2021 Report

for the

Saskatchewan Ministry of Agriculture's

Agricultural Demonstration of Practices & Technologies (ADOPT) Program

and Fertilizer Canada

Project Title: Canola Seed Safety and Yield Response to Novel Phosphorus Sources in Saskatchewan Soils

(Project #20200516)

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Project Identification

1. **Project Title:** Canola seed safety and yield response to novel phosphorus (P) fertilizer sources in Saskatchewan soils
2. **Project Number:** 20200516
3. **Producer Group Sponsoring the Project:** Indian Head Agricultural Research Foundation
4. **Project Location(s):** Field trials were located at Indian Head (#156), Melfort (#428), Outlook (#284), Redvers (#61), Scott (#380), Swift Current (#137), and Yorkton (#244), Saskatchewan
5. **Project start and end dates(s):** April-2020 to February-2021
6. **Project contact person & contact details:**

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Objectives and Rationale

7. Project Objectives:

The objective of this project was to demonstrate canola response to increasing rates of seed-placed phosphorus (P) fertilizer for various formulations. The focus was on both stand establishment and yield. The formulations were monoammonium phosphate, MicroEssentials® S15, and struvite (CrystalGreen®) applied alone or in a blend.

8. Project Rationale:

Results varied by region, but more than 75% of soil samples from Saskatchewan in 2021 had residual phosphorus (P) levels below 15 ppm (Olsen-P). For a large percentage of the major crop producing areas, well over half of the soils tested had pH values exceeding 7.3; however, this varied regionally with lower values in the more western and northern areas but much higher pH soils dominating the eastern half of the province (AGVISE Laboratories 2021). Higher pH soils result in reduced P fertilizer use-efficiency due to chemical reactions with calcium carbonate that reduce the solubility and crop availability of applied P. Saskatchewan farmers are increasingly aware of the long-term importance of P fertilization and many strive to maintain or build soil residual P over the long-term. Notably, P fertilizer use-efficiency in the year of application is notoriously low – generally below 30%. Many growers seek ways to improve this efficiency and novel formulations (i.e., MicroEssentials®, Alpine®, and CrystalGreen®) are often seen as possible solutions to this challenge. Still, monoammonium phosphate (MAP; 11-52-0) continues to be the dominant form used in Western Canadian canola production, holding 69% of the market by volume in 2020 with MicroEssentials® formulations accounting for 19% (Stratus Ag Research 2021).

While not exclusively a P product, MicroEssentials® S15 is a multi-nutrient fertilizer which is often recognized as having improved seed-safety (relative to MAP/ammonium sulfate (AS) blends) and providing a season-long sulfur (S) supply due to its composition of equal parts sulfate and elemental forms. Promotional material and internal research on S15 (Mosaic Company 2016) shows a 151 kg/ha advantage over MAP applied alone and a 78 kg/ha improvement over blended MAP + AS (average of 56 trials over a 9-year period). University of Manitoba research (Grenkow et al. 2013) showed improved seed safety over MAP/AS blends but warned that S15 may not be as effective at providing plant available S compared to conventional MAP/AS blends within the year of application. That aside, the claim specific to P is that the combination of nutrients in S15 creates a more acidic environment which helps keep the P in plant available, soluble forms for a longer time allowing for better overall uptake. A previous ADOPT project at Indian Head in 2018 showed a 56 kg/ha yield advantage to MES15 over MAP when averaged across rates but, the response was not quite significant at the desired probability level ($P = 0.063$; Holzapfel 2019).

Struvite is marketed under the trade name CrystalGreen® (5-28-0 plus 10% Mg) and promotional material (Ostara CrystalGreen® 2017) claims superior crop safety with a salt index of 8 (compared to 27 in MAP and 21 in S15) along with improved season-long availability. Early University of Manitoba research found that struvite increased dry matter yields and P recovery over the control but not to the same extent as MAP. They suggested that this may have been due to the lower solubility of struvite in the high pH Manitoba soils (Ackerman et al. 2013). In later evaluations, with wheat and canola, Katanda et al (2016) saw similar early-season dry matter yield and uptake efficiency with struvite versus MAP and, at higher rates, greater biomass yields and P recovery with struvite during the later crop phases. They concluded that struvite could supply sufficient P to sustain yields with overall P use-efficiencies matching or exceeding those for MAP. In order to achieve maximum P availability through the entire growing season, current recommendations for CrystalGreen® suggest blending with MAP so that struvite comprises 25% of the actual P_2O_5 provided by the blend (Ostara CrystalGreen® 2017).

Relative to many crops, canola is a large user of P and relatively responsive to fertilizer applications. It is well documented that high rates of seed-placed P fertilizer can reduce seedling survival and establishment in sensitive crops such as canola; however, many farmers prefer to place at least a portion of their P in the seedrow to ensure it is not limiting early in the season. While P fertilization will typically increase canola yields when residual levels of this nutrient are low, the response is often most evident early in the season with more vigorous growth frequently observed. This is often referred to as a 'pop-up' effect and is primarily attributed to seed-placed P fertilizer but can also occur with side-banding. Advantages with seed-placement compared to other placement options are often observed under dry conditions (due to reduced mobility of P in solution) but this is also when the risk of seedling injury is highest. While side-banding is widely recognized as a safe and viable application method, the majority of canola acres receive P applied in the seed-row (44% by volume compared to 31% for side-banding and 13% for mid-row banding (Stratus Ag Research 2021). Considering that it is both responsive to P fertilization and sensitive to injury with seed-placement of fertilizer products, canola was considered to be an ideal test crop for this project.

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Methodology and Results

9. Methodology:

Field trials with canola were conducted near Swift Current, Scott, Indian Head, and Yorkton in 2020 and repeated at these same four locations in 2021 with additional trials at Melfort, Outlook, and Redvers. These locations vary in both their major soil characteristics (i.e., texture, organic matter, pH) and long-term climatic conditions. With that, they also vary in terms of the relative risk of seedling injury that might be expected with in-furrow placement of P fertilizer. The project aimed to evaluate responses to a range of seed-placed phosphorus (P) fertilizer rates and formulations with a focus on crop establishment and yield. In addition to a control where no P was applied, the rates were 25, 45, and 65 kg P_2O_5/ha. Only granular options could be evaluated due to equipment limitations. The forms included monoammonium phosphate (MAP), MicroEssentials® S15, CrystalGreen®, and a 50:50 blend (by mass of product) of MAP and CrystalGreen®. This blend resulted in actual P_2O_5 proportions of 35:65 from CrystalGreen® and MAP which is comparable to the current industry recommended 25:75 blend. The total amount of nitrogen (N) applied was balanced across treatments within each location; however, the S15 treatments at Yorkton 2020 were discarded because a calculation error resulted in the supplemental urea rate coupled with this P formulation being too low. For simplicity, we did not necessarily attempt to balance total S rates across treatments but did require that S be not limiting; therefore, supplemental ammonium sulfate was applied in all cases. Phosphorus fertilizer products were always seed-placed while urea and ammonium sulfate were side-banded. Detailed treatment information is provided in Table 1.

Table 1. Treatment descriptions for ADOPT Novel Phosphorus demonstrations completed at Swift Current, Scott, Indian Head, and Yorkton in 2020.

#	Phosphorus Form [Z]	Nutrient Analyses	Phosphorus Rate
1	Control	Not applicable	0 kg P_2O_5/ha
2	Monoammonium phosphate	11-52-0	25 kg P_2O_5/ha
3	Monoammonium phosphate	11-52-0	45 kg P_2O_5/ha
4	Monoammonium phosphate	11-52-0	65 kg P_2O_5/ha
5	MicroEssentials® S15	13-33-0-15	25 kg P_2O_5/ha
6	MicroEssentials® S15	13-33-0-15	45 kg P_2O_5/ha
7	MicroEssentials® S15	13-33-0-15	65 kg P_2O_5/ha
8	CrystalGreen®	5-28-0 + 10% Mg	25 kg P_2O_5/ha
9	CrystalGreen®	5-28-0 + 10% Mg	45 kg P_2O_5/ha
10	CrystalGreen®	5-28-0 + 10% Mg	65 kg P_2O_5/ha
11	50:50 MAP:CrystalGreen®[Z]	8-40-0 + 5% Mg	25 kg P_2O_5/ha
12	50:50 MAP:CrystalGreen®	8-40-0 + 5% Mg	45 kg P_2O_5/ha
13	50:50 MAP:CrystalGreen®	8-40-0 + 5% Mg	65 kg P_2O_5/ha

[Z] Expressed as actual P_2O_5 the ratio is 65:35 MAP:CrystalGreen®

Selected agronomic information and dates of operations are in Table 9 of the Appendices. The specific canola hybrids varied across locations. Seeding rates also varied with most sites targeting 105 seeds/m^2, but Outlook-2021 and Swift Current-2021 utilizing higher rates to compensate for sub-optimal seeding conditions. All sites used drills equipped with hoe openers and row spacing ranging from 21-30 cm with target seeding depths of approximately 2-2.5 cm. Weeds were controlled using registered pre-emergent and in-crop herbicides. Fungicides were applied at the discretion of individual site managers; however, conditions were not conducive to disease at any location-years. Pre-harvest herbicides or desiccants were also utilized at the discretion of site-managers and the centre rows of each plot were straight-combined, avoiding outside rows, wherever possible.

