Final Report for the

SASKATCHEWAN CANOLA DEVELOPMENT COMMISSION (SASKCANOLA)

Enhancing Canola Production with Improved Phosphorus Fertilizer Management

(CARP SCDC ADF Project Number 201502 Brandt)

Northeast Agriculture Research Foundation

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Executive Summary:

Most soils in Saskatchewan are deficient in available phosphate (P_2O_5) and this macronutrient typically limits crop growth and yield. Furthermore, canola has a relatively high phosphate requirement compared to cereals. With the ever-increasing yield potential of newer canola hybrids, phosphate nutrition in this crop is crucial to ensure that yield potentials are optimized. Fertilizer phosphate (P) is used to augment soil available phosphate to meet the crops needs. Due to phosphate being relatively immobile, and because it becomes less soluble over time in most soils, how it is placed can influence how the crop can utilize it to support growth. Historically, it was recommended that fertilizer phosphate should be banded in the seed-row to optimize availability. However, the rate that can be safely placed with the seed is limited because high rates can reduce emergence. With high yielding canola hybrids, the safe rates for seed-row placement are typically insufficient for yield optimization. Therefore, producers question how to best apply these high rates. Additionally, safe rates with seed-row placement are not sufficient to offset crop removal, thus further depleting soil P reserves. As well, the logistics of seeding equipment sometimes means that the most logical way to place fertilizer sulphur (S) is together with fertilizer P in the seed-row.

The objective of this study was to evaluate the impact of rate and placement (seed-placed versus side-band) of fertilizer phosphate, either alone or in combination with fertilizer S, on canola P-uptake and yield across a range of soil and climatic conditions in Saskatchewan. The trial was designed as a two-factor factorial with treatments arranged in a four-replicate randomized complete block design. The first factor was five fertilizer P_2O_5 rates ranging from 0, 20, 40, 60, and 80 kg ha^{-1}. The second factor was placement which compared side-band, seed-placed, and seed-placed with fertilizer S. Small plot trials were established at Indian Head, Melfort, and Scott, Saskatchewan over a three-year period (2016-2018).

Results of this research illustrate that no rate of seed-placed P is really safe, as damage occurs even at very low rates. Although, if logistics dictate seed-placed P is required, the level of damage from low P rates, may be acceptable. However, predicting the degree of damage caused by seed-placed fertilizer is very difficult as it is influenced by other factors such as soil texture, soil organic matter, and moisture. Since these factors vary considerably across most fields, damage can be quite variable across the various landscape positions. Furthermore, even adding a small amount of ammonium sulphate to P in the seed-row can increase damage to seeds and reduce canola emergence. Therefore, this practice should be discouraged. Overall, we found no evidence of better responses associated with seed-placed P over side-band P, even at low rates, and that high rates of side-banded P are always equal to or greater than seed-placed.

Background/Introduction:

Approximately 81-82% of soil samples taken in Saskatchewan during 2010 and 2015, tested below critical levels required for optimal crop growth (International Plant Nutrition Institute [IPNI] 2015). In 2010, median soil test P levels for Saskatchewan were 14 ppm, compared to 21 in Alberta and 19 in Manitoba (IPNI 2015). In 2015, median soil test P levels in Saskatchewan and Alberta remained unchanged, while Manitoba dropped to 17 ppm (IPNI 2015). Historically, more P is removed by cropping than what was being replaced, because fertilizer P application was very limited prior to 1947 (Statistics Canada 1976; Saskatchewan Agriculture 1974). Since then, fertilizer P rates have increased, but even now they often fall short of replacing what is removed by crops. Based on phosphate fertilizer rates and P from manure applied in Saskatchewan, producers only replaced 73% of the P that was removed in the 2010 harvested crops (Canadian Fertilizer Institute 2010).

For each metric tonne of canola produced, the crop must take up 27 kg of phosphate (IPNI 2014). With each tonne of crop removed from the field, 16 kg of phosphate is removed in the seed (IPNI 2014). For example, a 35 bu ac^{-1} canola crop will take up 46 to 57 lb P_2O_5 ac^{-1} and remove 33 to 40 lb P_2O_5 ac^{-1} with the seed (Canadian Fertilizer Institute 1998). By comparison, wheat takes up 13 kg and removes 9.5 kg of phosphate per tonne of grain produced (IPNI 2014). Historically, canola yields rarely exceeded 1.5 t/ha (approximately 30 bu ac^{-1}), but with the development of high yielding hybrids, yields exceeding 3 t/ha are more consistently achieved (Canola Council of Canada [CCC] 2017; Canola Variety Performance Trials 2017).

Fertilizer phosphate is regularly used to augment soil available P to meet the needs of a canola crop. Canola is very responsive to fertilizer phosphate where the soil is P deficient; however, the Canola Council of Canada suggests that growers should only expect responses approximately 50% of the time (2017). Canola is effective at exploring and extracting both soil and fertilizer phosphate by acidifying the rhizosphere (Grant and Bailey 1993). Canola can do this by developing more root hairs when the crop is P deficient, and by growing more roots to where fertilizer P is located (CCC 2017). Canola seeds are small and contain only a limited reserve of P. Therefore, the crop needs early and consistent access to soil or fertilizer P in order to avoid yield limiting deficiencies.

Canola is often seeded early, into cool soils, where soil P is less readily available due to extremely low mobility and slow mineralization, under low temperatures. For these reasons, fertilizer P needs to be placed near the seed to ensure crop access shortly after emergence. Several studies indicate that seed-row placement of fertilizer P is the most efficient way to meet this requirement. However, when rates of phosphate exceed 28 kg ha^{-1}, excessive seed damage can occur (CCC 2017). This damage can negate the benefits of additional phosphate. Where soils are low or very low in available P, the recommended rate of fertilizer phosphate typically exceeds the 28 kg ha^{-1} safe rate.

Several studies have indicated that side-banded fertilizer P can be slightly less efficient than seed-placed when lower rates of phosphate are used (Lemke et al. 2009). However, side-banded fertilizer P can be more efficient towards yield enhancement when rates exceed the safe seed-placed rate (Slinkard and Henry 1977; Ukrainetz 1976). These studies found that when the rate of seed-placed phosphorus was increased, there was a sharp decline in subsequent canola plant densities. This resulted in a plant density reduction of 40 – 50% at the 20 kg ha^{-1} rate, and increased upwards of 70-80% when fertilizer P was increased to 60 kg ha^{-1}. In these studies, seed and fertilizer were placed in a very tight row, with a double disc opener. More recent research, with hoe-type openers, found the decline in plant densities to be less severe when seed-placed P rates increased. Multiple research studies by Grant (2012), Karamanos et al. (2014), and Mohr et al. (2013), found reductions of 10% or less with 20 kg ha^{-1} of P_2O_5 and 20-30% with 60 kg ha^{-1} of P_2O_5. Hoe-type openers, place seed and fertilizer in wider bands than double disc-type openers, which suggests damage from seed-placed P decreases when higher seed bed utilization is used. The benefit of using a wider band (higher seed bed utilization) from the more commonly used hoe-type openers can also be found with nitrogen fertilizer management (Saskatchewan Agriculture 2012).

Equipment limitations and the logistics of handling fertilizer in the spring sometimes mean that other fertilizers, such as ammonium sulphate, are applied in combination with P in the seed row. Recent work by Qian et al. (2002), indicated that there were detrimental additive effects to seed-placed phosphate with ammonium sulfate, when canola was grown under growth chamber conditions. Overall, there has been relatively little work done to establish safe rates of fertilizer applied in combination with each other using the hoe-type openers popular in today's agricultural practices.

Overall, with current canola hybrids readily yielding more than 3500 kg ha^{-1}, and two or more times the amount of P applied being removed with the crop, soil P reserves will slowly be depleted. Without strategies for higher and safer P replacement rates, soil P reserves will be further depleted and soil productivity will be reduced. Strategies that allow growers to economically apply as much or more P than is removed, are crucial for sustainable crop production throughout Saskatchewan.

Objectives:

This research will address the following questions:

1. Are current P fertilizer recommendations adequate for the high yielding cultivars currently used?
2. Does all fertilizer P need to be seed-placed, or can all or some be banded below and beside the seed?
3. Are the current recommendations regarding safe rates of P (with or without S) suitable for typical knife or hoe openers in use today?

Overall, the objective of this project is to provide the basis for updating the fertilizer P rate and placement recommendations for canola production in Saskatchewan.

Materials and Methods:

Small-plot research trials were conducted at three Saskatchewan locations varying in soil and climatic conditions. At Indian Head, Melfort, and Scott, trials were set up as a 5-by-3 factorial with 4 replicates in a randomized complete block design. The first factor was 5 rates of P_2O_5 applied using monoammonium phosphate (11-52-0 [MAP]). The second factor was placement method consisting of side-band (SB), seed-placed (SP), and seed-placed with fertilizer S as ammonium sulphate (21-0-0-24; 15AS). These two factors combined created 15 individual treatments (Table 1).

Table 1. Fertilizer P Rate and Placement Methods used to Evaluate Improved Phosphorus Management for Enhanced Canola Production at Indian Head, Melfort, and Scott SK., from 2016 to 2018.

Treatment Name	Phosphorus Rate (kg ha^{-1})	Fertilizer Placement
0P – SB	0 P_20_5	Side-band
20P – SB	20 P_20_5	Side-band
40P – SB	40 P_20_5	Side-band
60P – SB	60 P_20_5	Side-band
80P – SB	80 P_20_5	Side-band
0P – SP	0 P_20_5	Seed-placed
20P – SP	20 P_20_5	Seed-placed
40P – SP	40 P_20_5	Seed-placed
60P – SP	60 P_20_5	Seed-placed
80P – SP	80 P_20_5	Seed-placed
0P – SP+15AS	0 P_20_5	Seed-placed + 15 kg S/ha
20P – SP+15AS	20 P_20_5	Seed-placed + 15 kg S/ha
40P – SP+15AS	40 P_20_5	Seed-placed + 15 kg S/ha
60P – SP+15AS	60 P_20_5	Seed-placed + 15 kg S/ha
80P – SP+15AS	80 P_20_5	Seed-placed + 15 kg S/ha

At all nine site-years, plots were established on cereal stubble. Plot sizes varied depending on seeding equipment and row spacing, with a minimum 1.5m wide by 6m long plot used. At Indian Head and Melfort, rows were seeded 30 cm apart, while at Scott rows were 25 cm apart. Therefore, seedbed utilization was 8% and 10%, respectively. Seeding was completed in early to mid-May (Appendix A1). L140P (Liberty Link tolerant) canola was seeded at 120 seeds m^{-2} and adjusted for the seed weight and % germination of the seed lot at each location. Nitrogen, potassium, and additional sulphur fertilizers were applied, as required, based on soil test recommendations (Appendix A2). The total amount of nitrogen applied was balanced for the N supplied by other fertilizers. All pre-emergent herbicides, in-crop protection, and desiccant products were applied to ensure yield limiting factors were minimized (Appendix A3& A4). Harvest was completed during late August to early October with a plot combine, after all plots had reached maturity (Appendix A1).

Data collection consisted of plant density, biomass, phosphorus content, maturity, grain yield, green seed, and thousand kernel weight (TKW). Plant densities were assessed by counting all plants in a one-meter row at two locations per plot. This location was marked with pin flags so that plant densities could be measured at 2, 4, and 6 weeks after seeding. Plant densities were also measured after harvest near the original locations (due to logistics). Canola dry matter accumulation was assessed at GS50 (approximately 6 weeks after plant or when the green bud was first visible) by cutting and collecting the above ground biomass in a one-meter row at two locations per plot. Dry matter samples were weighed, ground, and analyzed by AgVise Laboratories to determine P uptake. The date when the entire plot reached 60% seed colour change was recorded to assess the number of days required to reach maturity (time of swathing). Yield was determined by cleaning, weighing the entire combined sample, and correcting for 10% moisture content. From the cleaned plot sample, a 100-seed sub-sample was crushed to determine the number of distinctly green seed. A further sub-sample was collected to determine the 1000 seed weight (TKW) of each plot.

Data was analyzed using "lme4" and "lmerTest" in R. Data was modelled using mixed-effects with phosphorus rate and fertilizer placement as fixed effects. Replicate within site-year (SY), phosphorus rate by site-year, fertilizer placement by site-year, and phosphorus rate and fertilizer placement by site-year were considered random effects. Regression analysis for both linear and quadratic forms were modeled. All results were considered significant at the $p<0.05$ level. There were significant fixed by random effect interactions for all measured variables. Therefore, all site-years were analyzed separately. However, where logical and statistically significant, site-years were combined for additional analysis.

Results and Discussion:

Residual Soil Nutrients

The site at Indian Head was located on the Thin Black soil zone, on a clay loam soil, with low to moderate soil organic matter, neutral pH, and low to moderate salinity (Table 2). The Melfort site was located in the Thick Black soil zone, on clay loam soil, with very high organic matter, slightly acidic, and non-saline. Scott is located in the Dark Brown soil zone, with the site located on a loam soil that was acidic, with low organic matter, and non-saline. Soil available P_2O_5 (P) levels were very low (0-10 ppm) Indian Head all three years and at Scott 2017, low (10-15 ppm) at Melfort 2016 and 2018, moderate (15-20 ppm) at Scott 2016 and 2018, and high (over 20 ppm) at Melfort 2017 (Table 2). Soil available nitrogen was low to very low (<40 lb/ac) at Indian Head all three years, Melfort 2018, and Scott 2017 and 2018, and moderate at Melfort 2016 and 2017 and Scott 2016 (Table 2). Potassium was high at all nine site-years (Table 2). Soil available sulphur was low to moderate at Indian Head 2016, Melfort 2016 and 2018, and all three years at Scott (Table 2). At Indian Head 2017 and 2018 along with Melfort 2017, soil available sulphur was high to very high. Overall, due to residual soil P levels, it is expected that there would be a significant response to phosphorus fertilizer at all Indian Head site-years and Scott 2017. There may be significant responses at Melfort 2016 and 2018 as well due to moderate soil P levels.

Table 2. Soil Characteristics at Indian Head, Melfort, and Scott, SK in 2016, 2017, and 2018.

	Indian Head (IH)			Melfort (ME)			Scott (SC)		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Soil Zone	Thin Black			Thick Black			Dark Brown		
Soil Texture	Clay Loam			Clay Loam			Loam		
Salinity	Non - Saline		Saline	Non-Saline			Non-Saline		
Soil pH (0-6")	7.9	8.0	7.2	6.2	6.1	6.2	5.2	5.6	5.8
Organic Matter (%) (0-6")	2.7	4.8	5.5	12.3	11.5	9.5	4.1	3.5	4.4
NO_3-N (lb/ac) (0-6")	10	11	7	39	35	21	17	9	9
NO_3-N (lb/ac) (6-24")	21	15	9	29	38	19	51	15	2
NO_3-N (lb/ac) (0-24")	31	26	16	68	73	40	68	24	11
P_2O_5 (ppm) (0-6")	6	7	9	11	43	12	18	9	18
K_2O (ppm) (0-6")	540+	701	719	357	796	598	312	380	332
SO_4-S (lb/ac) (0-6")	9	16	56	10	40	26	8	10	14
SO_4-S (lb/ac) (6-24")	28	60	360+	14	40	20	8	10	20
SO_4-S (lb/ac) (0-24")	37	76	416+	24	80	46	16	20	34

Weather

The long-term (1981-2010) average temperatures, over the growing season (May 1 to September 31) are similar at all three locations, with Indian Head being slightly warmer than Melfort and Scott (Table 3). Across all three locations May tended to be warmer than average. With warmer temperatures, the soil was also likely warmer, which could in turn make soil P more available. June tended to be warmer at Indian Head and Melfort. July through September were cooler on average at Indian Head, warmer at Melfort, while June through September were similar at Scott.

There was above average rainfall at all three locations in 2016, while both 2017 and 2018 received less than normal precipitation (Table 3). In Indian Head, there was 5% more precipitation in 2016, 54% less in 2017, and 33% less in 2018. The timely rains in June 2017 and sub-soil moisture from 2016 likely mitigated any drought-like symptoms in 2017. Once again, there were timely rains in June 2018, but the rest of the season received less than half of normal precipitation. Therefore, the late season drought is likely to have effect on 2018 canola yields. At Melfort, the 2016 growing season had 21% more precipitation on average, while there was 47% less precipitation than normal in 2017, and 10% less in 2018. The above average rainfall in 2016, along with timely rains in May and June 2017, mitigated any drought symptoms in 2017. The slightly less rain in 2018, was spread across the growing season, therefore it did not likely significantly impact yield. At Scott, there was 17% more precipitation in 2016, with 22% and 27% less precipitation in 2017 and 2018 than normal, respectively. Despite slightly less growing season precipitation overall, timely rains in May and August 2017 supported good plant stands and yields. Plant stands and yields may also be marked by the dry weather in May through August 2018, with the above average late-season precipitation delaying harvest and possibly having further negative effect on yield.

Table 3. Mean Temperature, Total Precipitation, and Long-Term Average (LT) at Indian Head (IH), Melfort (ME), and Scott (SC), SK During the 2016 through 2018 Growing Season (May 1 to September 31).

	May	June	July	August	September	Average/Total
			Mean Monthly Temperature (°C)			
IH 16	12.8	16.9	17.6	16.9	12.8	15.4
IH 17	11.6	15.5	18.4	16.7	11.3	14.7
IH 18	13.9	16.5	17.5	17.6	7.6	14.6
IH – LT[z]	***10.8***	***15.8***	***18.2***	***17.4***	***11.5***	***14.7***
ME 16	13.6	17.1	18.1	16.3	12.0	15.4
ME 17	10.8	15.2	18.7	17.2	12.5	14.9
ME 18	13.9	16.8	17.5	15.9	6.9	14.2
ME – LT[z]	***10.7***	***15.9***	***17.5***	***16.8***	***10.8***	***14.3***
SC 16	12.4	15.8	17.8	16.1	10.9	14.6
SC 17	11.5	15.1	18.3	16.6	11.5	14.6
SC 18	13.6	16.1	17.4	16.2	6.5	14.0
SC – LT[z]	***10.8***	***15.3***	***17.1***	***16.5***	***10.4***	***14.0***
			Total Monthly Precipitation (mm)			
IH 16	74.7	50.2	107.9	21.9	40.5	295.2
IH 17	10.4	65.6	15.4	25.2	12.4	129.0
IH 18	23.7	90.0	30.4	3.9	39.6	187.6
IH – LT[z]	***51.7***	***77.4***	***63.8***	***51.2***	***35.3***	***279.4***
ME 16	16.8	53.2	128.7	80.8	41.3	320.8
ME 17	46.4	44.1	33.3	3.1	13.2	140.1
ME 18	38.5	46.6	69.5	43.2	42.0	239.8
ME – LT[z]	***42.9***	***54.3***	***76.7***	***52.4***	***38.7***	***265.0***
SC 16	64.8	20.8	88.1	98.2	22.2	294.1
SC 17	69.0	34.3	22.4	53.0	18.9	197.6
SC 18	29.6	29.6	48.2	23.3	52.1	182.8
SC – LT[z]	***36.3***	***61.8***	***72.1***	***45.7***	***36.0***	***251.9***

[z] Long-Term Climate Normal from the closes Environment and Climate Change Canada Weather Station to location calculated from 1981-2010.

Plant Density

Two Weeks After Seeding

Two weeks after seeding, phosphorus rate had a significant effect on plant density at 8 of 9 site-years, while fertilizer placement only had a significant effect at Scott (Table 4). Furthermore, all three years at Scott and Melfort 2018, there was a significant two-way interaction. The two-way interaction was significant at p<0.1 at IH18, suggesting that there was some impact of placement and rate on plant density at this site-year as well. Overall, plant populations varied considerably across site-years. Initial plant populations were quite low at ME16 and Scott 2016 and 2018; while they were high at IH16 and Melfort and Scott 2017. To some extent, the lower density site-years also reflected the sites with limited seed-bed moisture at the time of seeding.

Table 4. Phosphorus Rate, Placement, and Interaction Effects on Plant Density (plants m^{-2}) Two Weeks After Seeding at Three Saskatchewan Locations, from 2016 to 2018.

	Indian Head[z]			**Melfort[z]**			**Scott[z]**		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Phosphorus Rate (R)	0.0013 **	<0.0001 ***	<0.0001 ***	0.2082	0.0163 *	0.0074 **	<0.0001 ***	0.0100 **	0.0148 *
Fertilizer Placement (P)	0.6880	0.3200	0.2507	0.6782	0.2930	0.1647	<0.0001 ***	<0.0001 ***	0.0263 *
R * P	0.1132	0.1547	0.0593	0.2880	0.2333	0.0463 *	0.0335 *	0.0010 **	<0.0001 ***

[z] p<0.05***; p<0.01**; p<0.0001***

At the four site-years where phosphorus rate was the only factor causing significant effects, plant density declined linearly (Figure 1). The plant populations at these locations decreased by a similar amount for each increase in fertilizer P; so that for every 10 kg P_2O_5 ha^{-1} increase, there was a loss of 2-3 plants m^{-2}. This translated to a 2% loss in plant population at IH16, 4-5% in ME17 and IH18, and 5-7% in IH17. Overall, plant density tended to decline with increasing phosphorus rate when averaged across the 9 site-years (Table B1).

