An Ontario P+K Database to Affirm and Update BMP's

in Field Crop Production Systems

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Executive Summary

This report summarizes the results of a project that reviewed phosphorous (P) and potassium (K) recommendations for major field crops (corn, soybeans, wheat and alfalfa) in Ontario. The main findings and recommendations are as follows:

1. Economic yield responses for corn, soybeans, wheat and alfalfa are generally small where soil-test P is over 12 ppm and can be obtained with P application rates that do not exceed 20 kg- P_2O_5/ha. The only change to P recommendation tables is to recommend 20 kg-P_2O_5/ha for wheat up to soil-test P of 30 ppm; the wheat P recommendation is currently 0 kg-P_2O_5/ha where soil-test p is over 20 ppm. There are no recommended changes for P recommendation tables for the other field crops.
2. Band applications of P for corn and wheat were a more effective and efficient application method when compared to broadcast. Band applied P should be actively promoted as a more effective method to apply P for corn and wheat, especially when application rates are relatively small (i.e. <50 kg-P_2O_5/ha).
3. Applying K usually did not result in economically significant corn or soybean yield increases where soil-test K was over 100 ppm. For alfalfa, applying removal rates of K are more than sufficient to ensure adequate K fertility where soil-test K is over 100 ppm. There are no changes proposed for K recommendation tables.
4. Crop nutrient removal tables were reviewed and updated. The proposed updated tables now provide nutrient concentrations for corn stover, soybean stalks and cereal straw. Nutrient removal for cereal straw can now be calculated separately from cereal grain removal.
5. A targeted maintenance P and K recommendation system is introduced that assists producers to apply appropriate P and K rates over a longer-term time horizon in order to maintain soil-tests within specified target ranges. The suggested target ranges are 12-18 ppm for P and 100-130 ppm for K. A targeted maintenance P and K Recommendation Calculator was developed which provides guidance to producers regarding the amount of P and K needed to maintain P and K soil-tests within specified target ranges based on 1.) initial soil-test P and K, 2) anticipated crops and yields over a specified longer-term time period and 3) P and K inputs during this time period. The calculator utilizes initial soil-test P and K and anticipated crop P and K removal to determine if proposed P and K applications within the specified time period will result in soil-test P and K levels that are within the targeted maintenance rage by the end of the specified time period. This tool should enable producers to be more aware of P and K inputs needed to maintain soil fertility that is at economically and environmentally appropriate levels.

1.0 Background

OMAFRA P and K recommendations for major field crops (corn, soybeans and winter wheat) were last updated in the 1970's. These P and K recommendations were developed based on the sufficiency approach which suggest P and K rates that are most likely to optimize economic returns for the crop produced that year. Using this approach would result in yearly applications of P and K on lower testing soils in order to avoid risk of yield loss due to inadequate P and/or K fertility.

Use of OMAFRA's P and K recommendations are often ignored because of a perception that crop yields have significantly increased since their introduction and the recommendations are no longer sufficient to support current high yielding corn hybrids and soybean and wheat varieties. Table 1 illustrates this concern by comparing 5-year average corn, soybeans and wheat grain provincial yields and associated grain P and K content for years 1981-85 and 2010-2014. Over these 30 years corn yields have increased by 60%, soybean yields by 40% and wheat yields by 45%. For a 3-year crop rotation of corn, soybeans and winter wheat the amount of P and K contained in the grain, which is removed when harvested, has increased by 50% since the early 1980's.

Table 1. Grain corn, soybean and wheat P and K removal and soil-test levels required to trigger a recommendation equivalent to removal based on 5-year average yields from 1981-1985 and 2010-2014.

			Phosphorous			Potassium		
Crop	Years	Grain Yield	Grain Conc.⁺	Grain Removal	Soil Test⁺⁺	Grain Conc.⁺	Grain Removal	Soil Test⁺⁺
		Mg/ha	kg-P_2O_5/Mg	kg-P_2O_5/ha	ppm-P_2O_5	kg-K_2O/Mg	kg-K_2O/ha	ppm-K_2O
Grain Corn	1981-85	6.1	7	44	12	5	30	120
	2010-14	9.92		71	9		49	100
Soybeans	1981-85	2.26	14	32	12	23	52	80
	2010-14	3.15		44	9		72	60
Wheat	1981-85	3.64	10	36	9	6	22	60
	2010-14	5.25		51	7		32	45

+ Grain concentrations obtained from Table 9. When concentrations are presented as a range the average of the low and high range values were used in calculations.

++ Soil-test levels required to trigger a sufficiency recommendation that is similar to the estimated crop removal.

Table 1 also includes the maximum P soil-test level that is needed to result in a P recommendation that is similar to grain removal. The corn and soybean P recommendations would maintain a soil-test P level of about 12 ppm based on grain P removal typical for the yields in the early 1980's. In contrast, soil-test

P levels would be maintained at about 9 ppm based on grain P removal typical for current corn and soybean yields. A similar effect was also observed for wheat where maximum P soil test to provide a recommendation equivalent to removal decreased from 9 ppm in the early 1980's to 7 ppm currently.

A similar analysis for the corn, soybean and winter wheat K recommendations indicates that soil-test K levels would be maintained about 20 ppm lower based on removal associated with current yields when compared to the early 1980's (Table 1). Soil-test K levels would be maintained at 100 ppm based on current average corn K removal, 60 ppm for current average soybean removal and 45 ppm for current average wheat removal. Based on average current K removal rates for a corn-soybean-wheat rotation soil-test K would be maintained at about 70 ppm if recommended K rates for each crop were applied.

An alternative approach is to target and then maintain soil-test P and K at levels which essentially assures that yields for each crop in the rotation are not significantly limited by inadequate P and/or K availability. Target soil-test ranges should be where crop yields are slightly responsive to P and K additions. Based on OMAFRA's current sufficiency P and K recommendations possible target soil-test ranges are 12-18 ppm for P and 100-130 for K. Where soil-test levels are below the target range, P and/or K additions are greater than crop removal in order to build soil-test K levels to within the target range. Where soil-test levels exceed the target ranges then P and K additions suggested by the sufficiency approach should be applied. These rates are generally less than grain removal and soil-test levels will over time decline into the target range. Where soil-tests levels are within the target range then P and K rates are similar to grain removal rates.

One of the advantages of the target and maintain approach is that where soil-test P and K levels are within the target range that applications do not have to occur yearly to ensure adequate crop P and K nutrition. For example, the bulk of the P and K needed to cover the grain removal associated with a corn-soybean-wheat rotation could be applied once in the rotation cycle. Many of Ontario's field crop producers periodically, rather than yearly, apply P and K and official adoption of a recommendation system that is suited for these producers should enhance use of OMAFRA's P and K recommendations.

2.0 Collection and Databasing of Research Data

A total of 368 Ontario research trials that evaluated field crop response to P and/or K fertilizers were identified and databased. It should be acknowledged that Tom Bruulsema (IPNI) in the late 1990's collected many Ontario research trial reports that evaluated P and K fertility for Ontario field crops and made this collection of reports available for this data basing effort. No doubt that some of the data that was databased would not have been available had Tom not actively collected research trial results in the late 1990's.

Whenever possible the replicated data was included in the database. Unfortunately, for many of the trials only treatment average data was available. Data basing included information on the location of the trial, relevant cropping history (when reported), tillage (when reported) pesticide inputs (when reported) and P and K fertilizer applied (including description of product, rates application timing and application methods). Data included in the database includes crop yield, soil fertility and soil texture and series (when reported). The data is currently compiled in both SAS dataset and excel formats.

3.0 Data Analysis

The research data was separated into 2 main groups:

1. Multiple rate trials where a nutrient (comprised of similar product, timing and method of application) was applied at more than 2 rates (including the control). For these trials economic nutrient rates were calculated based on regression analysis.
2. Two rate trials where various fertilizer products were compared to a control. For example trials evaluating various starter fertilizers typically apply the various starter products at 1 rate and compare the response to a no fertilizer control.

For trials where multiple rates of nutrient(s) were applied regression curves were fitted that described crop yield response to nutrient application rate. The data was fitted using a quadratic plateau model as follows:

$Yield=A + B*R – C*R^2$ where $R<Rmax$ else $Yield=A + B*R_{max} – C*R_{max}^2$ (Equation 1)

where:

Yield is the crop yield (kg/ha)

A is the fitted intercept of the quadratic equation

B is the linear coefficient of the fitted quadratic equation

C is the quadratic coefficient of the quadratic equation

R is the nutrient rate (kg-Nutrient/ha)

Rmax is the nutrient rate where the quadratic function attains it’s maximum (kg-Nutrient/ha)

Regression fitting included constraints on the B coefficient such that it could not be less than 0 and the C coefficient could not be greater than 0. For cases where a positive C coefficient would have been fitted without the constraint, the C coefficient is 0 resulting in a linear response. For cases where there was a tendency for decreasing yields with increasing nutrient rates the fitted equation had an intercept (A) value that was similar to the over all average trial yield and the B and C coefficients were 0 (non responsive).

