2022 Report

for the

Saskatchewan Ministry of Agriculture's

Agricultural Demonstration of Practices & Technologies (ADOPT) Program

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

(Project #20211080)

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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:** 20211080
3. **Producer Group Sponsoring the Project:** Indian Head Agricultural Research Foundation
4. **Project Location(s):** Over the three-year period (2020-22), field trials have been located near 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-2022 to February-2023
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, calcareous soils result in lower 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 (AMS) 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 + AMS (average of 56 trials over a 9-year period). University of Manitoba research (Grenkow et al. 2013) showed improved seed safety over MAP/AMS blends but warned that S15 may not be as effective at providing plant available S compared to conventional MAP/AMS 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 longer periods, 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. 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 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, most 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 an ideal test crop for this project.

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Methodology and Results

9. Methodology:

Field trials with canola were conducted over three growing seasons with the project locations varying from year-to-year. Collectively, the project has been conducted at 14 sites which were comprised of Indian Head (2020, 2021, and 2022), Melfort (2021 and 2022), Outlook (2021), Redvers (2021), Scott (2020, 2021, and 2022), Swift Current (2020, 2021, and 2022), and Yorkton (2021). 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 were 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, comparable to the current industry recommended 25:75 blend. The total amount of nitrogen (N) applied was balanced across treatments within each location and supplemental ammonium sulfate was also applied to ensure that S was not limiting in any treatments. Phosphorus fertilizer products were always seed-placed while urea and ammonium sulfate were always side-banded. Detailed treatment information is provided in Table 1.

Table 1. Treatment descriptions for ADOPT Novel Phosphorus demonstrations completed at 14 sites from throughout Saskatchewan in 2020, 2021, and 2022.

#	Phosphorus Form	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®[Z]	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®[Y]	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] CrystalGreen® will commonly be referred to as struvite throughout the report
[Y] Expressed as actual P_2O_5 the ratio is 65:35 MAP:CrystalGreen®

Selected agronomic information and dates of operations are in Table 10 of the Appendices. The specific canola hybrids varied across locations. Seeding rates also varied with most sites targeting 100-110 seeds/m^2, but Outlook-2021 and Swift Current in 2021 and 2022 utilizing higher rates to compensate for sub-optimal seeding conditions. All sites used drills equipped with narrow hoe openers and row spacing ranging from 21-30 cm. The target seeding depth was approximately 2-2.5 cm; however, the actual depth likely varied more than this across sites. Weeds were controlled using registered pre-emergent and in-crop herbicides. Most sites utilized preventive foliar fungicides for sclerotinia while foliar insecticides were only applied if the actual insect pressure justified it. The centre rows of each plot were straight combined for seed yield determination, avoiding outside rows, wherever possible.

Various data were collected at each site. Residual nutrient levels and basic soil information were derived from spring composite soil samples 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; 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 except for Redvers where data from a private station was utilized.

Response data from all locations were combined prior to analyses and 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. Heterogeneous variance component estimates (by site) were permitted for all variables because the variance significantly differed across sites and doing so improved model fit in all cases. Data from the unfertilized control treatment were excluded from the factorial analyses but were included in a separate model where orthogonal contrasts tested for linear and quadratic responses to P fertilizer rate. The Tukey-Kramer multiple comparisons test was used to separate treatment means. All effects and differences between means were considered significant at $P \leq 0.05$.

10. Results:

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. Over the four-month period, temperatures were warmer than average at 9/14 sites and close to average at 5/14 sites. Precipitation amounts were below average at 10/14 sites and above average at 4/14 sites. One of the sites where precipitation was above-average, Indian Head 2021, was still considered dry overall due to extremely low initial soil moisture reserves, high temperatures in June and July, and much of the August precipitation coming too late to benefit the crop. The Outlook site received supplemental irrigation and these amounts are also provided. Overall, the soil and weather conditions encountered provided a wide range of yield potential environments.

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-22	10.9	16.1	18.1	18.3	15.8 (101%)
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-22	9.8	15.2	18.2	18.7	15.5 (102%)
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-22	10.0	15.0	18.3	18.9	15.6 (105%)
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-22	10.8	15.7	19.7	20.9	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-22	97.7	27.5	114.5	45.9	286 (117%)
IH-LT	51.8	77.4	63.8	51.2	244
ME-21	31.4	37.6	0.2	69.3	139 (61%)
ME-22	90.8	78.1	34.9	36.5	240 (106%)
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-22	11.0	57.1	86.5	32.1	187 (83%)
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-22	43.2	31.2	83.5	6.7	165 (88%)
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 site 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 (5.5-6.6). Values at Indian Head, Outlook, and Redvers were comparatively high (7.8-8.0), and soil pH at Yorkton was neutral (7.1). 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 (9.3-12.1%). While also impacted by organic matter and pH, cation exchange capacity (CEC) is 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 (41-48 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 93% of the location-years with the sole exception being Swift Current-2021 (16 ppm). Residual P was 10 ppm or lower at 71% of the sites. 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 completed in 2020, 2021, and 2022 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
IH-22 (0-15)	8.0	5.2	48.3	3	6	596	9
IH-22 (15-60)	–	–	–	7	–	–	27
ME-21 (0-15)	5.9	12.1	n/a	19	8	418	13
ME-21 (15-30)	–	–	–	25 [Z]	–	–	13 [Z]
ME-22 (0-15)	5.7	9.3	–	72	10	476	25
ME-22 (15-30)	–	–	–	57 [Z]			25 [Z]
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
SC-22 (0-15)	5.8	4.2	13.3	19	8	242	13
SC-22 (15-60)	–	–	–	25		–	13 [Z]
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
SW-22 (0-15)	6.4	2.4	19.2	8	10	237	11
SW-22 (15-60)	–	–	–	19 [Z]	–	–	11 [Z]
YK-21 (0-15)	7.1	4.7	22.1	30	13	253	54
YK-21 (15-60)	–	–	–	54	–	–	128

[Z] Values are for the 15-30 cm depth and therefore may be underestimated relative to 15-60 cm depths
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 effects on stand establishment and yield. 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. Regarding establishment, we will mostly focus on the spring assessments; however, the final population numbers may provide useful insights. For example, if spring counts are ever completed too early, before emergence is complete, the final counts could provide a more accurate assessment of the treatment effects on establishment. Also, if populations are especially high due to better-than-expected establishment or high seeding rates, densities could decline over the season due to intraspecies competition. 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 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	<0.001
Rate (R)	<0.001	<0.001	<0.001
F × R	0.022	0.003	<0.001
S × F	<0.001	<0.001	<0.001
S × R	<0.001	0.004	0.167
S × F × R	0.026	0.008	0.319

Both the spring and final plant densities were affected by site (S), P form (F), P rate (R), and all possible interactions (P < 0.001-0.026). Seed yield was also affected by S, F, and R (P < 0.001) with an overall S x F interaction (P < 0.001) and strong site interactions with form (S x F; P < 0.001), but not rate (S x R; P = 0.167) or the F x R interaction (S x F x R; P = 0.319). Given the many interactions with site, we can draw broad conclusions based on the overall (across site) treatment averages; however, it is important to appreciate that the specific results varied depending on the environmental conditions. Site specific results are provided in all cases; however, the tables for these results are deferred to the Appendices and, due to the scope of this project, each individual site cannot be discussed in detail.