Various data were collected during the growing season and from the harvested seed. Residual nutrient levels and basic soil information were derived from spring composite soil samples which were submitted to AGVISE Laboratories (Northwood ND) for analyses. Spring plant densities were determined by counting seedlings in 4 x 1 m sections of crop row after emergence was complete. Final plant densities were determined at the end of the season by counting stubble in 4 x 1 m sections of crop row after harvest, except at Swift Current in 2020 where these counts were completed before combining. The maturity date was also recorded at all locations; however, treatment effects on this variable were always small, somewhat inconsistent, and of little agronomic importance; therefore, detailed results are not reported. Grain yields were determined from the harvested seed and are corrected for dockage and to 10% seed moisture content. Daily temperatures and precipitation amounts were recorded from the nearest Environment and Climate Change Canada weather stations for each location with the exception of Redvers where a privately own weather station was utilized.

Data from all locations were combined prior to analyses; however, Yorkton-2020 was excluded due to the missing treatments. Response data were analyzed using the generalized linear mixed model (GLIMMIX) procedure of SAS Studio. The effects of site (S), P form (F), P rate (R), and all possible two and three-way interactions were considered fixed, while the effects of replicate (within sites) were random. The unfertilized control was excluded from the factorial analyses, but was included in a separate model where orthogonal contrasts testing for linear and quadratic responses to P rate were utilized. Tukey's range test was used to separate individual treatment means and all treatment effects and differences between means are significant at $P \leq 0.05$.

10. Results:

Growing season weather and residual soil nutrients

Mean temperatures and total precipitation amounts for May through August are presented with the long-term averages for each location in Tables 2 and 3, respectively. Overall growing season temperatures were near average at Swift Current, Scott, and Indian Head in 2020 and both Indian Head and Swift Current were drier than average. Swift Current-2020 received 157 mm from May-August, 83% of its long-term average while Indian Head-2020 received 113 mm, 46% of average. In contrast, Scott-2020 received 258 mm (118% of average) over this four-month period. In 2021, all locations were much warmer than average (103-109%) and most of the locations were also dry. Indian Head and Redvers were the wettest locations in 2021 with 93-121% of average precipitation; however, much of this rain came late in August. Outlook was extremely dry with only 47% of average precipitation but received an additional 208 mm as irrigation. Yorkton, Swift Current, Scott, and Melfort were also much drier relative to normal with 54-66% of their long-term average precipitation amounts. With the combination of heat and low initial soil moisture reserves, yields were generally below average in 2021, even at locations that did receive more typical precipitation amounts.

Table 2. Mean monthly temperatures and long-term (LT; 1981-2010) averages for applicable growing seasons at Indian Head (IH), Melfort (ME), Outlook (OL), Redvers (RV), Scott (SCT), Swift Current (SW), and Yorkton (YK), Saskatchewan.

Year	May	June	July	August	May-Aug
	-- Mean Temperature (°C) --				
IH-20	10.7	15.6	18.4	17.9	15.7 (101%)
IH-21	9.0	17.7	20.3	17.1	16.0 (103%)
IH-LT	10.8	15.8	18.2	17.4	15.6
ME-21	9.6	18.2	20.1	16.9	16.2 (106%)
ME-LT	10.7	15.9	17.5	16.8	15.2
OL-21	10.2	18.6	21.6	17.9	17.1 (106%)
OL-LT	11.5	16.1	18.9	18.0	16.1
RV-21	10.0	18.7	20.8	17.5	16.8 (105%)
RV-LT	11.1	16.2	18.7	18.0	16.0
SC-20	9.9	14.8	17.2	16.3	14.6 (98%)
SC-21	8.9	17.3	19.6	17.2	15.8 (107%)
SC-LT	10.8	14.8	17.3	16.3	14.8
SW-20	10.4	15.5	18.1	19.4	15.9 (100%)
SW-21	9.5	18.3	21.6	17.9	16.8 (106%)
SW-LT	11.0	15.7	18.4	17.9	15.8
YK-21	8.9	19.1	21	17.3	16.5 (109%)
YK-LT	10.4	15.5	17.9	17.1	15.2

Table 3. Total precipitation amounts and long-term (LT; 1981-2010) averages for applicable growing seasons at Indian Head (IH), Melfort (ME), Outlook (OL), Redvers (RV), Scott (SCT), Swift Current (SW), and Yorkton (YK), Saskatchewan.

Year	May	June	July	August	May-Aug
	-- Total Precipitation (mm) --				
IH-20	27.3	23.5	37.7	24.9	113 (46%)
IH-21	81.6	62.9	51.2	99.4	295 (121%)
IH-LT	51.8	77.4	63.8	51.2	244
ME-21	31.4	37.6	0.2	69.3	139 (61%)
ME-LT	42.9	54.3	76.7	52.4	226
OL-21[Z]	44.1	13.1 (71)	1.5 (117)	37.7 (20)	96 (47%)
OL-LT	42.6	63.9	56.1	42.8	205
RV-21	41.4	95.2	38.4	72.1	247 (93%)
RV-LT	60.0	95.2	65.5	46.6	267
SC-20	51.9	55.9	123.0	27.0	258 (114%)
SC-21	43.9	43.8	10.4	51.3	149 (66%)
SC-LT	38.9	69.7	69.4	48.7	227
SW-20	30.0	70.9	52.6	3.3	157 (83%)
SW-21	30.0	26.8	36.6	53.5	147 (78%)
SW-LT	42.1	66.1	44.0	35.4	188
YK-21	24.6	18.1	35.2	69.7	148 (54%)
YK-LT	51.3	80.1	78.2	62.2	272

[Z] The site at Outlook also received supplemental irrigation, with amounts shown in brackets – moisture provided as irrigation was not included in the 4-month total

Soil test results for each location-year are provided in Table 4. Soil pH, organic matter, and C.E.C. values (where available) were considered typical for each location. The lowest soil pH generally occurred at Melfort, Scott and Swift Current (5.9-6.6), while Yorkton was neutral (7.1) and the observed soil pH values at Indian Head, Outlook, and Redvers were comparatively high (7.8-8). Soil organic matter was lowest at Outlook and Swift Current (2.4-2.8%), intermediate at Indian Head, Redvers, Scott, and Yorkton (3.6-5.2%), and highest at Melfort (12.1%). While also impacted by organic matter and pH, cation exchange capacity (CEC) is also a good indicator of soil texture with lower values being typical for coarser textured soils and higher values indicating finer texture and a greater percentage of clay particles. Soil CEC was not provided for all location-years but, for the sites where it was, the observed values were highest at Indian Head (41-47 meq), followed by Redvers (35 meq), Yorkton (22 meq), Outlook (20 meq), and Scott (13-16 meq). The expectation was that soils with coarser texture and lower CEC values would generally be more prone to seedling injury when in-furrow P fertilizer placement is combined with high application rates. Importantly, residual soil P levels were mostly low, below 15 ppm (Olsen-P) for 90% of the location-years with the sole exception being Swift Current-2021 (16 ppm). Residual NO_3-N, K, and S levels were also reported;

however, these nutrients were not the focus of this project and were intended to be non-limited in all treatments.

Table 4. Soil test results for canola phosphorus formulation demonstrations at Swift Current (SW), Scott (SCT), Indian Head (IH), and Yorkton (YK), Saskatchewan.

