Response of Canola to Low Plant Populations and Evaluation of Reseeding Options

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Background & Objectives: Current canola seeding rate recommendations are to achieve a target plant population of 70-140 plants m^{-2}, which, based on a typical 50% seed survival rate translates to a seeding rate of 140-280 seeds m^{-2} (Canola Council of Canada 2013). There have been numerous studies looking at canola seeding rates; however, there is limited data on the response of canola, particularly hybrids, to extremely low plant populations. Studies by Angadi et al. (2003) Shirtliffe (2009) and McGregor (1987) found minimal reductions in seed yield when plant populations were reduced to 40-45 plants m^{-2}. Newer hybrid canola cultivars may have a higher degree of phenotypic plasticity than open pollinated cultivars, and may be able to compensate at reduced densities with increased plant size. The potential drawbacks to low plant populations include reduced weed competition, extended maturity and difficult swathing. The objective of this trial is to determine the minimum plant population required to reach maximum yield and quality risks with each reseeding option in terms of maturity, yield and quality.

Methodology: Field experiments were conducted at Indian Head, Melfort, Saskatoon, Scott and Swift Current 2010-2012. Both experiment 1 and 2 were set up as a randomized complete block design with four replicates. Experiment 1 consisted of seven seeding rates varying: canola (5440LL) was seeded at 5, 10, 20, 40, 80, 150 and 300 seeds m^{-2}. At Scott and Melfort 5770LL was also seeded to all seven seeding rates. Experiment 2 consisted of re-seeding option: three varieties seeded in early or mid-June compared to two control plots (low and high plant population) seeded in early May. The variety 5440 LL was seeded at a rate of 150 seeds m^{-2} in one treatment, and at a rate of 40 seeds m^{-2} to the remaining seven treatments in early May. The 40 seed m^{-2} treatments were used to simulate poor emergence conditions. All but one of the treatments planted at 40 seeds m^{-2} was later killed with glyphosate. After glyphosate application, two hybrid canola cultivars, 5440LL and 9350RR, and a synthetic Polish canola variety were planted in early and mid-June. Plots in both experiments were fertilized to soil test recommendations and herbicides, insecticides and fungicides were applied as required. Plots were straight combined.

Data collection at all sites in experiment 1 included spring plant density, days to maturity, grain yield. At the Scott and Saskatoon locations data was also collected on branching, pods per plant and seeds per pod (data not shown). Spring plant density was measured at the two leaf stage by counting plants in two random 1 m paired rows within each plot. Grain yield was measured as clean seed weight per plot dried to an even moisture level. All variables were analyzed separately using analysis of variance (ANOVA) in the Proc Mixed procedure (SAS Institute, Inc. 2001). Site years were analyzed separately and combined. In the combined analysis treatment was considered a fixed effect and block and site year were considered random effects.

Homogeneity of variance was assessed with Levene's test and normality was assessed using Shapiro-Wilks (SAS Institute, Inc. 2001). Data transformations were performed when necessary to normalize the data so that all data conformed to the assumptions of the ANOVA. Separation of means was performed by Fisher's protected Least Significant Difference (LSD) test to determine significant differences ($P \leq 0.05$) among treatments. The plant density above which there is no significant change in yield, referred to as the breakpoint, and the plant density required to achieve 80 and 90% of maximum yield was determined using quadratic broken-line regression analysis according to procedures outlined by Robbins et al. (2006). The plant density above which there is no significant change in days to maturity, referred to as the breakpoint, was determined using straight broken-line regression analysis according to procedures outlined by Robbins et al. (2006).

Data collection in experiment 2 included spring plant density and grain yield using a similar protocol as experiment 1. Variables were analyzed separately using analysis of variance (ANOVA) in the Proc Mixed procedure (SAS Institute, Inc. 2001). Initially all site years were combined and analyzed with treatment considered a fixed effect and block and site year considered random effects. Because the treatment by site year interaction was significant for each variable, site years were also analyzed separately. Assumptions regarding the conformity of the data were tested using Proc Univariate. Data was tested for normality using the Shapiro-Wilk Statistic; all datasets followed a normal distribution; therefore, transformations were not required. Site years with unequal variance among treatments were corrected using the repeated statement. Separation of means was performed by Fisher's protected Least Significant Difference (LSD) test to determine significant differences ($P \leq 0.05$) among treatments.