To provide a sense of the variability across and within sites, overall site means, and standard errors of the treatment means for spring plant density, final plant density, and seed yield are presented in Table 6 below. Overall mean spring plant densities ranged from as low as 24 plants/m^2 at ME-22 to as high as 107 plants/m^2 at IH-22. In most cases, the final plant densities were similar or slightly lower in the fall; however, there were some exceptions (i.e., SC-21 and SW-22) where the final densities were substantially higher than what was measured in the spring. Lower numbers in the fall are likely due to in-season mortality due to factors such as insects, frost, or self-thinning while higher numbers in the fall are likely due to variable or poor initial emergence (i.e., due to drought) and a portion of the seeds germinating and emerging after the spring counts were completed. Seed yields also varied widely across sites. Yields at several locations were negatively affected by heat and drought, especially in 2021, averaging about 1600 kg/ha or lower (i.e., ME-21, RV-21, SC-21, SW-21, and YK-21). In contrast, conditions at a handful of sites were much more optimal and resulted in yields well over 3000 kg/ha (i.e., IH-20, IH-22, OL-21, and SC-20). The remaining five sites had more intermediate yields ranging from approximately 1900-2900 kg/ha. Again, the wide-range of conditions for emergence and overall potential yields allowed for a robust evaluation and demonstration of the different formulations and rates of seed-placed P.

Table 6. Main effect means for site (location x year) effects on canola emergence, final plant densities, and seed yield when averaged across 14 sites in Saskatchewan. The locations were Indian Head (IH), Melfort (ME), Outlook (OL), Redvers (RV), Scott (SC), Swift Current (SW), and Yorkton (YK). Means within a column followed by the same letter do not significantly differ (Tukey-Kramer, *P* < 0.05) and values in parentheses are the standard error of the treatment means. The 0 P control treatment was excluded from these means.

Main Effect	Spring Plant Density [Z]	Final Plant Density [Y]	Seed Yield
	---------- plants/m^2 ----------	----------- stems/m^2 -----------	------------- kg/ha -------------
IH-20	65.6 E (1.41)	56.1 F (1.44)	3311 B (48.5)
IH-21	70.5 DE (1.39)	69.6 D (0.67)	2936 C (55.1)
IH-22	106.9 A (2.05)	96.1 A (1.08)	3402 B (56.3)
ME-21	72.6 DE (0.38)	67.9 DE (2.97)	1371 GH (89.6)
ME-22	23.5 H (1.53)	27.7 G (1.78)	2593 CD (172.2)
OL-21	78.6 C (2.36)	74.0 CD (3.64)	4516 A (51.8)
RV-21	93.8 B 2.94)	72.7 CD (1.01)	1228 HI (68.4)
SC-20	52.7 F (0.65)	57.5 F (1.29)	3410 B (72.2)
SC-21	73.1 CDE (3.99)	87.8 B (1.20)	1582 G (56.1)
SC-22	53.1 F (1.13)	56.2 F (2.36)	2513 D (27.6)
SW-20	29.4 G (1.24)	31.6 G (0.93)	2180 E (37.1)
SW-21	78.6 CD (4.48)	78.9 C (3.34)	1338 H (39.6)
SW-22	74.5 CD (1.23)	102.2 A (3.82)	1922 F (21.6)
YK-21	71.1 DE (2.54)	58.6 EF (5.23)	1119 I (73.4)

[Z] Letter groupings for Spring Plant Density do not reflect all significant comparisons: IH-21 vs. SW-22, IH-20 vs. ME-21, and IH-20 vs. IH-21 also differ

[Y] Letter groupings for Final Plant Density do not reflect all significant comparisons: IH-21 vs. RV-21 also differ

Averaged across all 14 sites, we observed 72 plants/m^2, regardless of when the measurements were completed and the overall means and treatment effects were nearly identical for both the spring and fall assessments (Table 7). The form effects were such that the highest populations occurred with 100% struvite (CG) at 75 plants/m^2, followed by slightly lower values with the struvite:MAP blend (70 plants/m^2), 100% MAP (64 plants/m^2), and finally, S15 (59-61 plants/m^2). Notably, none of these averaged populations were low enough to potentially limit canola yields or result in agronomic issues; however, the relative rankings of plant populations with each formulation were as expected and all differences between forms were statistically significant. With the S x F interaction, however, we know that results varied across locations. Tables 11 and 12 of the Appendices show that plant populations were affected by form at 57% of the sites. Notably, the sites where P form did not affect plant populations did not show either rate effects or an overall treatment effect, suggesting that plant populations for all P treatments were comparable to the control at these sites, regardless of the form or application rate. For the responsive sites, the results were quite consistent in that pure struvite generally had no effect on emergence while MAP and/or S15 had the greatest impacts (Tables 14 and 16). As expected, plant populations at the responsive sites were generally intermediate between pure struvite and MAP/S15 with the struvite:MAP blend. Plant populations with MAP and S15 were often statistically similar within individual sites, but often trended higher with MAP and, when significant, favoured MAP. This was not unexpected and is attributable to the higher overall product and N rates associated with S15 relative to MAP. MicroEssentials® S15 is often considered a safer product for in-furrow placement, and this is true for equivalent blends of MAP and AMS; however, we only seed-placed the P fertilizer products in the current project.

The overall average rate effects were also significant and as expected when averaged across sites with both the initial and final plant populations declining with each incremental increase in the amount of seed-placed P applied (Table 7). Across the 14 sites, the number of plants ranged from 70-71 plants/m^2 at 25 kg P_2O_5, an amount broadly considered safe for in-furrow placement, to 63-64 plant/m^2 at 65 kg P_2O_5/ha. The overall rate effects were significant at 4-7 of 14 sites (depending when the measurements were completed) and, when they occurred, were due to overall plant populations declining relative to 25 kg P_2O_5/ha at rates of 45-65 kg P_2O_5/ha (Tables 14 and 16). Again, the control was excluded from the factorial analyses so rate effects would only be detected when the stands differed between 25-65 kg P_2O_5/ha. Importantly, most of the sites where P form and/or rate effects were detected, the F x R interaction was also significant (Tables 11-12); thereby indicating that the effects of P rate on plant densities varied depending on the specific formulation being evaluated.