Location / Depth (cm)	**pH**	**SOM** (%)	**CEC** (meq)	**NO_3-N** (kg/ha)	**Olsen-P** (ppm)	**K** (ppm)	**S** (kg/ha)
IH-20 (0-15)	7.9	5.2	40.6	8	7	583	7
IH-20 (15-60)	–	–	–	13	–	–	34
IH-21 (0-15)	7.8	4.8	47.2	10	8	654	5
IH-21 (15-60)	–	–	–	13	–	–	40
ME-21 (0-15)	5.9	12.1	n/a	19	8	418	13
ME-21 (15-30)	–	–	–	25	–	–	13
OL-21 (0-15)	7.9	2.7	19.9	33	11	239	128
OL-21 (15-60)	–	–	–	44	–	–	>135
RV-21 (0-15)	8.0	3.6	34.6	21	6	227	134
RV-21 (15-60)	–	–	–	24	–	–	403
SC-20 (0-15)	6.4	4.0	13.3	15	12	259	11
SC-20 (15-60)	–	–		24	–	–	101
SC-21 (0-15)	5.5	4.4	15.7	12	6	246	16
SC-21 (15-60)	–	–	–	20	–	–	128
SW-20 (0-15)	6.6	2.8	n/a	21	10	338	47
SW-20 (15-60)	–	–	–	34	–	–	54
SW-21 (0-15)	6.5	2.4	n/a	16	16	282	31
SW-21 (15-60)	–	–	–	44	–	–	40
YK-21 (0-15)	7.1	4.7	22.1	30	13	253	54
YK-21 (15-60)	–	–	–	54	–	–	128

n/a – not available

Again, the risk of seedling injury associated with seed-placed P fertilizer was expected to be highest in dry, coarse textured soils. The weather and soil conditions encountered over the duration of this project provided a wide range of environmental conditions to evaluate the P rate and formulation treatments with regard to their effects on stand establishment and yield.

Canola Response to Seed-Placed Phosphorus Fertilizer Formulations and Rates

Results from the overall tests of fixed effects are presented for all variables in Table 5 below; however, the effects on crop establishment and yield will be discussed separately. With regard to establishment, we will mostly focus on the spring assessments; however, the final population numbers may provide some insights. For example, if spring counts are ever completed too early, before emergence is complete, the final counts can provide a better assessment of the treatment effects. Also, if populations are relatively high due to better than expected establishment or high seeding rates, numbers could actually decline over the season due to intraspecies competition and, as such, treatment differences that were initially observed may be less prominent or disappear altogether at the end of the season. Due to the importance of plant densities for this particular project, the final populations are presented in detail regardless and will be discussed where considered appropriate.

Table 5. Overall tests of fixed effects for selected response variables in canola phosphorus (P) form by rate demonstrations. The data were analyzed using two separate models, a simple model including all treatments (Site and Entry) and factorial analyses where the 0 P control was excluded (Site, Form, and Rate). Both models included all possible interactions as fixed effects and data were analyzed using the generalized linear mixed model (GLIMMIX) procedure of SAS® Studio.

Source	Spring Plant Density (plants/m²)	Final Plant Density (stems/m²)	Seed Yield (kg/ha)
Simple Model	-- Pr > *F* (p-values)	--	
Site	<0.001	<0.001	<0.001
Entry	<0.001	<0.001	<0.001
Site × Entry	<0.001	<0.001	<0.001
Factorial Model			
Site (S)	<0.001	<0.001	<0.001
Form (F)	<0.001	<0.001	0.003
Rate (R)	<0.001	<0.001	<0.001
F × R	0.104	0.005	0.006
S × F	<0.001	<0.001	0.001
S × R	<0.001	0.018	0.433
S × F × R	0.185	0.012	0.223

[Z] Yorkton-2020 was excluded from the combined analyses due to missing treatments

Both the spring and final plant densities were affected by site (S), P form (F), P rate (R), S x F and S x R. The F x R interaction was not significant at the desired probability level for spring plant densities (P = 0.104) but was for the final counts (P = 0.005). Similarly, the three-way S x F x R interaction was not significant for the spring assessments (P = 0.185) but was post-harvest (P = 0.012). With these interactions in mind, we can draw broad conclusions for the overall averages presented in Tables 6 and 7; however, it is important to appreciate that the specific results varied with site.

Averaged across all 10 sites, we observed 76 plants/m^2 in the spring for the unfertilized control and, when assessed post-harvest, that number declined slightly to 72.5 stems/m^2 (Table 6). When averaged across P rates and for both spring and post-harvest assessments, the highest populations were observed with 100% struvite (CG) at 77 plants/m^2 in the spring and 74 stems/m^2 post-harvest – these values were similar to those observed in the control. The lowest populations occurred with S15 at 61 plants/m^2 (57 stems/m^2 post-harvest), followed by MAP at 65 plants/m^2 (63 stems/m^2 post-harvest), and the MAP:CG blend with 72 plants/m^2 (68 stems/m^2 post-harvest). Notably, none of these populations were low enough (on average), to limit canola yields or cause agronomic issues; however, the relative rankings of plant populations with the different forms were consistent with what was expected. Similarly, the average (across forms) rate effects were as expected with populations declining from 71-65 plants/m^2 in the spring as the P rate was increased from 22-65 kg

P_2O_5/ha (relative to 76 plants/m^2 in the control) and from 69-62 stems/m^2 in the fall assessments (relative to 73 stems/m^2 in the control). The difference between the 22-45 kg P_2O_5/ha was not significant in the spring assessments (70-71 plants/m^2), but was significant post-harvest (66-69 stems/m^2).

Table 6. Main effect means for seed-placed phosphorus (P) fertilizer formulation and rate effects on canola emergence, final plant densities, and seed yield when averaged across 10[Z] location-years in Saskatchewan. The F-test results are for Form and Rate effects and the 0 P control treatment was excluded from the factorial analyses.

Main Effect	Spring Plant Density	Final Plant Density	Seed Yield
	---------- plants/m^2 ----------	---------- stems/m^2 ----------	------------ kg/ha ------------
Control (0 P)	75.8	72.5	2138
P Form [Y]			
MAP	65.1 C	63.4 C	2313 A
S15	61.0 D	57.4 D	2336 A
CG	76.8 A	73.6 A	2242 B
MAP:CG	71.5 B	67.5 B	2305 A
S.E.M.	1.28	1.27	25.2
kg P_2O_5/ha			
25	71.1 A	68.6 A	2230 C
45	69.7 A	65.5 B	2303 B
65	65.1 B	62.3 C	2364 A
S.E.M.	1.14	1.14	23.4

[Z] Yorkton-2020 was excluded from the combined analyses due to missing treatments

[Y] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® - 5-28-0 + 10% Mg; MAP:CG - 8-40-0 + 5% Mg (50:50 by mass of product)

Again, with significant interactions between P form and rate, the main effect means do not tell the full story. Individual treatment means, averaged across the 10 sites, are presented in Table 7. For both the spring and fall assessments, these results show that plant populations declined linearly with increasing P rate for all formulations except 100% struvite, where there was no effect on canola establishment, regardless of rate. Consistent for the main effects of P form, the decline was most severe with S15 (53-56 plants/m^2 at 65 kg P_2O_5/ha), followed by MAP (58-59 plants/m^2 at 65 kg P_2O_5/ha), and the MAP:CG blend (66-68 plants/m^2 at 65 kg P_2O_5/ha).

Table 7. Individual treatment means for seed-placed phosphorus (P) fertilizer formulation by rate effects on canola emergence, final plant densities, and seed yield when averaged across 10[Z] location-years in Saskatchewan. The 0 P control treatment was excluded from the factorial analyses but was incorporated into the orthogonal contrasts. Values associated with the linear and quadratic orthogonal contrasts are p-values (Pr > *F*). The F-test results are for the Form x Rate interaction. Responses varied amongst individual location-years.