Results:

Experiment 1

Plant density increased with increasing seeding rates at all locations (data not shown). Reduced emergence at the highest seeding rates is likely the result of increased plant competition and self-thinning. At most site years, percent emergence was near or above 100% at the lowest seeding rates, due to the presence of volunteer canola.

Seed yield increased with increasing plant density at ten of the eleven locations (Table 1). There was no significant yield difference between seeding rates of 20, 40 and 80 seeds m^{-2} (corresponding to plant densities of 12-39 plants m^{-2}, on average) at six of eleven site years, and no significant yield difference between seeding rates ranging from 20 to 300 seeds m^{-2} at four site years (Table 1). As plant density increased yield reached a plateau; however, plant density was not high enough to result in a yield decrease, as seen in other studies.

There was a strong quadratic relationship at six of the ten site years (data not shown) and in the combined analysis of all site years (Figure 1). At the sites where there was a strong relationship between yield and plant density seed yield plateaued at plant densities ranging from 11 to 30 plants m^{-2} (data not shown). Ninety and 80% of maximum yield was achieved at plant densities ranging from 8 to 20 and 6 to 12 plants m^{-2}, respectively at the individual sites (data not shown). When site years were combined yield plateaued at 28 plants m^{-2} and 90 and 80% of maximum yield was achieved at plant densities of 18 and 12 plants m^{-2}, respectively (Figure 1). The results of this study found that plant density can be reduced to lower levels without significant yield reductions than those previously reported. However, these numbers should not be used as target seeding rates; the

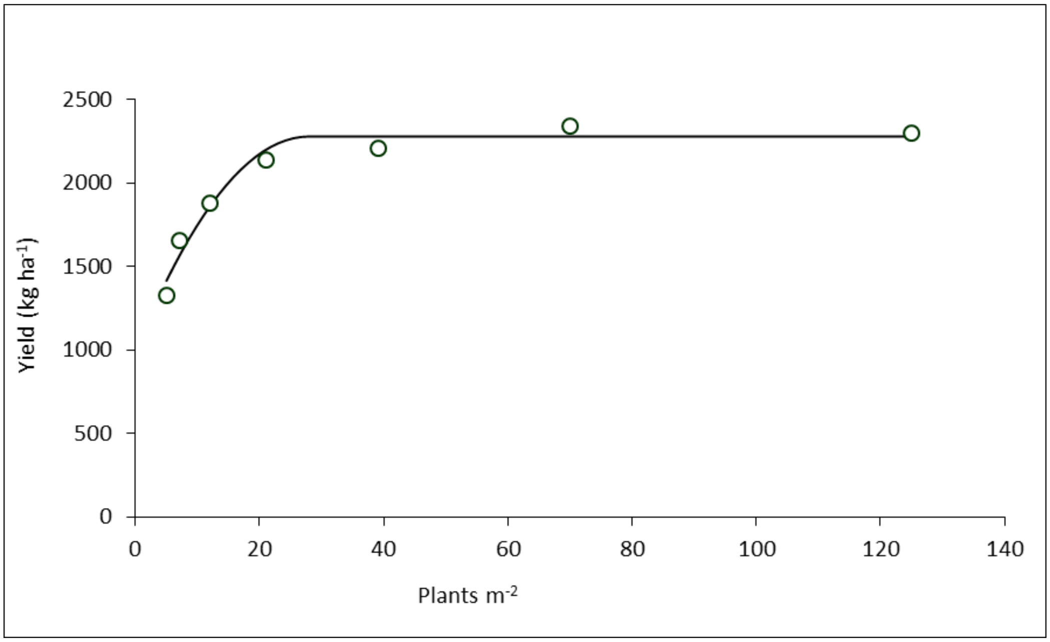

Figure 1. Mean quadratic response of seed yield to plant density. 100%, 90% and 80% of maximum yield achieved at 28, 18 and 12 plants m^{-2}, respectively.

