

FINAL REPORT

OPTIMAL SEEDING RATE BASED ON SEED SIZE IN CANOLA

(PROJECT # CARP SCDC 20 18-084 CATELLIER)

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For:

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ABSTRACT / EXECUTIVE SUMMARY

The Canola Council recommends seeding canola at a sufficient rate to achieve a spring plant density of 5-8 plants ft⁻², which allows for plant losses due to in-season stresses while maintaining the 4-5 plants ft⁻² population required to reach maximum canola yield potential. Variation in management factors, including seeding rate, seed size, and hybrid, has been shown to influence the weight per area seeding rate required to achieve the recommended plant population density and optimize canola yield potential. The objectives of this trial were to: 1) determine optimal seeding rate to achieve adequate plant populations and optimize yield under various environmental conditions in Saskatchewan; and 2) determine if optimal seeding rate varies with seed size and/or hybrid. A small-plot field trial was conducted at five locations (Indian Head, Yorkton, Melfort, Scott, and Outlook) in 2018. The treatments were a full factorial combination of two canola hybrids (InVigor L233P and Pioneer 45M35), two seed sizes of each hybrid ("Small" and "Large"), and three different seeding densities (5, 10, and 15 seeds ft⁻²). There was an effect of seeding rate on all crop response variables that were measured, and the response varied with seed size and/or hybrid. Emergence rates were very high at all locations in 2018, and in-season mortality was minimal. Thus, seeding rates required to achieve adequate plant populations and optimize yield were likely lower than would be expected. Seeding at the lowest seeding rate resulted in adequate plant population (>4 plants ft⁻²) for the two larger-seeded lots, but lower emergence and survival rates for smaller seed lots and for hybrid 45M35 resulted in marginally adequate final plant population for small-seeded L233P and less than adequate plant population for small-seeded 45M35 at the lowest seeding rate. The moderate seeding rate of 10 plants ft⁻² achieved more than adequate plant populations for all combinations of hybrid and seed size. Maturity was delayed with lower seeding rates. The yield response was quite different between hybrids. Yield of hybrid L233P did not respond to seeding rate or resulting plant population, and was not affected by seed size, whereas yield of 45M35 yield was significantly lower with a smaller seed lot, and the yield was optimized at the moderate seeding rate. If emergence and survival rates had been lower, we might have expected a greater yield penalty resulting from less than adequate plant population at the lowest seeding rate. It was concluded that the most economic and least risky seeding rate to achieve adequate plant population would be closer to the moderate 10 seeds ft⁻², but the minimum or adequate plant population required to optimize yield differs among hybrids, and the effect of seed size may or may not be important depending on the hybrid.

INTRODUCTION

The Canola Council recommends seeding canola at a sufficient rate to achieve a spring plant density of 5-8 plants ft⁻² (Canola Council 2019), which allows for plant losses due to in-season stresses (insects, frost, disease) while maintaining the 4-5 plants ft⁻² population required to reach maximum canola yield potential (Shirtliffe & Hartman 2009). Two major considerations when calculating the weight per area seeding rate required to achieve the recommended plant population are seed size (thousand seed weight, [TSW]), and field emergence rate. The average seed size of canola varies significantly among hybrids, and even among seed lots within hybrids. Furthermore, emergence rates can vary significantly with both management and environmental conditions (Hanson et al. 2008, Harker et al. 2012b). Variation in both seed size and emergence rates will affect the weight per area seeding rate required to achieve the recommended plant population density to optimize canola yield potential.

Seeding rate and seed size are in fact both management factors that have been examined for their effect on emergence rates and in-season mortality and subsequent effect on plant densities and yield, but results have been inconsistent in canola (Harker et al. 2017, Brill et al. 2016, Harker et al. 2015, Hwang et al. 2014, Yang et al. 2014, Kutcher et al. 2013, Harker et al. 2012a, Clayton et al. 2009, Elliot et al. 2008, Lamb and Johnson 2004). Studies assessing interactions between seeding rate and seed size on canola response variables have also shown inconsistent results (Harker et al. 2017, Harker et al. 2015). Variability in response among the studies appears to be a result of the actual seeding rates (weight per area or seeding density) and seed sizes examined in each trial, in addition to environmental interactions (Gan et al. 2016, Yang et al. 2014). In addition, several of the studies examine a single hybrid, and it may be possible that different hybrids respond differently to variations in seed size and seeding rate. Previous studies have also shown differing responses between hybrid and open-pollinated canola varieties (Brill et al. 2016, Harker et al. 2012b, Hanson et al. 2008). Furthermore, extensive private industry research has been carried out to examine the influence of seeding rate and seed size on canola productivity with InVigor hybrids (BASF Product Excellence Trials, unpublished), but the same effort has not been applied to other hybrids.

Thus, the objectives of this trial were to: 1) determine optimal seeding rate (seeding density) to achieve adequate plant populations and optimize yield under various environmental conditions in Saskatchewan; and 2) determine if optimal seeding rate (seeding density) varies with seed size and/or hybrid.

METHODOLOGY

I. *Experimental design*

A small-plot field trial was conducted at five locations (Indian Head, Yorkton, Melfort, Scott, and Outlook) in 2018. The trial was conducted using a split-plot design with four replicates. The treatments were a full factorial combination, the main blocks consisting of two canola hybrids with contrasting herbicide tolerance traits (InVigor L233P and Pioneer 45M35), and the subplots consisting of a full randomization of two seed sizes of each hybrid ("Small" and "Large"), seeded at three different seeding densities (5, 10, and 15 seeds ft⁻²). The treatments are listed in Table 1.