Main Effect	Spring Plant Density	Final Plant Density	Seed Yield
	------------------------------ plants/m^2	------------------------------	------------- kg/ha -------------
Control	75.8	72.5	2138
MAP-25	69.8 cde	71.2 ab	2242 efg
MAP-45	66.2 ef	61.0 ef	2330 bcde
MAP-65	59.2 gh	57.8 gf	2368 abc
MAP-lin	<0.001	<0.001	<0.001
MAP-quad	0.603	0.338	0.464
S15-25	64.8 ef	62.1 edf	2275 defg
S15-45	62.0 fg	57.1 fg	2400 ab
S15-65	56.3 h	53.1 g	2335 bcd
S15-lin	<0.001	<0.001	<0.001
S15-quad	0.290	0.196	0.005
CG-25	75.2 abc	73.7 a	2213 fg
CG-24	78.5 a	74.2 a	2197 fg
CG-65	76.7 ab	72.9 a	2315 bcde
CG-lin	0.491	0.824	<0.001
CG-quad	0.837	0.537	0.454
MAP:CG-25	74.4 abc	67.3 bcd	2192 g
MAP:CG-45	72.0 bcd	69.8 abc	2286 cdef
MAP:CG-65	68.0 de	65.5 cde	2437 a
MAP:CG-lin	0.005	0.028	<0.001
MAP:CG-quad	0.410	0.807	0.059
S.E.M.	2.08	2.03	36.4

[Z] Yorkton-2020 was excluded from the combined analyses due to missing treatments

[Y] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® - 5-28-0 + 10% Mg; MAP:CG - 8-40-0 + 5% Mg (50:50 by mass of product)

With regard to individual site results, the overall F-tests for the simple model which included the control (Table 10) indicated that there were no treatment effects on spring plant populations at 50% (5/10) of the sites including Indian Head (both years; *P* = 0.775-0.964), Melfort-2021 (*P* = 0.689), Scott-2020 (*P* = 0.302), and Swift Current-2020 (*P* = 0.885). At Scott-2020, there was, however, a significant form effect (*P* = 0.037) which was consistent with the overall, previously discussed, averaged form effects (Table 13) where the lowest populations occurred with S15 followed by MAP, MAP:CG, and CG. For the remaining 50% of the sites, the form (F) effect and F x R interactions were always at least marginally significant (P < 0.001-0.059) while the rate effect was significant in 3/5 cases. For the final plant populations (Table 11), the results for the tests of fixed effects were mostly consistent with the spring assessments except that the form effects at Scott-2020 had diminished (P = 0.132) and the rate effects generally became more prominent, significant at 50% of sites compared to only 30% in the spring. Focussing on the F x R interactions for the 50% of sites that were responsive, there were subtle differences amongst them and also between the spring (Table 14) and fall (Table 16) assessments; however, the responses were largely consistent with the overall averages already discussed. We generally saw the greatest reductions in plant stands with S15 as the rate of seed-placed P was increased, followed by MAP, and the MAP:CG blend, while struvite (CG) applied on its own rarely affected plant populations, except occasionally at the highest rate but only slightly compared to the other forms (i.e. spring counts from Redvers-2021). In many of the cases where no effects on emergence were detected (i.e. Indian Head and Melfort), we can largely attribute this lack of response to the finer soil texture, higher organic matter, and better moisture conditions; however, it is important to appreciate that seed-placing high rates of P fertilizer can still be risky in these environments. At Swift Current-2020, the risk of injury with seed-placed fertilizer was considered to be relatively high, but was not observed; however, overall seedling mortality at this location was quite high regardless of the treatment.

Moving on to canola seed yield responses to P forms and rates, there were generally fewer treatment effects and differences between means compared to the results for establishment. This was not necessarily expected given the generally low residual P levels; however, past experience has shown that responses to P fertilizer applications are often variable. According to the overall F-tests from the combined analyses (Table 5), the effects of site (S), form (F), rate (R), F x R, and S x F were significant (P < 0.001-0.006) but the S x R and S x F x R effects were not (P = 0.223-0.433). For the simplified analyses where the control was included, the effects of S, entry (E), and S x E were all highly significant for seed yield (P < 0.001).

When averaged across the 10 sites, the unfertilized control yielded 2138 kg/ha (Table 6). With respect to form effects, MAP, S15, and the MAP:CG blend all resulted in similar canola yields when averaged across sites and rates (2305-2336 kg/ha); however, the yield with pure struvite (CG) was slightly but significantly lower (2242 kg/ha). In terms of averaged rate responses, yields increased right to the highest P rate averaging 2230 kg/ha at 25 kg P_2O_5/ha, 2303 kg/ha at 45 kg P_2O_5/ha, and 2364 kg/ha at 65 kg P_2O_5/ha. The significant F x R interaction appeared to be due in part to the highest yields with S15 occurring at 45 kg P_2O_5/ha as opposed to 65 kg P_2O_5/ha for the other forms. Another inconsistency that likely contributed to this interaction was that yields with the MAP:CG blend trended higher than for MAP on its own at the 65 kg P_2O_5/ha rate but lower than MAP at the 22-45 kg P_2O_5/ha rates.

While the aforementioned results provide a good indication of average responses, the S x F and S x R interactions tell us that the specific results varied across sites. For the simplified analyses which included the control, the overall F-tests for Entry (Table 12) showed that there was, in fact, either no yield response or a weak responses at 6/10 sites. The exceptions were Melfort-2021, Outlook-2021, Redvers-2021, and Scott-2020. At Scott-2021, the overall effect of P rate was also significant (P = 0.022) despite the fact that the Entry effect (in the simplified model) was not (P = 0.176). Specifically looking at form, only 10% of the sites (Melfort-2021) had a significant effect (P < 0.001) suggesting that, when averaged across rates, all forms of P provided similar yield benefits at 90% of the sites. At Melfort-2021, the form effect was such that yields with MAP, S15, and the MAP:CG blend were similar (1410-1577 kg/ha); however, yields with struvite applied on its own were significantly lower (1009 kg/ha) and closer to the unfertilized control (912 kg/ha) than the other P forms (Table 17). In contrast, rate effects were significant (*P* = 0.001-0.022) at 40% of the sites; Melfort-2021, Redvers-2021, Scott-2020, and Scott-2021. Generally, a significant R effect indicated that more than 25 kg P_2O_5/ha was required to maximize seed yield as, since the control was excluded from the factorial analyses, it would still be possible to have had a response to P without a significant R effect (Table 17). Although the overall S x F x R interaction was not significant for seed yield (*P* = 0.223), Table 12 shows that there were, in fact, F x R interactions detected at 40% of the sites; Melfort-2021, Outlook-2021, Redvers-2021, and Scott-2020. Detailed yield results for individual treatments are provided in Table 18. At both Outlook and Redvers, this interaction appeared to be rather random and inexplicable. At Scott-2020, the interaction appeared to be due to subtle variation in the rate responses; however, yields increased linearly (*P* < 0.001-0.001) but not quadratically (*P* = 0.222-0.905) with increasing P rate for all four P formulations. At Melfort-2021, the interaction was more consistent with the previously discussed averaged (across sites) responses in that the response to MAP and S15 was stronger than that observed with the MAP:CG blend and, especially, to CG (struvite) applied on its own. This was verified by the orthogonal contrasts which showed linear/quadratic responses to MAP (*P* < 0.001-0.082), S15 (*P* < 0.001-0.035), and MAP:CG (*P* = 0.002-0.038), but no response to 100% struvite (*P* = 0.127-0.315). Again, these orthogonal contrasts also took the yields achieved in the 0 P control into consideration.

Economic Analyses
A basic economic analyses was conducted with the overall averaged results. The purpose of this analyses was to compare the relative costs and economic returns associated with the various P forms evaluated and their corresponding yield responses. This exercise was not completed for individual site years in the interest of space but also, importantly, because of the wide variation in observed responses. In some cases, yield differences may not be statistically significant but still large enough to have economic implications – working with the overall averages helps to eliminate some of that variability. Furthermore, phosphorus fertilizer is often considered to be a long-term investment into the overall fertility and productive capacity of our most valuable resource in crop production, the soil itself. With that in mind, P fertilization could show negative returns in the year of application but still be a sound economic investment over the longer-term. For the economic analyses, price quotes for urea, ammonium sulfate, MAP, S15, and CG (struvite) were all acquired on the same date, February 3, 2022. From this information, the cost per unit of actual P_2O_5 was calculated, taking into to consideration the value of any N and S that is also provided by the P products. The result of these calculations showed that, at this specific point in time, the cost of 1 kg P_2O_5 was $2.13, $3.06, $5.23, and $3.24 with MAP, S15, CG, and 50:50 MAP:CG, respectively (Table 8). Expressed as a percentage of MAP, the costs per unit of P for S15, CG, and MAP:CG were 144%, 246%, and 153%, respectively. To calculate gross revenues, a canola value of $900/Mt was assumed which was reasonably representative of the time period for which the fertilizer prices were obtained. When the gross revenues and total P costs (after discounting for N and S) were considered, the most profitable rates varied slightly across forms but all were reasonably competitive for MAP, S15, and the MAP:CG blend. Due to the higher cost and weaker yield response for 100% CG, the lowest rate was the most profitable for this formulation. Averaged across rates, marginal profits were highest for MAP ($1,986/ha), followed by S15 ($1,965/ha), the MAP:CG blend ($1,929/ha), and finally 100% CG ($1,782/ha). Monoammonium phosphate was the only formulation that was always more profitable than the control, regardless of rate; however, when averaged across rates, all formulations except 100% CG (struvite) were more profitable than the control.