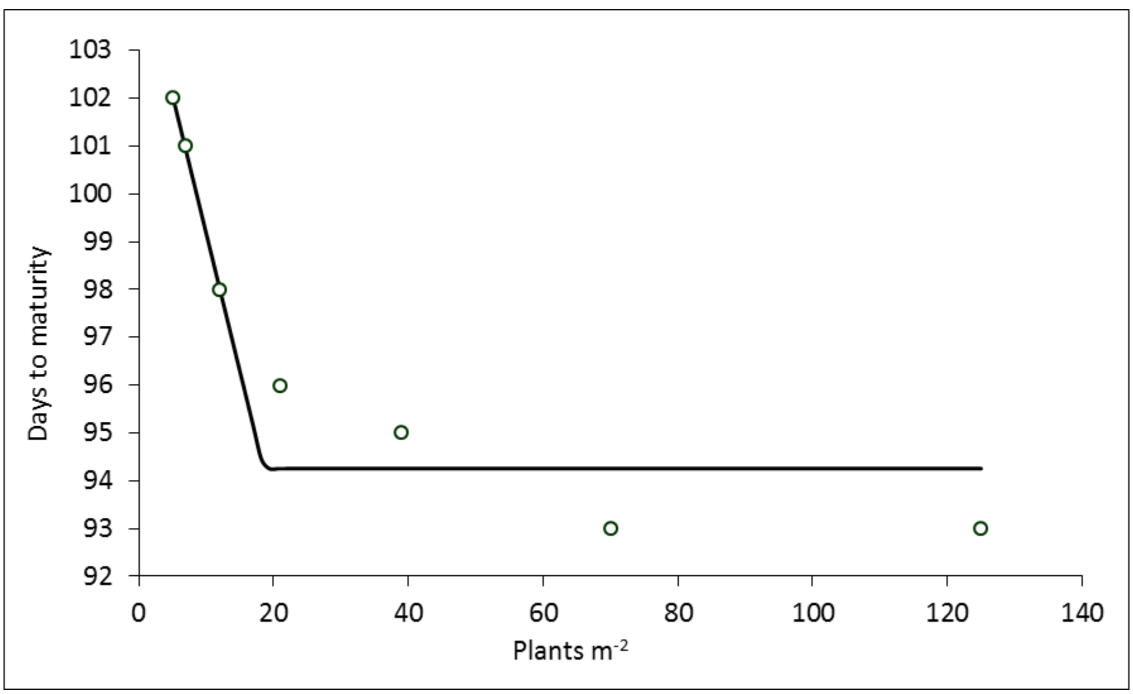

Figure 2. Mean quadratic response of days to maturity to plant density. The breakpoint, plant density above which there is no significant change in days to maturity, is 19 plants m^{-2}.

Table 1. Seed yield (kg ha^{-1}) response to various seeding rates at individual site years and mean plant density and seed yield across all site years.

Seeds m^{-2}	Mean plants m^{-2}	Indian Head			Melfort	Saskatoon			Scott	Swift Current			Mean seed yield
		2010	2011	2012	2011	2010	2011	2012	2011	2010	2011	2012	
5	5	2122^{c}	2245^{d}	1370	1702de	1404^{b}	1305^{c}	1337^{c}	1075^{d}	1327^{c}	574^{d}	818^{e}	1328^{f}
10	7	2010^{bc}	2934^{c}	1853	1627^{e}	1490^{b}	1657^{b}	1594^{c}	1637^{c}	1381^{bc}	1043^{c}	1063^{d}	1660^{e}
20	12	2254^{abc}	3080^{bc}	2056	1757^{cde}	1813^{ab}	1919^{ab}	1641^{c}	1778^{bc}	1619^{abc}	1279^{c}	1209^{cd}	1882^{d}
40	21	2631^{ab}	3437^{ab}	2075	2070^{bc}	1922^{a}	2337^{a}	2039^{b}	2359^{a}	1852^{ab}	1903^{b}	1314^{c}	2142^{c}
80	39	2512^{ab}	3509^{a}	1865	2010^{bcd}	2011^{a}	2326^{a}	2394^{ab}	2422^{a}	1844^{ab}	2140^{ab}	1483^{b}	2214^{bc}
150	70	2825^{a}	3511^{a}	2018	2403^{a}	2091^{a}	2389^{a}	2491^{a}	2282^{ab}	1930^{a}	2333^{a}	1590^{b}	2347^{a}
300	125	2710^{a}	3658^{a}	1873	2280^{ab}	1976^{a}	2429^{a}	2353^{ab}	2512^{a}	1842^{ab}	2344^{a}	1678^{a}	2304^{ab}

plant densities and associated yields reported in the present study can be used as a guideline for when reseeding is being considered. It is also important to consider environmental conditions when interpreting these results. With the exception of Melfort 2011, which experienced less than normal precipitation, precipitation was not limiting in any site year.