Maximum economic rates of P and K were calculated by setting the first derivative of Equation 1 equal to the Nutrient:Crop price ratio and solving for R as follows:

$Re=(PR-B)/(2*C)$ (Equation 2)

where

Re is the maximum economic nutrient rate (kg-Nutrient/ha)

PR is the Nutrient:Crop price ratio ($/kg-Nutrient)/($/kg-Crop simplifying to kg-Crop/kg-Nutrient)

B is the linear coefficient from the quadratic response equation (from Equation 1)

C is the quadratic coefficient from the quadratic response equation (from Equation 1).

In cases where there was no response to P or K the economic nutrient rate was set to 0 kg/ha. If the response was linear and the linear coefficient was less than the Nutrient:Crop price ratio then the maximum economic nutrient rate was set to 0 kg/ha. For linear responses with slopes greater than the Nutrient:Crop price ratio or quadratic responses where the calculated maximum economic rate exceeds the highest nutrient rate applied then maximum economic nutrient rate was set equal to the rate applied for the highest nutrient rate treatment. If Equation 2 solved to a negative value the maximum economic nutrient rate was set to 0 kg/ha.

Crop and nutrient specific economic assumptions will be described when results of analysis are discussed.

4.0 Evaluation of P and K Recommendations

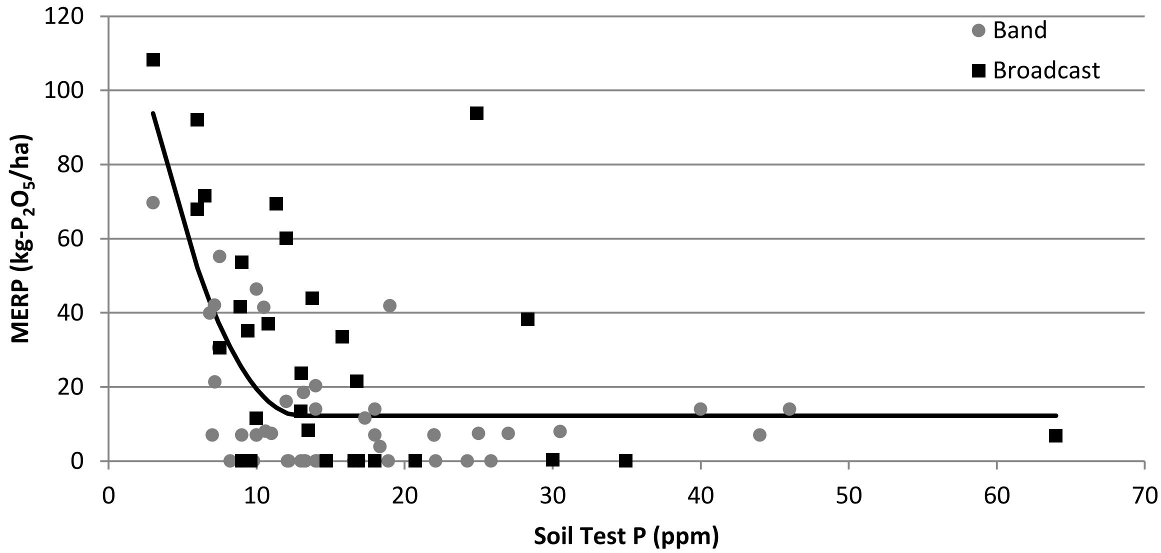
4.1 Corn

4.1.1 Phosphorous Multiple Rate Trials

A total of 77 sites were identified which evaluated corn yield response to multiple rates of P fertilizer. To be retained in the analysis the maximum corn yield had to exceed 6 Mg/ha. Soil-test P was less than 12 ppm on 30 of the 77 trials.

The relationship between maximum economic rate of phosphorous (MERP) and soil-test P is shown in figure 1. The MERP calculations assume a Phosphorous:Corn price ratio of 8; which is the price ratio if corn selling price is assumed to be $177/Mg ($4.50/bu) and MAP product cost of $740/Mg ($1.43/kg-P_2O_5). Regressing MERP onto soil-test P by fitting a quadratic function which transitions into a horizontal line when the quadratic curve attains it's minimum explained 39% of the variability in MERP. Sites with higher P requirements (over 25 kg-P_2O_5/ha) tended to have soil test P less than 12 ppm. When soil tests were over 12 ppm the fitted relationship predicted a P requirement of 12 kg-P_2O_5/ha; a rate that is similar to rates typically provided by planting in-furrow starter applications.

Figure 1. Relationship between maximum economic rate of phosphorous (MERP) at price ratio 8 and soil-test P from 77 research trials that evaluated corn yield response to multiple rates of P fertilizer that was either planter-band or broadcast applied (1969-2010). Prediction equation: MERP=150-21.3*Soil-p+0.823*Soil-P^2 for Soil-P<13 else MERP=12 R^2=0.39.



Band applied P was generally associated with higher MERP values when compared to broadcast (Fig. 1). Fitting separate regression curves for the banded and broadcast sites increased the variability explained by soil-test P by 11% (R^2=0.50) (data not shown). Both of the fitted regression curves reached their minimum at 13 ppm with predicted P requirements over 13 ppm that were 20 kg- P_2O_5/ha when banded and 8 kg- P_2O_5/ha when broadcast. For the trials included in this analysis phosphorous was applied either broadcast (mostly spring preplant) or planter-banded (2" by 2") (not both); so direct comparison of application efficiency is not possible. However the lower yield response generally associated with broadcast P when compared to planter-banded P suggests that for corn planter-banded P is a more effective method for applying P fertilizer. A proposed change to phosphorous recommendation tables for corn will include a statement that band applying phosphorous is more effective than broadcast, and is the preferred method when applications are less than 50 kg- P_2O_5/ha (Appendix 1).

OMAFRA's sufficiency P recommendations are higher than the average MERP predicted by the relationship shown in Figure 1, especially where soil-test P levels are less than 12 ppm (Table 2). Assuming a Nutrient:Corn price ratio of 5 rather than 8 increased recommended P by only 8 kg-P_2O_5/ha (data not shown) suggesting that within expected ranges of P and corn prices that the ratio of P and corn will have minimal impact on P recommendations. Soil-test P has a much greater influence on economic P rates for corn than does the yearly variations in P:Corn price ratios.

Table 2. Comparison of sufficiency recommendations for corn and predicted maximum economic rate of phosphorous based on analysis of 78 Ontario trials.

Soil-Test P	Sufficiency Recommendation	Regression Fitted+
ppm-P_2O_5	-------------- kg-P_2O_5/ha --------------	
0–3	110	110
4–5	100	60
6–7	90	40
8–9	70	30
10–12	50	10
13–15	20	10
16–20	20	10
21–30	20	10
31–60	0	10
61+	0	0

+ Regression fitted is based on the relationship between maximum economic rate of phosphorous and soil-test P shown in figure 1. The regression fitted value was calculated using the average of the first values from the current and next range categories. For example, the 10-12 ppm category the average was calculated using 10 (first value from the current category) and 13 (first value from the next category)

4.1.2 Potassium Multiple Rate Trials

A total of 58 trials were identified that evaluated corn response to multiple rates of potassium, 18 of which had soil-test K less than 100 ppm and 40 over 100 ppm. Maximum grain corn yields had to exceed 6 Mg/ha to be retained in this analysis. Soil-test K ranged from 52 to 230 ppm. The source of potassium at all trials was potash which was fall broadcast applied at 12 trials with the remainder of the trials having potash broadcast in the spring just before corn planting.