Table 7. 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 14 location-years in Saskatchewan. Means followed by the same letter do not significantly differ (Tukey-Kramer, *P* < 0.05) 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)	71.9	72.2	2200
<u>P Form</u> [Y]			
MAP	63.5 C	63.9 C	2397 A
S15	60.7 D	58.5 D	2429 A
CG	75.1 A	75.4 A	2324 B
MAP:CG	70.4 B	69.9 B	2400 A
S.E.M.	1.00	1.04	22.9
<u>kg P_2O_5/ha</u>			
25	70.3 A	70.7 A	2315 C
45	68.0 B	66.9 B	2395 B
65	63.9 C	63.2 C	2452 A
S.E.M.	0.89	0.94	21.7

[Z] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® (5-28-0 + 10% Mg); MAP:CG blend (8-40-0 + 5% Mg)

Focussing on the F x R interactions, individual treatment means, averaged across the 14 sites, are presented in Table 8. 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 (54-57 plants/m^2 at 65 kg P_2O_5/ha), followed by MAP (58 plants/m^2 at 65 kg P_2O_5/ha), and the MAP:CG blend (66-67 plants/m^2 at 65 kg P_2O_5/ha).

Table 8. Individual treatment means for seed-placed phosphorus (P) fertilizer formulation [Z] by rate [Y] effects on canola emergence, final plant densities, and seed yield when averaged across 14 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*). Responses varied amongst individual location-years.

Main Effect	Spring Plant Density	Final Plant Density	Seed Yield
	------------------------------ plants/m^2	------------------------------	------------- kg/ha -------------
Control	71.9	72.2	2200
MAP-25	69.0 c	71.4 b	2308 de
MAP-45	63.7 de	62.2 cd	2424 bc
MAP-65	57.8 f	57.9 de	2458 ab
MAP-lin	<0.001	<0.001	<0.001
MAP-quad	0.189	0.099	0.330
S15-25	64.3 de	63.4 c	2365 cd
S15-45	61.0 ef	57.7 e	2487 ab
S15-65	56.8 f	54.4 e	2434 bc
S15-lin	<0.001	<0.001	<0.001
S15-quad	0.443	0.196	<0.001
CG-25	74.0 ab	75.4 ab	2299 de
CG-45	77.5 a	76.4 a	2287 e
CG-65	73.8 ab	74.5 ab	2385 c
CG-lin	0.168	0.227	<0.001
CG-quad	0.093	0.119	0.936
MAP:CG-25	74.0 ab	72.5 ab	2288 e
MAP:CG-45	70.1 bc	71.2 b	2381 c
MAP:CG-65	67.2 cd	66.1 c	2529 a
MAP:CG-lin	0.014	0.007	<0.001
MAP:CG-quad	0.075	0.066	0.098
S.E.M.	1.64	1.65	31.1

[Z] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® (5-28-0 + 10% Mg); MAP:CG blend (8-40-0 + 5% Mg)

[Y] Rates are 25, 45, or 65 kg P_2O_5/ha

Regarding F x R interactions at individual sites (Tables 15 and 17), there was subtle variation between spring and fall assessments and across sites when they did occur, but the effects were generally consistent with the averaged results already discussed. Again, 43-50% of the sites showed no treatment effects on plant density whatsoever, even when the control was included in the analyses, but when effects were detected, there was usually an F x R interaction. Even though this is a powerful comparison, significant 'Check versus Rest' contrasts were less frequent than significant overall F-tests for entry (Tables 11-12). This was attributed to the fact that only certain products and/or rates significantly reduced plant densities and, occasionally, some treatments even tended to improve establishment relative to the control (i.e., IH-22, SW-21, SW-22). The non-responsive sites were Indian Head (all three years), Melfort (both years), Scott in 2020, and Swift Current in 2020. In 2022 at Indian Head, plant densities trended highest with struvite and the MAP:struvite blend (most prominent in the fall); however, the differences were never large enough to be significant according to the multiple comparisons test. With finer soil texture, higher organic matter, and generally better moisture conditions, Indian Head and Melfort were at a lower risk of stand reductions with seed-placed fertilizer than most of the other locations. At Melfort 2022, however, emergence was very poor overall, regardless of fertilizer treatment. For the sites where interactions were explicitly detected, subtle variation existed and, in some cases, treatment differences were inconsistent or not as expected, but the larger trends were broadly consistent with plant densities declining at higher P rates with MAP and S15 but to a much lesser extent with struvite, especially when used as the sole P source. While our ability to detect individual treatment differences within sites is limited compared to the main effects, the orthogonal contrasts are also useful for identifying subtle differences in the responses to each P form. For several of the sites that were broadly classified as non-responsive, the trends were often consistent with the responsive sites and overall main effects. For example, while Indian Head was generally considered non-responsive, the mean plant populations with struvite, especially when applied alone, were consistently amongst the highest observed in the trial. Scott in 2021 and 2022 were amongst the most responsive sites with respect to establishment and exhibited some of the strongest F x R interactions.

Moving on to seed yield, the overall F-tests (Table 5) indicated significant site (S), rate (R), and form (F) effects with F x R and S x F interactions also detected ($P < 0.001$). Overall site effects on yield were already discussed and, again, are summarized in Table 6. When averaged across the 14 sites, yields in the control were 2200 kg/ha while the canola that received P fertilizer yielded 8.5% higher, on average (2387 kg/ha). Yields were statistically similar with MAP, S15, and the MAP:struvite blend (2397-2429 kg/ha), but slightly yet significantly lower with pure struvite (2324 kg/ha). Again, with significant S x F interactions, the relative yield response to different P forms varied across sites; however, it is likely that this low solubility formulation was unable to completely meet the crop demands in some environments. The overall rate effect (across forms) was such that yields increased with each incremental addition of P. The first 25 kg P_2O_5/ha provided the greatest gains, increasing yields by 115 kg/ha from 2200 kg/ha to 2315 kg/ha. Increasing the P rate to 45 kg P_2O_5/ha improved canola yield by an additional 80 kg/ha (2395 kg/ha) and further additions to 65 kg P_2O_5/ha increased canola yield by another 57 kg/ha (2452 kg/ha). To put these rate responses into perspective, a 2500 kg/ha canola crop will take up a total of 66-82 kg P_2O_5/ha and remove 47-57 kg P_2O_5/ha. A common strategy is to try and match P additions with crop removal to maintain long-term soil fertility. The average (across sites) F x R interactions for seed yield were mainly due to the comparatively poor response to pure struvite. Responses to MAP and S15 were statistically similar but tended to favour S15 at the lower rates and MAP at the high rate. Yields with the MAP:struvite blend were lower than with S15 at rates of 25-45 kg P_2O_5/ha but higher than S15 at 65 kg P_2O_5/ha. This may have been partly due to S15 being less suitable for in-furrow placement at high rates. This is also reflected in the orthogonal contrast results. For MAP, struvite, and the MAP:struvite blend, the canola yield responses to P were linear ($P < 0.001$) but not quadratic ($P = 0.098$-0.936). In contrast, the response for S15 was quadratic, even declining slightly when the P rate was increased from 45 kg P_2O_5 to 65 kg P_2O_5/ha. The highest yielding treatment was the MAP:CG blend at 65 kg P_2O_5/ha (2529 kg/ha); however, this did not significantly differ from MAP at 65 kg P_2O_5/ha (2458 kg/ha) or S15 at 45 kg P_2O_5/ha (2487 kg/ha).