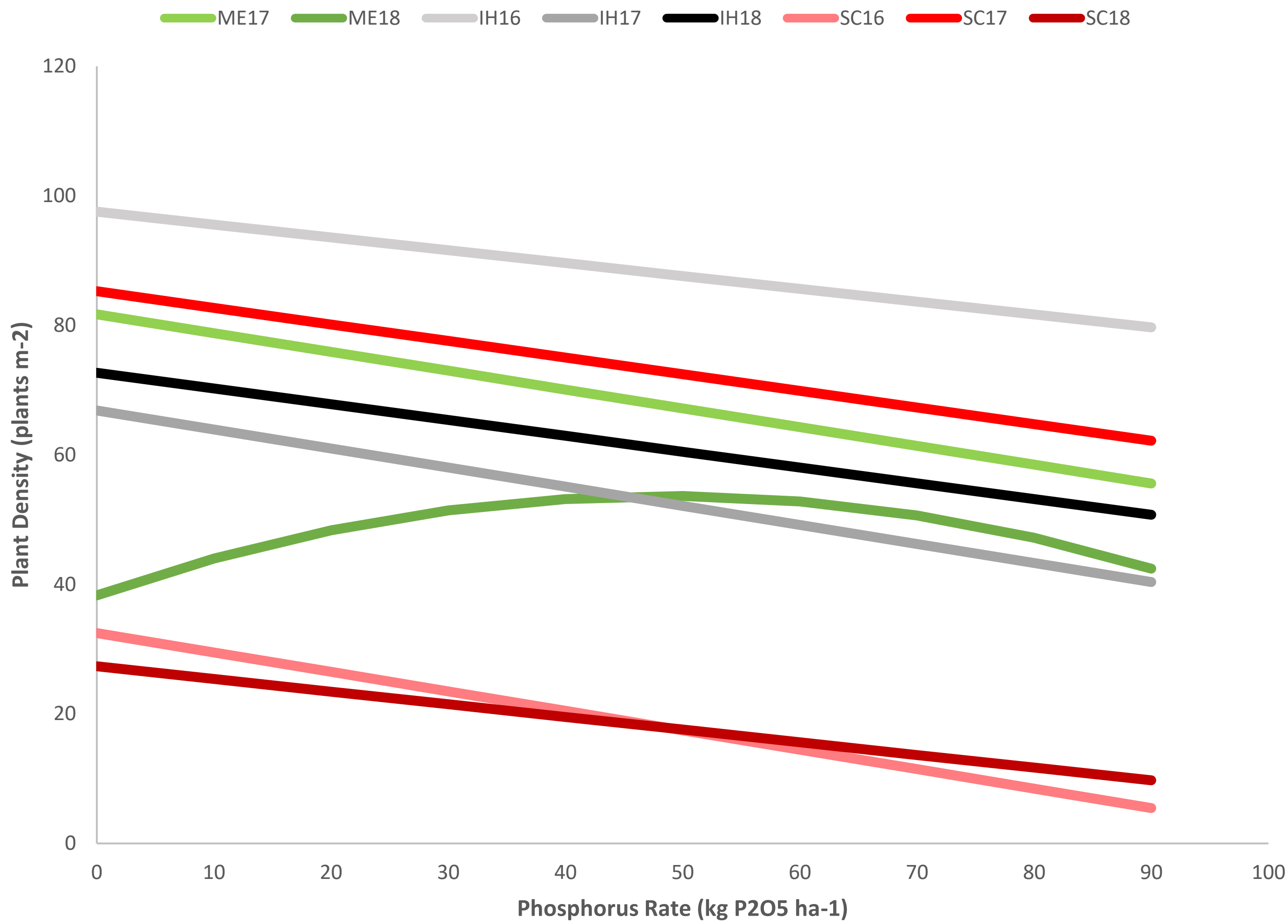

Figure 1. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Plant Density (plants m^{-2}) Two Weeks After Seeding at 8 of 9 Site-years.

Scott was the only location were fertilizer placement had a significant effect on initial plant density. All three years, there were significantly more plants per m^{-2} when fertilizer P was side-banded (Figure 2). The was also a significant difference between the plant densities of the two seed-placed treatments. By seed-placing P instead of side-banding, there was an overall 41% loss in 2016, 28% in 2017, and 27% in 2018. By adding 15AS to the seed-placed P, plant density declined a further 18% in 2017 and 34% in 2016 and 2018. Across all nine site-years, there was an average 15 to 20 more plants m^{-2} when P was side-banded, with only a 5 plants m^{-2} difference between the two seed-placed treatments (Table B1).

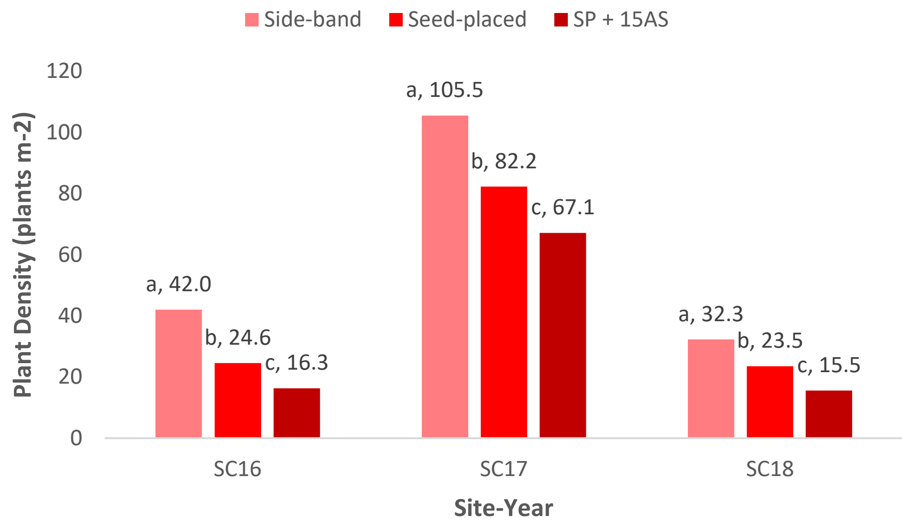

Figure 2. Phosphorus Placement Effect on Plant Density (plants m^{-2}) Two Weeks After Seeding at Scott from 2016 to 2018.

Two weeks after seeding at Melfort 2018, plant populations increased significantly when phosphorus was side-banded (Figure 3). Plant populations increased until 73 kg P_2O_5 ha^{-1} was applied, and then began to slowly decline. However, for every 1 kg P_2O_5 ha^{-1} there was a 2% increase in plant population up to 22 P_2O_5 ha^{-1} and then decreased to 1% as the P rate continued to increase. When the P was seed-placed, the effect of increasing P rate was similar to when it was side-banded. However, even with no applied P, the two seed-placed treatments had lower plant density. When seed-placed, plant density increased by approximately 3% until 11 P_2O_5 ha^{-1} was applied, then the rate of increase dropped to 2% until 59 kg P_2O_5 ha^{-1} was applied, then started to decline. When 15AS was added to the seed-placed P, the point at which plant density began to decrease was reduced to 38 kg P_2O_5 ha^{-1}.

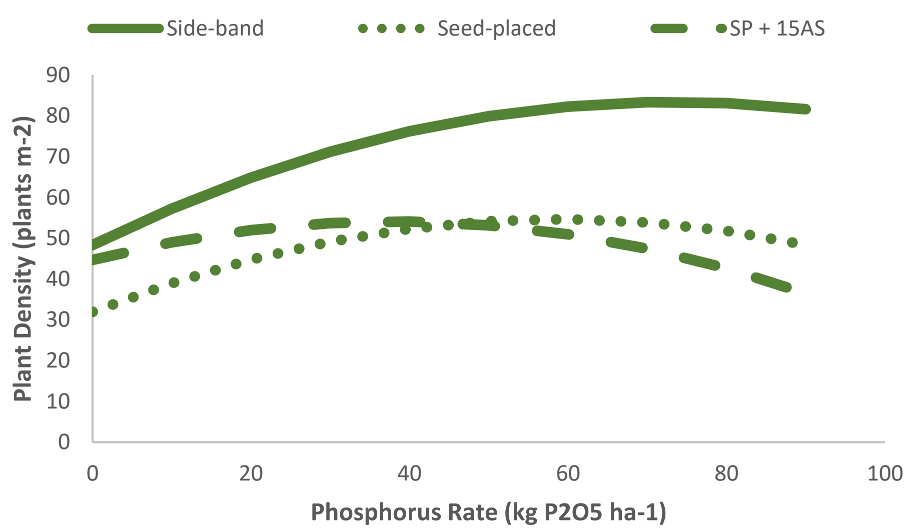

Figure 3. Phosphorus Rate and Placement Interaction Effect on Plant Density (plants m^{-2}) Two Weeks After Seeding at Melfort 2018.

Two weeks after seeding at Scott, plant populations decreased significantly when phosphorus was side-banded in 2016, were stable in 2017, and increased in 2018 (Figure 4). In 2016, there was an average 3% loss in plant density with every 10 kg P_2O_5 ha^{-1} side-band applied, while it increased by 4-5% in 2018. When phosphorus was seed-placed, there was a linear decline all three years. In 2016, the decline in plant populations ranged from 9 to 39%, as phosphorus rate increased. In 2017 and 2018, the decline was less severe at 5 to 8% and 7 to 16%, respectively. In 2017, when 15AS was added to the seed-placed P, plant density was relatively unaffected by the increasing P rate, but did decline slightly (1%). However, in 2016 and 2018, there was a linear decline across the entire range tested. In these years, the rate of decrease was similar to when P was seed-placed alone with loss rates of 9 to 30% and 7 to 18%, respectively. Overall, two weeks after seeding at Scott and averaged over placement, plant density decreased by 3 to 9% with every 10 kg ha^{-1} of P_2O_5 (Figure 1). Furthermore, averaged across P rate, plant densities were highest when side-banded, declined when seed-placed, and lowest when seed-placed with 15AS (Table B1).

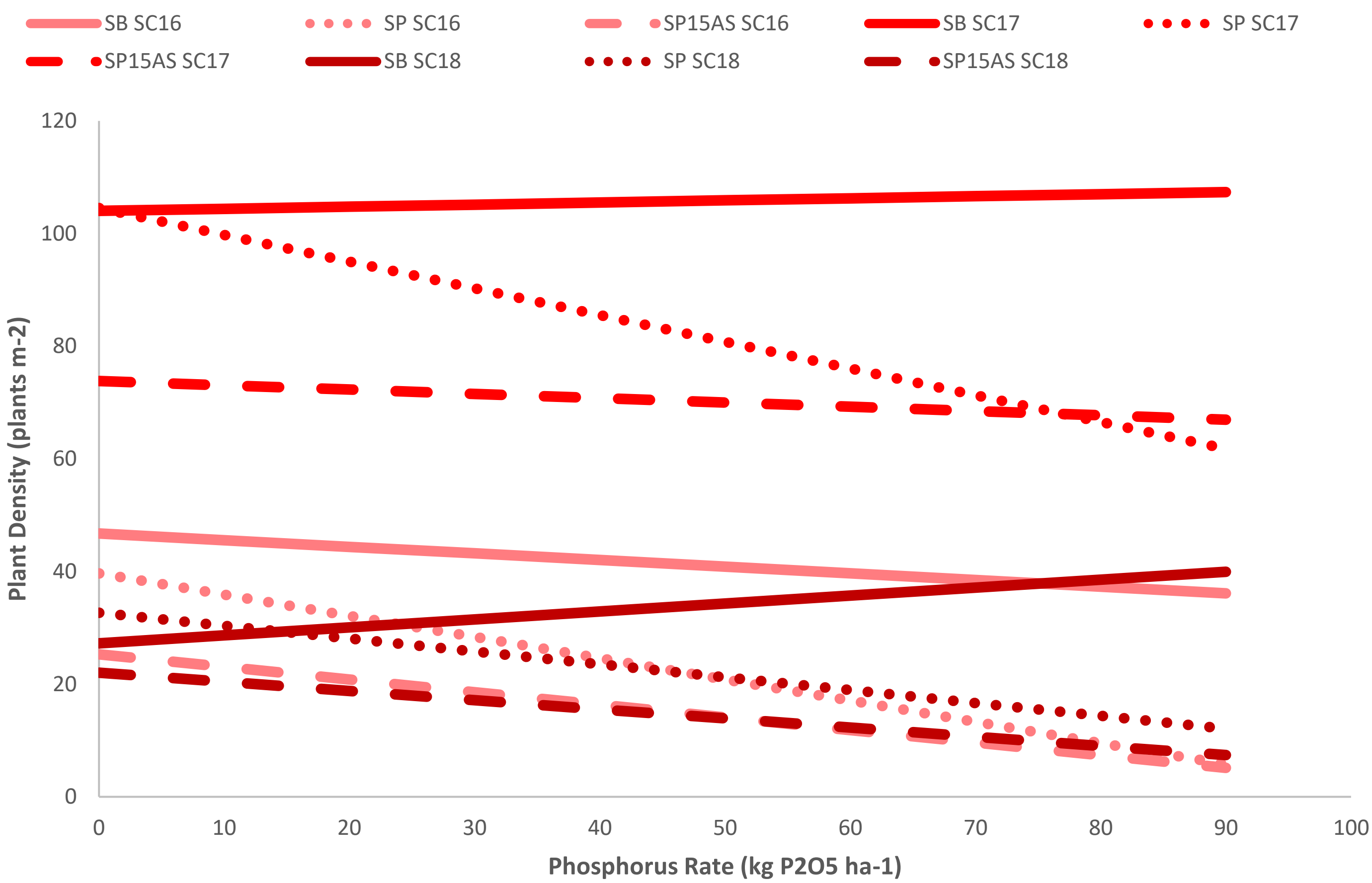

Figure 4. Phosphorus Rate and Placement Effect on Plant Density (plants m^{-2}) Two Weeks After Seeding at Scott from 2016 to 2018.

Data from Indian Head was combined over the three years and analyzed statistically. Both phosphorus rate and the two-way interaction had a significant effect on initial plant density. It was expected, that P rate would continue to be significant when combined over the three years. It was not expected that there would be a significant two-way interaction as it was only IH18 that was significant at the $P<0.1$ level. Averaged over the three years study period, canola plant stands were relatively unaffected by increasing P rate, when side-banded (Figure 5). Plant density did decline with this placement; however, it was by 1% across the rates tested. This contrary finding to the other sites may be due to the wet conditions in 2016, which could have resulted in less precise placement and subsequently less consistent separation between fertilizer and seed, resulting in slight seed damage. Similar effects occurred between the two seed-placed treatments. When seed-placed alone, plant density steadily declined by 3% across the range tested. By adding 15AS, there was an initial loss of 5 plants m^{-2} compared to the side-banded treatments, and density declined by 4% until 60 kg P_2O_5 ha^{-1} was applied, and then increased to 5%.

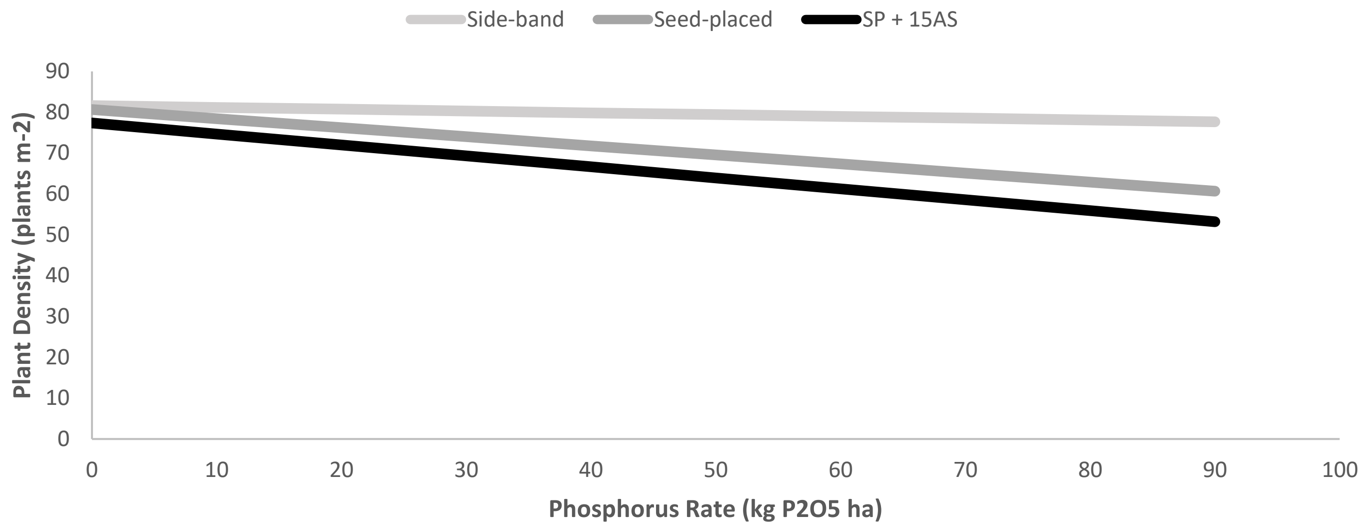

Figure 5. Phosphorus Rate and Placement Effect on Plant Density (plants m^{-2}) Two Weeks After Seeding at Indian Head Combined over 3 Years.

Four Weeks After Seeding

Four weeks after seeding, phosphorus rate had a significant effect on plant density at all 9 site-years (Table 5). Fertilizer placement only had a significant effect at SC17, but was also significant at the P<0.1 level at ME18 and SC18 as well. The two-way interaction was significant at the P<0.05 at 3 of 9 site-years and at the P<0.01 level at an additional 3 site-years. Generally, plant populations were similar or greater at four weeks after seeding compared to two weeks. A notable exception was Melfort 2018, where average plant density rose from 56 plants m^{-2} to 81. Furthermore, those sites which had lower plant densities at two-weeks continued to be lower at four weeks, while those that started with high densities continued to be high.

Table 5. Phosphorus Rate, Placement, and Interaction Effects on plant Density (plants m^{-2}) Four Weeks After Seeding at Three Saskatchewan Locations, from 2016 to 2018.

	Indian Head[z]			Melfort[z]			Scott[z]		
	2016	2017	2018	2016	2017	2018	2016	2017	2018
Phosphorus Rate (R)	0.0052 **	0.0048 **	0.0040 **	0.0034 **	0.0026 **	0.0092 **	<0.0001 ***	0.0404 *	0.0018 **
Fertilizer Placement (P)	0.2341	0.6804	0.4709	0.7414	0.9451	0.0501	0.1141	0.0030 **	0.0633
R * P	0.0684	0.3083	0.0302 *	0.1487	0.6968	0.0568	0.0049 **	0.0864	<0.0001 ***

[z] p<0.05***; p<0.01**; p<0.0001***

At the six site-years where phosphorus rate was the only factor causing significant effects, plant density declined linearly (Figure 6). At ME16, SC17, and all three years at Indian Head plant density declined by 2 to 8% with every 10 kg ha^{-1} increase in P_2O_5 (Figure 4). At ME17, plant density declined with increasing P rate up to 63 kg P_2O_5 ha^{-1} and then it began to recover, albeit still significantly lower than initial levels. At ME18, there was a steady 2% increase in plant population as the phosphorus rate increased. At SC16 and SC18, the decline in plant density was 7% at lower phosphorus rates, and increased to 15% at higher rates.Therefore, the slope of decrease is greater at these site-years compared to the other negative response sites. Overall, plant density tended to decline with increasing phosphorus rate when averaged across the 9 site-years (Table B2).

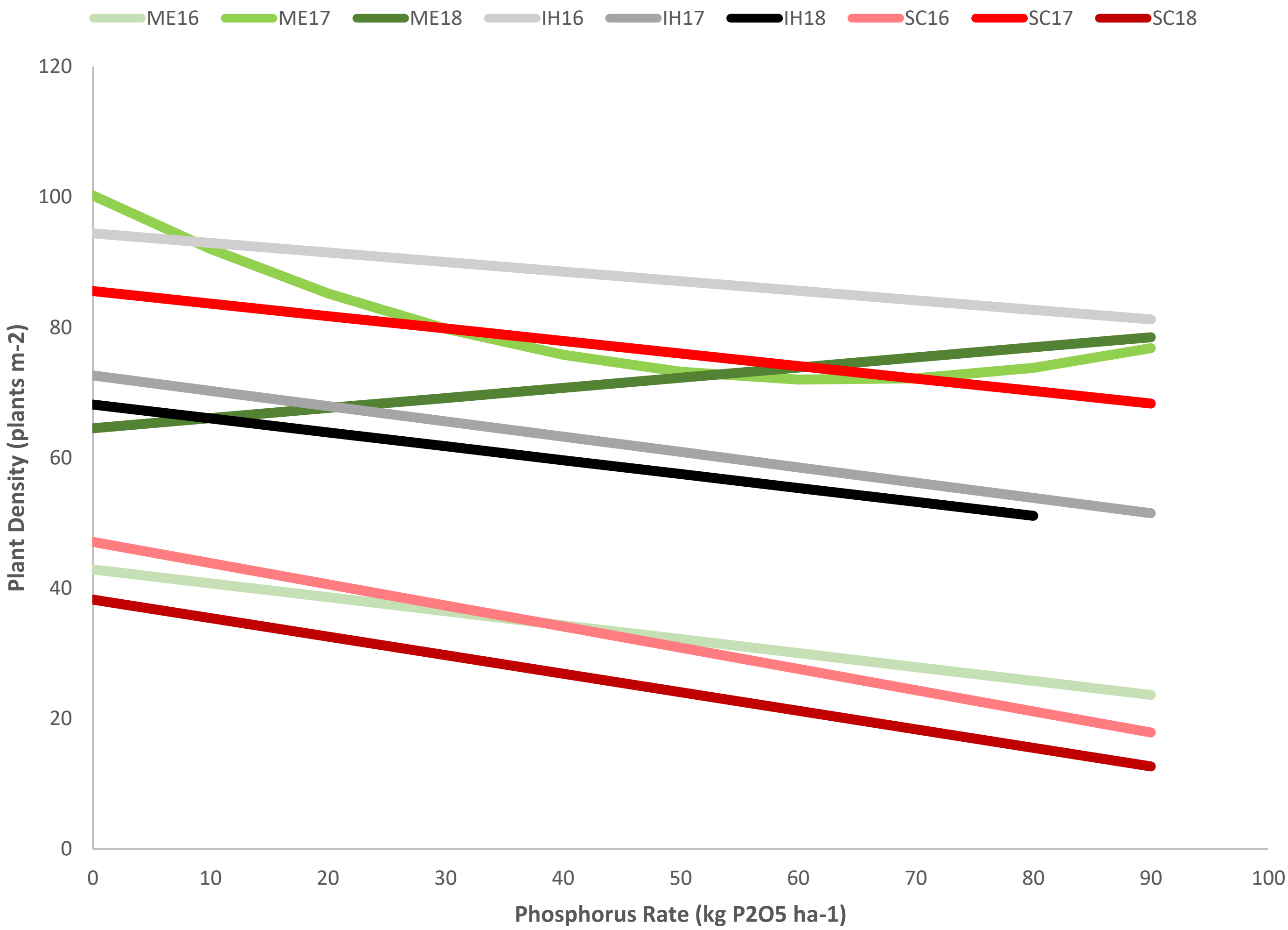

Figure 6. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Plant Density (plants m^{-2}) Four Weeks After Seeding at all 9 Site-years from 2016 to 2018.