Maximum economic rates of potassium (MERK) were less than 10 kg-K_2O/ha for half of the trials (Table 3). Table 3 contains the average and distribution (percentiles) for MERK and associated yield response (increase over control) for the 58 multiple K rate trials included in this analysis. The MERK calculations assume a Potassium:Corn price ratio of 5; which is the price ratio if corn selling price is assumed to be \$177/Mg (\$4.50/bu) and potash product cost of \$550/Mg (\$0.93/kg-K_2O). Where soil-test K was over 100ppm, half of the sites had MERK of 0 kg-K_2O/ha and only 25% required more than 25 kg- K_2O to achieve maximum economic yields.. Where soil-test K was less than 100 ppm average MERK was 31 kg-K_2O/ha and average yield increase was 0.49 Mg/ha. For the 18 trials with soil-test K less than 100ppm, only 4 trials had MERK over 50 kg-K_2O/ha and a yield increase to K fertilizer that was greater than 0.3 Mg/ha. A significant relationship between MERK (PR=5)and soil-test K could not be identified primarily because trials in this dataset with lower soil-test K often did not produce significantly higher yields when K fertilizer was applied. If a K:Corn price ratio of 3 is assumed then a significant relationship could be fitted (R^2=0.20) which predicted economic K_2O/ha rates of 90, 50, 35 and 20 kg-K_2O/ha where soil tests are 60, 80, 100 and >130 ppm, respectively (data not shown). These K recommendations are similar to OMAFRA's sufficiency K recommendations suggesting that they probably were developed using a price ratio closer to 3 rather than 5.

Table 3. Average and distribution of maximum economic rates of potassium at a Potassium:Corn price ratio of 5 and associated yields from 58 trials that evaluated corn yield response to multiple rates of K fertilizer (1969-2000). Analysis was grouped according to trials with soil-test K levels that were less than 100 ppm (18 trials) or greater than 100 ppm (40 trials).

Measurement					------------ Percentiles ------------					
Soil-Test	avg.	stderr	prt+	Min.	17	25	50	75	83	Max.
Rate (Kg-K_2O/ha)										
Less 100 ppm	31	12.0	0.0206	0	0	1	8	52	53	209
Greater 100 ppm	13	3.6	0.0006	0	0	1	2	25	30	125
Response (Mg/ha)										
Less 100 ppm	0.49	0.224	0.0445	0.00	0.00	0.00	0.07	0.33	0.52	3.09
Greater 100 ppm	0.15	0.043	0.0014	0.00	0.00	0.00	0.00	0.19	0.32	1.37

+ Probability that the average value is not different from 0.

<u>4.1.3 Recently Conducted Trials that Evaluated Corn Response to K</u>

OMAFRA staff have conducted 38 trials from 2008-2013 that evaluated corn yield response to planter-banded (2"x2") MAP and starter blends that contain both P and K. Within each trial both fertilizers applied equivalent P rates that averaged 47 kg-P_2O_5/ha (ranged between 43 and 58 kg-P_2O_5/ha). The K rate applied averaged 40 K_2O/ha (ranging from 70% to 100% of the P rate applied). Since multiple rates of K were not applied at these trials a direct relationship between MERK with soil-test K cannot be developed. However, evaluation of the relationship between yield increase for the P & K blended starter over the P only starter (P & K Blend-P Only) and soil-test K can be used to identify soil test K levels where application of K is likely to have minimal economic return.

Grain corn yield increase associated with including K in the starter fertilizer and soil-test K is shown in Figure 2. Where soil-tests were less than 90 ppm yield increases associated with applying 40 kg-K_2O/ha in starter blends were over 0.75 Mg/ha at 50% of the trials. Based on the fitted relationship shown in Figure 2 the break-even yield of 0.21 mg/ha (based on earlier described corn and potash price assumptions and a 40 kg-K_2O/ha application rate) is estimated to occur at soil-test K of 118 ppm. The starter K dataset indicates that 1) where soil-test K is less than 90 ppm that applying K fertilizer can substantially increase economic returns and 2) that where soil-test K is over 120 ppm that even applying relatively low rates of K (i.e. 40 kg-K_2O/ha) will likely not result in economically significant yield increases.

There also were 15 trials conducted from 1997-2013 that evaluated grain corn yield response to Higher K rates (120-270 kg-K_2O/ha) (data not shown). Soil-test-K at these trials ranged from 43 to 132 ppm Where soil-test K was less than 90 ppm (12 trials), the average yield increase associated with broadcast K was 1.48 Mg/ha (ranging from 0.06 Mg/ha to 5.52 Mg/ha). A significant relationship between yield response and soil-test K could not be identified, only that significant yield increases can occur when K is applied where soil-tests are less than 90 ppm.

Figure 2a. Relationship between corn grain yield response to MAP and Map/Potash blend starter fertilizers and soil-test P from 38 research trials conducted from 2008-2013. Prediction equations for P&K Blend is yield response=2.17-0.099*Soil-P+0.00122*SoilP^2 where Soil-P<40 ppm else Yield Response=0.22 R^2=0.38; and for MAP is Yield Response=0.61-0.014*Soil-P R^2=0.08.

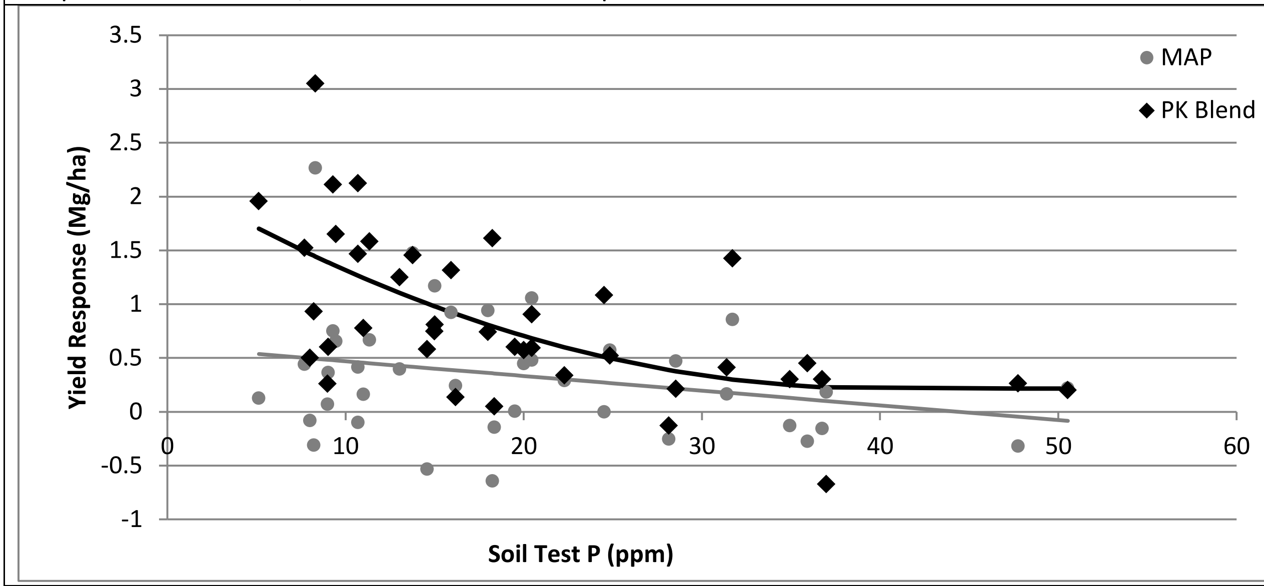
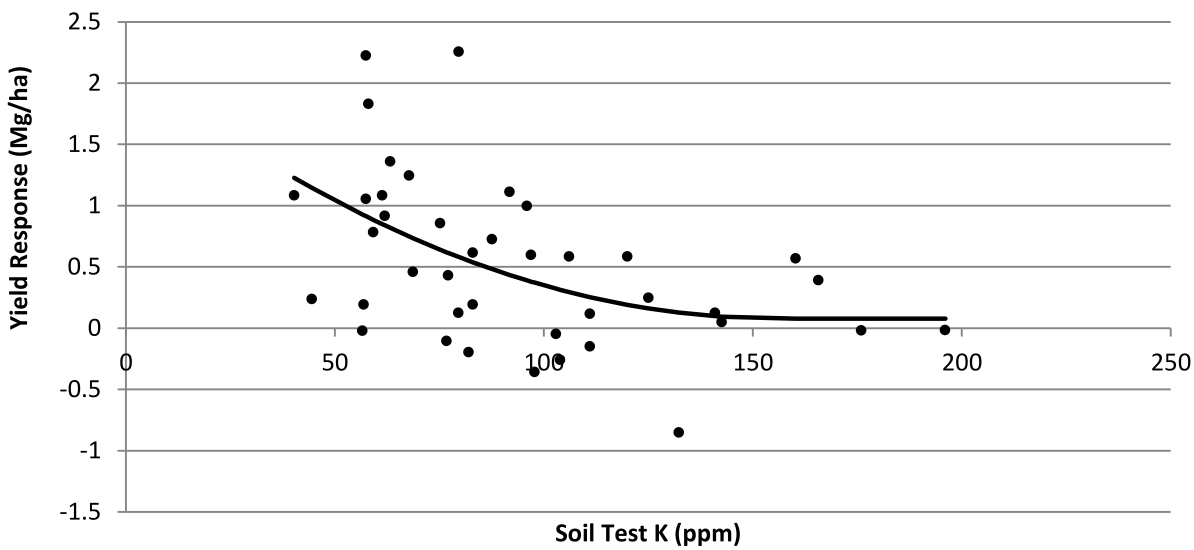


Figure 2b. Relationship between corn grain yield response associated with including potash in starter fertilizer blends and soil-test K from 38 research trials conducted from 2008-2013. Grain corn yield response was calculated as the yield obtained applying the P and K blend starter– yields obtained with applying only the MAP starter. Prediction equation: Yield Response=2.16-0.0266*Soil-K+0.0000851*Soil-K2 where Soil-K<156 ppm else Yield Response=0.08 R^2=0.23.