While the previously discussed results provide a good indication of average responses, there was a certain amount of variation across sites that should be acknowledged. The ‘Check versus Rest’ comparisons indicated that there was a significant overall yield response to P at 50% of the sites and an at least marginally significant ($P \leq 0.10$) response 64% of the time. The exceptions were IH-20, IH-21, OL-21, SW-21, and YK-21. While OL-21, SW-21, and YK-21 were amongst the highest residual P sites and yields at both SW-21 and YK-21 were severely limited by drought, the lack of response at IH-20 and IH-21 would not have been predicted based on soil test results and actual yield potential.

Experience from Indian Head has shown that, despite consistently low soil test levels, responses to P fertilization occur frequently, but not always, and the responses are often smaller than might be expected. It is possible that the fine-textured, reasonably high organic matter soils at this location are more effective at mineralizing and releasing P over the growing season than many soils with similarly low soil test P from other areas of the Prairies. Importantly, the various P forms performed similarly in most possible occasions, the exceptions being ME-21, ME-22, and SW-22 (Table 18). At Melfort in both years, the yield response to pure struvite (CG) was noticeably poorer than for all the other options to which it was compared. This was consistent with the overall averaged response, but more prominent. The trend was similar at Scott in both 2021 and 2022, but neither the F (P = 0.330-0.359) nor F x R (P = 0.178-215) effects were significant in these cases. At SW-22, the form effect was such that yields were highest with S15 (2071 kg/ha) while those achieved with the other forms were lower (1864-1884 kg/ha). Although the S x R interaction was not significant (P = 0.159), there was a certain amount of variation in the rate effects at individual sites with the significant site-specific tests of fixed effects for rate 50% of the time (Table 13). The lack of interaction was attributed to yield differences between 25-65 kg P_2O_5/ha rates being modest, even where they were clearly significant, and similar trends in many of the cases where differences were too small to be declared significant when considered on a site-by-site basis (Table 15). Treatment means for the F x R interactions at individual sites are presented in Table 19, regardless of statistical significance. The main sites where the interactions were particularly meaningful were ME-21 and ME-22. At ME-21, the responses were sizeable with significant linear and/or quadratic orthogonal contrasts for MAP, S15, smaller but still significant responses with the MAP:struvite blend, and essentially no response for pure struvite. At ME-22, the response to pure struvite was, again, poorer than with the other P forms and not statistically significant according to the orthogonal contrasts (P = 0.159-0.388). For S15 at ME-22, the trend was for yields to decline at the highest rate and this was confirmed by a significant quadratic response with S15 (P = 0.003) but no other forms. Overall, yield variability was high at ME-22, possibly due to the poor establishment.

Economic Analyses

A basic economic analysis was conducted with the overall averaged main effects. 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 major economic implications. Working with the overall averages helps to limit the impact of such variability. Furthermore, P 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. 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 results 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 9). 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 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 marginal profits were reasonably competitive for MAP, S15, and the MAP:CG blend. Profits were generally lower for 100% CG (struvite) due to the higher cost and slightly lower yields associated with this formulation. Averaged across rates, marginal profits were highest for MAP ($2,061/ha), followed by S15 ($2,048/ha), the MAP:CG blend ($2,014/ha), and finally 100% CG ($1,856/ha). Across formulations, marginal profits were similar for rates of 25-45 kg P_2O_5/ha ($1998-2002/ha), but slightly lower at 65 kg P_2O_5/ha due to the higher input costs and diminishing yield gains. For F x R interactions, the most profitable rate was 45 kg P_2O_5/ha for MAP and S15, 25 kg P_2O_5 for 100% GC, and 65 kg P_2O_5/ha for the MAP:CG blend.

Table 9. Relative costs of various phosphorus (P) fertilizer products, gross revenues, and marginal economic returns to applications based on averaged canola yield responses across 14 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)	$1,980			
25 kg P_2O_5/ha	$2,077	$2,129	$2,069	$2,059
45 kg P_2O_5/ha	$2,182	$2,238	$2,058	$2,143
65 kg P_2O_5/ha	$2,212	$2,191	$2,147	$2,276
	---------- $/ha P_2O_5 marginal profits [W] ----------			
0 P (control)	$1,980			
25 kg P_2O_5/ha	$2,024	$2,052	$1,938	$1,978
45 kg P_2O_5/ha	$2,086	$2,101	$1823	$1,997
65 kg P_2O_5/ha	$2,074	$1,992	$1,806	$2,066
Average	$2,061	$2,048	$1,856	$2,014

[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 14 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 and Gursahib Singh presented the 2021 ICDC results of the trial at the SIPA/ICDC AGM. In 2021, 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. 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, 2021, where it was discussed by Sean Senko of the Canola Council of Canada. At Redvers, Lana Shaw showed the plots during a small field day on July 15, 2021, which was attended by approximately 20 people. During the 2022 growing season, the project was shown during a SaskCanola-IHARF Canola Crop Walk at Indian Head on August 4 which was attended by approximately 40 producers and agronomists. Kayla Slind presented 2020 from all sites and 2021 highlights from Scott at the AgriARM Research Update webinar on January 13, 2022 and Jessica Enns presented project highlights during the WARC Crop Opportunity Update on March 2, 2022. Chris Holzapfel presented preliminary project highlights at the IHARF Winter Seminar and AGM (virtual) on February 2, 2022, and presented a full, in-depth summary of these results at the AGVISE 2022 Canada Soil Fertility Seminar (Portage la Prairie, MB) on March 15, 2022, and during the 2022 IHARF Winter Seminar on February 1, 2023 (Balcarres, SK). Chris Holzapfel also presented key project highlights during the Manitoba Soil Fertility Advisory Meetings in both 2021 and 2022. The full 2020 and 2021 technical reports have been available online on the IHARF website (www.iharf.ca) and the current, final report will 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 rates of contrasting P fertilizer formulations on canola establishment and yield for a wide 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 potentially high enough to 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, based on soil properties and moisture conditions alone (i.e., Swift Current-2020). While the observed stand reductions were mostly relatively minor, they were 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 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 used as the sole P source in low P soils, may not always be released quickly enough to meet the needs of the crop in the year of application. Bearing in mind that we did not compare it 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 applied on its own. Generally, yield responses to MAP were similar 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 many 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 may be enhanced with dual banding and documented yield advantages to in-furrow versus side-band placement are rare. With respect to rates, our results show that the amounts of fertilizer that are generally required to 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 the professional, technical, and summer staff at the various locations.