Table 1. List of treatments evaluated in 2018 field trial.

Entry	Hybrid	Seed size (g 1000 seeds ⁻¹)	Seeding rate (density) (seeds ft ⁻² / seeds m ⁻²)	Seeding rate (lb ac ⁻¹ / kg ha ⁻¹)
1	L233P	Small (4.3 g)	5 (54)	2.1 (2.3)
2		Small (4.3 g)	10 (108)	4.1 (4.6)
3		Small (4.3 g)	15 (161)	6.2 (6.9)
4		Large (5.5 g)	5 (54)	2.6 (3.0)
5		Large (5.5 g)	10 (108)	5.3 (5.9)
6		Large (5.5 g)	15 (161)	7.9 (8.9)
7	45M35	Small (4.8 g)	5 (54)	2.3 (2.6)
8		Small (4.8 g)	10 (108)	4.6 (5.2)
9		Small (4.8 g)	15 (161)	6.9 (7.7)
10		Large (5.9 g)	5 (54)	2.8 (3.2)
11		Large (5.9 g)	10 (108)	5.7 (6.3)
12		Large (5.9 g)	15 (161)	8.5 (9.5)

Note that the seeding rate treatments are specified as seeding densities (number of seeds per area), and were not adjusted for expected mortality or target plant density at any of the sites. The same four seed lots were used at each of the five sites. Thus, the weight per area seeding rates were the same at each site and varied with each combination of seed size and desired seed density, as shown in the last column of Table 1. Industry representatives were involved in sourcing the seed lots to ensure that the small and large seed lots represented the relatively lowest and highest range of commercially-available seed sizes for each of the two hybrids.

II. *Plot establishment and management*

Plot establishment and management was fairly consistent among sites and are detailed in Table 2.

Table 2. Outline of plot management at each site in 2018 field trials.

	Indian Head	Yorkton	Melfort	Scott	Outlook
Previous crop	Spring wheat		Wheat		Potato
Plot size	8' x 35' (2.4 x 10.7 m)	4' x 30' (1.2 x 9.1 m)	1.8 x 7.0 m	1.5 x 8.0 m	2.0 x 8.0 m
Seeding date	May 16	May 22	May 17	May 18	May 23
Seeder	SeedMaster	Cone	Fabro	Fabro	Fabro
Seeding depth	0.5-0.75" (1.5-2 cm)	0.5" (1.5 cm)	0.75-1" (2-2.5 cm)		0.5" (1.25 cm)
Row spacing	12" (30 cm)	12" (30 cm)	12" (30 cm)	10" (25 cm)	10" (25 cm)
Fertility	150-40-20-20 kg ha ⁻¹ actual N-P ₂ O ₅ -K ₂ O-S, urea + granular blend side-banded	89-34-0-17 kg ha ⁻¹ actual N-P ₂ O ₅ -K ₂ O-S, all side banded. High soil N -61 lb/ac 0-12"	150-40-20-20 kg ha ⁻¹ actual N-P ₂ O ₅ -K ₂ O-S, urea midrow, MAP side-band, K ₂ SO ₄ broadcast	165-23-0-40 kg ha ⁻¹ actual N-P ₂ O ₅ -K ₂ O-S, granular blend midrow + MAP side-band	60 kg N ha ⁻¹ + 35 kg P ₂ O ₅ ha ⁻¹ , urea + MAP, side-banded
In-crop herbicide	Liberty (1.6 L/ac) + Centurion, or Roundup Transorb (0.33L/ac) (June 16)	Liberty, or Roundup Transorb (0.33 L/ac) (June 13)	Liberty (1.35 L/ac) + Centurion, or Roundup 540 (0.51L/ac) (June 7) Assure II (300 mL/ac (June 25)	Liberty (1.6 L/ac) + Centurion, or glyphosate (0.66L/ac) (June 18)	Muster Toss n Go (12 g/ac) + Poast Ultra (0.45 L/ac) (June 19)
Fungicide	None	None	None	None	None
Insecticide	None	None	None	Decis (60 mL/ac) (Aug 13)	None
Pre-harvest operations	Roundup Weathermax (0.67 L/ac) (August 10)		Reglone (0.69 L/ac) (September 6)	Reglone (0.83 L/ac), Aug 23 – L233P, Aug 29 – 45M35	Swathed (August 20)
Harvest	Straight combined centre 5 rows (August 23)	September 18	September 25	September 8 (whole plots)	September 5

III. *Data collection and calculations*

Spring plant density was measured after emergence was complete (3-4 weeks after seeding). The number of plants in two 1-m sections of crop row was counted in each plot, and the counts were converted to plants m⁻², and percent emergence was calculated for each plot based on seeding density. Sclerotinia was not observed in any of the plots at any of the sites in 2018. Maturity date was recorded separately for each plot, when the majority of the plants were at 60% seed colour change on the main stem, and the number of days from seeding to maturity was calculated for each plot. Lodging was assessed after maturity and before harvest operations, but did not differ among plots at most sites, and so the data was not analyzed. Fall stubble density was measured after swathing or combining, in the same manner as spring plant density, and percent survival was calculated for each plot based on seeding density. Seed yield was calculated for each plot, corrected for dockage and to 10% seed moisture content.

IV. *Statistical analysis*

The data from all sites was combined for a multi-site analysis, to assess the overall response across environments. Prior to analysis, the range and variability of each response variable was explored using box-and-whisker plots against each explanatory variable, and possible outliers were noted.