4.2 Soybeans

4.2.1 Multiple Rate Phosphorous Trials

Soybean yield response to multiple rates of phosphorous were evaluated at 25 trials, all of which were conducted from 1972-1990. Soil-test P ranged from 6 to 28 ppm with 11 trials having soil-test levels that were less than 12 ppm. Phosphorous was broadcast applied preplant at all trials.

The Phosphorous:Soybean price ratio used for MERP calculations was 3.5; based on an assumed soybean price of $404/Mg ($11/bu) and MAP product cost of $740/Mg.

Maximum economic rate of phosphorous (MERP) at most sites was 0 kg-P_2O_5/ha (Table 4). The average and distribution (percentiles) of MERP and associated yield response to applying P fertilizer is shown in Table 4. Even where soil-test P was less than 12 ppm average economic rates of P did not differ from 0 kg-P_2O_5/ha and associated yield response (increase over control) also did not differ from 0 Mg/ha. A significant relationship between MERP and soil-test P could not be identified primarily because applying P at these 25 trials often did not result in economically significant yield increases. Even when P:Soybean ratio was 2 a significant relationship between soil-test P and MERP could not be identified.

Table 4. Average and distribution of maximum economic rates of Phosphorous at a Phosphorous:Soybean price ratio of 3.5 and associated yields from 25 trials that evaluated soybean yield response to multiple rates of P fertilizer (1969-1990). Analysis was grouped according to trials with soil-test P levels that were less than 12 ppm (11 trials) or greater than 12 ppm (14 ppm).

Measurement				Percentiles						
Soil-Test	avg.	stderr	prt+	Min.	17	25	50	75	83	Max.
Economic Rate (Kg-K_2O/ha)										
Less 12 ppm	1	1.5	0.3409	0	0	0	0	0	0	16
Greater 12 ppm	3	2.4	0.2572	0	0	0	0	0	0	33
Economic Response (Mg/ha)										
Less 12 ppm	0.01	0.006	0.3409	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Greater 12 ppm	0.02	0.020	0.2932	0.00	0.00	0.00	0.00	0.00	0.00	0.28

+ Probability that the average value is not different from 0.

4.2.2 Multiple Rate Potassium Trials

Soybean response to multiple-rates of potassium were evaluated on the same 25 trials where multiple-rate phosphorous responses were evaluated. Soil-test K ranged from 67 to 191 ppm, of which 13 of 25 trials had soil-test K levels below 100 ppm. Potash was broadcast applied preplant at all trials.

Maximum economic rates of potassium (MERK) were 0 kg-K_2O/ha at 8 of the 13 trials where soil-test K was less than 100 ppm and for 10 of 12 trials where soil-test K was over 100 ppm. The Potassium:Soybean price ratio used for MERK calculations was 2; based on an assumed soybean price of \$404/Mg (\$11/bu) and Potash product cost of \$550/Mg. The average and distribution (percentiles) of MERK and soybean yield response to applying K fertilizer are shown in Table 5. On average MERK did not differ from 0 kg-K_2O/ha with only 2 of 25 trials having MERK over 75 kg-K_2O/ha and a yield response that was over 0.2 Mg/ha. A significant relationship between MERK and soil-test K for these 25 trials could not be identified primarily because often applying K fertilizer did not substantially increase yields even when soil-test K levels were less than 100 ppm. A significant relationship between MERK and soil-test K also could not be fitted when the K:Soybean price ratio was 1.

Table 5. Average and distribution of maximum economic rates of potassium at a Potassium:Soybean price ratio of 2 and associated yields from 25 trials that evaluated soybean yield response to multiple rates of K fertilizer (1969-1990). Analysis was grouped according to trials with soil-test K levels that were less than 100 ppm (13 trials) or greater than 100 ppm (12 trials).

Measurement				Percentiles						
Soil-Test	avg.	stderr	prt+	Min.	17	25	50	75	83	Max.
Economic Rate (Kg-K_2O/ha)										
Less 100 ppm	13	6.6	0.0681	0	0	0	0	15	34	80
Greater 100 ppm	10	7.6	0.2349	0	0	0	0	0	0	90
Economic Response (Mg/ha)										
Less 100 ppm	0.05	0.024	0.0583	0.00	0.00	0.00	0.00	0.04	0.11	0.23
Greater 100 ppm	0.03	0.023	0.1665	0.00	0.00	0.00	0.00	0.00	0.00	0.21

+ Probability that the average value is not different from 0.

4.2.3 Recently Conducted Trials that Evaluated Soybean Response to P and K

OMAFRA staff conducted a total of 54 trials that evaluated soybean response to spring broadcast and planter-banded (2”x2”) applied P and K blended fertilizers from 2008 to 2013. The rate of P applied across the various trials ranged between 28 to 80 kg-P_2O_5/ha and K rate applied ranged from 40 to 80 kg-K_2O/ha.

Average soybean yield response to the P K blended fertilizer was 0.17 Mg/ha where soil-test K was less than 100 ppm (Table 6); a yield response that often was large enough to pay for the K component of the blend. The average yield response for sites with soil-test less than 12 ppm was not large enough to pay for the P component of the blend. Average soybean yield response to the PK blend was not more than 0.11 Mg/ha for sites where soil-test P exceeded 12 ppm or where soil-test K exceeded 100 ppm and these average yields were not sufficient to pay for either the P or K component of the fertilizer blend. These small soybean yield increases support the assumption that there is a low probability of obtaining an economic yield response by applying P fertilizer where soil-test is over 12 ppm and K fertilizer where soil-test is over 100 ppm.

Table 6. Soybean yield response to spring applied P and K fertilizer blends grouped according to soil-test P values that were less or greater than 12 ppm and soil-test K values that were less or greater than 100 ppm (2008-2013). The rate of P applied across the various trials ranged between 28 and 80 kg-P_2O_5/ha and K rate applied ranged from 40 to 80 kg-K_2O/ha.

	Soil_P		Soil_K	
Fertilizer	<12 ppm	>12 ppm	<100 ppm	>100 ppm
	------------------------- Mg/ha		-------------------------	
PK Blend	3.43	3.57	3.42	3.59
Control	3.37	3.47	3.25	3.52
Difference	0.05	0.11	0.17	0.07
Pr>|t|	0.287	0.003	0.034	0.018
TRMax	61.4	69.1	56.1	71.5
sites	11	43	14	40

+ Probability that the PK Blend and control yields are not different.

Soybean response to higher K rates of 130-270 kg-K_2O/ha was evaluated on 15 trials from 1998-2013 (data not shown). Soil-test K ranged from 35 ppm to 155 ppm with 10 sites having soil-test K that was less than 100 ppm. For the sites where soil-test K was less than 100 ppm, the average yield increase was 0.14 Mg/ha, the maximum increase was 0.56 Mg/ha and no yield increase was associated with applying K at 5 of 12 trials. Where soil-tests were over 100 ppm yields were usually not increased by K fertilizer. This data is similar to the other soybean data which suggests that applying K fertilizer to soybeans often will not increase yields; even where soil-test K is 60-100 ppm.

4.3 Forages

The forage trials were all Alfalfa based stands. Evaluation of P and K yields in the forage analysis were conducted in the production years, none of the yields were obtained in the establishment year. Forage yields were the total annual yield (usually the sum of 2 or 3 cuts). Phosphorous and potassium fertilizer was usually broadcast applied following the final cut (September).