Fertilizer placement only had a significant effect on plant density four weeks after seeding at SC17. Here, seed-placed P had on average 21 plants m^{-2} less than side-banded P (Figure 7). The addition of 15AS resulted in a further 7 plant m^{-2} loss compared to the seed-placed alone treatment. However, statistically these two seed-placed treatments were similar.

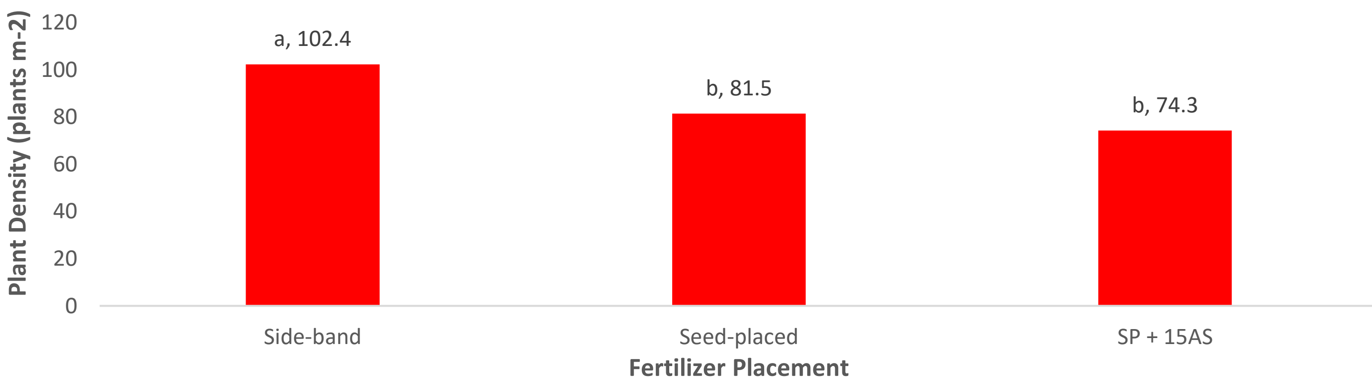

Figure 7. Phosphorus Placement Effect on Plant Density (plants m^{-2}) Four Weeks After Seeding at Scott 2017.

At the three site-years were there was a significant two-way interaction, side-banded P resulted in linear increases; while the two seed-placed treatments had linear decreases in plant population (Figure 8). At SC16, plant density was fairly similar across the range of side-banded P rates, with a slight increase. When fertilizer P was seed-placed at this location, as the rate increased, plant populations declined starting at 6% and increasing to 13%. When seed-placed with 15AS, results were only slightly different from P seed-placed alone, with the decline ranging from 7 to 19%. At SC18, plant density increased by 3% along the range of P rates tested, when side-banded. The seed-placed P resulted in a linear decline between 9 and 29% as the rate increased, while the addition of 15AS had a smaller negative effect at 6 to 10%. At IH18, side-banded P results were similar to SC16, where plant density was relatively stable over the range tested, yet slightly increased with increasing P rate. When P was seed-placed the rate of decline increased with phosphorus rate, going from 3 to 4%. When 15AS added to the seed-placed P, results were similar to P alone, however the increase in plant loss happened at a lower rate of P.

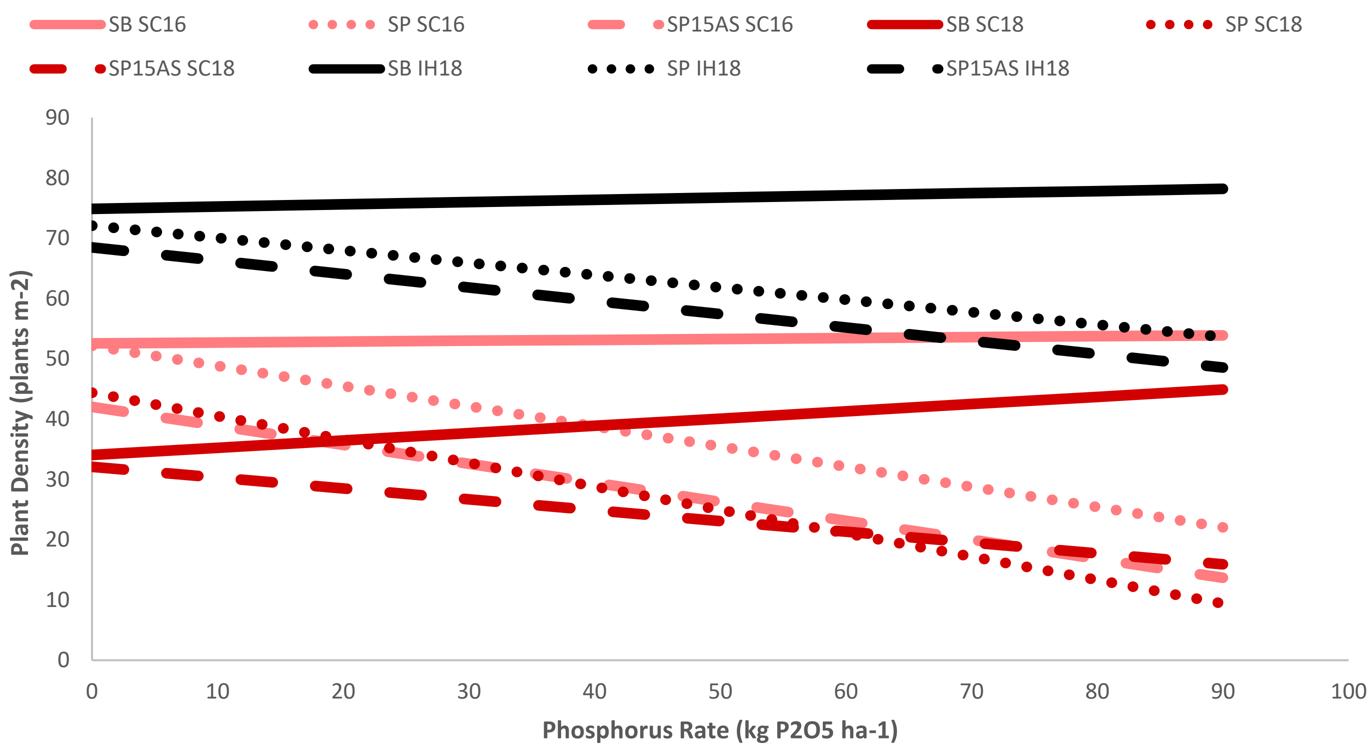

Figure 8. Phosphorus Rate and Placement Interaction Effect on Plant Density (plants m^{-2}) Four Weeks After Seeding at 3 site-years, from 2016 and 2018.

The three years at Indian Head were combined, as well as the three years at Scott for further statistical analysis. This allowed for average effects to be illustrated per location. At Indian Head, phosphorus rate and the two-way interaction were significant, while at Scott all three factors were significant. At Scott, plant density increased by 1% for every 10 kg ha^{-1} increase in side-banded P_2O_5 (Figure 9). With seed-row placement, plant density decreased by 6 to 10% as the P rate increased, resulting in a significant decline in density between the highest and lowest fertilizer P rates. When 15AS was added in Scott, the slope was less severe, as plant density only declined by 4% along the entire range of P rates tested. The result in Indian Head, was once again interesting as the interaction was only significant at one site-year, yet it was significant when years were combined. At this site, there was no change in plant density across the entire range of side-banded P. When fertilizer P was seed-placed, plant density declined by 2%, and when 15AS was added, the decline ranged from 3 to 4%.

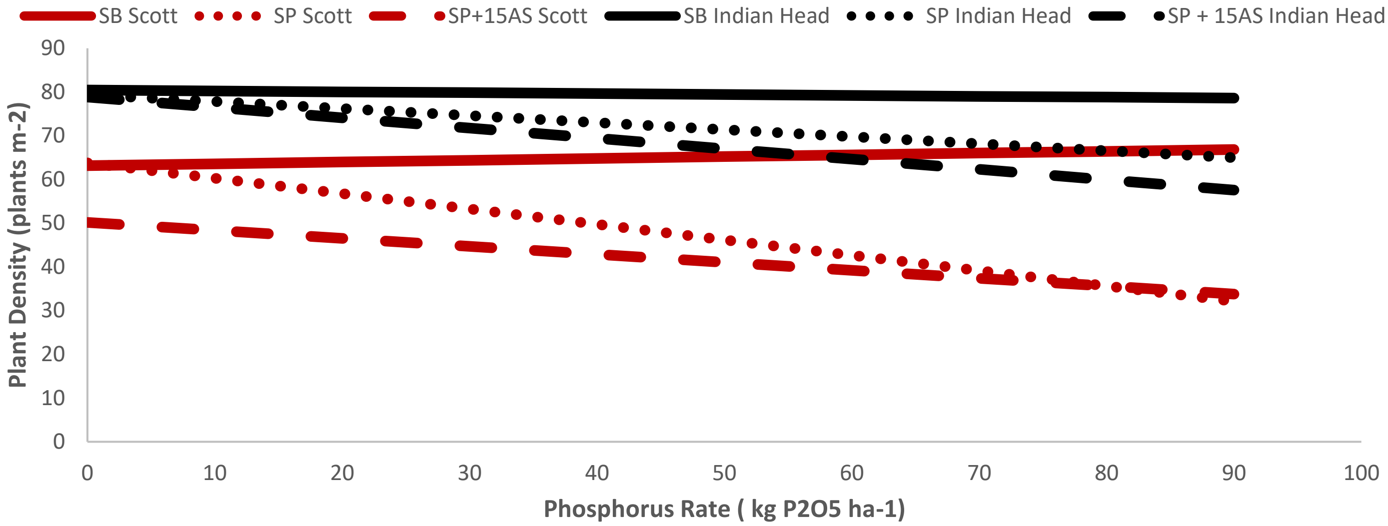

Figure 9. Phosphorus Rate and Placement Interaction Effect on Plant Density (plants m^{-2}) Four Weeks after Seeding at Scott and Indian Head, Combined over Three Years.

Six Weeks After Seeding

Six weeks after seeding, phosphorus rate had a significant effect on plant density at 5 of 9 site-years (Table 6). Placement had a significant effect at 3 site-years, and was also significant at P=0.1 level in SC17 as well. The two-way interaction was significant all three years at Scott and IH18. The interaction was almost significant at IH16, suggesting that there is a slightly influence of rate and placement at this site-year as well. Generally, plant densities were very similar between four and six weeks after seeding, except at ME17 and ME18. Plant densities decreased from 80 plants m^{-2} to 50 plants m^{-2}, on average (Table B3). This suggests that either there was a considerable increase in RR canola volunteers at 4 weeks that were eventually controlled by herbicide, or there was some insect damage occurring at these two site-years. Lastly, those sites that had initially low plant densities at two weeks continued to be lower at this time period as well, compared to the other locations. The same effect was found at the high plant density locations, which continued to be higher.

Table 6. Phosphorus rate, placement, and interaction effects on plant density (plants m^{-2}) six weeks after seeding at three Saskatchewan locations, from 2016 to 2018.

	Indian Head[z]			Melfort[z]			Scott[z]		
	2016	2017	2018	2016	2017	2018	2016	2017	2018
Phosphorus Rate (R)	<0.0001 ***	0.2251	0.0046 **	0.0113 *	0.9223	0.7642	<0.0001 ***	0.0364 *	0.1180
Fertilizer Placement (P)	0.2900	0.9214	0.3968	0.0239 *	0.2103	0.1224	0.0351 *	0.0859	0.0062 **
R * P	0.0657	0.3214	0.0372 *	0.9611	0.1788	0.3631	0.0062 **	0.0061 **	<0.0001 ***

[z] p<0.05***; p<0.01**; p<0.0001***

IH16, was the only site-year, where phosphorus rate was the only factor influencing plant density. Just as it was at 4 weeks after seeding, plant density continued to decline by 2% for every 10 kg ha^{-1} increase in P_2O_5 (Figure 10). ME16, IH18, and SC17 was also similar to the previous time period, as plant density continued to decline by 3-4% for every 10 kg ha^{-1} increase in fertilizer P. SC16 was also similar to the previous time period. However, plant density declined by 3%

between the first 10 kg ha^{-1} fertilizer P interval and by 15% between the last 10 kg ha^{-1}. This made the slope much greater than the other four site-years.

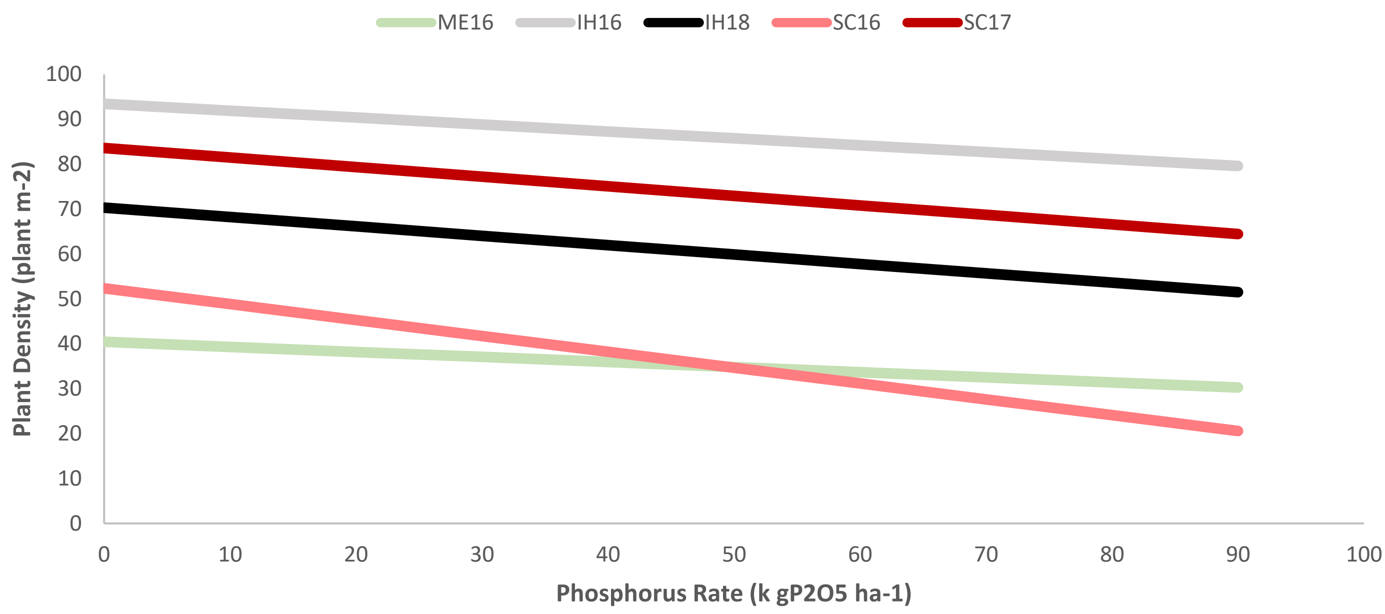

Figure 10. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Plant Density (plants m^{-2}) Six Weeks after Seeding at 5 Site-Years.

At ME16, side-banded P resulted in greater plant density than the two seed-placed treatments, which were similar to each other (Figure 11). In SC16, the side-banded P also had greater plant density than the two seed-placed treatments, with the addition of 15AS causing further losses in plant density. AT SC18, there was a significant difference between the side-band and SP+15AS treatments, while the density in the seed-placed alone treatments was similar to the two placements.

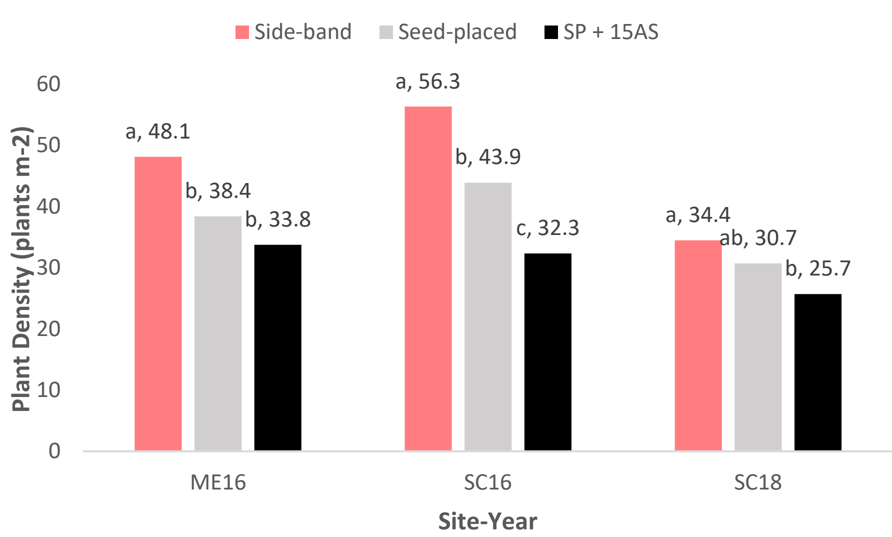

Figure 11. Phosphorus Placement Effect on Plant Density (plants m^{-2}) Six Weeks after Seeding at 3 Site-Years.

Six weeks after seeding, the effect of phosphorus rate on plant density was similar to four weeks after at Indian Head 2018. Plant density was unaffected by any phosphorus rate when it was side-banded (Figure 12). While there was a linear decline of 3% and 4% for every 10 kg P_2O_5 ha^{-1} increase when seed-placed and SP+15AS, respectively.

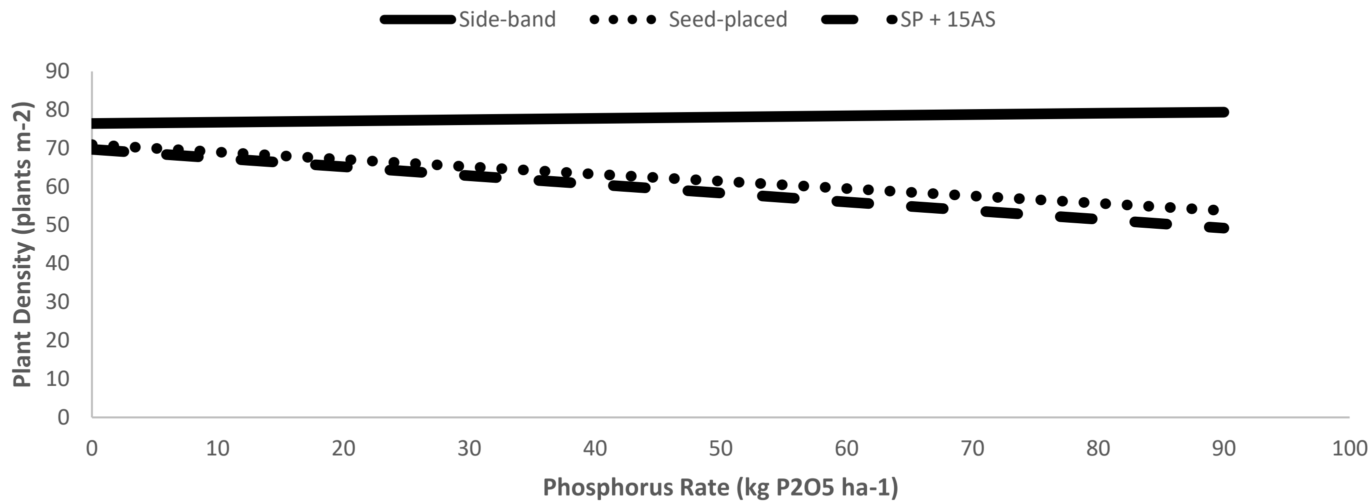

Figure 12. Phosphorus Placement Effect on Plant Density (plants m^{-2}) Six Weeks after Seeding at Indian Head 2018.

Although there was were significant differences in the overall plant densities each year at Scott, treatment effects were consistent. Plant density was either stable or increased, as the side-banded phosphorus rate increased (Figure 13). In 2017, the decline with seed-placed P was stable across the range tested, while in 2016 and 2018, the rate of loss increased as phosphorus rate increased. In 2017 and 2018, SP+15AS resulted in plant density to steadily decline across the rates tested, while in 2016 the rate of loss became greater as the fertilizer P rate increased.

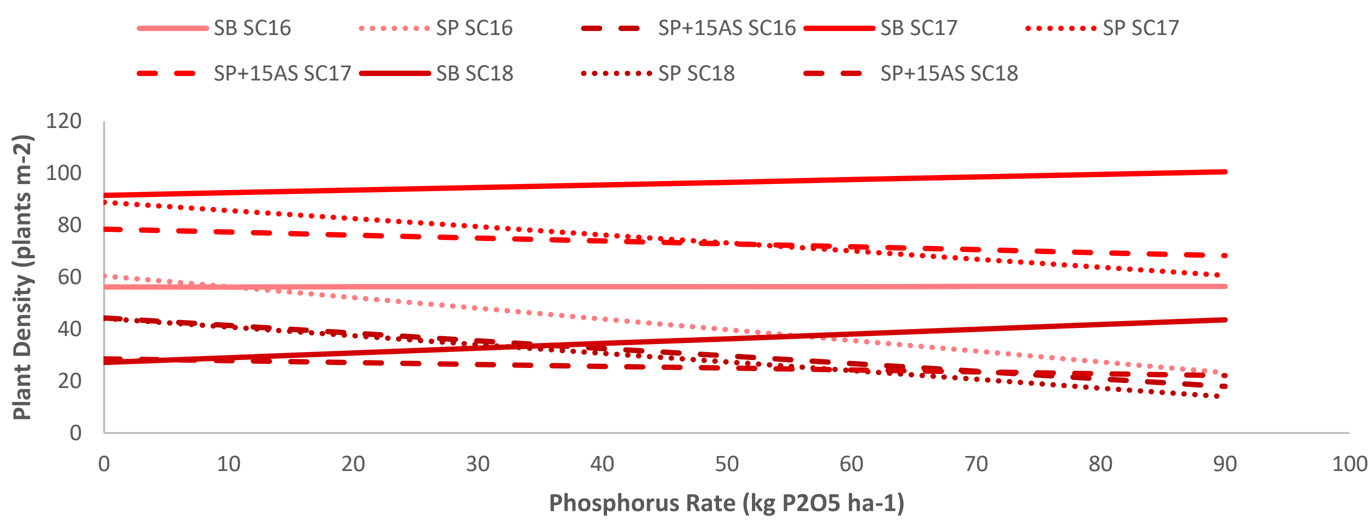

Figure 13. Phosphorus Placement Effect on Plant Density (plants m^{-2}) Six Weeks after Seeding at Scott, from 2016 to 2018.