13. Appendices:

Table 10. 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), 2021 (21), and 2022 (22).

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	Canary seed	May-13	105 seeds/m^2	30 cm	Jun-18	Sep-3	Sep-7
IH-22	Oat	May-26	105 seeds/m^2	30 cm	Jun-16	Sep-18	Oct-5
ME-21	Wheat	May-18	100 seeds/m^2	30 cm	Jun-14	Sep-8	Sep-9
ME-22	Wheat	May-26	114 seeds/m^2	30 cm	Jun-27	Sep-26	Sep-27
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
SC-22	Wheat	May-16	110 seeds/m^2	25 cm	Jun-8	Sep-5	Sep-14
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
SW-22	Wheat	May-4	179 seeds/m^2	21 cm	Jun-22	Aug-12	Aug-18
YK-21	Wheat	May-18	105 seeds/m^2	30 cm	Jun-8	Aug-26	Sep-8

Table 11. Tests of fixed effects phosphorus (P) Form, Rate, and Form x Rate for spring canola plant densities at 14 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.

	-------------- Factorial Analyses --------------			-------- All Treatments -------	
Location - Year	**Form**	**Rate**	**Form × Rate**	**Entry**	**Check vs Rest**
	-- Pr > F (p-value) --				
Indian Head – 2020	0.408	0.486	0.681	0.681	0.427
Indian Head – 2021	0.640	0.777	0.974	0.941	0.224
Indian Head – 2022	0.085	0.137	0.208	0.202	0.360
Melfort – 2021	0.614	0.772	0.616	0.578	0.300
Melfort – 2022	0.400	0.743	0.732	0.717	0.373
Outlook – 2021	<0.001	<0.001	<0.001	<0.001	<0.001
Redvers – 2021	0.038	0.641	0.003	0.002	0.213
Scott – 2020	0.022	0.569	0.185	0.194	0.475
Scott – 2021	<0.001	0.016	<0.001	<0.001	0.162
Scott – 2022	<0.001	0.092	<0.001	<0.001	0.262
Swift Current – 2020	0.270	0.555	0.782	0.825	0.858
Swift Current – 2021	<0.001	<0.001	<0.001	<.0001	0.398
Swift Current – 2022	0.086	0.008	<0.001	<0.001	0.436
Yorkton – 2021	<0.001	0.279	<0.001	<0.001	0.642

Table 12. Tests of fixed effects phosphorus (P) Form, Rate, and Form x Rate for final (fall) canola plant densities at 14 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.

	-------------- Factorial Analyses --------------			-------- All Treatments -------	
Location - Year	**Form**	**Rate**	**Form × Rate**	**Entry**	**Check vs Rest**
	-- Pr > F (p-value) --				
Indian Head – 2020	0.340	0.782	0.943	0.961	0.707
Indian Head – 2021	0.680	0.666	0.933	0.939	0.467
Indian Head – 2022	0.027	0.250	0.286	0.352	0.803
Melfort – 2021	0.883	0.783	0.851	0.897	0.969
Melfort – 2022	0.492	0.686	0.958	0.927	0.238
Outlook – 2021	<0.001	0.032	<0.001	<0.001	<0.001
Redvers – 2021	<0.001	0.006	<0.001	<0.001	0.014
Scott – 2020	0.108	0.709	0.679	0.606	0.192
Scott – 2021	<0.001	0.029	<0.001	<0.001	0.063
Scott – 2022	<0.001	0.027	<0.001	<0.001	0.054
Swift Current – 2020	0.469	0.546	0.937	0.961	0.971
Swift Current – 2021	<0.001	<0.001	<0.001	<0.001	0.951
Swift Current – 2022	<0.001	<0.001	<0.001	<0.001	0.989
Yorkton – 2021	<0.001	0.009	<0.001	<0.001	0.484

Table 13. Tests of fixed effects phosphorus (P) Form, Rate, and Form x Rate for canola seed yield at 14 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.

	--------------- Factorial Analyses ---------------			-------- All Treatments -------	
Location - Year	**Form**	**Rate**	**Form × Rate**	**Entry**	**Check vs Rest**
	-- Pr > F (p-value) --				
Indian Head – 2020	0.576	0.132	0.500	0.498	0.444
Indian Head – 2021	0.304	0.841	0.933	0.941	0.594
Indian Head – 2022	0.970	0.663	0.977	0.685	0.021
Melfort – 2021	<0.001	0.005	<0.001	<0.001	<0.001
Melfort – 2022	<0.001	0.001	<0.001	<0.001	<0.001
Outlook – 2021	0.918	0.571	<0.001	<0.001	0.485
Redvers – 2021	0.209	0.002	0.003	<0.001	<0.001
Scott – 2020	0.768	<0.001	0.020	<0.001	<0.001
Scott – 2021	0.359	0.013	0.215	0.097	0.052
Scott – 2022	0.330	0.005	0.178	0.042	0.013
Swift Current – 2020	0.854	0.525	0.901	0.674	0.060
Swift Current – 2021	0.705	0.115	0.442	0.474	0.679
Swift Current – 2022	0.022	0.061	0.070	0.031	0.065
Yorkton – 2021	0.385	0.935	0.880	0.783	0.172

Table 14. 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-Kramer; *P* ≤ 0.05).