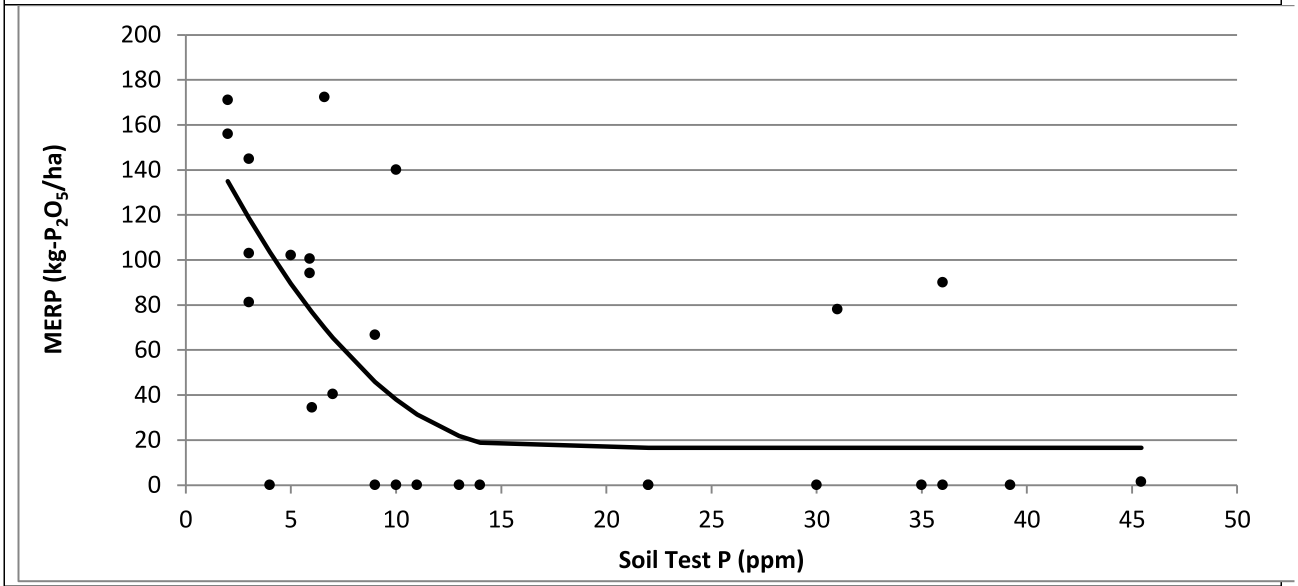
4.3.1 Phosphorous

Alfalfa response to phosphorous was assessed at 15 trials with many trials having assessments in the second and third production years resulting in a total of 28 trial-years. Soil test-P ranged from 2 to 45 ppm with 17 of the 28 trial-years having soil-test P that was less than 12 ppm.

The relationship between MERP and soil-test P is shown in Figure 3. The Phosphorous:Forage price ratio used for MERP calculations was 8; based on an assumed forage price of $175/Mg and Phosphorous product cost of $740/Mg. Soil-test P explained 46% of the variability in MERP. At soil-test P levels over 16 ppm predicted MERP was essentially 0 kg-P_2O_5/ha. The fitted regression suggests 17 kg-P_2O_5/ha for soil-test P levels over 15ppm because 2 of 9 trial-years with soil-test over 16 ppm had MERP of 80 and 90 kg-P_2O_5/ha while the remaining 7 had MERP of 0 kg-P_2O_5/ha.

Sufficiency P recommendations are higher than the average MERP predicted by the relationship shown in Figure 3, especially where soil-test P levels are less than 12 ppm (Table 7). Assuming a P:Forage price ratio of 5 rather than 8 increased P recommendations by 20 to 30 kg-P_2O_5/ha where soil-tests were within the range of 5 to 15 ppm (data not shown). Overall, soil-test P has a much greater effect on economic P rates than does the relative variation in likely forage and phosphorous prices (price ratios).

Figure 3. Relationship between maximum economic rate of phosphorous (MERP) and soil-test P from 15 research trials (28 production years) that evaluated alfalfa yield response to multiple rates of P fertilizer 1969-1988). Prediction equation: MERP=171-19.5Soil-P+0.611Soil-P^2 where Soil-P<16 ppm else MERP=17 R^2=0.46.



No changes to forage P recommendations are recommended even though at soil tests greater than 16 (9 observations) the fitted regression suggests a 20 kg-P_2O_5/ha requirement compared to the current sufficiency recommendation of zero. However upon close inspection of the data it is observed that 7 of these 9 observations had a MERP of 0 kg-P_2O_5/ha. The decision was made to leave the current recommendations unchanged. (Figure 3, Table 7).

Table 7. Comparison of sufficiency recommendations for alfalfa and predicted maximum economic rates of phosphorous and potassium based on analysis of Ontario yield response trials.

	Phosphorous			Potassium	
Soil-Test P	Sufficiency Recommendation	Regression Fitted+	Soil-Test K	Sufficiency Recommendation	Regression Fitted+
ppm-P_2O_5	---------- kg-P_2O_5/ha ----------		ppm-K_2O	---------- kg-K_2O/ha ----------	
0–3	180	140	0–15	480	230
4–5	120	90	16–30	400	190
6–7	90	70	31–45	320	160
8–9	60	50	46–60	270	120
10–12	30	30	61–80	200	90
13–15	20	20	81–100	130	60
16–20	0	20	101–120	70	40
21–25	0	20	121–150	20	30
26–30	0	20	151–180	0	20
31–40	0	20	180 - 250	0	20
41–50	0	20	251+	0	20

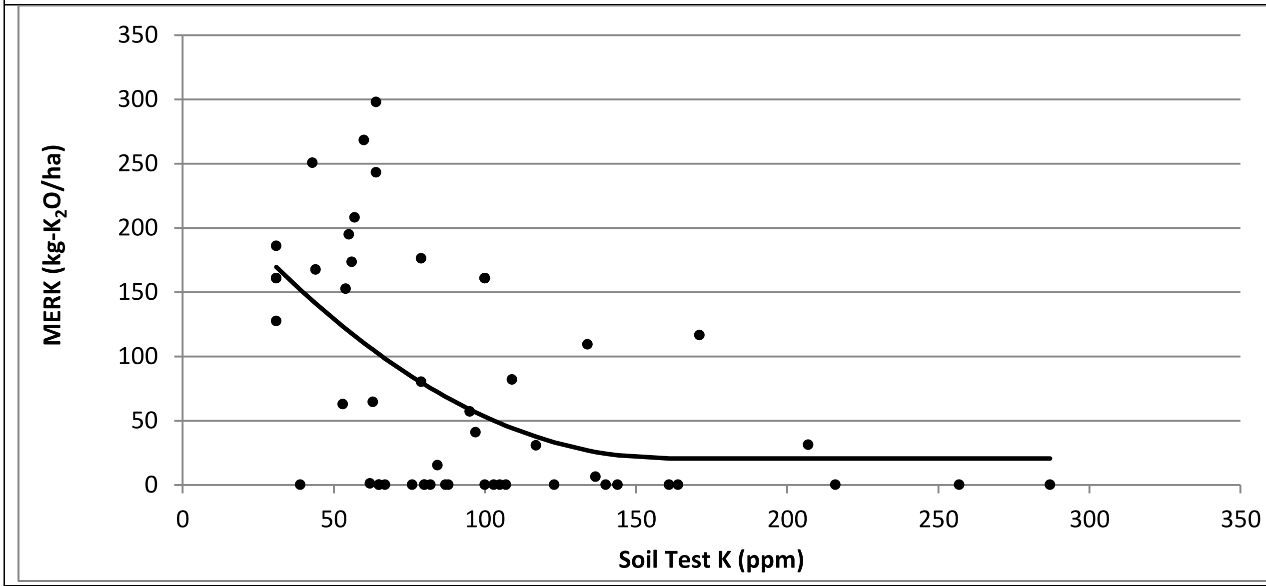
+ Regression fitted is based on the relationship between maximum economic rate of phosphorous and soil-test P shown in figure 3 or maximum economic rate of potassium and soil-test K shown in figure 4. The regression fitted value was calculated using the average of the first values from the current and next range categories. For example, for the 10-12 ppm soil-test P category the average was calculated using 10 (first value from the current category) and 13 (first value from the next category)

4.3.2 Potassium

Alfalfa yield response to applied potassium was assessed at 26 trials with most trials having data for 2 or 3 production years resulting in a total of 53 trial-years. Soil-test K ranged from 31 to 287 ppm with 31 of the 53 trial-years having soil-test K less than 100 ppm.

The relationship between MERK and soil-test K is shown in figure 4. The Potassium:Forage price ratio used for MERK calculations was 5; based on an assumed forage price of $175/Mg and Potash product cost of $550/Mg. Soil-test K explained 26% of the variability in MERK. Maximum economic Rates of Potassium often were greater than 200 kg-K_2O/ha when soil-tests were less than 70 ppm. Maximum economic rates of potassium did not exceed 100 kg-K_2O/ha when soil-test K exceeded 170 ppm.