The three-year dataset from each Melfort, Indian Head, and Scott were combined for further analysis. At Melfort, only placement had a significant effect on plant density six weeks after seeding. Averaged over the three years, the side-banded P had 20% more plants across seeding rates, then the two seed-place treatments (Figure 14). This suggests that side-banding fertilizer regardless of rate is beneficial in Melfort. It also suggests that adding 15AS does not provide an additive risk to canola establishment when paired in the seed-row with fertilizer P under the conditions encountered at Melfort.

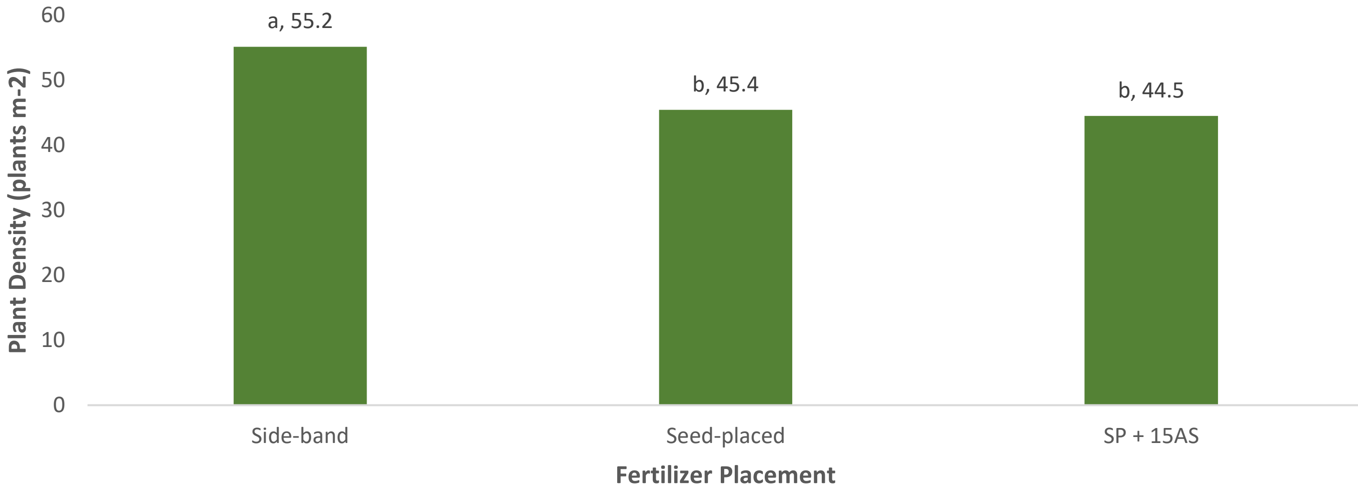

Figure 14. Phosphorus Placement Effect on Plant Density (plants m^{-2}) Six Weeks after Seeding at Melfort Combined over Three Years.

At Indian Head, phosphorus rate and two-way interaction had a significant effect on canola density six weeks after seeding. Plant density was not significantly impacted by increasing phosphorus rate when it was side-banded (Figure 15). Initially the two seed-placed treatments had similar plant densities (up to 30 kg P_2O_5 ha^{-1}). After this rate, the addition of 15AS double the rate of decline (2 to 4%). Overall, regardless of the rate applied or placement method, the average plant density in Indian Head was sufficient for supporting high canola yields. However, the SP+15AS treatments at the high rates were close to being yield limiting.

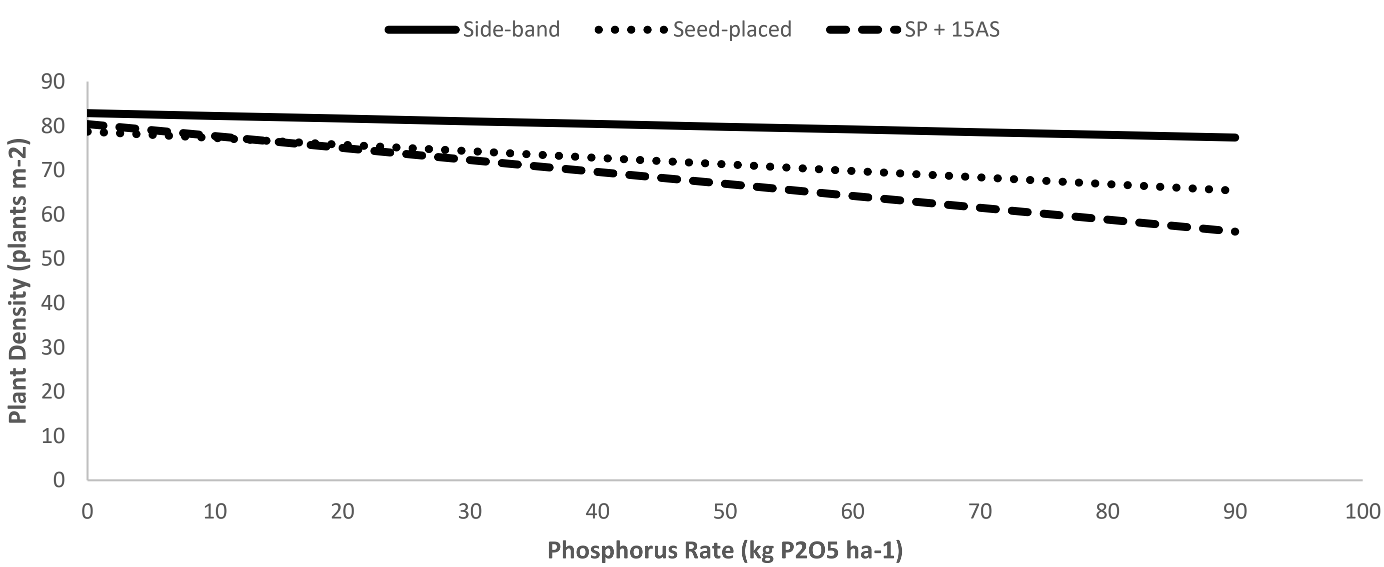

Figure 15. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Plant Density (plants m^{-2}) Six Weeks after Seeding at Indian Head Combined over Three Years.

When the three-year dataset was combined at Scott, side-banded fertilizer P resulted in a significant increase in plant density throughout the range of rates tested (Figure 16). On average, seed-placed P had higher initial plant density than the other two treatments. This was offset by the linear decline as the phosphorus rate increased. With SP+15AS, the decline in plant density was less severe than seed-placed alone. This suggests that the 15AS was beneficial for plant establishment and not harmful. However, all rates were lower than 50 plants m^{-2}, which is the threshold before density becomes yield limiting in canola product. Whereas when seed-placed alone, up to 30 kg P_2O_5 ha^{-1} could be applied before this threshold was breached.

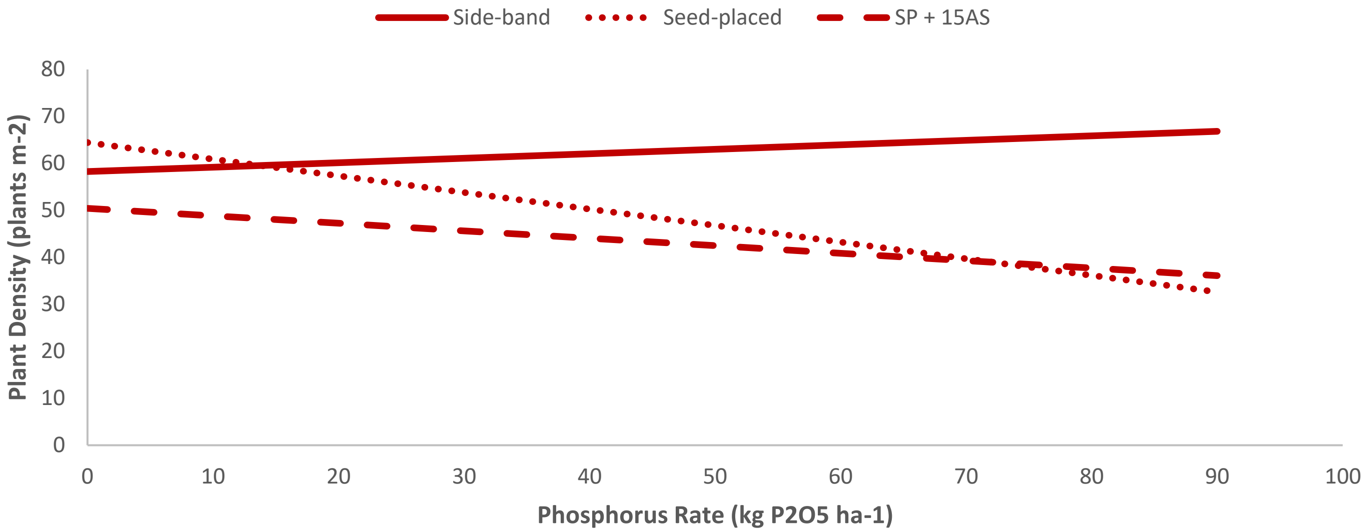

Figure 16. Phosphorus Rate and Placement Effect on Plant Density (plants m^{-2}) Six Weeks after Seeding at Scott Combined over Three Years.

POST Harvest

After harvest, canola stems were counted near the previous locations. Phosphorus rate had a significant effect at 5 of 9 site-years, while it was almost significant at an additional 2 site-years (Table 7). Fertilizer placement was significant at 2 of 3 years at Scott. Lastly, the two-way interaction was only significant at 4 of 9 site-years. Overall, the plant density values after harvest were similar to those at 6 six weeks after seeding. This suggests that there was no substantial self-thinning to due excessive growth, increase in the number of volunteer plants, and/or further insect damage. Furthermore, the site-years at Melfort and Scott in 2016 and 2018 were very low. Average densities were under the 50 plants m^{-2} threshold set by the CCC, in which anything below this rate is likely to be a yield limiting factor (Table B4).

Table 7. Phosphorus Rate, Placement, and Interaction Effects on Plant Density (plants m^{-2}) After Harvest, at three Saskatchewan locations from 2016 to 2018.

	Indian Head[z]			Melfort[z]			Scott[z]		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Phosphorus Rate (R)	0.1213	<0.0001 ***	0.1426	0.0997	0.0268 *	<0.0001 ***	0.0011 **	0.0698	0.0341 *
Fertilizer Placement (P)	0.7287	0.4232	0.9034	0.3091	0.2774	0.7799	0.0019 **	0.0148 *	0.0655
R * P	0.5617	0.0147 *	0.0048 **	0.6494	0.3763	0.5087	<0.0001 ***	0.0970	0.0128 *

[z] p<0.05***; p<0.01**; p<0.0001***

At ME17, plant density continued to slowly decline with increasing phosphorus rate, as illustrated at 6 weeks after seeding (Figure 17). The result at ME18, was more similar to 4 weeks after seeding, except for this time there was quadratic response, not linear. Here plant density increased until 68 kg P_2O_5 ha^{-1} was applied, and then it began to decline. Results at IH17 and SC16 were very similar to each other with a 4 to 6% decrease in plant density as phosphorus rate increased. SC18 was similar to SC16, in that initially the rate of decline was similar but, it was less severe as fertilizer P rate increased.

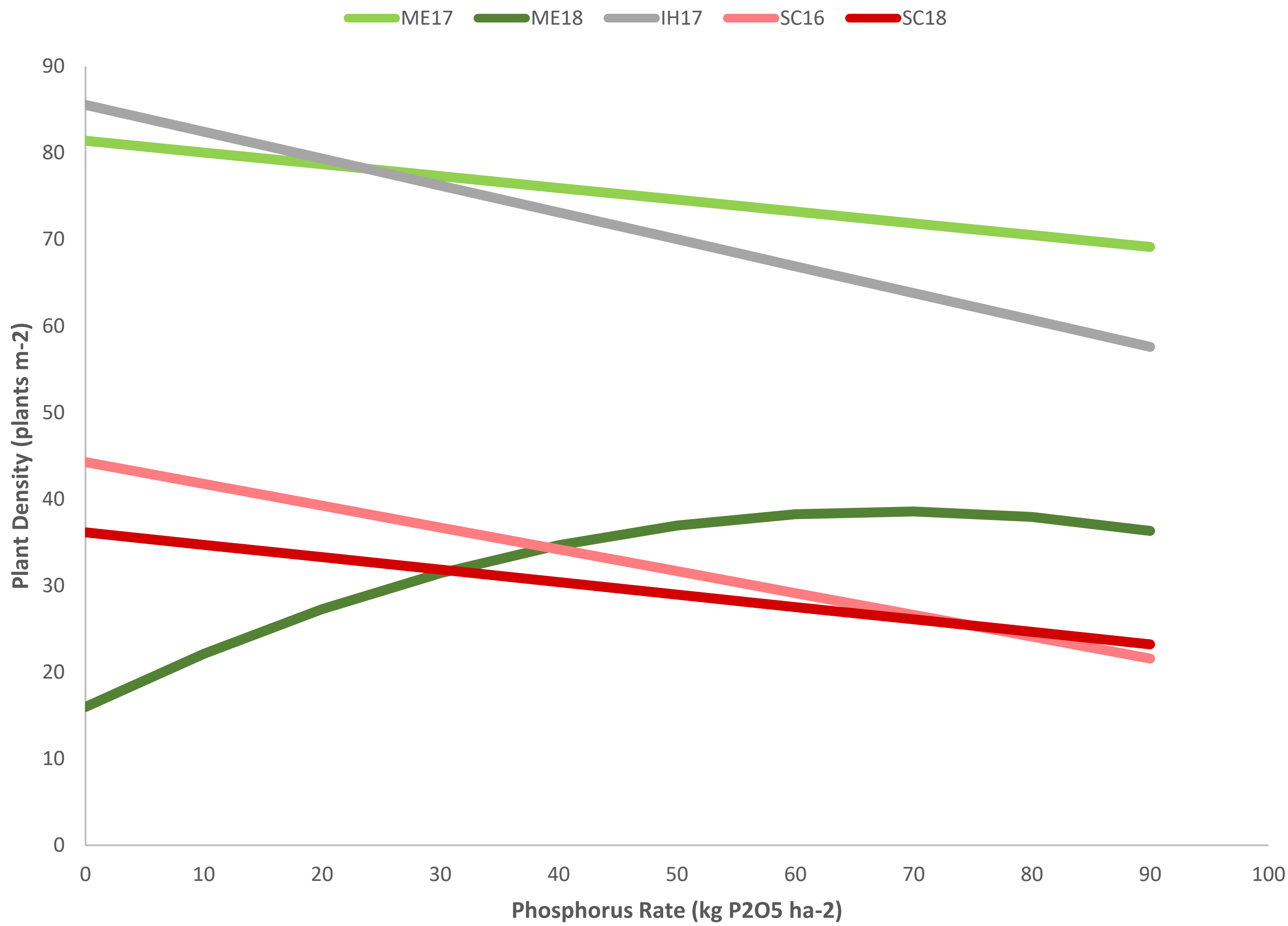

Figure 17. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Plant Density (plants m^{-2}) After Harvest at 4 of 9 Site-years.

At Scott 2016 and 2017, phosphorus placement continued to have an effect on plant density when sampled after harvest. In 2016, when the overall density was lower, there was a significant difference between the three placements (Figure 18). In 2017, when plant densities were much higher, the two seed-placed treatments were significantly lower than the side-banded treatment but were similar to each other. Therefore, in 2016 regardless of placement method, plant density likely had an overall effect on canola yield. Whereas in 2017, plant populations with any phosphorus placement method on average would have supported high yields.

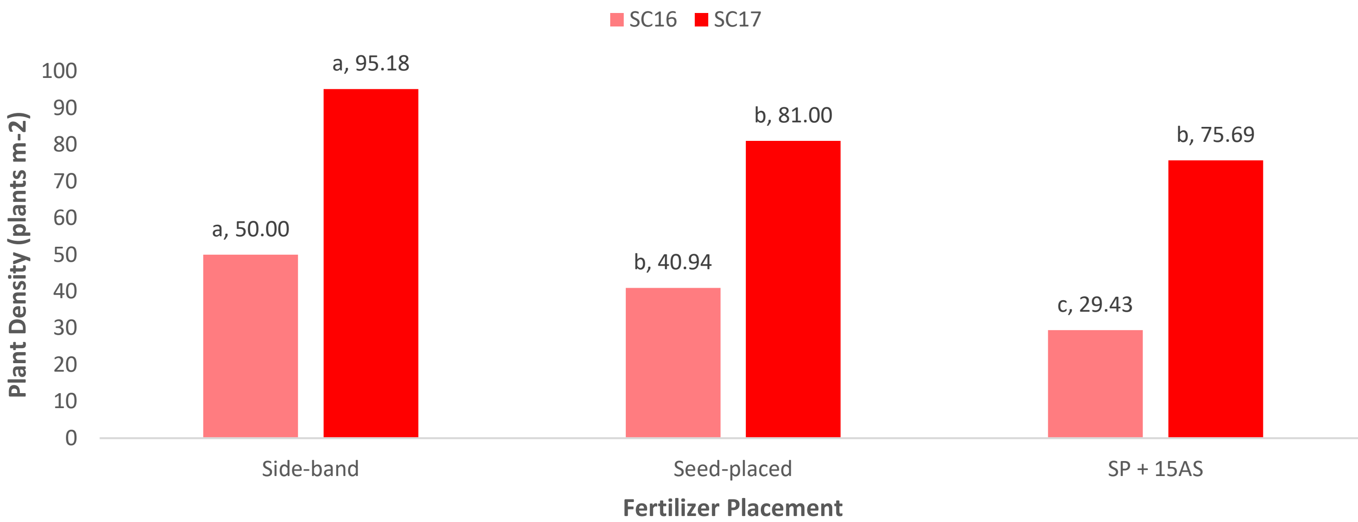

Figure 18. Phosphorus Placement Effect on Plant Density (plants m^{-2}) After Harvest at Scott 2016 and 2017.

Despite climatic and soil zone differences between Indian Head and Scott and years, when the interaction between phosphorus rate and placement was significant, there were some similar trends (Figure 19). Generally, side-banded fertilizer phosphorus had similar or increasing plant density as the fertilizer rate increased. The rate of increase at both locations was greater than 2018 than 2016 or 2017. When the fertilizer was seed-placed, with and without 15AS, there was a linear decline in plant density as the phosphorus rate increased. Generally, Indian Head had greater density than Scott, and the rate of change with increasing phosphorus rate was dependent on the year and location.

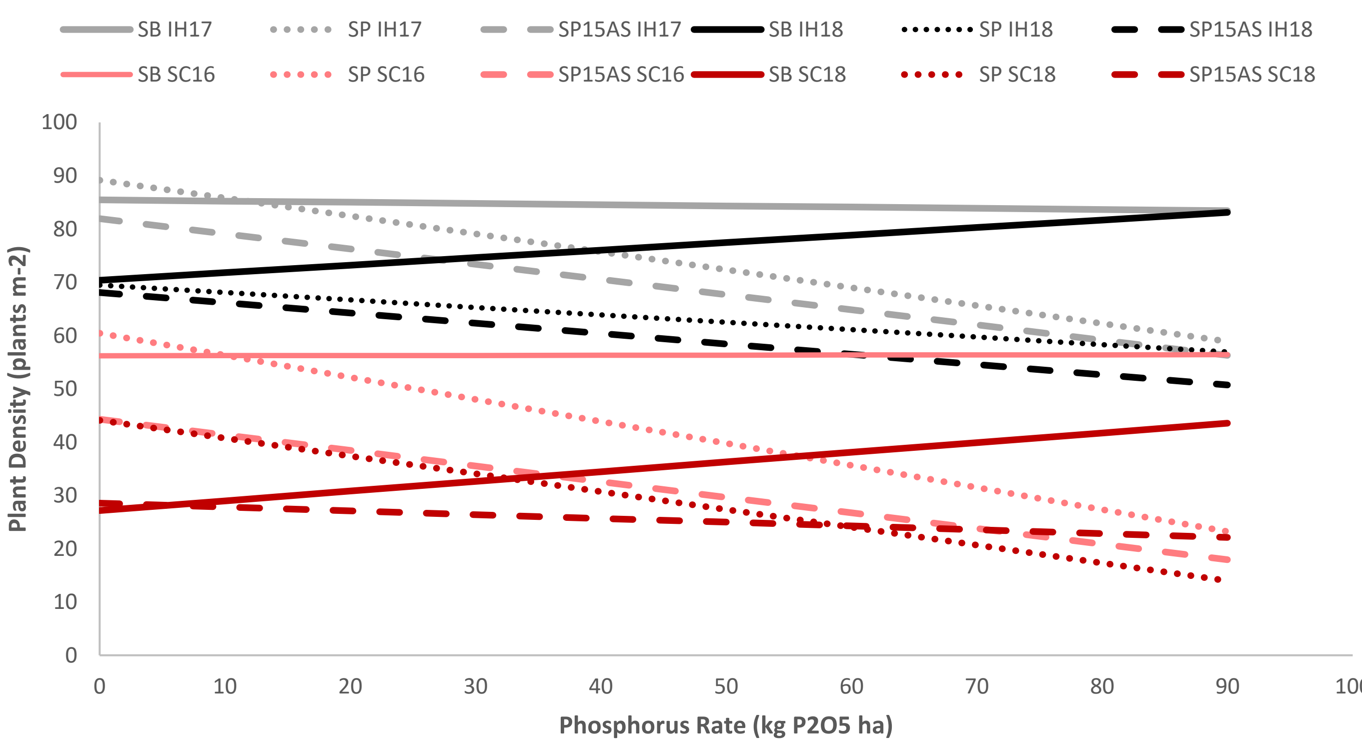

Figure 19. Phosphorus Rate and Placement Effect on Plant Density (plants m^{-2}) After Harvest at IH17 & 18 and SC16 & 18.

The three-year dataset from Scott was combined for further analysis. Averaged across years, phosphorus rate, fertilizer placement, and their interaction were all statistically significant. In Scott, increasing the rate of side-banded phosphorus increased plant density along the entire range tested. This illustrates that at Scott, any rate of phosphorus applied, as long as it is placed in a side-band, was beneficial for canola establishment and can help to build up soil P reserves. Conversely, when fertilizer P is seed-placed at this location, there are severe negative effects on plant populations as the rate increased. Initially, plant density losses were at 4% for every 10 kg P_2O_5 ha^{-1}, increasing to 6% after 60 kg ha^{-1} was applied. Therefore, rates above 20 kg P_2O_5 ha^{-1} of seed-placed P at Scott appear to negatively impact plant establishment with the effect becoming more severe at higher rates. The 2 to 3% loss in plant populations for every 10 kg ha^{-1} increase in fertilizer P, when applied with 15AS, suggests that sulphur had a beneficial effect. Although there was an initial deficit in plant populations by adding 15AS, the rate of loss was less than with seed-placed P alone. Therefore, adding sulphur fertilizer to the seed-row does not appear to have an additional negative effect and actually may be helpful, if sites are low and/or responsive to sulphur. Lastly, plant population trends after harvest were similar to those that already appeared four weeks after seeding.