Mixed-effects models were fitted for each response variable individually, with hybrid, seed size, seeding rate, and all two- and three-way interactions as fixed effects, and hybrid (main split-plot) within replicate within site as random effects. Seeding rate was included as a continuous variable, resulting in regression-type models. In some cases, possible quadratic responses to seeding rate were identified in the data exploration stage, and the quadratic term for seeding rate, along with all two- and three-way interactions with hybrid and seed size, were included as fixed effects. Seed size was included as a discrete variable (i.e. small vs large, within hybrid), regardless of absolute seed size, to allow us to control for the effect of hybrid, as average seed size varies significantly among hybrids. It is reasonable to assume that within hybrids, smaller seed lots are generally less vigorous than larger seed lots, while the same cannot be assumed when using absolute seed size of several hybrids. Furthermore, the effect of hybrid was of particular interest in this trial.

Data were analyzed with the R statistical program, version 3.5.1 (R Core Team 2018), using the *lme4* package (Bates et al. 2015) for fitting mixed-effects models, and the *lmerTest* package (Kuznetsova et al. 2017) for assessing model fit and treatment differences. A model simplification approach was used where the least significant interactions and variables are removed from the model one at a time, as long as the reduced model did not result in a significant reduction in model fit (non-significant ($P>0.1$) chi-square test). Higher-order interactions and quadratic terms are removed before simpler interactions and linear effects. A marginal cut-off of $P>0.1$ was used for assessment of model fit so as to not leave out potentially important variables, since all sites were combined in this analysis, which increased variability in the data. Once the final reduced model was reached, model checking plots were used to assess whether the model residuals met the assumptions of normality and homogeneity of variance and to identify the presence of potentially influential outliers.

RESULTS & DISCUSSION

I. Growing season conditions

In general, all locations experienced above-average temperatures and below-normal precipitation in 2018. In particular, above-average temperatures during the emergence period appears to have contributed to the strong emergence rates at all sites. The field trial at Outlook received additional in-season irrigation of 140 mm. The field trial in Scott was affected by hail on July 21.

Table 3. Mean daily temperature and precipitation by month over the 2018 growing season in Indian Head, Yorkton, Melfort, Scott, and Outlook, along with 1981-2010 Climate Normals for each location.

Location	Year	May	June	July	August	
		Mean temperature				Avg.
Indian Head	2018	13.9	16.5	15.4	17.6	15.9
	<i>Long-term</i>	10.8	15.8	18.2	17.4	15.6
Yorkton	2018	13.9	17.6	18.3	18.1	17.0
	<i>Long-term</i>	10.4	15.5	17.9	17.1	15.2
Melfort	2018	13.9	16.8	17.5	15.9	16.0
	<i>Long-term</i>	10.7	15.9	17.5	16.8	15.2
Scott	2018	13.6	16.6	17.5	15.9	15.9
	<i>Long-term</i>	10.8	14.8	17.3	16.3	14.8
Outlook	2018	14.9	17.4	18.5	17.5	17.1
	<i>Long-term</i>	11.5	16.1	18.9	18.0	16.1
		Precipitation				Total
Indian Head	2018	23.7	90	30.4	3.9	148
	<i>Long-term</i>	49	77.4	63.8	51.2	241.4
Yorkton	2018	0.8	120.1	53.8	21.1	195.8
	<i>Long-term</i>	51	80	78	62	271
Melfort	2018	38.5	46.6	69.5	43.2	197.8
	<i>Long-term</i>	39.8	54.3	76.7	52.4	223.2
Scott	2018	29.6	58	85.8	20.2	193.6
	<i>Long-term</i>	38.9	69.7	69.4	48.7	226.7
Outlook	2018	24.9	12.9	35.2	12.6	85.6
	<i>Long-term</i>	39	63.9	56.1	42.8	201.8

II. Percent emergence and spring plant density

The initial analysis revealed several outliers in the spring plant density data which resulted in non-normal residuals, and significantly affected model fit and the results of the model simplification process. Model residuals were well behaved after removal of six outliers. The same six outliers were removed from the percent emergence data because plant density is used to calculate percent emergence.

The reduced model for percent emergence included hybrid ($p=0.070$), seed size ($p=0.028$), and seeding rate ($p=0.002$) as fixed effects (full vs reduced model $\chi^2=3.26$, $df=4$, $p=0.515$). Percent emergence decreased with seeding rate equally in both hybrids, and was significantly lower for small-seeded lots than for large-seeded lots, regardless of hybrid (Figure 1). The effect of hybrid was only significant at $P<0.1$, but suggests that percent emergence was higher in L233P than in 45M35. Emergence was high at all sites in 2018, in the range of 65-85% on average.

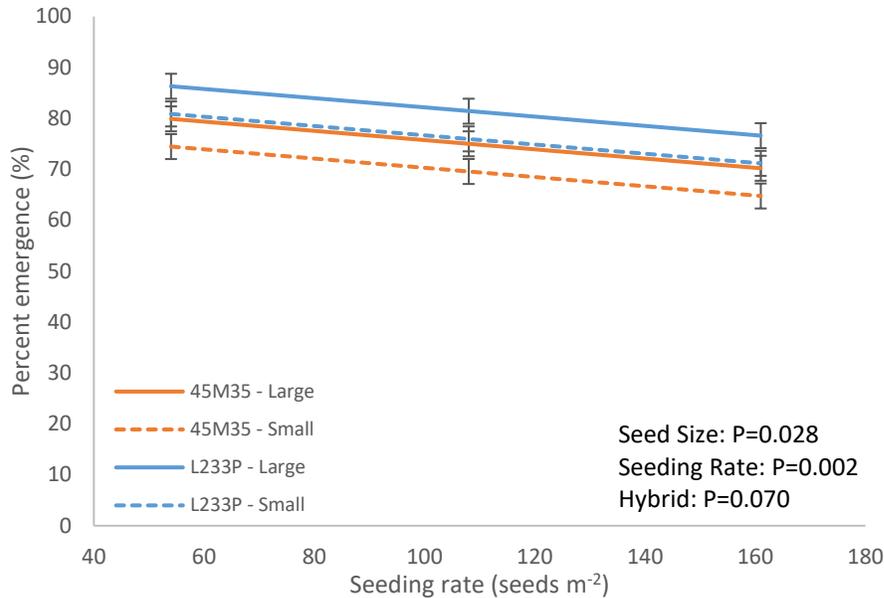


Figure 1. The effect of hybrid, seed size, and seeding rate on percent emergence in canola, averaged over multiple environments in 2018. The error bars indicate the standard error within treatments.