Table 8. Relative costs of various phosphorus (P) fertilizer products, gross revenues, and marginal economic returns to applications based on averaged canola yield responses across 10 location-years in Saskatchewan.

	Monoammonium Phosphate	MicroEssentials® S15	Crystal Green® Struvite	50:50 Blend of MAP:CG
Fertilizer Prices	(MAP; 11-52-0)	(S15; 13-33-0-15)	(CG; 5-28-0)	(MAP:CG; 8-40-0)
\$/Mt [Z]	\$1,250	\$1,250	\$1,500	\$1,375
\$/kg P_2O_5 [Y]	\$2.13	\$3.06	\$5.23	\$3.24
% of MAP	100%	144%	246%	153%
P Rate	\$/ha P_2O_5 cost			
25 kg P_2O_5/ha	\$53.25	\$76.50	\$130.82	\$80.96
45 kg P_2O_5/ha	\$95.85	\$137.71	\$235.47	\$145.73
65 kg P_2O_5/ha	\$138.45	\$198.91	\$340.12	\$210.49
	\$/ha P_2O_5 gross revenue [X]			
0 P (control)	\$1,924			
25 kg P_2O_5/ha	\$2,018	\$2,048	\$1,992	\$1,973
45 kg P_2O_5/ha	\$2,097	\$2,160	\$1,977	\$2,057
65 kg P_2O_5/ha	\$2,131	\$2,102	\$2,084	\$2,193
	\$/ha P_2O_5 marginal profits [W]			
0 P (control)	\$1,924			
25 kg P_2O_5/ha	\$1,965	\$1,971	\$1,861	\$1,892
45 kg P_2O_5/ha	\$2,001	\$2,022	\$1,742	\$1,912
65 kg P_2O_5/ha	\$1,993	\$1,903	\$1,743	\$1,983
Average	\$1,986	\$1,965	\$1,782	\$1,929

[Z] All fertilizer prices (including urea and ammonium sulfate) are based on retail quotes from Feb-3, 2022

[Y] Prices per unit of P_2O_5 are adjusted for both the N and S (where applicable) provided by the P fertilizer products. The prices used for these adjustments were \$1145/Mt for urea (46-0-0) and \$750/Mt for ammonium sulfate (21-0-0-24)

[X] Based on average yields achieved over 10 location-years in Saskatchewan and canola price of \$900/Mt which is reasonably representative of the period during which the fertilizer was priced.

[W] \$/ha P_2O_5 costs subtracted from \$/ha gross revenues. Values do not account for fixed costs or variable costs other than P fertilizer after adjusting for the value of N and S

Extension Activities

Due to COVID-19 restrictions, we were not able to show the field trials on any summer field tours or workshops during the 2020 season; however, highlights of this work from that season were presented by Kayla Slind at WARC's Crop Opportunity 2021 webinar on March 3, 2021. In 2022, Chris Holzapfel showed the plots and discussed findings from the previous season and basic P fertility considerations at IHARF's annual Crop Management Field on July 20, 2021. This event was attended by 70-75 participants, not including staff and directors. At Swift Current, the trial was promoted on a segment of a CKSW radio program titled, "Walk the Plots" that was broadcasted on a weekly basis throughout the summer, as well as on Facebook, Twitter and the Swift Current Online Podcast. The trial was also featured on WCA's Annual field tour on July 15, 2022, presented by Sean

Senko of the Canola Council. At Redvers, Lana Shaw showed the plots during a small field day on July 15, 2022 which was attended by approximately 20 people. Kayla Slind presented 2020 results and 2021 highlights from Scott at the AgriARM Research Update webinar on January 13, 2022. Gursahib Singh presented the 2021 ICDC results of the trial at the SIPA/ICDC AGM held at the Dakota Dunes Casino on December 7, 2021 with 130 registered in-person and 29 on-line participants. Chris Holzapfel presented preliminary highlights from the two seasons at the IHARF Winter Seminar and AGM (virtual) on February 2 which, to date has been viewed 184 times. Chris Holzapfel will also present a full summary of these results at the AGVISE 2022 Canada Soil Fertility Seminar on March 15, 2022 in Portage la Prairie, and this presentation will be available on the AGVISE website after the live event has concluded. The 2020 technical report has been available online on the IHARF website (www.iharf.ca) since spring 2021 and this final report will also be available online in the coming months. Results from this project will continue to be presented and shared as opportunities arise.

11. Conclusions and Recommendations

This project has demonstrated the effects of seed-placing various P fertilizer formulations on canola establishment and yield for a range of Saskatchewan environments. In addition to a control, the rates at which the products were applied ranged from relatively safe for seed-row placement (25 kg P_2O_5/ha) to rates high enough to potentially cause serious seedling injury and stand reduction (i.e., 45-65 kg P_2O_5/ha). We expected the risks of seedling injury to be highest with S15, followed by MAP, the MAP:CG blend, and finally CG. This is generally what was observed; however, there was essentially no effect on emergence, regardless of form or rate, for approximately 50% of the sites. In some cases (i.e. Indian Head and Melfort), we attributed the lack of injury to the relatively high organic matter and fine-textured soils combined with good initial soil moisture or timely precipitation after seeding. There were, however, instances where the lack of response was less expected and more difficult to explain (i.e. Swift Current-2020), based on soil properties and moisture conditions alone. While the observed stand reductions were never catastrophic, they were certainly frequent and unpredictable enough to justify caution when seed-placing higher than recommended rates of P fertilizer, especially but not exclusively if other products (i.e. ammonium sulfate, potash) are also included in the seed-placed blend. In cases where seed-placing higher than recommended rates cannot be avoided, choosing a product such as struvite (CG), alone or in a blend, can substantially reduce the risk of injury. That said, this product is relatively expensive and, if applied on its own in low P soils, may not be released quickly enough to meet the needs of the crop in the year of application. Bearing in mind that we are not comparing to equivalent blends of MAP/ammonium sulfate, this project also showed that S15 is as, or more, likely to result in seedling injury than MAP on its own. Generally, yield responses to MAP were similar to or better than those achieved with the forms to which it was compared; however, other formulations can be advantageous with respect to overall ease of handling (i.e. S15) or suitability for in-furrow placement at high rates (i.e. struvite) so may still be a good fit for individual operations. While not something that we looked at in the current project, it is important to acknowledge that side-banding is also a safe and effective placement option for P fertilizer. Most western Canadian research has shown side-banding to be as effective as in-furrow placement, or even advantageous if utilizing rates that have potential to reduce stands. Dual banding P fertilizer with high rates of urea can reduce its availability early in the season; however, late-season availability can be enhanced with dual banding and documented yield advantages to seedrow versus side-band placement are rare. With respect to rates, our results show that the amounts of fertilizer that are generally required to, at minimum, replace the P removed by the crop are also profitable when averaged across a range of environments. While yield responses to P can be variable on a field-to-field basis, it must be appreciated that P fertilization is also a long-term investment that is necessary for maintaining or building the overall productivity of our land, regardless of the chosen formulation or responses in the year of application.

Supporting Information

12. Acknowledgements:

This project was supported by the Agricultural Demonstration of Practices and Technologies (ADOPT) initiative under the Canadian Agricultural Partnership bi-lateral agreement between the federal government and the Saskatchewan Ministry of Agriculture. Additional funding was provided by Fertilizer Canada. The participating organizations provided the land, equipment, and infrastructure required to complete this project and IHARF, NARF, WARC, and WCA also have strong working relationship and memorandums of understanding with Agriculture & Agri-Food Canada which help to make work like this possible and should be acknowledged. The MicroEssentials® S15 and Crystal Green® used in the project were donated by Richardson-Pioneer and Taurus Ag, respectively, and many of the crop protection products used in the field trials were also donated. Finally, none of this work would have been possible without all of the professional, technical, and summer staff at the various locations.

13. Appendices:

Table 9. Selected agronomic information and dates of operations from canola phosphorus fertilizer demonstrations completed at Indian Head (IH), Melfort (ME), Outlook (OL), Redvers (RV), Scott (SC), Swift Current (SW), and Yorkton (YK) 2020 (20) and 2021 (21).