Main Effect	Location-Year													
	IH-20	**IH-21**	**IH-22**	**ME-21**	**ME-22**	**OL-21**	**RV-21**	**SC-20**	**SC-21**	**SC-22**	**SW-20**	**SW-21**	**SW-22**	**YK-21**
	Spring Plant Density (plants/m^2)													
Control	60.7	77.9	101.3	79.0	18.0	111.8	101.4	57.1	81.7	60.0	30.5	83.8	69.7	74.0
P Form [Y]														
MAP	64.4 a	67.9 a	102.1 a	70.2 a	19.5 a	64.9 b	96.5 ab	48.3 ab	64.3 b	43.8 b	32.4 a	77.7 b	73.1 a	64.1 b
S15	61.8 a	73.3 a	102.9 a	70.9 a	27.2 a	58.0 b	90.1 ab	46.8 b	63.8 b	39.6 b	25.9 a	61.0 c	69.4 a	58.7 b
CG	69.9 a	68.8 a	110.5 a	76.1 a	21.9 a	94.8 a	100.6 a	59.9 a	90.5 a	69.3 a	33.2 a	90.5 a	81.6 a	84.2 a
MAP:CG	66.2 a	71.9 a	112.1 a	73.3 a	25.2 a	96.8 a	87.9 b	55.9 ab	73.9 b	59.8 a	26.1 a	85.1 ab	73.8 a	77.7 a
S.E.M.	3.30	3.29	3.61	3.00	3.35	3.80	4.19	3.04	4.97	3.18	3.23	5.38	3.22	3.91
kg P_2O_5/ha														
22	68.4 a	69.2 a	111.6 a	70.9 a	24.3 a	79.5 a	91.7 a	55.1 a	77.2 a	57.2 a	31.6 a	92.4 a	80.8 a	74.6 a
45	63.7 a	72.1 a	105.5 a	73.3 a	21.6 a	88.8 a	95.6 a	52.4 a	76.1 a	54.1 a	29.5 a	74.4 b	74.8 ab	71.0 a
65	64.5 a	70.1 a	103.5 a	73.7 a	24.5 a	67.6 b	94.1 a	50.7 a	66.1 b	48.1 a	27.1 a	69.0 b	67.7 b	67.9 a
S.E.M.	2.81	2.80	3.18	2.46	2.87	3.39	3.82	2.52	4.67	2.68	2.73	5.10	2.72	3.51

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton

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

Table 15. Individual treatment means and orthogonal contrast results for seed-placed phosphorus (P) fertilizer form and rate effects on spring 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-Kramer; *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).

Main Effect	Location-Year													
	IH-20	IH-21	IH-22	ME-21	ME-22	OL-21*	RV-21*	SC-20	SC-21*	SC-22*	SW-20	SW-21*	SW-22*	YK-21*
	Spring Plant Density (plants/m^2)													
Control	60.7	77.9	101.3	79.0	18.0	112	101.4	57.1	81.7	60.0	30.5	83.8	69.7	74.0
MAP-25	69.1	67.9	106.8	74.9	21.7	83.0 abc	87.9 ab	52.9	69.9 a-d	49.3 bc	30.5	98.7 ab	90.6 ab	63.3 abc
MAP-45	60.7	69.7	98.6	71.4	16.4	65.8 cde	101.9 ab	49.0	71.9 a-d	43.8 bc	34.4	72.1 bcd	70.9 abc	64.9 abc
MAP-65	63.4	66.0	100.9	64.4	20.5	46.0 e	99.6 ab	43.1	51.2 d	38.5 c	32.3	62.2 cd	57.7 c	64.1 abc
MAP-lin	0.974	0.184	0.745	0.074	0.925	<0.001	0.806	0.081	<0.001	0.007	0.724	0.001	0.054	0.259
MAP-quad	0.573	0.607	0.718	0.742	0.991	0.715	0.275	0.815	0.400	0.736	0.892	0.015	0.002	0.411
S15-25	70.5	68.9	100.5	66.0	30.3	54.5 de	81.4 ab	53.9	69.4 a-d	42.8 c	33.2	82.0 abc	78.4 abc	68.2 abc
S15-45	59.7	75.5	105.0	77.5	19.7	74.0 bcd	98.9 ab	43.1	61.3 cd	39.5 bc	24.2	49.1 d	69.7 abc	56.6 bc
S15-65	55.2	75.7	103.2	69.1	31.6	45.5 e	90.1 ab	43.6	60.8 cd	36.5 c	20.4	52.1 d	60.1 bc	51.2 c
S15-lin	0.339	0.946	0.706	0.457	0.236	<0.001	0.466	0.051	0.006	0.004	0.145	<0.001	0.184	0.003
S15-quad	0.179	0.402	0.972	0.640	0.924	0.016	0.281	0.875	0.396	0.273	0.496	0.973	0.095	0.874
CG-25	66.9	71.8	118.6	74.2	24.2	95.3 ab	93.8 ab	54.4	89.1 ab	69.5 ab	33.5	88.8 abc	71.5 abc	84.7 a
CG-24	68.5	67.9	106.9	70.8	19.1	106.8 a	100.4 ab	62.8	96.2 a	79.8 a	34.7	94.5 ab	94.2 a	82.6 ab
CG-65	74.2	66.7	106.0	83.3	22.4	82.3 abc	107.5 a	62.5	86.2 abc	58.8 abc	31.4	88.2 abc	79.0 abc	85.1 a
CG-lin	0.107	0.146	0.836	0.765	0.743	0.003	0.380	0.363	0.398	0.723	0.862	0.443	0.052	0.214
CG-quad	0.977	0.733	0.102	0.148	0.776	0.505	0.180	0.756	0.163	0.013	0.603	0.372	0.235	0.493
Blend-25	67.3	68.3	120.6	68.5	20.9	85.3 abc	103.6 ab	59.3	80.5 abc	67.3 ab	29.3	99.9 a	82.9 abc	82.2 ab
Blend-45	65.9	75.5	111.6	73.4	31.2	108.5 a	81.2 ab	54.7	74.8 a-d	53.5 abc	24.8	82.0 abc	64.3 bc	79.8 ab
Blend-65	65.4	72.0	104.2	78.1	23.6	96.5 ab	79.0 a	53.6	66.5 bcd	58.8 abc	24.2	73.6 a-d	74.2 abc	71.1 abc
Blend-lin	0.600	0.651	0.899	0.991	0.296	0.320	<0.001	0.585	0.055	0.534	0.375	0.090	0.899	0.729
Blend-quad	0.555	0.566	0.019	0.182	0.440	0.158	0.498	0.740	0.473	0.755	0.987	0.022	0.654	0.141
S.E.M.	5.87	5.87	6.06	5.71	5.90	6.17	6.42	5.74	6.96	5.81	5.83	7.25	5.83	6.24

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton

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

Table 16. Main effect means for seed-placed phosphorus (P) fertilizer form and rate effects on final (fall) canola plant densities for individual location-years in Saskatchewan. Values within a column followed by the same letter do not significantly differ (Tukey-Kramer; *P* ≤ 0.05).