Figure 4. Relationship between maximum economic rate of potassium (MERK) and soil-test K from 26 research trials (53 production years) that evaluated alfalfa yield response to multiple rates of K fertilizer 1960-1989). Prediction equation: MERK=249-2.8*Soil-K+0.00885*Soil-K^2 where Soil-K<161 else MERK=20 R^2=0.26.



Sufficiency K recommendations are higher than the average MERK (price ratio=5) predicted by the relationship shown in Figure 4, especially where soil-test K levels are less than 120 ppm (Table 7). For a K:Forage price ratio of 3 the fitted relationship between MERK and soil-test K (R^2=0.30) predicted MERK at 270, 210, 160, 120, and 70 kg-K_2O/ha for soil-test K of 40, 60 80 100 and 130 ppm, respectively. The predicted MERK values at price ratio 3 are similar to the sufficiency K recommendations for forages suggesting that probably the forage K recommendations were developed with an assumed K:Forage price ratio that was closer to 3 than 5.

4.4 Winter Wheat

If trials that evaluated wheat yield response to multiple rates of P or K fertilizers were conducted in Ontario, we were unable to source this data.

4.4.1 Phosphorous

OMAFRA staff conducted 28 on-farm trials that evaluated winter wheat yield response to starter fertilizer. Soil-test P ranged from 6 to 56 ppm with 10 trials having soil-test P that was less than 13 ppm.

As expected, the largest wheat yield increases associated with applying P fertilizer occurred where soil-test P was less than 13 ppm (Table 8). Similar yields between the 19 kg-P_2O_5/ha in-furrow starter and 76 kg-P_2O_5/ha broadcast treatments suggest that more efficient utilization of P fertilizer occurred when banded.

Table 8. Winter wheat yield response to P fertilizer that was broadcast or band in-furrow applied from 28 on-farm research trials grouped according to soil-test P levels (2010-2013).

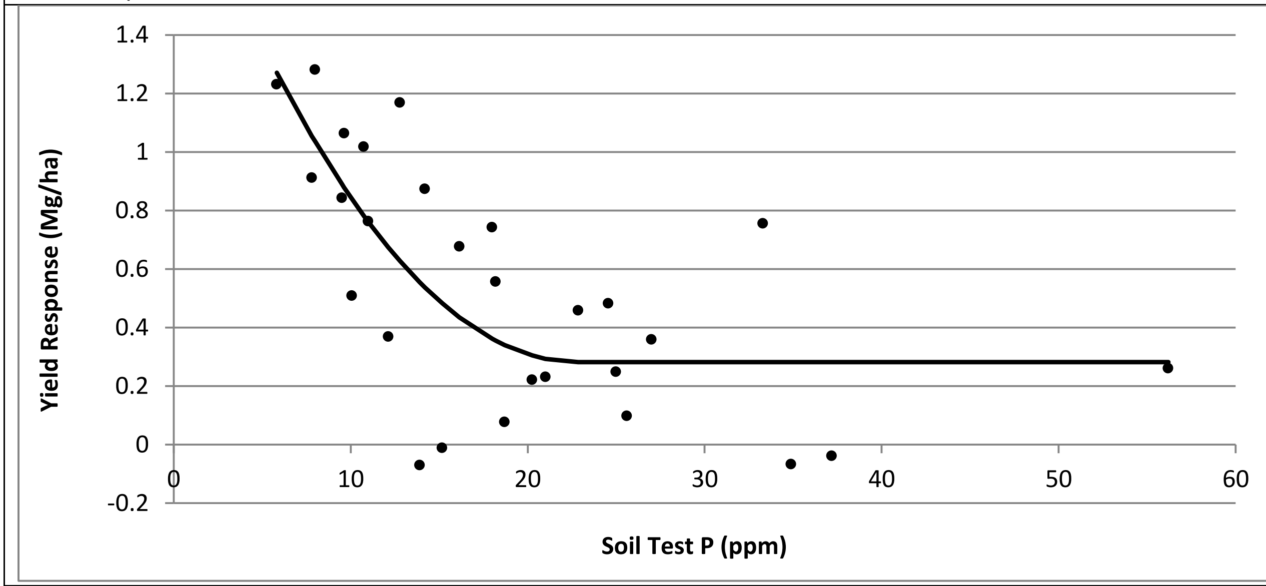
	Soil Test P		
Fertilizer	6-13 ppm	13-21 ppm	21-56 ppm
	----- Mg/ha -----		
58 kg-P_2O_5/ha (In-Furrow)	6.23	6.31	6.27
19 kg-P_2O_5/ha (In-Furrow)	5.89	6.23	6.19
76 kg-P_2O_5/ha (Broadcast)	5.95	6.15	6.25
None Applied	5.31	5.94	5.98
$LSD_{(P=0.05)}$ ++	0.17	0.19	0.19
Sites	10	9	9

+ Least significant difference at the 5% level of probability.

The relationship between the wheat yield increase associated with the in-furrow 58 kg-P_2O_5/ha application and soil-test P is shown in figure 5. The larger (>0.8 Mg/ha) yield responses to P fertilizer occurred where soil-test P was less than 15 ppm. Where soil-test P was over 15 ppm often smaller (<0.5 Mg/ha) wheat yield increases were observed with the fitted relationship predicting a yield response of 0.28 Mg/ha where soil-test is over 20 ppm.

The wheat yield increases that occurred where soil-test P levels were over 20 ppm were often high enough to easily pay for the addition of 20 kg-P_2O_5/ha as an in-furrow starter application (Fig. 5, Table 8). Based on these results the P recommendations for wheat should be updated to apply a 20 kg-P_2O_5/ha rate up to a soil-test P of 30 ppm; the current P recommendations are 0 kg-P_2O_5/ha over 20 ppm. The proposed phosphorous rate updates are included in the phosphorous recommendation table for cereals shown in Appendix 2. A statement was also included that band/in-furrow applied phosphorous is more effective than broadcast phosphorous, and that band/in-furrow applied P is preferred when rates are less than 50 kg-P_2O_5/ha.

Figure 5. Relationship between winter wheat yield response to in-furrow applied P at 57 kg-P_2O_5/ha and soil-test P from 28 research trials that evaluated winter wheat yield response to starter fertilizers (2010-2013). Prediction equation: Yield Response=2.1-0.16*Soil-P+0.00342*Soil-P^2 where Soil-P<23 ppm else Yield Response=0.28 R^2=0.50.



5.0 Updates to Crop Nutrient Removal

The crop nutrient removal P and K values suggested in the Agronomy Guide 2nd edition and used by NMAN were reviewed and updated. Updated P and K removal values for grains and oilseeds are in Table 9a and updated P and K removal values for silage and forage crops are in Table 9b. A significant change from earlier versions is that nutrient concentrations for corn stover, soybean stalks and cereal straw are included in the nutrient removal tables. Cereal straw removal assumptions were included in earlier nutrient removal tables but were presented as straw-grain combined nutrient concentrations. In the new proposed nutrient removal table straw nutrient concentrations are presented separately from grain nutrient removal concentrations which will enable direct calculation of P and K removal values associated with just the cereal straw.

6.0 Proposed New Targeted Maintenance Based Recommendations.

The new proposed targeted maintenance based P and K recommendations will suggest P and K rates needed to maintain soil-test P and K levels within a target range. The proposed default target ranges are:

1. 12-18 ppm for phosphorous

2. 100-130 ppm for potassium

For corn, soybeans, wheat and alfalfa the above analysis of Ontario research data indicates that at soil-test P levels above 12 ppm that P rates needed to economically maximize yields are 20 kg-P_2O_5/ha or less. Therefor the suggested target range to maintain soil-test P is 12-18 ppm.

Analysis of Ontario research data indicated that field crop response to potassium was more variable than for phosphorous. However, there generally was a greater chance for large economically significant yield responses to K fertilizer application for corn, soybeans and alfalfa where soil test levels were less than 100 ppm. Therefore the suggested target range for potassium is 100-130 ppm. Targeted maintenance recommendations within the target range will provide sufficient K fertility even for alfalfa (assumed average dry matter yield is 5 Mg/ha with K content of 24 kg-K_2O/ha= recommended targeted maintenance application rate of 120 kg-K_2O/ha which is more than the sufficiency recommendation for soil-test K in the range of 100-130 ppm (table 7).

Targeted maintenance ranges for P and K that are higher than those suggested above should be discouraged since there is no support in the current database that maintaining soil-tests greater than these ranges increases profitability.