The reduced model for spring plant density included hybrid ($p=0.543$), seed size ($p=0.070$), seeding rate ($p<0.001$), and the seeding rate by hybrid interaction ($p=0.080$) as fixed effects (full vs reduced model $\chi^2=3.35$, $df=3$, $p=0.341$). The only effect significant at $p<0.05$ was seeding rate, indicating that plant density significantly increased with seeding rate for all hybrids and seed sizes (Figure 2). The seeding rate by hybrid interaction was only significant at $P<0.1$, but indicates that the rate of increase with seeding rate was less for 45M35 than L233P, and so density of 45M35 was lower at the highest seeding rate. Plant density tended to be lower for small-seeded lots than large-seeded lots, regardless of hybrid, but again, the effect was only significant at $P<0.1$.

The recommended target spring plant density of 5-8 plants ft⁻² was attained by seeding at the 10 plants ft⁻² seeding rate/density for all four seed lots (Figure 2). At this seeding rate, plant density on average was at the higher end of the recommended range.

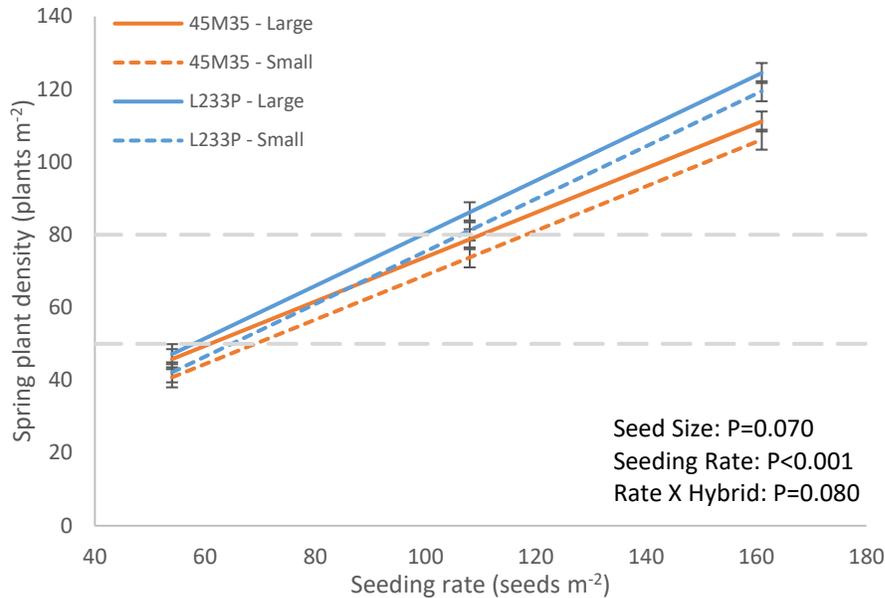


Figure 2. The effect of hybrid, seed size, and seeding rate on spring plant density in canola, averaged over multiple environments in 2018. The error bars indicate the standard error within treatments. The area within the dashed grey lines indicates the industry recommended target spring plant density.

Percent emergence was negatively affected by increases in seeding rate (Figure 1), but the effect on the resulting plant densities was small as plant densities still increased linearly with seeding rate overall. Compared to the percent emergence data, we see that the seed size effect is no longer significant at $p < 0.05$, and this also indicates that the difference in emergence rate between small- and large-seeded lots was not large enough to significantly affect the resulting plant densities. The marginal effect of hybrid on plant emergence (Figure 1) was likely related to the greater plant density of L233P at higher seeding rates.

Similarly, Harker et al. (2017) found a significant seed size by seeding rate interaction, where seeding rate had a positive effect on canola density, large seed had greater density than small seed overall, and seeding rate increases led to slightly greater canola densities with large seed compared to small. This trial used the same range of seeding rates as the present trial, and size was treated as a discrete variable (single seed lot segregated into “small” and “large” fractions, with different seed lots in each year). In contrast, Harker et al. (2015) observed that a higher seeding rate led to higher spring plant density, but the emergence rate did not differ between seeding rates, and there was no effect of seed size. In this trial, seeding rate was treated as a discrete variable with two levels (75 and 150 seeds m⁻²), while seed size was treated as a continuous variable. Elliot et al. (2008) and Brill et al. (2016) also found that larger canola seed resulted in greater canola emergence and/or higher resulting plant densities compared to small seed, while other studies did not observe an effect of seed size on canola emergence and plant density (Hwang et al. 2014, Clayton et al. 2009, Lamb and Johnson 2004). Private industry trials have shown that percent establishment declines with increasing seeding rate, consistently across InVigor hybrids, but there was no difference in percent emergence between seed lots of the same hybrid with different TSWs, when seeded at the recommended density of 10 plants ft⁻².