Location-Year	Prev. Crop	Seeding Date	Seed Rate	Row Spacing	Plant Counts	Harvest Date	Stem Counts
IH-20	Oat	May-15	105 seeds/m^2	30 cm	Jun-10	Sep-10	Sep-10
IH-21	Canaryseed	May-13	105 seeds/m^2	30 cm	Jun-18	Sep-3	Sep-7
ME-21	Wheat	May-18	100 seeds/m^2	30 cm	Jun-14	Sep-8	Sep-9
OL-21	Potato	May-6	200 seeds/m^2	25 cm	Jun-2	Sep-8	Sep-8
RV-21	Wheat	May-15	105 seeds/m^2	25 cm	Jun-9	Sep-9	Sep-9
SC-20	Wheat	May-18	105 seeds/m^2	25 cm	Jun-15	Sep-10	Sep-11
SC-21	Wheat	May-13	105 seeds/m^2	25 cm	Jun-14	Aug-26	Aug-26
SW-20	Wheat	May-14	105 seeds/m^2	21 cm	Jun-8	Aug-27	Aug-20
SW-21	Field Pea	May-19	179 seeds/m^2	21 cm	Jun-18	Sep-1	Sep-2
YK-20	Oat	May-14	105 seeds/m^2	30 cm	Jun-2	Sep-2	Sep-4
YK-21	Wheat	May-18	105 seeds/m^2	30 cm	Jun-8	Aug-26	Sep-8

Table 10. Tests of fixed effects phosphorus (P) Form, Rate, and Form x Rate for spring canola plant densities at 10 site-years in Saskatchewan. Results were based on a combined analyses with site as a fixed effect and heterogeneous variance estimates permitted across sites. The 0 P_2O_5/ha control treatment was removed for the factorial analyses but was included in a separate model (All Entries) to allow for orthogonal contrasts and to compare the control to the combined fertilized plots.

	Spring Plant Density (plants/m^2)			
	Factorial Analyses			All Entries
Location - Year	**Form**	**Rate**	**Form × Rate**	**Entry**
	Pr > F (p-value)			
Indian Head – 2020	0.465	0.529	0.767	0.775
Indian Head – 2021	0.685	0.800	0.984	0.964
Melfort – 2021	0.661	0.796	0.712	0.689
Outlook – 2021	<0.001	<0.001	<0.001	<0.001
Redvers – 2021	0.059	0.675	0.009	0.008
Scott – 2020	0.037	0.608	0.281	0.302
Scott – 2021	<0.001	0.026	<0.001	<0.001
Swift Current – 2020	0.326	0.595	0.847	0.885
Swift Current – 2021	<0.001	<0.001	<0.001	<0.001
Yorkton – 2020[Z]	–	–	–	–
Yorkton – 2021	<0.001	0.324	<0.001	<0.001

[Z] Yorkton – 2020 was excluded from the combined analyses due to missing treatments

Table 11. Tests of fixed effects phosphorus (P) Form, Rate, and Form x Rate for final canola plant densities at 10 site-years in Saskatchewan. Results were based on a combined analyses with site as a fixed effect and heterogeneous variance estimates permitted across sites. The 0 P_2O_5/ha control treatment was removed for the factorial analyses but was included in a separate model (All Entries) to allow for orthogonal contrasts and to compare the control to the combined fertilized plots.

	Final Plant Density (stems/m^2)			
	---------------------- Factorial Analyses ----------------------			---- All Entries ---
Location - Year	**Form**	**Rate**	**Form × Rate**	**Entry**
	-------------------------------------- Pr > F (p-value) ---			
Indian Head – 2020	0.376	0.797	0.957	0.971
Indian Head – 2021	0.706	0.687	0.949	0.953
Melfort – 2021	0.894	0.798	0.882	0.920
Outlook – 2021	<0.001	0.042	<0.001	<0.001
Redvers – 2021	<0.001	0.009	<0.001	<0.001
Scott – 2020	0.132	0.727	0.734	0.667
Scott – 2021	<0.001	0.038	<0.001	<0.001
Swift Current – 2020	0.504	0.572	0.952	0.971
Swift Current – 2021	<0.001	<0.001	<0.001	<0.001
Yorkton – 2020[Z]	–	–	–	–
Yorkton – 2021	<0.001	0.013	<0.001	<0.001

[Z] Yorkton – 2020 was excluded from the combined analyses due to missing treatments

Table 12. Tests of fixed effects phosphorus (P) Form, Rate, and Form x Rate for final canola plant densities at 10 site-years in Saskatchewan. Results were based on a combined analyses with site as a fixed effect and heterogeneous variance estimates permitted across sites. The 0 P_2O_5/ha control treatment was removed for the factorial analyses but was included in a separate model (All Entries) to allow for orthogonal contrasts and to compare the control to the combined fertilized plots.

	Seed Yield (kg/ha)			
	---------------------- Factorial Analyses ----------------------			---- All Entries ---
Location - Year	**Form**	**Rate**	**Form × Rate**	**Entry**
	-- Pr > F (p-value) --			
Indian Head – 2020	0.625	0.167	0.607	0.620
Indian Head – 2021	0.360	0.858	0.956	0.965
Melfort – 2021	<0.001	0.008	<0.001	<0.001
Outlook – 2021	0.930	0.609	<0.001	<0.001
Redvers – 2021	0.260	0.004	0.009	<0.001
Scott – 2020	0.800	0.001	0.045	<0.001
Scott – 2021	0.415	0.022	0.314	0.176
Swift Current – 2020	0.876	0.565	0.934	0.770
Swift Current – 2021	0.743	0.148	0.552	0.597
Yorkton – 2020[Z]	–	–	–	–
Yorkton – 2021	0.441	0.942	0.919	0.855

[Z] Yorkton – 2020 was excluded from the combined analyses due to missing treatments

Table 13. Main effect means for seed-placed phosphorus (P) fertilizer form and rate effects on spring canola plant densities for individual location-years in Saskatchewan. Values within a column followed by the same letter do not significantly differ (Tukey; $P \leq 0.05$).

	Location-Year [Z]									
Main Effect	**IH-20**	**IH-21**	**ME-21**	**OL-21**	**RV-21**	**SC-20**	**SC-21**	**SW-20**	**SW-21**	**YK-21**
	Spring Plant Density (plants/m^2)									
Control	60.7	77.9	79.0	111.8	101.4	57.1	81.7	30.5	83.8	74.0
<u>P Form</u> [Y]										
MAP	64.4 A	67.9 A	70.2 A	64.9 B	96.5 AB	48.3 B	64.3 B	32.4 A	77.7 B	64.1 B
S15	61.8 A	73.3 A	70.9 A	58.0 B	90.1 B	46.8 B	63.8 B	25.9 A	61.0 C	58.7 B
CG	69.9 A	68.8 A	76.1 A	94.8 A	100.6 A	59.9 A	90.5 A	33.2 A	90.5 A	84.2 A
MAP:CG	66.2 A	71.9 A	73.3 A	96.8 A	87.9 B	55.9 AB	73.9 B	26.1 A	85.1 AB	77.7 A
S.E.M.	3.47	3.46	3.19	3.95	4.32	3.23	5.09	3.40	5.49	4.06
<u>kg P_2O_5/ha</u>										
22	68.4 A	69.2 A	70.9 A	79.5 B	91.7 A	55.1 A	77.2 A	31.6 A	92.4 A	74.6 A
45	63.7 A	72.1 A	73.3 A	88.8 A	95.6 A	52.4 A	76.1 A	29.5 A	74.4 B	71.0 A
65	64.5 A	70.1 A	73.7 A	67.6 C	94.1 A	50.7 A	66.1 B	27.1 A	69.0 B	67.9 A
S.E.M.	2.95	2.94	2.61	3.50	3.92	2.67	4.75	2.87	5.17	3.62

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton (YK-20 excluded due to missing treatments)

[Y] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® - 5-28-0 + 10% Mg; MAP:CG - 8-40-0 + 5% Mg (50:50 by mass of product)

Table 14. Individual treatment means and orthogonal contrast results for seed-placed phosphorus (P) fertilizer form and rate effects on final canola plant densities for individual location-years in Saskatchewan. Values associated with the linear and quadratic orthogonal contrasts are p-values (Pr > *F*). Values within a column followed by the same letter do not significantly differ (Tukey; *P* ≤ 0.05); however, letter groupings for individual treatments are only provided for location-years where the Form x Rate interaction was significant (denoted by an asterisk).