The number of pods per plant, branches per plant and seeds per pod were measured at the Saskatoon and Scott locations. As plant density decreased the number of branches per plant increased and pods per plant increased (data not shown). Averaged across years and locations, the number of pods per plant increased from 150 at 150 and 300 seeds m^{-2} to 851 at 5 seeds m^{-2}. In general, the increase in pods per plant was due to increased podding on primary and secondary branches, not the main raceme (data not shown). The number of seeds per pod was fairly stable across the range of plant populations and ranged from 25 to 27 seeds per pod.

Although seed yield was maintained at low plant populations, other agronomic factors can be affected. The length of flowering period generally increased with decreasing plant density, on average by 6 days as plant density decreased from 70 to 21 plants m^{-2}. At some sites, this period was prolonged; for example, at Scott and Indian Head, length of flowering at 70 plants m^{-2} was 9-24 days shorter than at 5 plants m^{-2}. Increasing plant density also significantly reduced days to maturity (data not shown). The combined analysis found that when the plant population was reduced from 70 to 5 plants m^{-2} there was a 9 day increase in days to maturity, however, reductions from 70 plants m^{-2} to 21 plants m^{-2} (approximate value where 90% maximum yield achieved) resulted in a 3 day increase in days to maturity. The increase in flowering time and days to maturity at lower plant densities was likely a result of increased branching. Averaged across all site years, the plant density at which days to maturity plateau's is 19 plants m-2 (Figure 2). Across the nine site years the breakpoint ranged from 8 to 67 plants m^{-2} (data not shown). A greater percentage of green seed at lower seeding rates reflects the increase in days to maturity when plant density decreases. Percent distinctly green seed decreased with increasing plant density, with significant differences between plant densities at seven of ten sites where green seed was measured. Averaged across site years there were significant differences in percent green seed, 5 plants m^{-2} resulted in 0.76% greater green seed than a density of 70 plants m^{-2}.

Plant density had a significant effect on lodging at four of seven sites where lodging was measured (data not shown). Results were inconsistent however: at Indian Head in 2011 and 2012 lodging was observed at the higher plant densities, while at Scott in 2011 and 2012 there was more lodging at the lower plant densities. Increased lodging at lower plant densities occurred due to the canola plants becoming so large that the stem was unable to support the pant at maturity. In some cases the stems were susceptible to breaking.

In general, seed weight was not strongly influenced by plant density and inconsistent effects among site years occurred: seed weight decreased with increasing plant density at two sites and increased with increasing plant density at two sites (data not shown).

At Scott and Melfort, where 5770LL was compared to 5440LL, there were no significant yield difference between the two cultivars at any seeding rate (data not shown). On average, 5770LL reached maturity three days later than 5440LL, which resulted in 5770LL having a greater percentage of distinctly green seed (data not shown).

Experiment 2

The low plant population control had, on average 21 plants m^{-2} compared to 79 plants m^{-2} in the high plant population control. All re-seeding options provided plant populations significantly higher than the low plant population control seeded in early May, however, reseeding in mid-June resulted in a reduced plant stand compared to early June seeding (Table 2).

The high plant population control seeded in early May had significantly higher yields at eight of 12 sites years compared to the low plant population control (Table 3), which illustrates the importance of targeting adequate plant populations to begin. Reseeding a low plant stand of canola to 5440 LL in early June resulted in a significant yield increase in six of 12 site years and in the combined analysis (Table 3). Reseeding to 9350RR resulted in a significant yield increase in only three site years (Table 3). At both Swift Current site years reseeding resulted in a significant yield decrease (data not shown), likely to hot and dry conditions in August. Generally, reseeding in mid-June resulted in a lower yield. Although the polish canola requires a shorter growing season, it did not provide a yield benefit over the low plant population control seeded in early May treatment when reseeded in both early or mid-June (Table 3). The B. napus varieties yielded significantly higher than the B. rapa when seeded in early June; however, there was no significant yield difference between B. napus and B. rapa at the mid-June seeding date (Table 3).

Percent green seed increased as seeding dates were delayed. Averaged across site years, green seed increased from approximately 1% with early May seeded canola to over 5% with mid-June seeded canola (data not shown). There was generally no significant difference in percent green seed between cultivars at either reseeding date or between the low and normal seeding rate treatments planted in early May.