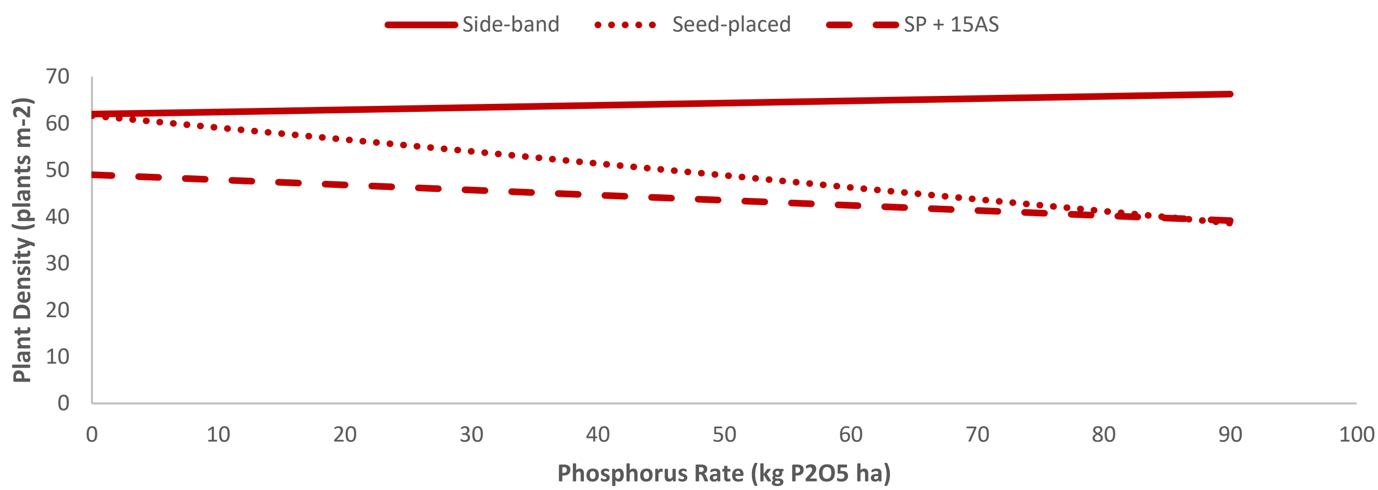

Figure 20. Phosphorus Rate and Placement Effect on Plant Density (plants m^{-2}) After Harvest at IH17 & 18 and SC16 & 18.

Generally, damage from seed-placed fertilizer is typically higher on coarse textured than fine textures soils, on soils with low vs. high soil organic matter, and where soil moisture in the seed-bed is limited (Sask. Ministry of Agriculture 2012). Therefore, it was not unexpected that rate, placement, and interaction effects were most commonly noted at the Scott site, since it is on a loam soil with limited organic matter. At Scott, phosphorus rate of side-banded P had minimal, if any, impact on plant density when averaged across plant density measurement times (Table B1- B4). When seed-placed, plant density declined as P rate increased by approximately 5% for each 10 kg ha^{-1} of additional P. The addition of 15AS without any phosphorus, resulted in an initial reduction of plant density by 23% compared to the 0 P side-band and seed-placed treatments. Thereafter, plant density declined as P rate increased by approximately 5% for each 10 kg ha^{-1} of additional P. In comparison, when averaged over plant density measurement times at Indian Head, seed-placed fertilizer had little effect on plant density. In 2016 at Indian head, soil organic matter was very low (2.7%), but there was 75mm of rainfall during May. This suggests that when damage from SP fertilizer would be high due to low soil organic matter, ample rainfall can mitigate any negative effects even at lower P rates. However, as one can not predict the amount of rainfall during early parts of the growing season, SP fertilizer at low organic matter sites should be very limited or not practiced. By contrast, at Indian Head 2017, where there was slightly more organic matter (4.8%) and low rainfall in May, the damage from seed-placed P and P+15AS increased with increasing P rate. This suggests that under very dry conditions, seed damage can also be extensive even on higher organic matter, where damage is normally lower. Overall, these results demonstrate the high degree of risk associated with seed-placed fertilizer when soil and climatic conditions are conducive to high levels of fertilizer damage. They also demonstrate the high level of crop safety associated with side-band placement of fertilizer when it is banded away from the seed.

Biomass Yield and Tissue Phosphorus Levels

Phosphorus rate had a significant effect on canola biomass yield at 5 of 9 site-years, which occurred in 2016 and 2018 (Table 8). Placement was significant at SC16 and the two-way interaction was significant at SC16 and SC18. At IH16 & 17, biomass yield was significantly higher than at the other 7 site-years (Table B5). This difference is largely due to the rapid growth that occurs at GS50; which if sampling is delayed, can have a significant impact. Regardless, treatments effects are expected to remain proportional.

Table 8. Phosphorus Rate, placement, and Interaction Effects on Canola Biomass Yield (g m^{-2}) at Three Saskatchewan Locations, from 2016 to 2018.

	Indian Head[z]			Melfort[z]			Scott[z]		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Phosphorus Rate (R)	0.0012 **	0.2568	0.0428 *	<0.0001 ***	0.3157	<0.0001 ***	0.0640	0.7266	<0.0001 ***
Fertilizer Placement (P)	0.0998	0.0708	0.9127	0.5262	0.9680	0.7799	0.0404 *	0.8912	0.0701
R * P	0.6691	0.1889	0.3561	0.1473	0.9121	0.5087	0.0015 **	0.1451	0.0027 **

[z] p<0.05***; p<0.01**; p<0.0001***

At ME16, ME18, and IH16, there was a significant increase in biomass with phosphorus application (Figure 21). At ME16, biomass increased until 55 kg P_2O_5 ha^{-1}, in ME18 the rate was 68 kg P_2O_5 ha^{-1}, and at IH16 57 kg P_2O_5 ha^{-1}. Conversely, at IH18 and SC18, biomass significantly declined with increasing phosphorus application. At IH18 the decline was linear across all rates applied, while at SC18 the significant decline began at 34 kg P_2O_5 ha^{-1}.

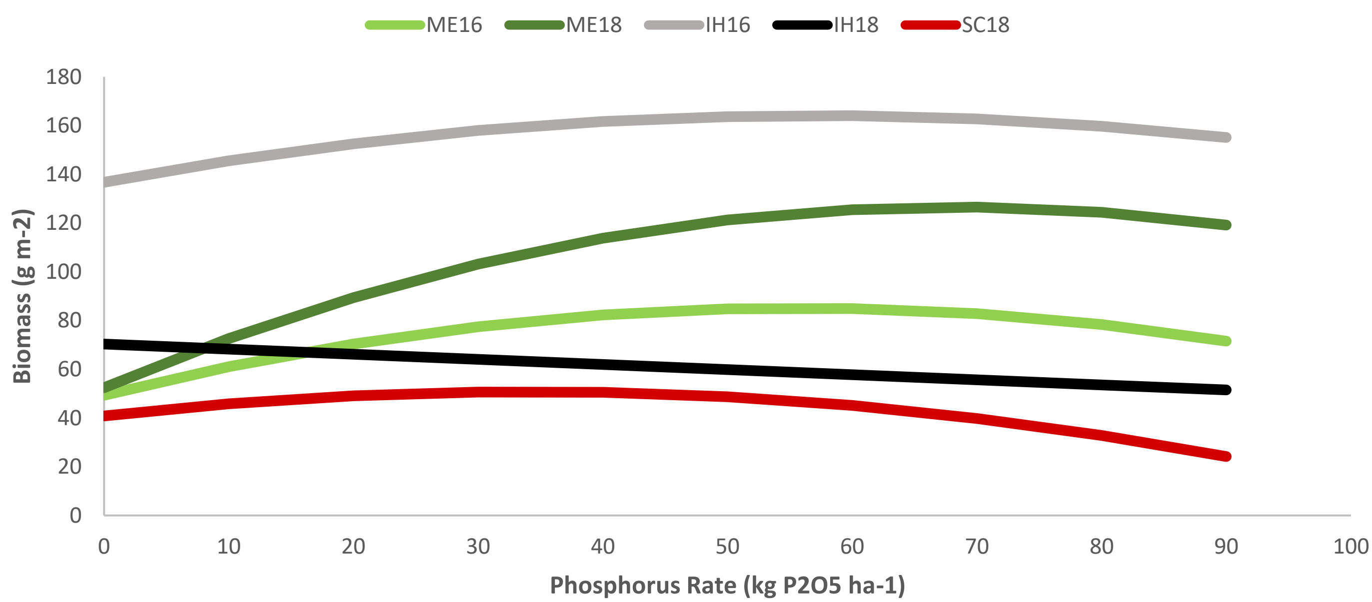

Figure 21. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Canola Biomass (g m^{-2}) at two Melfort Site-years, two Indian Head Site-years, and one Scott Site-year.

At Scott, the side-banded treatments both years had more biomass than the seed-placed and seed-placed + 15AS (Figure 22). Initially, the seed-placed treatments had similar rates to the side-band treatments, but as the P rate increased, the biomass produced became similar to the rates with additional AS in 2016 and intermediate in 2018. Despite negative effects on plant density, biomass yield often increases due decreased plant competition. However, when plant density is not significantly impacted, biomass increases with increasing P until the amount applied exceeds crop needs or other competition effects take hold (ie. Self thinning, light competition, etc.). This effect can be noted with side-banded treatments. Conversely, when seed-placed, biomass increased with increasing P at low rates because increased crop growth offset the loss in plant density. However, at high rates, the loss of plants was too high to offset the effect and biomass declined. With SP+15AS, the detrimental effect on plant density was too great for any increases in biomass yield to offset.

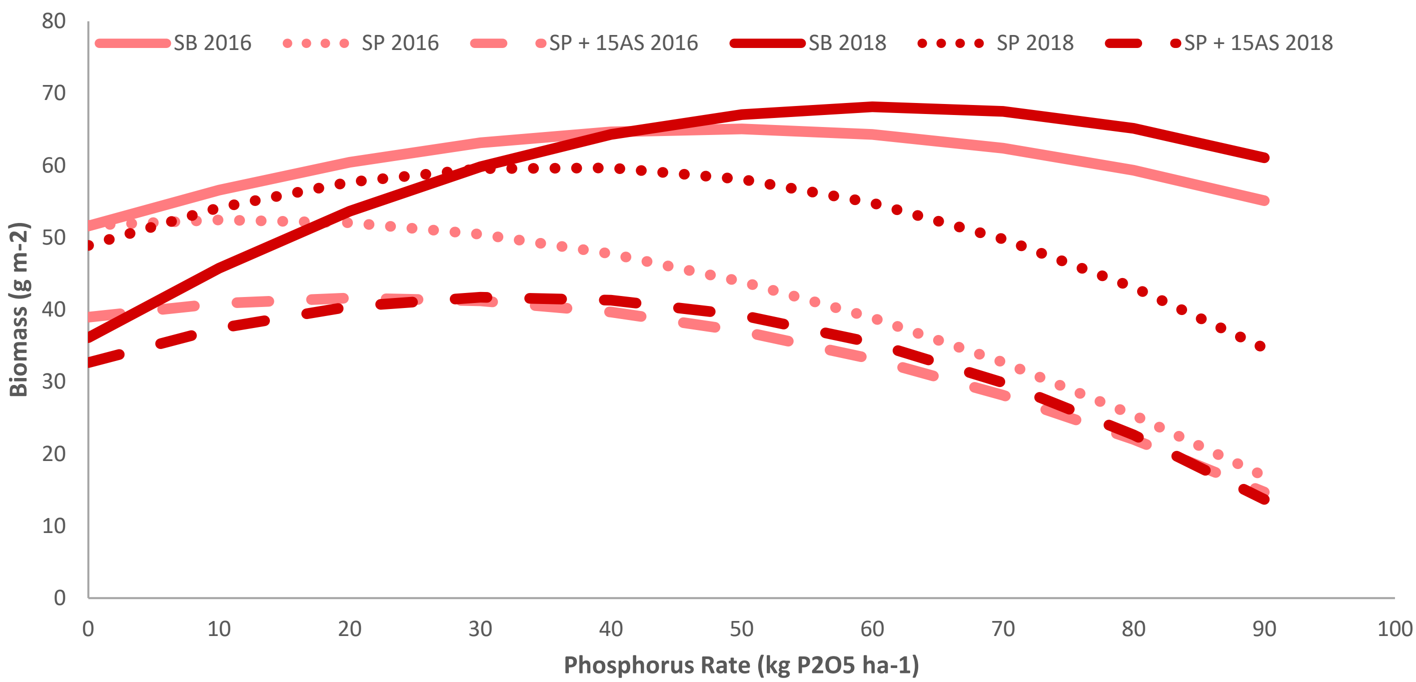

Figure 22. Phosphorus Rate and Placement Interaction Effects on Canola Biomass (g m^{-2}) at Scott 2016 and 2017.

Phosphorus rate had a significant effect on tissue P at 7 of 8 site-years, as expected (Table 9). Neither placement nor the two-way interaction had a significant effect on tissue phosphorus levels. Between years and locations, tissue P levels were very similar (Table B6). Due to an oversight, tissue P levels were not measured at SC18.

Table 9. Phosphorus Rate, Placement, and Interaction Effects on Tissue Phosphorus Levels (ppm) at Three Saskatchewan Locations, from 2016 to 2018.

	Indian Head[z]			Melfort[z]			Scott[z]		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Phosphorus Rate (R)	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	0.4993	<0.0001 ***	<0.0001 ***	<0.0001 ***	NA
Fertilizer Placement (P)	0.6079	0.5777	0.8894	0.9813	0.9838	0.2751	0.0835	0.7295	NA
R * P	0.2999	0.6435	0.5094	0.2765	0.4915	0.7328	0.0988	0.2467	NA

[z] p<0.05***; p<0.01**; p<0.0001***

Much like biomass yield, phosphorus rate had a significant effect at almost all locations. At all significant locations, tissue phosphorus levels increased with increasing phosphorus application (Figure 23). This was as expected, and the highest tissue P values were found at 80 kg P_2O_5 ha^{-1}. Although there was a quadratic response at ME18, the actual point of decline was beyond the rates tested.

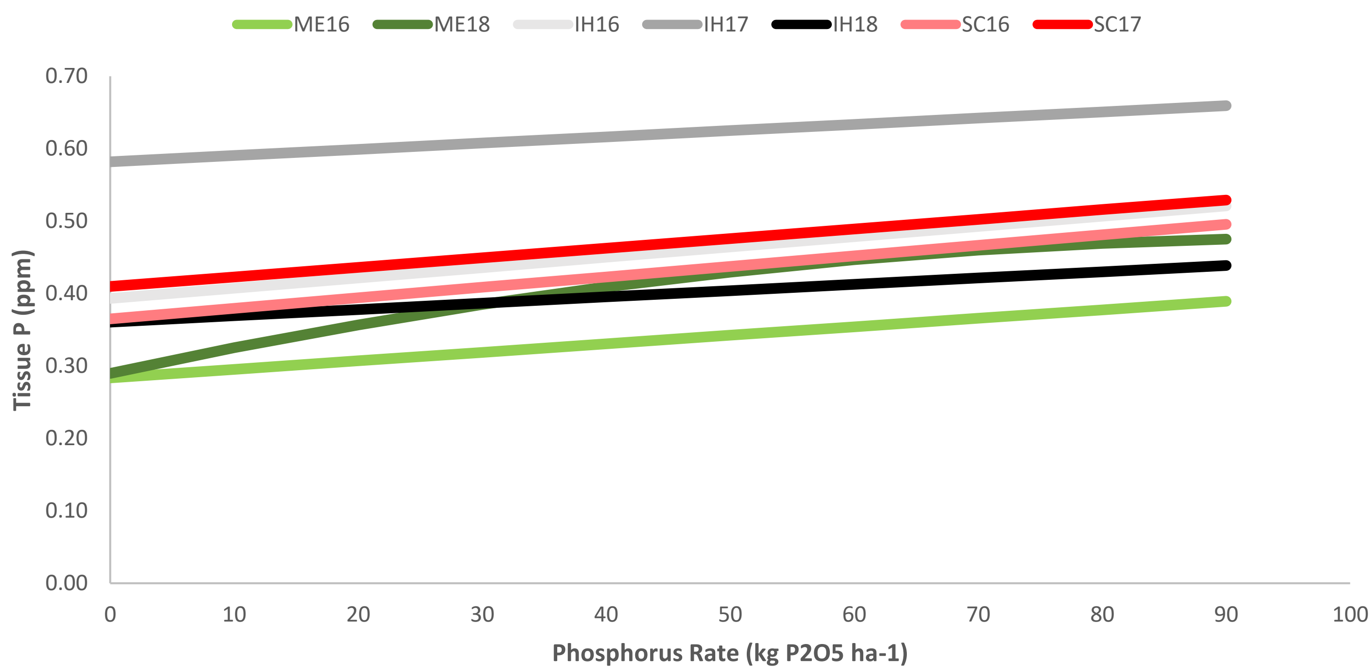

Figure 23. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effects on Tissue Phosphorus Accumulation (ppm) at 7 of 9 Site-years.

Maturity

At Melfort 2016 & 2017, maturity differences between treatments were not noted per plot and therefore were not included in this analysis. At the remaining 7 site-years, phosphorus rate had a significant effect 71% of the time (5/7), placement was significant 43% (3/7), and the two-way interaction was significant 43% of the time as well (Table 4). Overall, maturity was very similar between 2016 and 2017 at each location. An exception was Melfort 2017 where canola matured 11 days sooner than in 2016 (Table B7). Lastly, due to the dry conditions, at each location maturity occurred 6 to 10 days sooner in 2018 than in 2016 or 2017.

Table 10. Phosphorus Rate, Placement, and Interaction Effects on Days to Maturity at Three Saskatchewan Locations, from 2016 to 2018.

	Indian Head[z]			Melfort[z]			Scott[z]		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Phosphorus Rate (R)	0.1058	<0.0001 ***	0.0136 *	NA	NA	0.0663	<0.0001 ***	0.0320 *	0.0022 **
Fertilizer Placement (P)	0.6323	0.2781	0.0017 **	NA	NA	0.8462	0.0019 **	0.7192	<0.0001 ***
R * P	0.4124	0.0284 *	<0.0001 ***	NA	NA	0.4355	0.1159	0.4489	<0.0001 ***

[z] p<0.05***; p<0.01**; p<0.0001***

At the five site-years were phosphorus rate had a significant effect, increasing phosphorus rate delayed maturity (Figure 24). At IH17, the 80 kg P_2O_5 ha^{-1} rate matured one day later than any other treatment. At IH18, maturity was similar between 0 and 50 kg P_2O_5 ha^{-1}, one day later thereafter as the P rate increased. At SC16, for each 20 kg P_2O_5 ha^{-1} increase, maturity was delayed by 1-day, generally. In Sc17, maturity increased by 1 days when 50 kg P_2O_5 ha^{-1} was applied and in 2018 when 40 kg P_2O_5 ha^{-1} was applied.

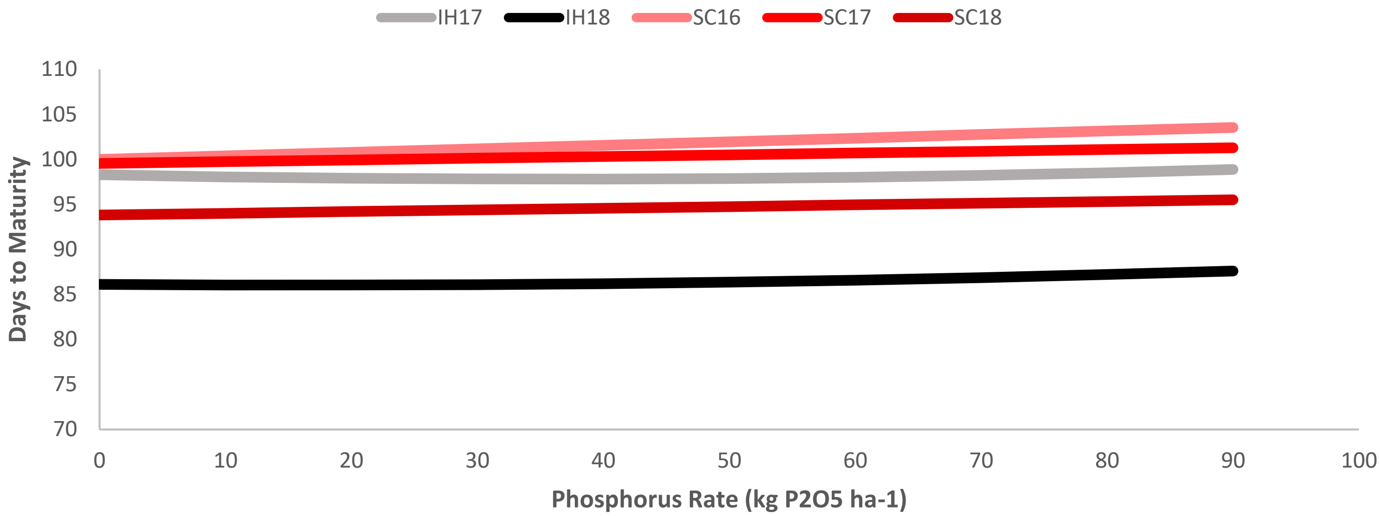

Figure 24. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Days to Maturity in Canola at Indian Head two years, and Scott three years.

At IH18, when averaged across placements methods, there were no significant differences between the three treatments (Figure 25). At SC16, the seed-placed P and side-banded P treatments matured 1 to 2 days sooner than the SP+15AS. Similarly, at SC18, the addition of 15AS resulted in a two-day delay in maturity. Overall, even though statistically significant, the effect that phosphorus placement has on canola maturity is practically insignificant as all maturities were within 1 to 2 days of each other. In most cases, the delay in maturity associated with seed-placed P compared to side-band, reflected the differences in plant density.