III. *Percent survival and fall stubble density*

The reduced model for percent survival included hybrid ($p=0.002$), seed size ($p=0.001$), and seeding rate ($p<0.001$) as fixed effects (full vs reduced model $\chi^2=3.84$, $df=4$, $p=0.428$). These results are similar to the percent emergence results; however, the hybrid effect is now significant at $p<0.05$, indicating that 45M35 experienced greater in-season mortality than L233P (Figure 3).

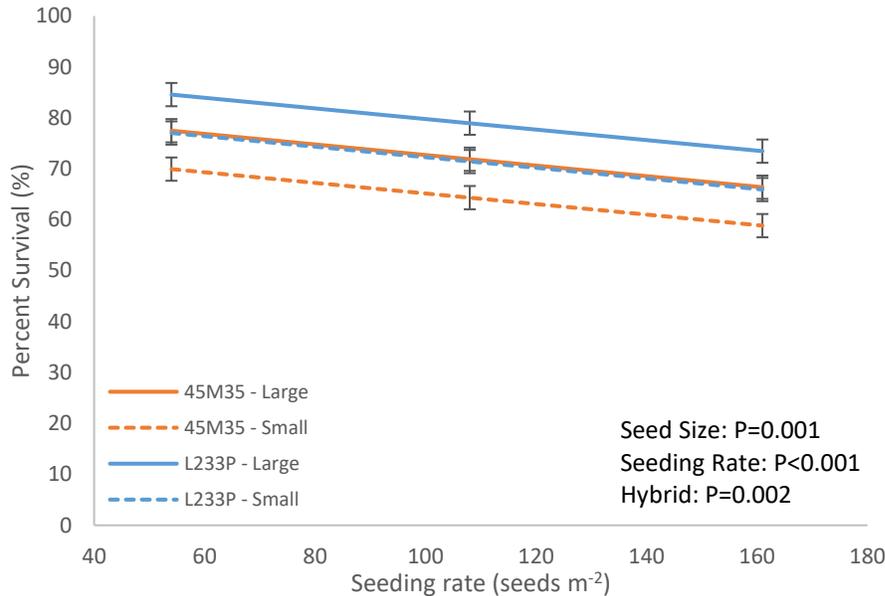


Figure 3. The effect of hybrid, seed size, and seeding rate on percent survival in canola, averaged over multiple environments in 2018. The error bars indicate the standard error within treatments.

The reduced model for fall stubble density included hybrid ($p=0.584$), seed size ($p=0.001$), seeding rate ($p<0.001$), and the seeding rate X hybrid interaction ($p=0.043$) as fixed effects (full vs reduced model $\chi^2=3.06$, $df=3$, $p=0.383$). The results are similar to the spring plant density results, however seed size and the seeding rate by hybrid interaction are now significant at $p<0.05$. The results could partly be due to lower variability in fall stubble count data compared to spring density data, due to in-season mortality and thinning, but there does appear to be a greater separation between seed sizes within hybrids and between hybrids within the same seed size (Figure 4). This indicates that small seed lots experienced relatively greater in-season mortality than large seed lots, and that 45M35 experienced relatively greater increase in in-season mortality than L233P with increasing seeding rates.

The minimum canola plant density required for maximum potential yield was attained at the 10 plants ft⁻² seeding rate/density, with plants to spare for all four seed lots, and even at the 5 plants ft⁻² seeding rate for large-seeded lots (Figure 4).

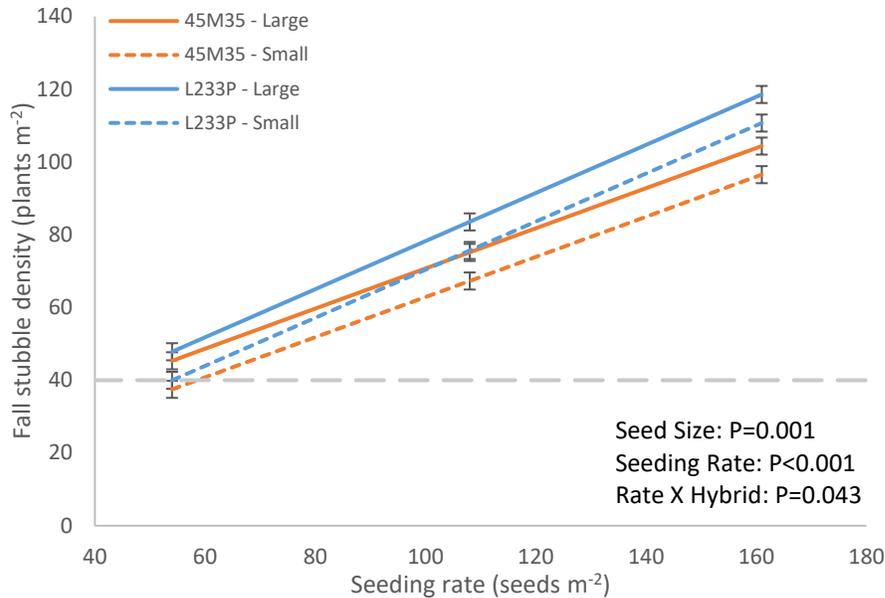


Figure 4. The effect of hybrid, seed size, and seeding rate on fall stubble density in canola, averaged over multiple environments in 2018. The error bars indicate the standard error within treatments. The grey dashed line indicates the minimum plant density required to achieve maximum yield potential in canola.