The economic analysis only includes variable costs that differ between treatments, i.e. seed and herbicide costs (Table 4). Canola seeded in early May at a rate of 150 seeds m^{-2} provided the greatest economic return (Table 4). On average, reseeding to 5440LL resulted in positive net returns compared to the low plant population control seeded in early May (Table 4). When including the SCIC establishment benefit of \$148 ha^{-1} there is a positive net return for 9350RR seeded in early June as well (Table 4). Although the seed costs for the polish variety are lower than that of a hybrid, it did not make economic sense to reseed to polish canola at either reseeding date (Table 4).

Conclusions: Canola plants exhibited a high level of plasticity and were able to maintain seed yield across a range of plant populations. When results from all site years were combined a plant population of 18 plants m^{-2} was required to achieve 90% of maximum yield, compensating by increasing the number of branches and pods per plant. A potential drawback of reduced plant populations is increased days to maturity and green seed. There was no significant difference between the low and high plant populations seeded in early May but as seeding date was delayed to mid-June there was a significant increase in green seed content. Distribution of the canola plants in the field is another consideration: non-uniform distribution of seedlings may yield lower than uniformly distributed plants at very low plant populations.

Table 2. Influence of seeding date, variety and seeding rate on spring plant density.

	Indian Head		Melfort		Swift Current		Scott	Saskatoon		
Treatment[1]	2010	2011	2010	2012	2011	2012	2011	2010	2012	Mean
	(plants m^{-2})									
EM - 5440 LL - 20	19[d]	12[b]	45c[d]	28[e]	18[c]	16[c]	4[b]	29[d]	17[d]	21[e]
EM - 5440 LL - 150	90[ab]	85[a]	84[a]	88[c]	79[a]	84[a]	27[b]	78[c]	94[ab]	79[abc]
EJ - Polish - 150	79[bc]	87[a]	46[d]	87[c]	44[b]	58[b]	59[a]	92[bc]	79[bc]	70[b]c
EJ - 5440 LL - 150	96[ab]	97[a]	81[ab]	114[a]	83[a]	80[a]	69[a]	128[a]	111[ab]	95[a]
EJ - 9350 RR - 150	103[a]	95[a]	58[abc]	60[d]	74[a]	78[a]	74[a]	109[ab]	120[a]	86[ab]
MJ - Polish - 150	63[c]	8[b]	15[d]	88[c]	52[b]	11[c]	65[a]	-	52[cd]	45[d]
MJ - 5440 LL - 150	98[ab]	6[b]	24[cd]	108[ab]	80[a]	20[c]	59[a]	-	85[abc]	61[cd]
MJ - 9350 RR - 150	93[ab]	5[b]	26[cd]	93[bc]	81[a]	16[c]	72[a]	-	90[ab]	61[cd]
LSD	21.46	13.40	35.07	19.56	12.87	10.62	23.01	28.38	38.35	21.98
CV	37.31	88.01	71.37	35.03	37.00	69.89	51.56	46.47	47.30	56.47

[1]Seeding date – variety – seeding rate (seeds m^{-2})

Table 3. Influence of seeding date, variety and seeding rate on yield.

	Indian Head		Melfort			Swift Current		Scott		Saskatoon			
Treatment[1]	2010	2011	2010	2011	2012	2011	2012	2010	2011	2010	2011	2012	Mean
	yield (kg ha^{-1})												
EM - 5440 LL - 20	1737^{c}	1841^{c}	1116	2502	2623^{cd}	714^{b}	1023^{b}	1010^{b}	1752^{d}	1051^{b}	1607^{b}	1606	1549^{bc}
EM - 5440 LL -150	2403^{a}	2951^{a}	1310	2239	3001^{ab}	1050^{a}	1634^{a}	2724^{a}	2385^{bc}	1530^{b}	2277^{a}	1916	2121^{a}
EJ - Polish - 150	993^{e}	810^{d}	1147	2559	1594^{f}	266^{e}	380^{d}	635^{b}	1548de	1039^{b}	1162^{b}	1521	1139^{d}
EJ - 5440 LL - 150	2194^{ab}	2374^{b}	1746	3007	3216^{a}	456^{d}	648^{c}	2492^{a}	2664^{a}	2631^{a}	1782^{ab}	1878	2092^{a}
EJ - 9350 RR - 150	2002^{bc}	2109^{bc}	1496	1579	2794^{bc}	590^{c}	700^{c}	2181^{a}	2186^{c}	2259^{a}	1765^{ab}	1985	1808^{ab}
MJ - Polish - 150	1036^{e}	250^{e}	1264	1986	1362^{f}	110^{f}	-	220^{b}	1329^{e}	-	1290^{b}	1103	935^{d}
MJ - 5440 LL - 150	1313^{d}	86^{e}	1379	2790	2475^{d}	173^{f}	-	-	866^{f}	-	1538^{b}	1714	1270^{cd}
MJ - 9350 RR - 150	1342^{d}	198^{e}	1536	2222	1998^{e}	269^{e}	-	571^{b}	1389^{e}	-	1702^{ab}	1859	1246^{cd}
LSD	287.73	396.39	ns	ns	266.78	69.36	256.60	886.03	212.34	516.30	604.65	ns	392.68
CV	35.67	84.12	30.41	29.17	27.82	67.29	53.37	55.26	33.34	42.73	29.84	27.14	52.30