	---------- Location-Year [Z] ----------									
Entry	**IH-20**	**IH-21**	**ME-21**	**OL-21***	**RV-21***	**SC-20**	**SC-21***	**SW-20**	**SW-21***	**YK-21***
	---------- Spring Plant Density (stems/m²) ----------									
Control	60.7	77.9	79.0	111.8	101.4	57.1	81.7	30.5	83.8	74.0
MAP-25	69.1	67.9	74.9	83.0 bcd	87.9 bcd	52.9	69.9 cde	30.5	98.7 a	63.3 def
MAP-45	60.7	69.7	71.4	65.8 de	101.9 ab	49.0	71.9 bcde	34.4	72.1 bc	64.9 b-f
MAP-65	63.4	66.0	64.4	46.0 f	99.6 abc	43.1	51.2 f	32.3	62.2 cd	64.1 cdef
MAP-lin	0.975	0.214	0.095	<0.001	0.818	0.103	0.002	0.741	0.002	0.291
MAP-quad	0.598	0.630	0.758	0.733	0.307	0.826	0.431	0.899	0.023	0.441
S15-25	70.5	68.9	66.0	54.5 ef	81.4 cd	53.9	69.4 cdef	33.2	82.0 ab	68.2 a-f
S15-45	59.7	75.5	77.5	74.0 cd	98.9 abc	43.1	61.3 ef	24.2	49.1 d	56.6 ef
S15-65	55.2	75.7	69.1	45.5 f	90.1 abcd	43.6	60.8 ef	20.4	52.1 d	51.2 f
S15-lin	0.371	0.949	0.486	<0.001	0.495	0.068	0.011	0.173	<0.001	0.005
S15-quad	0.208	0.432	0.662	0.025	0.313	0.883	0.427	0.524	0.975	0.882
CG-25	66.9	71.8	74.2	95.3 ab	93.8 abcd	54.4	89.1 ab	33.5	88.8 ab	84.7 a
CG-24	68.5	67.9	70.8	106.8 a	100.4 ab	62.8	96.2 a	34.7	94.5 a	82.6 ab
CG-65	74.2	66.7	83.3	82.3 bcd	107.5 a	62.5	86.2 abc	31.4	88.2 ab	85.1 a
CG-lin	0.131	0.174	0.779	0.006	0.411	0.394	0.429	0.871	0.473	0.245
CG-quad	0.978	0.750	0.176	0.533	0.210	0.771	0.191	0.627	0.403	0.521
MAP:CG-25	67.3	68.3	68.5	85.3 bc	103.6 ab	59.3	80.5 abcd	29.3	99.9 a	82.2 abc
MAP:CG-45	65.9	75.5	73.4	108.5 a	81.2 cd	54.7	74.8 bcde	24.8	82.0 ab	79.8 abcd
MAP:CG-65	65.4	72.0	78.1	96.5 ab	79.0 d	53.6	66.5 def	24.2	73.6 bc	71.1 a-e
MAP:CG-lin	0.623	0.672	0.992	0.351	0.002	0.609	0.073	0.407	0.113	0.746
MAP:CG-quad	0.581	0.591	0.212	0.187	0.526	0.756	0.501	0.988	0.032	0.169
S.E.M.	6.23	6.22	6.08	6.51	6.74	6.10	7.26	6.19	7.54	6.58

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton (YK-20 excluded due to missing values)

[Y] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® - 5-28-0 + 10% Mg; MAP:CG - 8-40-0 + 5% Mg (50:50 by mass of product)

Table 15. Main effect means for seed-placed phosphorus (P) fertilizer form and rate effects on final canola plant densities for individual location-years in Saskatchewan. Values within a column followed by the same letter do not significantly differ (Tukey; *P* ≤ 0.05).

	Location-Year [Z]									
Main Effect	**IH-20**	**IH-21**	**ME-21**	**OL-21**	**RV-21**	**SC-20**	**SC-21**	**SW-20**	**SW-21**	**YK-21**
	Final Plant Density (stems/m^2)									
Control	53.8	74.1	67.7	103.5	87.8	65.4	99.2	31.4	79.3	62.9
P Form [Y]										
MAP	59.1 A	66.3 A	66.7 A	62.3 B	71.7 B	55.9 A	84.0 BC	34.1 A	80.1 A	53.4 B
S15	52.0 A	70.1 A	70.1 A	53.2 B	64.6 B	51.4 A	72.8 C	28.4 A	60.2 B	51.2 B
CG	59.1 A	72.1 A	66.8 A	87.9 A	86.1 A	62.3 A	102.8 A	34.5 A	91.4 A	72.7 A
MAP:CG	54.0 A	69.9 A	67.9 A	92.6 A	68.6 B	60.2 A	91.6 B	29.5 A	83.7 A	56.9 B
S.E.M.	3.38	3.13	4.26	4.75	3.22	3.32	3.29	3.20	4.53	6.06
kg P_2O_5/ha										
22	56.6 A	71.7 A	68.6 A	70.6 B	80.0 A	58.9 A	89.8 AB	34.2 A	89.6 A	65.8 A
45	57.2 A	68.0 A	66.2 A	80.3 A	71.5 AB	57.9 A	92.1 A	29.8 A	75.7 B	56.4 B
65	54.4 A	69.1 A	68.9 A	71.1 B	66.8 B	55.6 A	81.5 B	31.0 A	71.3 B	53.5 B
S.E.M.	2.88	2.59	3.88	4.41	2.69	2.81	2.77	2.66	4.17	5.80

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton (YK-20 excluded due to missing treatments)

[Y] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® - 5-28-0 + 10% Mg; MAP:CG - 8-40-0 + 5% Mg (50:50 by mass of product)

Table 16. Individual treatment means and orthogonal contrast results for seed-placed phosphorus (P) fertilizer form and rate effects on final canola plant densities for individual location-years in Saskatchewan. Values associated with the linear and quadratic orthogonal contrasts are p-values (Pr > *F*). Values within a column followed by the same letter do not significantly differ (Tukey; *P* ≤ 0.05); however, letter groupings for individual treatments are only provided for location-years where the Form x Rate interaction was significant (denoted with an asterisk).

	---------- Location-Year [Z] ----------									
Entry	**IH-20**	**IH-21**	**ME-21**	**OL-21***	**RV-21***	**SC-20**	**SC-21***	**SW-20**	**SW-21***	**YK-21***
	---------- Final Plant Density (stems/m^2) ----------									
Control	53.8	74.1	67.7	103.5	87.8	65.4	99.2	31.4	79.3	62.9
MAP-25	62.6	71.4	68.3	74.8 cd	81.0 abc	55.9	95.7 ab	34.7	103.2 a	64.9 abc
MAP-45	58.4	60.1	69.3	55.0 e	67.2 cd	59.8	88.8 bc	34.1	72.1 cd	45.5 cd
MAP-65	56.2	67.5	62.6	57.3 de	66.9 cd	51.9	67.4 d	33.5	65.2 cde	50.0 cd
MAP-lin	0.859	0.247	0.617	<0.001	0.005	0.171	<0.001	0.819	0.013	0.037
MAP-quad	0.351	0.487	0.540	0.029	0.733	0.893	0.101	0.751	0.004	0.981
S15-25	52.1	67.3	66.5	51.0 e	80.7 abcd	54.9	77.0 cd	33.8	74.2 c	63.6 abc
S15-45	54.8	72.8	69.7	57.3 de	63.5 de	49.2	74.6 cd	25.4	51.5 e	52.1 bcd
S15-65	49.2	70.4	74.2	51.3 e	49.5 e	50.2	67.0 d	26.0	55.0 de	38.0 d
S15-lin	0.694	0.810	0.415	<.0001	<0.001	0.054	<0.001	0.381	<0.001	0.002
S15-quad	0.758	0.693	0.602	<0.001	0.392	0.403	0.290	0.806	0.683	0.161
CG-25	57.0	76.7	71.6	93.8 bc	84.9 ab	60.8	100.9 ab	34.4	83.7 bc	73.1 a
CG-24	60.7	69.3	57.2	96.0 ab	86.6 a	63.5	106.3 a	34.1	96.3 ab	71.5 ab
CG-65	59.7	70.1	71.6	74.0 cd	86.9 a	62.8	101.1 ab	35.0	94.2 ab	73.6 a
CG-lin	0.424	0.497	0.921	0.002	0.950	0.826	0.667	0.691	0.035	0.245
CG-quad	0.770	0.812	0.467	0.281	0.783	0.735	0.613	0.871	0.714	0.515
MAP:CG-25	54.7	71.4	67.9	62.8 de	73.3 abcd	64.2	85.4 bc	33.8	97.5 ab	61.6 abc
MAP:CG-45	54.8	69.9	68.7	113.0 a	68.7 bcd	59.1	98.7 ab	25.4	82.9 bc	56.6 abcd
MAP:CG-65	52.5	68.5	67.3	102.0 ab	63.8 cde	57.4	90.6 abc	29.3	70.9 cde	52.5 bcd
MAP:CG-lin	0.902	0.504	0.992	0.156	0.004	0.287	0.600	0.599	0.194	0.192
MAP:CG-quad	0.788	0.943	0.898	0.004	0.509	0.908	0.573	0.972	0.009	0.751
S.E.M.	6.03	5.89	6.56	6.89	5.94	5.99	5.98	5.93	6.74	7.85