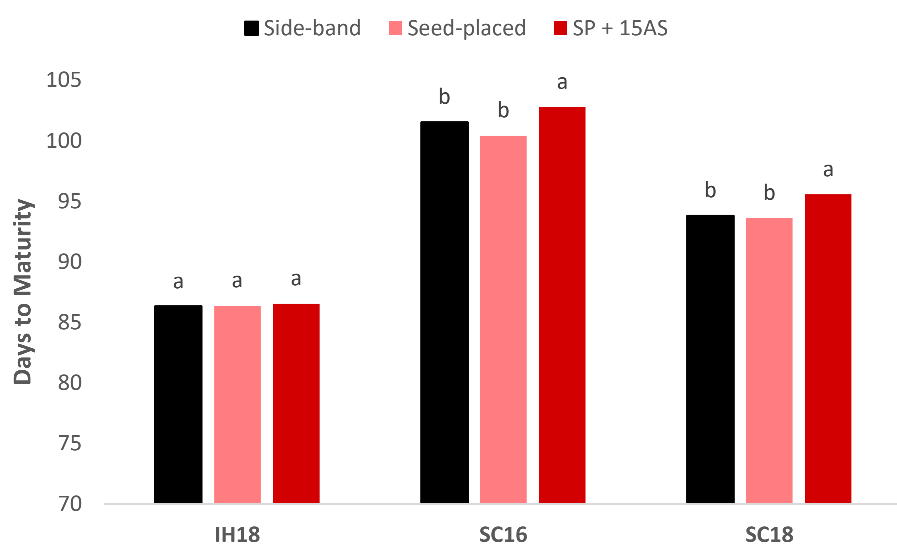

Figure 25. Phosphorus Placement Effect on Days to Maturity in Canola at Indian Head one year, and Scott two years.

At Indian Head 2017 & 2018, the effects of the interaction between phosphorus rate and placement were similar between the two years (Figure 26). In 2017, all three placement methods saw the crop mature sooner as the P rate increased from 0 to 40 kg P_2O_5 ha^{-1} and then delayed as the rate was further increased. However, there was only 0.5 to 1 day difference between the highest and lowest treatments. In 2018, the point at which maturity began to delay was more variable with it occurring between 30 and 50 kg P_2O_5 ha^{-1}. This also resulted in a 1 to 1.5-day difference in maturity between treatments. In SC18, all responses were linear, with a 0.75 to 1.5-day difference in the maturity of all treatments between the lowest and highest P rates. Here, increasing the rate of P reduced maturity when side-banded, increased when seed-placed, regardless of whether 15AS was included in the blend.

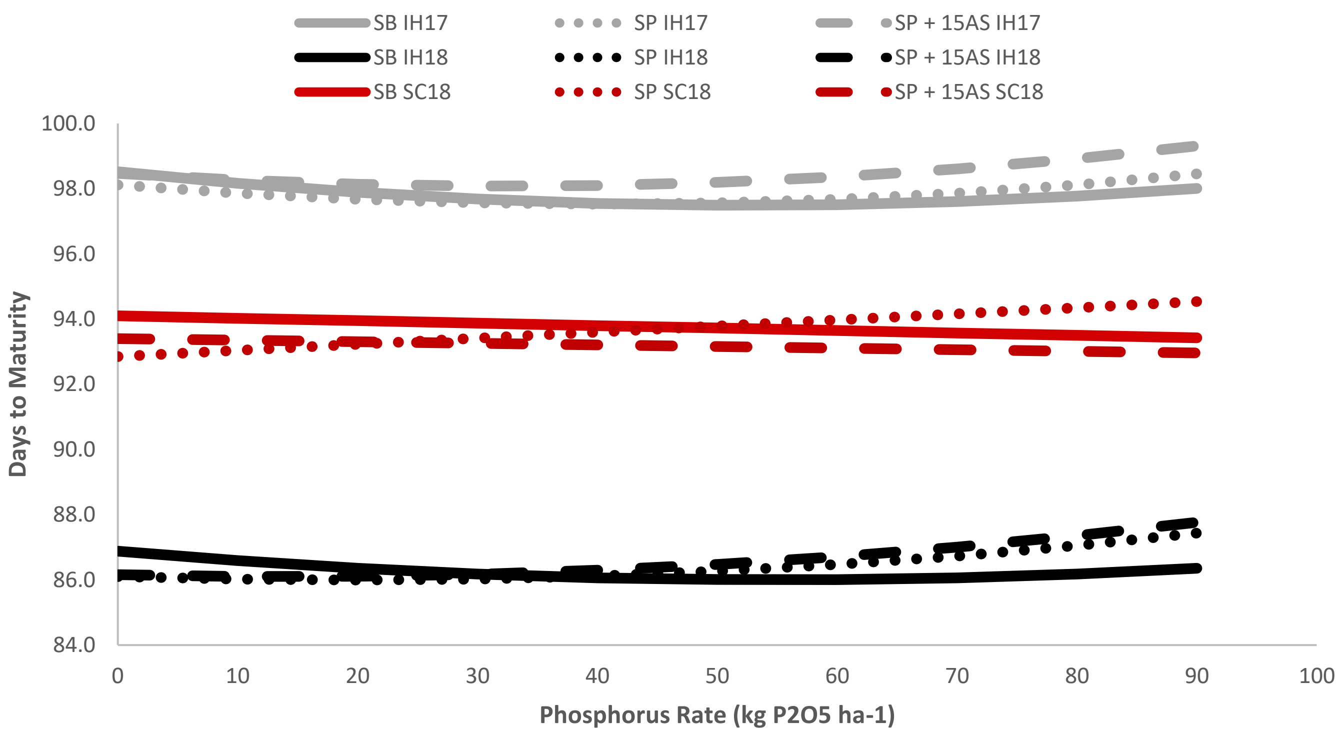

Figure 26. Phosphorus Rate and Placement Interaction Effect on Days to Maturity in Canola at Indian Head one year, and Scott two years.

Yield

Phosphorus rate was significant at 5 site-years, while fertilizer placement did not have any significant effects on canola yield (Table 11). Furthermore, the rate by placement interaction was only significant at Scott 2016 and 2018. The lack of response at Melfort 2017 was not unexpected as soil available P tested 43 ppm (Table 2). With this much available soil P, a response to fertilizer was unlikely. At Indian Head all three years, soil test P was 6 to 9 ppm. With these low levels, it was expected that relatively large responses to fertilizer P would occur. The lack of response in 2016, combined with higher yields without fertilizer P, is troubling. It may suggest that the soil tests are not providing adequate estimates of available P from the soil or cycling of organic P and overall P mobility in the soil may simply have been higher under the warm, wet conditions encountered.

Table 11. Phosphorus Rate, Placement, and Interaction Effects on Canola Grain Yield (kg ha^{-1}) at Three Saskatchewan Locations, from 2016 to 2018.

	Indian Head[z]			**Melfort**[z]			**Scott**[z]		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Phosphorus Rate (R)	0.3789	<0.0001 ***	<0.0001 ***	<0.0001 ***	0.5014	0.0234 *	0.2821	<0.0001 ***	0.1819
Fertilizer Placement (P)	0.5984	0.6393	0.9666	0.4342	0.0975	0.4573	0.1785	0.4609	0.8058
R * P	0.9535	0.7395	0.4056	0.8691	0.1342	0.5195	<0.0001 ***	0.2243	0.0163 *

[z] p<0.05***; p<0.01**; p<0.0001***

The five site-years that responded to fertilizer P rates showed some similar responses, despite one being quadratic. At all the site-years where there was a linear response, 80 kg P_2O_5 ha^{-1} produced the largest yields (Figure 27; Table B8). This treatment resulted in yield increases between 120 and 850 kg ha^{-1}. At ME16, yields increased with phosphorus application and were maximized at 72 kg P_2O_5 ha^{-1}, which resulted in an 892 kg ha^{-1} yield increase over the control. This site-year also had the highest yield gains from phosphorus application of the five significant site-years. In contrast, IH18 had the lowest yield gains from phosphorus application at 116 kg ha^{-1} between the control and 80 kg P_2O_5 ha^{-1}. At the remaining site-years, there was an average 243 kg ha^{-1} yield increase between the lowest and highest phosphorus rates applied.

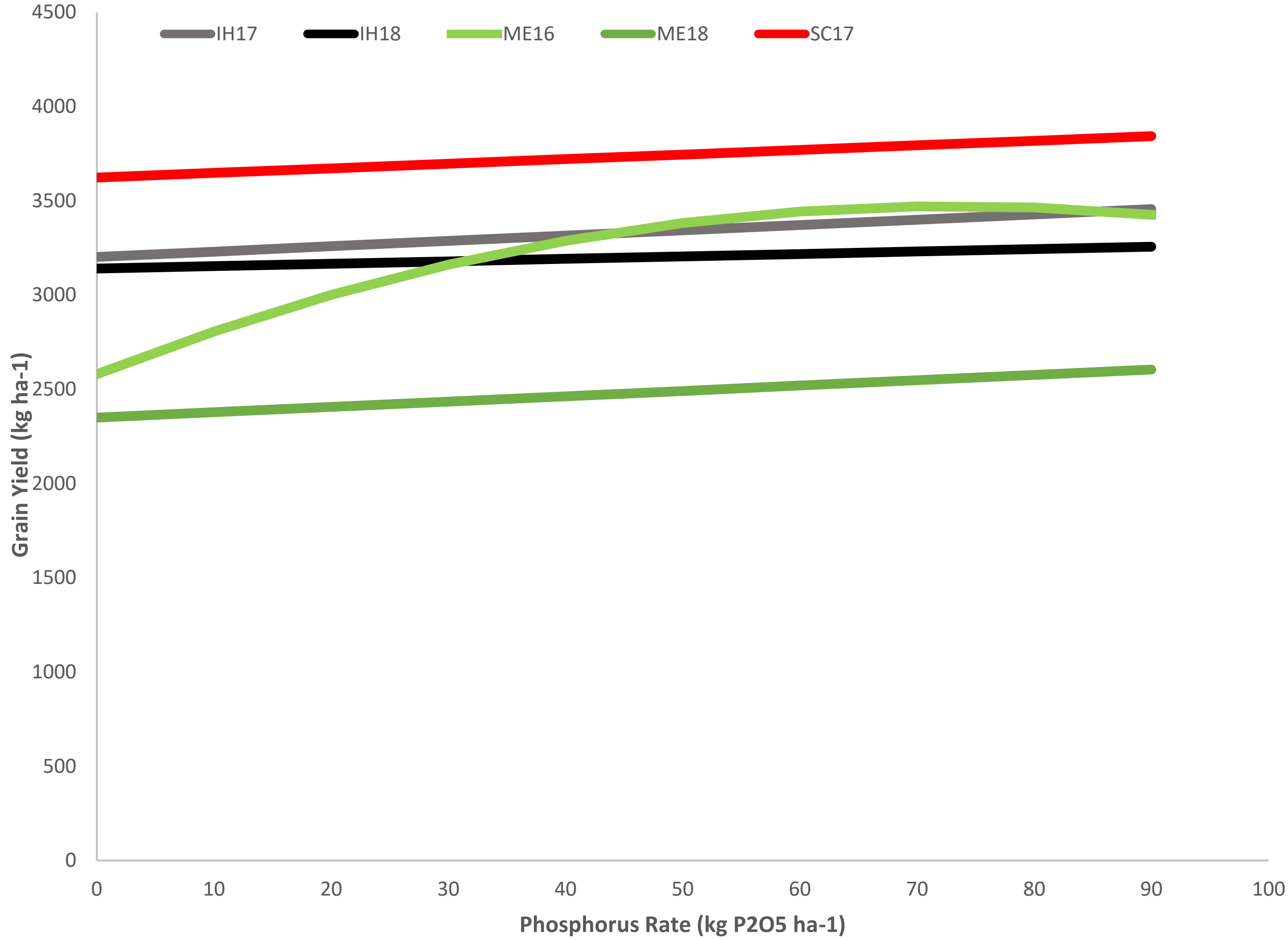

Figure 27. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Canola Grain Yield (kg ha^{-1}) at Indian Head two years, Melfort two years, and Scott one year.

At Scott 2016 and 2018, where the interaction between rate and placement was significant, yield continued to increase, with increasing phosphorus rate when it was side-banded (Figure 28). This resulted in yield increases of 350 kg ha^{-1} in 2016 and 420 kg ha^{-1} in 2018. In 2016, seed-placed phosphorus resulted in declining yields across the phosphorus rate treatment by 283 kg ha^{-1}, while in 2018 seed-placed phosphorus slightly increased yield by 25 kg ha^{-1}. In both years, seed-placed P with 15AS resulted in significant yield increases of 267 kg ha^{-1} in 2016 and 130 kg ha^{-1} in 2018.

The three site-years at Scott were suitable to be combined statistically. When combined, the two-way interaction continued to be significant. The responses to phosphorus rate and placement were linear across placements and rate. As the rate of side-banded phosphorus increased, yield continued to increase with yield gains of 373 kg ha^{-1} with the highest rate (Figure 28). Seed-placed phosphorus resulted in slightly increased yields across the rates applied, with only 32 kg ha^{-1} between the highest and lowest rates. When 15 kg ha^{-1} of AS was applied with the seed-placed P, yield declined as the phosphorus rate increase with yield losses of up to 104 kg ha^{-1}.

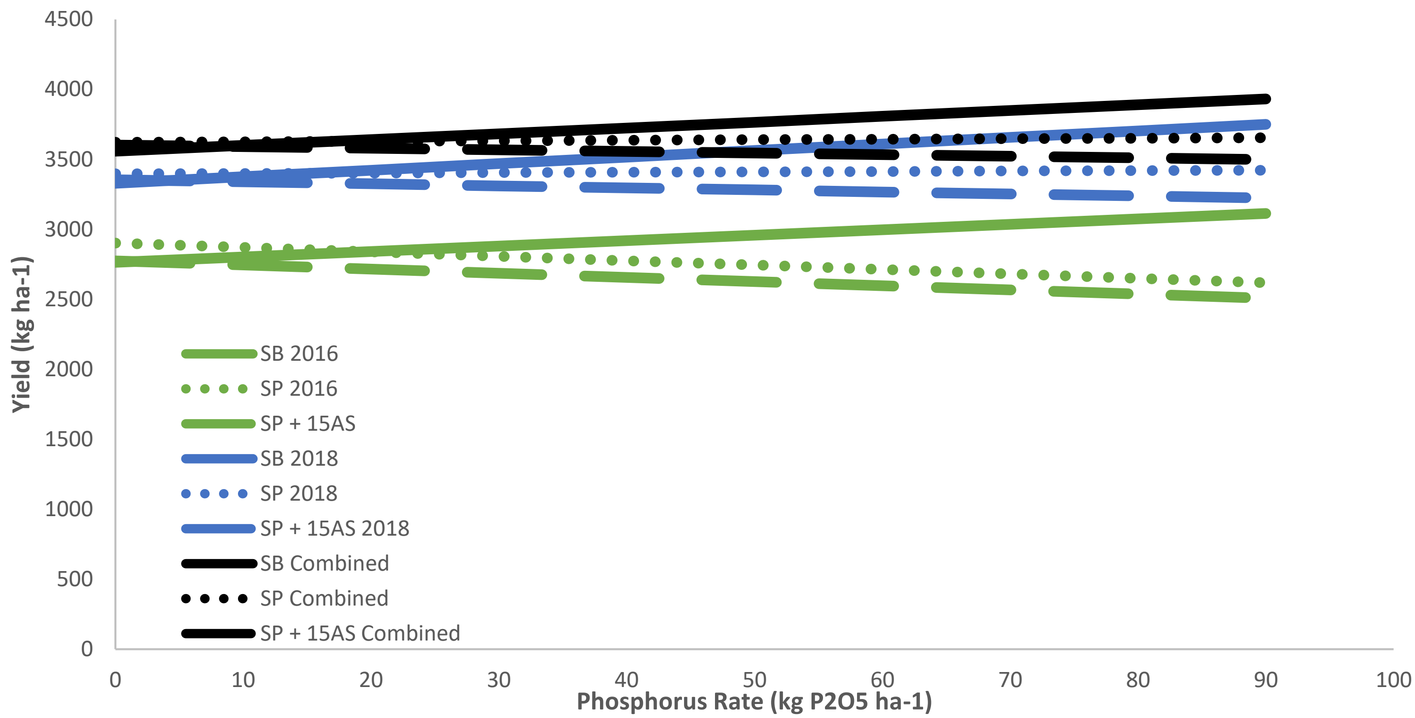

Figure 28. Phosphorus Rate and Placement Interaction Effects on Canola Grain Yield (kg ha^{-1}) at Scott 2016 and 2018, and the Combined 3-year Average.

Quality (TKW & Green Seed)

Thousand kernel weight or seed weight was largely unaffected by the applied treatments. However, the effect of phosphorus rate was significant at IH17, ME16, and ME18 (Table 12). Overall, all TKWs were in the expected 2.5 to 4 mg/seed range (Table B9). Where phosphorus rate was significant (IH17 and ME16), TKW increased with increasing phosphorus rate (Figure 29). In ME16 the increased was larger at 0.23 g 1000^{-1} $seeds^{-1}$, than IH17 which was 0.06 g. Conversely, TKW declined with increasing phosphorus rate at ME18 with a loss of 0.30 g.

Table 12. Phosphorus Rate, Placement, and Interaction Effects on Thousand Kernel Weight (g 1000^{-1} $seeds^{-1}$) at Three Saskatchewan Locations, from 2016 to 2018.

	Indian Head[z]			Melfort[z]			Scott[z]		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Phosphorus Rate (R)	0.1737	0.0062 **	0.2106	0.0018 **	0.9900	<0.0001 ***	0.1746	0.9362	0.4171
Fertilizer Placement (P)	0.5084	0.0988	0.6987	0.3879	0.9894	0.1431	0.5892	0.6253	0.7996
R * P	0.6502	0.0836	0.4896	0.6405	0.7353	0.7962	0.5287	0.2360	0.4682

[z] p<0.05***; p<0.01**; p<0.0001***

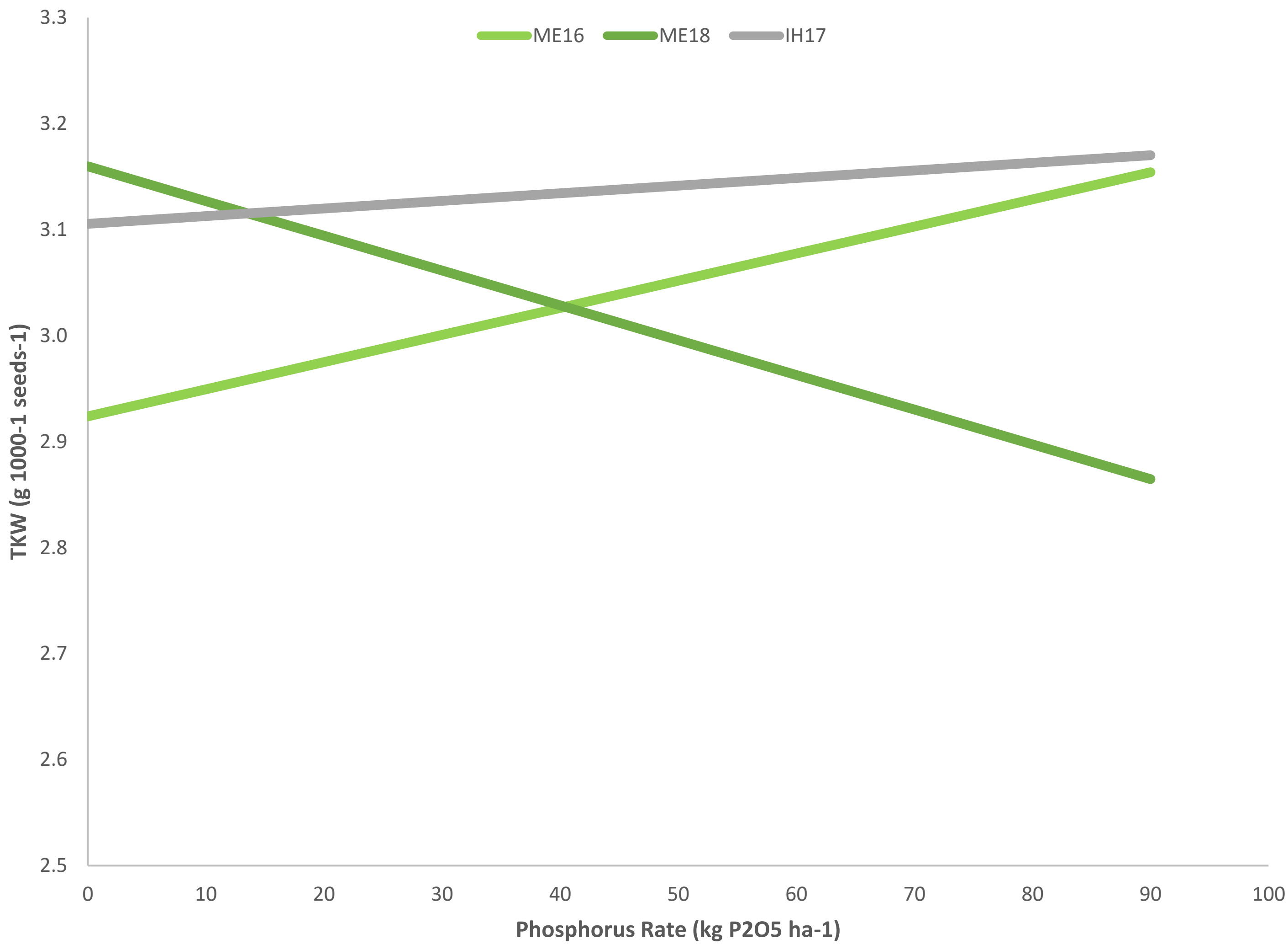

Figure 29. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Thousand Kernel Weight (g 1000^{-1} $seeds^{-1}$) at Three Site-years.

Green seed values were affected by rate at 4 of 9 site-years, placement at ME16, and the two-way interaction at SC16 (Table 13). As expected, there was considerable variability between treatment means ranging from less than 1% up to 3% (Table B10). Overall, green seed was very low all three years, so treatment effects are likely of little practical significance as levels were below the 5% threshold where downgrading occurs.

Table 13. Phosphorus rate, Placement, and Interaction effects on Green Seed (%) at Three Saskatchewan Locations, from 2016 to 2018.

