0, 0.51, 0.85 lb P_2O_5/bu respectively for grain only				

Appendix 1. Nitrogen and phosphorus removal at harvest for typical crops in Manitoba.

		Typical Nutrient Removal (lb) Per Unit of Crop Grown	
Crop	Units	N	P_2O_5
Alfalfa	tons/ac	58.0	13.8
Barley - Grain	bu/ac	0.97	0.43
Barley - Silage	dry tons/ac	34.4	11.8
Canola	bu/ac	1.93	1.04
Corn - Grain	bu/ac	0.97	0.44
Corn - Silage	dry tons/ac	31.2	12.7
Dry edible beans	lb/ac	0.042	0.014
Fababeans	lb/ac	0.050	0.018
Flax	bu/ac	2.13	0.65
Grass hay	tons/ac	34.2	10.0
Lentils	lb/ac	0.034	0.010
Oats	bu/ac	0.62	0.26
Peas	bu/ac	2.34	0.69
Potatoes	cwt/ac	0.32	0.09
Rye	bu/ac	1.06	0.45
Soybeans	bu/ac	3.87	0.84
Sunflowers	lb/ac	0.027	0.011
Wheat - Spring	bu/ac	1.50	0.59
Wheat - Winter	bu/ac	1.04	0.51
Derived from Manitoba Soil Fertility Guide, Table 1			

Appendix 2. Phosphorus recommendations for field crops in Manitoba based on soil test levels and placement (Manitoba Soil Fertility Guide).

Soil phosphorus (sodium bicarbonate P test)			FERTILIZER PHOSPHATE (P_2O_5) RECOMMENDED lb/ac													
			Cereal	Corn Sunflower	Canola Mustard Flax		Buckwheat Faba beans		Potatoes		Peas Lentils Field beans Soybeans		Legume forages		Perennial grass forages	
ppm	lb/ac	Rating	S[1]	Sb[2]	B[3]	S[1]	B[3]	S[1]	B[3]	PPI[4]	B[3]	S[1]	Seeding PPI[5]	Est stand BT[6]	Seeding PPI[5]	Est stand BT[6]
0	0	VL	40	40	40	20	40	20	55	110	40	20*	75	55	45	30
	5	VL	40	40	40	20	40	20	55	110	40	20*	75	55	45	30
5	10	L	40	40	40	20	40	20	50	100	40	15*	75	55	45	30
	15	L	35	35	35	20	35	20	45	90	35	15*	65	50	35	25
10	20	M	30	30	30	20	30	20	45	90	30	10*	60	40	30	20
	25	M	20	20	20	20	20	20	40	80	20	10*	50	35	20	15
15	30	H	15	15	15	0	15	20	35	70	15	0	45	30	15	10
	35	H	10	10	10	0	10	20	30	60	10	0	35	25	5	5
20	40	VH	10	10	10	0	10	20	30	60	10	0	30	20	0	0
20+	40+	VH+	10	10	10	0	10	20	30	60	10	0	25	20	0	0

S[1] – seed-placed rates
Sb[2] – side banded rates for row crops
B[3] – banded away from the seed
PPI[4] – if P is broadcast, rates must be 2 X that of banding to be as effective.
PPI[5]– for forages phosphorus is applied most effectively by banding 1 inch to the side and below the seed. If phosphate cannot be banded, then broadcast and preplant incorporate.
BT[6] – broadcast for established stands of forages
Est stand = established stands of forages
* for field beans and soybeans, safe rates of seed-placed P are limited to 10 lb P_2O_5/ac with narrow row widths (<15”) and no seed-placed P when grown in wider row widths.