Over the time horizon of interest (3-10 years) the targeted maintenance P and K recommendations suggest P and K rates that will:

1. Increase P and K soil tests where soil-tests are less than the targeted maintenance range. The recommended P and K rates are the sum of crop P and K removal and additional P and K needed to increase soil-tests into the targeted maintenance range.
2. Maintain soil-test P levels when soil-tests are within the targeted maintenance range. The recommended P and K rates are equivalent to anticipated crop P and K removal.
3. Decrease soil-test levels when soil-tests are above the targeted maintenance range. The only P or K rates recommended are the low P and K rates associated with the sufficiency recommendations which will usually be the lower P and K rates that are usually associated with starter fertilizer applications.

Figure 6 shows the display of an excel based calculator that will provide the targeted maintenance recommendations. The calculator inputs include:

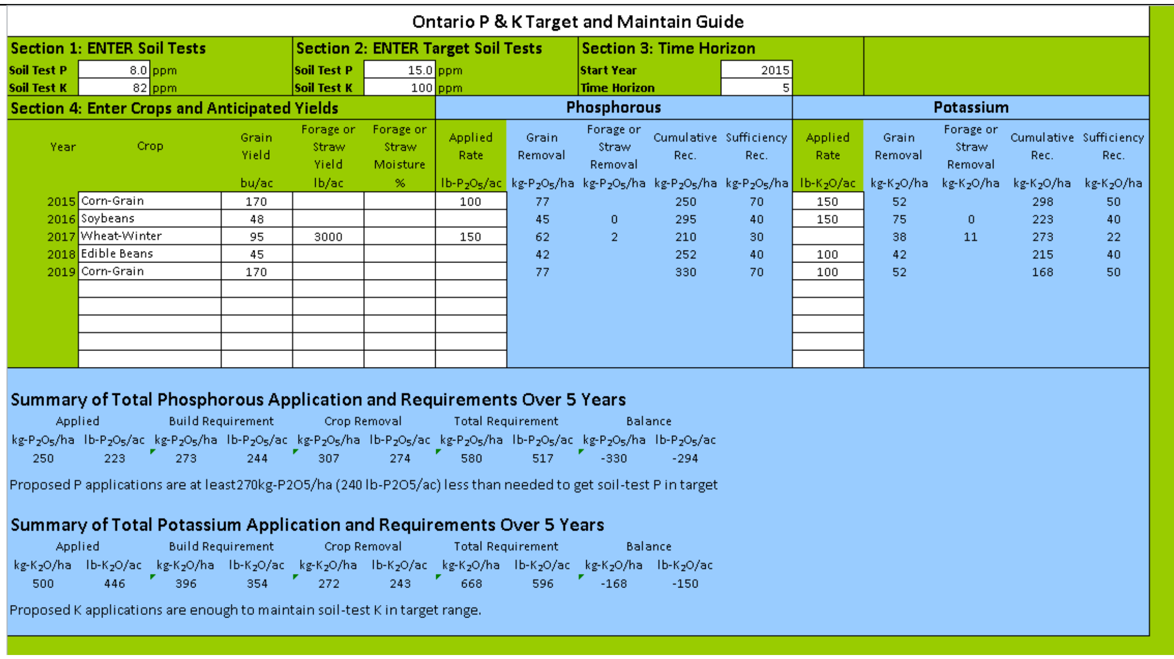
1. Soil-test P and K.
2. Time horizon over which the targeted maintenance recommendations are to be applied over.
3. The desired target soil-test P and K by the end of the specified time horizon.
4. Crops and anticipated grain and/or biomass yields for each year of the specified time horizon.

Using the above inputs the targeted maintenance calculator provides:

1. P and K removal for each crop specified.
2. The sufficiency P and K recommendation for each crop.

3. The requirement for P and K to increase soil-tests when below the desired targeted soil-test P and K ranges.

Figure 6. Screen shot of input and results for targeted maintenance P and K recommendation calculator.



Ontario P & K Target and Maintain Guide

Section 1: ENTER Soil Tests			Section 2: ENTER Target Soil Tests			Section 3: Time Horizon	
Soil Test P	8.0	ppm	Soil Test P	15.0	ppm	Start Year	2015
Soil Test K	82	ppm	Soil Test K	100	ppm	Time Horizon	5

Section 4: Enter Crops and Anticipated Yields					Phosphorous					Potassium				
Year	Crop	Grain Yield	Forage or Straw Yield	Forage or Straw Moisture	Applied Rate	Grain Removal	Forage or Straw Removal	Cumulative Rec.	Sufficiency Rec.	Applied Rate	Grain Removal	Forage or Straw Removal	Cumulative Rec.	Sufficiency Rec.
		bu/ac	lb/ac	%	$lb\text{-}P_2O_5/ac$	$kg\text{-}P_2O_5/ha$	$kg\text{-}P_2O_5/ha$	$kg\text{-}P_2O_5/ha$	$kg\text{-}P_2O_5/ha$	$lb\text{-}K_2O/ac$	$kg\text{-}K_2O/ha$	$kg\text{-}K_2O/ha$	$kg\text{-}K_2O/ha$	$kg\text{-}K_2O/ha$
2015	Corn-Grain	170			100	77		250	70	150	52		298	50
2016	Soybeans	48				45	0	295	40	150	75	0	223	40
2017	Wheat-Winter	95	3000		150	62	2	210	30		38	11	273	22
2018	Edible Beans	45				42		252	40	100	42		215	40
2019	Corn-Grain	170				77		330	70	100	52		168	50

Summary of Total Phosphorous Application and Requirements Over 5 Years

Applied		Build Requirement		Crop Removal		Total Requirement		Balance	
$kg\text{-}P_2O_5/ha$	$lb\text{-}P_2O_5/ac$	$kg\text{-}P_2O_5/ha$	$lb\text{-}P_2O_5/ac$	$kg\text{-}P_2O_5/ha$	$lb\text{-}P_2O_5/ac$	$kg\text{-}P_2O_5/ha$	$lb\text{-}P_2O_5/ac$	$kg\text{-}P_2O_5/ha$	$lb\text{-}P_2O_5/ac$
250	223	273	244	307	274	580	517	-330	-294

Proposed P applications are at least270kg-P2O5/ha (240 lb-P2O5/ac) less than needed to get soil-test P in target

Summary of Total Potassium Application and Requirements Over 5 Years

Applied		Build Requirement		Crop Removal		Total Requirement		Balance	
$kg\text{-}K_2O/ha$	$lb\text{-}K_2O/ac$	$kg\text{-}K_2O/ha$	$lb\text{-}K_2O/ac$	$kg\text{-}K_2O/ha$	$lb\text{-}K_2O/ac$	$kg\text{-}K_2O/ha$	$lb\text{-}K_2O/ac$	$kg\text{-}K_2O/ha$	$lb\text{-}K_2O/ac$
500	446	396	354	272	243	668	596	-168	-150

Proposed K applications are enough to maintain soil-test K in target range.

The targeted maintenance P and K calculator provides information on total system P and K removal over the specified time horizon and the additional P and K inputs required to maintain soil-tests in the desired targeted maintenance soil-test range. A detailed description of P recommendations shown in figure 6 is as follows:

1. Initial soil-test P of 8 ppm (Section 1) with a target soil-test P of 15 ppm (Section 2) which is to be obtained at the end of 5 years (Section 3). Upper limit for time horizon is 10 years.
2. Crop sequence with anticipated yields and P applications is entered in Section 4 which for this case is 5 years.
3. Based on entered yields, P removal for each crop is calculated and shown in results section of Section 4. The sufficiency recommendations for each crop are also shown in Section 4.
4. The P summary section states that 250 kg-P_2O_5/ha is planned to be applied over 5 years. The amount of P needed to increase soil-test P from 8 to 15 ppm is 273 kg-P_2O_5/ha and crop P removal over 5 years is estimated at 307 kg-P_2O_5/ha which results in an estimate of 580 kg-P_2O_5/ha to replace P associated with crop removal and increase soil-test P from 8 to 15 ppm. The difference between planned application and requirement, referred to in the summary as Balance, is -330 kg-P_2O_5/ha which indicates in this case that planned P fertilizer or manure inputs are 330 kg-P_2O_5/ha less than needed to replace P removed by crops and increase soil-test P to desired target P range over the next 5 years

5. There is also a text summary that provides guidance regarding the planned P inputs. In this case an additional 270 kg-P_2O_5/ha is recommended in order to reach target soil-test P range at the end of 5 years. The text guidance recommended 270 kg-P_2O_5/ha since this additional amount of applied P will likely result in soil-tests P that are in the 12-18 ppm target range (Target soil-test P +/-3 ppm).
6. A similar set of inputs, calculations and guidance is also provided for K applications.