Main Effect	IH-20	IH-21	IH-22	ME-21	ME-22	OL-21	RV-21	SC-20	SC-21	SC-22	SW-20	SW-21	SW-22	YK-21
	Final Plant Density (plants/m²)													
Control	53.8	74.1	94.6	67.7	20.5	103.5	87.8	65.4	99.2	68.9	31.4	79.3	102.3	62.9
P Form [Y]														
MAP	59.1 a	66.3 a	91.9 a	66.7 a	25.3 a	62.3 b	71.7 b	55.9 a	84.0 bc	45.8 b	34.1 a	80.1 a	97.4 b	53.4 b
S15	52.0 a	70.1 a	90.1 a	70.1 a	25.0 a	53.2 b	64.6 b	51.4 a	72.8 c	40.5 b	28.4 a	60.2 b	88.9 b	51.2 b
CG	59.1 a	72.1 a	101.7 a	66.8 a	29.2 a	87.9 a	86.1 a	62.3 a	102.8 a	73.4 a	34.5 a	91.4 a	115.7 a	72.7 a
MAP:CG	54.0	69.9 a	100.7 a	67.9 a	31.3 a	92.6 a	68.6 b	60.2 a	91.6 ab	65.1 a	29.5 a	83.7 a	106.8 a	56.9 b
S.E.M.	3.28	3.02	3.13	4.18	3.44	4.68	3.11	3.21	3.18	3.77	3.09	4.45	4.82	6.00
kg P_2O_5/ha														
22	56.6 a	71.7 a	100.0 a	68.6 a	28.8 a	70.6 b	80.0 a	58.9 a	89.8 ab	61.4 a	34.2 a	89.6 a	113.4 a	65.8 a
45	57.2 a	68.0 a	95.0 a	66.2 a	28.8 a	80.3 a	71.5 ab	57.9 a	92.1 a	57.0 ab	29.8 a	75.7 b	100.5 b	56.4 ab
65	54.4 a	69.1 a	93.3 a	68.9 a	25.6 a	71.1 ab	66.8 b	55.6 a	81.5 b	50.3 b	31.0 a	71.3 b	92.7 b	53.5 b
S.E.M.	2.80	2.49	2.63	3.82	2.99	4.36	2.60	2.73	2.69	3.37	2.58	4.12	4.51	5.76

Location-Year columns.

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton

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

Table 17. Individual treatment means and orthogonal contrast results for seed-placed phosphorus (P) fertilizer form and rate effects on final (fall) 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-Kramer; *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).

Main Effect	Location-Year													
	IH-20	IH-21	IH-22	ME-21	ME-22	OL-21*	RV-21*	SC-20	SC-21*	SC-22*	SW-20	SW-21*	SW-22*	YK-21*
	Final Plant Density (plants/m²)													
Control	53.8	74.1	94.6	67.7	20.5	103.5	87.8	65.4	99.2	68.9	31.4	79.3	102.3	62.9
MAP-25	62.6	71.4	97.6	68.3	25.8	74.8 bc	81.0 a	55.9	95.7 ab	49.0 bcd	34.7	103.2 a	115.2 ab	64.9 abc
MAP-45	58.4	60.1	90.4	69.3	27.3	55.0 c	67.2 ab	59.8	88.8 abc	48.3 bcd	34.1	72.1 bcd	95.1 bc	45.5 bc
MAP-65	56.2	67.5	87.6	62.6	23.0	57.3 c	66.9 ab	51.9	67.4 c	40.3 cd	33.5	65.2 cd	82.0 c	50.0 abc
MAP-lin	0.854	0.229	0.302	0.605	0.707	<0.001	0.004	0.156	<0.001	0.001	0.812	0.010	0.004	0.030
MAP-quad	0.333	0.471	0.550	0.525	0.428	0.023	0.723	0.889	0.089	0.407	0.742	0.003	0.014	0.981
S15-25	52.1	67.3	93.1	66.5	26.3	51.0 c	80.7 a	54.9	77.0 bc	43.3 cd	33.8	74.2 bcd	103.5 abc	63.6 abc
S15-45	54.8	72.8	90.8	69.7	23.2	57.3 c	63.5 ab	49.2	74.6 bc	39.0 d	25.4	51.5 d	84.1 c	52.1 abc
S15-65	49.2	70.4	86.3	74.2	25.7	51.3 c	49.5 b	50.2	67.0 c	39.3 cd	26.0	55.0 d	79.3 c	38.0 c
S15-lin	0.683	0.803	0.312	0.398	0.618	<0.001	<0.001	0.046	<0.001	<0.001	0.363	<0.001	0.001	0.002
S15-quad	0.749	0.682	0.759	0.589	0.770	<0.001	0.375	0.386	0.272	0.048	0.800	0.672	0.435	0.146
CG-25	57.0	76.7	102.7	71.6	30.8	93.8 ab	84.9 a	60.8	100.9 ab	73.3 ab	34.4	83.7 abc	111.9 ab	73.1 a
CG-24	60.7	69.3	99.6	57.2	28.9	96.0 ab	86.6 a	63.5	106.3 a	80.8 a	34.1	96.3 ab	118.4 ab	71.5 ab
CG-65	59.7	70.1	102.7	71.6	27.9	74.0 bc	86.9 a	62.8	101.1 ab	66.3 abc	35.0	94.2 ab	117.0 ab	73.6 a
CG-lin	0.407	0.481	0.396	0.918	0.407	0.001	0.948	0.820	0.656	0.880	0.680	0.029	0.050	0.228
CG-quad	0.762	0.805	0.663	0.451	0.342	0.264	0.775	0.726	0.600	0.109	0.866	0.704	0.413	0.500
Blend-25	54.7	71.4	106.4	67.9	32.2	62.8 c	73.3 ab	64.2	85.4 abc	80.0 a	33.8	97.5 ab	123.2 a	61.6 abc
Blend-45	54.8	69.9	99.0	68.7	35.7	113.0 a	68.7 ab	59.1	98.7 ab	60.0 a-d	25.4	82.9 abc	104.4 abc	56.6 abc
Blend-65	52.5	68.5	96.6	67.3	26.1	102.0 a	63.8 ab	57.4	90.6 abc	55.3a-d	29.3	70.9 bcd	92.8 bc	52.5 abc
Blend-lin	0.899	0.488	0.973	0.992	0.393	0.141	0.003	0.268	0.587	0.036	0.586	0.178	0.106	0.176
Blend-quad	0.780	0.940	0.200	0.894	0.080	0.003	0.494	0.905	0.559	0.097	0.971	0.006	0.003	0.742
S.E.M.	5.81	5.67	5.73	6.37	5.91	6.71	5.72	5.78	5.76	6.11	5.71	6.55	6.81	7.69

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton

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

Table 18. 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-Kramer; *P* ≤ 0.05).