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton (YK-20 excluded due to missing values)

[Y] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® - 5-28-0 + 10% Mg; MAP:CG - 8-40-0 + 5% Mg (50:50 by mass of product)

Table 17. Main effect means for seed-placed phosphorus (P) fertilizer form and rate effects on canola seed yield for individual location-years in Saskatchewan. Values within a column followed by the same letter do not significantly differ (Tukey; $P \leq 0.05$).

	Location-Year [Z]									
Main Effect	**IH-20**	**IH-21**	**ME-21**	**OL-21**	**RV-21**	**SC-20**	**SC-21**	**SW-20**	**SW-21**	**YK-21**
	Seed Yield (kg/ha)									
Control	3236	2988	912	4585	743	2973	1391	1996	1297	1253
P Form [Y]										
MAP	3317 A	2965 A	1487 A	4502 A	1167 A	3421 A	1597 A	2195 A	1299 A	1182 A
S15	3367 A	3001 A	1577 A	4549 A	1262 A	3369 A	1600 A	2151 A	1387 A	1101 A
CG	3257 A	2916 A	1009 B	4500 A	1174 A	3450 A	1499 A	2213 A	1348 A	1051 A
MAP:CG	3305 A	2860 A	1410 A	4513 A	1307 A	3398 A	1632 A	2163 A	1319 A	1141 A
S.E.M.	79.6	79.6	79.6	79.6	79.6	79.6	79.6	79.6	79.6	79.6
kg P_2O_5/ha										
22	3259 A	2913 A	1243 B	4475 A	1138 B	3276 B	1469 B	2137 A	1283 A	1113 A
45	3286 A	2943 A	1415 A	4540 A	1179 B	3409 AB	1615 A	2194 A	1313 A	1133 A
65	3389 A	2951 A	1454 A	4533 A	1366 A	3544 A	1662 A	2210 A	1418 A	1111 A
S.E.M.	73.9	73.9	73.9	73.9	73.9	73.9	73.9	73.9	73.9	73.9

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton (YK-20 excluded due to missing treatments)

[Y] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® - 5-28-0 + 10% Mg; MAP:CG - 8-40-0 + 5% Mg (50:50 by mass of product)

Table 18. Individual treatment means and orthogonal contrast results for seed-placed phosphorus (P) fertilizer form and rate effects on seed yield for individual location-years in Saskatchewan. Values associated with the linear and quadratic orthogonal contrasts are p-values (Pr > *F*). Values within a column followed by the same letter do not significantly differ (Tukey; *P* ≤ 0.05); however, letter groupings for individual treatments are only provided for location-years where the Form x Rate interaction was significant.

	Location-Year [Z]									
Entry	**IH-20**	**IH-21**	**ME-21***	**OL-21***	**RV-21***	**SC-20***	**SC-21**	**SW-20**	**SW-21**	**YK-21**
	Seed Yield (kg/ha)									
Control	3236	2988	912	4585	743	2973	1391	1996	1297	1253
MAP-25	3324	2990	1229 bc	4546 bcd	1095 b	3191 c	1495	2147	1228	1177
MAP-45	3179	2965	1674 a	4422 bcde	1166 b	3556 ab	1621	2180	1322	1209
MAP-65	3449	2941	1559 a	4536 bcd	1240 b	3516 ab	1674	2257	1345	1161
MAP-lin	0.280	0.721	<0.001	0.537	<0.001	<0.001	0.031	0.067	0.624	0.576
MAP-quad	0.389	0.878	0.082	0.501	0.218	0.339	0.904	0.768	0.604	0.892
S15-25	3279	2997	1425 ab	4372 cde	1275 b	3299 bc	1526	2133	1395	1045
S15-45	3374	2986	1639 a	4959 a	1245 b	3379 abc	1672	2167	1380	1197
S15-65	3447	3019	1667 a	4317 de	1265 b	3429 abc	1603	2153	1383	1062
S15-lin	0.110	0.858	<0.001	0.637	<0.001	0.001	0.077	0.245	0.570	0.324
S15-quad	0.801	0.906	0.035	0.067	0.015	0.222	0.380	0.484	0.645	0.681
CG-25	3186	2861	947 c	4664 b	1085 b	3346 abc	1408	2247	1357	1032
CG-24	3332	2924	925 c	4235 e	1144 b	3354 abc	1517	2229	1238	1069
CG-65	3252	2964	1155 bc	4602 bc	1295 b	3649 a	1572	2162	1448	1053
CG-lin	0.678	0.940	0.127	0.399	<0.001	<0.001	0.153	0.246	0.469	0.188
CG-quad	0.953	0.392	0.315	0.241	0.424	0.805	0.773	0.122	0.483	0.321
MAP:CG-25	3248	2804	1370 ab	4317 de	1096 b	3266 bc	1448	2020	1152	1196
MAP:CG-45	3260	2896	1425 ab	4545 bcd	1162 b	3347 abc	1651	2201	1309	1059
MAP:CG-65	3407	2880	1434 ab	4678 ab	1664 a	3582 ab	1798	2268	1495	1168
MAP:CG-lin	0.258	0.566	<0.002	0.321	<0.001	<0.001	0.002	0.029	0.118	0.371
MAP:CG-quad	0.476	0.388	0.038	0.036	0.338	0.905	0.519	0.709	0.077	0.467
S.E.M.	115.3	115.3	115.3	115.3	115.3	115.3	115.3	115.3	115.3	115.3

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton (YK-20 excluded due to missing values)

[Y] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® - 5-28-0 + 10% Mg; MAP:CG - 8-40-0 + 5% Mg (50:50 by mass of product)

Abstract

14. Abstract/Summary

With field trials at Swift Current, Scott, Indian Head, and Yorkton in 2020 and these four locations plus Melfort, Outlook, and Redvers in 2021, a project was conducted to demonstrate the effects of various seed-placed phosphorus (P) fertilizer formulations on canola establishment and yield. The formulations were monoammonium phosphate (MAP), MicroEssentials® S15, CrystalGreen® (CG), and a MAP:CG blend where 35% of the P_2O_5 came from CG. In addition to a control, the rates were 25, 45, and 65 kg P_2O_5/ha. All sites were reasonably low in residual P with less than 15 ppm 90% of the time. Response data included spring and fall plant densities, maturity, and yield; however, maturity effects were rarely significant and too small to be of agronomic importance. Treatment effects on establishment occurred at approximately 50% of the sites. While the lack of response could sometimes be reasonably explained by soil properties and/or moisture conditions, it was more difficult to explain at others and confirms the unpredictable nature of seedling injury with in-furrow P fertilizer placement. Where they did occur and when averaged across sites, stand reductions were usually most severe with S15, followed closely by MAP and were less severe with the MAP:CG blend and essentially non-existent with 100% CG. On average, yields increased up to the highest P rate and the responses were similar for all forms except CG applied on its own which performed slightly poorer. For individual sites, yield responses to P were significant less than half the time; however, yields for many sites were below average and P fertilization is also important from a long-term perspective when considering the poor uptake-efficiency in the year of application. From an economic perspective, all forms performed reasonably well except 100% GC due to its higher cost and weaker yield response. On average, the rates required to at least maintain P fertility over the long-term were also profitable. In conclusion, MAP generally performed as well or better than the options to which it was compared; however, other forms may be advantageous from a logistic/handling perspective (i.e. S15) or with regard to seed safety (i.e. MAP:CG blends) and, as such, may still be a good fit for individual operations.