The targeted maintenance P and K recommendation calculator can be used to make informed decisions for periodic bulk applications of P and K fertilizers; which is how a significant amount of P and K is currently applied in Ontario. Providing P and K recommendations in this format should increase the relevance, and use, of OMAFRA's field crop P and K recommendations.

7.0 Recommended Updates to OMAFRA's Field Crop P and K Recommendations.

1. Extend the 20 kg-P_2O_5/ha sufficiency recommendation for cereals up to a soil-test P of 30ppm. The P recommendation for cereals over 20 ppm is currently 0 kg-P_2O_5/ha (shown in Appendix 2).
2. Band applied phosphorous for both corn and wheat (cereals) appears to be more efficient than broadcast applications and especially for lower rate sufficiency recommendations banded P applications should be promoted over broadcast applications (shown in Appendix 1 for corn and Appendix 2 for cereals).
3. Update nutrient removal values to those included in tables 9a and 9b.
4. Introduce the targeted maintenance recommendations as an alternative to the current sufficiency P and K recommendations.

Table 9a. Average Nutrient (N, P_2O_5, K_2O) Removal by Grains and Oilseeds			
Grains, Oilseeds	**Removal kg/tonne** (lb/bushel)		
	N[2]	**P_2O_5**	**K_2O**
Grain corn	**11.5–18** (0.65–1.0)	**6.6–7.9** (0.37–0.44)	**4.6–5.2** (0.26–0.30)
Corn stover	**8**	**2.9**	**20**
Soybeans	**62–67** (3.7–4.0)	**13–15** (0.80–0.88)	**23** 1.4
Soybean stover	**20**	**4.4**	**19**
Winter wheat (grain only)	**19–21** (1.15–1.25)	**9.1–10.4** (0.55–0.63)	**6** 0.36
Winter wheat (straw)[1]	**7**	**1.7**	**12**
Barley (grain only)	**18–23** (0.87–1.1)	**8** 0.4	**5.3–7.2** (0.25–0.35)
Barley (straw)	**6.5**	**2.6**	**20**
Oat (grain only)	**18–24** (0.63–0.80)	**7.5** 0.25	**5.8** 0.19
Oat (straw)	**6**	**3.2**	**19**
Winter rye (grain only)	**19–22** (1.1–1.2)	**6.1–8.2** (0.3–0.5)	**6.25** 0.35
Winter rye (straw)	**6**	**1.5**	**11**
Dry beans	**42** 2.5	**14** 0.83	**14** 0.83
Canola	**40–44** (2.0–2.2)	**22–27** (1.1–1.3)	**11–13** (0.55–0.67)

Source: Based on Ontario data where possible and general North American data where local data was insufficient.

[1] The range of P_2O_5 and K_2O in cereal straw and dry hay will be reduced (leached) if heavy or frequent rainfall occurs while the material is in windrows in the field.

[2] Soybeans, dry beans and forage legumes receive most of their nitrogen from the air.

Table 9b. Average Nutrient (N, P_2O_5, K_2O) Removal by Silage and Forage Crops

Silage and Forage Crops	Removal in DM[3] kg/tonne (lb/ton)		
	N[4]	P_2O_5	K_2O
Corn silage	**11–15** (22–30)	**4.6–6.8** (9.3–14)	**8.3–15** (17–30)
Legume haylage	**27–37** (53–73)	**5.3–7.9** (11–16)	**22–35** (45–71)
Mixed haylage	**23–34** (46–68)	**5.2–7.8** (10–16)	**22–35** (45–71)
Grass haylage	**16–27** (32–55)	**4.9–7.8** (9.8–16)	**20–36** (41–72)
Legume hay	**22–33** (45–66)	**5.2–8.0** (10–16)	**21–35** (41–70)
Mixed hay	**17–27** (34–55)	**5.0–7.2** (10–14)	**17–30** (34–59)
Grass hay (1st cut)	**13–23** (26–45)	**4.4–7.0** (8.8–14)	**14–28** (28–56)
Mixed hay (2nd cut)[5]	**25–36** (51–72)	**5.7–7.8** (11–16)	**20–32** (40–64)

Source: Based on Ontario data where possible and general North American data where local data was insufficient.
Forage crop data from Agri-Food Laboratories, Guelph. (1990–95).

[1] The range of P_2O_5 and K_2O in cereal straw and dry hay will be reduced (leached) if heavy or frequent rainfall occurs while the material is in windrows in the field.

[2] Soybeans, dry beans and forage legumes receive most of their nitrogen from the air.

[3] To convert from “as harvested” to “dry matter yield,” multiply the as-harvested yield by the dry matter content of the crop (e.g., 25T corn silage x 40% DM (60% moisture) = DM yield of 10T)

[4] The range of N removal is large, because hay is harvested at a wide range of protein levels. Generally, higher protein means lower yield.

[5] 2nd cut generally has a higher legume content.

8.0 Appendix

Appendix 1. Phosphate (P_2O_5) Recommendations for Corn Based on OMAFRA-Accredited Soil Tests

Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

Response to Phosphorous fertilizer is more efficient when banded. To maximize effectiveness Phosphorous should be banded near seed rows when rates are less than 50 kg-P_2O_5/ha (45 lb-P_2O_5/ac).

Where manure is applied, reduce the fertilizer application according to the amount and quality of manure (see Table 9–8, *Typical Amounts of Available Nitrogen, Phosphate and Potash From Different Types of Organic Nutrient Sources*, on page XX).

HR = high response
LR = low response
NR = no response
MR = medium response
RR = rare response

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Phosphate Required kg/ha
0–3	110 (HR)
4–5	100 (HR)
6–7	90 (HR)
8–9	70 (HR)
10–12	50 (MR)
13–15	20 (MR)
16–20	20 (MR)
21–30	20 (LR)
31–60	0 (RR)
61+	0 (NR)[1]

100 kg/ha = 90 lb/acre

[1] When the response rating for a nutrient is "NR," application of phosphorus in fertilizer or manure may reduce crop yield or quality. For example, phosphate applications may induce zinc deficiency on soils low in zinc and may increase the risk of water pollution.

Appendix 2. Phosphate (P_2O_5) Recommendations for Cereals Based on OMAFRA-Accredited Soil Tests

Profitable response to applied nutrients occurs when the increase in crop value, from increased yield or quality, is greater than the cost of the applied nutrient.

Response to Phosphorous fertilizer is more efficient when banded. To maximize effectiveness Phosphorous should be banded near seed rows when rates are less than 50 kg-P_2O_5/ha (45 lb-P_2O_5/ac).

Where manure is applied, reduce the fertilizer application according to the amount and quality of manure (see Manure, on page 69).

HR = high response MR = medium response LR = low response
RR = rare response NR = no response

Sodium Bicarbonate Phosphorus Soil Test (ppm)	Spring Barley Spring Wheat Mixed Grain	Oat Spring Triticale Spring Rye	Winter Wheat Winter Rye, Winter Barley Winter Triticale	Winter or Spring Grains Seeded Down
	Phosphate Required[2] (kg/ha)			
0–3	110 (HR)	70 (HR)	70 (HR)	130 (HR)
4–5	100 (HR)	60 (HR)	60 (HR)	110 (HR)
6–7	90 (HR)	50 (HR)	50 (HR)	90 (HR)
8–9	70 (HR)	30 (HR)	30 (HR)	70 (HR)
10–12	50 (MR)	20 (MR)	20 (MR)	50 (MR)
13–15	20 (MR)	20 (MR)	20 (MR)	30 (MR)
16–20	20 (MR)	0 (LR)	20 (MR)	20 (MR)
21–25	0 (LR)	0 (LR)	20 (MR)	20 (MR)
26–30	0 (LR)	0 (LR)	20 (MR)	0 (LR)
31–40	0 (RR)	0 (RR)	0 (LR)	0 (LR)
41–50	0 (RR)	0 (RR)	0 (RR)	0 (RR)
51–60	0 (RR)	0 (RR)	0 (RR)	0 (RR)
61+	0 (NR)[1]	0 (NR)[1]	0 (NR)[1]	0 (NR)[1]

100 kg/ha = 90 lb/acre

[1] When the response rating for a nutrient is "NR," application of phosphorus in fertilizer or manure may reduce crop yield or quality. For example, phosphate applications may induce zinc deficiency on soils low in zinc and may increase the risk of water pollution.