	Indian Head[z]			Melfort[z]			Scott[z]		
	2016	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Phosphorus Rate (R)	0.0146 *	0.7721	0.7344	0.0017 **	0.4980	0.4127	0.0016 **	0.2909	0.0415 *
Fertilizer Placement (P)	0.5100	0.3408	0.5518	<0.0001 ***	0.1804	0.7522	0.4736	0.6071	0.71857
R * P	0.7523	0.8213	0.6870	0.1524	0.3132	0.5227	<0.0001 ***	0.5305	0.3232

[z] p<0.05***; p<0.01**; p<0.0001***

At ME16, green seed doubled when 15AS was seed-placed with P, compared to side-band and seed-placed P (Table B10). The SB and SP P was similar at 0.03%, thus even with levels doubled in the alternative treatment, this effect was of little importance. At SC16, where the two-way interaction was significant, the average green seed percentage nearly doubled as between side-band and seed-placed, and then again between SP and SP + 15AS. Phosphorus rate more often had a significant effect on green seed, than the other two factors. The largest increase in green seed, as phosphorus rate increased, was at SC16 where green seed values increased by 64% between the highest and lowest P rates (Figure 30). However, even at the highest rate, green seed was less than 3.5%. At SC18, the response to increasing P rate was also linear, but had less impact. The difference in the green seed values increased by 49%, with 0.54% difference between the highest and lowest applied rates. At ME16 and IH16, the response to increasing P rate was quadratic. At ME16, green seed declined with increasing P rate, until 39 kg P_2O_5 ha was applied, and then it was similar at 0.03%. At IH16, green seed declined up to 32 kg P_2O_5 ha was applied, and then increased, with the highest and lowest P rates ranging from 0.09 to 0.11%. In general, side-band P did not impact green seed, while it was sometimes affected by seed-placed with or without 15AS. This likely reflects reduced plant density, with these two placements. When plant density is decreased, the crop attempts to increase branching and flowering in order to compensate. This results in more seed development, but seeds develop at different rates. This not also results in variable maturity of the whole plant, but also increases the green seed count in the harvest sample.

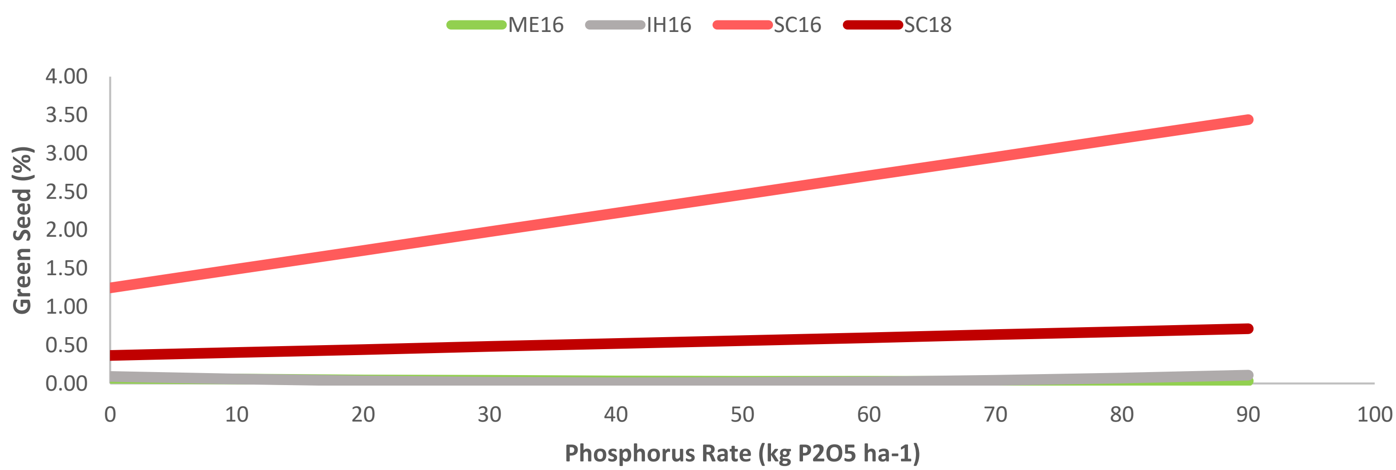

Figure 30. Phosphorus Rate (kg P_2O_5 ha^{-1}) Effect on Green Seed (%) at 4 of 9 Site-years.

Summary and Conclusion:

In general, plant populations declined significantly as P rates increased with both seed-placed and SP + 15AS treatments, but not with the side-band placement. The level of damage from the seed-placed treatments varied across location and years, from rather extensive damage in Scott 2016 to limited or no damage at other locations. Damage from these two placement methods were noted at 2, 4, and 6 weeks after seeding, as well as post-harvest. There was some indication that damage was less severe with later evaluation timings, particularly where the SP + 15AS treatments were in combination with high rates of fertilizer P. It was also apparent that the damaging effects of seed placed P and S were additive when significant at Indian Head and Melfort. Yet, at Scott, the effect was still damaging but to a lesser extent. This may have been due to the location being responsive to sulphur, which somewhat offset the damaging effect of increasing P rate.

Results also suggest that damage from seed-placed phosphorus may not be as severe as suggested by the initial studies used to determine safe rates. This may reflect the greater seedbed utilization of hoe type openers compared to the disc type openers used in the earlier trials. Results also suggest that side-banded fertilizer P can be as or more efficient than seed-placed P even at lower rates, for canola establishment. Slinkard and Henry (1977), found plant density reductions of 40 to 50% when the safe rate of seed-placed P was exceeded, and upwards of 70 to 80% when fertilizer P was increased to 60 kg ha^{-1}. The results of our study suggest that when significant, there is only a maximum of 40% decline in plant populations when fertilizer P was increased to 80 kg ha^{-1}. Therefore, our results are similar to those of Grant (2012), Karamanos et al. (2014), and Mohr et al. (2013), who found reductions of 10 to 30% with rates of 60 kg ha^{-1} of fertilizer P. This effect is largely attributed to the wider band width of a hoe-type opener than a double disc-type opener, which diminishes the damage from seed-placed P as there is higher seedbed utilization. In addition to horizontal separation, hoe-type openers may also result in more vertical spread of seed and fertilizer compared to double disc openers, effectively increasing the seed-bed utilization even further.

Biomass production increased with phosphorus fertilizer application and was greatest when side-band applied. There also was an indication that biomass production may decline when high rates of phosphorus are seed-placed alone or with sulphur, likely due to reductions in plant population. Overall, there was also a trend for biomass to reflect the final in-crop plant population assessment. As expected, tissue P levels increased with all fertilizer P application rates. This indicates that the P levels used in this trial were not excessive or toxic to plant growth.

In general, treatment effects on maturity were variable between treatments and no trends clearly emerged. In most cases, treatment effects were less than one day. At some locations, there were maturity delays of two to 3 days. Overall, any effects on maturity are of little practical significance as effects are associated with decreases in plant density rather than nutrition.

Yield was affected by phosphorus rate and in some cases, the interaction between rate and placement. On average, side-banded P resulted in yield increases of up to 263 kg ha^{-1}. Canola yields generally increased with increasing P rate and optimal yields were reached between 70 and 80 kg ha^{-1} of fertilizer P. Therefore, if high rates of phosphorus are required, fertilizer P should be side-banded to minimize seed damage and maximize yields as it was the most consistent and beneficial application method. Furthermore, results suggest that recommended phosphorus rates for canola should also be re-examined. Quality parameters (TKW and Green Seed) were largely affected by fertilizer P rate alone, and very seldomly placement. Higher rates tended to increase % green seed and mean seed weight, particularly when seed-placed. This further suggests that maturity delays are associated with reduced plant populations. Albeit the response in TKW and green seed were of little agronomic significance.

Overall, the optimal phosphorus management practices have changed for growing canola in Saskatchewan. All or most of the phosphorus fertilizer applied should be side-banded, especially when higher rates are needed. No rate of seed-placed P was found to be safe, as damaged occurred at very low rates, although damage maybe deemed acceptable at low rates. Also, at low rates, there was no evidence that seed-placed P provided better responses, as they were always equal to or less than side-banded P. Furthermore, the degree of damage from seed-placed P fertilizer is very difficult to predict due to soil characteristics and spring moisture, and thus the degree of damage is likely to change across the landscape. The sites-years were there were very low to moderate levels of soil available P, all showed a yield benefit from side-banded P. This effect was also seen at fertilizer P rates above soil test recommendations. At site-years that were high in soil available P, there was no negative consequences to added fertilizer P, suggesting that this practice can be used as a method to build or maintain soil P reserves. Furthermore, the effects of applying sulphur in the seed-row is detrimental to crop establishment and can have a negative additive effect to seed-placed P. Therefore, the practice of P and S in the seed-row should be discouraged. Consequently, if logistics allow, P and S fertilizer should all be side-banded to maintain plant populations and yield potential. The results of this research also suggest that the current phosphorus fertilizer recommendations should be reconsidered for the high yielding cultivars currently used.

Acknowledgements:

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This project was featured as a part of the 2017 Joint Annual Field Day at the Melfort Research Farm and presented by Jessica Weber of Western Applied Research Corporation. Jessica also presented this trial at the 2016 Soils and Crops Conference in Saskatoon, and at the 2017 Agri-ARM Update at the Western Canadian Crop Production Show in Saskatoon. The project was also highlighted at the 2017 IHARF Field Day where Stu Brandt provided background on the project and results to date to approximately 200 guests.

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Appendix A

Table A1. Seeding and Harvest dates at Indian Head, Melfort, and Scott, SK for Enhanced Canola Production with Improved Phosphorus Fertilizer Management in 2016, 2017, & 2018.

	Seeded			Harvested		
Location	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**
Indian Head	May 17	May 13	May 14	September 13	September 3	August 22
Melfort	May 18	May 30	May 17	September 20	September 18	October 4
Scott	May 11	May 11	May 19	September 1	August 30	September 19

Table A2. Fertilizer Rates, Products, and Placements at Indian Head, Melfort, and Scott, SK for Enhanced Canola Production with Improved Phosphorus Fertilizer Management in 2016, 2017, & 2018.

	Nitrogen			Potassium			Sulphur		
Location	**Rate ($kg\ ha^{-1}$)**	**Product**	**Placement**	**Rate ($kg\ ha^{-1}$)**	**Product**	**Placement**	**Rate ($kg\ ha^{-1}$)**	**Product**	**Placement**
2016									
Indian Head	135	46-0-0	Side-band	49	0-0-53-18	Broadcast	17	0-0-53-18	Broadcast
Melfort	159	46-0-0	Side-band	56	0-0-50-17	Broadcast	19	0-0-50-17	Broadcast
Scott	120	46-0-0	Side-band	0	NA	NA	0	NA	NA
2017									
Indian Head	135	46-0-0	Side-band	55	0-0-53-18	Broadcast	19	0-0-53-18	Broadcast
Melfort	153	46-0-0	Side-band	0	NA	NA	15	21-0-0-24	Broadcast
Scott	86	46-0-0	Side-band	56	0-0-50-17	Midrow	28	0-0-50-17	Midrow
2018									
Indian Head	135	46-0-0	Side-band	55	0-0-53-18	Broadcast	19	0-0-53-18	Broadcast
Melfort	223	46-0-0	Side-band	0	NA	NA	15	21-0-0-24	Broadcast
Scott	175	46-0-0	Side-band	0	NA	NA	0	NA	NA

Table A3. Herbicide and Desiccant Applications at Indian Head, Melfort, and Scott, SK for Enhanced Canola Production with Improved Phosphorus Fertilizer Management in 2016, 2017, & 2018.

	Pre-Emergent Herbicide			In-crop Herbicides			Desiccant		
Location	**Product**	**Rate**	**Date**	**Product**	**Rate**	**Date**	**Product**	**Rate**	**Date**
2016									
Indian Head	Glyphosate 540 gae/L	0.67 L/ac	May 15	Glufosinate 150 g/L	1.6 L/ac	Jun. 15	Glyphosate 540 gae/L	0.67 L/ac	Aug. 25
				Clethodim 240 g/L	50 mL/ac	Jun. 15			
Melfort	Not Applied			Glufosinate 150 g/L	1.6 L/ac	NA	Diquat 240 g/L	0.7 L/ac	NA
Scott	Glyphosate 540 gae/L	0.75 L/ac	NA	Glufosinate 150 g/L	1.08 L/ac	Jun. 13	Diquat 240 g/L	0.69 L/ac	Aug. 24
				Clethodim 240 g/L	26 mL/ac	Jun. 13			
2017									
Indian Head	Glyphosate 540 gae/L	0.67 L/ac	May 10	Clopyralid 360 gae/L	225 mL/ac	Jun. 6	Glyphosate 540 gae/L	0.67 L/ac	Aug.20
				Glufosinate 150 g/L	1.6 L/ac	Jun. 18			
				Clethodim 240 g/L	78 mL/ac	Jun. 18			
Melfort	Not Applied			Glufosinate 150 g/L Clethodim 240 g/L	1.35 L/ac 0.77 L/ac	Jul. 5 Jul. 5	Glyphosate 540 gae/L	0.67 L/ac	Sept. 6
Scott	Glyphosate 540 gae/L	0.75 L/ac	May 6	Glufosinate 150 g/L	0.81 + 0.61 L/ac	Jun. 7 + 20	Diquat 240 g/L	0.83 L/ac	Aug. 23
	Bromoxynil 280 g/L	0.4 L/ac	May 6	Clethodim 240 g/L	75 mL/ac	Jun. 20			
2018									
Indian Head	Glyphosate 540 gae/L	0.67 L/ac	May 14	Glufosinate 150 g/L	1.6 L/ac	Jun. 13	Glyphosate 540 gae/L	0.67 L/ac	Aug. 8
				Clethodim 240 g/L	75 mL/ac	Jun. 13			
Melfort	Not Applied			Glufosinate 150 g/L	1.35 L/ac	Jun. 6	Not Applied		
				Clethodim 240 g/L	0.77 mL/ac	Jun. 6			
				Quizalofop 96 g/L	300 mL/ac	Jun. 25			
Scott	Glyphosate 540 gae/L	1 L/ac	May 15	Glufosinate 150 g/L	1.62 L/ac	Jun. 18	Glyphosate 540 gae/L	0.67 L/ac	Aug. 23
	Carfentrazone 240 g/L	25 mL/ac	May 15	Clethodim 240 g/L	77 mL/ac	Jun. 18	Saflufenacil 342 g/L	59 mL/ac	Aug. 23

Table A4. Fungicide and Insecticide Applications at Indian Head, Melfort, and Scott, SK for Enhanced Canola Production with Improved Phosphorus Fertilizer Management in 2016, 2017, & 2018.

	Insecticide			Fungicide		
Location	**Product**	**Rate**	**Date**	**Product**	**Rate**	**Date**
			2016			
Indian Head	Not Applied			Boscalid 70%	142 g/ac	July 5
Melfort	Not Applied			Boscalid 70%	140 g/ac	July 5
Scott	Lambda-cyhalothrin 120 g/L	34 mL/ac	Jun. 23	Fluxapyroxad 167 g/L + Pyraclostrobin 333 g/L	120 mL/ac	June 29
			2017			
Indian Head	Not Applied			Boscalid 70%	140 g/ac	July 5
				Pyraclostrobin 250 g/L	0.13 L/ac	July 5
Melfort	Not Applied			Picoxystrobin 250 g/L	350 mL/ac	July 18
Scott	Deltamethrin 50 g/L	40 mL/ac	May 29 & Aug. 7	Fluxapyroxad 167 g/L + Pyraclostrobin 333 g/L	180 mL/ac	July 8
			2018			
Indian Head	Not Applied			Boscalid 70%	140 g/L	June 28
				Pyraclostrobin 250 g/L	0.13 L/ac	June 28
Melfort	Not Applied			Picoxystrobin 250 g/L	350 mL/ac	July 9
Scott	Deltamethrin 50 g/L	60 mL/ac	Aug. 13	Fluxapyroxad 167 g/L + Pyraclostrobin 333 g/L	180 mL/ac	July 12

Appendix B

Table B1. Influence of Phosphorus Rate and Placement on Canola Plant Density (plants m^{-2}) Two Weeks After Seeding at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	93.8	70.5	78.3	44.7	101.3	47.2	53.6	109.7	28.1	69.7
20P – SB	90.0	63.6	84.5	46.3	74.6	58.6	32.0	105.8	32.5	65.3
40P – SB	102.3	69.7	75.0	30.6	93.5	91.9	41.8	93.0	27.6	69.5
60P – SB	85.3	70.5	75.5	47.2	87.8	89.8	49.7	105.3	35.9	71.9
80P – SB	92.7	61.9	81.2	52.5	82.4	75.0	33.0	113.7	42.3	70.5
0P – SP	97.0	63.2	77.5	34.0	80.9	31.2	37.9	106.3	32.0	62.2
20P – SP	92.7	75.9	69.7	49.6	72.6	43.5	31.0	78.1	27.1	60.0
40P – SP	88.4	65.2	59.1	41.0	72.2	58.6	26.6	89.1	25.6	58.4
60P – SP	89.0	48.0	59.1	45.5	60.7	48.8	23.6	72.8	20.7	52.0
80P – SP	88.0	46.3	57.8	23.0	70.1	53.3	3.9	61.5	12.3	46.3
0P – SP+15AS	97.6	56.6	67.7	36.9	100.9	54.1	25.6	67.9	22.1	58.8
20P – SP+15AS	100.7	64.4	72.2	36.5	57.0	37.2	20.7	69.6	23.6	53.5
40P – SP+15AS	79.8	42.2	61.9	34.0	81.6	50.4	15.7	68.2	6.6	49.0
60P – SP+15AS	87.8	56.6	45.9	25.0	53.7	53.7	12.3	62.5	10.8	45.4
80P – SP+15AS	75.3	32.4	55.8	26.8	56.2	45.1	7.4	68.4	12.3	42.2
All SB	93.4	67.3	78.9	44.6	87.9	70.4	42.0	105.5	32.3	69.1
All SP	91.0	59.7	4.6	38.6	70.8	47.1	24.6	82.2	23.5	55.8
All SP+15AS	88.2	50.4	61.5	32.1	69.9	48.7	16.3	67.1	15.5	50.0
0 P_2O_5	97.1	63.4	74.5	38.5	95.6	44.2	39.0	94.7	27.4	63.8
20 P_2O_5	94.5	67.9	75.5	44.2	68.1	47.3	27.9	86.6	27.7	60.0
40 P_2O_5	90.2	59.1	65.3	35.6	82.4	62.0	28.1	84.8	21.1	58.7
60 P_2O_5	87.4	58.4	61.4	39.2	67.4	64.1	28.5	80.9	22.5	56.6
80 P_2O_5	85.3	46.9	64.9	33.0	69.6	57.8	14.8	81.2	18.3	52.4
Site-Year Average	*90.7*	*59.1*	*68.2*	*38.2*	*76.4*	*55.7*	*27.7*	*85.0*	*23.8*	*58.3*

Table B2. Influence of Phosphorus Rate and Placement on Canola Plant Density (plants m^{-2}) Four Weeks After Seeding at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	93.7	74.6	75.5	45.9	101.7	78.7	56.1	98.4	34.0	73.2
20P – SB	89.0	70.9	77.1	49.6	90.2	67.3	42.8	115.2	35.9	70.9
40P – SB	94.5	69.3	73.4	41.8	87.8	95.7	56.6	95.0	40.4	72.7
60P – SB	83.7	80.4	76.3	46.3	78.3	100.1	62.5	96.9	40.4	73.9
80P – SB	90.8	65.6	79.6	45.4	86.9	105.0	47.7	106.3	43.8	74.6
0P – SP	90.4	68.5	75.9	37.3	102.3	50.9	49.3	92.5	44.3	67.9
20P – SP	88.2	79.6	65.2	43.5	87.4	64.8	48.2	82.7	33.5	65.9
40P – SP	89.0	70.1	61.1	38.5	70.5	83.3	38.9	94.5	35.9	64.7
60P – SP	91.5	57.0	58.6	41.4	77.1	73.8	35.4	74.3	16.7	58.4
80P – SP	84.5	56.6	58.6	22.1	77.1	84.5	22.1	63.5	13.8	53.7
0P – SP+15AS	94.3	64.0	66.4	42.2	104.2	83.7	42.3	74.3	30.0	66.8
20P – SP+15AS	100.3	73.4	67.7	39.4	70.9	77.5	36.4	75.3	33.0	63.8
40P – SP+15AS	85.1	51.3	59.9	33.2	87.8	82.4	29.0	81.2	23.1	59.2
60P – SP+15AS	85.9	70.1	52.1	21.7	68.1	90.8	20.7	67.9	19.7	55.2
80P – SP+15AS	76.5	41.8	52.1	25.2	69.3	71.4	18.7	72.8	18.7	49.6
All SB	90.3	72.2	76.4	45.8	89.0	89.0	53.1	102.4	38.9	73.0
All SP	88.7	66.4	63.9	36.6	81.8	71.4	38.8	81.5	28.8	62.0
All SP+15AS	88.4	60.1	59.6	32.4	80.1	80.6	29.4	74.3	24.9	58.8
0 P_2O_5	92.8	69.0	72.6	41.8	102.7	71.1	49.2	88.4	36.1	69.3
20 P_2O_5	92.5	74.6	70.0	44.6	82.8	69.9	42.5	91.0	34.1	66.9
40 P_2O_5	89.5	63.6	64.8	37.9	82.0	86.3	41.5	90.2	33.1	65.4
60 P_2O_5	87.0	69.2	62.3	36.5	74.5	88.0	39.5	79.7	25.6	62.5
80 P_2O_5	83.9	54.7	63.4	30.0	77.8	86.9	29.5	80.9	25.4	59.2
Site-Year Average	*89.2*	*66.2*	*66.6*	*38.2*	*83.9*	*80.6*	*40.5*	*86.1*	*30.9*	*64.7*