Greater apparent in-season mortality for small seed compared to large seed, and for 45M35 compared to L233P at higher seeding rates, resulted in a significant seed size effect and seeding rate by hybrid interaction in fall stubble density, whereas these effects were not significant at spring density timing. Yet, for each of the four seed lots, fall stubble density still increased with seeding rate overall, and density was above the minimum population required for optimizing canola yield potential when seeded at the industry-recommended 10 plants ft⁻², and even at the 5 plants ft⁻² rate for larger-seeded lots (Figure 4). Greater in-season mortality could be a result of the crop self-thinning due to intra-species competition at high plant densities or high crop biomass (Yang et al. 2014), but since greater mortality was seen in the seed lots that already had marginally lower densities in the spring, mortality could also be related to the seed lots' resilience to in-season stresses.

Similarly, Harker et al. (2017) observed a linear increase in plant mortality with increasing seeding rates, and lower in-season plant mortality for larger seed compared to small seed. In contrast, there did not appear to be a difference in mortality between the two seeding rates examined by Harker et al. (2015), as neither emergence rate or survival rate differed between the two, and there was no effect of seed size. Private industry trials with InVigor hybrids showed that mortality (in-season thinning) increased with seeding rate, however the greatest increase in mortality was observed at seeding rates beyond 15 plant ft⁻² (BASF, unpublished).

IV. Days to maturity

The reduced model for days to maturity included hybrid ($p < 0.001$), seed size ($p = 0.323$), seeding rate ($p < 0.001$), and the seeding rate by seed size interaction ($p = 0.068$) as fixed effects (full vs reduced model $\chi^2 = 5.09$, $df = 3$, $p = 0.165$). Days to maturity decreased with seeding rate and was lower overall for L233P

than for 45M35 (Figure 5). In the lower density canopies resulting from the lowest seeding rate, canola plants will branch more and maturity can be delayed significantly (Angadi et al. 2003). The seeding rate by seed size interaction was only significant at $P < 0.1$ but indicates that the rate of decrease in days to maturity with seeding rate was greater in large seed lots compared to small seed lots, and is likely due to a reduction in compensatory growth with denser plant populations and potentially greater biomass of large seed lots at higher seeding rates (Angadi et al. 2003). Greater early-season biomass with large seed lots compared to small seed lots is unconfirmed in this trial, but was demonstrated in several studies (Harker et al. 2017, Brill et al. 2016, Harker et al. 2015, Hwang et al. 2014, Elliot et al. 2008).

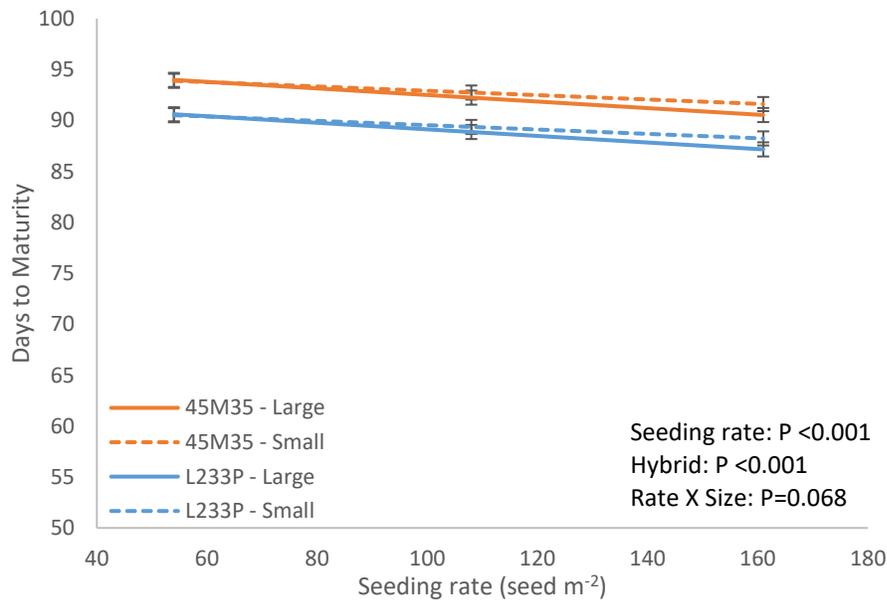


Figure 5. The effect of hybrid, seed size, and seeding rate on days to maturity in canola, averaged over multiple environments in 2018. The error bars indicate the standard error within treatments.

In comparison, Harker et al. (2017) observed that days to maturity decreased linearly with seeding rate, and that large seed decreased days to maturity compared to small seed, but there was no interaction between seeding rate and seed size. Also, Harker et al. (2015) observed that higher seeding rate reduced days to maturity, but there was no effect of seed size on maturity. However, there was a significant decrease in days to start and end of flowering with large seed size in this study. Clayton et al. (2009) did not detect seed size effect on canola maturity. Private industry trials with InVigor hybrids also showed that days to maturity decreased with increasing seeding rates.

V. Seed yield

Data exploration indicated a possible quadratic response of yield to seeding rate, thus the quadratic term for seeding rate and the two- and three-way interactions with hybrid and seed size were also included as fixed effects in the full model. Also, the initial analysis revealed issues with model residuals and very high standard error, which it was determined was attributable to high variability in yield data at

Melfort. The analysis was repeated with Melfort data removed and the results were unchanged but model residuals were well behaved and standard error was greatly reduced. Thus, the results presented below do not include yield data from Melfort.