Main Effect	Location-Year													
	IH-20	**IH-21**	**IH-22**	**ME-21**	**ME-22**	**OL-21**	**RV-21**	**SC-20**	**SC-21**	**SC-22**	**SW-20**	**SW-21**	**SW-22**	**YK-21**
	Seed Yield (kg/ha)													
Control	3226	2990	3176	912	2236	4585	743	2973	1391	2270	1996	1297	1741	1253
P Form [Y]														
MAP	3317 a	2965 a	3388 a	1487 a	2601 ab	4502 a	1167 a	3421 a	1597 a	2567 a	2195 a	1299 a	1864 b	1182 a
S15	3367 a	3001 a	3406 a	1577 a	2621 a	4549 a	1262 a	3369 a	1600 a	2542 a	2151 a	1386 a	2071 a	1101 a
CG	3257 a	2916 a	3392 a	1009 b	2409 b	4500 a	1174 a	3450 a	1499 a	2431 a	2213 a	1348 a	1884 ab	1051 a
MAP:CG	3305 a	2860 a	3423 a	1410 a	2741 a	4513 a	1307 a	3398 a	1632 a	2513 a	2163 a	1319 a	1869 b	1141 a
S.E.M.	68.2	73.1	74.0	101.6	178.7	70.6	83.6	86.7	73.8	55.2	60.7	62.2	52.7	86.9
kg P_2O_5/ha														
22	3259 a	2913 a	3406 a	1243 b	2452 b	4475 a	1138 b	3276 b	1469 b	2397 b	2137 a	1283 a	1850 b	1113 a
45	3286 a	2943 a	3370 a	1415 a	2698 a	4540 a	1179 b	3409 ab	1615 ab	2527 ab	2194 a	1313 a	1906 ab	1133 a
65	3389 a	2951 a	3431 a	1454 a	2630 a	4533 a	1366 a	3544 a	1662 a	2616 a	2210 a	1418 a	2009 a	1111 a
S.E.M.	62.3	67.7	68.6	97.8	176.6	65.0	78.8	82.3	68.4	47.8	55.7	54.0	44.8	82.3

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton
[Y] MAP - monoammonium phosphate (11-52-0); S15 - MicroEssentials® S15 (13-33-0-15); CG - Crystal Green® (5-28-0 + 10% Mg); MAP:CG blend (8-40-0 + 5% Mg)

Table 19. Individual treatment means and orthogonal contrast results for seed-placed phosphorus (P) fertilizer form and rate effects on canola 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-Kramer; *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).

Main Effect	Location-Year													
	IH-20	IH-21	IH-22	ME-21*	ME-22*	OL-21*	RV-21*	SC-20*	SC-21	SC-22	SW-20	SW-21	SW-22	YK-21
	Seed Yield (kg/ha)													
Control	3226	2990	3176	912	2236	4585	743	2973	1391	2270	1996	1297	1741	1253
MAP-25	3324	2990	3393	1229 b-e	2356 c	4546 abc	1095 b	3191 b	1495	2407	2147	1228	1731	1177
MAP-45	3179	2965	3429	1674 a	2709 abc	4422 bc	1166 b	3556 ab	1621	2620	2180	1322	1878	1209
MAP-65	3449	2941	3341	1559 abc	2738 abc	4536 abc	1240 ab	3516 ab	1674	2674	2257	1345	1983	1161
MAP-lin	0.250	0.704	0.180	<0.001	<0.001	0.510	<0.001	<0.001	0.021	<0.001	0.051	0.601	0.044	0.551
MAP-quad	0.359	0.870	0.121	0.063	0.878	0.473	0.189	0.309	0.897	0.822	0.754	0.581	0.454	0.885
S15-25	3279	2997	3413	1425 abc	2476 abc	4372 bc	1275 ab	3299 ab	1526	2438	2133	1395	2031	1045
S15-45	3374	2986	3309	1639 ab	2885 a	4959 a	1245 ab	3379 ab	1672	2574	2167	1380	2059	1197
S15-65	3447	3019	3497	1667 ab	2501 abc	4317 bc	1265 ab	3429 ab	1603	2614	2153	1383	2122	1062
S15-lin	0.088	0.849	0.038	<0.001	0.003	0.615	<0.001	<0.001	0.059	0.005	0.216	0.545	0.005	0.293
S15-quad	0.789	0.900	0.796	0.024	0.003	0.051	0.009	0.193	0.349	0.604	0.456	0.623	0.271	0.662
CG-25	3186	2861	3408	947 de	2378 c	4664 abc	1085 b	3346 ab	1408	2364	2247	1357	1907	1032
CG-24	3332	2924	3381	925 e	2444 abc	4235 c	1144 b	3354 ab	1517	2393	2229	1238	1838	1069
CG-65	3252	2964	3388	1155 cde	2406 bc	4602 abc	1295 ab	3649 a	1572	2536	2162	1448	1905	1053
CG-lin	0.658	0.937	0.130	0.104	0.159	0.368	<0.001	<0.001	0.128	0.051	0.216	0.440	0.293	0.160
CG-quad	0.950	0.362	0.246	0.285	0.388	0.211	0.395	0.793	0.758	0.737	0.100	0.454	0.596	0.290
Blend-25	3248	2804	3410	1370 a-d	2598 abc	4317 bc	1096 b	3266 ab	1448	2379	2020	1152	1731	1196
Blend -45	3260	2896	3359	1425 abc	2753 abc	4545 abc	1162 b	3347 ab	1651	2522	2201	1309	1848	1059
Blend-65	3407	2880	3498	1434 abc	2873 ab	4678 ab	1664 a	3582 ab	1798	2638	2268	1495	2027	1168
Blend-lin	0.228	0.541	0.027	<0.001	<0.001	0.290	<0.001	<0.001	<0.001	0.003	0.020	0.096	0.025	0.341
Blend-quad	0.448	0.358	0.639	0.027	0.300	0.023	0.308	0.899	0.492	0.836	0.691	0.060	0.261	0.439
S.E.M.	104.0	107.2	107.8	128.4	195.2	105.6	114.6	116.9	107.7	95.6	99.2	100.1	94.5	117.0

[Z] IH - Indian Head; ME - Melfort; OL - Outlook; RV - Redvers; SC - Scott; SW - Swift Current; YK – Yorkton

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

Abstract

14. Abstract/Summary

With field trials at 14 sites spanning the major soil climatic zones of Saskatchewan and a range of weather and yield potential environments, a project was conducted to demonstrate the effects of contrasting, 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 the 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 soil P, with less than 15 ppm 93% of the time and less than or equal to 10 ppm 71% of the time. 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, this was not always the case 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, were less severe with the MAP:CG blend, and were essentially non-existent with 100% CG. Across forms and sites, 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 at least marginally significant 64% of the time. The non-responsive sites could usually, but not always, be explained a combination of low yields (due to drought) and at least moderately high residual soil P levels. When considering the poor uptake-efficiency in the year of application, P fertilization is also important from a long-term outlook. 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 maintain P fertility over the long-term (i.e., approximately 45 kg P_2O_5/ha) 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, will still commonly be a good fit for individual operations.