[1]Seeding date – variety – seeding rate (seeds m^{-2})

Table 4. Influence of reseeding canola on economic return at Indian Head, Melfort, Saskatoon, Scott and Swift Current in 2010, 2011 and 2012.

	Early May		Early June			Mid June		
	5440LL	5440LL (Low)	5440LL	9350RR	Polish	5440LL	9350RR	Polish
Expenses								
Seed cost ($ kg^{-1})[1]	27.56	27.56	27.56	27.56	10.56	27.56	27.56	10.56
Seeding rate (kg ha^{-1})[2]	8.88	8.88	8.88	5.97	3.83	8.88	5.97	3.83
Initial seed cost ($ ha^{-1})	244.73	244.73	244.73	244.73	244.73	244.73	244.73	244.73
Reseeding seed cost ($ ha^{-1})	0	0	244.73	164.53	40.44	244.73	164.53	40.44
Cost of seeding ($ ha^{-1})[3]	38.14	38.14	76.27	76.27	76.27	76.27	76.27	76.27
In crop herbicide[1]	59.28	59.28	33.35	5.56	64.22	33.35	5.56	64.22
Burn off[1]	0	0	5.56	5.56	5.56	5.56	5.56	5.56
Cost of spraying ($ ha^{-1})[3]	24.70	24.70	24.70	24.70	24.70	24.70	24.70	24.70
Total ($ ha^{-1})	366.85	366.85	629.35	521.36	455.93	629.35	521.36	455.93
Income								
Yield (kg ha^{-1})	2121.00	1549.00	2092.00	1808.00	1139.00	1270.00	1246.00	935.00
Crop Value ($ ha^{-1})[4]	1230.18	898.42	1213.36	1048.64	660.62	736.60	722.68	542.30
Income - Expenses ($ ha^{-1})	863.33	531.57	584.01	527.28	204.69	107.25	201.32	86.37
Gain or loss from low ($ ha^{-1})	331.76		52.45	-4.28	-326.87	-424.31	-330.24	-445.19
Gain or loss including reseeding benefit[5]	331.76		200.65	143.92	-178.67	-276.11	-182.04	-296.99

[1]Costs obtained in spring 2013 from industry
[2]Based on a seeding rate of 150 live seeds m^{-2} for all treatments. Treatment 2 was seeded at 20 seeds m^{-2}; however, this was to mimic a situation where canola was seeded at a typical seeding rate and environmental conditions resulted in a low plant stand.
[3]Based on costs from custom rate guide (Saskatchewan Ministry of Agriculture 2012).
[4]Based on a price of $0.58 kg^{-1}
[5]Includes Saskatchewan Crop Insurance Corporation (SCIC) establishment benefit of $148.20 ha^{-1} to help cover reseeding costs

If faced with a canola stand with lower than the optimum plant density the decision to reseed will be based on plant density, date and uniformity of the plant stand. The results of the reseeding study show that when faced with a plant stand of 20 plants m^{-2} or less, reseeding in early June to hybrid canola provides a yield and economic benefit compared to leaving the stand of low density canola. Although B. rapa will mature earlier than B. napus it is lower yielding. This study found no advantage to reseeding with B. rapa, even when reseeding was postponed to mid-June. When reseeding is required, it is recommended that producers reseed as early as possible to reduce the risk of yield and quality reductions due to fall frost. If conditions do not allow for reseeding to occur in late May or early June it is not recommended that producers reseed to canola.

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