The reduced model for seed yield included hybrid ($p=0.009$), seed size ($p=0.001$), seeding rate ($p=0.038$), seeding rate² (0.083), the hybrid by seed size interaction ($p=0.006$), the seeding rate by hybrid interaction ($p=0.009$), and the seeding rate² by hybrid interaction ($p=0.012$) as fixed effects (full vs reduced model $\chi^2=2.89$, $df=4$, $p=0.576$). The seeding rate by hybrid and seeding rate² by hybrid interactions were such that yield of 45M35 had a quadratic response to seeding rate, but yield of L233P did not appear to respond to seeding rate (Figure 6). The hybrid by seed size interaction indicated that there was a significant increase in yield with larger seed size in 45M35 but not in L233P. Thus, the effect of hybrid appears to outweigh the effects of seeding rate and seed size on canola yield. Yield of L233P was consistent across seeding rate and seed size, regardless of differences in plant populations and maturity, while yield of 45M35 appears to be indirectly affected by seeding rate and seed size effects on emergence rate, spring plant density, survival rate, fall stubble density, and maturity. Hybrid L233P achieved maximum yield at the lowest seeding rate, and we saw that fall stubble density of L233P was close to or above minimum required to achieve maximum potential yield (Figure 4).

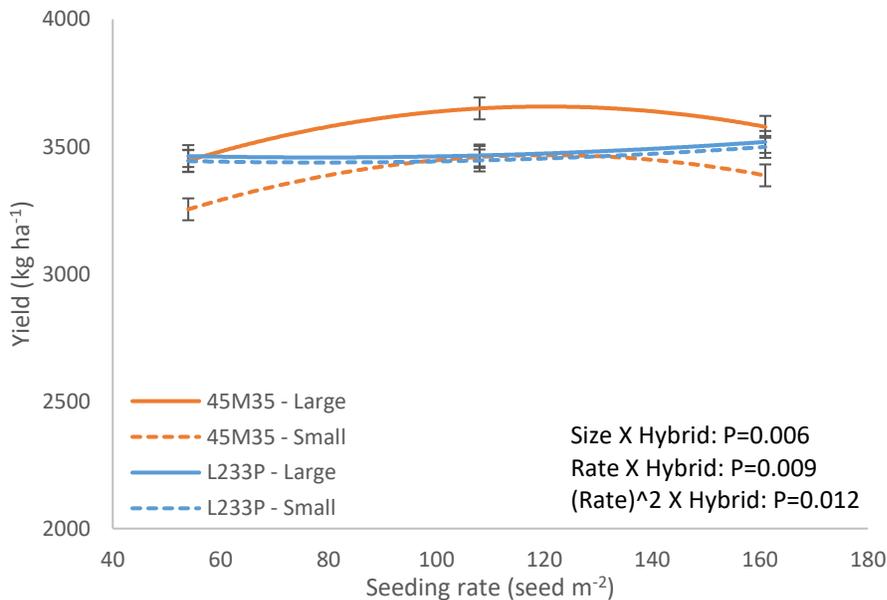


Figure 6. The effect of hybrid, seed size, and seeding rate on canola seed yield, averaged over multiple environments in 2018. The error bars indicate the standard error within treatments.

In comparison, Harker et al. (2017) found a significant interaction of seeding rate and seed size on seed yield, such that yield increased with seeding rate for small seed but not for large seed. Most of the yield response to seeding rate with smaller seed occurred at lowest seeding rates (50 to 75 seeds m⁻²). In the same study, plant density and early crop biomass increased with seeding rate and with seed size. Also, Harker et al. (2015) observed that higher seeding rate did not result in higher yield, even though spring plant density and early crop biomass increased with seeding rate, and there was no effect of seed size. Recall that the seeding rates examined in this trial were 75 and 150 seed ft⁻². In some studies, canola

yield increased with seeding rate (Harker et al 2012a, 75 and 150 seeds m^{-2}), and in other studies seeding rate did not influence yield (Kutcher et al 2013). Gan et al. (2016) observed that yield response to seeding rates appeared to depend not only on environment, but which seeding rates or plant densities were being compared; lower seeding rates were more likely to show yield responses to increased seeding rates than higher seeding rates. Also, Yang et al. (2014) found that seed yield increased with seeding rate, but leveled off at higher plant densities. In regards to seed size, yield benefit from larger canola seed was observed by Elliot et al. (2008) and Brill et al. (2016), while Harker et al. (2015), Clayton et al. (2009), and Lamb and Johnson (2004) did not see a benefit of larger seed on canola yield. Private industry trials showed a quadratic yield response to seeding rate, but there was no difference in yield between seed lots of the same hybrid with different TSWs, when seeded at the recommended density of 10 seeds ft^{-2} . The quadratic yield response appeared to be a result of significant increases in yield at the lowest seeding rates, which were lower than the seeding rates used in the present study (2 to 4 seeds ft^{-2}), and relatively smaller increases in yield with higher seeding rates (BASF, unpublished).

Increased intra-crop competition, observed as greater in-season mortality at higher seeding rates, can potentially affect yield due to plants competing for resources (Angadi et al. 2003). Though we didn't statistically assess in-season mortality as a response variable, the difference in spring plant density and fall stubble density suggested that mortality increased with seeding rate in the hybrid 45M35. Thus, the quadratic yield response of hybrid 45M35 to increases in seeding rate, with a relatively smaller increase in yield at the higher seeding rate, could be a result of greater intra-species competition at higher plant densities.

Plant population effects on plant structure and crop development in canola (Angadi et al. 2003) can also have indirect effects on yield through effects on flowering period, evenness of crop maturity, and harvestability (Gan et al. 2016). In the present trial, we observed a decrease in days to maturity with increasing seeding rate, and a potentially greater rate of decrease with large seed compared to small seed (Figure 5), but this did not appear to translate into yield benefits. However, even with the benefit of early and even maturity with higher seeding rates, there is a case for moderate seeding rates over high seeding rates. Canola yield can also be indirectly affected by seeding rate through plant population influence on disease incidence. Jurke and Fernando (2006) found that when seeding rates resulted in high canola densities, stems were very thin and more susceptible to lodging and infection by disease vectors, and the denser canopy could also create a better microenvironment for diseases like sclerotinia. Private industry trials with InVigor hybrids also showed that lodging increased linearly with seeding rate, and the rate of increase was greater in hybrids already susceptible to lodging. However, environmental conditions in 2018 were not conducive to lodging or sclerotinia development and so we were unable to confirm this relationship.