Table B3. Influence of Phosphorus Rate and Placement on Canola Plant Density (plants m^{-2}) Six Weeks After Seeding at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	95.8	77.1	75.5	52.5	54.5	57.4	61.5	91.5	23.6	65.5
20P – SB	91.7	69.7	80.8	50.4	55.0	54.1	43.8	100.4	33.0	64.3
40P – SB	92.1	77.1	73.4	46.3	59.9	67.3	61.5	87.6	39.9	67.2
60P – SB	82.8	81.6	80.0	47.2	59.5	63.6	62.0	92.0	34.9	67.1
80P – SB	88.6	61.1	79.2	42.7	58.6	55.4	52.7	105.8	40.8	65.0
0P – SP	89.4	66.0	73.8	40.6	41.8	47.6	54.1	88.1	42.3	60.4
20P – SP	88.2	79.6	66.4	40.2	46.3	50.0	58.1	78.7	37.9	60.6
40P – SP	88.8	74.2	59.9	38.5	47.6	53.3	45.3	79.2	36.9	58.2
60P – SP	91.2	58.6	57.0	43.5	47.6	49.2	40.4	78.2	17.2	53.7
80P – SP	82.8	56.2	59.5	29.1	49.6	56.6	21.7	57.1	19.2	48.0
0P – SP+15AS	92.3	72.2	68.5	38.5	58.0	57.0	45.8	78.2	31.0	60.2
20P – SP+15AS	98.6	69.7	68.5	32.8	39.0	52.9	37.4	75.8	29.5	56.0
40P – SP+15AS	81.8	58.2	59.1	40.2	52.9	57..0	32.0	78.7	18.7	53.2
60P – SP+15AS	88.2	67.3	54.1	27.5	38.1	52.5	25.1	64.0	21.2	48.7
80P – SP+15AS	71.8	41.0	52.9	28.4	42.2	50.0	22.6	72.8	28.1	45.5
All SB	90.2	73.3	77.8	48.1	57.5	59.5	56.3	95.5	34.4	65.8
All SP	88.1	66.9	63.3	38.4	46.6	51.3	43.9	76.3	30.7	56.2
All SP+15AS	86.5	61.7	60.6	33.8	45.4	53.9	32.6	73.9	25.7	52.7
0 P_2O_5	92.5	71.8	72.6	43.9	50.9	54.0	53.8	86.0	32.3	62.0
20 P_2O_5	92.8	73.0	71.9	41.1	46.8	52.4	46.4	85.0	33.5	60.3
40 P_2O_5	87.6	69.9	64.1	41.7	53.5	59.2	46.3	81.9	31.8	59.5
60 P_2O_5	87.4	69.2	63.7	39.4	48.4	55.1	42.5	78.1	24.4	56.5
80 P_2O_5	81.1	52.8	63.8	33.0	50.2	54.0	32.3	78.6	29.4	52.8
Site-Year Average	*88.3*	*67.3*	*67.2*	*39.9*	*50.0*	*54.9*	*44.3*	*81.9*	*30.3*	*58.2*

Table B4. Influence of Phosphorus Rate and Placement on Canola Plant Density (plants m^{-2}) After Harvest at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	77.9	84.5	64.4	51.3	82.4	16.5	48.2	96.9	47.2	63.3
20P – SB	75.0	93.9	81.6	58.6	88.6	24.0	45.8	98.4	42.8	67.6
40P – SB	88.2	78.7	74.2	41.8	80.0	27.0	47.7	89.6	44.3	63.5
60P – SB	75.5	73.0	81.2	45.1	72.2	43.1	59.1	90.6	44.3	64.9
80P – SB	77.5	92.7	78.7	54.1	60.3	38.2	49.2	100.4	53.6	67.2
0P – SP	80.0	87.8	74.2	43.1	82.4	12.3	54.6	90.1	38.9	62.6
20P – SP	83.9	83.7	66.8	46.3	82.0	33.1	51.2	82.2	35.4	62.7
40P – SP	77.3	76.3	51.7	49.6	90.6	34.1	33.5	86.6	32.5	59.1
60P – SP	80.4	69.7	66.0	32.8	77.9	37.4	38.4	84.2	24.6	56.8
80P – SP	72.2	61.1	60.7	35.3	59.9	43.5	27.1	62.0	29.0	50.1
0P – SP+15AS	77.7	80.0	65.6	41.8	77.5	12.6	36.4	73.3	34.4	55.5
20P – SP+15AS	86.5	83.3	65.2	43.5	68.5	33.6	33.0	82.7	31.0	58.6
40P – SP+15AS	75.5	66.4	62.7	40.6	72.2	33.5	25.6	76.3	31.0	53.7
60P – SP+15AS	75.0	59.9	58.6	46.3	78.7	34.5	31.5	68.4	21.7	52.7
80P – SP+15AS	74.8	632	49.6	33.4	69.7	33.8	20.7	77.8	25.6	49.8
All SB	78.8	84.6	76.0	50.0	76.7	29.7	50.0	95.2	46.5	65.3
All SP	78.7	75.7	63.9	41.4	78.6	32.1	40.3	81.0	31.9	58.3
All SP+15AS	77.9	70.5	60.4	41.5	73.3	29.6	29.47	75.7	28.7	54.1
0 P_2O_5	78.5	84.1	68.1	45.4	80.8	13.8	46.4	86.8	40.2	60.5
20 P_2O_5	81.8	86.9	714.2	49.5	79.7	30.2	43.3	87.8	36.5	63.0
40 P_2O_5	80.3	73.8	62.9	44.0	80.9	31.5	35.6	84.2	35.9	58.8
60 P_2O_5	77.0	67.5	68.6	41.4	76.3	38.3	43.0	81.0	30.2	58.1
80 P_2O_5	74.8	72.3	63.0	40.4	63.3	38.5	32.3	80.1	36.1	55.6
Site-Year Average	*78.5*	*76.9*	*66.8*	*44.2*	*76.2*	*30.5*	*40.1*	*84.0*	*35.8*	*59.2*

Table B5. Influence of Phosphorus Rate and Placement on Canola Biomass Yield (g m^{-2}) at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	122.4	228.6	69.3	43.3	32.4	54.1	54.5	75.9	43.6	80.4
20P – SB	134.3	221.5	62.7	72.1	44.4	78.6	51.8	78.3	46.3	87.8
40P – SB	161.4	162.0	74.8	72.1	41.8	88.7	68.5	103.7	60.0	92.5
60P – SB	151.3	276.4	68.1	98.5	37.5	141.4	71.0	92.9	69.1	111.8
80P – SB	157.1	236.3	79.5	121.7	44.6	125.2	54.6	97.3	68.5	109.4
0P – SP	136.5	225.7	60.3	49.8	34.1	40.5	54.9	84.1	42.4	80.9
20P – SP	165.9	341.6	75.4	73.2	38.6	108.7	48.3	74.7	59.3	109.5
40P – SP	168.9	267.3	83.0	83.3	39.3	111.7	43.8	80.2	69.6	105.2
60P – SP	166.8	251.5	82.5	111.9	33.6	122.7	45.5	77.5	56.6	105.4
80P – SP	161.0	189.5	74.4	71.8	89.5	142.7	23.4	67.0	36.5	89.5
0P – SP+15AS	130.8	206.2	64.1	38.4	40.8	41.3	39.2	63.9	31.8	72.9
20P – SP+15AS	156.7	240.8	71.7	76.9	34.8	110.1	40.9	95.0	46.7	97.1
40P – SP+15AS	140.4	191.5	69.2	81.7	40.8	109.7	41.7	84.7	34.4	88.2
60P – SP+15AS	161.7	245.1	69.5	71.1	38.3	113.0	30.5	69.2	34.2	92.5
80P – SP+15AS	160.9	163.5	65.7	69.8	44.5	110.8	23.2	73.6	25.5	81.9
All SB	145.3	228.3	70.9	79.4	40.1	97.6	60.1	89.6	57.5	96.5
All SP	159.8	251.9	75.1	78.0	37.0	105.2	43.2	76.7	52.8	97.8
All SP+15AS	150.1	209.4	68.0	67.5	39.8	97.0	35.1	77.2	34.5	86.5
0 P_2O_5	129.9	219.6	64.6	43.8	35.8	45.3	49.5	74.6	39.2	78.0
20 P_2O_5	152.3	261.3	69.9	74.0	39.3	99.1	47.0	82.6	50.7	97.4
40 P_2O_5	156.9	211.0	75.6	79.0	40.6	103.4	51.4	49.5	54.6	91.3
60 P_2O_5	159.9	257.6	73.4	93.8	36.5	125.7	49.0	79.8	53.3	103.2
80 P_2O_5	159.7	196.4	73.2	86.2	42.9	126.2	33.7	79.3	43.5	93.4
Site-Year Average	*151.7*	*229.7*	*71.3*	*75.5*	*39.0*	*99.9*	*46.1*	*79.4*	*48.3*	*93.4*

Table B6. Influence of Phosphorus Rate and Placement on Tissue Phosphorus Accumulation (ppm) at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	0.38	0.55	0.37	0.28	0.41	0.29	0.37	0.40		0.38
20P – SB	0.40	0.61	0.38	0.31	0.40	0.40	0.40	0.44		0.42
40P – SB	0.46	0.59	0.38	0.38	0.39	0.43	0.42	0.43		0.44
60P – SB	0.45	0.61	0.42	0.41	0.41	0.48	0.44	0.47		0.46
80P – SB	0.47	0.67	0.42	0.41	0.41	0.47	0.46	0.48		0.47
0P – SP	0.40	0.58	0.34	0.28	0.38	0.34	0.36	0.40		0.38
20P – SP	0.44	0.59	0.40	0.28	0.43	0.33	0.39	0.44		0.41
40P – SP	0.43	0.63	0.41	0.38	0.40	0.41	0.42	0.46		0.44
60P – SP	0.47	0.65	0.40	0.35	0.41	0.46	0.43	0.48		0.45
80P – SP	0.49	0.66	0.42	0.34	0.38	0.46	0.50	0.51		0.47
0P – SP+15AS	0.40	0.58	0.38	0.29	0.40	0.30	0.39	0.41		0.39
20P – SP+15AS	0.38	0.62	0.36	0.30	0.42	0.35	0.40	0.45		0.41
40P – SP+15AS	0.49	0.60	0.39	0.33	0.40	0.41	0.43	0.46		0.44
60P – SP+15AS	0.47	0.63	0.43	0.37	0.42	0.43	0.45	0.51		0.46
80P – SP+15AS	0.53	0.64	0.44	0.38	0.43	0.49	0.49	0.51		0.49
All SB	0.43	0.61	0.39	0.35	0.41	0.41	0.42	0.44		0.43
All SP	0.45	0.62	0.39	0.32	0.40	0.39	0.42	0.46		0.43
All SP+15AS	0.45	0.61	0.40	0.33	0.41	0.40	0.43	0.47		0.44
0 P_2O_5	0.39	0.57	0.36	0.28	0.40	0.30	0.37	0.40		0.38
20 P_2O_5	0.41	0.61	0.38	0.30	0.42	0.36	0.40	0.44		0.41
40 P_2O_5	0.46	0.61	0.39	0.36	0.39	0.42	0.42	0.45		0.44
60 P_2O_5	0.46	0.63	0.42	0.37	0.34	0.45	0.44	0.49		0.45
80 P_2O_5	0.50	0.65	0.43	0.37	0.41	0.47	0.48	0.50		0.48
Site-Year Average	*0.44*	*0.61*	*0.39*	*0.34*	*0.40*	*0.40*	*0.42*	*0.46*		*0.43*

Table B7. Influence of Phosphorus Rate and Placement on Days to Maturity at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	97.4	98.5	86.9	103.0	92.0	98.0	101.3	99.3	94.0	96.7
20P – SB	97.1	97.9	86.3	103.0	92.0	96.0	100.8	101.0	94.0	96.4
40P – SB	97.1	97.5	86.1	103.0	92.0	97.5	100.3	97.5	94.0	96.1
60P – SB	97.1	97.8	86.3	103.0	92.0	96.0	103.8	100.0	93.5	96.6
80P – SB	97.4	97.6	86.0	103.0	92.0	94.3	101.5	100.0	93.5	96.1
0P – SP	97.4	98.5	86.3	103.0	92.0	96.3	98.5	98.8	93.3	96.0
20P – SP	97.3	97.1	85.9	103.0	92.0	98.0	99.5	100.5	93.0	96.3
40P – SP	97.4	97.4	86.0	103.0	92.30	97.5	98.5	99.5	93.3	96.1
60P – SP	97.8	98.1	86.5	103.0	92.0	94.3	102.8	100.8	93.8	96.5
80P – SP	97.4	98.0	87.1	103.0	92.0	98.0	102.8	100.5	94.8	97.1
0P – SP+15AS	97.4	98.4	86.3	103.0	92.0	96.0	102.3	100.3	94.3	96.6
20P – SP+15AS	97.5	98.1	85.9	103.0	92.0	97.8	101.5	99.5	95.8	96.8
40P – SP+15AS	97.6	98.5	86.4	103.0	92.0	96.0	103.5	101.3	95.8	97.1
60P – SP+15AS	97.8	98.0	86.9	103.0	92.0	86.0	103.0	100.5	96.0	97.0
80P – SP+15AS	97.8	99.0	87.3	103.0	92.0	92.5	103.5	101.8	96.0	97.0
All SB	97.3	97.9	86.3	103.0	92.0	96.4	101.5	99.6	93.8	96.4
All SP	97.4	97.8	86.4	103.0	92.0	96.8	100.4	100.0	93.6	96.4
All SP+15AS	97.6	98.4	86.5	103.0	92.0	95.6	102.8	100.7	95.6	96.9
0 P_2O_5	97.4	98.5	86.5	103.0	92.0	96.8	100.7	99.4	93.8	96.4
20 P_2O_5	97.3	97.7	86.0	103.0	92.0	97.3	100.6	100.3	94.3	96.5
40 P_2O_5	97.4	97.8	86.2	103.0	92.0	97.0	100.8	99.4	94.3	96.4
60 P_2O_5	97.5	98.0	86.5	103.0	92.0	95.4	103.2	100.4	94.4	96.7
80 P_2O_5	97.5	982	86.8	103.0	92.0	94.9	102.6	100.8	94.8	96.7
Site-Year Average	*97.4*	*98.0*	*86.4*	*103.0*	*92.0*	*96.3*	*101.5*	*100.1*	*94.3*	*96.6*

Table B8. Influence of Phosphorus Rate and Placement on Grain Yield (kg ha^{-1}) at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	3588	3107	3065	2820	2562	2551	3708	3619	3340	3151.2
20P – SB	3586	3309	3252	3060	2411	2370	3910	3620	3429	3216.4
40P – SB	3592	3215	3235	3493	2846	2474	3900	3714	3522	3332.4
60P – SB	3608	3363	3281	3760	2424	2589	4058	3830	3535	3383.0
80P – SB	3627	3324	3230	3763	2770	2575	4023	3902	3755	3441.2
0P – SP	3642	3191	3190	2745	2740	2393	3893	3481	3321	3177.1
20P – SP	3528	3318	3123	2926	2857	2190	3811	3704	3404	3206.7
40P – SP	3660	3265	3243	3466	2921	2510	3795	3778	3524	3351.4
60P – SP	3549	3392	3226	3385	3064	2775	3800	3877	3484	3394.6
80P – SP	3655	3402	3325	3535	2244	2477	3584	3788	3308	3257.7
0P – SP+15AS	3676	3151	3123	2347	2580	2439	3690	3752	3229	3109.6
20P – SP+15AS	3675	3320	3132	3167	2483	2346	3860	3575	3496	3228.3
40P – SP+15AS	3591	3276	3205	3168	2454	2480	3591	3759	3312	3204.0
60P – SP+15AS	3621	3425	32204	3380	2879	2551	3635	3722	3227	3293.6
80P – SP+15AS	3765	3414	3164	3327	2958	2504	3507	3773	3219	3292.3
All SB	3360	3264	3213	3359	2603	2512	3920	3737	3516	3275.9
All SP	3607	3314	3221	3211	2765	2471	3776	2726	3408	3277.7
All SP+15AS	3666	3317	3166	3065	2671	2464	3656	3716	3296	3224.1
0 P_2O_5	3635	31650	3126	2637	2627	2467	3764	3617	3297	3146.7
20 P_2O_5	3596	3316	3169	3051	2584	2302	3860	3633	3443	3217.1
40 P_2O_5	3614	3252	3228	3376	2741	2486	3762	3751	3453	3295.7
60 P_2O_5	3593	3393	3237	3508	2789	2638	3831	3810	3415	3357.1
80 P_2O_5	3683	3380	3240	3541	2657	2519	3705	3821	3428	3330.3
Site-Year Average	*3613.8*	*3298.1*	*3199.9*	*3221.4*	*2679.5*	*2481.8*	*3784.3*	*3726.3*	*3407.0*	*3268.0*

Table B9. Influence of Phosphorus Rate and Placement on Thousand Kernel Weight (g 1000^{-1} $seeds^{-1}$) at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	3.0	3.0	3.0	2.9	3.4	3.2	3.0	3.1	2.8	3.0
20P – SB	3.0	3.1	3.0	2.9	3.5	3.3	3.0	3.1	2.8	3.1
40P – SB	3.1	3.2	3.0	3.1	3.4	3.1	3.0	3.1	2.9	3.1
60P – SB	3.1	3.1	3.0	3.1	3.5	3.0	3.0	3.1	2.8	3.1
80P – SB	3.1	3.2	3.0	3.2	3.5	3.1	3.0	3.2	2.8	3.1
0P – SP	3.1	3.2	3.0	2.9	.5	3.1	3.0	3.1	2.8	3.1
20P – SP	3.0	3.1	3.0	3.0	3.4	3.1	3.0	3.1	2.7	3.0
40P – SP	3.1	3.1	3.0	3.4	3.4	3.0	2.9	3.1	2.8	3.1
60P – SP	3.1	3.1	3.0	3.2	3.4	3.0	3.0	3.1	2.7	3.1
80P – SP	3.1	3.1	3.0	3.1	3.5	3.0	3.0	3.1	2.9	3.1
0P – SP+15AS	3.0	3.1	3.0	2.8	3.5	3.3	3.0	3.2	2.7	3.1
20P – SP+15AS	3.0	3.1	3.0	3.1	3.4	3.0	3.0	3.1	2.8	3.0
40P – SP+15AS	3.0	3.1	3.0	2.9	3.5	3.0	2.9	3.1	2.7	3.0
60P – SP+15AS	3.0	3.1	3.0	3.0	3.5	3.0	3.0	3.0	2.7	3.0
80P – SP+15AS	3.0	3.2	3.0	3.1	3.5	3.0	3.0	3.1	2.7	3.0
All SB	3.1	3.1	3.0	3..0	3.4	3.1	3.0	3.1	2.8	3.1
All SP	3.0	3.1	3.0	3.1	3.4	3.0	3.0	3.1	2.8	3.1
All SP+15AS	3.0	3.1	3.0	2.9	3.5	3.1	3.0	3.1	2.8	3.0
0 P_2O_5	3.0	3.1	3.0	2.9	3.5	3.2	3.0	3.1	2.8	3.1
20 P_2O_5	3.0	3.1	3.0	3.0	3.4	3.1	3.0	3.1	2.8	3.1
40 P_2O_5	3.0	3.2	3.0	3.1	3.5	3.0	2.9	3.1	2.8	3.1
60 P_2O_5	3.1	3.1	3.0	3.1	3.4	3.0	3.0	3.4	2.8	3.1
80 P_2O_5	3.0	3.2	3.0	3.1	3.5	3.0	3.0	3.0	2.8	3.1
Site-Year Average	*3.0*	*3.1*	*3.0*	*3.0*	*3.4*	*3.1*	*3.0*	*3.1*	*2.8*	*3.1*

Table B10. Influence of Phosphorus Rate and Placement on Green Seed (%) at Indian Head, Melfort, and Scott, SK from 2016 to 2018.

	Indian Head			Melfort			Scott			Grand
Treatment	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**2016**	**2017**	**2018**	**Mean**
0P – SB	0.2	0.0	0.1	0.0	0.0	0.0	1.6	0.2	0.4	0.3
20P – SB	0.1	0.0	0.1	0.0	0.0	0.0	1.4	0.7	0.5	0.3
40P – SB	0.1	0.0	0.0	0.0	0.1	0.0	1.6	0.4	0.4	0.3
60P – SB	0.0	0.0	0.1	0.0	0.0	0.0	0.9	0.5	0.5	0.2
80P – SB	0.2	0.0	0.1	0.0	0.0	0.0	0.8	0.6	0.4	0.2
0P – SP	0.1	0.0	0.1	0.1	0.0	0.0	1.3	0.5	0.4	0.3
20P – SP	0.1	0.0	0.1	0.0	0.0	0.3	1.2	0.5	0.3	0.3
40P – SP	0.1	0.0	0.1	0.0	0.0	0.5	2.0	0.7	0.5	0.4
60P – SP	0.1	0.0	0.1	0.0	0.0	0.0	2.0	0.3	0.7	0.3
80P – SP	0.1	0.0	0.0	0.0	0.0	0.5	2.8	0.6	0.7	0.5
0P – SP+15AS	0.1	0.0	0.1	0.1	0.0	0.3	1.5	0.4	0.4	0.3
20P – SP+15AS	0.0	0.0	0.0	0.1	0.0	0.0	2.0	0.4	0.4	0.3
40P – SP+15AS	0.1	0.0	0.1	0.1	0.0	0.0	3.0	0.5	0.6	0.5
60P – SP+15AS	0.0	0.0	0.1	0.1	0.0	0.0	1.8	0.6	0.7	0.4
80P – SP+15AS	0.1	0.0	0.0	0.0	0.0	0.3	0.6	0.4	0.6	0.6
All SB	0.1	0.0	0.1	0.0	0.0	0.0	1.3	0.5	0.4	0.3
All SP	0.1	0.0	0.1	0.0	0.0	0.3	1.9	0.5	0.5	0.4
All SP+15AS	0.0	0.0	0.0	0.1	0.0	0.1	2.6	0.4	0.5	0.4
0 P_2O_5	0.1	0.0	0.1	0.1	0.0	0.1	1.5	0.3	0.4	0.3
20 P_2O_5	0.0	0.0	0.1	0.0	0.0	0.1	1.5	0.5	0.4	0.3
40 P_2O_5	0.1	0.0	0.1	0.0	0.0	0.2	2.2	0.5	0.5	0.4
60 P_2O_5	0.0	0.0	0.1	0.0	0.0	0.0	1.6	0.5	0.6	0.3
80 P_2O_5	0.1	0.0	0.0	0.1	0.0	0.1	2.6	0.4	0.5	0.4
Site-Year Average	*0.1*	*0.0*	*0.1*	*0.0*	*0.0*	*0.1*	*1.9*	*0.5*	*0.5*	*0.3*