Canola yield can also be indirectly affected by seed size influence on crop biomass and resilience to in-season stresses (insects, disease, frost). Elliot et al. (2008) determined that larger canola seed produced significantly larger seedlings, and concluded that higher yields with larger canola seed may be related to resilience of larger seedlings to flea beetle attack. Several other studies that showed increased biomass with larger seed also showed significant yield increases with larger seed (Harker et al. 2017, Brill et al. 2016, Elliot et al. 2008). However, early season biomass was not measured in this trial.

CONCLUSIONS AND RECOMMENDATIONS

Objective 1: Determine optimal seeding rate (seeding density) to achieve adequate plant populations and optimize yield under various environmental conditions in Saskatchewan:

Results of this trial indicate that there was an effect of seeding rate on all crop response variables that were measured. Plant populations resulting from specific seeding rates are a product of emergence rates and survival rates or mortality. Emergence rates were very high at all locations in this trial, compared to published values, and in-season mortality was minimal. Thus, seeding rates required to achieve adequate plant populations and optimize yield were likely lower than would be expected. Spring plant densities were below the industry recommended 5 to 8 plants ft⁻² for all seed lots at the lowest seeding rate, but with low in-season mortality, fall stubble density indicated plant population was actually adequate at lowest seeding density for the two larger seed lots of each hybrid. However, maturity was delayed with lower seeding rates. A moderate seeding rate of 10 plants ft⁻² achieved more than adequate plant populations for all four seed lots.

A yield response to seeding rate is less likely when high emergence rate results in adequate plant populations at low seeding rates (Gan et al. 2016, Yang et al. 2014). If emergence and survival rates had been lower, we might have expected a greater yield penalty resulting from less than adequate plant population at the lowest seeding rate. We did not observe any negative effect of seeding at the highest rate, though negative effects of high seeding rates have been shown in other studies, and the only positive effect was a slight reduction in days to maturity. Thus, with the lack of yield benefit at the highest seeding rate, the most economic and least risky seeding rate would be closer to the moderate 10 seeds ft⁻².

Objective 2: Determine if optimal seeding rate (seeding density) varies with seed size and/or hybrid.

The crop response to seeding rate did vary with seed size and hybrid, and sometimes both. Lower emergence and survival rates for smaller seed lots and for hybrid 45M35 resulted in marginally adequate plant population for small-seeded L233P and less than adequate plant population for small-seeded 45M35 at the lowest seeding rate. In year or locations with lower (closer to normal) emergence rates, we would expect less than adequate plant populations for all seed lots at this seeding rate. The moderate seeding rate of 10 plants ft⁻² achieved more than adequate plant populations for all combinations of hybrid and seed size. However, the yield response was quite different between hybrids. Yield of hybrid L233P did not respond to seeding rate or resulting plant population, and was not affected by seed size, whereas yield of 45M35 yield was significantly lower with a smaller seed lot, and the yield was optimized at the moderate seeding rate, even though plant population was adequate at the lowest seeding rate. Thus, the minimum or adequate plant population required to optimize yield differs among hybrids, and the effect of seed size may or may not be important depending on the hybrid.

Effect of environment

In our analysis, site was included as a random effect and individual site responses were not examined. Response to seeding rate and seed size is very likely dependent on environmental conditions. Harker et al. (2017) found that there was a significant site by seeding rate interaction, indicating that emergence, and the relationship with seeding rate, varied significantly with environment. Private industry trial with InVigor hybrids also indicated that yield response to seeding rates varied across locations depending on

yield potential. The yield response to seed size observed by Elliot et al. (2008) was attributed to larger seedlings being more resilient to flea beetles, and so would only apply in situations with flea beetle pressure. However, with only five sites and no replication within sites (one year only), it was more appropriate to combine sites and examine the overall response, which would be the most likely or average response expected, across the environmental conditions experienced in this trial. With more environmental replication, site-years could be grouped, for example, by low or high emergence rate or yield potential, and this would be more insightful than exploring results at individual site-years.

Recommendations

The differing response between hybrids was prominent in this study. However, only two hybrids were examined, and so it will be difficult to predict other hybrids' precise response to seeding rate and seed size from these results. It is also difficult to know the precise emergence and mortality rates that can be expected in any environment. Thus, the least risky and most economical choice would be to seed canola at or near the moderate seeding rate of 10 seeds ft⁻², and consider using larger seed lots or a slightly higher seeding density with relatively smaller seed lots.

In consideration of seed size, producers have little control over the TSW of the seed that they purchase, and the disadvantage of large seed is the higher weight and cost required to achieve the same plant population compared with when smaller seeds are planted. The benefits of large seed as demonstrated by this trial are not likely large enough to balance the differential in weight per area seeding rates required to achieve similar plant populations with large compared to small seed.

It is also in producers' best interest to monitor emergence and/or survival rates on a field-by-field and yearly basis to be able to determine typical or expected rates for their operation and management system. Producers who can ensure a high emergence rate and are willing to assume the risk of potential in-season plant loss may be able to use slightly lower seeding rates.

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APPENDICES

Tabulated data and detailed results of statistical analyses can be provided upon request. Plot photos are also available.